GreenZyme®

Analysis of Greenzyme® in Oilfield Recovery: Biological enzyme treatment to remove blockage, Oil Well WeiZhou 11-4-A3

April 30, 2003

CNOOC (China) Limited Zhanjiang Branch
Apollo Company, United States
GuiLin Technology College, China
Pacific Limited, Houston, United States

GEOLOGICAL STRUCTURE CHARACTERISTICS

The WeiZhou 11-4 oilfield is located in the north bay of the South China Sea. It is 103 km from PeiHai of Guangxi Province and 55 km from WeiZhou Island. It is 17 km from the WeiZhou 10-3 oilfield and 30 km from the WeiZhou 12-1 oilfield. The scope of the mineral area is 20°39'-20°42' N, 108°38'-108°44' E. The water depth in the sea area where the oilfield is located is about 42-44 m.

The WeiZhou 11-4 structure is a drape anticline structure growing on a bedrock projection. It has a complete structure and a simple form. No fractures are present in the oil-containing area of the oilfield. The below-ground depth of the structure is 870-1030 m. The oil zone is upper third Jiaowei [transliteration] group section two and the Xiayang [transliteration] group and is divided into oil groups I, II, III from the top to bottom. Said oil zones I and II are the upper third Jiaowei section two stratums, while oil group III is the Xiayang formation stratum. The three oil zones have a similar primary structural form, and the apexes are basically superimposed. The main oil zone in oil group II has a length of 9.3 km and a width of 2.5 km. The structural apex is –930 m. The closed height is 45 m. The closed area is 17.7 km^2. None of the three oil zones has a high oil column. The oil column heights of oil zones I, II, III are 28 m, 39 m, 14 m, respectively.

The three reservoir zones form three independent oil reservoir units. The confining type of all three oil reservoirs belongs to structural control but is also subjected to lithologic control. Zone I is a lithologic-structural oil reservoir, while zones II and III are structural oil reservoirs.

The WZ11-4-A3 well is an inclined well of platform A. The production reservoir is Jiaowei formation zone II.

WELL HISTORY

Drilling of this well started in 1992. Drilling was completed at a well depth of 1217 m on August 31. Well completion started on January 3, 1994 and ended on January 5th. Production started on January 6, 1994. Up to January 2003, the well had produced 388800 m^3 oil and 1398300 m^3 natural gas and 138400 m^3 water. The production situation was initially good. The initial submersible electric pump discharge amount was 100 m^3/d with oil production of 148 m^3/d and zero water content. As the water content increased, the oil production dropped gradually. This well was subjected to the first major pump extraction on December 1, 2000. The pump discharge rate changed to 200 m^3/d. A relatively good extraction oil increase effect was realized after the change. Before the change, the oil production was 98.1 m^3/d, and the water content was 36.7%. The fluid generation rate was 155 m^3/d. After the change, the oil production was 160 m^3/d, the water content was 44.2%, and the fluid generation rate was 287 m^3/d. The second major pump extraction was conducted on June 2, 2001. The pump discharge rate was changed to 300 m^3/d. The extraction effect was insignificant after the change. The oil production prior to the change was 124 m^3/d, the water content was 49.5%, and the fluid generation rate was 245 m^3/d. After the change, the oil production was 145 m^3/d, the water content was 50.2%, and the fluid generation rate was 291 m^3/d. The oil production had dropped to 49 m^3/d, the fluid generation rate had dropped to 200 m^3/d, and the water content was 76%. This indicates the wellbore of the oil well had been blocked, hindering the flow of oil and water.

BASIC WELL DATA

- Well No.: WZ11-4-A3
- Well type: Producing well
- Substrate hole No.: 2#
- Complete drilling well depth: 1217 m
- Complete drill stratum position: Xiayang formation
- Artificial well bottom: 1180 m
- Maximum well inclination: 45°/826.0-872.0 m
- Current Production Zone: Jiaowei formation II
- Well completion method: Filled with gravel
- Casing data(see Figure 1)
- Well position diagram (see Figure 2)

CASING DATA (Figure 1)

Casing Size	30"	13 3/8"	9 5/8"	7"
Depth (m)	143	0	279.5	1208.46

OIL ZONE DATA

Zone	Sub-layer	Sub-layer Straight well section (m)	Zone data					
			Thickness of the sand layer (m)	Effective thickness		Effective permeability	Porosity (%)	Oil content saturation degree
				Oil layer (m)	Gas layer			
I	Poor oil layer							
	Oil Layer							
	Water layer							
II	Loose oil layer	970.1-973.8	3.7	3.7	0	1415.4	29.4	77.2
	Upper calcium-containing oil layer	973.8-982.6	8.8	8.8	0	521.99	19.5	84.4
	Lower calcium-containing oil layer	982.6-995.6	13	13	0	1170.33	27.3	79.1
	Compact layer	995.6-996.2	0.6	0	0	0.79	5.4	0
	Water layer	996.2-1014.7	18.5	0	0	958.13	24.9	14
III	Oil layer	1020.2-1028.9	8.7	8.7	0	538.64	18.5	82.7
	Water layer							

PERFORATION DATA

Zone	Perforation Zone	Oil section length (m)
II	1095.9-1108.2 970.1-980.0 (TVD)	12.3

STIMULATION OBJECTIVE

Inject Greenzyme® to remove blocking in order to lower the water content, stabilize oil and control water, and increase the crude oil production.

GEOLOGICAL AND JOB REQUIREMENTS

1) Geological requirements

The submersible electric pump in the A3 well has a relatively poor oil extracting effect and is unable to meet the rated discharge rate of the electric pump. Also, this well has relatively high water content (75%). Injection of Greenzyme® is required to improve the oil flow of the reservoir, lower the water content, and increase the crude oil production.

2) Job requirements

Based on calculations from experience, this well should use 15 barrels (15x0.2=3 m^3) Greenzyme®. Since this well has a high water content, the recommended concentration is 8% Greenzyme® solution, prepared using the formation water. The temperature of the injected solution should be higher than 50°C.

3) Method for treatment

The treatment process has the following requirements:

a) Injection method: Squeeze reversely from the casing to directly enter the reservoir.

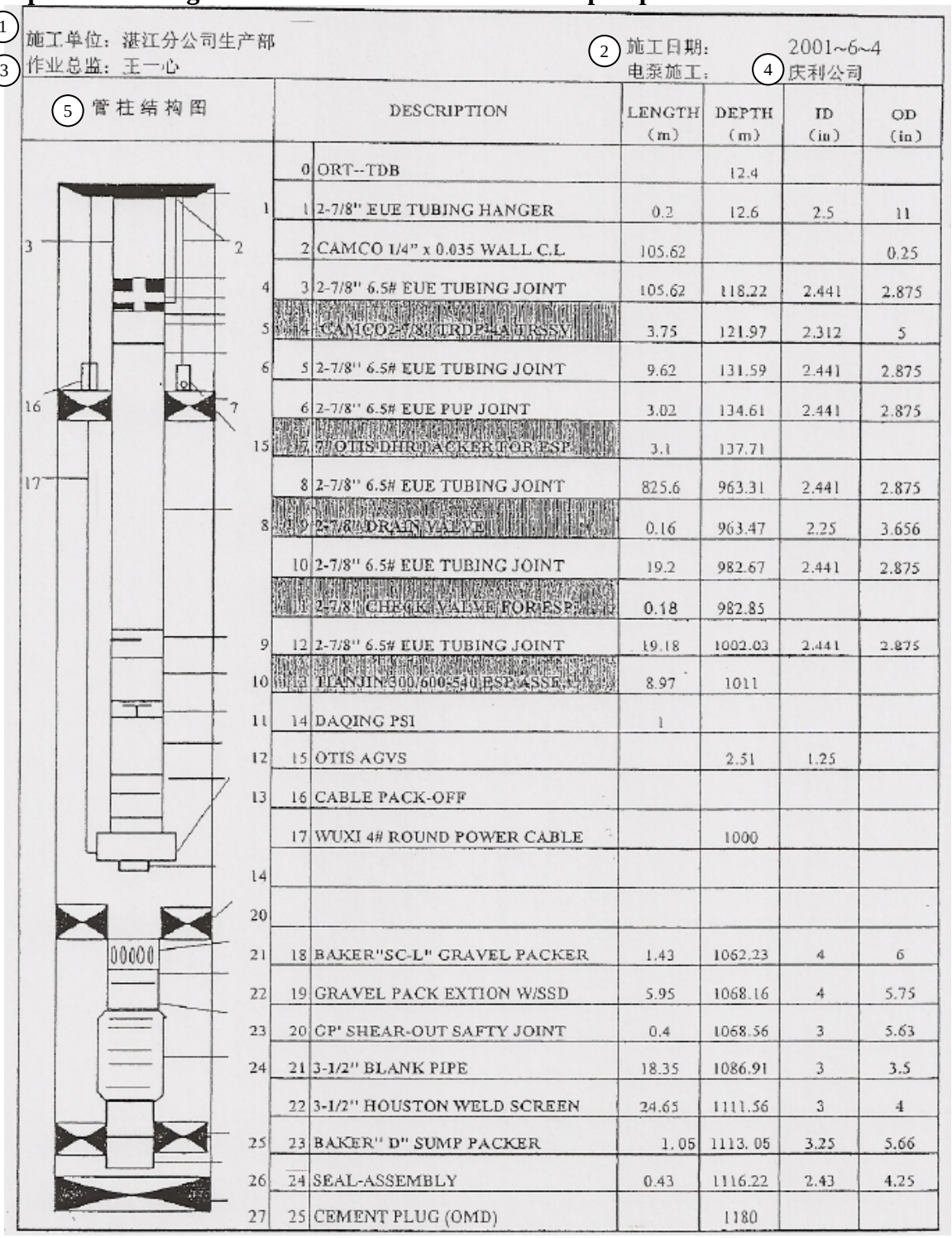
b) Pumping rate: 0.5-1.2 m^3/min. This can be determined based on pumping pressures encountered on-site.

c) Pumping pressure: Lower than 20 MPa

d) Injection procedure:

- First, mix 15 barrels of Greenzyme® solution into 37 m^3 formation water to prepare 40 m^3 of 8% Greenzyme® solution.
- It is important to keep the temperature above 50°C.
- Use a pump to inject the solution into the stratum, followed by pumping 18 m^3 diesel fuel to close the well.
- It is necessary to close the well 4 days before resuming production.

Pipe column diagram of the W11-4-A3 well electric pump



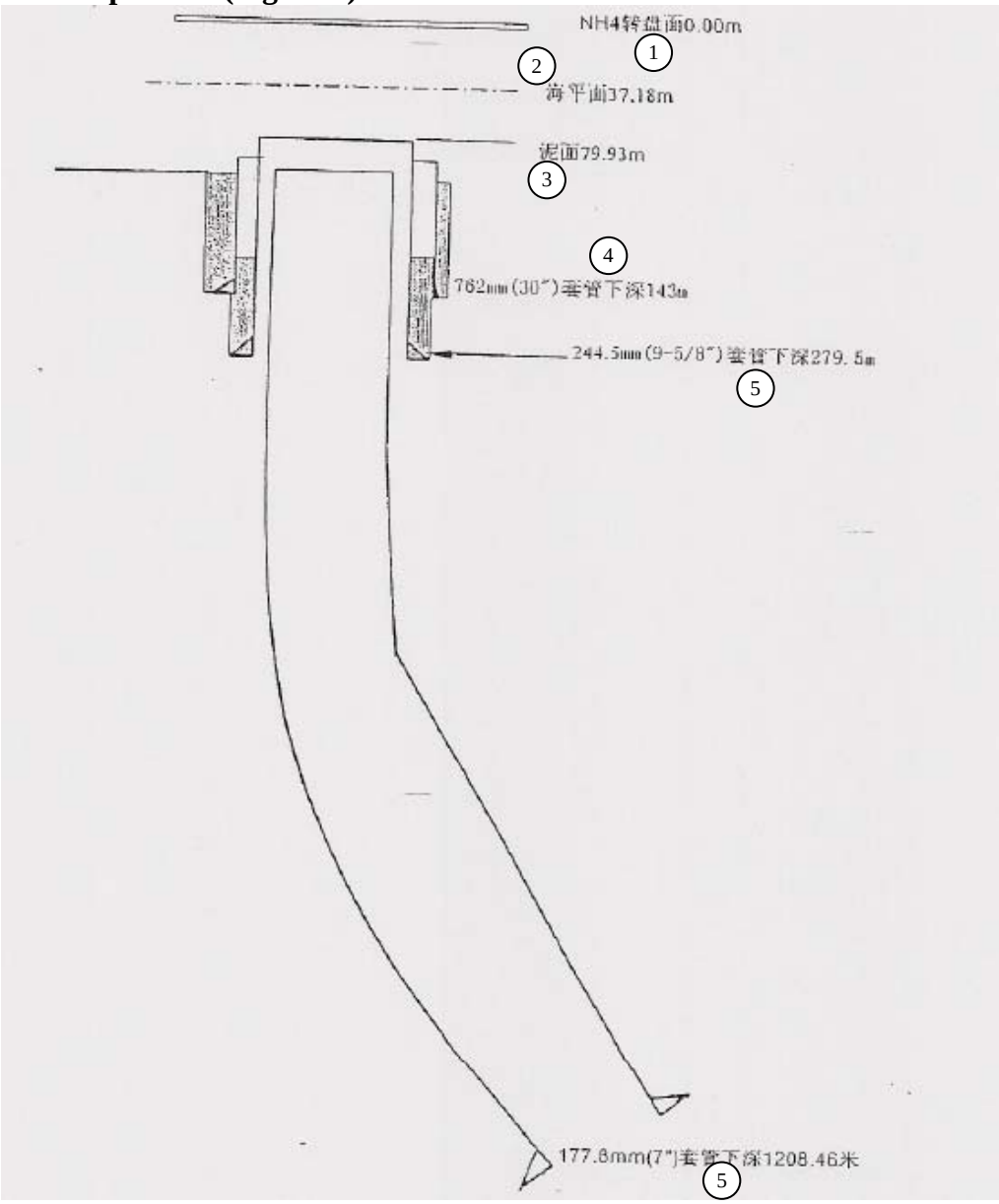
施工单位：湛江分公司生产部　　施工日期：2001~6~4
作业总监：王一心　　电泵施工：庆利公司

管柱结构图

		DESCRIPTION	LENGTH (m)	DEPTH (m)	ID (in)	OD (in)
	0	ORT--TDB		12.4		
1	1	2-7/8" EUE TUBING HANGER	0.2	12.6	2.5	11
	2	CAMCO 1/4" x 0.035 WALL C.L	105.62			0.25
4	3	2-7/8" 6.5# EUE TUBING JOINT	105.62	118.22	2.441	2.875
5	4	CAMCO2-7/8" TRDP-4AURSSV	3.75	121.97	2.312	5
6	5	2-7/8" 6.5# EUE TUBING JOINT	9.62	131.59	2.441	2.875
	6	2-7/8" 6.5# EUE PUP JOINT	3.02	134.61	2.441	2.875
15	17	7" OTIS DHR PACKER FOR ESP	3.1	137.71		
	8	2-7/8" 6.5# EUE TUBING JOINT	825.6	963.31	2.441	2.875
8	9	2-7/8" DRAIN VALVE	0.16	963.47	2.25	3.656
	10	2-7/8" 6.5# EUE TUBING JOINT	19.2	982.67	2.441	2.875
	11	2-7/8" CHECK VALVE FORESP	0.18	982.85		
9	12	2-7/8" 6.5# EUE TUBING JOINT	19.18	1002.03	2.441	2.875
10	13	TIANJIN 500/600-540 ESP ASSE	8.97	1011		
11	14	DAQING PSI	1			
12	15	OTIS AGVS		2.51	1.25	
13	16	CABLE PACK-OFF				
	17	WUXI 4# ROUND POWER CABLE		1000		
14						
20						
21	18	BAKER"SC-L" GRAVEL PACKER	1.43	1062.23	4	6
22	19	GRAVEL PACK EXTION W/SSD	5.95	1068.16	4	5.75
23	20	CP' SHEAR-OUT SAFTY JOINT	0.4	1068.56	3	5.63
24	21	3-1/2" BLANK PIPE	18.35	1086.91	3	3.5
	22	3-1/2" HOUSTON WELD SCREEN	24.65	1111.56	3	4
25	23	BAKER" D" SUMP PACKER	1.05	1113.05	3.25	5.66
26	24	SEAL-ASSEMBLY	0.43	1116.22	2.43	4.25
27	25	CEMENT PLUG (OMD)		1180		

Key:
1 Job unit: Production Department, Zhanjiang Branch
2 Job date: 2001-6-4
3 Job supervisor: Wang Yixin
4 Electric pump operated by Qingli Company
5 Structural diagram of pipe column

Diagram of well position (Figure 2)



Key:
1 NH4 rotary panel surface
2 Seal level
3 Mud line
4 Conductor pipe depth (30”)
5 Casing depths (9 5/8”, 7”)

TREATMENT PROCEDURE REQUIREMENTS

1) Check and fasten the screw bolts and parts of the producing well opening to make sure that there is no penetration.
2) Wash the pump and the pipelines of the system. Use hot water to circulate and wash the pump and the pipelines of the system until dirty water is not discharged.
3) Tank cleaning: It is required that the tank valve works well and that the tank be clean. One 30 m^3 tank.
4) Use heating equipment to heat all of the injected solutions to a temperature above 60°C.
5) Prepare a pump with a pressure higher than 2500 Psi. Connect the well opening to the pipeline pump hose and test whether there is leakage under a pressure of 2500 Psi.
6) The treatment steps must strictly follow the order of the treatment design. The process can be interrupted, but the temperature of the injected solution must be kept above 50°C.
7) After finishing the fluid injection, close the well for soak time and carefully observe the pressure change.

DATA RECORDING AND FOLLOW-UP NEEDED

It is important to record the following information:

1. Record the pressure, discharge rate, pumping rate, and the corresponding times as well as abnormalities during the treatment.
2. Record pressure changes and abnormality in the well valve when closing the well. Increase the frequency of recording data if the pressure changes significantly.

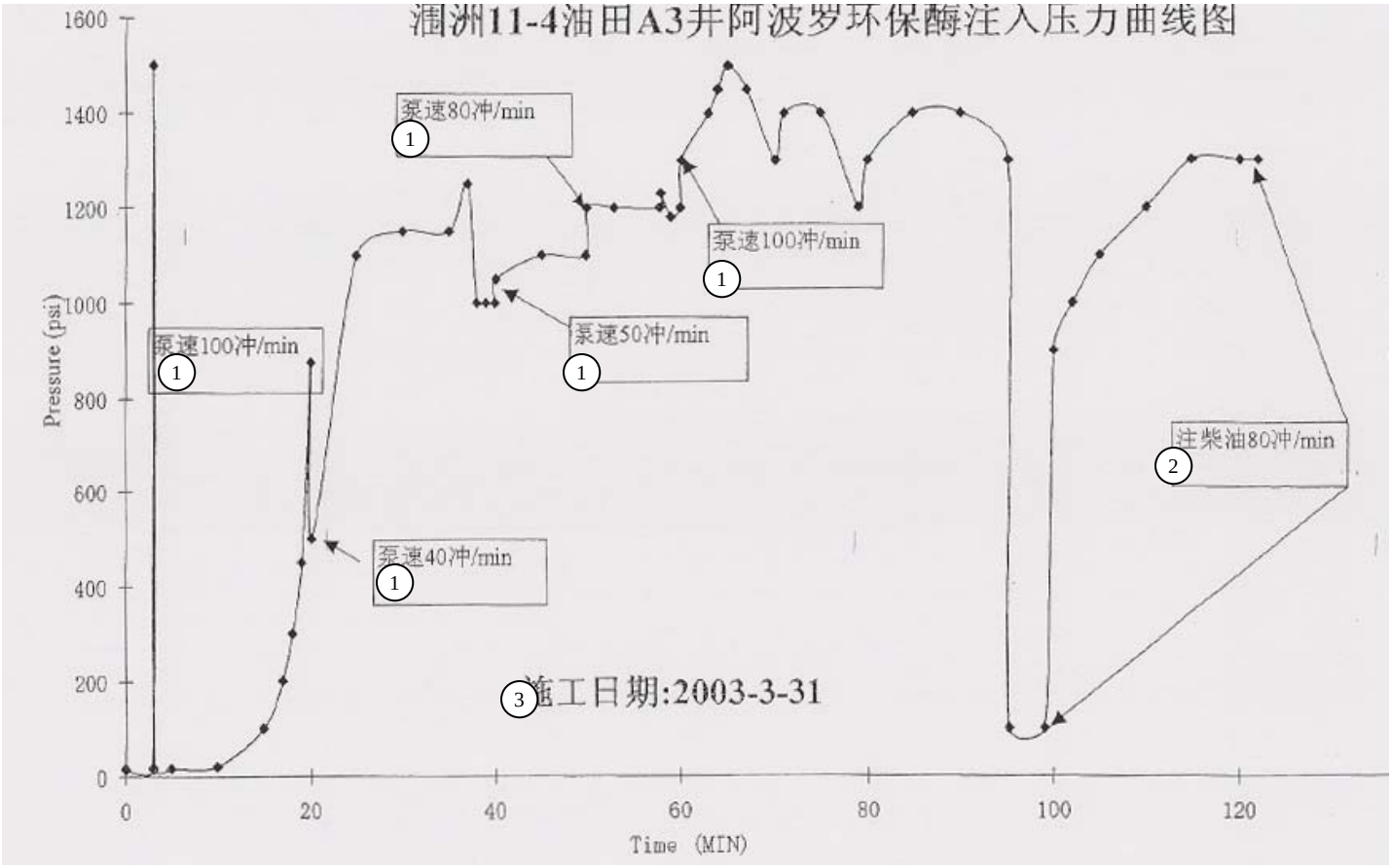
TREATMENT DETAILS

Preparation of the material was started at 6:30 PM on March 31, 2003. Hot water (70°C) and 14 barrels of Greenzyme® were added at the same time into a mud tank with a volume of 37 m^3 to prepare an 8% biological enzyme solution. The temperature of the solution in the tank was measured as 55°C. After a certain amount of Greenzyme® solution was injected into the formation, 2.8 m^3 of hot water and one barrel of Greenzyme® were added.

At 7:55 PM, injection of the biological enzyme into the formation was started. The pump speed was 100 SPM (strokes per minute). The pump pressure was lower than 100 psi. Three minutes later, the pump pressure suddenly rose to 1500 psi. Tens of seconds later, the pump pressure dropped sharply back to 100 psi temporarily. It was believed that this was the result of opening the exhaust valve in the sleeve pipe from the closed state. 20 min after the solution was injected, the pump pressure rose very quickly. Then, the pump speed was reduced to 40 strokes per minute. The pump pressure became stable and started to drop after about 20 min.

Therefore, the pump speed was raised back to 100 strokes per minute. The pump pressure dropped but stayed in a stable range of 1500-1300 psi. At 9:30 PM, the injection of 40 m^3 of 8% biological enzyme was finished. At 9:34 PM, post diesel solution was pumped into the well. The pump speed was 80 strokes per minute. The pump pressure was 1300 psi. A total of 18 m^3 diesel was pumped in. The well was sealed at 10:00.

Apollo environment-friendly enzyme injection pressure curve of the WeiZhou 11-4 oilfield A3 well



Key: 1 Pump speed ___ strokes/min
2 Diesel injection 80 strokes/min
3 Job date: 2003-3-31

PUMPING SEQUENCE AND TIME - MARCH 31, 2003

- 18:30 Prepared 40 m^3 of 8% biological enzyme solution.
- 19:55 Started to inject the biological enzyme. The pump speed was 100 strokes per minute. The pump pressure was lower than 100 psi.
- 19:58 The pump pressure suddenly rose to 1500 psi and dropped back to 100 psi temporarily after ten seconds.
- 20:15 The pump pressure rose sharply. The pump speed was reduced to 40 strokes per minute.
- 20:35 The pump speed was raised to 50 strokes per minute.
- 20:45 The pump speed was raised to 80 strokes per minute.
- 20:55 The pump speed was raised to 100 strokes per minute.
- 21:30 Injection of the biological enzyme was finished.
- 21:34 Pumping of 18 m^3 of displacement solution for the enzyme fluid was started.
- 22:00 After finishing injection of the displacement solution, the well was shut in for 90 h.

RESULTS AND ANALYSIS

Production was resumed at 4 PM on April 4 after the Wei 11-4-A3 well had been closed for 90 h. After the well was opened, the total fluid production rate rose continuously. Three days later, the fluid production rate rose from 200 m^3 per day to about 430 m^3 per day. The oil production rose from 49 m^3 per day to 76 m^3 per day, and the water content changed from 76% to about 82%. This situation has now been stable for almost one month. Many data points have stayed on the same levels. This means that blockage in the oil layer has been completely removed. Currently, the fluid production rate exceeds the capability of the pump (300 m^3/d). The fluid flow capability of the formation is very sufficient. Although the water content has increased (by 6%), the experiment was still very successful. It has proved that Greenzyme® is the best choice for removing blockage in oil wells.

According to the Darcy's law, the flow of oil and water in an oil reservoir can be expressed as follows:

$$Q_o = -K_{ro}/\mu_o * K\Delta P/(R^2 - r^2)$$
$$Q_w = -K_{rw}/\mu_w * K\Delta P/(R^2 - r^2)$$

Q_o, Q_w = Flow rates of oil, water K_{ro}, K_{rw} = Relative permeability coefficients for oil, water

μ_o, μ_w = Viscosities of oil, water K = Absolute permeability of the oil reservoir

r = Radius of the oil well R = Radius of a certain spot in the oil reservoir

ΔP= Pressure difference between position R in the oil reservoir and the well hole

Results of using Greenzyme® to remove blocking in the WeiZhou 11-4-A3 well

井号 (1)	时间 (2)	含水率 (3)	产油量 (4)	总液量 (5)
WII-4-A03	2003-2-15	76.3	50.4	212.6582278
WII-4-A03	2003-2-25	75.7	51	209.8765432
WII-4-A03	2003-3-3	75.7	49.9	205.3497942
WII-4-A03	2003-3-9	75.4	49.9	202.8455285
WII-4-A03	2003-3-16	75.7	49.2	202.4691358
WII-4-A03	2003-3-22	75.7	49.2	202.4691358
WII-4-A03	2003-3-28	75.5	49.2	200.8163265
WII-4-A03	2003-3-29	75.7	48.7	200.4115226
WII-4-A03	2003-3-30	75.6	48.9	200.4098361
WII-4-A03	2003-4-5	81.3	49.6	265.2406417
WII-4-A03	2003-4-9	82.1	76.7	428.4916201
WII-4-A03	2003-4-10	81.9	77.8	429.8342541
WII-4-A03	2003-4-11	82.1	76.7	428.4916201
WII-4-A03	2003-4-12	82.2	76.4	429.2134831
WII-4-A03	2003-4-13	82.3	76.1	429.9435028
WII-4-A03	2003-4-14	82.4	75.6	429.5454545
WII-4-A03	2003-4-15	82.7	75.2	434.6820809
WII-4-A03	2003-4-16	82.4	76.3	433.5227273
WII-4-A03	2003-4-20	82.5	75	428.5714286
WII-4-A03	2003-4-26	82.9	74.9	438.0116959
WII-4-A03	2003-5-4	82.9	73.4	429.2397661

Note: Blocking in the A3 well was successfully removed by using Greenzyme® on April 4

Key: 1 Well No.
2 Time
3 Water content
4 Oil production
5 Total fluid amount

After operation of the A3 well was resumed, the total fluid flow rate had increased from 200 m^3/d to 430 m^3/d. The water content increased from 75.6% to 82.1%. The oil production increased from 48.9 m^3/d to 76.7 m^3/d. The fluid pressure at the bottom of the well increased from 2.33 Mpa to 6.57 Mpa.

Through its powerful capability of peeling off hydrocarbon compounds and its deemulsification capability, Greenzyme® increased the absolute permeability K of the oil reservoir and thus increased the flow rates Qo and Qw of the oil and water. As can be seen from the injection pressure curve, this well had a certain degree of blocking. As Greenzyme® was injected, the blockage and positive skins were continuously broken down and penetrated. Therefore, the

injection pressure fluctuated continuously. After the pollution was cleared up, the channel of the oil reservoir became unblocked to significantly increase the flow rates of the oil and water. Greenzyme® can also change the wettability (change to water-wet) of the rock particles to increase the relative permeability coefficient Kro of the oil and hinder flow of the water to lower the water content. The results of tests conducted at many oilfields have powerfully proved this. The test results of the Wei 11-4-A3 well showed no drop in water content; on the contrary, it increased slightly. The change in Kro was insignificant. This might be related to the fact that the oilfield was originally water-wetted. In the meantime, since the properties are very good, the total fluid amount has greatly increased. A certain degree of waterconing is occurring, which also causes an increase in the water content.

The aforementioned equations also show that a well to be unblocked must have a capacity (ΔP) for this method to be effective. If ΔP is close to zero, it is necessary to inject water or use another method to generate capacity in order to achieve said effect.

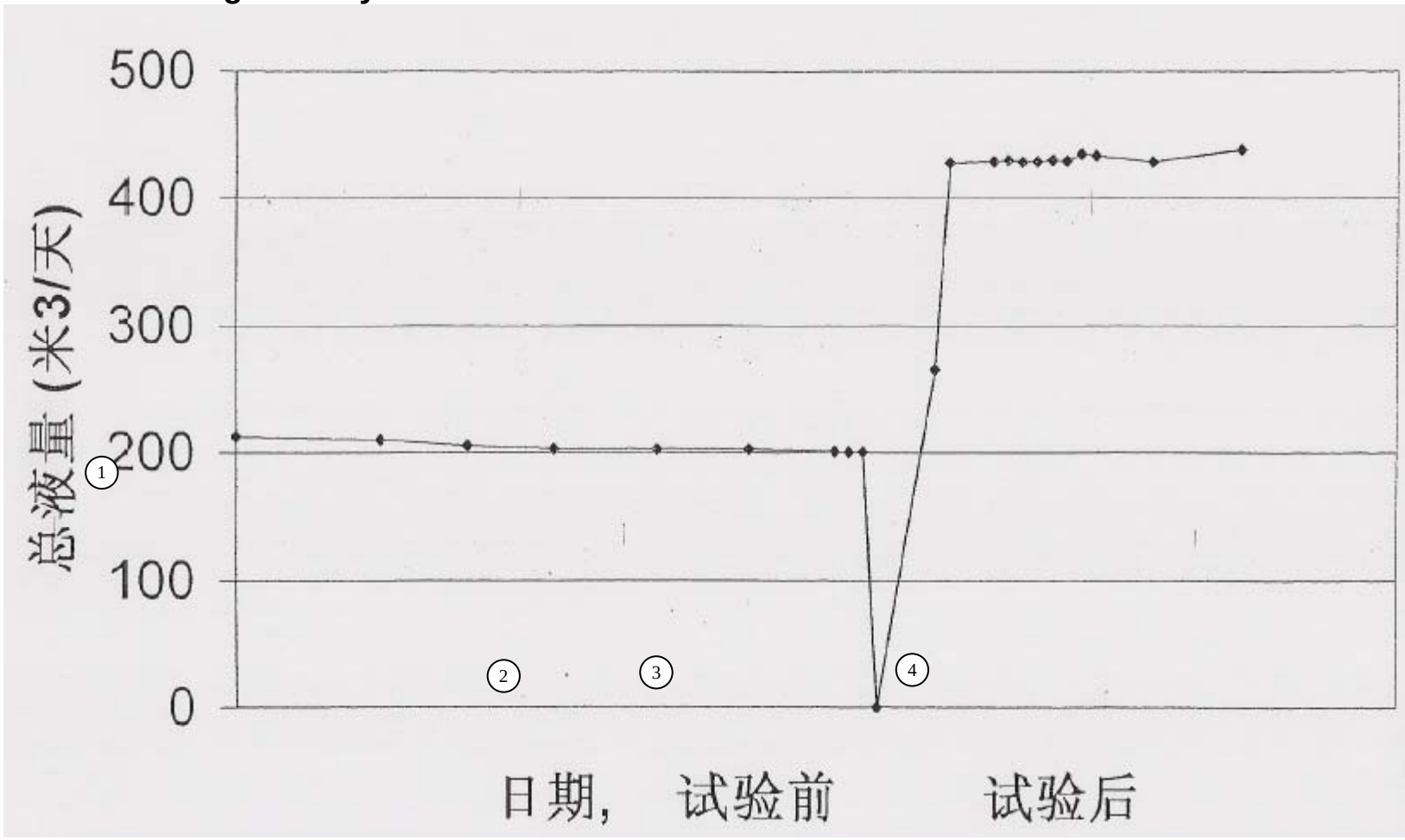
SUMMARY

Unblocking effect of environment-friendly enzyme on the WeiZhou 11-4 oilfield A3 well

Since the submersible electric pump with a discharge rate of 100 m^3/d was changed to a pump with a higher discharge rate of 200 m^3/d in November 2000 at the WeiZhou 11-4 oilfield A3 well, the fluid production rate has been unable to reach the rated discharge rate of the pump and has continued to drop. Since the oilfield has sufficient natural bottom water energy, the problem cannot be lack of energy. After analysis, it was believed that the submersible electric pump had problems in its working situation. Therefore, in June 2001, the pump with a discharge rate of 200 m^3/d was replaced by a pump with a discharge rate of 300 m^3/d. As a result, the fluid production rate dropped from an initial 291 m^3/d to 200 m^3/d. The production situation was the same as that of the pump with a discharge rate of 200 m^3/d.

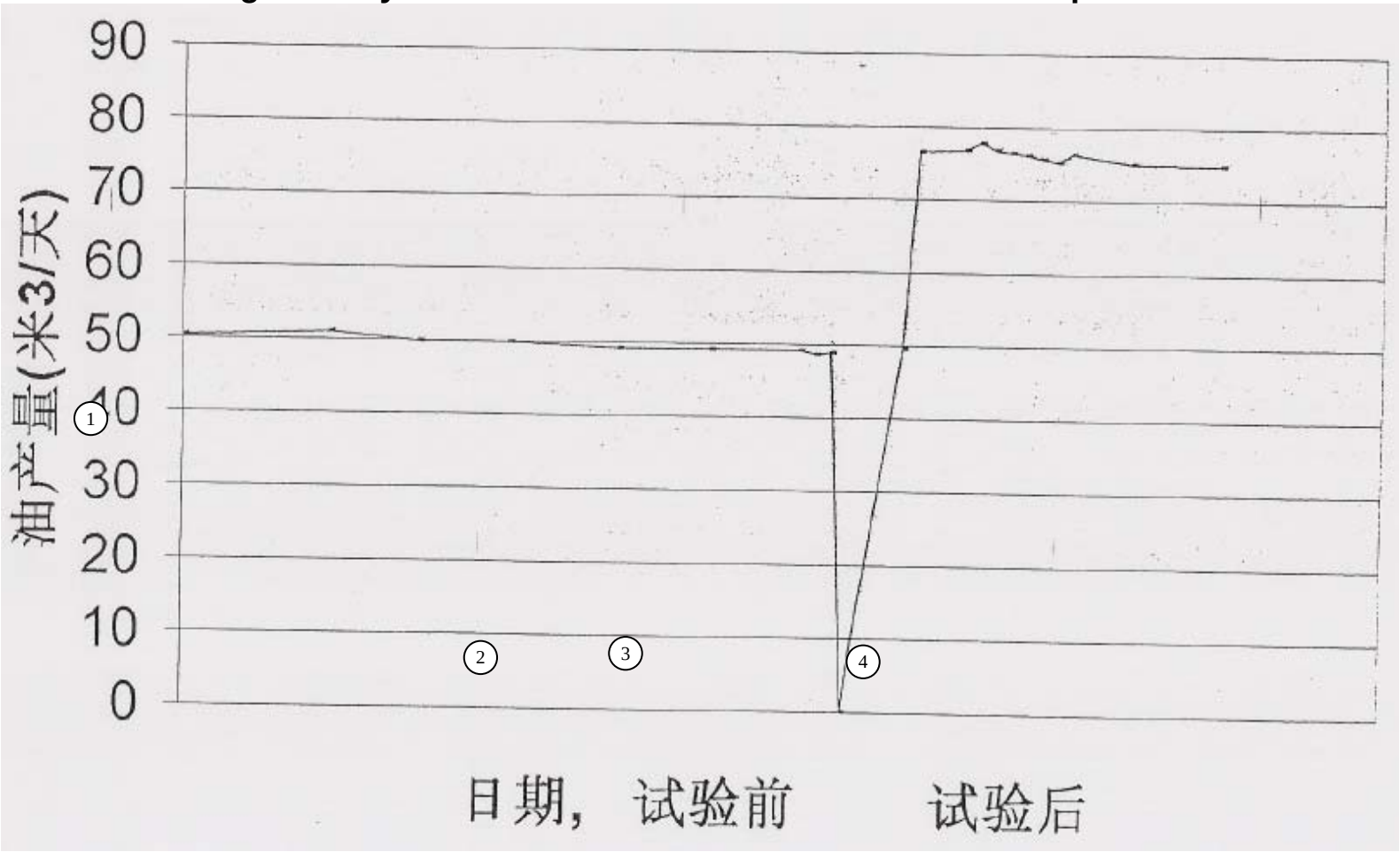
Based on analysis, it was believed that the well was damaged during the drilling and completion process. There was damage in the formation close to the well, which increased the wellbore skin coefficient and lowered the oil well fluid productivity index. A resistance band was formed around the wellbore to cause insufficient fluid flow to the wellbore. Therefore, a determination was made to conduct an unblocking operation on this well.

Biological enzyme test result of the Wei 11-4-A3 well – Total fluid amount



Key:
1 Total fluid amount (m^3/day)
2 Date
3 Prior to the test
4 After the test

Biological enzyme test result of the Wei 11-4-A3 well – Oil production



Key:
1 Oil production (m^3/day)
2 Date
3 Prior to the test
4 After the test

GuiLin Engineering Institute conducted unblocking using Greenzyme® on the A3 well from March 31 to April 4, 2003. After the unblocking operation was conducted, the fluid generating rate reached 430 m^3/d. The daily oil production was 77.8 m^3d. The water content was 81.9%. Before the unblocking operation, the amount of fluid generated daily was 200 m^3/d. The daily oil production was 48.9 m^3/d, and the water content was 75.6%. After the unblocking operation, the fluid amount increased by 230 m^3/d, the oil production increased by 29 m^3/d, and the water content increased by 6%. Although the water content increased after the unblocking operation, the fluid amount doubled. The unblocking effect was very good. Also, the fluid amount held at a stable level. The cumulative increase in oil production up to the end of August, 2005 was $0.9x10^4$ m^3/d. This technology was successfully applied to unblocking the WeiZhou 11-4 oilfield.

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Zhonghai Petroleum (China) Co., Ltd.
Production Department
Zhanjiang Branch, Production Department
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