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Biology Enzyme EOR for Low Permeability Reservoirs

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Abstract

Biology enzyme may change wettablity of rocks, release surface hydrocarbon of formation rock particles, and reduce interfacial tension. These properties may be used to reduce water injection pressure of low-permeability oil reservoirs, to enlarge swept volume and enhance recovery rate. We applied 4 types of biology enzyme solutions with different concentrations ranging from 0.5% to 5.0%, to conduct depressurization experiments on 6 artificial cores and 3 natural cores. When concentration of biology enzyme was 2.0%, injection pressure dropped significantly by 22.6% to 72.7%, averagely a drop of 51.4%. Pilot tests have been carried out based on indoor experiment results, as well as economic factors and operating convenience considerations, and other oilfield experiment parameters references. When volume multiple of injected biology enzyme was chosen to be 0.6%PV, production declination of connected oil wells was controlled and production rose gradually, showing that formation pressure has been restored and biology enzyme has played a part in enhancing the oil recovery rate.

Induction

Daqing Chaoyanggou Oilfield is ultra-low permeability oilfield, showing non-Darcy seepage flow property. The water injection pressure is high, and oil well pressure build-up level is low, causing low water-flooding recovery rate.

In order to improve the development effect of Chaoyanggou Oilfield, we started a biology enzyme depressurization stimulation testing zone.

We selected a 6-waterwell and connected 24-oilwell block as a testing well group. The oil-bearing area of the testing well group is 1.26 km^2, average net pay thickness is 11.5m，active porosity is 15.0%，air permeability is $4.2\times10^{-3}\mu m^2$，initial oil saturation is 54.0%，oil bed temperature is 64.5□，and saturation pressure is 5.34MPa.

Conditions of the six water injection wells are: the average water injection pressure is 15.5MPa，daily single well injection rate is 13 m^3，a cumulative single well water injection rate is 2.75×10^4 m^3.

The situation of the 24 oil well is: daily single well oil output is 1.4t，combined water cut is 11.7%，cumulative single well oil output is 0.35×104t，cumulative water output is 0.06×104 m^3.

I. Biology enzyme performance evaluation

Biology enzyme has extra high ability of releasing reservoir rock particle surface hydrocarbon. It may change wettability of rocks and reduce interfacial tension of rock particle surface, thus reducing the flowing resistance of crude oil in reservoir pores, and obtaining the effect of depressurization stimulation and recovery rate growth.

1. Oil flushing ability evaluation

Combining and agitating crude oil samples and silica sand, before putting in different biology enzyme solution, to observe oil flushing effect. When biology enzyme solution contacts oil-sand, crude oil separates from silica sand surface and formulates floated oil drops and lumps, the sand particle surface turns to be clean and oil water interface is clear, this illustrates that the oil flushing ability of Biology enzyme is rather good.

2. Interfacial tension test

Interfacial tension tester has given tests on Chaoyanggou Oilfield under different enzyme concentrations. From the testing results, we can see that interfacial tension is rather low when concentration of enzyme is around 0.5%~2% (see Table 1).

Table 1 Correlation of biology enzyme concentration vs. crude oil interfacial tension

Biology enzyme concentration (%)	0.20	0.50	2.00	6.00	10.00
Interfacial tension ($\times 10^{-1}$mN/m)	4.88	2.01	2.52	7.15	9.50

3. Surface adsorptivity evaluation

Injecting 1PV biology enzyme solution with concentration of 2.0%, to displace 2PV water, the outlet enzyme albumen content is tested. The unit porous volume adsorptivity is 441.54μg/ml, and under this adsorptivity, residue oil saturation can be reduced significantly (see Table 2).

Table 2 Adsorptivity of biology enzyme solution

Sample	2%enzyme solution	Solution after displacing 2PV	Injected enzyme albumen (μg)	produced enzyme albumen (μg)	Unit porous volume adsorptivity (μg/ml)
enzyme albumen content (μg/ml)	787.54	173.00	4347.22	1909.92	441.54

4. Corrosivity test

In hanging sheet corrosometer reactor, N80 sheet is put in the enzyme solution, after 4h reaction, the sheet is dried and weighed, the mass change of the tested sheet before and after the test shows that enzyme solution has no corrosion impact on N80 steel.

Table 3 Corrosivity of biology enzyme solution

Sheet no.	Length of sheet (mm)	Width (mm)	thickness (mm)	Mass (g)		Soak time (h)	Corrosion rate (g/m2·h)
				Before test	After test		
721	50.03	10.02	3.00	11.7447	11.7447	4	0
722	50.02	10.01	3.00	11.7445	11.7445	4	0
723	50.03	10.01	3.01	11.7446	11.7446	4	0

5. Impact of injection method on injection pressure

We adopt continous injection and multi plug injection in the testing. Results show that in the whole process, pressure drop is roughly the same, this indicates that injection method has little impact on biology enzyme depressurization ability (see Table 4).

Table 4 Core parameter

Core no.	length(cm)	radius(cm)	porosity(%)	permeability($\times10^{-3}\mu m^2$)
T-1	8.66	2.50	13.6	33.8
T-3	9.01	2.50	12.9	32.9

Table 5 Biology enzyme depressurization ability by different injection methods

Inject. method	Pinj (MPa)	Displacing liquid pressure under different displacting multiples									
		PV	0.000	0.125	0.250	0.375	0.500	0.625	0.750	0.875	1.000	2.000
Continu. Inject.	1.15	media	Biology enzyme solution									water
		Pinj .(MPa)	0.995	0.87	0.955	1.000	1.035	1.025	1.030	1.040	1.040	1.060
		P Drop (%)	13.48	24.35	16.96	13.04	10.00	10.87	10.43	9.57	9.57	7.83
Separate Plug inject.	1.23	media	0.5PV Enzyme	water	water	water	water	enzyme	enzyme	enzyme	enzyme	water
		Pinj .(MPa)	1.091	1.038	1.064	1.092	1.121	1.123	1.134	1.141	1.140	1.151
		P drop (%)	11.30	15.61	13.50	11.22	8.86	8.70	7.80	7.24	7.32	6.42

6. Biology enzyme depressurization ability

Applying 4 types of different biology enzyme solution between concentration of 0.5%～5.0%, on 6 artificial cores and 3 natural cores to conduct depressurization experiments. When biology enzyme concentration is 2.0%, injection pressure drops significantly by 22.6%～72.7%, averagely 51.4%，so in site injected biology enzyme concentration is fixed at 2.0% (see Table 6).

Table 6 Indoor core biology enzyme depressurization experiments

Core no.	Gas log Permea. ($\times10^{-3}\mu m^2$)	Enz. Concen. (%)	Water flood, Press. gradient (at/cm)	Enzyme. Injection Press. gradient (at/cm)	Enzyme. Injection Press. gradient drop(%)	Succeeding Watr. Flood Press. gradient (at/cm)	Succeeding Watr. Flood Press. gradient drop(%)
Artifi.D-6	33.7	0.5	0.234	0.190	18.8	0.158	32.6
Artifi. D-3	33.7	1.0	0.215	0.128	40.5	0.136	36.7
Artifi. D-4	33.7	2.0	0.418	0.114	72.7	0.189	54.8
Artifi. D-5	33.7	5.0	0.358	0.105	70.3	0.154	57.0
Artifi. D-2	33.7	5.0	0.382	0.075	80.3	0.234	38.7
Artifi. 2	58.0	5.0	0.248	0.179	27.8	0.163	34.3
Natural 2	73.0	2.0	0.889	0.688	22.6	0.296	66.7
Natural 5	33.8	2.0	0.946	0.334	64.7	0.541	42.8
Natural 6	6.3	2.0	3.790	2.160	45.6	2.460	35.1

According to indoor experiment results, considering economic and site operating convenience, as well as other oilfield adopted parameters, the injected biology enzyme volume multiple is chosen to be 0.6%PV.

II. Site injection plan

1. Injection rate

According to injection parameter determined from indoor experiments, we should prepare $1.265\times10^4 m^3$ biology enzyme solution with concentration of 2%, biology enzyme liquid consumption is 253.0t, single well injection rate will be based on geological plan (see Table 7).

Table 7 Biology enzyme consumption design

Well no.	Net pay thick(m)	Daily water Injection(m^3)	Injection time(d)	Total injection rate(m^3)	Biology enzyme (t)
104-new60	13.4	20	110	2200	44
104-62	18.6	25	110	2750	55
106-64	8.2	15	110	1650	33
107-61-1	9.2	15	110	1650	33
108-62	10.8	20	110	2200	44
108-64	19.0	20	110	2200	44
total	79.2	115		12650	253

2. Ground injection flow design

Test well 108-64 is located at $20^{\#}$-2 water allocation room, water is injected by pump truck at well head by plug type flow. Five other test wells are located at $20^{\#}$-1 water allocation room, injection flow is based on the water allocation room flow, the injection water is added to tank to prepare biology enzyme solution, before injected into wells by single well flow with plunger displacement pump.

III. Test effect analysis

Site injection of biology enzyme started from December 26, 2007 to April 20, 2008. Total biology enzyme liquid consumption is 270t, enzyme solution injection rate is 11422m^3(see Table 8).

Table 8 Biology enzyme site operation

Injec. Meth.	Well no.	Injection. Time	Enzyme solution Accumulative injection (m^3)	Enzyme acumulative consumption (t)	Injected enzyme solution concentration (%)	Displacting concentr. (%)	Injected Plug No.
Well group Continu. injection	5	Dec. 26, 2007 ～ April 20,2008	11112	226	2	2	
single well plug injection	1	January 4,2008 ～ March 18,2008	310	44	14.2	2	13
total	6		11422	270			

Since biology enzyme was injected, water wells have shown depressurization stimulation effect, connected oil well production declination trend has been controlled and production gradually rises, formation pressure has been restored. After half a year test, produced liquid from oil wells was tested to contain biology enzyme, meanwhile, properties of crude oil and salinity of produced liquid have some changes, these indicate that new oil production sections imerge, showing reservoir productivity rise.

Compared with 110-66 , 110-68, 112-68 and 112-70 in the same block, biology enzyme test zone shows depressurization stimulation effect.

1. Water well injection state analysis

□Injection pressure of water well declines, water absorption index rises

Biology enzyme injection has lasted for 13 months, within one year of biology enzyme injection, average water injection pressure rises and than drops in the whole process. After one year of injection, injection pressure starts to rise. Within half a year of test, when boosting is adopted, average injection pressure rises from 15.5MPa to 16.0MPa, average daily water injection rate rises from 13m^3/d (before boosting) to 19m^3/d, all water wells meet allocation requirements, water absorption index rises from 0.84m^3/d·MPa to 1.19m^3/d·MPa.

After half a year of test, under condition of injected water volume meeting allocation requirements, water injection pressure shows declination trend, average water injection pressure drops from 16.0MPa in the sixth month of test to 15.6MPa currently, water absorption index rises from 1.19m^3/d·MPa to 1.22m^3/d·MPa, water well absorption ability has been strengthened.

Table 9 Test zone water well injection state

Well no.	Injec. (m^3/d)	Watr.injec. press. (MPa)					Daily injection(m^3/d)					Water absorp. index(m^3/d·MPa)				
		2007-06	Before	Half Year later	2008-12	2009-03	2007-06	before	Half Year late	2008-12	2009-03	2007-06	before	Half Year Late	2008-12	2009-03
104-60	20	15.0	15.3	15.5	15.4	15.4	20	20	20	20	20	1.33	1.31	1.29	1.30	1.30
104-62	25	15.6	16.0	16.7	15.5	15.5	9	8	25	25	23	0.58	0.50	1.50	1.61	1.48
106-64	15	15.7	15.8	17.0	16.1	17.3	9	5	15	15	13	0.57	0.32	0.88	0.93	0.75
107-61-1	15	15.6	15.8	17.1	16.1	16.3	6	4	15	15	13	0.38	0.25	0.88	0.93	0.80
108-62	20	15.0	15.3	15.5	14.5	14.8	20	20	20	20	20	1.33	1.31	1.29	1.38	1.35
108-64	20	14.5	14.7	14.4	14.2	14.5	20	20	20	20	20	1.38	1.36	1.39	1.41	1.38
average	19	15.2	15.5	16.0	15.3	15.6	14	13	19	19	18	0.93	0.84	1.19	1.24	1.15

In 2009, water well injection pressure started to rise, average pressure has risen from 15.3MPa in December, 2008, to 15.6MPa at present, water well absorption state worsens. Compared with 110-66, 110-68, 112-68, 112-70, in the same block, water well depressurization stimulation in enzyme test zone is rather effective (see Table 9).

Average water injection pressure of biology enzyme test zone rises from 15.5MPa before test to 15.6MPa at present， water absorption index rises from 0.84m^3/d·MPa to 1.15m^3/d·MPa, a 0.31m^3/d·MPa increase. However, water injection pressure in comparative wells rises from 14.3MPa to 14.7MPa(0.4MPa increase), water absorption index drops from 1.33m^3/d·MPa to 1.22m^3/d·MPa(0.11m^3/d·MPa drop). Eventhough biology enzyme zone adopts boosting injection, injection pressure change trend of water wells are totally different from boosting injection zone in edges of 45 Block.

In 45 Block, boosting injection zone has oil bearing area of 1.35km^2， gelogical reserves of 84.97×10^4t， reservoir porosity of 16.5%, permeability of $9.0\times10^{-3}\mu m^2$. Totally 20 oil water wells are located in the block, among them, 6 wells are water wells, average daily allocation rate before boosting is 18m^3, actual daily injection rate is 13m^3, injection pressure is 13.3MPa， boosting injection was applied from June, 2002, to june, 2003.

In the process of boosting injection in 45 Block, under the condition of daily injection rate maintaining unchanged, injection pressure continues to rise, from 13.4 MPa to 14.8MPa. While water well injection pressure of biology enzyme zone drops significantly after half year test. This shows that biology enzyme has depressurization stimulation effect.

□ Interlayer water absorption situation has been improved

Comparing water absorption profile data before and after biology enzyme injection, we can see that water well interlayer water absorption difference decreases.

Annual comparision water absorption layer number increases by 12.5%，sand thickness water absorption increases by 11.0% ，net pay thickness water absorption increases by 12.7%, swept volume of injected water is enlarged and remained oil is driven effectively (see Table 10).

Table 10 Test zone water well interlayer water absorption

Well No.	Whole well			Year 2007 test						Year 2008 test					
				Value			percentage			value			percentage		
	Layer No.	sand	Net pay	Layer No.	sand	Net pay	Layer No.	sand	Net pay	Layer No.	sand	Net pay	Layer No.	sand	Net pay
104-new 60	7	22.4	13.4	3	11.8	7.6	42.9	52.7	56.7	3	11.8	7.6	42.9	52.7	56.7
104-62	7	23.4	18.6	3	11.2	8.0	42.9	47.9	43.0	3	11.2	8.0	42.9	47.9	43.0
106-64	3	9.6	8.2	1	5.1	4.0	33.3	53.1	48.8	2	8.4	7.0	66.7	87.5	85.4
107-61-1	3	10.0	9.2	1	3.6	3.2	33.3	36.0	34.8	2	7.0	6.4	66.7	70.0	69.6
108-62	6	12.0	10.8	2	3.8	3.4	33.3	31.7	31.5	3	8.2	7.4	50.0	68.3	68.5
108-64	6	22.2	19.0	2	9.2	8.2	33.3	41.4	43.2	3	9.1	8.0	50.0	41.0	42.1
Total	32	99.6	79.2	12	44.7	34.4	37.5	44.9	43.4	16	55.7	44.4	50.0	55.9	56.1
difference										4	11.0	10.0	12.5	11.0	12.7

2. Connected oil well production analysis

□ Oil well production rise slightly back, combined watercut is stable

There are 24 oil wells in test area, among them, 5 wells are shut up wells, and 19 wells are producing, 3 wells are biology enzyme treated wells, and 16 wells are comparative wells. By using production data of comparative wells one year before test, and through tracing back the data, we find that the test wells decline progressively; annual declination rate is 14.3%，average monthly declination rate is 1.2%. Forecast has been made on the production of wells without biology enzyme treatment.

Through comparing forecasted production and actual production, production declination trend of the comparative wells has been controlled and production rises back when not been adjusted or stimulated by other means. In 2008, daily production of the annual comparison rises from 27.9t to 30.7t，a 2.8t rise，combined watercut remains stable.

Since the first quarter of 2009, production of oil wells drops back, daily production drops from 30.7t to 28.6t，a drop of 2.1t. Till the end of March, accumulative increased oil of the test area is 2208t，recovery rate is 0.24%，if not considering oil well production declination factor, accumulative increased oil is 826t only. Biology enzyme test facilitates production declination control and periodic recovery rate enhancement results.

Different from comparative wells 110-66, 110-68， 112-68, 112-70, whose prodution declines continuously, biology enzyme test zone production declination control proves to be effective.

Comparative well group contains 12 wells, among them, 3 wells are shut up wells, 9 wells are producing, 9 wells are comparative wells.

Using production data of 2007, through tracing back the data, we have obtained comparative well group declination law: annual declination rate is 10.6%，average monthly declination rate is 0.9%. And annual declination rate of 2008 is 9.9%，average monthly declination rate is 0.8%，the oil well production declines continuously. While in the biology enzyme area, in 2007, monthly declination rate reaches 1.2%, yet through biology enzyme test, average monthly increase rate of 2008 is 0.8，showing a significant effect of biology enzyme on production drop control.

□ Formation pressure buildup

Before and after test, 2 connected oil wells have undergone pressure buildup test. Logging data shows that formation pressure rises continuously after test, indicating that biology enzyme has depressurization stimulation ability and may cause formation pressure buildup.

For example, 105-63-2 well illustrates: 2 years before test, the formation pressure rise is 0.37MPa， after test, from April to August, a period of nearly 5 months, the formation pressure rises to 0.56MPa， pressure buildup rate rises significantly, verifying that biology enzyme may enhance displacing efficiency (see Table 11).

Table 11 Pressure tests on test wells

Well no.		Before test		after		
105-63-2	Time of test	2005-11-23	2007-10-28	2008-4-2	2008-5-26	2008-8-20
	Press.(MPa)	3.78	4.15	4.12	4.39	4.68
109-63	Time of test		2007-11-29	2008-2-29		2008-8-20
	Press.(MPa)		10.57	10.87		12.5
average			7.36	7.5		8.59

□ Produced biology enzyme composition test

In order to test biology enzyme frontier advancing rate, qualative tests on produced liquid from connected oil wells have been carried out to obtain biology enzyme composition. Results show that sample wells yield biology enzyme after half a year of test, biology enzyme is injected in water wells and displaced to oil wells and be produced thereafter, realizing influencing the oil layers and advancing evenly. In the oil layers, biology enzyme separates the oil film and drives the remained oil, forming an oil driving force, which enhances the recovery rate (see Table 12).

In March of 2009, 19 oil wells underwent biology enzyme composition tests, and none of them yielded biology enzyme, indicating that biology enzyme injected to the oil layers have been fully produced.

Table 12 Produced liquid biology enzyme testing results

Well no.	Test date								
	March.26	June 20	July 24	august22	Septembe 27	Octo.3	december11	Janua.7	Feburary18
105-63-2	×	√	√	√	√	√	√	√	×
107-63-2	×	√							
105-61-1	×	√							
109-63			×	√	√	√	√	√	×
107-65-2			√						

□ Properties and salinity of produced crude oil change significantly

Before and after the test, 3 oil wells in the test zone underwent oil sample analysis. Results show that viscosity of crude oil and asphalt content rise, showing that biology enzyme displacing agent may clear the oil layer channels, influence the untouched oil layers, enlarge the swept volume, and enhance the oil driving effect (see Table 13 and 14).

Table 13 Oil well overall analysis

Well no.	Time	Crude oil watercut (%)	Produced liquid (t/d)	50℃viscosity (MPa·s)	Gel content (%)	Asphalt content (%)
105-61-1	Before Test	12.5	1.6	26.02	11.82	0.32
	After	3.4	2.1	30.65	8.25	1.23
105-63-2	Before	6.7	1.9	30.21	11.56	0.43
	After	4.1	2.5	35.04	12.72	4.56
107-63-2	Before	22.6	1.4	25.13	11.09	0.46
	after	16.8	1.7	28.89	10.49	2.42

In the produced liquid, Cl^- ion content and salinity rise markedly, showing that the untouched oil layers in water flooding stage are driven by biology enzyme, and new production section emerges, oil layer displacement state has been improved.

Table 14 Ion content and salinity of produced liquid

Well no.	Cl^-(mg/l)		salinity(mg/l)	
	before	after	before	after
103-61-2	486.85	593.85	1574.02	1774.59
107-63-2	83.32	233.21	1093.08	1667.58
105-59	332.92	432.35	2430.47	2670.62
105-61-1	499.47	709.6	1878.13	2031.45
105-61-2	751.17	822.32	1789.25	2124.22
105-63-1	666.15	698.13	1613.43	1800.43
105-63-2	449.55	533.73	1422.67	1636.4
106-62	649.49	658.93	1641.85	1857.04
average	489.87	585.27	1680.36	1945.29

IV. Conclusions

 For the water wells, general injection pressure shows rise-and-than-drop trend, after the test, all water wells may meet requirements, water well absorption ability is strengthened, illustrating that biology enzyme may cause depressurization stimulation effect in low permeability reservoirs. From the water absorption profile test, water well interlayer absorption difference is improved and new affected zones appear.

 Production declination trend of connected oil wells have been controlled and production rises back, till the end of March, 2009, accumulative increased oil is 2208t， and meanwhile, the formation pressure is builtup, proving that biology enzyme plays a part in releasing reservoir rock particle surface hydrocarbon and increasing liquid seepage ability, the recovery velosity is thus improved.

 Produced biology enzyme test and sample analysis for the oil wells show that biology enzyme driving frontier may evenly advance, and separate the oil film and drive remained oil as well as improve untouched reserves development. From the ion content and salinity test of produced liquid, we may see that new production section is developed and oil layer displacement state is good.

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