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PRRC 94-14

Quarterly Technical Report

INTEGRATION OF ADVANCED GEOSCIENCE AND ENGINEERING TECHNIQUES TO QUANTIFY INTER-WELL HETEROGENEITY

DOE Contract No. DE-AC22-93BC14893

New Mexico Petroleum Recovery Research Center
New Mexico Institute of Mining and Technology
Socorro, NM 87801
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Anticipated Completion Date: September 30, 1996
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Reporting Period: January 1 to March 31, 1994

OBJECTIVES

The purpose of this project is to conduct a variety of laboratory and field tests and utilize all the geological, geophysical, and engineering information collected to develop a reservoir model by the use of global optimization methods. The interdisciplinary effort will integrate advanced geoscience and reservoir engineering concepts to quantify reservoir heterogeneity and the dynamics of fluid-rock and fluid-fluid interactions. The reservoir characterization will include geological methods (outcrop and reservoir rock studies), geophysical methods (interwell acoustic techniques), and other reservoir/hydrologic methodologies including analyses of pressure transient data, field tracer tests, and laboratory core studies. The field testing will be conducted at the Sulimar Queen Unit with related laboratory testing at the Petroleum Recovery Research Center (PRRC) on core samples from the Sulimar site and Queen sandstone outcrops. Research methods will involve the acquisition of data obtained at different scales and integration of the data into a reservoir model.

The goals of the project are to: (1) characterize lithologic heterogeneity, (2) quantify changes in heterogeneity at various scales, (3) integrate the wide variety of data into a model that is jointly constrained by the interdisciplinary interpretive effort, and (4) achieve greater accuracy and confidence during simulation and modeling as steps toward optimizing recovery efficiency from existing petroleum reservoirs.

Dr. Jerry Harris, Associate Professor in the Department of Geophysics at Stanford University and Dr. Gary Pope, Director of the Center for Petroleum and Geosystems Engineering at the University of Texas at Austin, will collaborate on the project. Several members of the PRRC staff will participate in the development of improved reservoir description by integration of the field and laboratory data as well as in the development of quantitative reservoir models to aid performance predictions.

LABORATORY STUDIES

DIAGENESIS STUDY

A report on the diagenesis in the cored interval of Well 1-16 was revised during this quarter. This report is available for interested parties.

Diagenesis of the Shattuck Member of the Queen Formation within the Sulimar Queen Field is very similar to that of other sandstone units within the Permian basin, and is in many ways analogous to modern-day diagenesis in the sabkha areas of the Persian Gulf. The core examined in this study records a transgressive event that, either through a lowering of sea level or increased clastic supply, produced a succession of lithologies ranging from fine-grained, probably water-laid sands upwards into dolomite capped by interbedded evaporites and redbeds. Diagenetic minerals within the sequence include anhydrite, gypsum, halite, quartz, dolomite, feldspar, and rutile.

Early diagenetic events generally occluded primary porosity through precipitation of evaporite minerals, authigenic feldspar, and authigenic quartz, whereas later events increased both porosity and permeability through dissolution of grains and cement. Oil emplacement may have actually occurred prior to optimum timing, as secondary porosity apparently increased following hydrocarbon migration into the reservoir. Examination of this core demonstrates quite clearly the combination of depositional and diagenetic effects that served to create a hydrocarbon reservoir in the Sulimar Queen Field.

PRELIMINARY STUDIES OF WETTING WITH SULIMAR QUEEN CRUDE OIL

A sample of Sulimar Queen crude oil was obtained in January 1994. Preliminary wettability testing of this oil sample has been conducted with a series of standard brines of fixed pH and ionic composition for comparison to other crude oils. Other measurements have been made to characterize the oil including density, viscosity, asphaltene content, and elemental analysis.

Oil Properties

The oil sample used in this study (SQ-94) has been stored in the five-gallon plastic container in which it arrived. Part of the sample is oil and the rest is produced brine, but the relative amounts are not known. The physical properties of the oil are summarized in Table 1.

Kinetic viscosity was measured with a Cannon-Fenske viscometer; density was measured using a Mettler/Paar DMA40 densitometer; asphaltenes were determined by the standard ASTM method;[1] and elemental analyses were performed by Huffman Laboratories.

Wettability Tests

Adhesion: Interactions between SQ-94 and flat, solid surfaces have been observed in two tests. In the first of these is the adhesion test,[2,3] in which a drop of oil is trapped under brine between a smooth glass surface and the buret used to form the drop. After a short time, typically two minutes, the drop volume is decreased and interaction between the oil and solid is observed. The observations fall into three broad categories: drops that leave no oil on the surface (nonadhesion), drops that adhere to the surface and break off from the oil in the buret as the volume is reduced, and an intermediate case, referred to as temporary adhesion, where the buoyancy force is sufficient to peel the adhering drop slowly off the glass surface. An adhesion map is generated for brines of varying pH and ionic strength. The adhesion map for SQ-94 at ambient conditions of temperature and pressure is shown in Figure 1.

All three types of adhesion behavior are exhibited by SQ-94. Dependence of adhesion principally on pH and secondarily on ionic strength is typical of most of the crude oils studied previously by this technique. pH is varied over the range of 4 to 8 or 10, as shown on the Y-axis. The X-axis is a log scale over which the molar concentration of NaCl varies by two orders of magnitude, but it is important to note that only monovalent ions are included in these brines. Addition of other ionic species, particularly divalent or multivalent ions, affects crude oil adhesion in ways that are neither predictable nor well understood.

Adsorption: A second test of crude oil/brine/solid interactions has been developed to study changes in wetting over longer periods of time.[4-6] In this test, glass is equilibrated in brine, drained, then immersed in crude oil and aged. The aging time ranges from a few hours to a month or more and the aging temperature can be varied. At the end of the aging period, a glass slide is removed from the crude oil and rinsed with toluene to remove bulk oil. It is then immersed in decane and contact angles are measured with a drop of distilled water.

The results of tests of adsorption onto wet glass from crude oils show pH and ionic strength dependence, related to the adhesion behavior. For SQ-94, three values of pH (4, 6, and 8) have been tested at low (0.01 *M*) and high (1.0 *M*) ionic strengths. The aging times varies from a minimum of six hours to a maximum of 22 days and the aging temperature was maintained at 80°C. The results are shown in Figure 2; the values in braces are the brine pH and ionic strength: {pH, I}.

Adsorption from SQ-94 at all conditions studied led to water advancing contact angles (θ_a) less than 100°. These are substantially lower than the maximum values of θ_a that have been observed for other crude oils,[5] especially at pH 4. Adsorption is suppressed at pH 6 at both low and high ionic strength and is higher in the lowest and highest pH brines (pH 4 and 8).

Discussion

The oils studied previously by the methods described above have been chosen because they appeared to have unusual surface active properties (e.g., Moutray crude oil), high asphaltene content (Alaska-93), or some other indication that wetting of the oil/brine/rock system was other than strongly water-wet. Thus, our data are probably not a representative cross section of crude oils.

Preliminary indications are that SQ-94 is not typical of the oils we have been studying. It is significantly more saturated than other oils we have studied (H/C ratio of 1.825 compared with a range of 1.576 for Alaska-93 to 1.693 for Schuricht) and has a lower, but still significant, percentage of asphaltenes. The range of adhesive conditions is not unusual, but the contact angles on surfaces after longer exposure to SQ-94 are, in general, lower than we have observed previously with other oils. At most, surfaces are altered into the range of neutral wetting.

In previous studies, a general correspondence has been noted between adhesion and adsorption test results for comparable conditions of brine pH and ionic strength. Conditions that led to adhesion after two minutes of exposure of oil to solid also showed a high degree of wetting alteration after much longer exposure times. The very low contact angles observed after adsorption for glass treated with the {6, 0.01} brine appear to contradict that general observation, probably because the tests were conducted at different temperatures. Adhesion was tested at room conditions, while the adsorption test samples were aged at 80°C. The higher temperature was chosen to accelerate adsorption, but the effects of temperature can be two-fold. Previous test have shown that the rate at which a surface is altered by adsorption can increase significantly, but the conditions of brine composition that lead to adhesion change with temperature as well. The adhesion area decreases to encompass only brines of the lowest pH and ionic strength tested.[6]

Overall, the results to date suggest that SQ-94 is not likely to be oil-wetting on silica surfaces, but these preliminary results cannot be readily extrapolated to predict reservoir wetting. Specific interactions between multivalent ions in reservoir brines and crude oil components may dominate wetting behavior. Tests with a simulated reservoir brine (composition as shown in Table 2) are underway.

FIELD ACTIVITIES

OUTCROP STUDIES

The Queen Formation crops out in south-central Eddy County, New Mexico. The goals of the outcrop portion of this study are 1) to ascertain if the Queen in outcrop is similar enough to the Queen in the subsurface to serve as a reservoir analogue, and 2) if so, to examine outcrops and characterize their lateral, vertical, and areal heterogeneity.

Preliminary work for the outcrop phase of this study includes collecting aerial photos, geologic and topographic maps of the area, and driving the roads in the area to identify Queen outcrops that may be useful for our study. We will choose for further work Queen outcrops containing rocks most closely resembling those seen in the Sulimar Queen core. Emphasis will be placed on outcrops having the potential for examination in three dimensions, particularly those with great areal exposure. A trip was made to the field area this quarter, and a few promising outcrops were located.

After suitable outcrops have been identified, the second phase of study will begin. This will include collecting samples for examination in the laboratory, but most importantly, using a portable minipermeameter to make field permeability measurements. Temco has offered us the use of their portable minipermeameter for this study. This work will be carried out during the spring and summer of this year.

FIELD TESTS

As required by the Bureau of Land Management (BLM), a plan of operations for the Unit during the coming year was submitted. The plan was approved by the BLM on February 3, 1994.

The status of all the wells in the Sulimar Queen Unit as of early January 1994 is shown in Table 3. The New Mexico Oil Conservation Division has scheduled bradenhead tests in all injection wells on April 6, 1994. These tests are required to ensure that all injectors are mechanically sound.

Static reservoir pressures throughout the field were determined in early January 1994. Static bottomhole pressures for all wells tested are listed in Table 4. These data serve as background information for the individual well and interwell tests that are scheduled. The feasibility of applying an inverse drillstem test (DST) technique to estimate the flow capacity (permeability-thickness or kh product) is being evaluated.

The PRRC pressure testing equipment and trailer were thoroughly evaluated, and necessary replacement parts were ordered. This equipment will be refurbished and installed at the Sulimar Queen Unit for the pressure transient tests that are scheduled for the next quarter.

REFERENCES

1. ASTM D2007-80, "Standard Test Method for Characteristic Groups in Rubber Extender and Processing Oils by the Clay-Gel Adsorption Chromatographic Method," ASTM (1980).

2. Buckley, J.S., Takamura, K., and Morrow, N.R.: "Influence of Electrical Surface Charges on the Wetting Properties of Crude Oils," *SPEFE* (August 1989) 332-340.

3. Buckley, J.S. and Morrow, N.R.: "Characterization of Crude Oil Wetting Behavior by Adhesion Tests," paper SPE/DOE 20263 presented at the 1990 SPE/DOE EOR Symposium, April 23-25.

4. Buckley, J.S. and Morrow, N.R.: "An Overview of Crude Oil Adhesion Phenomena," 1991 IFP Research Conference on Exploration-Production, Saint-Raphaël, France, September 4-6.

5. Liu, Y.: "Wetting Alteration by Adsorption from Crude Oils," Master's thesis, New Mexico Institute of Mining and Technology, Socorro, NM (1993).

6. Liu, Y. and Buckley, J.S.: "Crude Oil Aging Time and Wetting," Quarterly Report for the project "Evaluation of Reservoir Wettability and its Effect on Oil Recovery," July 1 - September 30, 1993, PRRC Report No. 93-36.

7. Martin, F.D., Weiss, W.W., Cowen, T.M., Beck, F.E., and MacMillan, J.R.: "Planning Phase for the New Mexico Improved Oil Recovery Project," Annual Report to NMRDI, DOE, and Industry, April 1991.

Table 1. Properties of Sulimar Queen Crude Oil

	crude oil	n-pentane ppt (40:1) (asphaltenes)	n-pentane ppt (5:1)	n-heptane ppt (40:1)
Viscosity	7.06 cp (at 25°C)			
Density	0.8381 g/ml (at 25°C)	(API gravity = 36°)		
Asphaltene content		4.07%		1.44%
Elemental analysis weight %				
C	85.13	84.71	84.23	83.87
H	12.95	8.14	8.43	7.94
N	0.06	0.40	0.37	0.39
S	0.89	3.39	3.26	3.24
O	1.07	1.61	1.71	1.65
atomic ratio				
H/C	1.825	1.153	1.201	1.136
N/C	0.001	0.004	0.004	0.004
S/C	0.004	0.015	0.015	0.014
O/C	0.009	0.014	0.015	0.015

Table 2. Composition of Synthetic Brine for Sulimar Queen*

$NaHCO_3$	282	mg/L
Na_2SO_4	4,303	
$CaCl_2 \cdot 6H_2O$	7,776	
$MgCl_2 \cdot 6H_2O$	74,612	
NaCl	262,314	
TDS	307,712	
Ionic Strength	5.8	*M*
pH	6.2	

* Based on analysis of Sample #1 in reference 7.

Table 3
Sulimar Queen Unit Well Status Report
January 1994

WELL NO.	PERFORATIONS	TO	TD	CASING	GROUND LEVEL ELEVATION	PACKER SETTING DEPTH	COMMENTS
1-2	1972 -	1979	2005	5 1/2"	3933	R-4 @1927	INJECTOR - O.K. - 2 3/8"
1-3	1980 -	1992	2020	5 1/2"	3936	R-4 @1958	INJECTOR - O.K. - 2 3/8"
1-4	1975 -	1988	2012	5 1/2"	3926	R-4 @1883	INJECTOR - O.K. - 2 3/8"
1-5	1976 -	2006	2016	5 1/2"	3907	R-4 @1950	INJECTOR - 2 3/8"-HEAVY PARAFFIN @ 15' &700'
1-6	1967 -	1975	2003	5 1/2"	3948		NO TUBING-INJECTOR
1-7	1960 -	1967	1999	5 1/2"	3927		T/A CIBP @1880'
1-9	1965 -	1971	1992	5 1/2"	3938	R-4 @1916	INJECTOR - 2 3/8"-20' FILL ABOVE PERFS
1-12	1960 -	1970	2010	5 1/2"	3931	R-4 @1912	INJECTOR - O.K. - 2 3/8"
1-13	1955 -	1957	1975	5 1/2"	3926	R-4 @1909	INJECTOR - O.K. - 2 3/8"
1-14	1970 -	1978	2010	5 1/2"	3937	R-4 @1948	INJECTOR - 2 3/8"-PARAFFIN @ 310'
1-15	1990 -	1996	2020	5 1/2"	3959		RODS IN WELL-2 3/8"
1-16	1995 -	2006	2064	5 1/2"	3958		RODS IN WELL-2 3/8"
2-2	2027 -	2030	2055	7"	3948	R-4 @1995	INJECTOR - O.K. - 2 3/8"
2-3	2015 -	2032	2045	5 1/2"	3950	R-4 @1962	INJECTOR - O.K. - 2 3/8"
2-4	2018 -	2034	2053	5 1/2"	3940		T/A CIBP @1918'
2-7	2020 -	2028	2046	5 1/2"	3938	R-4 @1968	INJECTOR - 2 3/8"-TUBING BENT @ SURF.
3-1	2031 -	2039	2063	7"	3955	R-4 @2002	INJECTOR - O.K. - 2 3/8"
3-2	1988 -	2002	2035	5 1/2"	3935	PKR @1850	2 3/8", CIBP
3-3	2014 -	2026	2056	5 1/2"	3933	PKR @1890	T/A CIBP @1914'
3-4	1989 -	2002	2038	5 1/2"	3920	R-4 @1965	INJECTOR - 2 3/8"-FILL 10' BELOW PKR.
3-6	1988 -	1994	2023	5 1/2"	3929	PKR @1850	T/A CIBP @1888'
4-1	1962 -	1968	2006	4 1/2"	3936	PKR @1880	T/A - 2 3/8", CIBP
4-2	1946 -	1952	1980	4 1/2"	3933	R-4 @294	300' TUBING IN WELL-INJ. 2 3/8"-PARAFFIN @ 175'
5-1	1973 -	1982	2004	5 1/2"	3926	R-4 @292	300' TUBING IN WELL-INJ. 2 3/8"
5-2	1954 -	1963	1985	5 1/2"	3915	PKR @1880	T/A, CIBP
5-3	1938 -	1948	1975	4 1/2"	3927	PKR @1850	T/A - 2 3/8", CIBP
6-1	1958 -	1970	1996	4 1/2"	3919	R-4 @1900	INJECTOR - 2 3/8"-PARAFFIN @ 900'
8-1	2003 -	2012	2048	4 1/2"	3958	R-4 @1961	INJECTOR - O.K. - 2 3/8"

(shaded) RULE 203 WELLS - T/A STATUS APPROVED UNTIL 12-7-94.

Table 4
Sulimar Queen Unit Static Reservoir Pressures
January 1994

WELL NO.	DATUM @ +1960	PRESSURE PSIA	DEPTH	GRADIENT PSI/FT.	GROUND LEVEL ELEVATION	PRESSURE @ DATUM +1960
1-2	1960	775.9	1975	0.5805	3933	774.7
1-3	1960	752.5	1986	0.4790	3936	747.7
1-4	1960	775.9	1981	0.4922	3926	768.5
1-5	1960	780.6	1991	0.5155	3907	757.9
1-6	1960	779.1	1971	0.4205	3948	786.2
1-7	1960				3927	N/A
1-9	1960	765.0	1942	0.5063	3938	783.2
1-12	1960	794.0	1965	0.4793	3931	796.9
1-13	1960	927.6	1956	0.5010	3926	932.6
1-14	1960	769.7	1974	0.5030	3937	771.2
1-15	1960	18.3	1990	0.4950	3959	22.8
1-16	1960	719.0	1995	0.4950	3958	720.5
2-2	1960	808.8	2029	0.0341	3948	807.4
2-3	1960	799.4	2023	0.5817	3950	780.2
2-4	1960				3949	N/A
2-7	1960				3938	N/A
3-1	1960	771.3	2035	0.4855	3955	751.9
3-2	1960				3935	N/A
3-3	1960				3933	N/A
3-4	1960	754.1	1975	0.5022	3920	746.6
3-6	1960				3929	N/A
4-1	1960				3936	N/A
4-2	1960	663.4	1900	0.4689	3933	697.6
5-1	1960	718.1	1978	0.5269	3926	711.8
5-2	1960				3915	N/A
5-3	1960				3927	N/A
6-1	1960	729.1	1964	0.4956	3919	726.6
8-1	1960	779.1	2008	0.5072	3958	774.0

N/A means not accessible

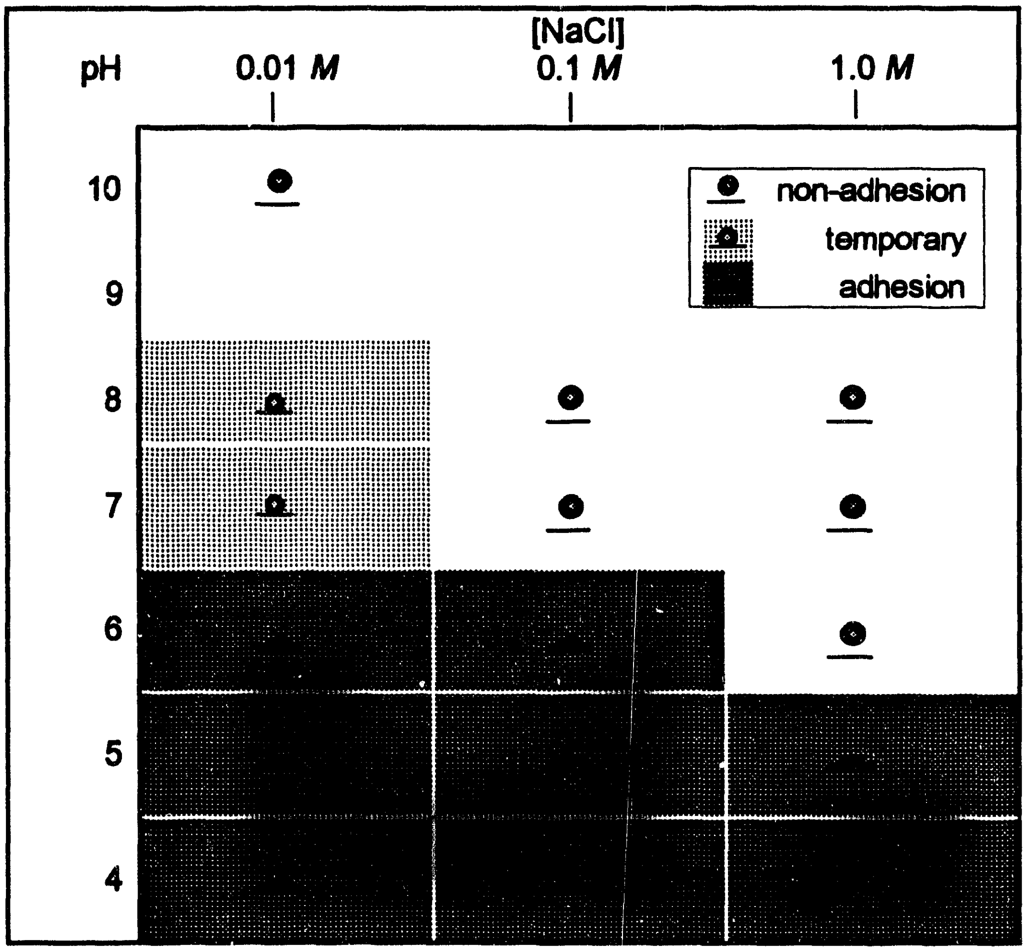

Figure 1. Adhesion Map of Sulimar Queen Crude Oil (SQ-94) at 25°C

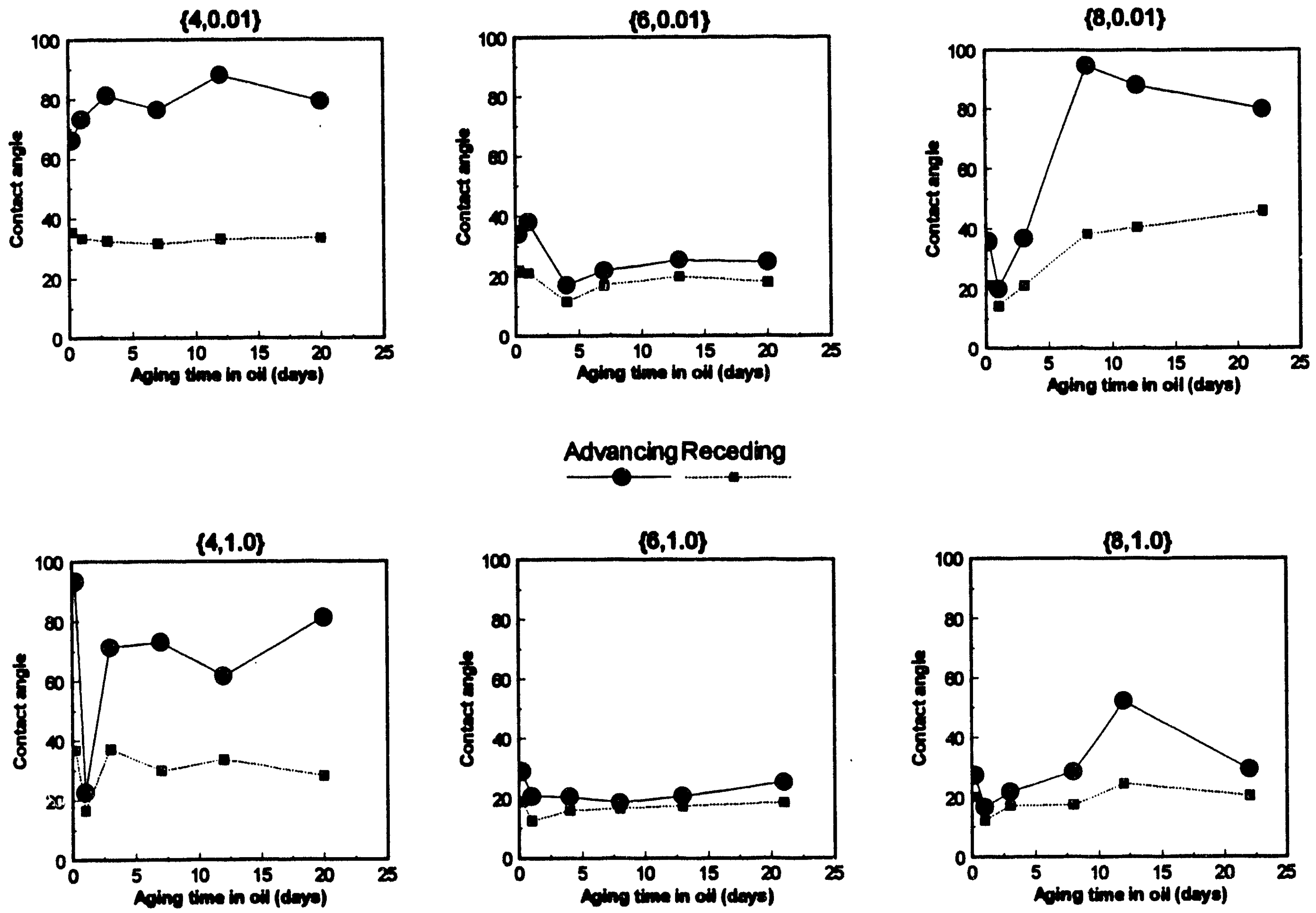

Figure 2. Adsorption from Sulimar Queen Crude Oil (SQ-94) at 80°C, {pH, Ionic Strength}

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