Evaluation of Capillary Characteristics in Petroleum Reservoir Rock Using Three Wells in Sirte Basin

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Abstract

The main goal of core analysis is to reduce uncertainty in reservoir evaluation processes created at the different levels from reserve estimate level and reservoir performance level. In order to reach these targets, the exact determination of certain petrophysical properties is necessary such as rock porosity, relative permeability, water saturation, and capillary pressure at all stages of reservoir life and rock wettability.

The overall aim of this paper is to calculate capillary pressure curve for 18 carbonate samples in three wells, compute one J-function representing the whole reservoir, determine transition zone height for the

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reservoir, and study the variation effect of permeability on capillary pressure curve. This work concentrates on improving the confidence in measuring capillary pressure scanning curves and the motivation was to improve the recovery mechanisms in fractured chalk reservoirs and increase the reliable input parameters for numerical simulations of such oil reservoir.

The main findings are that the regression trend fits the wells data in strong degree and the universal J-function equation represents the type of lithology for the area of study.

Key words: *Capillary pressure, Wettability, Core sample, Carbonate reservoir, J-function.*

1. Introduction

Current laboratory-based techniques require the use of rock-fluid systems that are representative of in situ reservoir wettability. Several parameters like relative permeability, residual saturations, and capillary pressure curves change with the wettability state of the reservoir [1].

Wettability of reservoir rocks is the actual process by which a liquid spread on (wets) a solid substrate or surface. Different methods for measuring the wettability include: contact angles, (Amott), and USBM (U.S. Bureau of Mines) wettability. The contact angle measures the wettability of a specific surface, while the Amott and USBM methods measure the average wettability of a core. Changes in the wettability of cores have been shown to affect electrical properties, capillary pressure, relative permeability, irreducible water saturation (IWS), and residual oil saturation (ROS) [3].

The capillary pressure J-function is a dimensionless measure of the capillary pressure of a fluid in a porous medium. The function was derived based on a capillary bundle model. However, the dependence of the J-function on the saturation Sw is not well understood. A prediction model for it is presented based on capillary pressure model, and the J-function prediction model is a power function instead of an exponential or polynomial function. Relative permeability is calculated with the J-function prediction model, resulting in an easier calculation and results that is more representative [10, 11].

2. Methodology

Three wells (A1, A2, and A3) from Libyan carbonate gas reservoir in Sirte-Basin were used in order to achieve this work. Six samples from each well (Table 1)are tested. All the calculation in this work was done by using Excel sheets.

For each sample, the special core analysis is applied in order to determine the water saturation and capillary pressure characteristics of 18 core samples.

The main rock petrophysical properties (porosity, permeability, water saturation and capillary pressure) are obtained from special core analysis, after that, a variety of equations are used to calculate the Leverett's J-Function which used in a case of rock samples with different pore-size distribution, permeability, and porosity will yield different capillary pressure curves. Leverett's J-function is a technique for correlating capillary pressure to water saturation and rock properties.

The capillary forces in a petroleum reservoir are the result of the surface and interfacial tensions of the rock and fluids, pore size and geometry and wetting characteristics of the system. When two immiscible fluids are in contact, a discontinuity in pressure exists between the two fluids, which depend upon the curvature of the interface separating the fluids. We call this pressure difference the Capillary pressure (pc) .

Table 1: Samples Distribution of Core Plugs

Well No.	Sample No.
1	3 - 12 - 24 - 51 - 54 - 55
2	17 - 53 - 65 - 129 - 141 - 184
3	15 - 25 - 46 - 49 - 69 - 110

3. Results

3.1 Universal J-Function, Capillary Pressure and Height Calculations

Based on Eq. (1) below, the universal J-function with water saturation, is plotted for the whole Gialo formation, of the three wells, Fig. (1).

$$\mathbf{J}(\mathbf{S_w}) = 0.21645\ (\mathbf{P_{cLab}}/\sigma)\sqrt{(K/\varphi)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

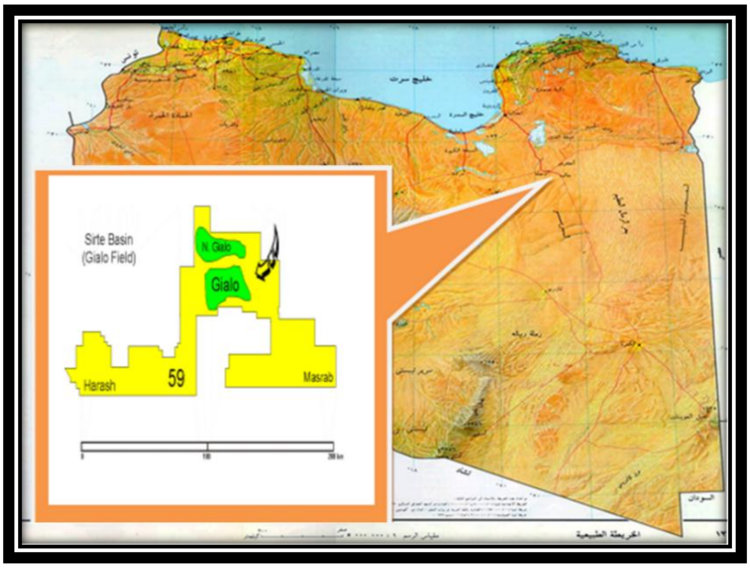

Figure1: Location Map for Gialo Oil Field (*Libyan Survey Department, 1977*)

The corresponding capillary height, h, was calculated from the following relation:

h = **Pc** / (water pressure gradient – gas pressure gradient) …… (2)

Geophysical log interpretations and core analysis establish the following additional data:

Gas density = 7.15 lb/ft^3

Water density = 64.1 lb/ft^3

Interfacial tension = 50 dynes/cm

Water pressure gradient = 0.46 psi/ft

Gas pressure gradient = 0.0513 psi/ft.

Figure (2) below shows the relationship between water saturation and J function which have been calculated using equation (1) for all core samples.

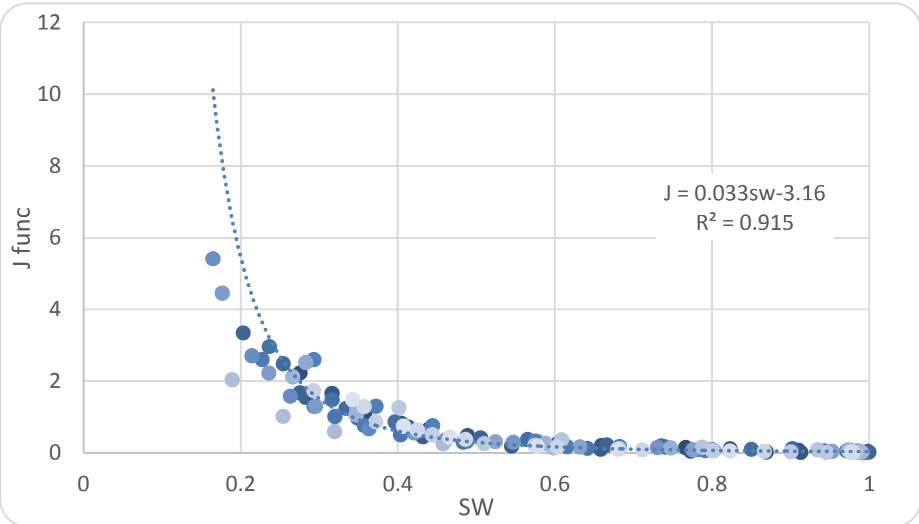

Figure 2: J-Function with Water Saturation for Gialo Formation of The Wells' Area

3.2 Effect of Permeability Variation on The Capillary Pressure

The effect of permeability variation on the capillary pressure P_c and consequently on capillary height h, is studied and the results are in Tables 2, 3 and figures 2, 3.

Table 2: Capillary Pressure at Different Permeability's for the 3 Wells

Porosity, %Ave.	S_w New	J-function New	Capillary pressure $\mathbf{P_c}$, at **K**, mD:				
			0.5	1	10	100	1000
19.7811	1	0.033	4.383679	3.72809	2.3088866	0.6662739	0.224096
	0.9	0.046037	6.115506	5.20092	2.4718413	0.92949374	0.3126285
	0.8	0.066796	8.87308	7.54609	3.5864316	1.34861641	0.4535974
	0.7	0.10186	13.53097	11.5074	5.4691156	2.05656761	0.6917117
	0.6	0.165789	22.02322	18.7296	8.9016181	3.34730162	1.1258408
	0.5	0.294964	39.18263	33.3228	15.83732	5.95535404	2.0030405
	0.4	0.597041	79.31023	67.4492	32.056591	12.0543342	4.0543886
	0.3	1.481872	196.8501	167.411	79.565307	29.9191764	10.0631
	0.2	5.336532	708.8984	602.881	286.53133	107.74522	36.23933

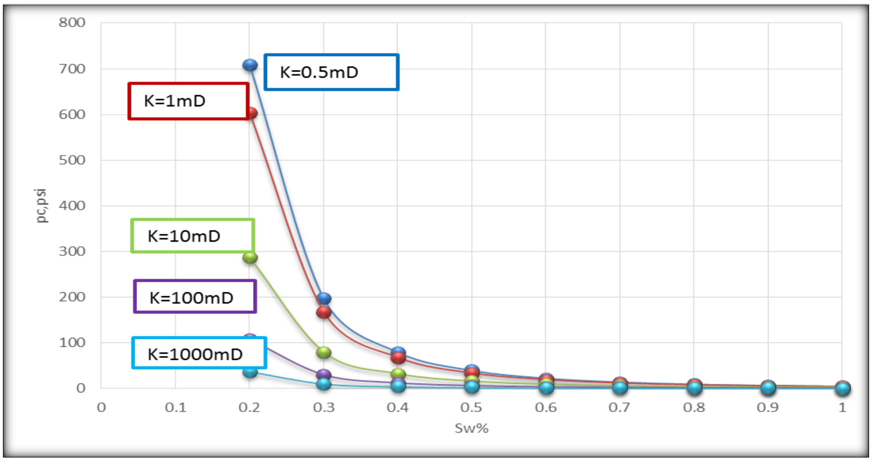

Figure 3: P_c- S_w Curves at Different Permeability's

Table 3: Capillary height at different permeability's for the 3 wells

Porosity, % Average	S_w New	J-function Height	Capillary height **h**, at **K**, mD: 0.5	1	10	100	1000
19.7811	1	0.033	0.5483152	1.6302273	5.6493432	9.12182	10.72591
	0.9	0.046037	0.764934	2.274269	6.0480579	12.7255	14.96331
	0.8	0.066796	1.1098542	3.29977101	8.7752179	18.4636	21.7105
	0.7	0.10186	1.6924681	5.03197361	13.381736	28.1561	33.10734
	0.6	0.165789	2.7546876	8.19011896	21.780323	45.8272	53.88603
	0.5	0.294964	4.9010044	14.5714559	38.750477	81.5336	95.87136
	0.4	0.597041	9.9202069	29.4943336	78.435505	165.034	194.0549
	0.3	1.481872	24.622216	73.2057166	194.679	409.618	481.6493
	0.2	5.336532	88.669757	263.629117	701.07985	1475.12	1734.52

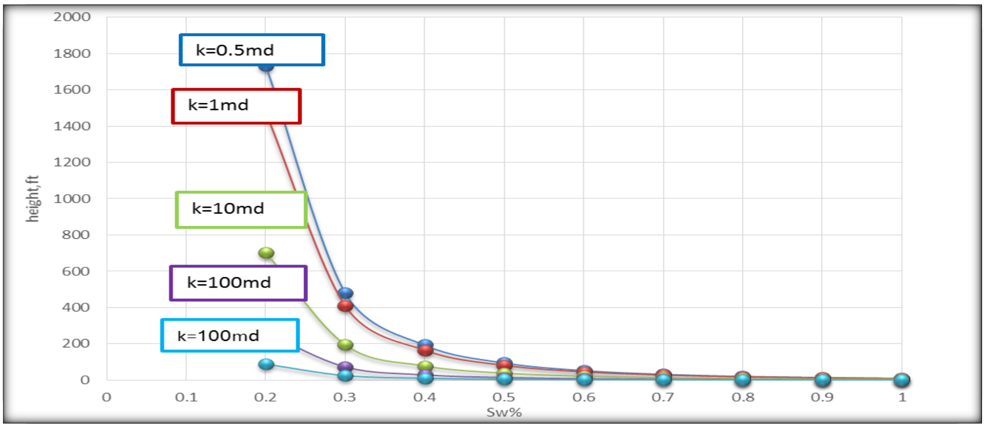

Figure 4: H_c- S_w Curves at Different Permeability's

4. Discussion

From the results obtained in Tables (2 and 3) and corresponding curves in Figures (2 to 4), it was found that:

- The high R-squared value (0.915) of Fig. 1, indicates that regression trend fits the wells' data in strong degree and the universal J-function equation represents the type of lithology for the area of study.
- The water saturation (S_w), critical water saturation (S_{wc}), connate water saturation (S_{wi}) , and irreducible water saturation (I_{WS}), are extensively used interchangeably to define the maximum water

saturation at which the water phase will remain immobile to oil /or and gas in reservoir. This value is affected by:

- Porosity, direct slightly.
- Permeability, k, inverse strongly.

This effect was clearly through all samples in the three wells, as shown in table **4**.

Table 4: Summary of The Samples' Results

well No.	sample	ϕ, %	k_g, md	PcL/res, psi	Sw
1	3	15.25	2.533	120/ 83	0.266238
	12	19.37	2.978		0.189285
	24	11.98	0.702		0.401413
	51	18.4	2.05		0.292931
	54	18.4	0.91		0.356957
	55	15.6	1.28		0.342272
average		16.500	1.7		0.3
2	17	20.92	3.02	120/ 83	0.3200
	53	21.61	5.412		0.227315
	65	16.41	4.11		0.293064
	129	29.37	31.85		0.164596
	141	31.91	23.46		0.176517
	184	25.48	5.98		0.282782
average		24.283	12.305		0.244
3	15	17.67	3.251	120/ 83	0.275488
	25	14.4	1.47		0.275488
	46	16.57	1.47		0.282762
	49	25.33	10.49		0.203178
	69	20.35	4.639		0.254158
	110	17.04	5.533		0.236567
average		18.560	4.476		0.2546
av. All		19.7811	6.174		0.269

From the previous table, it is clear that the minimum permeability value which is 0.702, lies at sample 24 in the well No.1, had recorded maximum saturation value, 0.40, the worst position of hydrocarbon reserve. Furthermore, the maximum permeability value which is 31.85, lies at sample **141** in the well No.2, had recorded minimum saturation value, 0.165, the worst position of hydrocarbon reserve. The variation in saturation height is related to permeability values differences, and the Leverett J-function decreases the uncertainty of the reservoir estimation faced due to extremely variation of the petrophysical properties such as porosity, permeability and water saturation through reservoir rocks.

5. Conclusions

- Changing the wettability cause a change in capillary pressure curve.
- From the routine core analysis, the average porosity of core samples is 19.7%.
- The transition zone height for the reservoir is nearly 290 ft.
- Several methods are used today to predict saturation-height to estimate volumetric hydrocarbon in place.
- Four of the more popular methods are: Leverett, Johnson, Cuddy and Skelt. In this work, J-Leverett function (J-function) was used.
- The universal equation of j-function that representing the whole reservoir is J = 0.033sw-3.16
- The larger pores, which means high permeability values, the lower irreducible water saturation is.

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