胜利地质
SHENGLI GEOLOGY

Research and application of CO_2 flooding technology in low permeability reservoir in Shengli Oilfield

Geological Scientific Research Institute in Shengli Oilfield

2011. 7

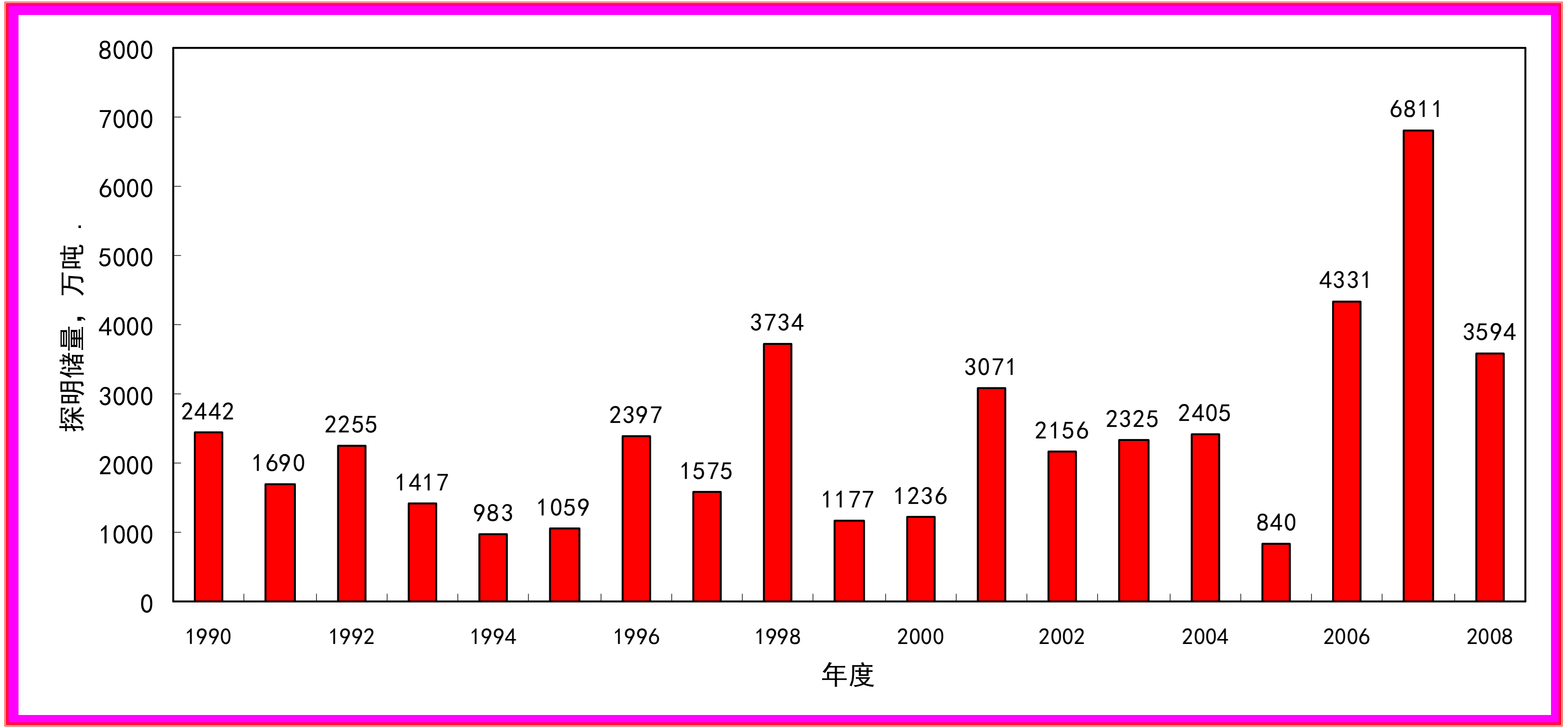
China Australia Geological Storage of CO_2
中澳二氧化碳地质封存

outline

- Preface
- Block Screening
- Experimental of EOR of CO_2 flooding
- Optimum Design of CO_2 flooding
- Implementation Effect

First: Preface

There is abundant low-permeability reservoir in Shengli Oilfield

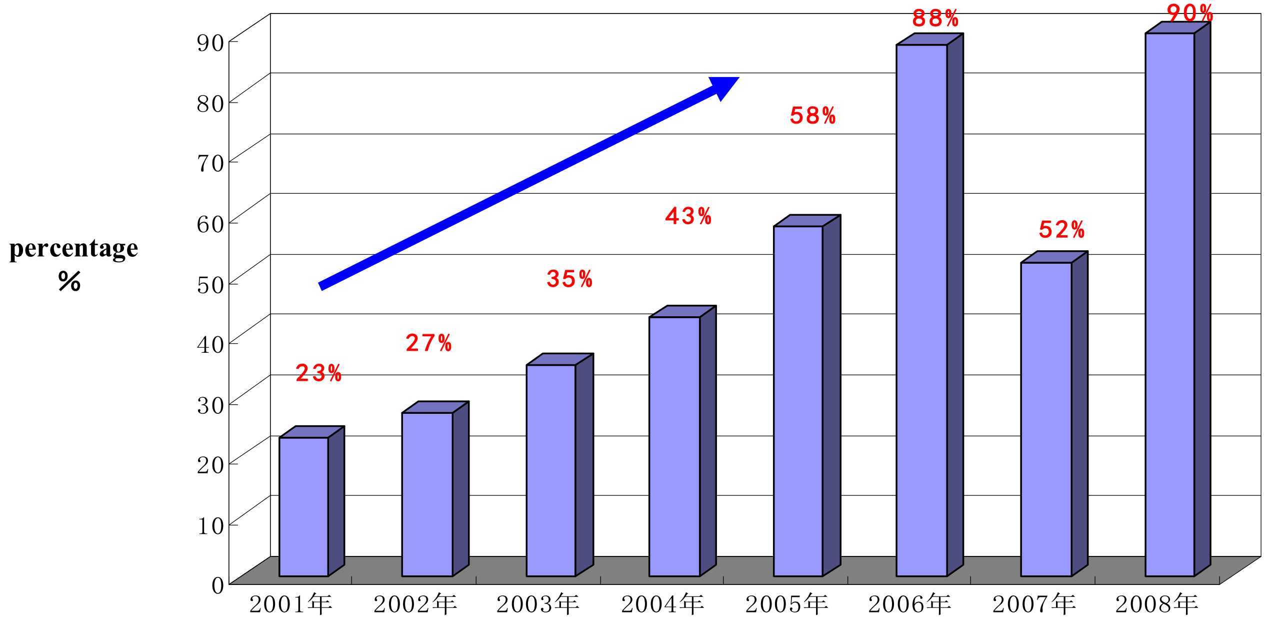


Up to the end of 2008, new proved reserves is 767 Mt, proved reserves of 2006, 2007is 43.31,68.11 Mt, seize 44.7%, 64.6% of proved reserves.

First: Preface

The proportion of ultra low permeability（K<10×10^{-3} μ m^2） proved reserves in low permeability reserves new proved became larger and larger Since 2001, ultra low permeability reserve become main type of new proved reserves inch by inch in Shengli Oilfeild.

The proportion of ultra low permeability proved reserves in new low permeability proved reserves in Shengli Oilfield

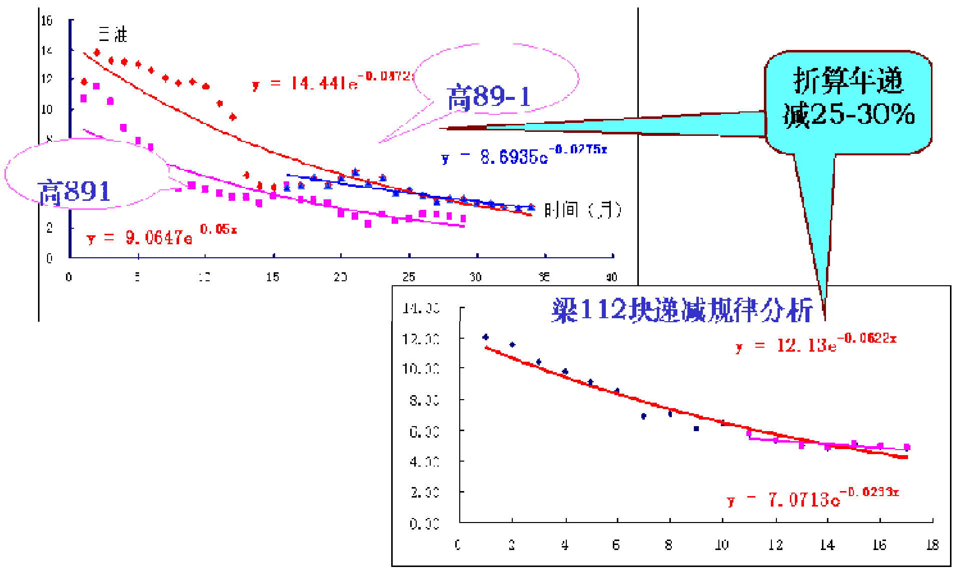


First: Preface

Difficulties in developing ultra low permeability reservior.

(1) Low recovery, fast decrease caused by massive hydraulic fracture resilience development.

(2) It’s difficult to supplement energy by flooding.



梁4块注水情况统计表

井号	转注日期	初期			目前			累注 m³
		泵压 MPa	油压 MPa	日注 m³	泵压 MPa	油压 MPa	日注 m³	
梁9-13	200207	35	34.4	77	37.6		套坏	48334
梁9-8	200207	35	33.9	53	37.9		套坏	29386
梁9-15	200209	36.3	36	45	38.3	38	32	25260
梁9-16	200301	35.4	35	25	37.5	37	16	15788
平均			34.8			37.5		

wherefore,research the methods of supplement energy for ultra low permeability reservior and enhancing recovery of low permeability reservior has import sense.

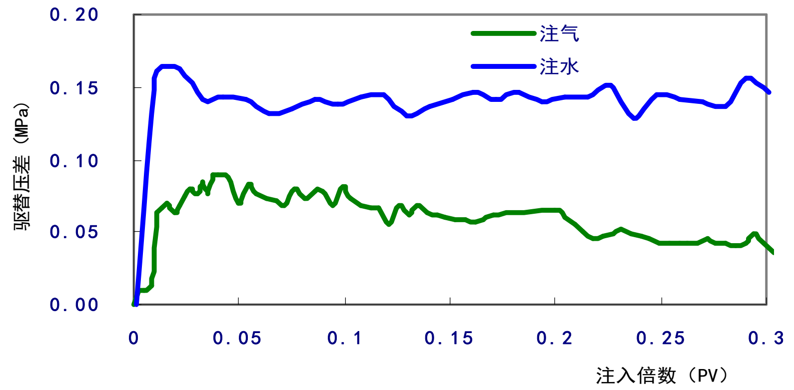
First: Preface

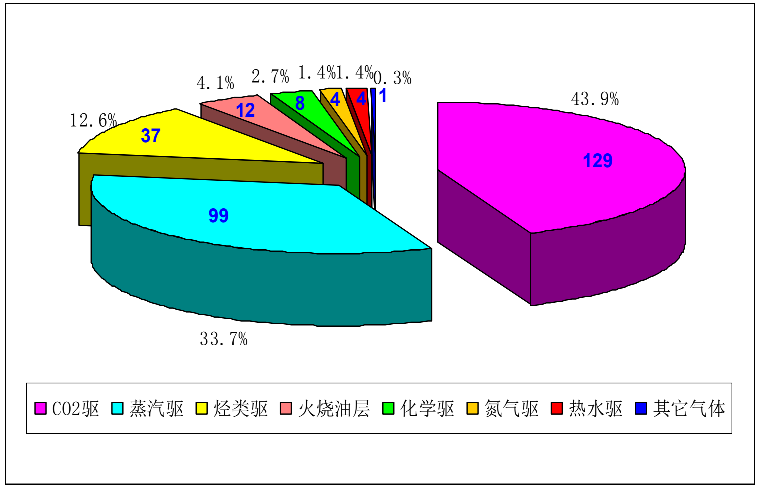
Mechanism researching and external field practice demonstrate that CO_2 flooding can enhance recovery of low permeability reservior by a wide margin.

Oil displacement mechanism by CO_2 flooding

- Thin out the crude
- Miscible phase with crude oil
- Decince interfacial tension
- Make crude oil swelled
- Increasing producing energy

Curve of differential displacement pressure with total injection volume





数据引自“Oil & Gas Journal / Apr,19,2010”

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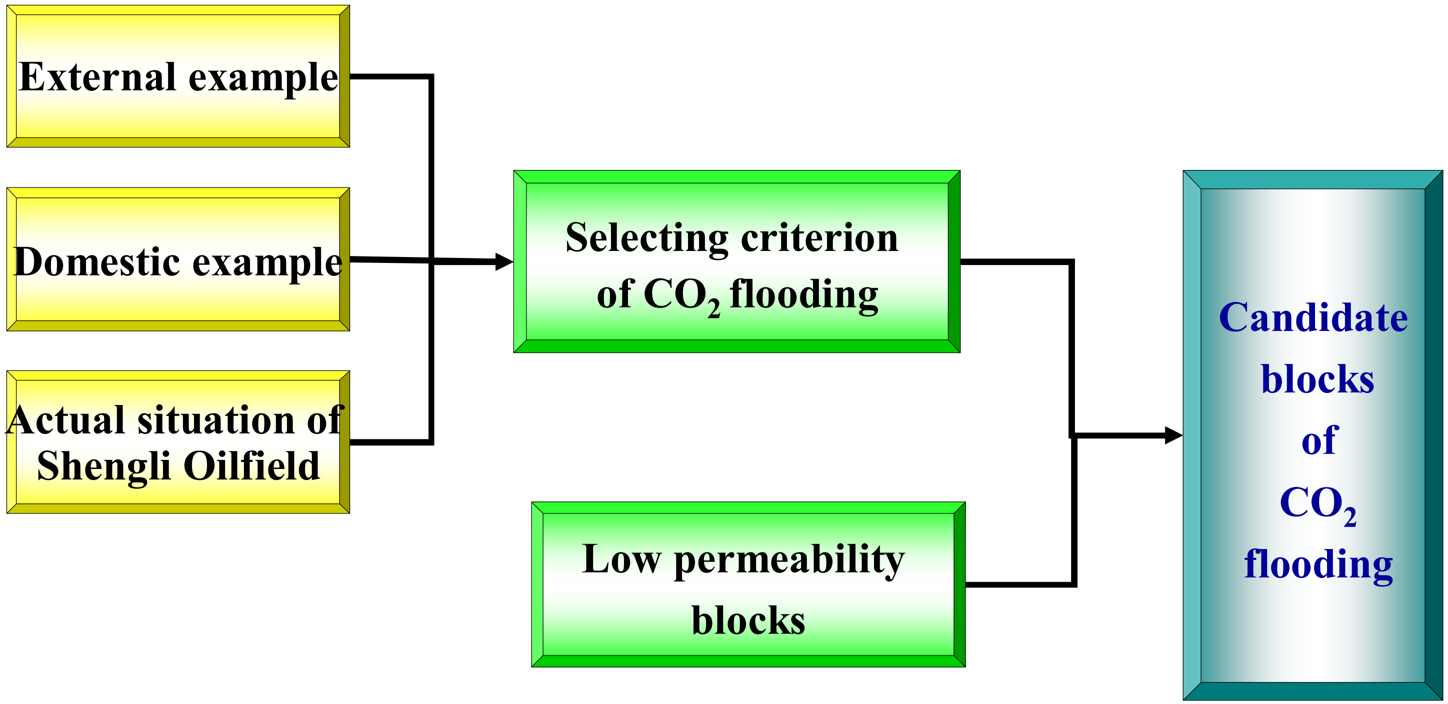
Second: Block Screening

Rule: first, make selecting criterion; then evaluate concrete block; finally, fix type block.



Flow diagram of block screening

Second: Block Screening

1、 Selecting criterion

Analysing CO_2 flooding succesful examples home and abroad, refer to actual situation of Shengli Oilfield, make selecting criterion of CO_2 miscible displacement in low permeability reservior.

Selecting parameters	Selecting criterion
Crude oil's viscosity in place， mPa.s	<12
Crude oil's density in place， $10^3 kg/m^3$	<0.8762
Remainder oil saturation， %	>25
Reserves abundance， $10^4 t/km^2$	>3.4
Porosity×saturation	>0.04
Reservoir depth， m	>1000
Reservoir pressure, MPa	>MMP

Second: Block Screening

2、Resources potential evaluation of CO_2 flooding in Shengli Oilfield

There are 47 blocks fit to CO_2 miscible displacement, 95.56Mt geologic reserve. according to enhancing recovery 15-20%, expect it can increase 14.33-19.11Mt recoverable reserves.

单元名称	公报储量	空气渗透率	剩余油饱和度	原始油藏压力	混相压力	目前压力
	10^4t	$10^{-3}\mu m^2$	%	MPa	MPa	MPa
大373	184	23.00	58.00	35.97	29.4	30.00
大52块	386	26.00	49.00	33.70	29.1	31.50
车408	289	7.80	53.00	45.50	29.8	33.90
丰11	74	46.00	44.00	30.00	27.4	28.00
史112－119	232	22.00	58.00	44.10	29.1	35.70
夏502	334	9.00	52.81	40.87	29.3	29.55
临95沙二下	279	50.00	45.53	31.30	27.9	30.52
牛23-A	142	32.00	61.00	40.10	29.8	33.87
牛25-C	272	32.00	43.00	45.20	29.9	39.79
牛41-A	33	18.50	55.00	36.90	29.6	29.66
桩23	606	0.96	47.00	52.93	29.9	35.80
桩39-3	24	21.00	52.45	29.60	29.3	29.55
…	…	…	…	…	…	…
正理庄樊144	401	4.00	64.00	47.67	29.9	42.30

二、CO_2驱区块筛选研究

2、Resources potential evaluation of CO_2 flooding in Shengli Oilfield

There are 62 blocks fit to CO_2 miscible displacement closely, 190.45Mt geologic reserve. according to enhancing recovery 15-20%, expect it can increase 19.05-28.57Mt recoverable reserves.

单元名称	公报储量	空气渗透率	剩余油饱和度	原始油藏压力	近混相压力	目前压力
	10^4t	$10^{-3}\mu m^2$	%	MPa	MPa	MPa
滨420块	90	44.90	58.44	28.80	22.4	23.02
滨660块	529	11.70	60.69	28.60	23.2	23.96
利古3块	103	20.20	50.36	32.22	23.5	24.04
纯化纯17块	666	27.00	48.73	34.10	23.1	25.40
纯化纯69块	116	23.65	40.80	33.75	23.5	27.20
纯化纯69块	267	46.00	46.34	32.70	23.3	28.60
大芦湖樊120	130	33.40	62.70	36.80	23.8	24.00
大芦湖樊12S3中4	345	6.30	51.56	32.20	23.7	27.96
大芦湖樊15	39	48.00	27.72	28.93	23.3	26.60
大芦湖樊23块7组	408	48.00	48.94	30.45	23.7	28.91
…	…	…	…	…	…	…
大芦湖樊29S3中5	27	32.11		47.31	23.7	26.71

3、Block Screening

Rules of block screening：

(1) Close to gas source；

(2) Present representativeness;

(3) Possess miscible phase condition.

Basic parameters of low permeability reservior in Shengli Oilfeild

区块	面积 Km^2	储量 10^4t	深度 ■	孔隙度 %	渗透率 10^{-3}u■^{2}	原油密度 g/c■^{3}	原油粘度 ■Pa.s
史深100	14.1	1442	3200	14.8	6.5	0.8782	1.9
桩74	13.1	1690	3500	16.6	6.4	0.858	1
纯97-7	2.1	122	2900	19.0	10.0	0.868	1.4
商550	3.90	434	3100	15.0	5.2	0.86	0.5
商742	1.50	102	2900	15.0	3.1	0.87	0.5
商847	5.70	303	2800	15.0	4.3	0.87	0.4
高89-1	4.33	289	3000	13.0	4.7	0.872	1.5
高891-1	7.09	353	3000	13.0	3.8	0.872	1.5
高89	80.50	3689	3100	12.5	3.5	0.871	1.5
樊142	64.23	3319	3100	12.3	5.3	0.872	1.5

方法	考虑因素	混相压力，MPa	备注
Cronguist (1978)	C_{5+}平均分子量、N_2、CH_4和油藏温度	26.46	经验公式
Alston(1985)	C_1 C_5, C_{5+}的平均分子量和油藏温度	24.58	经验公式
Y—M公式	油藏温度	29.43	经验公式
Glaso(1985)	C_{7+}的平均分子量和油藏温度	26.92	经验公式
外推蒸气压法（PRI1）	油藏温度和泡点压力	33.6	经验公式
外推蒸气压法（PRI2）	油藏温度和泡点压力	24.96	经验公式
状态方程法	油藏温度和原油组分、C_{7+}的平均分子量、密度	28.42	状态方程
图版法	温度	30.51	图版
平均		28.11	

Select G89-1 as CO_2 flooding experimental block.

outline

- Preface
- Block Screening
- Experimental of EOR of CO_2 flooding
- Optimum Design of CO_2 flooding
- Implementation Effect

Third: Experimental of EOR of CO_2 flooding

By means of experimental study, we recognize that affection of the phase of crude oil after CO_2 dissolve in it, fix the mechanism of oil displacement of CO_2 flooding; At the same time, offer complete set of phase parameters and alternation regularity for numerical simulation.

1、Research the characteristics of the phase of initial oil and CO_2;

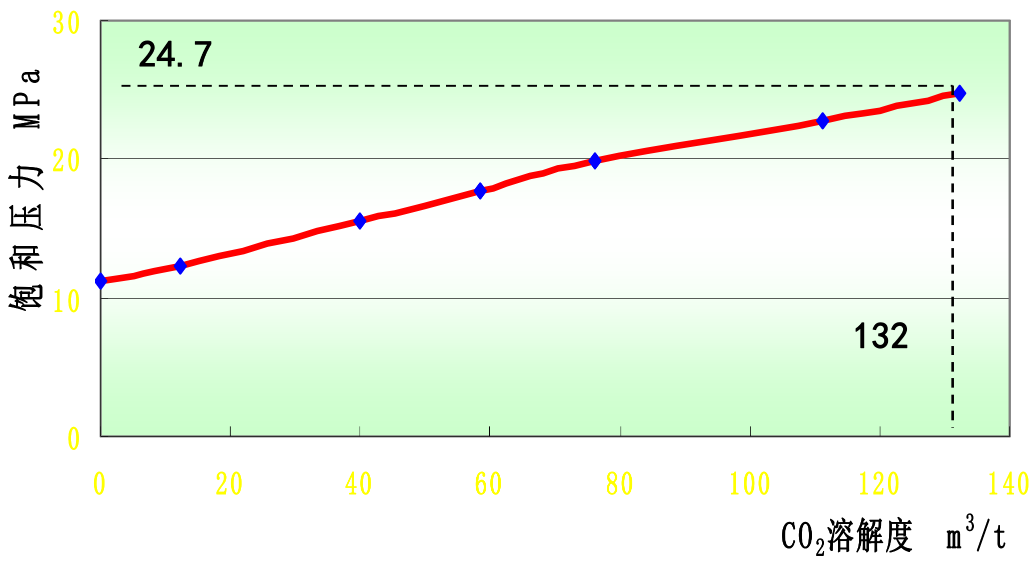
2、 Research the MMP of CO_2 and initial oil;

3、 Research the displacement experiment of long core model.

Third: Experimental of EOR of CO_2 flooding

1、Reseach the PVT of initial oil and CO_2

The relation of initial oil's saturation pressure and CO_2's influx

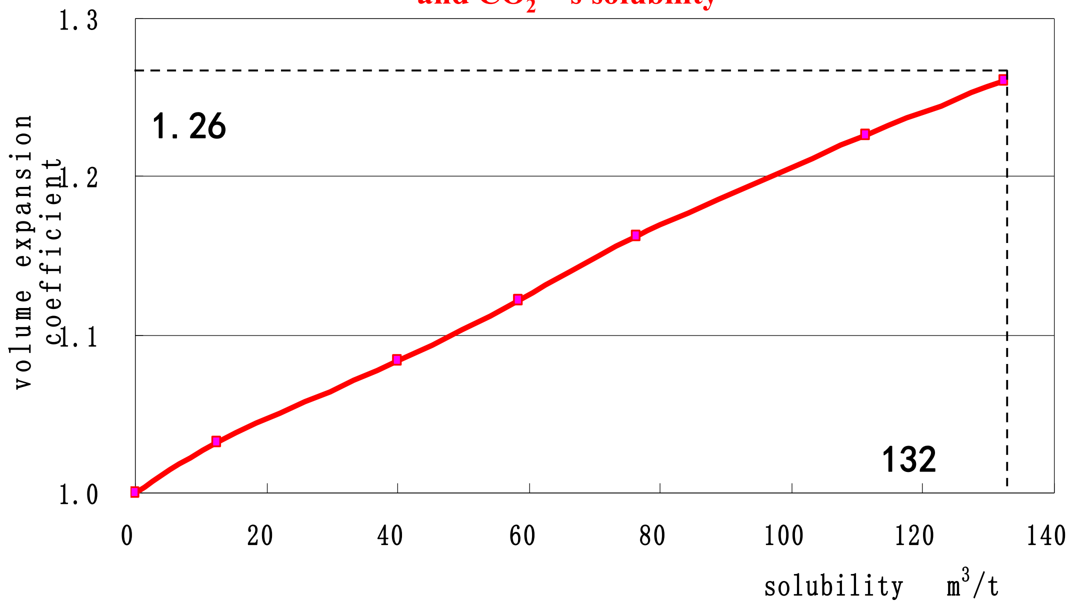


Along with the increasing of CO_2's influx, initial oil's saturation pressure rises inch by inch, it shows that initial oil has a big dissolving capacity to CO_2.

Third: Experimental of EOR of CO_2 flooding

1、Reseach the PVT of initial oil and CO_2

The relation of initial oil's coefficient of cubic expansion and CO_2's solubility

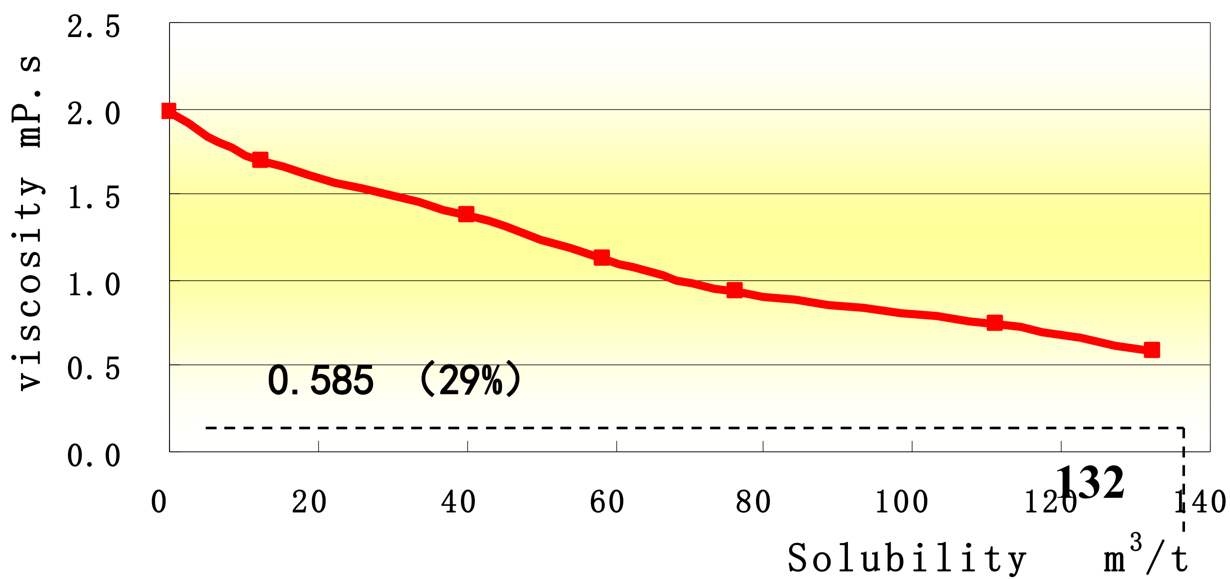


Along with the increasing of CO_2 dissolved, coefficient of cubic expansion increase, it shows that CO_2 has a greater capacity to make initial oil expand.

Third: Experimental of EOR of CO_2 flooding

1、Reseach the PVT of initial oil and CO_2

The relation of initial oil's viscosity and CO_2's solubility



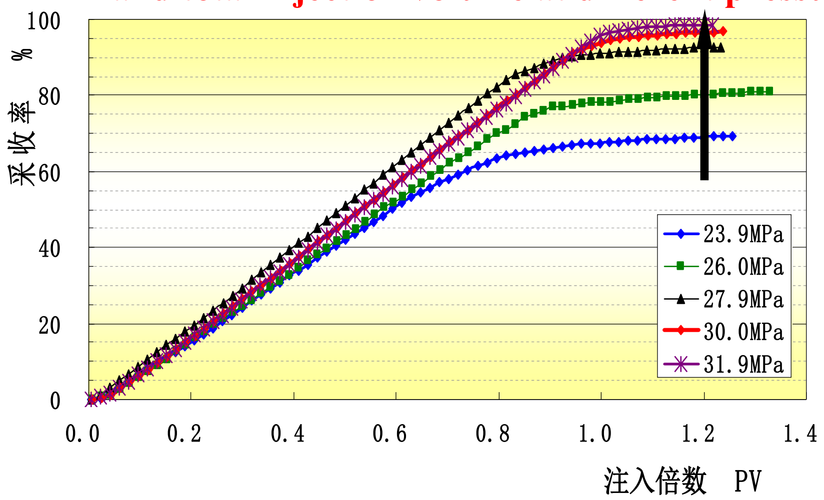
Along with the increasing of CO_2 dissolved, initial oil's viscosity decline, it shows that CO_2 has a better visbreaking effect to make initial oil.

2、Long macaroni pipe model studies

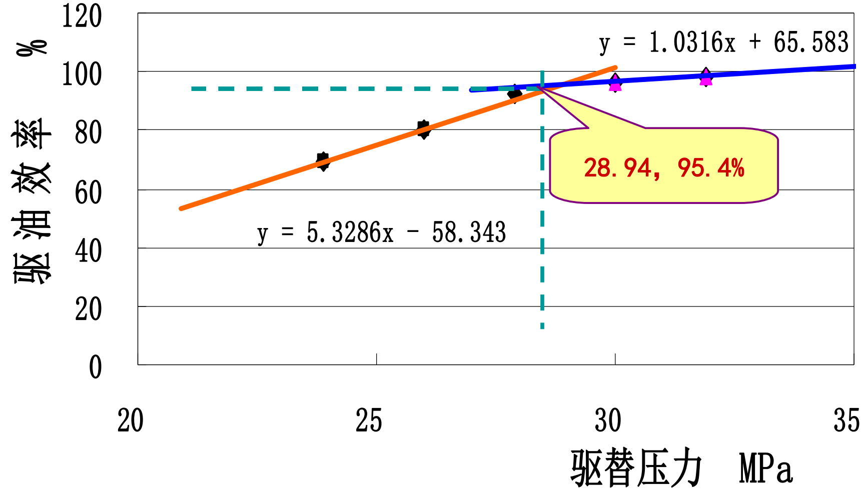
Model parameters

Tubule's length m	Tubule's diameter mm	Permeability mD	Porosity %	Temperature ℃	Displacement velocity m/h
16	6. 35	<10. 0	32. 25	126	0. 873

The relation of displacement efficiency and total injection volume at different pressure



MMP's definition



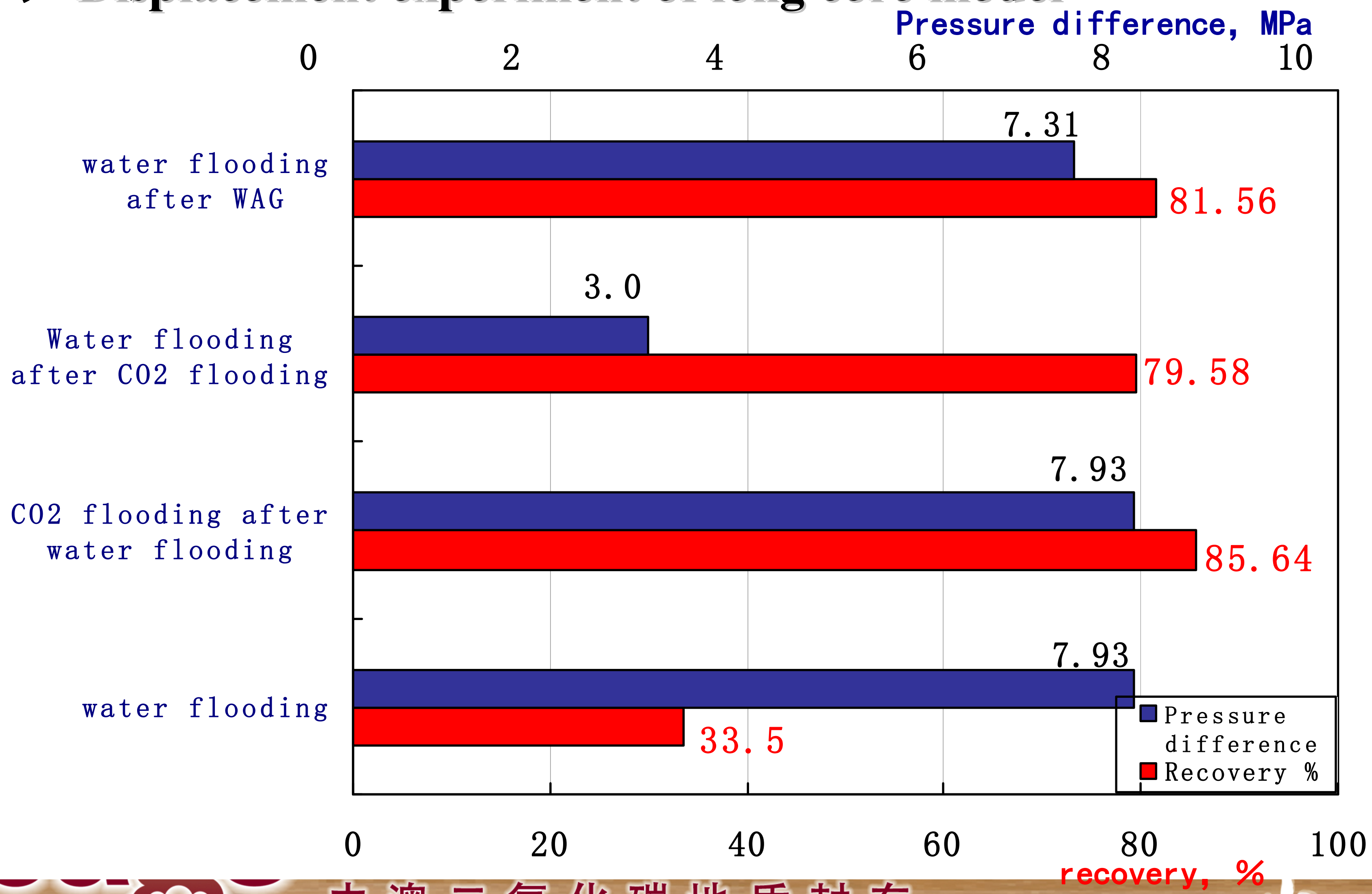
3、 Displacement experiment of long core model

Experiment design

- **Water displacing oil** — Finish it when cut reach 98% with water flooding.
- **CO_2 flooding after water flooding** — After cut reach 98% with water flooding, continuously inject CO_2 untill no oil out.
- **CO_2 displacing oil with different inject means**
  - Continuously inject CO_2 at the beginning, turn to water flooding when no oil out.
  - Alternately inject CO_2 and water at the beginning, turn to water flooding when no oil out.

Third: Experimental of EOR of CO_2 flooding

3、 Displacement experiment of long core model



outline

- Preface
- Block Screening
- Experimental of EOR of CO_2 flooding
- **Optimum Design of CO_2 flooding**
- Implementation Effect

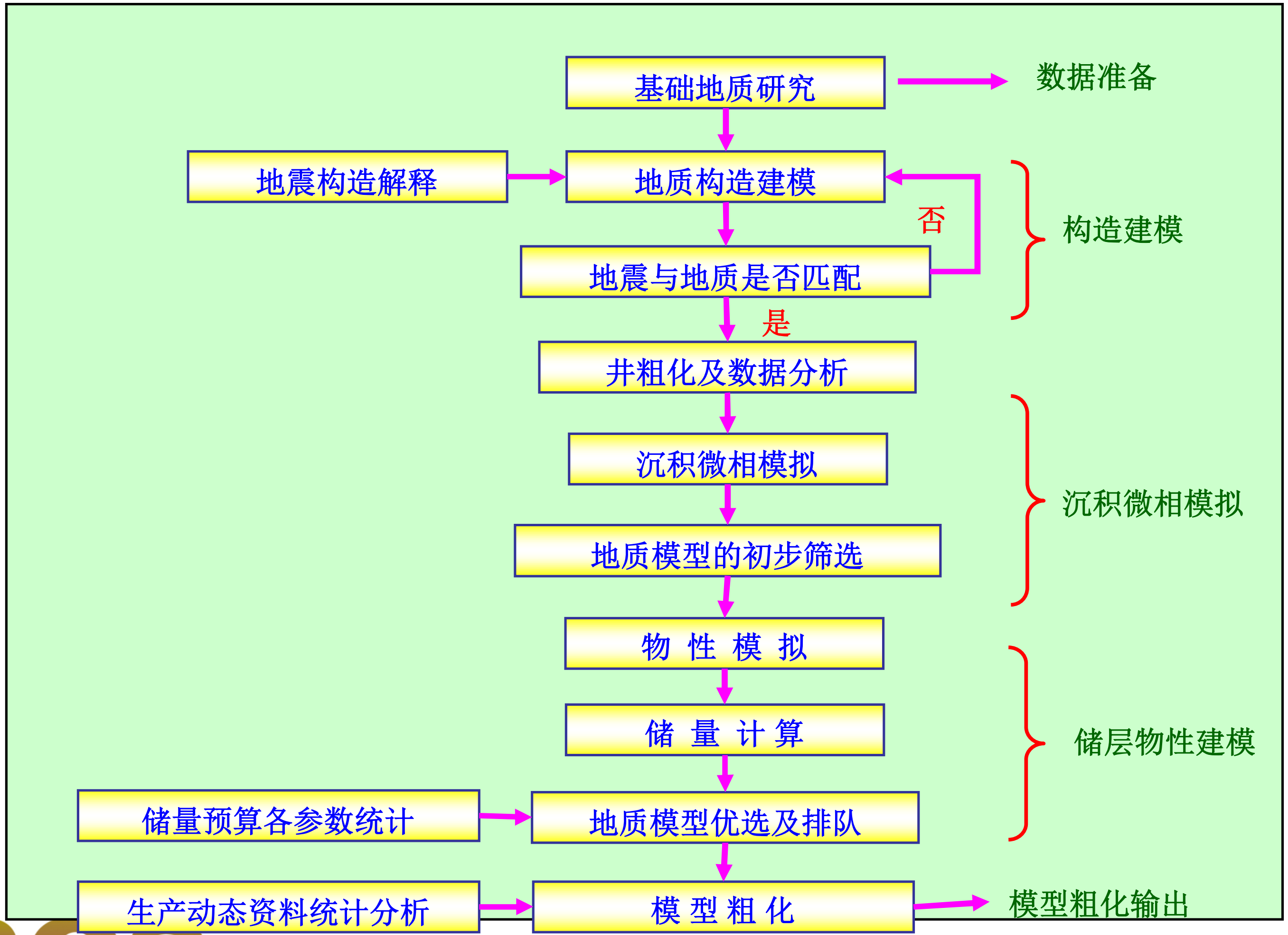
Fourth: Optimum Design of CO_2 flooding

Program design circuit of CO_2 flooding

- Establish geologic model
- Reseach of layer series of development
- Design of pattern well spacing
- Establish reservoir model
- Optimization of injection/ production parameters
- Forecast program target

1. Establish triaxial geologic model fit for gas drive

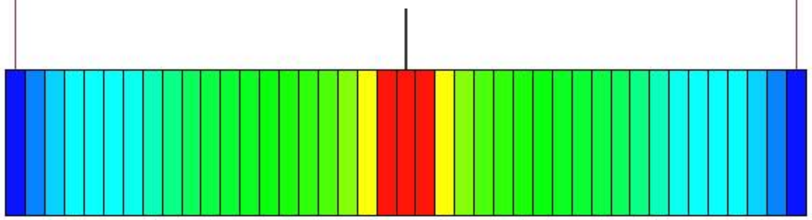
Circuit of establish G89-1 geologic model for CO_2 flooding



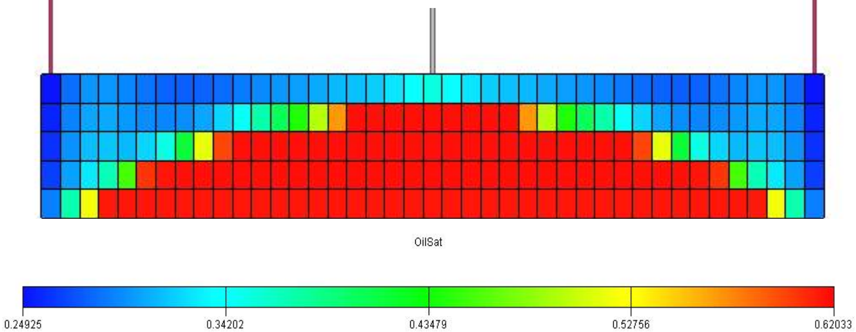
1. Establish triaxial geologic model fit for gas drive

It require to adopt fine grid to accurately describing gas overlapping and cusping.

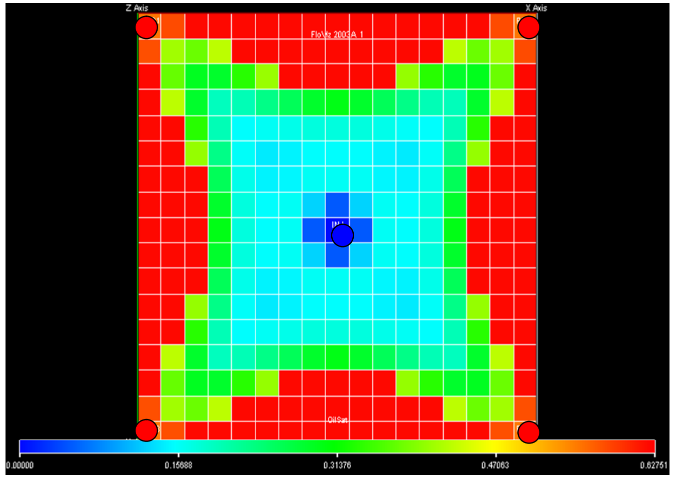
纵向1层饱和度分布图



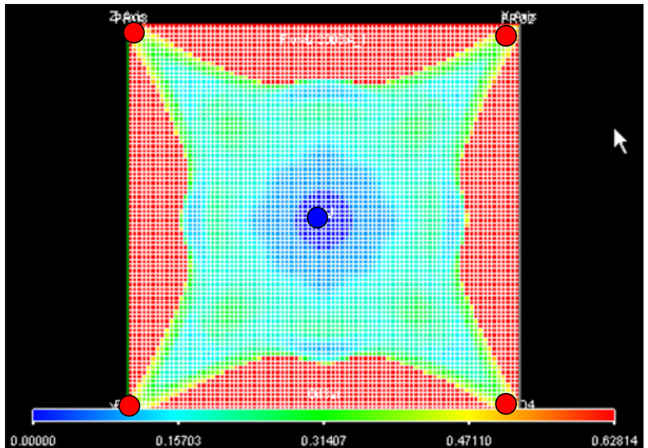
纵向5层饱和度分布图



25米网格步长模型驱替体积



5米网格步长模型驱替体积



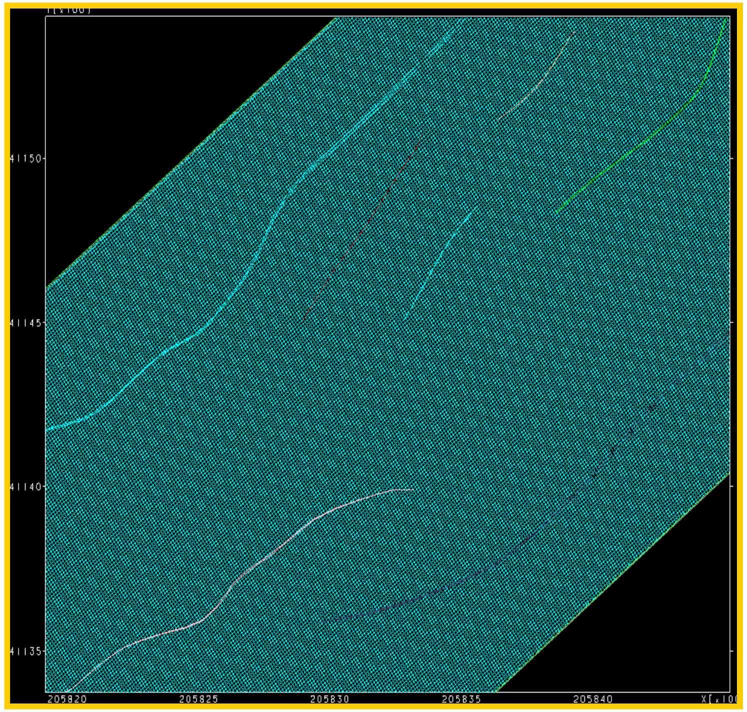
1. Establish triaxial geologic model fit for gas drive

The rule of establish fine geologic model: To intended zone, main layer regard single sand body as unit; no-main layer regard sublayer as unit.

沙四砂层组地层划分一览表

油层	砂层组	小层	单砂体数
沙四	1	1	2
		2	2
		3	2
		4	2
	2	1	2
		2	3
		3	2
		4	2
	3	1	2
		2	2
		3	2
		4	2
		5	2
	4	1	1
		2	1

高89-1块平面网格划分图



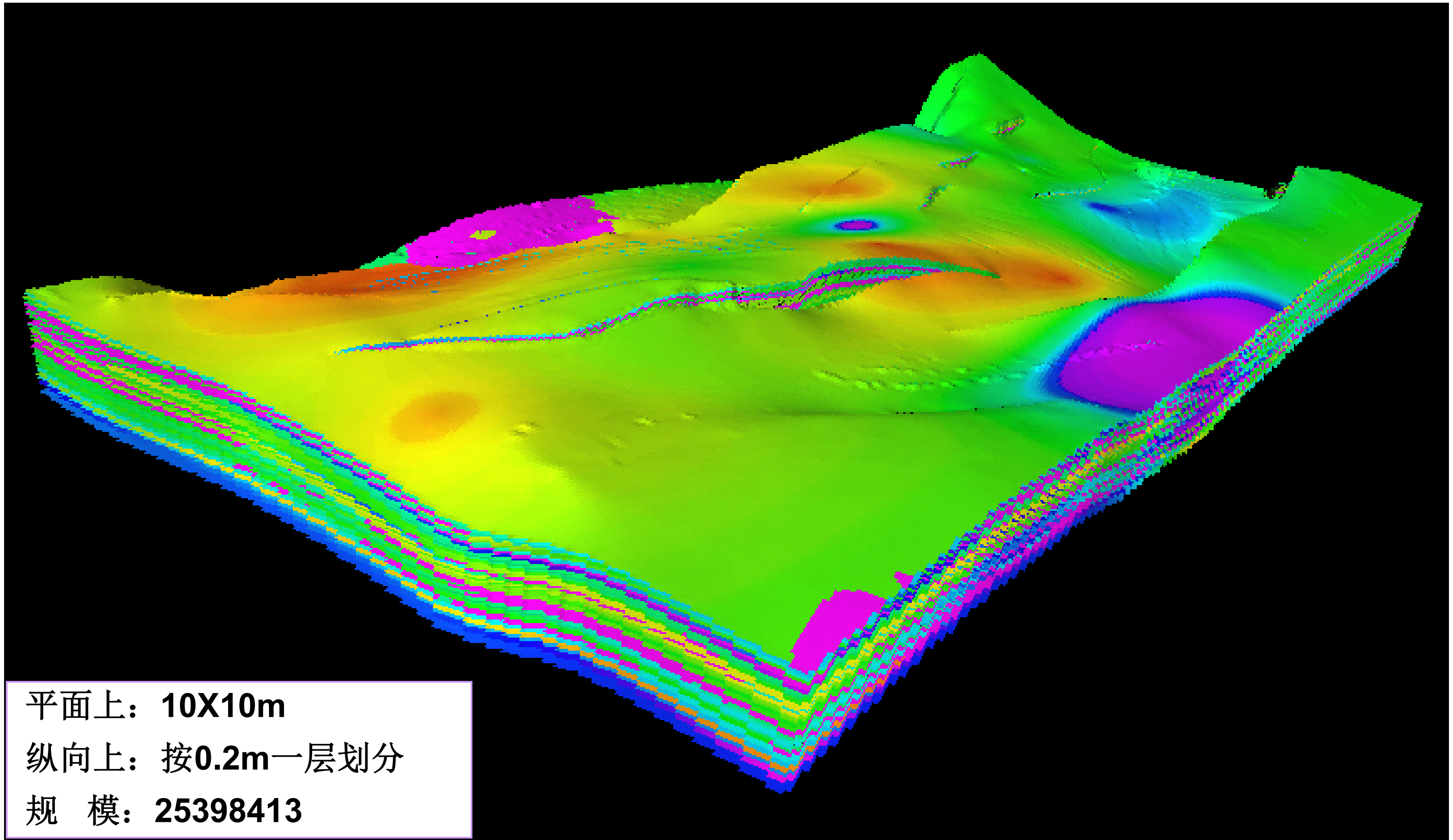
Grid driving

DX × DY：10m×10m

DZ ： 0.2m

1. Establish triaxial geologic model fit for gas drive

Fine triaxial geologic model of G89-1



2. Reseach of layer series of development

G89's reserves cartogram

层位	面积(Km^2)	厚度(m)	储量(10^4t)	占总储量百分数(%)
1砂组	3.36	4.4	84.6	34
2砂组	3.25	7.8	144.9	59
3砂组	0.95	2.5	13.3	5
4砂组	0.45	1.6	4.2	2
合计	4.1	10.6	247	100

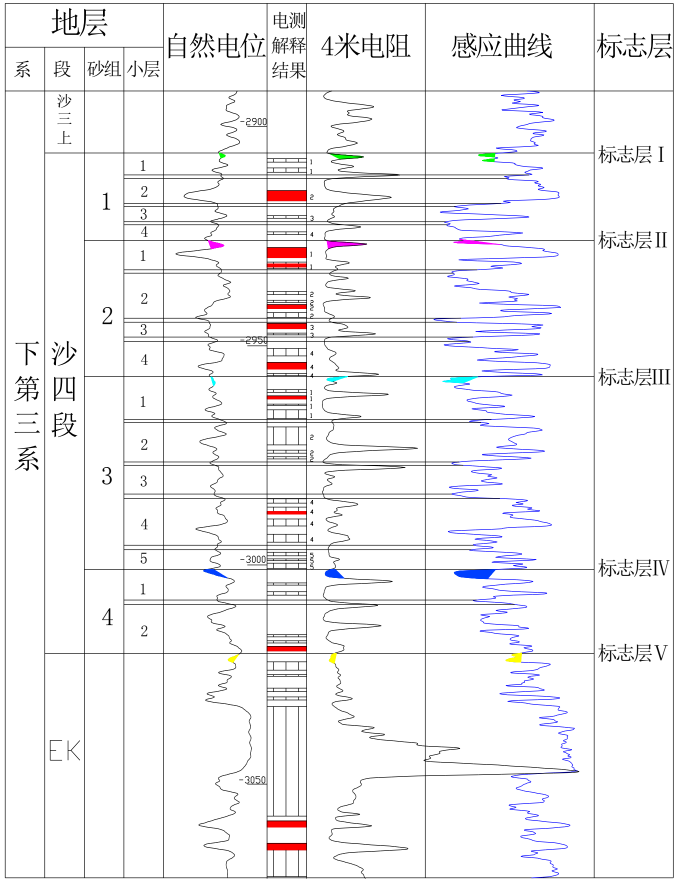
1、G89's main layers($S_4$1.2) are projecting, seize 93% of this block's reserves.

2、No-main layers's area is little, their reserves is small, they don't possess the material base to subdivide layer system.

3、this block's layers have more folding in vertity, hydrocarbon bearing interval is short, main layers needn't subdivide.

Then, we adopt one layer system to develop it.

高89-8井地层柱状图



3. Design of pattern well spacing

Definition rational spacing between wells certain of CO_2 flooding of G89-1			
Synectics	Reservoir engineering method		Real well spacing of G89-1 m
Well spacing for gas drive in low permeability reservior home and abroad m	Technique ultimate injector producer distance m	Economic limit injector producer distance m	
200-600	240	250-350	270-750

G89-1's well spacing for inject gas should be controlled from 270m to 350m.

3. Design of pattern well spacing

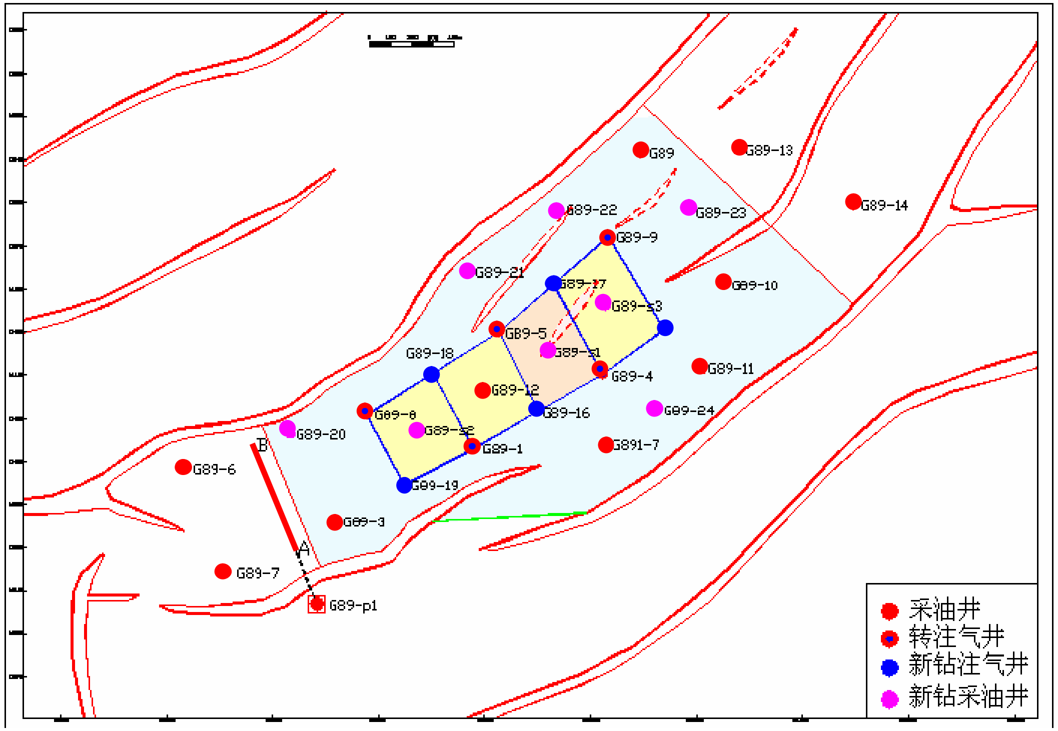
Principle of well network design

1、Using existing well network of G89-1 block;

2、Possessing center response wells;

3、Experomental area mainly adopt five-spot network, well alignment along with the fracture extension.

Well location of G89-1 for CO_2 flooding

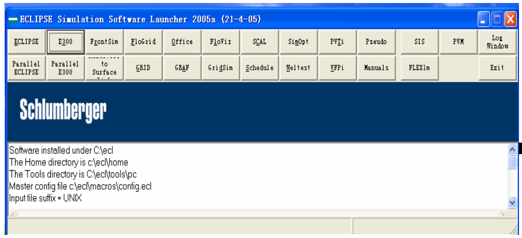


All wells of experomental area：24 wells（There are 14 oil wells,10 gas injection wells in it.），.

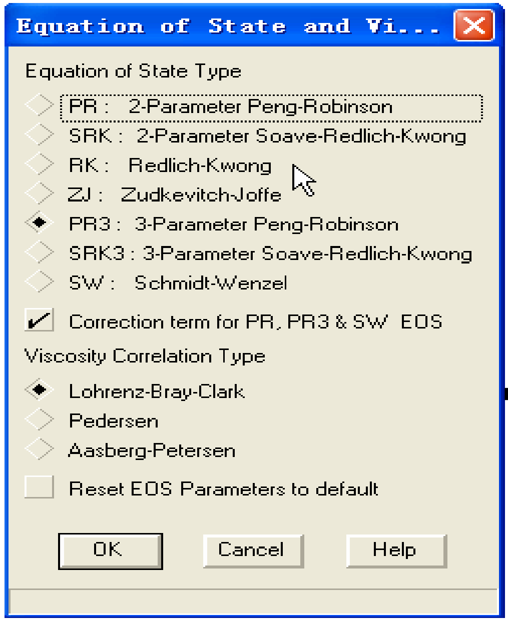
There are 14 wells in Center experomental borefild：4 oil wells, 10 gas injection wells，

4. Establish reservoir model

ECLIPSE



Compositional model



Phase software package

Mechanism of CO_2 miscible displacement

- Make crude oil swelled
- Improve oil's fluidity
- Create depletion drive
- Extraction
- Decrease boundary

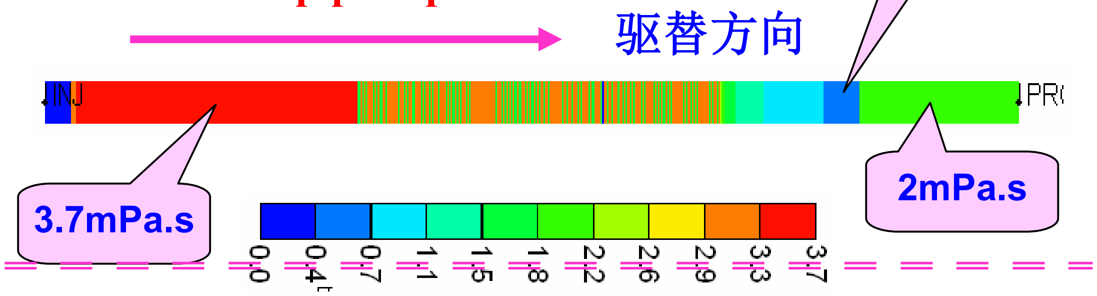
1、Establish phase model of fluid

Fifth step: Examine state equation—show displacement mechanism of CO_2

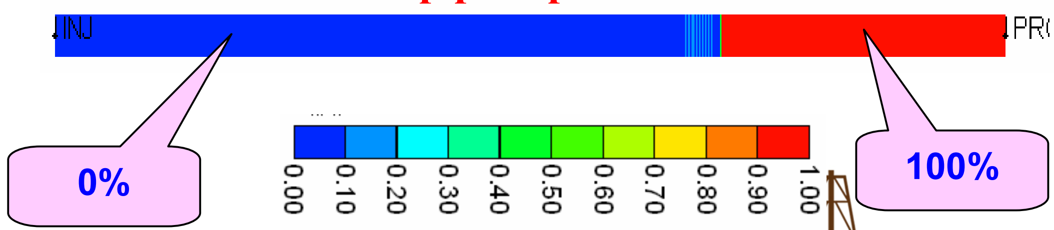
Displacement mechanism of CO_2

- Make crude oil swelled
- Improve oil's fluidity
- Create depletion drive
- Extraction
- Decrease boundary

Field pattern of viscosity in macaroni pipe experiment



Field pattern of oil saturation in macaroni pipe experiment



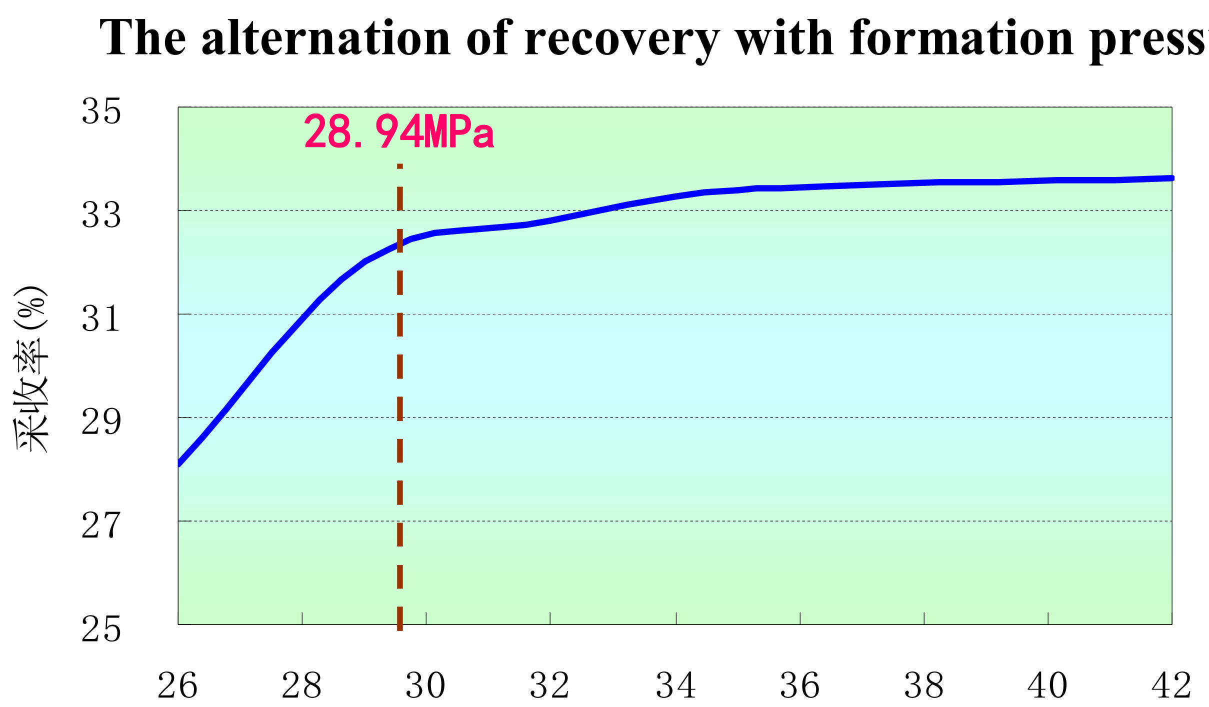
5. Optimization of injection/ production parameters

Optimization design table of CO_2 flooding of G89-1

Optimize parameters	Program	Parameters
Pressure maintenance	1	26MPa
	2	28MPa
	3	30MPa
	4	32MPa
	5	34MPa
	6	36MPa
	7	38MPa
Production rate	1	1.50%
	2	2.00%
	3	2.50%
	4	3.00%
	5	3.50%
Influx	1	0～0.6PV

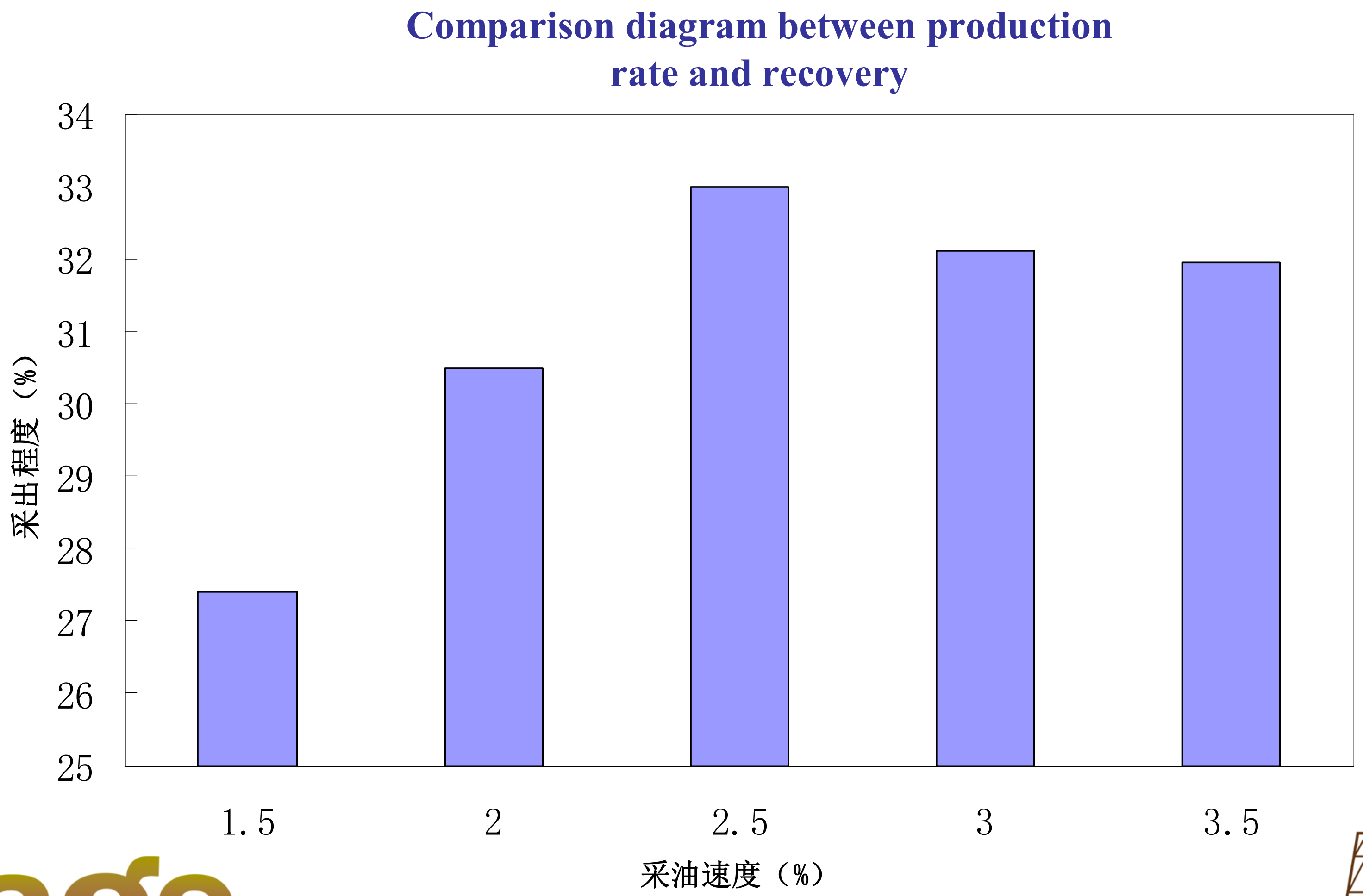
5. Optimization of injection/ production parameters

1、Optimize keeping pressure



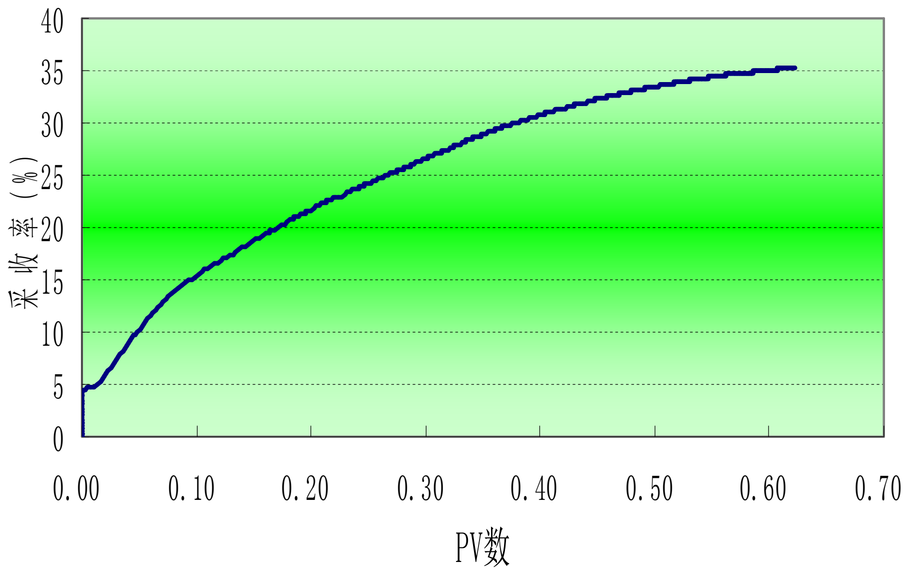
Below the miscibility pressure(28.94MPa),along with the increacing of pressure,the recovery increases quickly. Over the miscibility pressure, the recovery increase slowly. Wherefore, pressure should be kept at 30MPa.

2、 Optimization of production rate

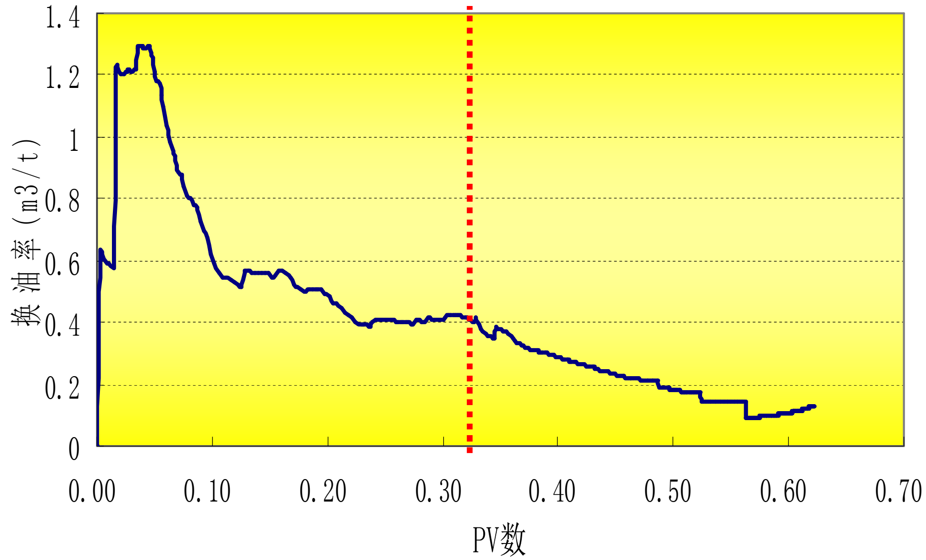


3、 Optimization of CO_2's influx

Relation curve between recovery and PV



Relation curve between daily oil-draining ratio and PV



Along with the increasing of injecting PV, the recovery increases, daily oil-draining ratio decline, accounting economic benefit, the optimal influx is 0.33PV.

6. Forecast recommended program target

Recommended program

（1） One layer series of development

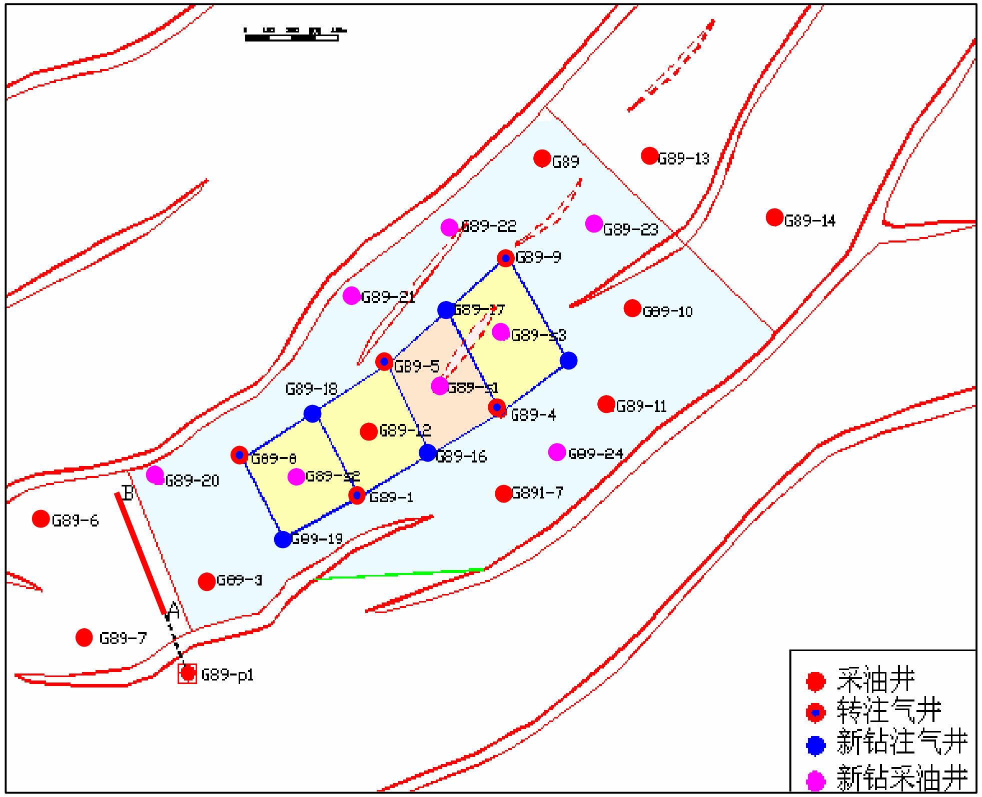
（2） Five-spot network， well spacing： 230-350m

（3）Reservoir pressure maintenance： 30MPa

（4）production rate:2.5%

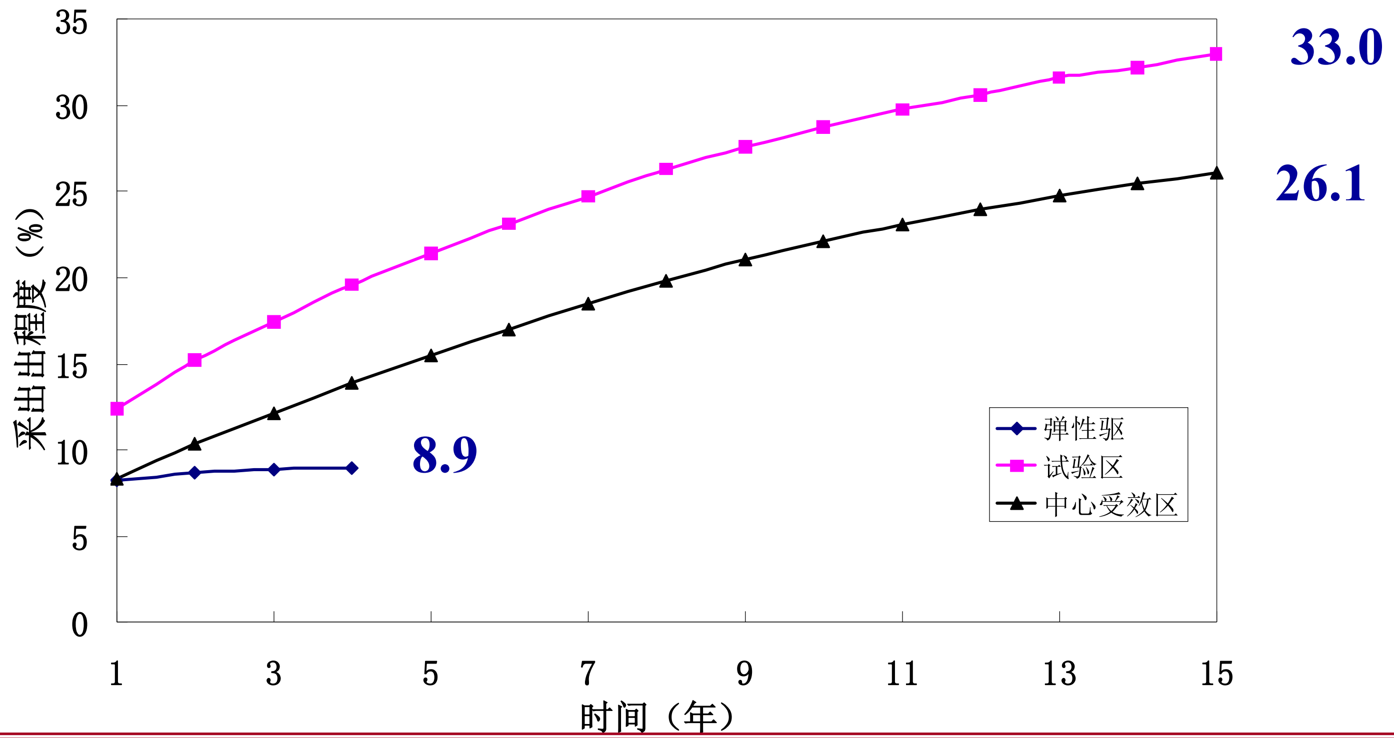
（5） CO2’s influx:0.33PV

Well location of G89-1 for CO_2 flooding



6. Forecast recommended program target

Correlation curve between CO_2 flooding and elasticity development



The degree of reserve recovery of CO_2 flooding is 26.1% after 15 years, advancing 17.2% than elasticity development. the degree of reserve recovery of center response area is 33.0%, cumulative oil production is 16.7×10^4t, per well production is 4.2×10^4t。

outline

- Preface
- Block Screening
- Experimental of EOR of CO_2 flooding
- Optimum Design of CO_2 flooding
- Implementation Effect

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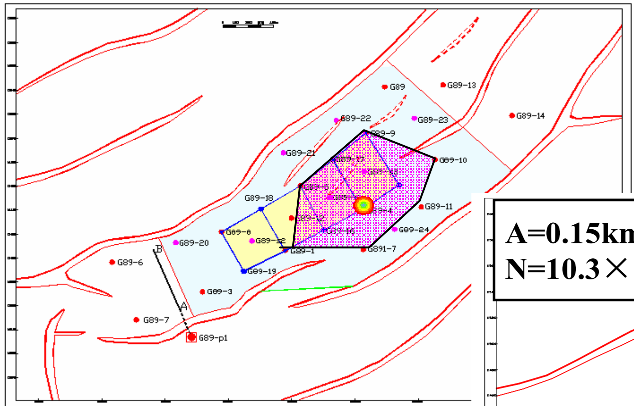
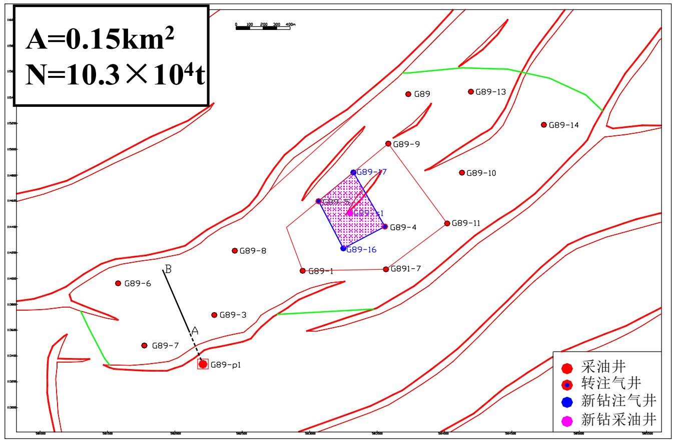
Fifth : Implementation Effect

In accordance with "first single-well test injection, and then the overall promotion ", "three steps" to implement.

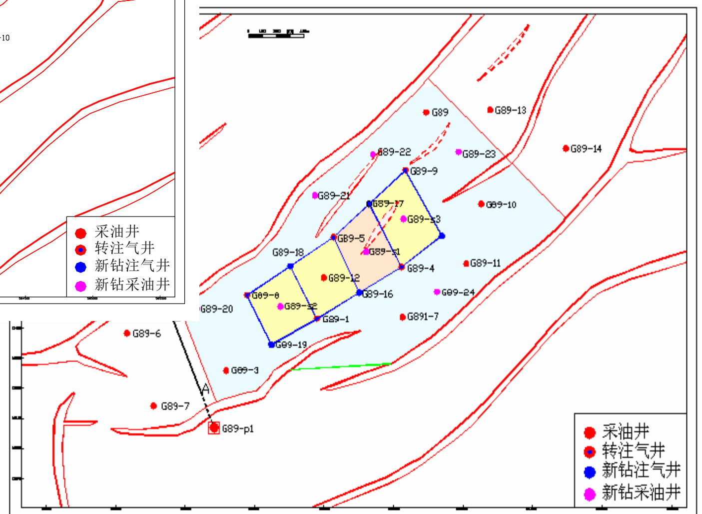
①高89－4井试注



②高89－试1井组



③高89－1块



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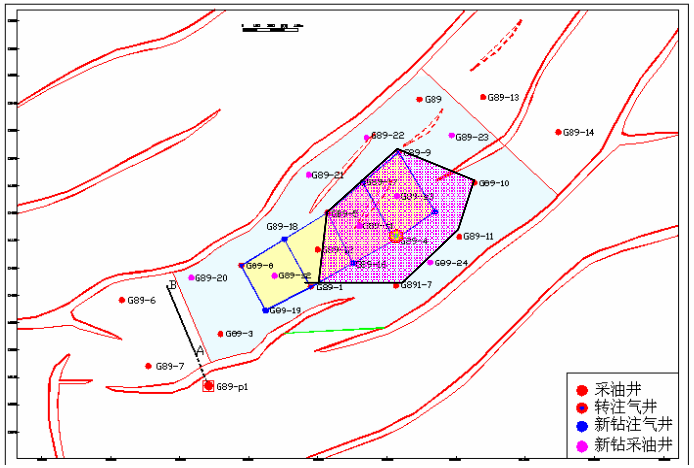
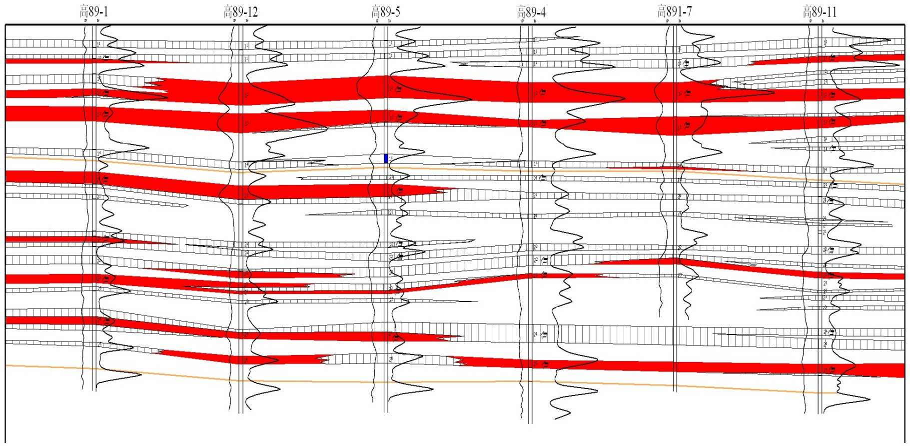
Fifth： Implementation Effect

1、The basic situation of injection well

Gao 89-4 wells around the six production wells , the section of injection-production well shows that: the main layer of good connectivity



Section of injection-production well



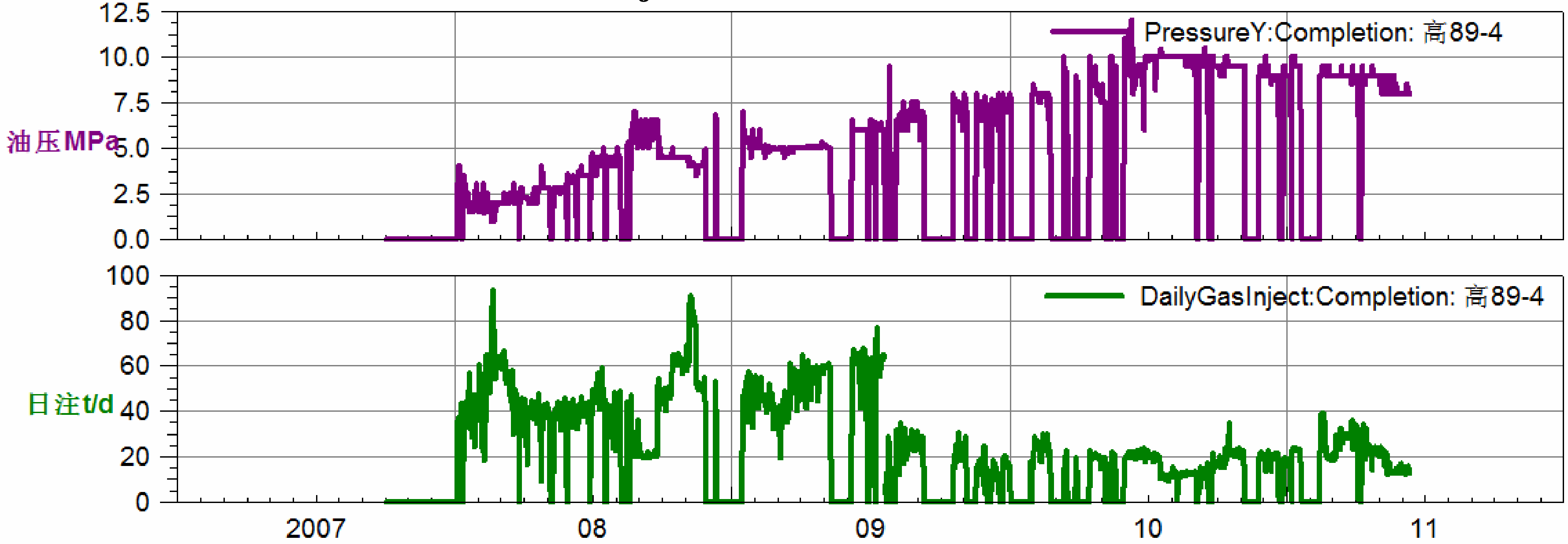
高89-4井基本参数

生产层位		$S_41^{(2\sim3)}$、$S_42^{(1、2、4)}$
生产井段		2935.0-2981.6m
有效厚度		11.6m/6层
压裂情况	压裂液量	355.6m³
	总加砂量	56m³
	破裂压力	66.69MPa
	停泵压力	16.38MPa
累计采液		14472吨

2、Dynamical Laws of Injection

The formation have a stronger suction capacity: January 2, 2008 began injecting CO_2, stable injection pressure 4MPa, injection rate CO_2 40t/d. According to G89-4 wells, the Injectivity Index is 1.57t / (d · MPa · m)

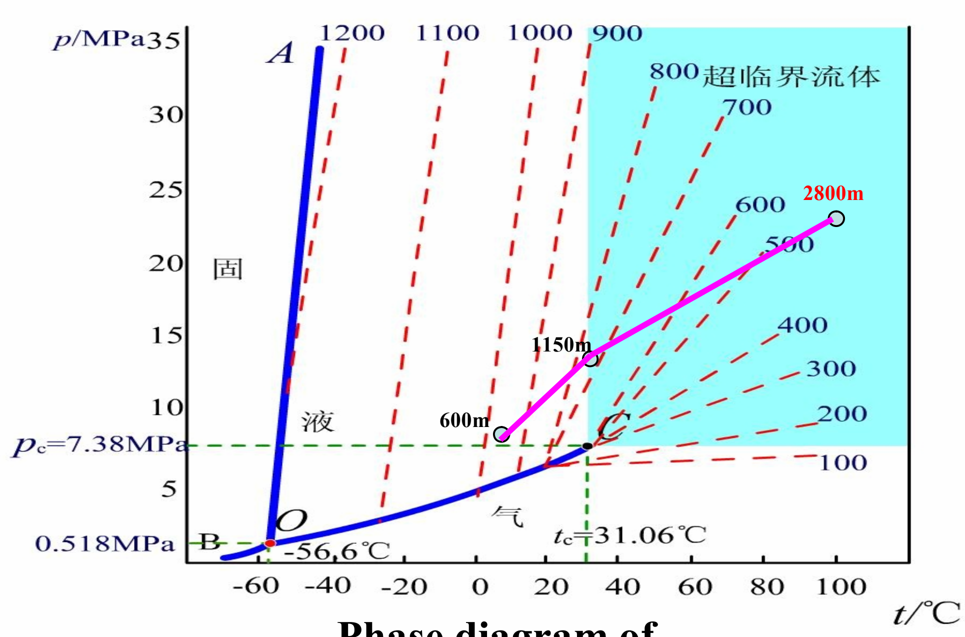
Gas injection curve of G89-4



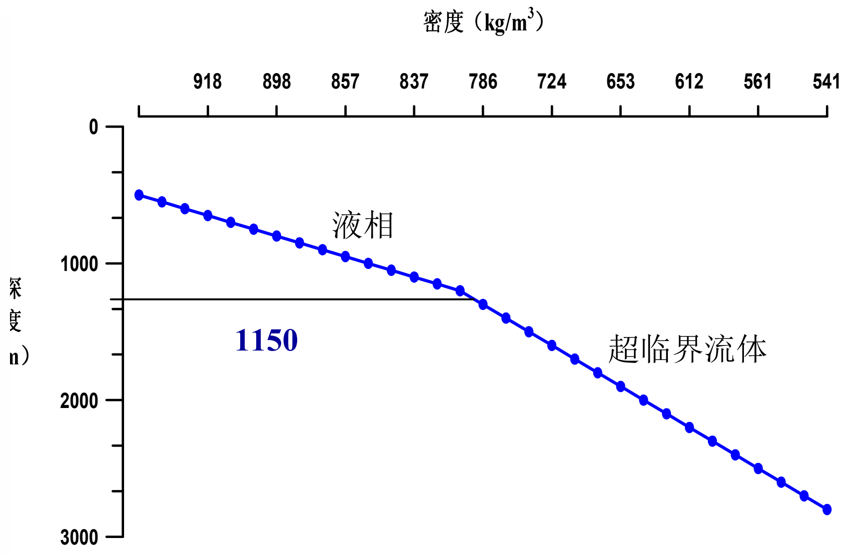
Fifth： Implementation Effect

2、Dynamical Laws of Injection

In the depth of 1150m (12.09MPa, 31.3 ℃), CO_2 is a supercritical state.



Phase diagram of carbon dioxide



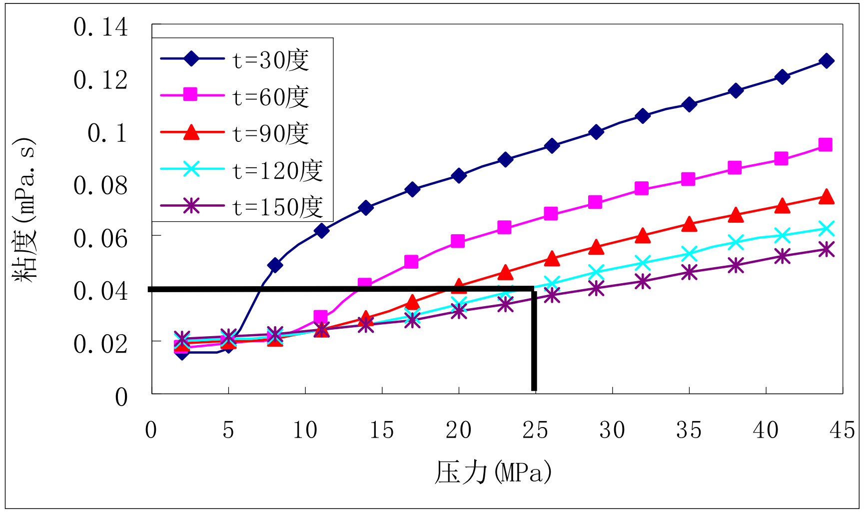
CO_2 density curve with the depth

Fifth： Implementation Effect

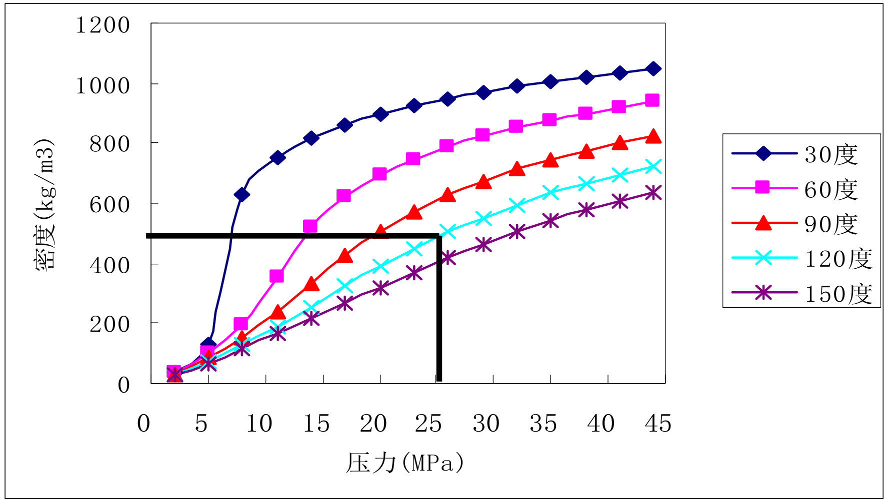
2、Dynamical Laws of Injection

Supercritical fluid has a similar low viscosity of gas, liquid high-density, while both low surface tension properties.

CO_2 viscosity decreases with pressure, temperature variation curve



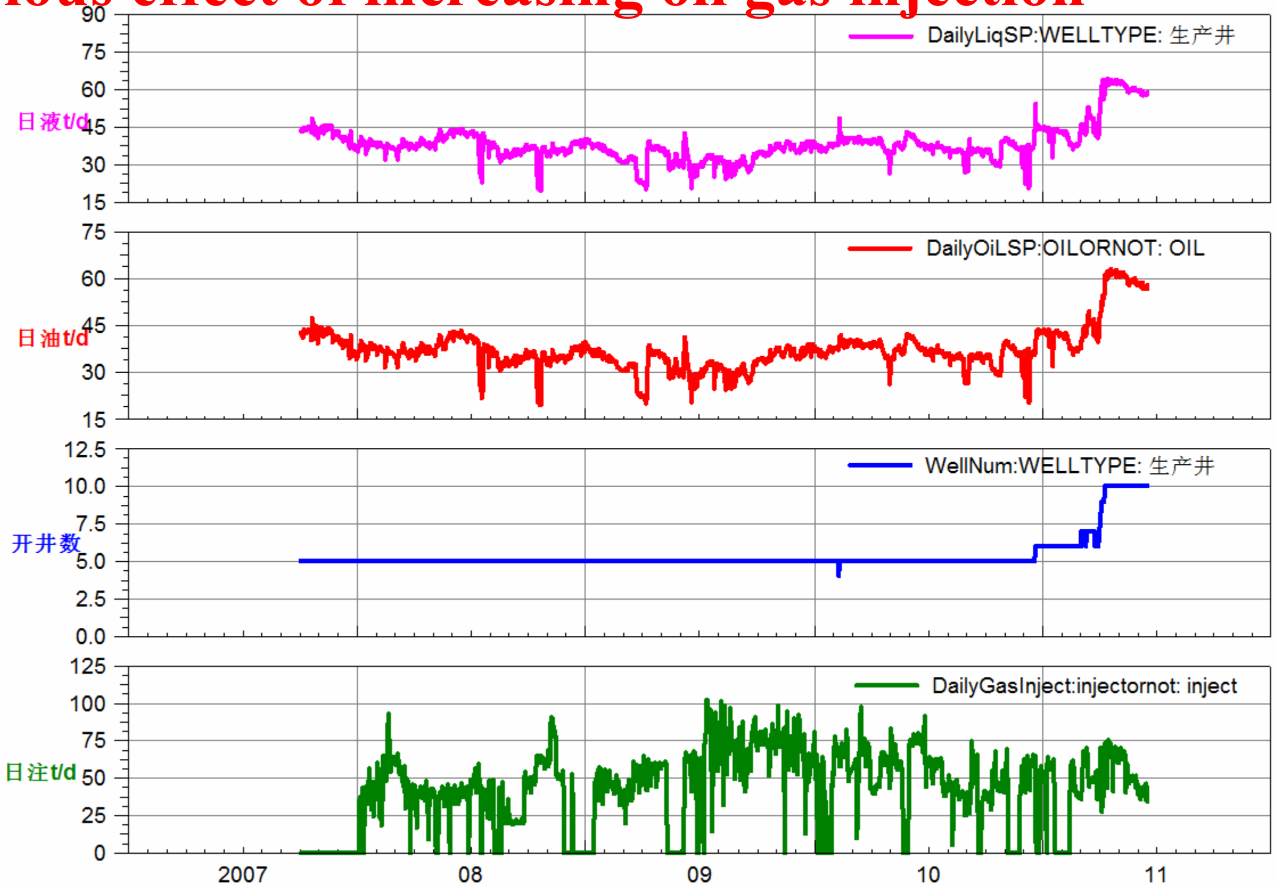
CO_2 Density with pressure, temperature variation curve



Fifth : Implementation Effect

3、Effect of gas injection

◆ **Obvious effect of increasing oil gas injection**

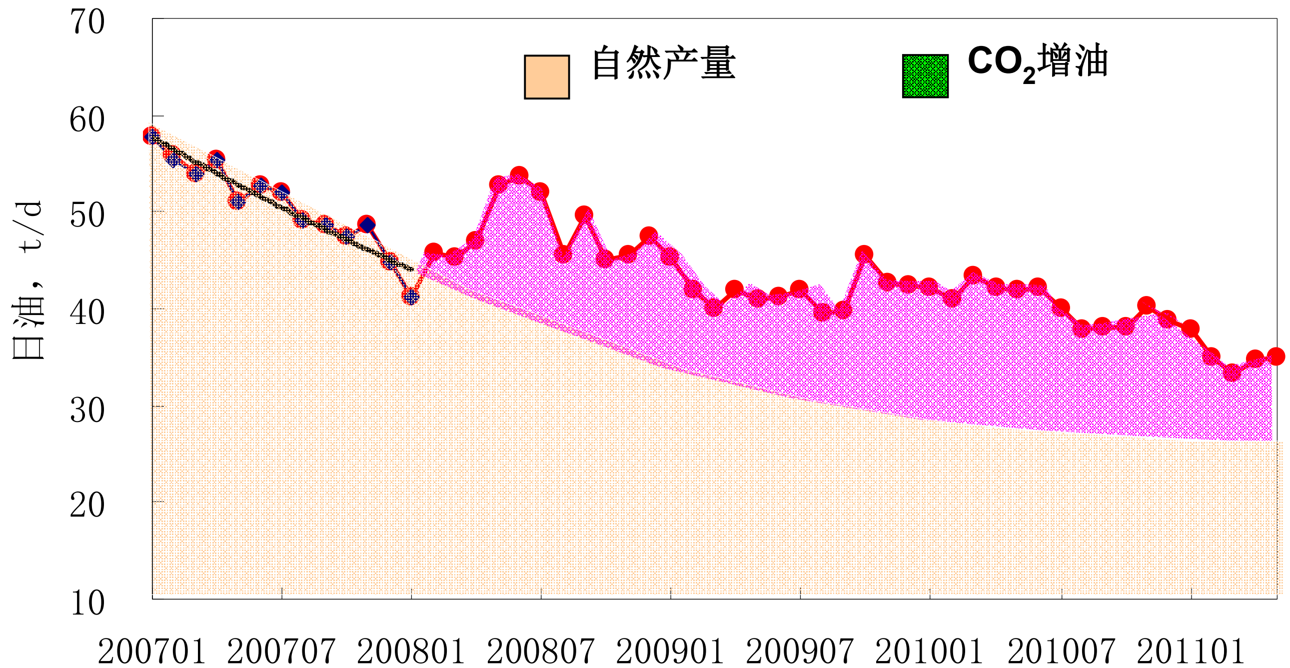


Fifth： Implementation Effect

3、Effect of gas injection

◆ **Obvious effect of increasing oil gas injection**

Oil-producing wells curve of G89-4 well group



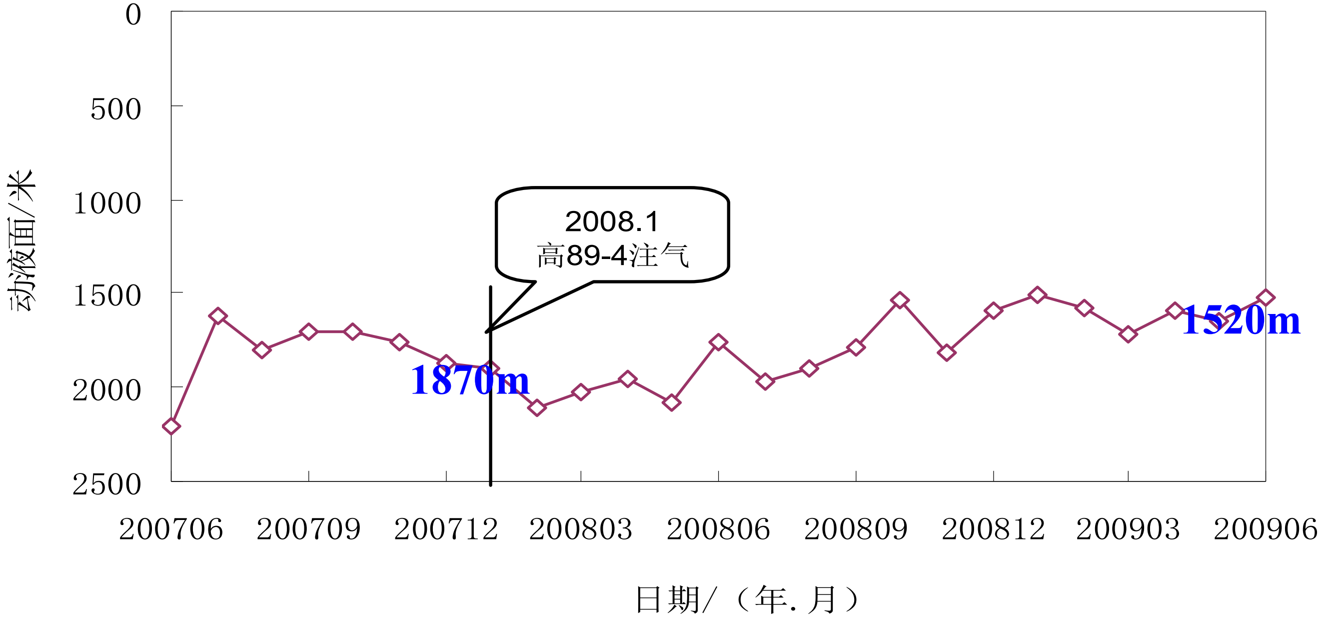
Cumulative increase of oil 11700 tons of well group according exponential decline

Fifth： Implementation Effect

3、Effect of gas injection

◆ Gradual restoration of energy

Producing wells average fluid level curve in the G89-4 Well Group



After gas injection, the fluid level around the producing wells prior to 1870m from the gas injection rose to 1520m. Further indicates that: The CO_2 injection can effectively complement the low permeability reservoir formation energy.

Fifth ： Implementation Effect

3、Effect of gas injection

◆ Part of the nature of crude oil changed for the better after the gas injection

Crude nature of the statistical tables in Unit 89-4

Well	G89-5		G89-9		G89-11	
Date	Dynamic viscositym Pa.s	Freezing Point ℃	Dynamic viscositym Pa.s	Freezing Point ℃	Dynamic viscositym Pa.s	Freezing Point ℃
2008.1	16.85	36	17.4	36	18.18	34
2008.3	12.74	32	16.94	33		
2008.5	14.73	31	13.41	30	8.8	29
2008.7	9.94	28	10.73	30	8.37	27

Thank you!