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Quarterly Technical Report

ADVANCED RESERVOIR CHARACTERIZATION AND EVALUATION OF CO_2 GRAVITY DRAINAGE IN THE NATURALLY FRACTURED SPRABERRY RESERVOIR

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New Mexico Petroleum Recovery Research Center
New Mexico Institute of Mining and Technology
Socorro, NM 87801
(505) 835-5142

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Program Manager:	Paul McDonald Parker and Parsley Petroleum USA, Inc.
Principal Investigator:	David Schechter New Mexico Petroleum Recovery Research Center
Contracting Officer's Representative:	Jerry Casteel Bartlesville Project Office
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Abstract

Progress has been made in the area of laboratory analysis of Spraberry oil/brine/rock interactions during this quarter. Water imbibition experiments were conducted under ambient conditions, using cleaned Spraberry cores, synthetic Spraberry reservoir brine, and Spraberry oil. It has been concluded that the Spraberry reservoir cores are weakly water-wet. The average Amott wettability index to water is about 0.55. The average oil recovery due to spontaneous water imbibition is about 50% of original oil in place.

Table of Contents

List of Figures

List of Tables

Executive Summary

The Spraberry Class III Field Demonstration project is now entering the last quarter of the first year. During the first three quarters, we have achieved considerable progress in reservoir characterization from a combination of laboratory and field data. Coring and testing of the central production well is complete and plans are being arranged to core a dual lateral horizontal well, probably in the first quarter of the second year.

In the lab, extensive imbibition and CO_2 floods are being conducted to quantify transfer mechanisms occurring between Spraberry matrix rock and the predominant set of natural fractures which occur in Spraberry. Interesting results have been observed for Spraberry imbibition experiments, of which some of the results are presented in this report.

Introduction

To understand the crude oil/brine/rock interaction in Spraberry Trend Area reservoirs, we have performed water and oil imbibition experiments using Spraberry oil, synthetic Spraberry reservoir brine, and Spraberry reservoir rock. Macroscopic displacement efficiency of water-to-oil in core samples due to capillary forces has been determined by spontaneous imbibition tests. It varies from 40% to 70% depending upon core permeability. Effects of core cleaning and aging on displacement efficiency and wettability have been investigated. Wettability of Spraberry cores taken from the Spraberry Shackelford 1-38A has been estimated, based on spontaneous water and oil imbibition tests. The cores are weakly water-wet with mixed wetting behavior. The Amott wettability index to water (I_W) of the cores has been determined to be between 0.5 and 0.7.

Summary of Technical Progress

Experimental Procedure for Imbibition Tests

We received 4-inch-diameter whole cores, taken from the Spraberry Shackelford 1-38A. We cut core plugs horizontally to fit our core holders. The core plugs are 1.5 inch in diameter and about 2 inches long. Core plugs were stored in an oven at 172°F before initiation of imbibition experiments. The experimental procedure follows:

1. Measure core dimensions, weigh core in air, and measure permeability to air (k_a).
2. Vacuum core for 72 hours, then saturate core in vacuum with synthetic reservoir brine, let the core age in brine, and weigh until the weight stabilizes. Estimate core porosity (ϕ).
3. Inject brine into the core under 200 psig of injection pressure and 500 psig overburden pressure for 2 pore volumes. Estimate core permeability to brine (k_W).
4. Inject oil into the core under 200 psig of pressure. Measure brine and oil flow rate until initial brine saturation (S_{Wi}) is established in the core. Estimate permeability to oil at initial brine saturation (k_O).
5. Age the fluid-saturated core in oil under ambient conditions and weigh core until core weight stabilizes. The aging time should be at least 2 weeks before proceeding to the next step.

6. Place core into a beaker filled with brine at ambient conditions. Weigh core in brine after removing produced oil from the core surface. Calculate oil recovery based on change in weight of the core as a function of imbibition time. Terminate imbibition experiment when recovery stabilizes.

7. Displace the residual oil in the core by waterflooding at 200 psig injection pressure. Calculate Amott wettability index to water (I_W).

In order to assure that reservoir conditions were established in the core prior to water imbibition, we cleaned some core plugs by injecting chloroform into them. To investigate the effect of cleaning on rock properties, the chloroform was injected into the core after step 3 and followed by another water injection before proceeding to step 4.

Results and Discussion

Untreated Cores Assuming we received clean whole cores, the first 10 core plugs were not treated with chloroform. Oil recovery curves obtained from some of the uncleaned core plugs are presented in Fig. 1. Brine imbibition rate varies from core to core (Fig. 1). Final oil recovery due to imbibition varies from 10% to 40%. Properties of the cores and fluids, final recoveries, and wettability indices to water are summarized in Table 1.

Table 1. Properties of rock and fluids used in completed tests

Test No.	ϕ (%)	k_a (md)	k_w (md)	k_o (md)	S_{wi} (%)	ρ_w (g/cc)	ρ_o (g/cc)	μ_w (cp)	μ_o (cp)	R_{im} (%)	R_{wf} (%)	I_w
SP-1	10.0	0.43	0.28	0.09	13.9	1.09	0.86	1.16	16.4	38	41	0.45
SP-2	10.0	0.45	0.22	0.10	18.4	1.09	0.87	1.18	22.4	38	38	0.50
SP-3	9.8	0.44	0.23	0.14	21.3	1.08	0.87	1.17	21.8	41	22	0.64
SP-4	10.0	0.46	0.14	0.06	14.3	1.08	0.87	1.17	19.5	40	27	0.59
SP-5	10.7	0.49	0.27	0.09	15.3	1.08	0.87	1.18	19.5	35	40	0.47
SP-6	9.8	0.43	0.22	0.06	17.2	1.08	0.87	1.18	19.5	>11	25	0.31
SP-7	10.4	0.34	0.20	0.08	22.0	1.08	0.75*	1.18	1.72*	>10		
SP-8	5.9	0.06	0.03		18.8	1.08	0.87	1.18	19.8			
SP-9	6.5	0.06	0.03		18.4	1.08	0.87	1.18	19.8			
SP-10	12.8	0.36	0.15	0.05	26.5	1.08	0.87	1.18	19.5	21	24	0.46
Average	10.4	0.43	0.21	0.08	18.6	1.08	0.87	1.18	19.8	32	31	0.50

*Soltrol 220

Cleaned Cores To establish actual reservoir wetting conditions, some cores were cleaned with chloroform before imbibition tests. Oil recovery curves obtained from some of the core plugs are presented in Fig. 2. This figure indicates that brine imbibition rate varies from core to core. Final oil recovery due to imbibition varies from 15% to 70%. Comparison between Fig. 1 and Fig. 2 reveals that the rate of water imbibition was significantly improved after cleaning the cores with chloroform. Final oil recovery by spontaneous imbibition was also improved. Rock properties before and after chloroform cleaning are shown in Table 2 indicating that both porosity and permeability increased. Comparison of the residual water saturation data from Table 1 and Table 2 indicates that the residual water saturation after oil injection under 200 psig increased from 18.6% to 42.2% due to chloroform cleaning. This result suggests that the cores became more water-wet after the cleaning procedure. This was confirmed by improved Amott wettability index to water (I_W) calculated

after waterflooding the core. The average I_W was increased from 0.5 to 0.6. However, the results include uncertainties due to possible trapping of water by chloroform during core cleaning.

Several factors may affect the final oil recovery during brine imbibition. These factors should include core permeability, initial water saturation, and core wettability. The final oil recovery by imbibition versus core permeability to brine is plotted in Fig. 3. This figure indicates that the final oil recovery increases with core permeability. Scatter of data is probably due to variations in initial water saturation and wettability of the cores.

We have also investigated brine recovery during spontaneous imbibition of oil into a Spraberry core (core No. SP-10 in Table 1). Figure 4 shows the resultant recovery curve. This curve indicates that a small portion of the rock is oil wet since the core imbibes oil.

In order to exclude the effect of aging time in oil on the result, the final oil recoveries from completed tests with cleaned cores are plotted against aging time in Fig. 5. This figure shows that if the data beyond three weeks of aging time is considered equilibrated, then the final oil recovery due to spontaneous water imbibition should be about 50% of original oil in place (OOIP). The Amott wettability indices to water for various cores are plotted versus the aging time in Fig. 6. This plot indicates that if the data below three weeks aging time are disregarded, the I_W of Spraberry reservoir rock should be about 0.55, which implies a weakly water-wet system.

Table 2. Rock Properties and Results of Water Imbibition Experiments

Test No.	Before Cleaning			After Cleaning			t_{oil}	R_{im}	Iw
	ϕ(%)	k_w (md)	S_{wi} (%)	ϕ(%)	k_w (md)	S_{wi} (%)	(Day)	(OOIP)	
SP-8a	5.9	0.03		9.9	0.12	52	14	>0.36	
SP-9a	6.5	0.03		9.0	0.18	47	21	>0.16	
SP-10	12.8	0.15		14.3	0.45	32		0.09*	
SP-11	10.0	0.11		13.2	0.31	38	6	0.71	0.76
SP-15	3.1	0.02		6.9	0.06	55	16	0.70	
SP-16	2.1	0.01		9.2	0.07	53	25	>0.14	
P-17	3.1	0.02		7.7	0.08	54	7	0.40**	
SP-19	5.0	0.03		12.3	0.32	36			
SP-21	10.8	0.10		14.4	0.35	36	15	0.45	0.64
SP-22	5.0	0.03		10.1	0.25	42	49	0.42	0.49
SP-24	4.1	0.03		11.6	0.36	38	1	0.79	0.75
SP-25	4.0	0.02		10.4	0.27	40	20	0.72	
SP-27	6.8	0.04		10.6	0.29	39	30	0.57	0.66
SP-28	2.9	0.02		7.8	0.09	53	90	0.29	0.35
SP-30	7.0	0.04		9.7	0.26	41	41	0.48	0.52
SP-33	11.8	0.21		13.9	0.41	35	60	0.47	0.55
SP-34	11.1	0.17		13.2	0.34	40	28		
SP-1	10.0	0.28	13.9	12.0	0.34	37	21	0.50	0.55
SP-3	9.8	0.23	21.3	11.2	0.34	33	21	0.15**	
Average						42.2			

* Brine recovery during oil imbibition
** Imbibition performed at 138°F and 1250 psig

Conclusion

The core-cleaning procedure used in this study may result in some uncertainties regarding the established initial core condition. This is because water and chloroform are not miscible, and the chloroform may remain in the core and may mix with the oil. Therefore, quantitative use of the data in this report should be used with care. The core-cleaning procedure has been modified for our ongoing experiments. More reliable data will be reported in the near future.

Clearly though, imbibition experiments conducted under ambient conditions using cleaned cores indicate that Spraberry reservoir fabric is weakly water-wet with mixed wetting behavior. The average Amott wettability index to water is about 0.55. The average oil recovery due to spontaneous water imbibition is about 50% of original oil in place.

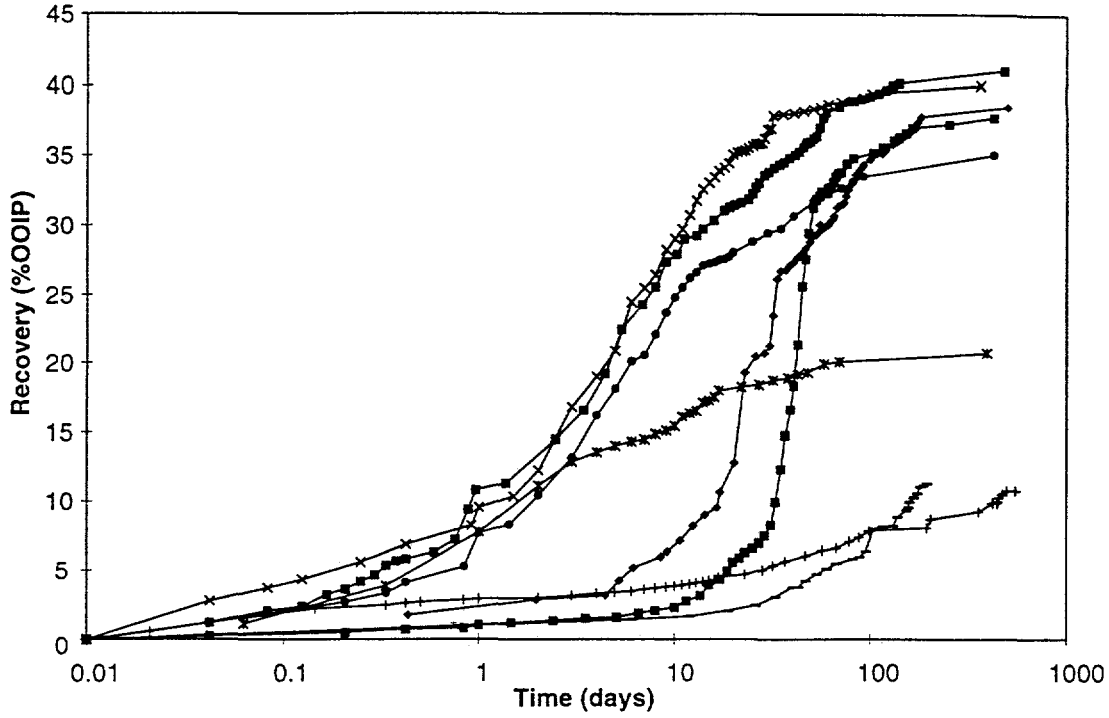

Fig. 1. Oil recovery from untreated cores during water imbibition.

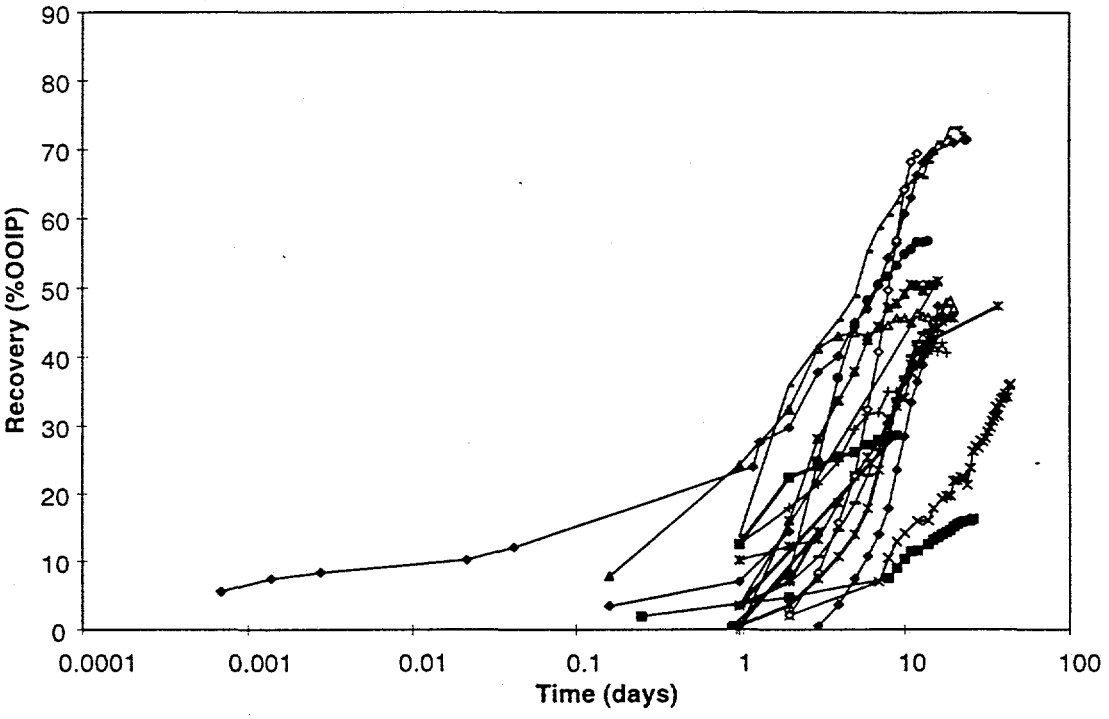

Fig. 2. Oil recovery from cleaned cores during water imbibition.

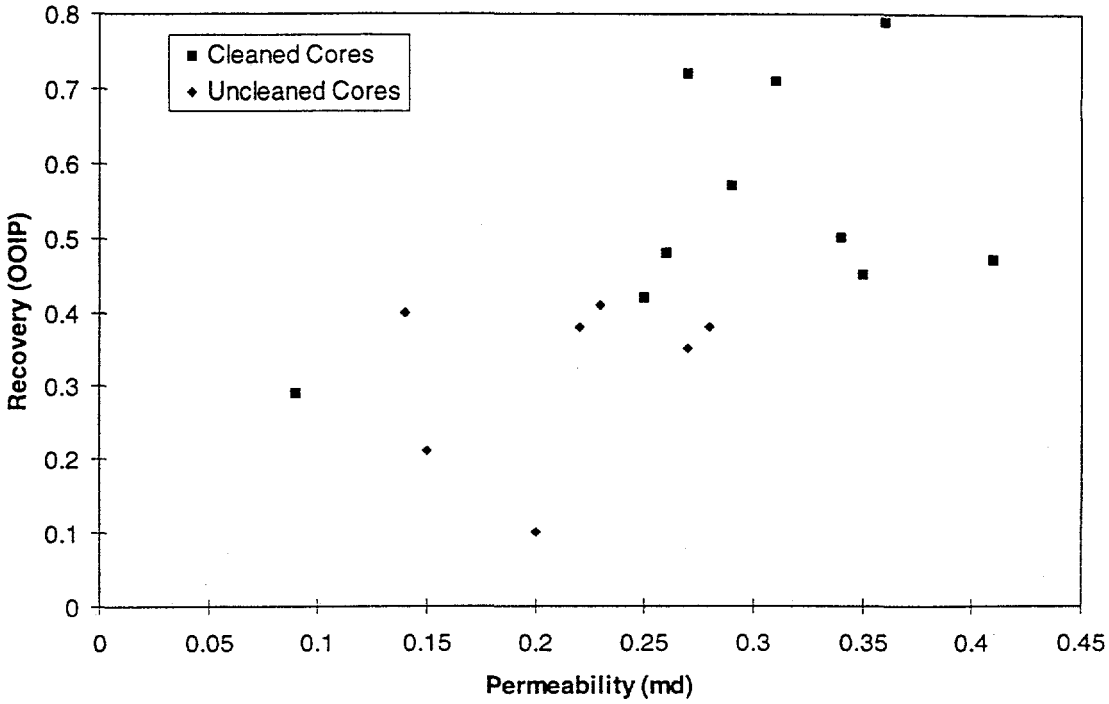

Fig. 3. Effect of permeability on final oil recovery.

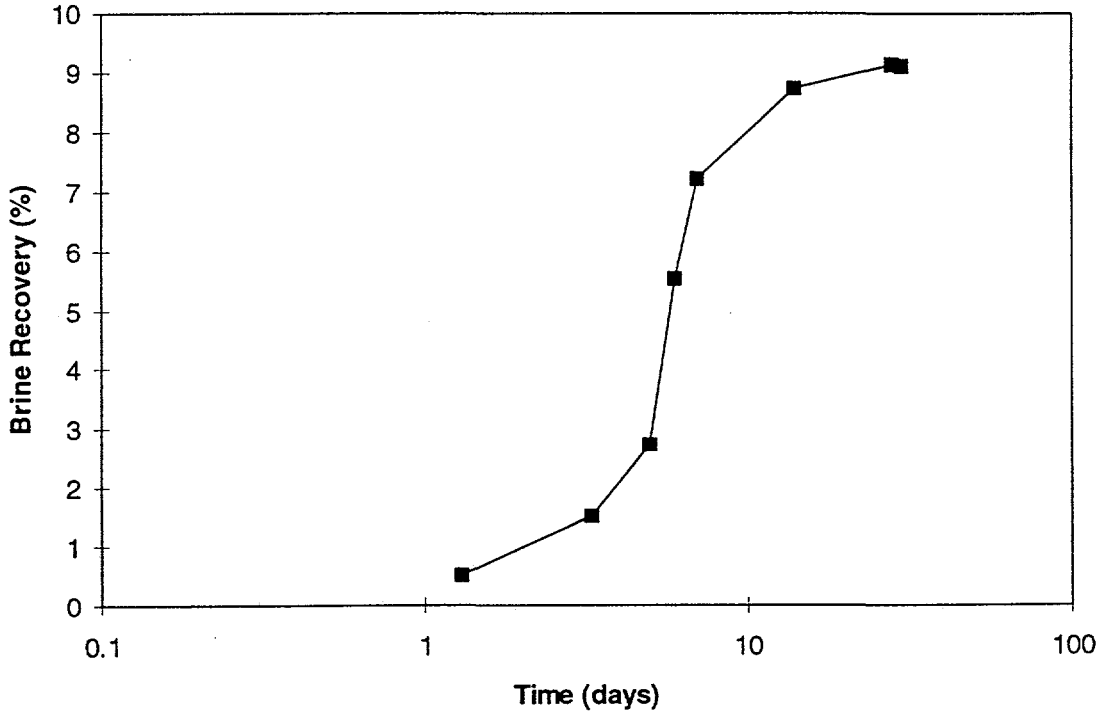

Fig. 4. Brine recovery from a reservoir core during oil imbibition.

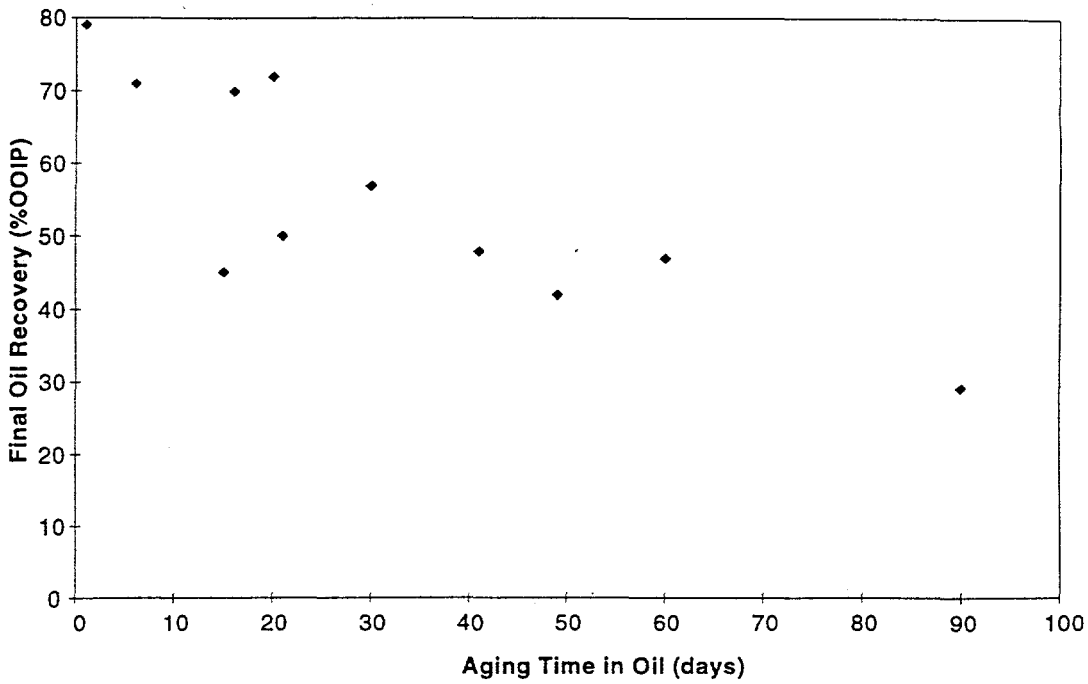

Fig. 5. Final recovery versus corresponding aging time in oil.

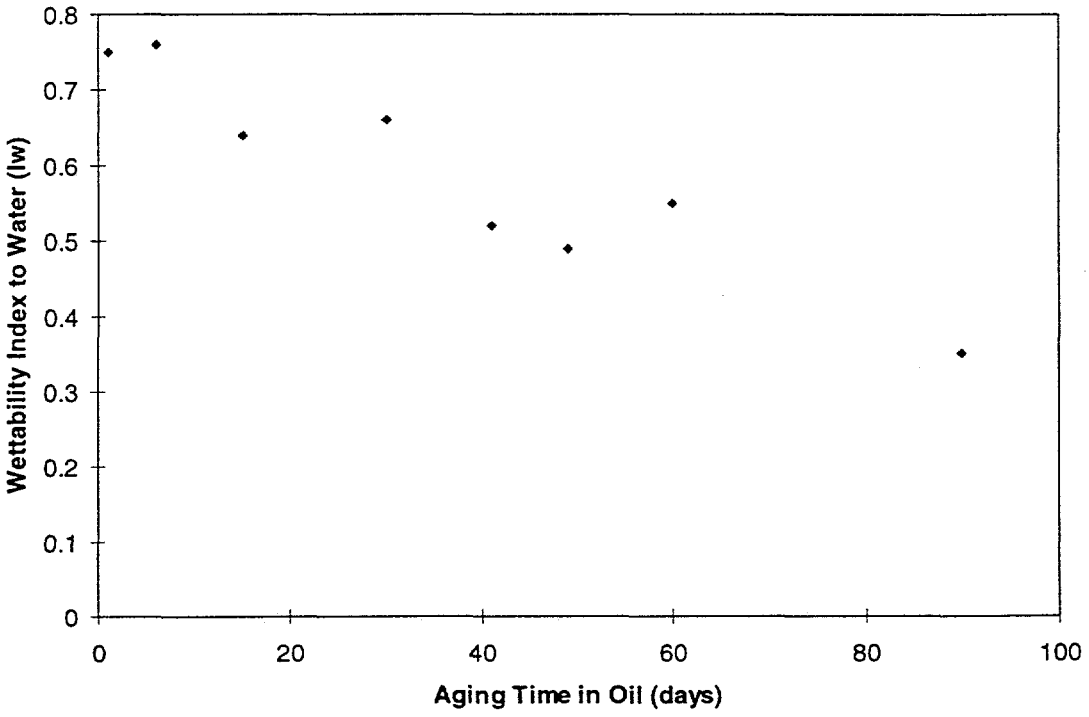

Fig. 6. Effect of aging of core in oil on wettability to water.