INVESTIGATION ON THE EFFECT OF STRESS ON CEMENTATION FACTOR OF IRANIAN CARBONATE OIL RESERVOIR ROCKS

R. Behin, RIPI, NIOC

This paper was prepared for presentation at the International Symposium of the Society of Core Analysts held in Abu Dhabi, UAE, 5-9 October 2004

ABSTRACT

Electrical resistivity is one of the important petrophysical properties of oil reservoir rocks. Cementation Factor or Formation Resistivity Factor (FRF) is widely used in studies to estimate porosity and water saturation. Some researchers have studied the effect of many factors on the cementation factor “m”, mostly with sandstone rocks, and occasionally with carbonates rocks. Since the carbonate rocks contain nearly half of the world’s petroleum reserves and also most of Iranian oil and gas reserves, therefore it is very important to determine the petrophysical properties of carbonate rocks.

This paper reports an experimental investigation on the influence of variations in confining pressure on cementation factor of some Iranian carbonate rocks with similar and substantial high porosity in two different oil fields. This work included the following sequences: cleaning and drying, porosity and Pore Size Distribution determination, and electrical resistivity measurements at different confining pressures. The Pore Size Distribution carried out with high pressure mercury intrusion techniques. Cementation Factor was calculated for both field’s rocks at each pressure.

Effect of confining stress on electrical properties of rock samples were studied. This study indicates that the influence of the confining pressure variations depends on the nature and pore structure of rock sample. Even though pore volume and porosity changes were same for both reservoir samples, but rock samples with non-uniformly pores have higher change of cementation factor and resistivity , than rocks with uniformly pores due to confining pressure variations.

The above conclusion empowered the idea that, electrical resistivity of rocks is function of Pore Size Distribution and therefore resistivity of rocks strongly depend on the way that fluids are distributed in the pore space.

INTRODUCTION

The cementation or Archie porosity exponent “m” plays an important role in the calculation of hydrocarbon/water saturations with Archie equation. In his classic 1942 paper, Gus Archie [1] proposed an empirical relationship linking a rock’s resistivity Ro with it’s porosity Ø:

$$F_R=R_o/Rw=1/Ø^m \qquad (1)$$

Where F_R – Formation Resistivity Factor found from Ro/Rw, Ro – resistivity when the sample is fully water saturated (Sw = 100%) and Rw – formation water resistivity. The conventional procedure to determine m is by the cross plot techniques. Plotting Formation Resistivity Factor FR, versus core or log porosity on the log-log paper is used to find “m” values. The value of “m” is the slope.

Winsauer et.al.[2] later modified this expression by inserting the constant “a”:

$$F_R=R_o/Rw=a/Ø^m \qquad (2)$$

This relationship is known as the modified Archie equation. The constant “a“ named tortuosity or consolidation factor and is conventionally determined with the intercept of the trend line with the 100% porosity.

Hydrocarbon saturations calculated with the conventional value m = 2. But reservoir engineers have been able to apply a constant m with some success in clean clastic sandstone reservoirs. The pore geometry is often complex and intrinsic heterogeneity is very common in carbonate reservoirs. The Middle East contains some of the world’s largest carbonate reservoirs. The pore systems in most of the Middle East reservoir formations commonly include secondary pore types and unfortunately, the geometry varies from zone-to-zone and from well-to-well in the same field.

T.Shamsi Ara et.al. [3] in their in-depth investigation on the validity of the Archie equation in carbonate rocks, it was concluded that the consolidation and cementation factors are functions of many rock parameters, such as composition , pore geometry and pressure. J.W.Focke et.al. [4] also in study of Middle Eastern Carbonate Reservoirs concluded that rock types with more tortuous and or poorly interconnected porosity, however, show well-defined trends of increasing “m” with increasing porosity.

The investigation by Watfa and Nurmi [5] shows that even though the porosity is kept constant, changes in radius will change the value of m from m = 2 to m = 3.21. Formation Resistivity Factor and cementation exponent data in carbonate reservoirs indicate large variations, therefore heterogeneous carbonate reservoirs should be split into layers on the basis of dominant rock type by core studies to allow the measurement of different m values, to be applied in each layer.

PROCEDURE

The electrical resistivity cell is a hydrostatic triaxial stainless steel core holder containing a core plug approximately 1.5 inch in diameter and min. 1.8 inch long. The measurement principle is known as the two-electrode method. The resistivity cell is connected to a LCR- meter capable of measuring the electrical impedance. The conditions are 1V, 1 kHz. The stress is maintained by mineral oil at about max 10000 psi or 700 bar. PV changes at the each stress can determined with connected burette to the outlet of the core.

The series of experiments were carried out using a number of carbonate rocks. In order to compare the experimental results, the samples were have been chosen with similar high porosity from P and S oil fields. The selected samples were without fracture and clays. Initially, core plugs were cleaned by toluene in Soxlet Distillation / Extraction apparatus

and dried in oven. Their porosity were measured by helium porosimeter. Then core plugs completely saturated with NaCl brine, specified ppm under 3000 psi. Initial brine PV was determined with difference of dry and saturated plugs weight. Porosity of samples at each stress determined by PV changes. 5PV brine was injected with constant rate pump to ensure that plug was saturated. Confining pressure applied, starting from 400 to 5000 psi and was increased when volume of water and resistivity values had stabilized.
Mercury injection in porous media provides detail information about pore size distribution, therefore brine distribution, also can contribute to understand character of electrical conductivity of rock samples. PSD measurements were carried on the natural core pieces by high pressure mercury intrusion technique. The method consists of injecting mercury at increasing pressure to30000 psi into a sample, which has been previously evacuated. As mercury is strongly non-wetting and this character contribute for determine pores down to 0.004 microns diameter.

RESULTS

The electrical resistance and Pore Size Distribution measurements carried out on six samples of each field. The selected samples have the phi values given in Table3. Table1 and 2 give the relative variations of PV reduction and FRF for an increase in stress from 400 psi to 5000 psi. These variations show, PV change were similar for both reservoir samples (5.21% and 5.05%), but increasing in the FRF, also resistivity of samples were greater for S field than P field. The mean variation of FRF was 10.4% for P field and 54.5% for S field. Figures1-4 illustrates curves PV and FRF relative variations versus stress for P and S fields. Calculated m at differential confining pressure for each field given in Table 4. In order to get nearly reservoir condition, brine simulated with specified ppm and resistance 0.075Ω*m for P field and 0.040 Ω*m for S field were obtained with a Schlumberger [6] electrical resistivity nomograph. Figure 5 and 6 illustrate Hg-injection curves which provide information on the PSD for P and S field rocks. They show that, the range of the pore size P field rocks is 0.01-1μm and these samples possess a modal pore distribution. In S field the range of pore size is greater (0.1-10 μm) than P field, but samples of S field were heterogeneous and possess bi-modal pore distribution. Figure 7 and 8 illustrate curves cementation factor versus stress for different field rocks.
Investigation on cementation exponent of carbonate reservoir rocks in two field shows that, “m” was increased by increasing stress, but this change is different for these fields.

DISCUSSION

In a uniformly porous media, conductor brine is occupying all the connected pores, therefore all the pore brine is continuous phase and can conduct electrical current. This phenomenon decreased the length of the conducting paths. In the P field’s rocks, although the most of pores are in range of microports and mesoports, but since they are connected effectively and continuously, therefore they possess high porosity. When the rock is compacted as a result of the confining pressure, the matrix is under stress and porosity decreases. Increasing confining pressure caused increase of "m " value and shrinkage of pore system, but this shrinkage strongly depends upon pore geometry of rock. Uniformly distributed pores in P field is the main reason for equally shrink of all pores and for cementation exponent being 2.02 at 400 psi and max. value 2.12 at 5000 psi. In non-uniformly pores, heterogeneity in Pore Size Distribution causes non-uniform brine distribution in the Porous Media. When a change in porous media occurs in different proportion to the change in other pores, therefore there is more disconnection and isolation of globules of brine and this isolated brine cannot contribute to the current flow. It implies that increasing resistivity is caused by decreasing pore cross-sectional area available for conductor brine and increasing grain size. Therefore this phenomenon caused high change of cementation factor from 2.45 at 400 psi to 2.80 at 5000 psi.

CONCLUSIONS

Investigation on the effect of stress on cementation factor of Iranian carbonate rocks in two fields indicate although the shrinkage of pore volume and porosity were similar for both field samples, but change of cementation factor in field S was greater than field P. Only a small increase was noted in the cementation factor for P field rocks and an increase up to 0.10 unit was observed from 400 psi to 5000 psi confining pressure. A larger increase in cementation factor observed for S field by increasing stress and this change was from 2.45 at 400 psi to 2.80 at 5000 psi, i.e. increase of "m" nearly 15% of initial value. Increase of stress causes shrinkage of pore system and also increase of resistivity, but resistivity variations strongly depend upon pore geometry. Rock samples with non-uniformly pores have higher resistivity change than uniformly pores. Consequently, resistivity effect and cementation factor strongly depend upon the way that conductor brine is distributed in the pore space. A rock with bi-modal pore distribution possesses high resistivity.

NOMENCLATURE

F = Formation Factor
Rw = The resistivity of brine, [Ω*m] Ro = The resistivity of rock at Sw=100%, [Ω*m]
m = Archie's cementation exponent
a = Tortuosity factor
Ø = Porosity, [%]

ACKNOWLEGMENTS

The author thanks Dr. E.Kazemzadeh, Head of Core Lab for his kind help and also Dr.M.Kamali, Director of E&P Research Center, RIPI for permission to publish this paper.

REFERENCES

[1] Archie, G.E.: “The electrical resistivity log as an aid in determining some reservoir characteristics”, Petroleum Transactions, *AIME*, (1942) v.**146**, pp54-62
[2] Winsauer, W.O. et al.: “Resistivity of Brine Saturated Sands in Relation to Pore Geometry”, *AAPG Bull*. (1952) V.**36**, pp253-77
[3] Shamsi Ara, T. et al.: “In-Depth Investigation of the Validity of the Archie Equation in Carbonate Rocks”, *SPE* paper **67204**.
[4] Focke, J.W., and Munn,D.: “ Cementation Exponents in Middle Eastern Carbonate Reservoirs”, *SPE Formation Evaluation*, (June 1987), pp155-67.
[5] Watfa, M., and Nurmi, R.: “ Calculation of Saturation, Secondary Porosity and Producibility in Complex Middle East Carbonate Reservoirs”, SPWLA 28 - th Annual Logging Symposium, June 29 – July 2, 1987.
[6] Log Interpretation Charts, Schlumberger, New York City, (1972).

Table 1: Rock Properties of P field

Rock properties	*Sample no*					
	1	2	3	4	5	6
Brine PV @ 400 psi	7.06	12.7	10.7	13.0	13.1	16.5
Brine PV @ 5000 psi	6.81	12.1	10.2	12.4	12.1	15.5
PV reduction %	3.54	4.72	4.67	4.62	7.63	6.1
FRF @ 400 psi,	75.6	16.5	22.7	15.0	15.8	13.2
FRF @ 5000 psi,	86.4	18.2	25.9	15.6	17.6	14.3
Change of FRF %	14.3	10.3	14.1	4.0	11.4	8.33

Table 2. Rock Properties of S field

Rock proper	*Sample no*					
	1	2	3	4	5	6
Brine PV @ 400 psi	12.5	10.7	13.2	13.0	12.5	9.50
Brine PV @ 5000 psi	11.9	10.0	12.3	12.6	12.0	9.02
PV reduction %	4.8	6.54	6.82	3.08	4.0	5.05
FRF @ 400 psi,	32.5	60.1	43.0	46.3	44.4	92.5
FRF @ 5000 psi,	37.5	84.8	73.9	72.1	71.2	169
Change of FRF %	15.4	41.1	71.9	55.7	60.4	82.7

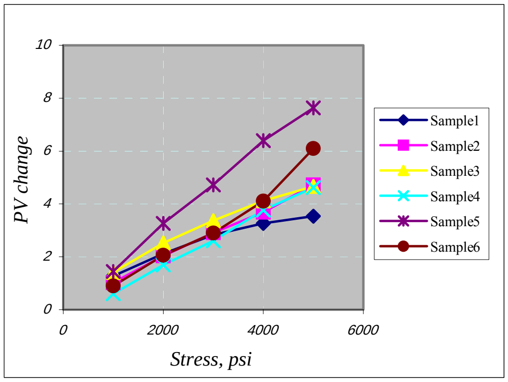

Fig 1. Relative PV variation in P field

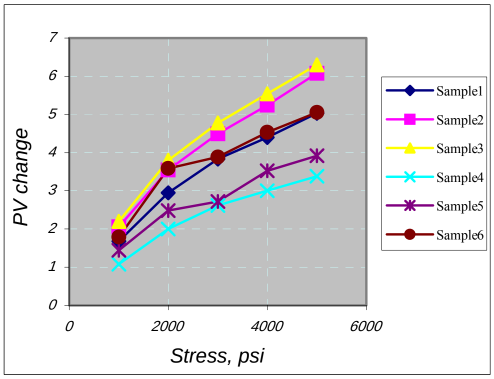

Fig 2. Relative PV variation in S field

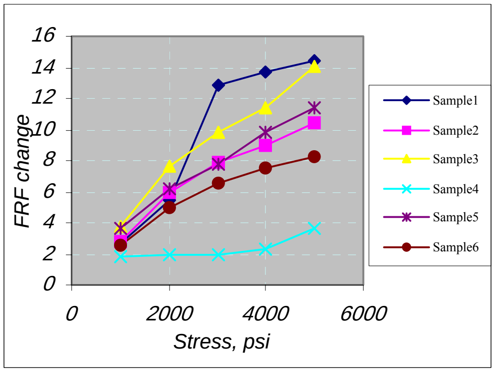

Fig 3. Relative FRF variation in P field

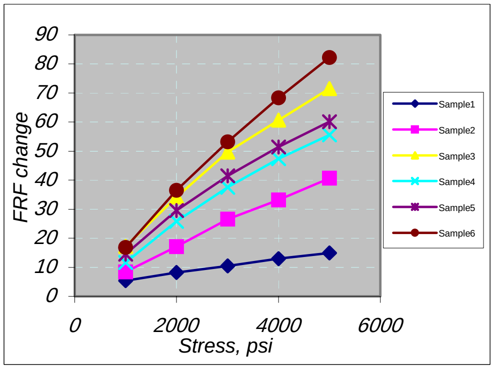

Fig 4. Relative FRF variation in S field

Table 3: Porosity values P and S oil field rock samples

Sample no of P field	Porosity Ø , (%PV)	Sample no of S field	Porosity Ø, (%PV)
1	13.3	1	22.8
2	23.2	2	18.8
3	19.9	3	23.3
4	24.9	4	22.6
5	24.1	5	21.4
6	28.8	6	16.7

Table 4: Cementation Factor of P and S field at differential confining pressure

Confining Pressure, psi	Cementation Factor m	
	P Field	S Field
400	2.02	2.45
1000	2.02	2.49
2000	2.02	2.56
3000	2.09	2.64
4000	2.11	2.71
5000	2.12	2.80

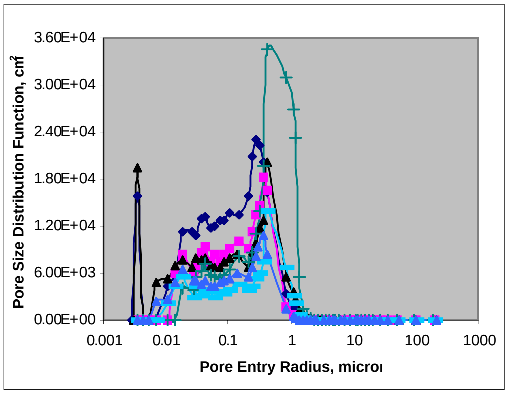

Figure 5. Pore Size Distribution curves P field samples

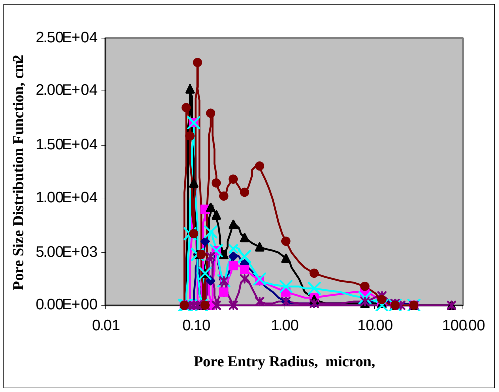

Figure 6. Pore Size Distribution curves S field samples

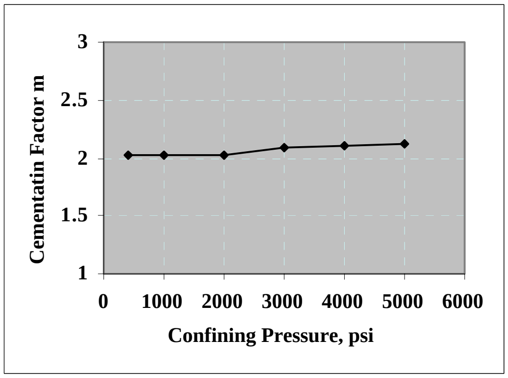

Figure 7. Cementation exponent at differential confining pressure P field

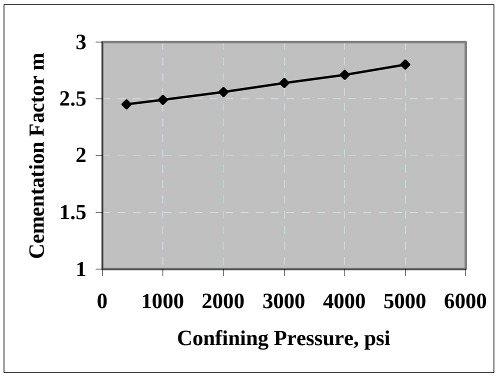

Figure 8. Cementation exponent at differential confining pressure S field