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Application of production logging tools in estimating the permeability of fractured carbonated reservoirs: A comparative study

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Fractured carbonated reservoir is one type of unconventional reservoirs which has low permeability rather than conventional reservoirs in terms of complex depositional and diagenetic environment. In most of the fractured carbonated reservoirs, fluid flow characteristics such as permeability and porosity are generally difficult to estimate and the most porous intervals are not always the best reservoirs as the intervals of equivalent porosity. Permeability plays the substantial role in moving the fluid flow from the fractures of the reservoir to the wellbore. Due to the fact that, calculating the appropriate amount of permeability was seriously doubted and there were numerous challenges for petroleum engineers to obtain the accurate quantity. Estimation of permeability using regular methods such as core analysis and well testing methods are outrageously expensive and time consuming. Furthermore, a simple correlation between permeability and porosity cannot be developed. Therefore, the prediction of permeability in heterogeneous carbonates by production logging tools is a preferable methodology to reduce the squander sums of money and time in measuring the fluid properties of a carbonate reservoir such as permeability, measuring the well fluid profile, detection of mechanical problems and evaluation of well completion procedures. That is to say that, production logging tools is performed as a powerful and applicable instrument to estimate the flow rate, water-oil contact, and other fluid properties.

Key words: Unconventional reservoirs, permeability estimation, production logging tools, fluid properties.

INTRODUCTION

Permeability is one of the most important reservoir property parameters in reservoir engineering, reservoir management, and enhanced recovery design which accurately affect the total volume of production. Comprehensive knowledge of rock permeability and its spatial distribution throughout the reservoir is of utmost importance. In addition, in most reservoirs, permeability measurements are rare and therefore permeability must be predicted from the available data. Thus, the accurate estimation of permeability can be considered as a difficult task (Adeboye, 2010; Aigbedion, 2007; Babadagli and Salmi, 2004). There are a wide variety of methodologies for calculating and estimating the quantity of permeability which entail laboratory such as core analysis and

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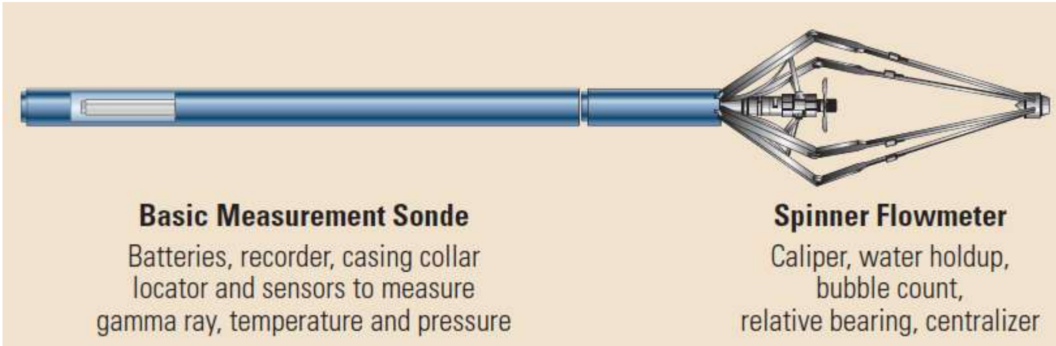

Figure 1. Production logging tools.

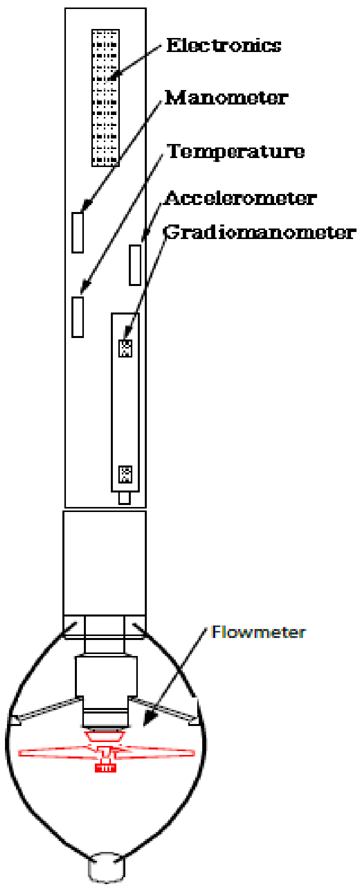

Figure 2. Instruments and other logs in the production logging tools.

theoretical measurements are based on well test techniques. The well testing and coring methods are, however, very expensive and time consuming compared to the wire-line logging techniques (Carlos, 2004; Cozzi and Ruvo, 2007; Dale, 1949). As the well log data are usually available for most of the wells, many researchers attempt to predict permeability through establishing a series of statistical empirical correlation between permeability, porosity, water saturation, and other physical properties, of rocks. This technique has been used with some success in sandstone and carbonate reservoirs, but it often shows short of the accuracy for permeability prediction from well log data in heterogeneous reservoirs (Grayson et al., 2002; Hoffman, 2012; Kading, 1975).

Production logging tools

Due to the fact that production logging tools investigate and evaluate the dynamic properties of the reservoir in the wellbore; in respect of the way, it is the reflection of absolute reservoir permeability (Quintero and Boyd, 1999; Sullivan, 2007; Faroognia et al., 2011). Thereby, the obtained permeability from these logs is fundamentally similar to realistic reservoir properties and act as the proper amount of permeability especially in fractured carbonated reservoirs which are considered as tight reservoirs in terms of creating dual permeability between matrix and fracture permeability. This is why it leads to a complex behavior of these reservoirs. Production logging is one of the kind of cased hole well logging services which include flow meter log, Gradiomanemeter log, Thermometer log, Manometer log and caliper log. One of the chief aims of production logging tool is to evaluate the fluid flow inside and outside the casing or in some occasions to evaluate the well completion directly. The major application of this tool is to obtain current profile in the wellbore; in respect of the way, the distribution of fluid flow in the wellbore is being measured (Li and Zhao, 2014). The schematic of production tools and its instruments are as shown in Figures 1 and 2.

Application of production logging tools

Production logs are used to allocate production on a zone by zone basis and also to diagnose production problems such as leaks or cross flow. These various tasks can be splitted between those where the target production is into or out of the well and those where the flow never enters the well, typically flow behind pipe. The former is usually easier and more quantitative while the latter is more qualitative. Production logging tools are used in the following situations:

(1) In those wells that produce from multi layers where the location of production and percentage of production in each layer are investigated and calculated.
(a) Before and after the acidizing procedures to assure which layers are more active and are blocked and do not any production.
(b) It is used in injection wells to determine the injection scenarios to the layers.
(c) In the wells which have unreasonably produced water and gas to determine the location of this inefficiency.
(d) To investigate the wellbore production power by considering wellbore internal pressure.
(e) Investigating the contact level between oil and gas and oil and water.
(f) Internal wellbore radius is being measured by caliper log especially in open hole drilling (Aghli et al., 2016).

(2) Major applications of production logging are as follows:
(a) Detection of mechanical problems of the well,
(b) Evaluation of completion efficiency,
(c) Monitoring production and injection profiles,
(d) Determining reservoir characteristics,
(e) Evaluation of treatment effectiveness, and
(f) Detection of thief zones and channeled cement (McCain et al., 2011; Harald et al., 2016).

Emeraude software

Because production logging tools are so new, few specialist and engineers know how to interpret logs they produce. Accordingly, Halliburton offers interpretation as a service using specialized, proprietary software. This software integrates data provided by traditional sensors with the newer arrays, and then outputs the results into Kappa's industry-leading Emeraude® package, resulting in a comprehensive analysis in an easy-to-read log format. This allows engineers to easily develop intervention programs that truly address production issues.

METHODOLOGY

Field description

The studied reservoir was a geophysical reservoir which was located in the Persian Gulf; in respect to the way, the subsequences of drilled sections or layers are being considered normally no fault was found during the drilling procedures that may cause duplication or elimination of geological layers. In this oilfield, six production wells and four water injection wells were being drilled. Production crude oil from this reservoir is being categorized in the high quality crude oil with the number of 44 API which has the comparative potential with Brent crude oil. Rock properties of drilled formations in the studied well were based on the obtained cuttings during the drilling operations and in some occasions obtained in similarity from interpretation of production logging tools.

Analysis of permeability measurements by two different methods

Due to the fact that calculating the appropriate amount of permeability with core analysis is one of the prohibitively expensive methods, in this paper by using production logging interpretation and its comparison with obtained permeabilities of real reservoir samples, try to conduct an investigation into measured data from both methods and propose proper methods to virtually eliminate the vast investments of laboratory experiments.

The application of wide variety of logs which are used in Emeraude software are clearly shown in Figure 3 as the following.

For each flow profile in each meter (h = 1), column flow was considered and permeability calculate by Equation 1.

$$k_{plt} = \frac{c * q_i * \mu_o * \beta_o}{(p_e - p_{wf})}\left[Ln\left(\frac{r_d}{r_w}\right) + s'\right] \quad (1)$$

where C is the constant of the equation, q_i is the flow that is achieved by Emeraude software, μ_o is the viscosity, P_e is the external border pressure, P_{wf} is the internal well pressure, S is the skin factor, B_o is the oil formation volume factor, r_d is the evacuation radius, r_w is the radius of the well. As shown in Figure 4, the amounts of permeability were fundamentally different from both methods and it showed that production logging tools were located improperly and it needed to accurately be corrected and some unnecessary and unimportant data from the top and bottom of cores must be deleted to gain proper results.

After correcting and eliminating unnecessary data, it is clarified that obtained permeability from Emeraude software are relatively close to average permeability which was calculated from core analysis. This comparison is as shown clearly in Figure 5.

RESULTS AND DISCUSSION

The use of production logging tools is necessitated in homogenous, single phase flow and steady state system. Production logging tools provided sufficient information about the status of production layers, type and amount of produced fluid from each layer, flowing well inefficiency and fluid behavior in the time of moving oil through the reservoir and wellhead. Production logging tools are provided extensive and accurate information from the status of productive layers, type and quantity of produced fluid from each layer, well flow problems, and well flow behavior during the coming out of the reservoir and moving through the wellbore. The primary data of production logs are raw enough and it needs to be interpreted properly. Some of these processes are

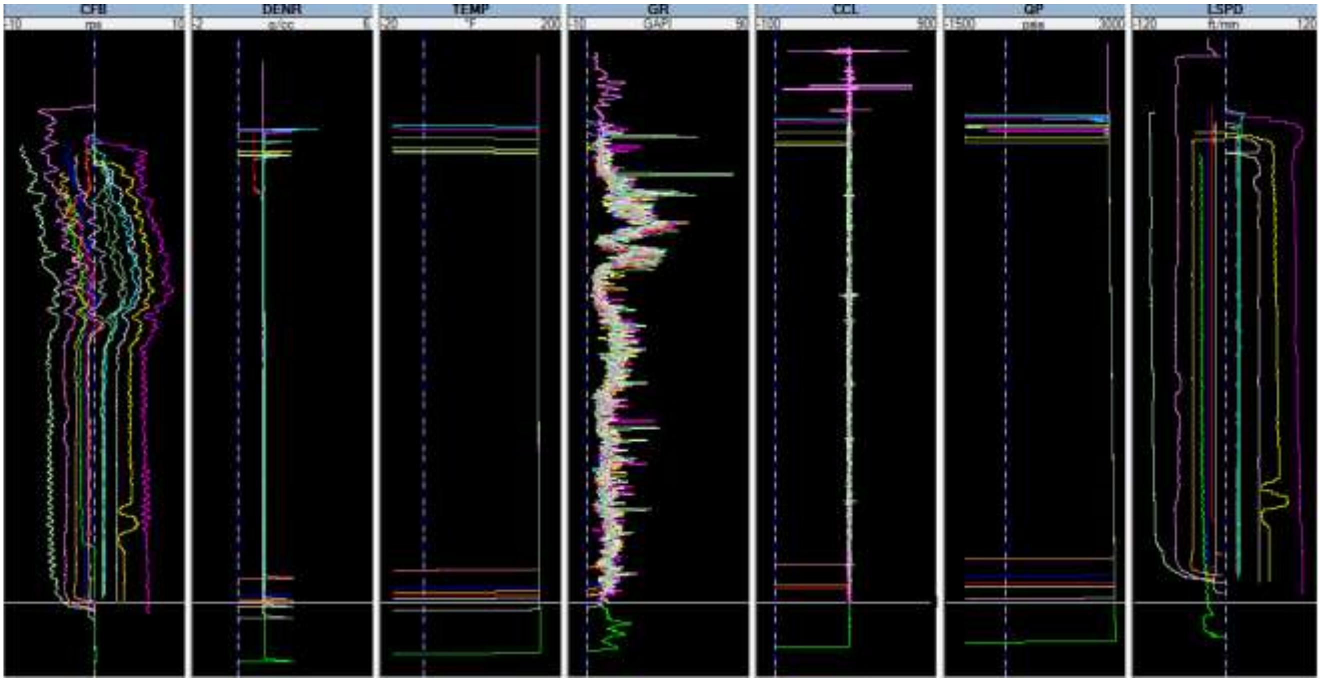

Figure 3. Different logs in production logging tools.

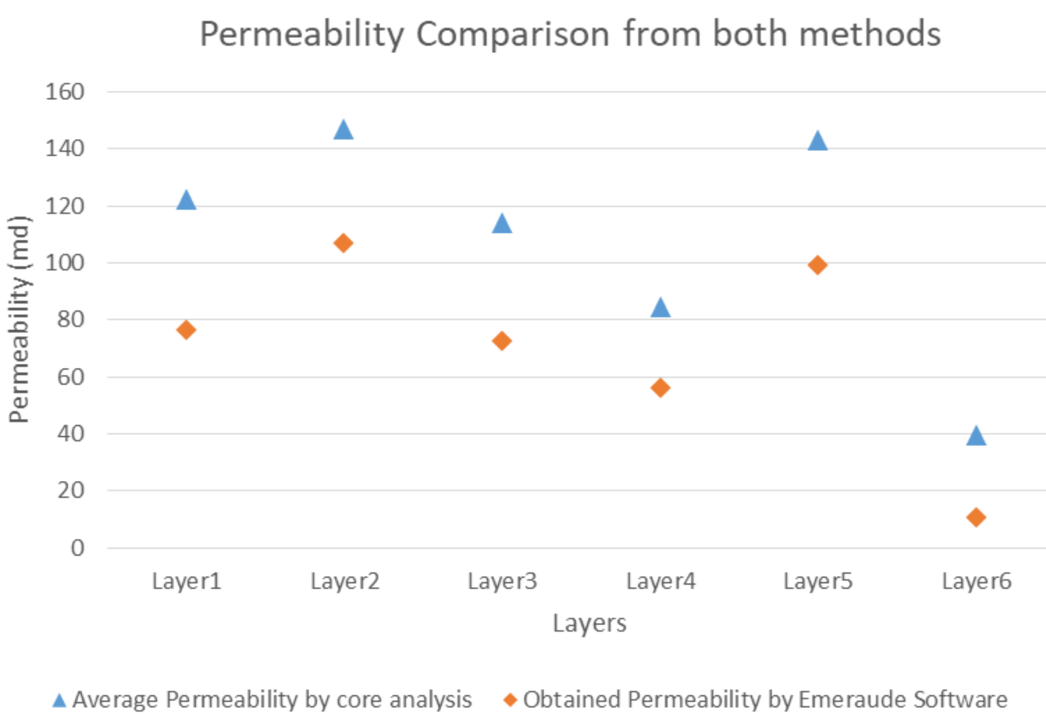

Figure 4. Permeability measurements by both methods.

related to the measuring wellbore instruments and other information are related to flow regime and wellbore geometric properties. Permeability obtained from the software compared to the permeability obtained from core in such areas (1, 2, 3, 5) are close to each other; in some areas (4, 6), results obtained from the two

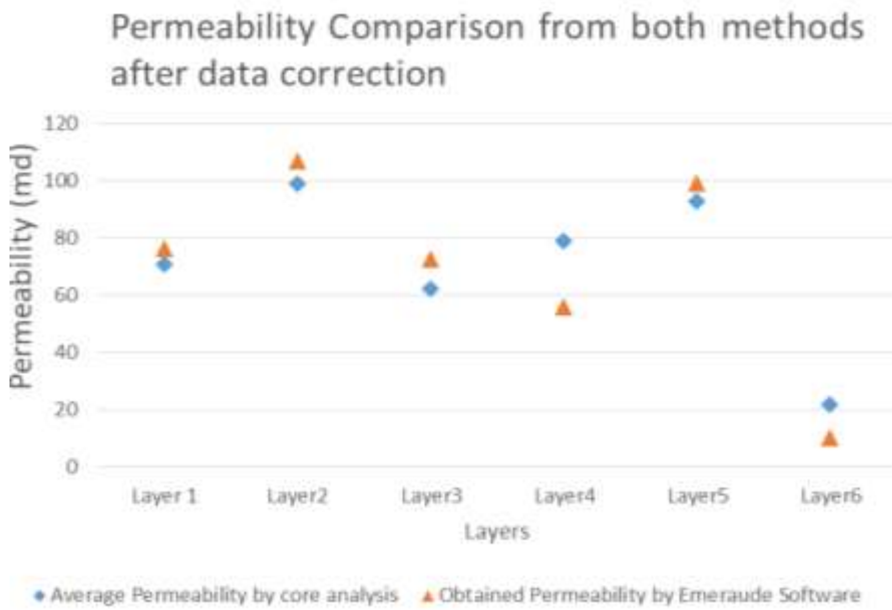

Figure 5. Permeability measurements by both methods after correcting core data.

methods are far from each other.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Nomenclature

AOF = Specific productivity index, STB/day/psi/ft
B_o = Oil formation volume factor, BBL/STB
K = Permeability, md
M_u = Viscosity, Cp
P_{avg} = Average pressure in external borders, Psi
P_e = external borders pressure, Psi
PLT = Production logging tools
PI = Productivity index, dimensionless
P_{wf} = Wellbore pressure for flowing well, Psi
Q = Flow rate according to standard condition, STB/day
R_e = Distance from well center to external border, in
r_w = well center Distance to wellbore, in
S = Skin effect, dimensionless
Ø = porosity, %
H_c = Hydraulic content, dimensionless
r_p = Assume radius pipe, m

SI Metric conversion factors.

Field unit	Conversion factor	SI unit
Psi	*6.894 757	Kpa
Psi^{-1}	*1.450 377 E–01	Kpa^{-1}
°F	(°F–32)/1.8	ºC
in.	*2.54	cm.
ft	*3.048*E-01	m
bbl.	*1.589 873 E–01	m^3
SCF/STB	* 1.801175 E–01	sm^3/stm^3