HANDLING UNCONSOLIDATED SANDSTONE CORES TO PRESERVE WETTABILITY AND PORE STRUCTURE

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ABSTRACT

Certain major reservoirs in Saudi Arabia are producing from highly friable or loosely consolidated sandstone formations. Therefore, such sandstone samples must be utilized to derive meaningful two-phase flow data for predicting flow behavior in the reservoir. In order to obtain accurate data, the wettability and pore structure of a core tested in the laboratory should be the same as in the reservoir for reliable water/oil relative permeability and capillary pressure measurements. This study explains a method developed for handling core from coring to testing to keep its wettability and pore structure unchanged.

Plastic-sleeved core is cut using bland mud to prevent exposing the rock to surfactants which might affect its wettability. Upon recovery, the plastic-sleeved core is cut into 15-foot sections. Qualitative wettability tests are performed at the well site on each section. Then the plastic sleeves are flushed with nitrogen to displace air, thereby preventing oxygen from contacting the core. The preserved cores, kept in nitrogen, are transferred to the laboratory for plugging with liquid nitrogen. The frozen sample is then mounted in a triaxial core holder for establishing connate water saturation and for additional studies. Actual dead oil is used at slightly above 0°C to keep oil/water viscosity ratio high to obtain a representative connate water saturation. Water/oil relative permeability and capillary pressure tests are performed under reservoir conditions. Centrifuge and high viscous mineral oil flooding are avoided, to minimize changes in pore geometry and wettability of the rock sample.

The comparison between laboratory and wellsite wettability studies showed that the applied technique was successful in maintaining the wettability of rock samples and keeping pore geometry of the reservoir sand unchanged.

INTRODUCTION

Oil-water distribution and their flow behavior in a reservoir can be predicted through capillary pressure and relative permeability data obtained in the laboratory under simulated reservoir condition. Wettability and pore structure has major impact on those measurements. Consequently core studies intended to predict field behavior should be performed on native state core samples having the same wetting characteristics and pore structure.

Wettability is a qualitative term relating to whether the rock will be preferentially wet by water or by oil in the presence of both fluids. Absorption of oil or water on the rock surface in preference to another is very important because it greatly affects the movement and distribution behavior of oil and water. These phenomenons are discussed by several authors(1). The wettability and pore structure can be altered either; (1) during the pre-test core handling which includes coring, packing, transportation and storing, and/or (2) during the sample selection, sample preparation, connate water saturation establishment and special core analysis.

CORE HANDLING

The first alteration in wettability may take place during the drilling process by drilling fluid invasion, especially if the mud contains surfactant or has a pH different from that of the reservoir(2). Table 1 presents the allowed and prohibited additives recommended for drilling fluids to keep the formation wettability unchanged during the coring operation. However CMC and dextrid were reported as additives that reduce permeability significantly(3). Table 2 exhibit properties of drilling fluid which was used in the coring operation relevant to this study where four inches diameter plastic sleeve core in the interval of 6583-7060 feet was cut through the loosely consolidated sandstone formation in the Northern Area of ARAMCO fields. The potential change in pore structure due to pressure decline from in-situ value to the atmospheric was prevented by PVC sleeve coring.

However, it was not possible to control the effect of temperature and pressure drop on wettability as the core is brought to the surface. After the core is recovered it has to be protected from wettability alteration due to exposure to air which cause oxidation of the substances in the crude to form polar products changing the wettability. The classical techniques to prevent wettability alteration are; (1) wrapping of core in foil and sealing in paraffin, and (2) storing the core in deaerated formation brine[4]. The first technique was not preferred in this study due to impracticality of wrapping and sealing of 468 ft. of core in paraffin. The second one was also avoided because of potential change in pore geometry caused by clay swelling and/or disaggregation of the unconsolidated core in water environment. Therefore the following were implemented as a pre-test core handling procedure;

- Cut 30 feet plastic sleeve core into two 15 feet long portions.

- Take core samples from both ends of the PVC tubes to perform qualitative wettability tests on rig site. The wettability test are performed by placing core samples from the same location in two separate beakers one filled with kerosene and the other filled with water. Then the wettability of the rock are determined based on degree of aggregation and disaggregation in water and kerosene. These studies showed that there is a trend of decrease in wetting affinity to oil from top to oil-water contact. The rock cored in water zone showed higher wetting affinity to water.

- Flush nitrogen through PVC tube to displace air to prevent core exposing the oxygen.

- Wrap both ends with saran; seal with rubber caps; then seal rubber caps with tape.

- Transfer 15 feet long core from well site to lab.

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low temperature on wettability is ignored since (1) the sample is already exposed to low temperature by immersing into the liquid nitrogen during the plugging and (2) relatively short period of flooding to achieve a new equilibrium state of wettability change[5].

SPECIAL CORE ANALYSIS

Fifteen samples are selected as a first set to perform studies based on the flow diagram shown in Figure 2. The connate water established native state core is mounted in a gas flooding system to determine gas-oil relative permeability characteristics. The oil permeability at connate water saturation is measured first under ambient condition as the Net Overburden Pressure maintained at 2500 psi. Unsteady state Gas/Oil Relative Permeability data is obtained by oil/water saturated nitrogen flooding at room temperature as the Net Overburden Pressure maintained at 2500 psi. After completing the gas flood the sample is re-saturated with oil and oil permeability at connate water saturation is measured to compare it with the permeability measurement prior to gas-flood. This comparison was used to control wettability and/or pore structure alteration. Then unsteady-state Water-Oil Relative Permeability is performed under simulated reservoir condition.

The second set of the samples were tested for capillary pressure characteristics based on the flow diagram shown in Figure 3. Sixteen native state and connate water established samples are tested for Water-Oil Imbibition Capillary Pressure by centrifuge at 160^{o}F and under 2500 psi Net Overburden Pressure. The centrifuge speed is ranged from 400 rpm to 2400 rpm creating water-oil capillary pressure between 0 to -12 psi. In the end of Imbibition Capillary Pressure studies the samples are extracted by Dean-Stark for fluids saturation calculation. The dried jacketed samples are re-mounted in triaxial core holder and Gas-Oil Drainage Capillary Pressure are performed at ambient condition as the NOB maintained at 2500 psi. The special core analysis data showed that; (a) Relative Permeability to water at residual oil saturation has a tendency to decrease with depth. Table 3, Fig. 4. (b) The water saturation at which oil and water relative permeabilities are equal, has a trend of increase with depth, Fig. 5. Both end point and cross-saturation data are consistent with the field wettability measurement confirming that water wetness increase with depth. (c) The change in connate water saturation with respect to depth has a scatter characteristics, Fig. 6. However, average connate water saturation above and below water-oil contact are around twenty per cent pore volume, Table 3. The similar phenomena are observed by Raza et al as an exception to the rules of thumb [6]. (d) The residual oil saturation obtained by either waterflooding or centrifuge imbibition capillary pressure have a trend to decrease with depth on the contrary of what is expected, [7] Fig. 7 and Fig. 8. This phenomena is probably due to improvement of reservoir quality with depth, Fig. 9. In other words, as the oil permeability at connate water saturation increases, the residual oil saturations determined by both centrifuge and displacement techniques have a trend to decrease Fig. 10, Fig. 11. Naturally the decrease in residual oil saturation with depth is more likely due to pore geometry rather than wettability.

CONCLUSION:

- The core handling techniques to keep pore structure of the rock samples unaltered is successful based on; (a) Consistency between log porosity and test plug porosity, (b) The increase in the test sample permeability through the oil-water contact as the reservoir quality improved.

- The rig-site qualitative wettability measurement showed that there is a trend in increase wetting affinity to water from top to bottom of the cored interval. The consistency between this trend and the special core analysis data confirms that the applied technique for handling core from coring to testing had maintained the wettability of rock sample unchanged. However, it is highly recommendable to perform further studies at a different well by determining wettability index at every one ft. interval of the core both on the rig-site and in the lab.

ACKNOWLEDGEMENT

Appreciation is given to the Saudi Arabian Ministry of Petroleum and Mineral Resources and to the Arabian American Oil Company for permitting the publication of this paper.

APPROVED CORING FLUID ADDITIVES	
ADDITIVES	**FUNCTION**
Attapulgite	Gel Strength
Bentonite	Gel strength
Dextrid	Filter loss control
CMC	Filter loss control
Barite	Weight control
Calcium carbonate	Weight control
Calcium chloride	Salinity control
Sodium chloride	Salinity control
Potassium chloride	Salinity control
Formalin	Bactericide

PROHIBITED CORING FLUID ADDITIVES

a) All surfactants:
- *All bactericides <u>except</u> formalin.
- *Defoaming agents.
- *Lignosulfanetes, such as Q-Broxin or quebracho.
- *Emulsifiers.
- *De-emulsifiers.
- *Corrosion inhibitors.

b) All acids <u>except</u> hydrochloric acid.

c) All caustics including
- *Lye.
- *Soda Ash.

TABLE 1: Recommended and Prohibited Coring Fluid Additives for Wettability Preserved Core.

CORING FLUID CHARACTERISTICS

PROPERTIES	ADDITIVES
*Less than 10 cc. API filter loss. *pH from 7 to 9 *Low solid content	*Attapulgite (Zeogel) *Dextrid *CMC, if needed to control filter loss. *15000 ppm CaCl by weight or more. *Barite as needed. *Formation Bactericide as needed if coring fluid starts to turn sour.

PROHIBITED ADDITIVES:

*All surfactants (Defoaming agents, Lignosulfanetes such as Q-Broxin emulsifier, corrosion inhibitors).
*All acids except hydrochloric acid with no additives.
*All caustics (lye, soda ash).

Table 2: Drilling Fluid Properties Utilizied in Wettability Preserved Coring in subject Well.

Sample No:	Ø % PV	Pre-test Scw	Ko@ Scw	WATERFLOOD Sor	End Krw	Sw @ Krw=Kro	Kb@ Sor	Ko / Kb	Pc Imb. Sor
26A	26.2	20.6	450	23.10	25	52	147	3.1	
26B	27.6	27.2	332						16.9
70B	28.1	29.2	221						8.1
102B	26.2	19.2	397	30.30	45	44	257	1.5	
102C	29.2	30.2	459						14.8
104A	26.6	15.7	1180	27.20	29	44	384	3.1	
104B	28.5	24.9	511						18.9
151A	28.4	11.7	658	32.20	35	44	442	1.5	
151B	30.3	25.6	578						9.8
153A	28.4	14.6	735	29.50	25	47	187	3.9	
153B	30.1	20.2	958						9.5
154A	28.3	15.7	593	23.00	40	51	273	2.2	
154B	27.8	22.6	622						10.5
AVRG:	28.1	21.3	592	27.55	33	47	282	2.6	12.6
188B	25.6	19.0	1185	24.10	27	52	495	2.4	
199A	23.3	16.1	1594	27.80	17	51	359	4.4	
199B	25.7	24.5	1283						17.2
210B	28.9	21.2	1167						8.7
211A	27.4	13.9	1363	25.40	35	48	811	1.7	
211B	29.1	17.3	984						10.6
212B	27.8	17.0	1198	25.10	24	49	1743	0.7	
213C	29.0	20.8	2111						5.6
214A	25.8	13.8	875	27.70	40	43	748	1.2	
252A	28.2	22.4	1476	23.00	40	55	767	1.9	
253A	29.4	24.0	1487						8.4
256A	26.7	34.1	1829	6.20	13	67	394	4.7	
256B	29.2	22.9	194						8.3
256C	28.2	25.3	1473						8.2
AVRG:	27.5	20.9	1301	22.75	28	52	760	2.4	9.6
				W/O CONTACT					
280A	23.1	14.7	1132	22.60	23	55	356	3.2	
280B	22.9	26.2	488						9.9
282A	24.6	13.0	1078	23.30	21	49	409	2.6	
282B	27.0	26.0	851						7.7
AVRG:	24.4	20.0	887	22.95	22	52	383	2.9	8.8

Table 3: Unsteady-state Relative Permeabilty and Centrifuge Imbibition Capillary Pressure Test data obtained under simulated reservoir condition.

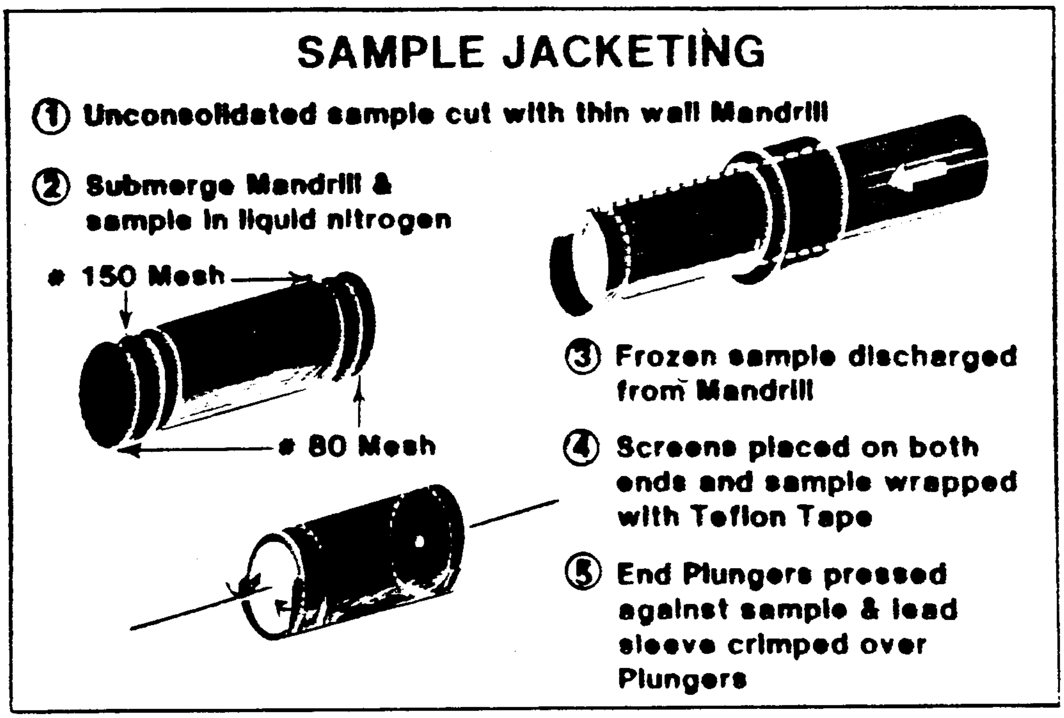

FIGURE 1

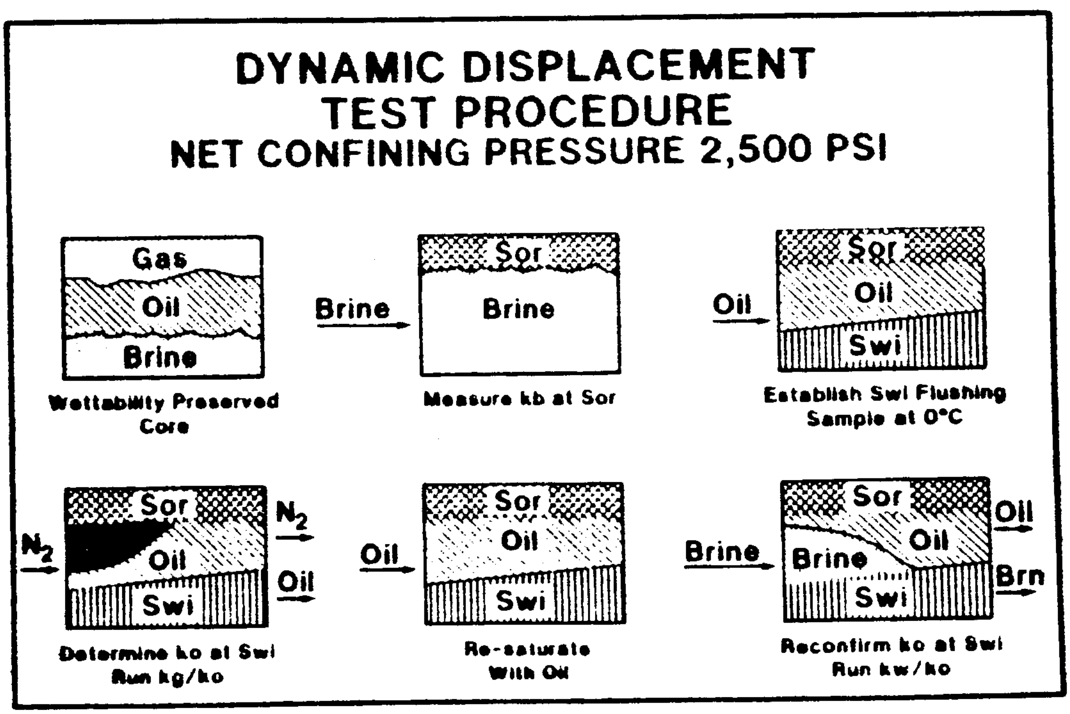

FIGURE 2

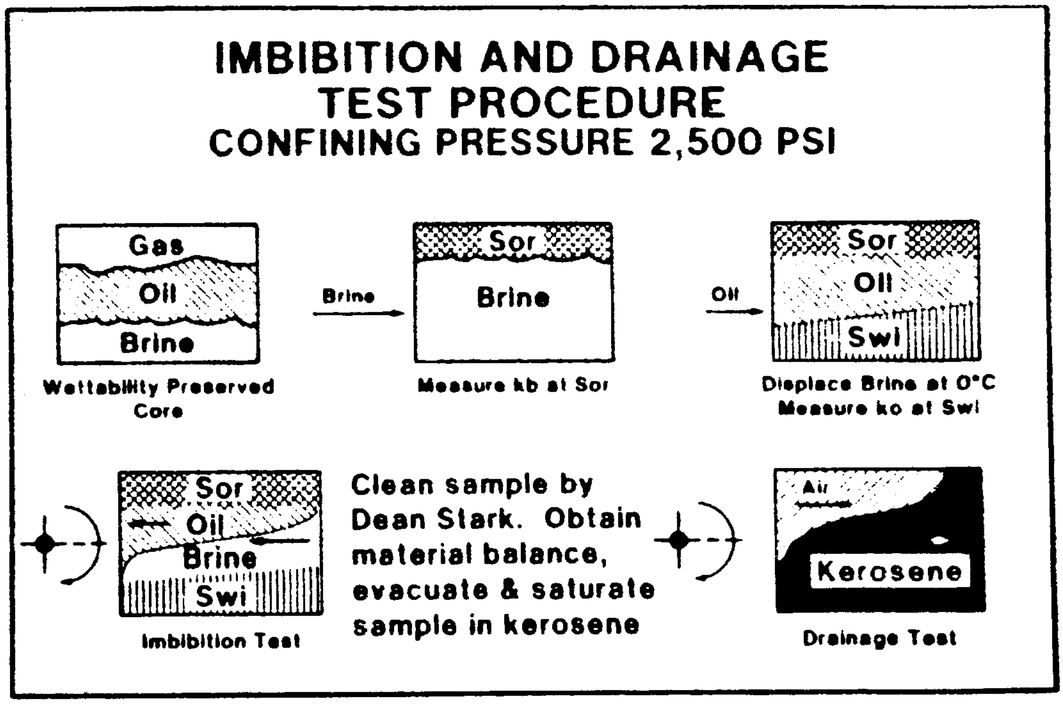

FIGURE 3

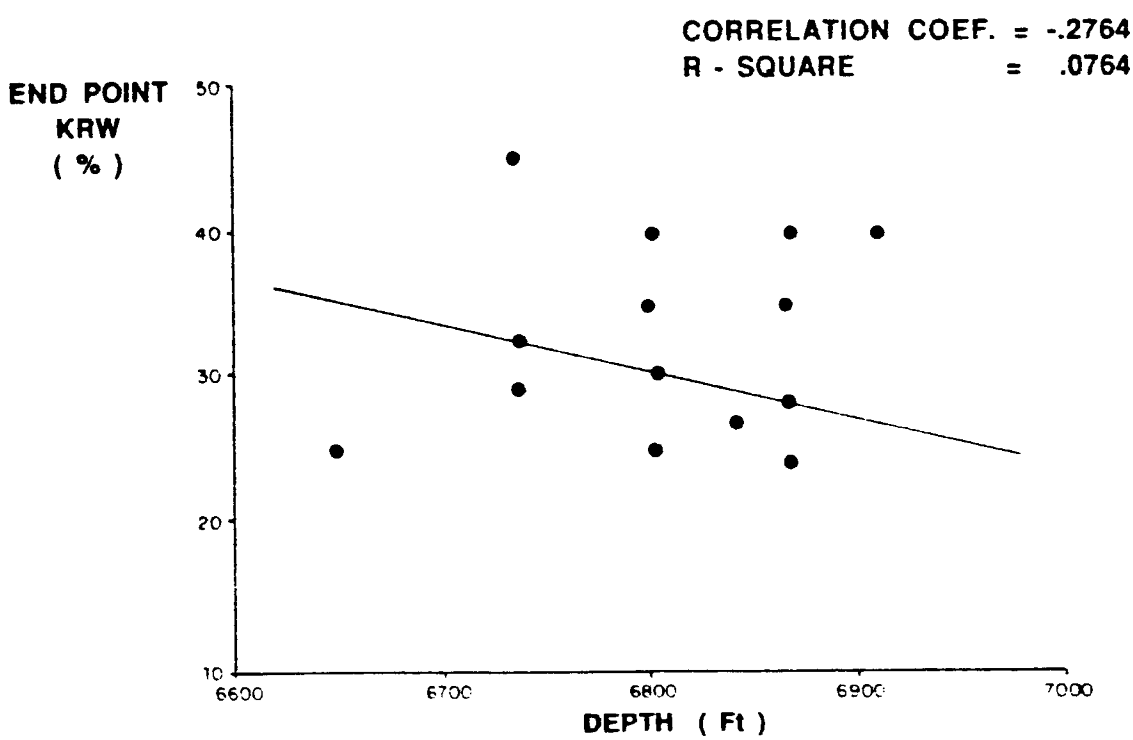

FIG.4. RELATIVE PERMEABILITY TO WATER AT RESIDUAL OIL SATURATION VERSUS DEPTH.

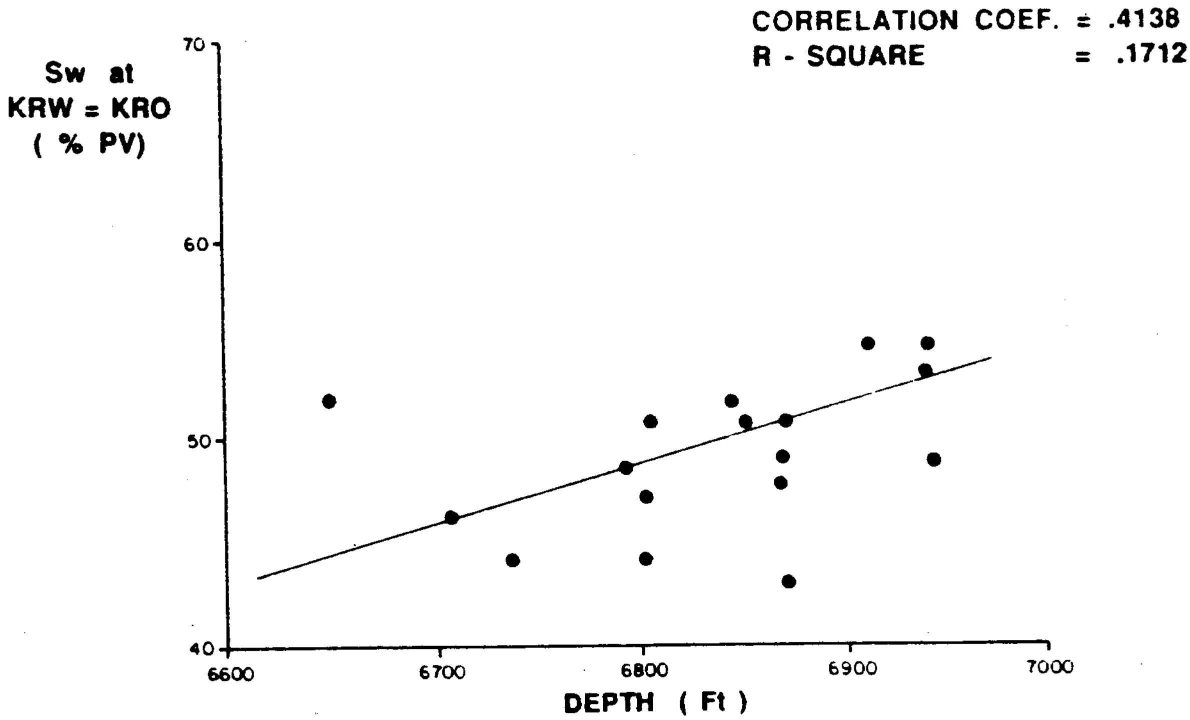

FIG.5. WATER SATURATION AT WHICH OIL AND WATER RELATIVE PERMEABILITIES ARE EQUAL VERSUS DEPTH.

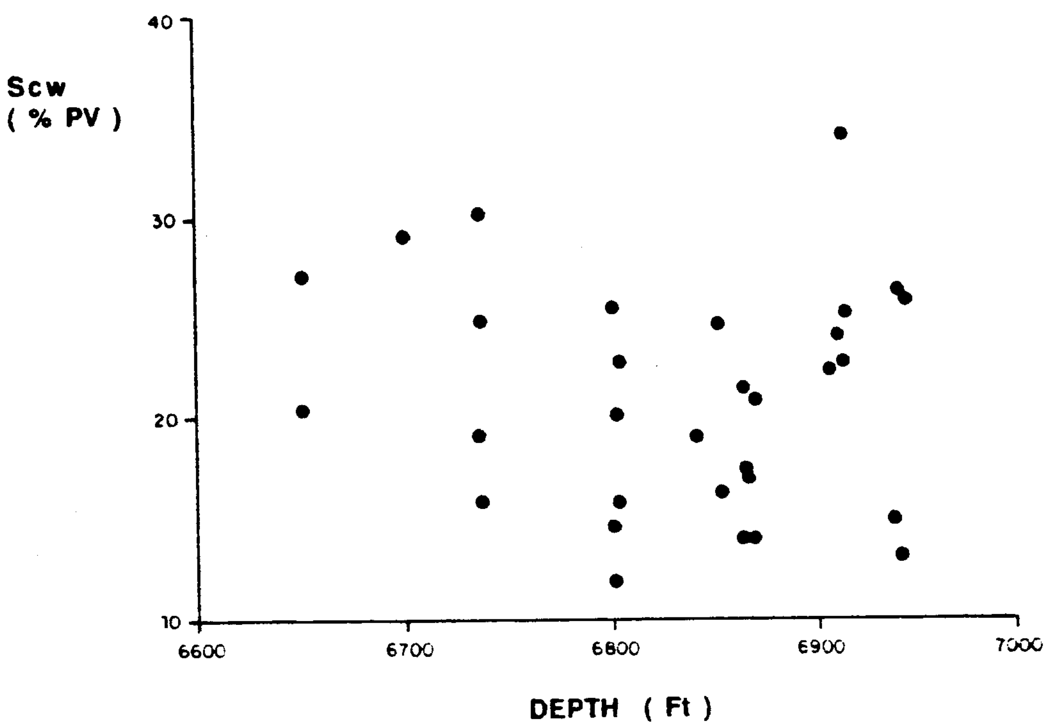

FIG.6 CONNATE WATER SATURATION VERSUS DEPTH.

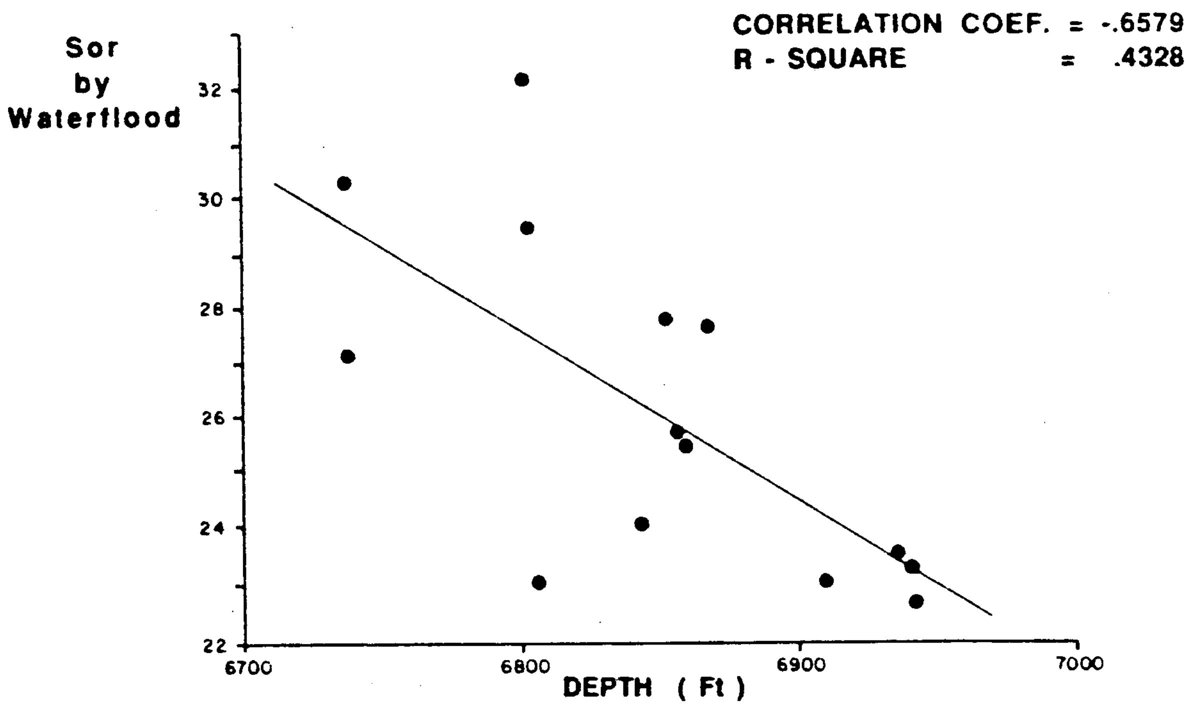

FIG.7 RESIDUAL OIL SATURATION BY WATERFLOOD VERSUS DEPTH.

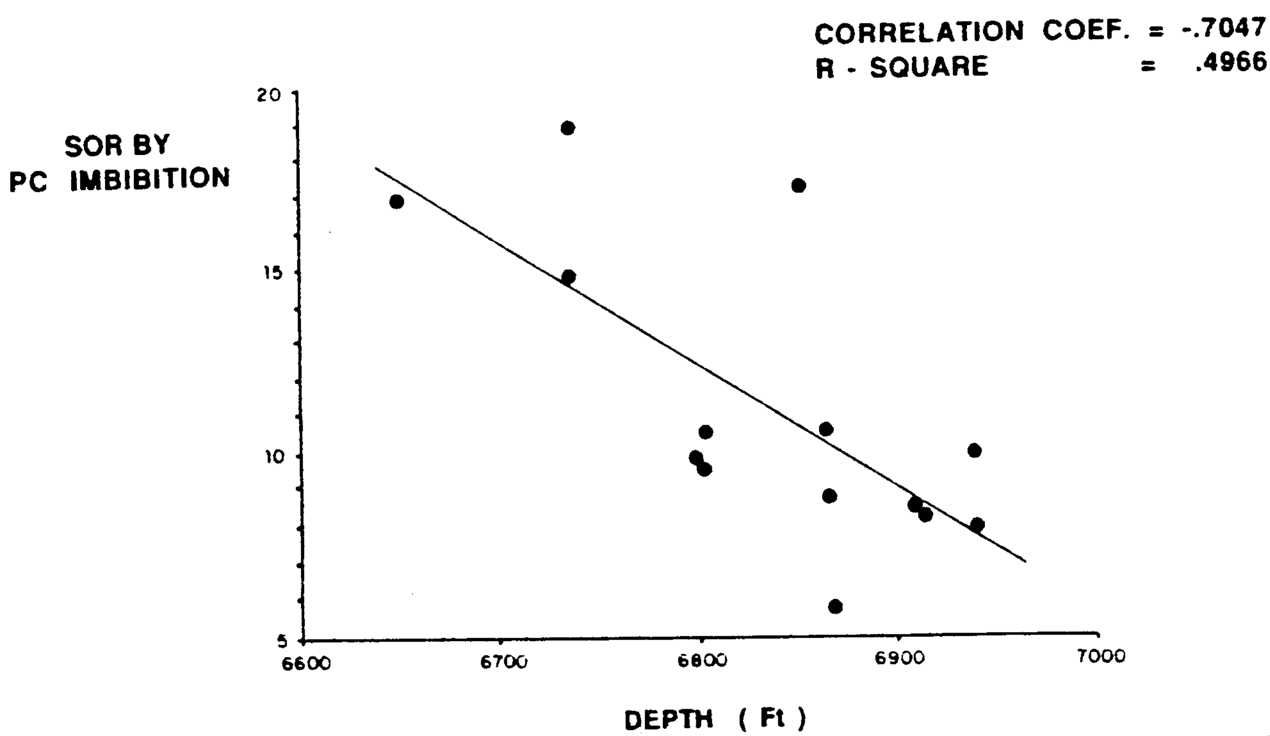

FIG.8 RESIDUAL OIL SATURATION BY CENTRIFUGE IMBIBITION CAPILLARY PRESSURE VERSUS DEPTH.

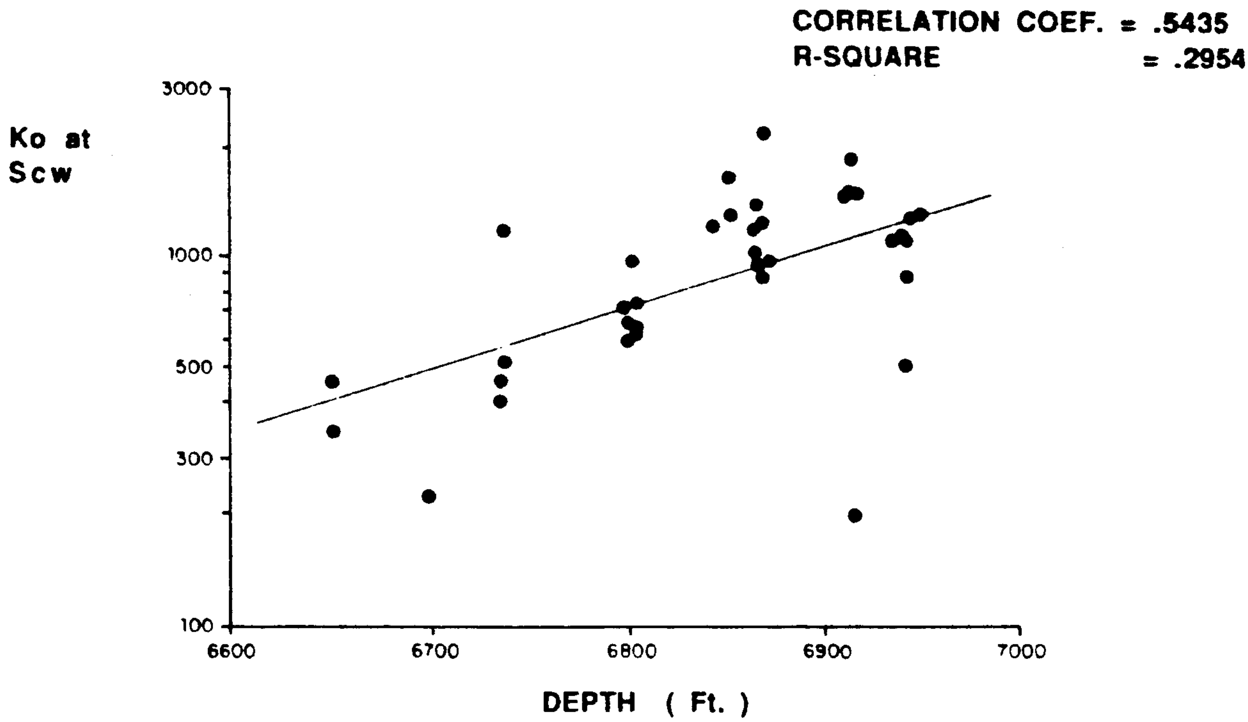

FIG.9 OIL PERMEABILITY AT CONNATE WATER SATURATION VERSUS DEPTH.

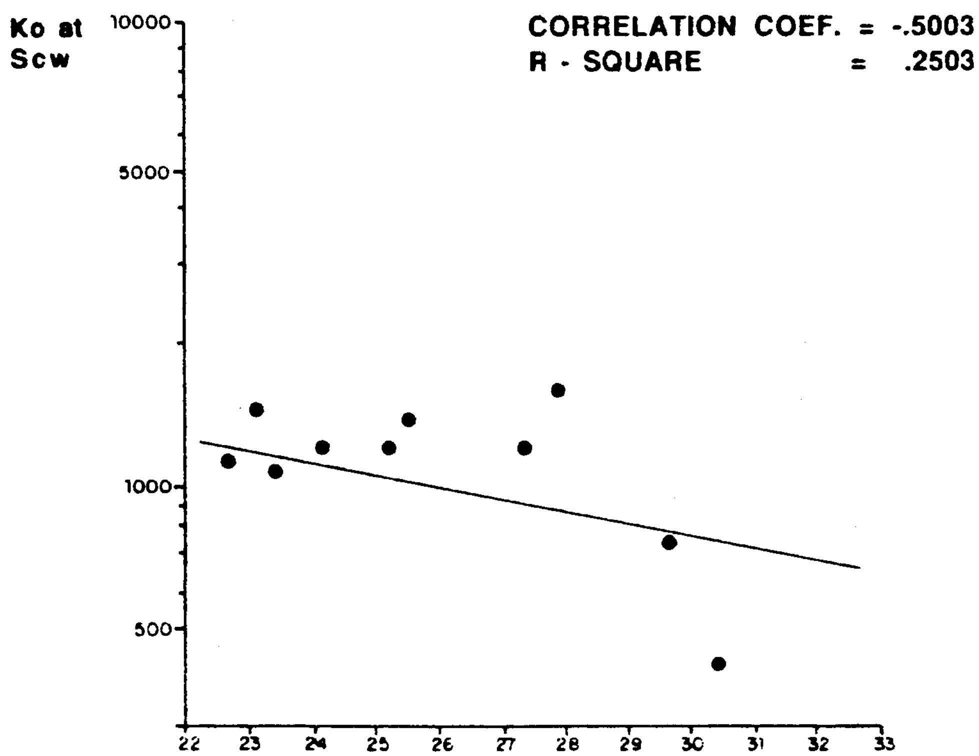

FIG.10. OIL PERMEABILITY AT CONNATE WATER SATURATION VERSUS WATERFLOOD - RESIDUAL OIL SATURATION.

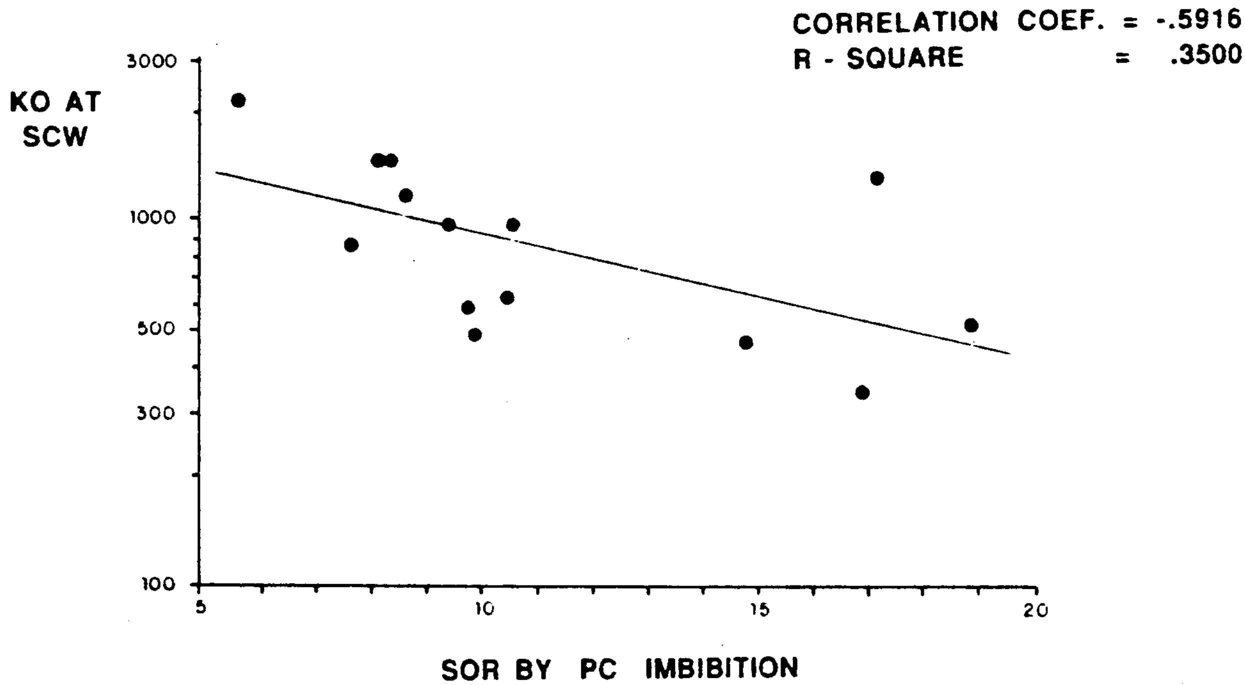

FIG.11 OIL PERMEABILITY AT CONNATE WATER SATURATION VERSUS CENTRIFUGE CAPILLARY PRESSURE RESIDUAL OIL.

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