China-Australia Geological Storage of CO_2

Research Project2: Geological Storage of CO2 and Enhanced Oil Recovery at Liaohe Oilfield

Summary Report

China University of Petroleum(Beijing)

Institute of Geology and Geophysics, Chinese Academy of Science

Research Institute of Safety & Environment Technology, CNPC

2011．12

Overview to the Research Project 2

1. Objects and Tasks

The research project aims at assessments the CO2 storage potential, safety, and possibility in Liaohe Oilfield, the safety and environmental assessment method and technology for CO2-EOR, and the CO2 storage and EOR preferred plan in Liaohe Oilfield.

Basing on above objects, three main tasks have been included in the research project:

(1) Building criteria for CO2 geological storage assessment in oil/gas reservoir in Liaohe Oilfield, meanwhile identifying its EOR potential. The reservoir characteristic and the chemical reaction rules in the process of CO2 storage in oil/gas reservoir in Liaohe Oilfield will also be studied.

(2) Building criteria for CO2 geological storage assessment in saline aquifers in Liaohe Oilfield, meanwhile identifying its storage potential. The hydrological and geological condition in saline aquifers in Liaohe Oilfield will also be studied.

(3)Building safety and environmental evaluation system for CO2 geological storage and CO2-EOR.

2 Research Units

Leading Units:

China University of Petroleum(Beijing)

Participating Units:

Institute of Geology and Geophysics, Chinese Academy of Sciences

Research Institute of Safety and Environment Technology,CNPC

Project Summary

1. Project Review

Basing on the mechanism and affecting factors for CO2 storage in oil/gas reservoir and CO2-EOR, the criteria, principle, phases, and evaluation systems for CO2 storage in oil/gas reservoir and CO2-EOR have been studied and built by the research groups in China University of Petroleum (Beijing). All research results have been collected and titled as “ Site Selection Criteria for CO2 storage in oil/gas reservoirs ” as one of chapters in the book “Site Selection Criteria for CO2 Geological Storage”, which will be published recently.

Basing on the date about the overall geological structure in Liaohe Oilfield, the model for CO2 storage in oil/gas reservoir has been built by the research group in China University of Petroleum(Beijing), meanwhile, the soft for evaluating CO2 storage potential and EOR has been explored.

Basing on series experiments, CO2 solubility in oil/water, the rules for CO2/H2O/Rock, the characteristics for oil/gas reservoir have been studied and confirmed by the research group from China University of Petroleum(Beijing). The CO2 storage potential and CO2-EOR potential have also been calculated by the soft explored by the group.

The geological formation, structure features and hydrological environment in the western depression of Liaohe oilfield have been investigated by the research group from the Institute of Geology and Geophysics, Chinese Academy of Science. At the same time, the corresponding reservoir characteristics have been described. The risk and the suitability for the CO2 storage in saline aquifer in the western depression have also been assessed.

The policy, standards for CO2 storage and also the safety and environmental evaluation system in different countries have been collected and concluded by the research group from the Institute of Safety and Environmental Technology, CNPC. UI and CO2 storage regulations in the United States, European Union and other developed countries have also been commented. The safety and environment assessment methods in China, including Environmental Risk Assessment Guidelines, Environmental Impact Assessment of Oil and Gas industry, and Safety Assessment have also been concluded.

2. Main Outcomes

Outcome 1：“Site Selection Criteria for CO2 storage in oil/gas reservoirs ”

Basing on the mechanism and affecting factors for CO2 storage in oil/gas reservoir and CO2-EOR, the criteria, principle, phases, and evaluation systems for CO2 storage in oil/gas reservoir and CO2-EOR have been studied and built. All research results have been collected and titled as “ Site Selection Criteria for CO2 storage in oil/gas reservoirs ” as one of chapters in the book “Site Selection Criteria for CO2 Geological Storage”, which will be published recently.

Outcome 2: Confirmation of Caprock and reservoir geo-structure for oil/gas reservoir and saline aquifer in Liaohe oilfield.

For the target area for CO2 geological storage in Liaohe oilfield, the geological condition and the characteristics for oil/gas reservoir and saline aquifer in Liaohe oilfield have been analyzed. The different geological layers and construction, caprock and reservoir in different depressions have been checked and confirmed. The construction feature, the oil and water properties in the eastern depressions, the western depressions and Damingtun depressions have been investigated in detail. The controlling effect on the caprock and reservoir distribution by the geological construction has also been analyzed.

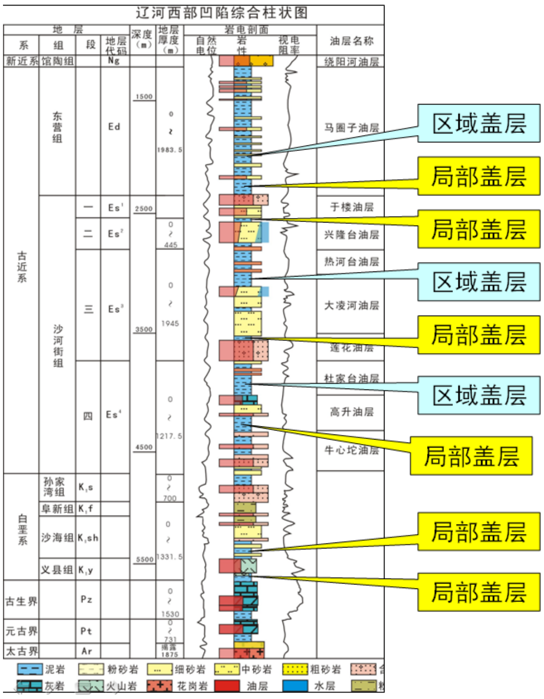


Fig. 1 Geological layer in Liahe western depression

The main typical oil reservoir is fault block reservoir in Liaohe oilfield. Shahejie group, Dongyin group lithologic reservoir, basal palaeoburied reservoirs, dongying group three sections of lithologic reservoirs or rolling anticline have also been involved. The characteristics for reservoir in western depression in Liaohe oilfield has been described. The distribution features for the reservoir and caprock and the relationship to the sedimentary phases have also been described.

.

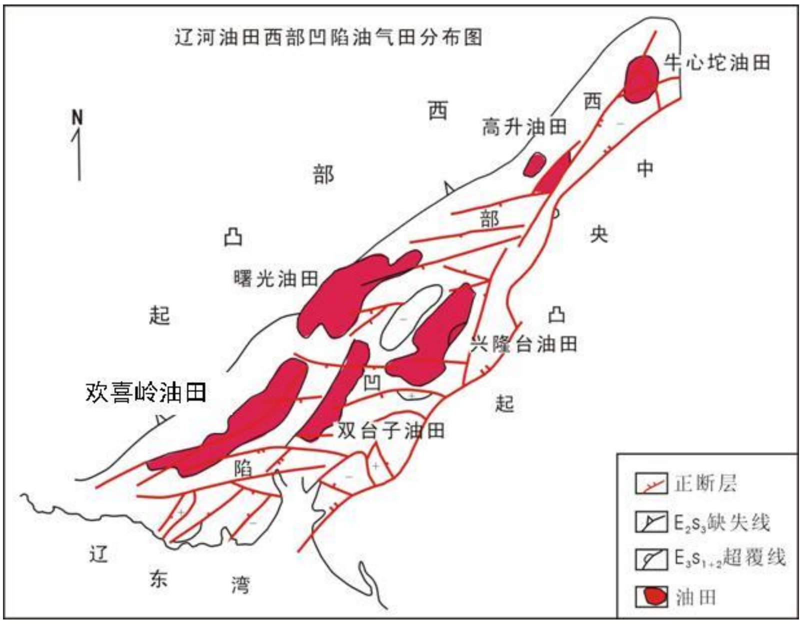


Fig. 2 Oil-gas reservoir distribution in Liaohe western depression

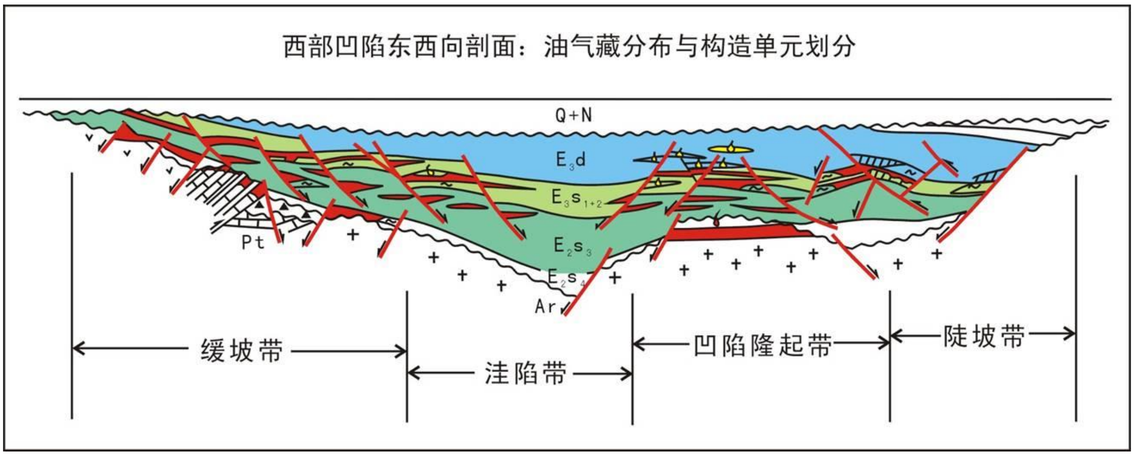


Fig 3 The oil reservoir distribution and geological construction unit division in east-west profile in Liaohe oilfield

Outcome 3: Analysis and Evaluation for the suitability and risk for CO2 storage in saline aquifer in Liaohe oilfield.

To select suitable areas for CO2 storage in Saline aquifers, and establish the potential storage capacity assessment system in Saline aquifers of liaohe oil field,We did a geological survey of the Saline aquifers for CO2 storage in the western depression. According to the survey, the lithology of the seal is mainly belong to mudstone. As for the horizontal continuity and consistency, both the commonly developed regional seal and the many local seal exist. Overlying seals are extensively developed and direct seals are wide distributed.

Secondly, the characteristics of the saline aquifer of the western depression of liaohe oilfield have been described and analyzed. The underpart of the liaohe depression is a catchment basin ,which is embraced on three sides by mountains and one side by sea. Both the surface water and groundwater have adequate supplemental sources. The salinity of both the western depression and the eastern depression are higher than that of the damintun depression , but they have the same cause of the formation of the oil field water .

Statistics indicates that oilfield water in the western depression of Liaohe oilfield can reach the saline water standards where the western depression of liaohe oilfield buried deep below the 2500m. And it is regarded that the advantageous region of the saline aquifer for CO2 storage in the western depression of Liaohe oilfield is in the eastern part of the depression.

下辽河坳陷油田水矿化度与埋藏深度关系

井号	层位	埋藏深度（m）	矿化度（mg/l）	井号	层位	埋藏深度（m）	矿化度（mg/l）
欢35	E_3s_2	1441.4-1475.2	2425.4	海27	Ng	1246-1310	601-841
	E_3s_2	1487.6-1492.6	2467.2	海31	E_3d	1787-1871	2627-2835
	$E_3s_3^{下}$	2474.0-2481.8	4977.3	海26	E_3d	2540-2600	6900
	E_2s_4	2538.4-2565.0	4339.5	海22	E_3s_2	3249-3253	7244
黄7	E_3d	2222.6	2500	沈24	E_3s_2	2169.0-2178.6	2559.88
	$E_3s_1^{中}$	2500	2419		E_2s_3	2169.0-2200	3962.20
	$E_3s_1^{中}$	2714	4160		E_2s_3	2187.8-2200	2684.6
	$E_3s_1^{中}$	2717.4	5726		E_2s_3	2169.0-2539.4	3611.98
	$E_3s_1^{下}$	3007.0	7136		E_3s_3	2530.4-2539.4	4301.11
	E_2s_3	3097.0	8292				

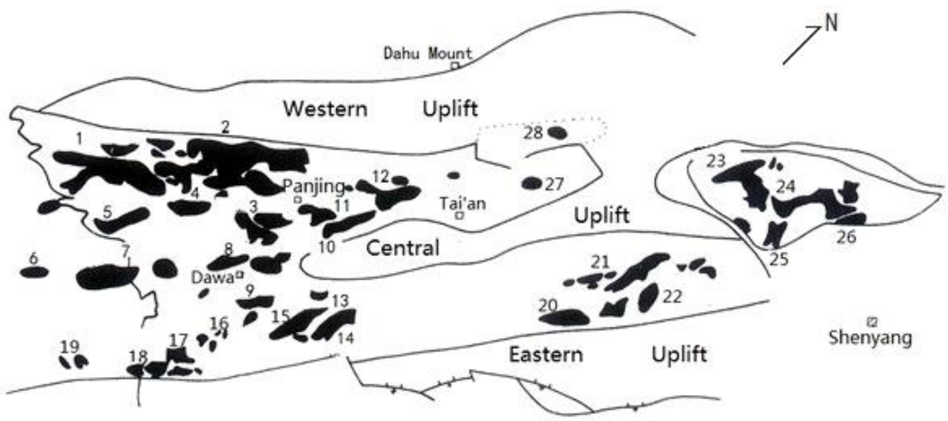
Table 1. The relationship between the oilfield water in the underpart of the liaohe depression and the buried depth

Oilfield water can reach the saline water standards where the western depression of liaohe oilfield buried deep below the 2500m. Due to the depth of 2500m is too deep which make the injection cost high, it is not suitable for CO2 storage such deep underground. And the brackish water have other applications, so it is suggested not to storage CO2 in the brackish water aquifers.

On the other hand, the preliminary risk assessment of CO2 storage in the western depression of Liaohe oilfield saline aquifer has been done.According to the character of the fault block of the western depression of liaohe oilfield, the fault covering type accounts for a large proportion. Based on the importance of the effect of the fault, the storage risk has been analysed. It is raised that the anticline traps have the lowest risk , followed by the broken anticline traps, and the fault traps have relatively high risk. And it is thought that the western depression belongs to the high risk class for CO_2 storage with the developed fracture and fault trap.

Outcome 4: The characteristic of CO_2 in the condition of Liaohe oil/gas reservoir, the solubility of CO_2 in crude oil, and the CO_2/H_2O/Rock reaction rules have been studied and confirmed.

Basing on the collected date and series experiments, the oil properties in the conditions of Liaohe Oilfield, the solubility of CO_2 in Liaohe crude Oil, and the rules for CO2/H20/Rock reaction have been confirmed.



1-Huanxiling oil field 2-Shuguang oil field 3-Xinglongtai oil field 4-Shuangtaizi oil field 5-Shuangnan oil field 6-Yuehai oil field 7- Haiwaihe oil field 8-Dawa oil field 9-Xinkai oil field 10-Xiaowa oil field 11-Lengjia oil field 12-Gaosheng oil field 13-Rehetai oil field 14-Yulou oil field 15-Huangjindai oil field 16-Taipingfang oil field 17-Rongxingtun oil field 18-Taiyangdao oil field 19-Kuihuadao oil field 20-Qinglongtai oil field 21-Ciyutuo oil field 22-Niuju oil field 23-Damintun oil field 24-Jing'anbao oil field 25-Fahaniu oil field 26-Biantai oil field 27-Niuxintuo oil field 28-Songjia oil field

Fig. 4 Oil fields in lower Liaohe depression

Fig.5 Rules for CO_2/H_2O/Rock Reaction

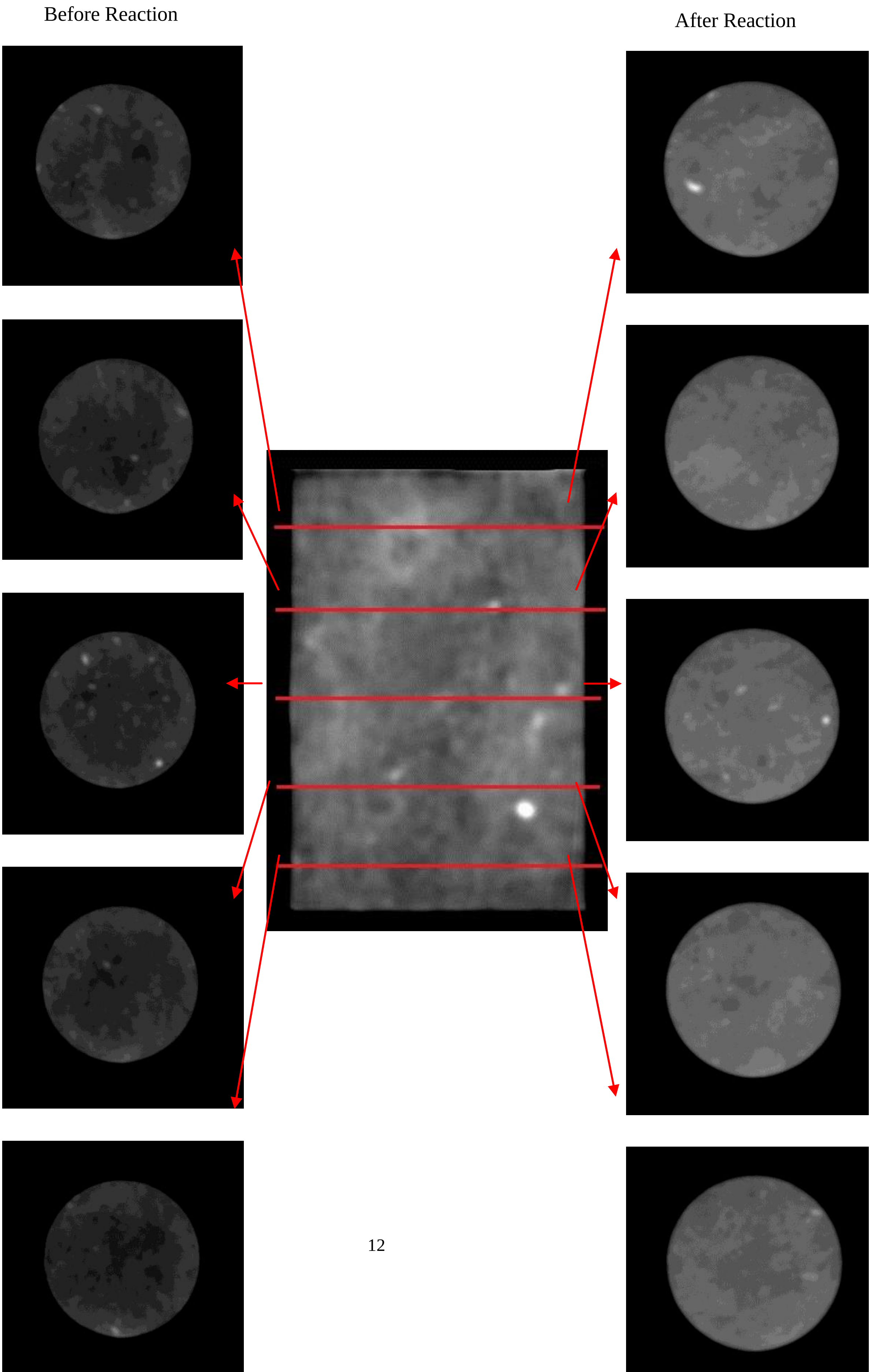


Table 2 Physical properties of Liaohe oil fields

Oil fields	A (km^2)	H (m)	φ (%)	Mp (10^4 t)	ρ_f (Kg/m^3)	T (°C)	P (MPa)
Qinglongtai	15.4	20.0	19.8	1883	928	68	17.7
Huangjindai	17.5	8.9	20.6	1239	833	87	26.1
Niuju	14.8	33.0	19.0	2124	821	79	22.9
Yulou	19.6	10.8	19.4	1010	834	86	23.0
Rehetai	9.7	7.9	22.1	826	859	74	26.1
Huanxiling	160.5	36.2	20.3	28085	890	72	18.6
Gaosheng	32.7	67.6	24.5	9993	948	53	15.9
Shuguang	171.6	18.5	23.8	39671	889	82	17.6
Xinglongtai	56.8	13.6	22.0	5356	858	78	19.5
Shuangtaizi	14.9	16.2	18.0	1202	827	92	24.5
Damintun	53.3	21.0	19.4	5188	853	85	18.4
Jing'anbao	74.0	24.6	20.0	13424	860	79	28.8
Fahaniu	21.3	17.3	19.8	2462	844	86	16.7

Table 3 Basic reservoir properties and CO_2 solubility in crude oil

Oil fields	T (°C)	P (MPa)	ρ_o (kg/m^3)	C_{os} (kg/kg)	C_{os} (m^3/m^3)
Qinglongtai	68	17.66	928	0.155	0.232
Huangjindai	87	26.14	833	0.157	0.211
Niuju	79	22.90	821	0.163	0.216
Yulou	86	23.00	834	0.142	0.190
Rehetai	74	26.07	859	0.216	0.299
Huanxiling	72	18.64	890	0.153	0.220
Gaosheng	53	15.90	948	0.200	0.305
Shuguang	82	17.60	889	0.116	0.167
Xinglongtai	78	19.45	858	0.139	0.193
Shuangtaizi	92	24.47	827	0.134	0.179
Damintun	85	18.43	853	0.116	0.159
Jing'anbao	79	28.76	860	0.210	0.292
Fahaniu	86	16.65	844	0.103	0.140

Outcome 5: The model and calculatar soft for CO2 Storage potential in oil/gas reservoir in Liaohe oilfield has been confirmed and explored. The CO2 storage potential in Liaohe Oilfield has been calculated basing on the model and the soft.

1. Evaluation Model for CO2 Storage in Liaohe Oilfield

When CO2 storage capacity in Liaohe oil field is assessed on the reservoir-scale, it calls for more practical consideration. Making a combination of reservoir development characteristics and CO2 storage mechanism, for instance, taking trapping mechanisms into consideration is of great use to get close to effective storage capacity.

Since most of Liaohe oil fields are still in producing, the practical process could be summarized as water flooding in earlier production along with CO2 storage and enhancing oil recovery in later period. Therefore, assessment of CO2 storage potential had better make a combination of both issues and fully consider reservoir structure and production history of Liaohe oil fields. The structural model of Liaohe oil–bearing reservoir and water formation is shown in Fig. 5.

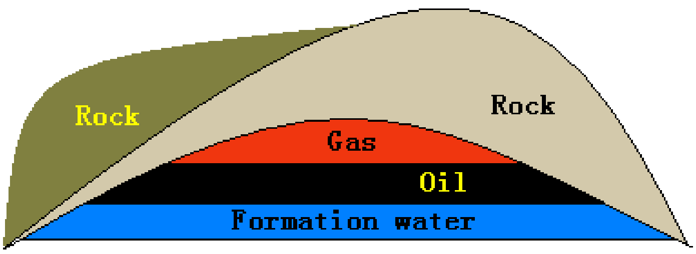


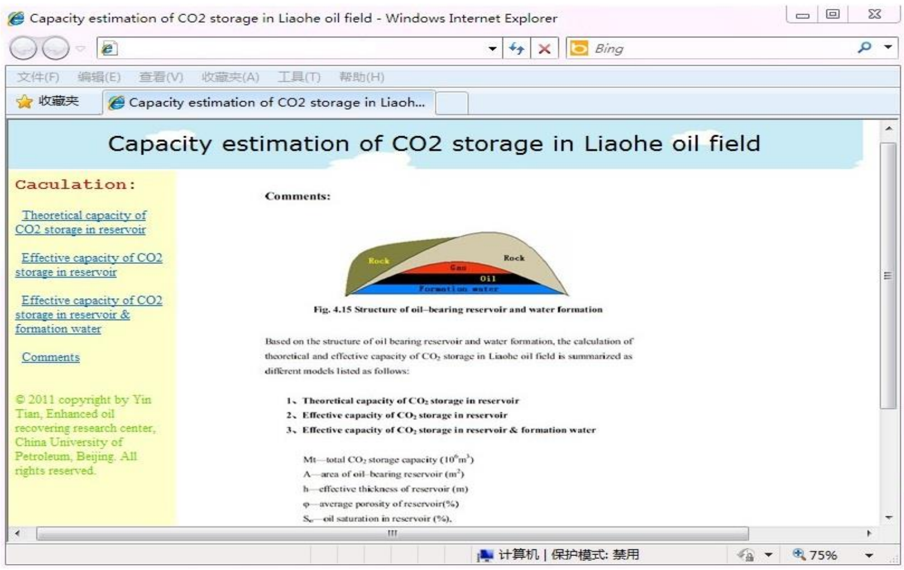
Fig.5. Structure of oil–bearing reservoir and water formation

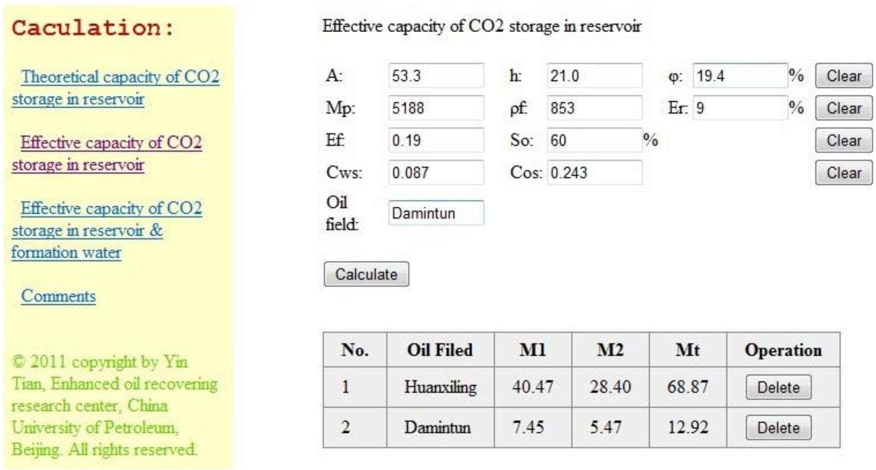
The calculation model of CO2 storage capacity is developed based on geological conditions and the properties of rock, crude oil and formation water in Liaohe oil field complex. The further amended equation used for calculating CO2 storage capacity in oil–bearing reservoirs and water formations is as follows:

$$M_{CO2} = M_1 + M_2 + M_3$$

where, M_1 represents the CO2 storage capacity as dissolved in oil and water (10^6 m^3); M_2 is the CO2 storage capacity during CO2 flooding process (10^6 $m^{3)}$; M_3 is the volume of CO2 stored as mineral trapping (10^6 m^3).

2. Calculator Soft for CO2 Storage Potential





3. CO2 Storage Potential and CO2-EOR Potential in Liaohe OilfieldCO_{2h}

Table 4 Theoretical capacity of CO_2 storage in Liaohe oil fields

Oil fields	M_1 ($\times10^6 m^3$)	M_1/Mt (%)	M_2 ($\times10^6 m^3$)	M_2/Mt (%)	Mt ($\times10^6 m^3$)
Qinglongtai	11.0	85.8	1.8	14.2	12.8
Huangjindai	5.8	81.2	1.3	18.8	7.1
Niuju	16.8	87.8	2.3	12.2	19.1
Yulou	7.4	87.2	1.1	12.8	8.5
Rehetai	3.1	77.9	0.9	22.1	3.9
Huanxiling	213.0	88.2	28.4	11.8	241.4
Gaosheng	97.8	94.9	9.5	5.1	107.3
Shuguang	136.5	77.3	40.2	22.7	176.6
Xinglongtai	30.7	84.5	5.6	15.5	36.3
Shuangtaizi	7.8	85.7	1.3	14.3	9.2
Damintun	39.2	87.8	5.5	12.2	44.7
Jing'anbao	65.8	82.4	14.0	17.6	79.8
Fahaniu	13.2	83.4	2.6	16.6	15.8
Total/Average	648.0	85.0	114.6	15.0	762.6

It could be seen from the calculation results of CO_2 storage capacity in the thirteen oil fields, theoretical storage capacity of structural trapping is about 114.6×10^6 m^3 (71.0 Mt), and that of dissolved trapping is about

648.0×10^6 m^3 (401.8 Mt). Total theoretical volume of CO_2 storage is 762.6×10^6 m^3 (472.8 Mt) in Liaohe oil field. Besides, CO_2 dissolution (M_1) accounts for approximate 85.0% of the total capacity during CO_2 flooding and sequestration, which indicate that taking CO_2 solubility into consideration is essential for assessing CO_2 storage potential.

Table 5 Effective-capacity of CO_2 storage in Liaohe oil fields

Oil fields	M_w (×$10^6 m^3$)	M_o (%)	M_1 (×$10^6 m^3$)	M_2 (×$10^6 m^3$)	Mt (×$10^6 m^3$)
Qinglongtai	0.38	1.61	2.0	1.8	3.82
Huangjindai	0.21	0.77	1.0	1.3	2.32
Niuju	0.60	2.29	2.9	2.3	5.21
Yulou	0.26	0.89	1.1	1.1	2.24
Rehetai	0.11	0.58	0.7	0.9	1.56
Huanxiling	7.26	29.58	36.8	28.4	65.24
Gaosheng	3.46	18.83	22.3	9.5	31.78
Shuguang	4.42	14.38	18.8	40.2	58.97
Xinglongtai	1.05	3.74	4.8	5.6	10.40
Shuangtaizi	0.28	0.89	1.2	1.3	2.47
Damintun	1.29	3.94	5.2	5.5	10.70
Jing’anbao	2.49	12.12	14.6	14.0	28.66
Fahaniu	0.42	1.16	1.6	2.6	4.21
Total/Average	22.22	90.78	113.0	114.6	227.57

Total effective capacity for CO_2 storage is 227.6×10^6 m^3 (152.4 Mt), while the amount of CO_2 dissolved trapping is 113.0×10^6 m^3 (70.1 Mt), and accounts for 49.7% of the total volume. When compared with the former results of effective storage capacity, there is a small decrease in the total volume of CO_2 dissolved in both water and oil. However, a small increase could be seen in the Jing’anbao oil field, its relatively lower reservoir temperature and higher pressure is able to promote the dissolution of CO_2, as well as the lower density of Jing'anbao oil. Those comprehensive elements all play a positive role in CO_2 storage.

Table 6 Oil production in CO_2-EOR process

Oil fields	4%	5%	6%	7%	8%	9%
Niuju	0.85	1.06	1.27	1.49	1.70	1.91
Huanxiling	11.23	14.04	16.85	19.66	22.47	25.28
Gaosheng	4.00	5.00	6.00	7.00	7.99	8.99
Shuguang	15.87	19.84	23.80	27.77	31.74	35.70
Xinglongtai	2.14	2.68	3.21	3.75	4.28	4.82
Damintun	2.08	2.59	3.11	3.63	4.15	4.67
Jing'anbao	5.37	6.71	8.05	9.40	10.74	12.08
Fahaniu	0.98	1.23	1.48	1.72	1.97	2.22
Total (Mt)	42.52	53.15	63.78	74.41	85.04	95.67

Outcome 6: Summarize CCS-EOR safety and environment assessment technology of developed countries, formulate environmental and safety assessment technical methods and evaluation system of domestic CCS-EOR project.

Summarize CCS-EOR safety and environment assessment technology of developed countries: there is no specific assessment of the technical methods for CCS abroad currently, but there are many policies and regulations on carbon storage, we summarized them and main introduce the UI regulations of United States.

Analyze the relation between domestic and overseas safety and environment assessment technology: Environmental assessment of internal is limited to things like general,now we are mainly based on our guidelines, taking into account the evaluation of UI for additional analysis.

Confirm project safety and environment assessment content by domestic typical CCS-EOR researches combined other project achievements: typical CCS-EOR project in Jilin oil field, through analyze the Process/risk identification/source item analysis/consequence calculation/risk calculation and assessment/risk management/emergency measures, to determine the safety and environmental assessment technical methods and evaluation system of CCS-EOR project.

(The appendix is about the safety and environmental assessment technical methods and evaluation system of CCS-EOR project.)

Appendix:

PART ONE FOREIGN LAWS AND REGULATIONS RELATED TO CARBON SEQUESTRATION POLICY AND RELATED ASSESSMENT

1. The United State

1.1 Standard of the Policy

The United State	In 2007, The Safe Drinking Water Act proposed and established The Deep Injection Control Scheme which established a criterion of safely recharging waste water and forbid certain method of recharging water simultaneously to ensure that underground deep injection will not affect the current and future safety of underground drinking water.
	In February 2008, Wyoming issued three bills of Carbon Capture and Storage(CCS) in which regulations of carbon dioxide leakage and diffusion are made that the geological storage point of carbon dioxide should have the following characteristics: the trap ability that can meet the geological storage of carbon dioxide; the relatively thick storage layer whose porosity and permeability permit a large quantity of carbon dioxide injection; existing a closed layer with relatively low permeability above the storage layer; temperature, pressure and the chemical properties of rock-fluid that should be suitable for the storage of large quantity of carbon dioxide and not damage the layer in the same time.
	In July 15, 2008 EPA issued a management measure to avoid pollution of drinking water caused by CO2 storage, which is EPA's first management measure of CO2 storage, including establishing a special well for CO2 injection, finding a large number of storage point and making test and monitor for large quantities of leak.
	In July, 2008, EPA drafted a CO2 storage law referring to The Clean Water Act of the United State requiring monitoring for the CO2 injected underground.2
	In May 28, 2009, the Department of Conservation of Pennsylvania, US, claimed to collect seismic data within the state in order to storage point suitable for CO2 storage. 2
	The US's CO2 Capture, Transport and Storage Guidelines prescribed the capture, transport and storage process and made a special reference to the setters, operators, managers of the policy.
EU	In January, 2008, the CO2 Storage Instruction Draft was issued, which prescribed in detail that:(1) the permission of locating and exploring storage point; (2) the permission of storage; (3) the operation, shutdown and responsibility after the shutdown of storage point; (4) third part right; (5) general criterion and the amendment for previous instructions.
IEA	Issued the Regulatory Framework for Carbon Capture and Storage Model

1.2 Underground Injection in the US

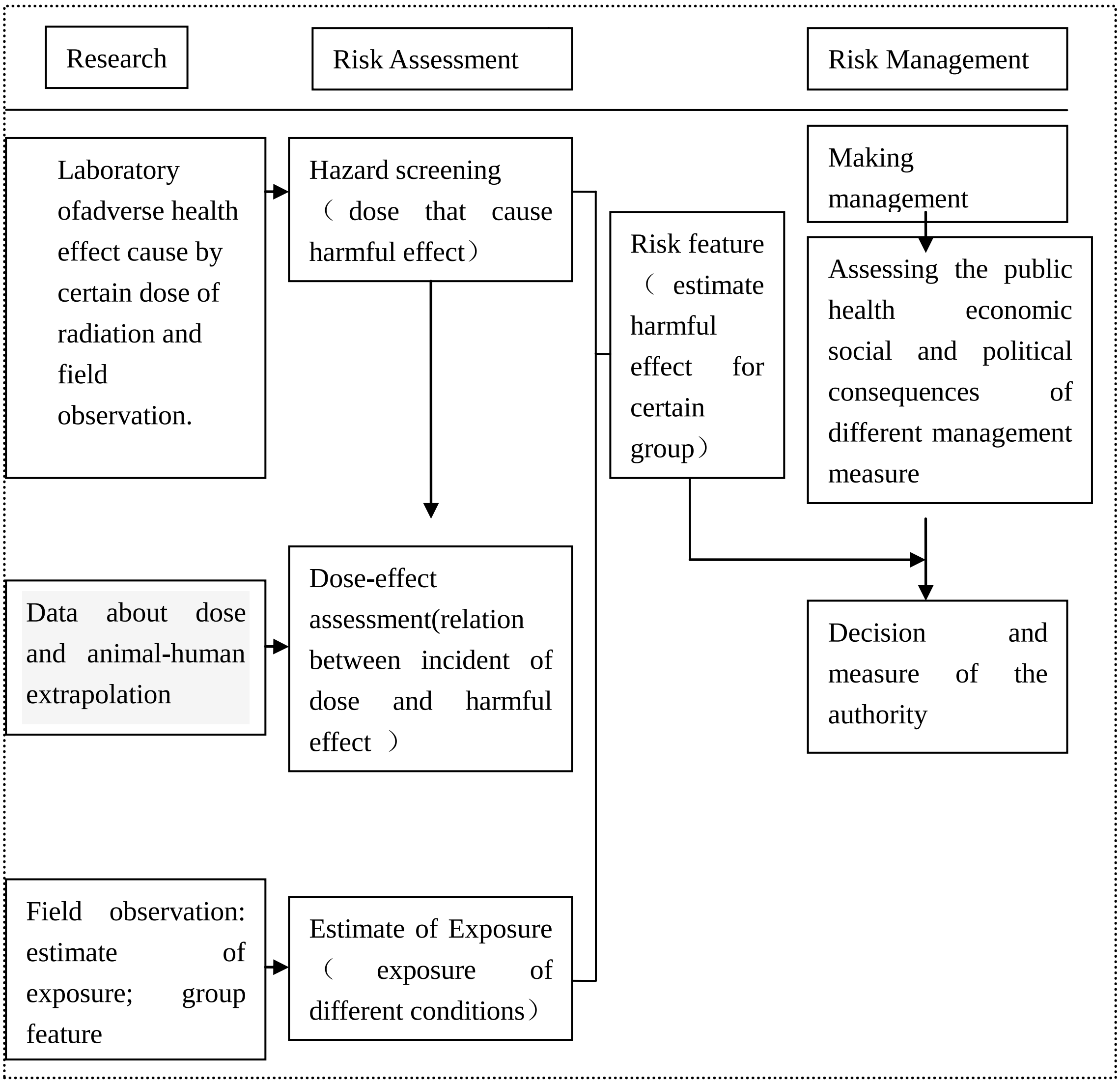
The US regulations for underground injection are mainly in the Code of Federal Regulations (CFR) Title40, including the legal requirement for class I hazardous waste injection. Other regulations related to underground injection mainly includes the Underground Injection Control

Program, The Safe Drinking Water Act, the Hazardous and Solid Waste Amendments, Underground Injection Control Regulations and Resource Conservation and Recovery Act etc.

1.3 Block diagram of environmental risk assessment of the US

This risk assessment was adopted by USEPA in 1986, after proposed by the AmericanAcademy of SciencesNational Research Council in 1983.

A



2. Europe

The risk assessment determined by European Parliamentand the Council mainly includes following aspects:

1）risk description

Implementing risk description should be based on the possibility of leak of compounds, which mainly refers to Description of dynamic modeling and security

2）Exposure assessment

The implement of exposure assessment is based on the description of CO_2 storage point ,human activities nearby and identification of dynamic trend of CO_2 leak in step 1).

3）Effect assessment

The implement is based on the identification of special related species, communities or habitat in leak event. In the mean time, the assessment of possible leakage of CO2 in the air affecting other substances should also be made(including Impurities in the air injected, floating by the new material formed by the injection or storage of CO2). This kind of effect should be considered within a short space and be combined with events of different level.

4）Risk assessment
This includes Security and integrity assessment of the length of the storage period, the leaking risk assessment under conditions of use and the worst condition and health-threatening condition.

PART TWO SAFETY AND ENVIRONMENTAL RISK ASSESSMENT IN CHINA

2.1 Security Assessment

According to the related requirements in the Production Safety Law of the People's Republic of China and the Notice of the Simultaneously Strengthening the Security Facilities of Construction Project (［2003］1346 in the investment launched by National Development and Reform Commission and the State Administration of Work Safety)

At present the security assessment mainly includes General Safety Assessment, Pre-evaluation of Safety Guidelines, Safety Guidelines for Acceptance Evaluation and Safety Guidelines for Assessment of Present and also Onshore Oil and Gas Industry Safety Assessment Guidelines

2.2 Environmental Risk Assessment

According to item No. 77 ofEnvironmental Impact Assessment Lawof the PRC decreed by the President of PRC and item NO. 253 of Construction Project Environmental Regulations decreed by the President of PRC, environmental assessment should be made for the project.

The main basis of the environmental assessment includesTechnical Guideline for Environmental Risk Assessment of Construction Project, Technical Guidelines for Environmental Impact Assessment of Petroleum and Natural Gas Development Projects, and also observing the technical requirements related to this industry in the NotificationOn the strengthening of environmental impact assessment management to prevent environmental risk and Notification on the inspection of chemical petrochemical project environment risk, issued by State Environmental Protection Administration

PART THREE TYPICAL RESEARCH PROJECTS

3.1 Process Analysis

The gas after dehydration in the gas dehydration station, is pushed into Liquefied storage system passing through pipeline, and is injected by Injection system achieving the effect of oil displacement. Then after collected by Oil and gas gathering and transportation system, the gas enters CO2 recycling processing system to be isolated and is finally recycled.

3.2 Environmental Risk

Major hazardous materials involved include carbon dioxide, liquid ammonia/propane, crude oil etc. The feature of the hazardous materials and their hazard category of fire and explosion should be listed.

Risk accidents and health and environmental effect caused by different processes

Process	Risk accident	Health and environmental effect
Well drilling Downhole operation	Blowout, well leakage, fire, explosion	Hydrocarbonscausing poisoning, carbon dioxide harming human body, fire and explosion causing casualties and facility damage, fire emissions and hydrocarbons polluting air, mud sprayed from oil well causing damage to Local soil and environment, leaked oil and drilling mud polluting Groundwater
Oil and gas mining Oil and gas processing	Hydrocarbon gases, carbon dioxide, oil, oily water leakage, fire, explosion	Hydrocarbon gases causing poisoning, carbon dioxide having effect on human body and ecological system, oily sewage polluting soil and environment, fire explosion causing casualties
Oil and gas gathering and transportation	Fire caused by oil and gas leaks, explosion, carbon dioxide leak	Crude oil leak polluting water within an area; soil and environment; fire explosion caused by oil and gas leak seriously influence atmospheric environment, causing casualties; carbon dioxide's effect on human body and ecological system
Construction of auxiliary facilities	Falls, electric shock, burns, etc.	casuaties

3.3 Security Risk

（1） Dangerous and hazardous factors in the production process：

Carbon dioxide injection system： pressure out of control and gas channeling；

Oil and gas gathering and transportation system：

Two-phase separators, pumps, oil well fire and explosion and mechanical accident

（2）Accident Risk Analysis: Carbon dioxide leak：the effect on climate, human health, plants and animals, groundwater;

Corrosion of carbon dioxide;

Fire and explosion;

Blowout;

Induced seismicity;

Low temperature, frostbite.

3.4 Selecting analysis method

For site selection, blueprint and layout, check list method should be used; for the risk of equipment and facilities, fault tree, fire, explosion, Risk index assessment method and Pre-analysis of risk assessment method should be used; for public projects, fault tree method should be used

PART 4 THE ESTABLISHMENT OF EVALUATION SYSTEM

The hermetic storage of carbon dioxide and the enhancement of the gathering ratio involve two major factors: ground engineering and underground storage. Starting with the project itself, the ground engineering is not beyond the area of petro chemist, which indicates that it can be evaluated by a state-related risk assessment.While no available state-related evaluationguidelines of Geological Storage ofCarbon Dioxide exists in the nation, the only reference is that the Vulnerability Assessment Framework which is established by U.S. underground perfusion along with U.S. Environmental Protection Agency. Concentrate on the referring dangerous substances. Substances referred in the project, including carbon dioxide, ammonia and crude oil, are all within the limitation illustrated in the Constructionproject environmentalrisk assessmentguidelines. So this particular category of items can be applied in formula of Technical Guideline for Environmental Risk Assessment of Construction Project. The project of underground storage can be applied in formula of U.S.undergroundperfusionand vulnerability assessmentframework.

4.1 The Establishment of Environmental Risk Assessment

To establish the environmental technical guideline of environmental risk assessment, riskanalysis ofsource term, prediction of the consequences, establishment of methods of risk prevention and the basis of preparation of contingency plans should all be taken in account.

4.1.1 Analysis of source term

（1） The suffocation of carbon dioxide towards the human health

Carbon dioxide is asphyxiating gases, the leakage of which may influence the health of site staff passively.

The concentration of IDLH ppm	The conversion factor of 1ppm to mg/m3 （20℃）	The concentration of IDLH mg/m3 （20℃）
50000	1.83	92000

（2） The transportation of carbon dioxide and the impurities may cause passive influence towards groundwater, soil and plants.

4.1.2 The calculation of the consequence

The diffusion of the leakage of hazardous substances is of the multi-puff model. The correspondent amendment should be taken in order to aim at the hazardous substances diffusion in the alternative of mass of the gas, the complexion of geographical condition.

To settle the diffusion, in the condition of the groundwater, the model recommendation of HJ 610 is strongly recommended.

4.1.3 The environmental risk management

The environmental risk management includes mainly the analysis of environmental risk prevention measures and the basis of preparation of contingency plans.

4.2 The risk assessment of security

4.2.1 The recognition and analysis of dangerous and hazardous items

According to the object of specific circumstances, we recognize and analyze the dangerous and hazardous factors and verify the exact parts of occurrence, model, and ways of occurring and the regulation of variation.

（1） The harm caused by the leakage of carbon dioxide

（2） The security of project itself which includes breaking of the covering, channelformationfracture and Geological disasters

4.2.2 The method of assessment

The method of security evaluation is through the quantitative and qualitative safety evaluation instruments. Then the context and the indicators of that should be correspondent with the variation of purpose and safety evaluation object.

4.2.3 To provide the method of safety strategy and proposal

According to the result of danger and hazardous factors and quantitative and qualitative evaluation, we should follow thespecification, technical feasibility, economicrationalityprinciple and provide the proposal of eliminate or diminish the danger, the dangerous technology and the strategy of administration.

The category of administration strategy should be fundamentally detailed and feasible. The alternate of applying completely or partly to a particular method should be provided.