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EVALUATION OF PERMEABILITY IN FRACTURED CARBONATE RESERVOIRS BY PRODUCTION LOGGING TOOLS (PLT)

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ABSTRACT: *Permeability in oil wells can be achieved by different methods. Each method has its own constraints and supplementary techniques are necessary. Using Production Logging Tools (PLT) is an appropriate means for controlling the accuracy of the permeability obtained from other techniques. In as much as in different removals of Production Logs, the tools are driven once, the exploration cost is decreased. PLT in carbonate reservoirs assumes homogeneous, single-phase flow, and steady state. The core data verify the permeability values predicted by Emeraude software. The output of the software with the results of the core, in the oil wells in most areas, with the difference varied between 7 to 50%. The percentage error fractured carbonate reservoirs, is acceptable. However, in certain regions, significant differences were observed that could have been due to the assumptions made.*

KEYWORDS: Permeability, Fractured Carbonate Reservoirs, Production Log Tools (PLT), Emeraude

INTRODUCTION

In Reservoir engineer, determination of the permeability in detection of fluid flow is very important. There are several ways to describe and get the permeability in the reservoirs, which include: empirical relationships, use of cores, numerical methods, neural network, using production logs, analysis of drilling mud recognition (Ruvo and Cozzi 2007). Permeability is generally calculated by using core or well test data. Neural network with various well charts, often with one or more variable regression, linear or non-linear like Gaussian procedure have been investigated. Well testing methods and coring are generally time-consuming and expensive. Therefore, recently the use of production log methods to determine the permeability was presented. Production logs suggested when the well was in steady-state and current can be considered as single-phase with the homogeneous environment. This method is suitable in sandstone reservoirs, but this method used in carbonate reservoirs for progress in obtaining permeability. The most important feature of production logs is properly vertical distribution can be achieved by permeability that help to correct description of the flow in the reservoir (Hegeman and Pelissier 1997). In Tengiz reservoir in the West of Kazakhstan with using of production logs the volume of permeability by solving Darcy law in the different well intervals, using flow pressures and static pressure, in addition well properties, reservoir, and fluid as Input measured in throughput. Models of production log data provide reliable estimates for the injection of gas in the Tengiz platform "et al." (Sullivan et al. 2006) Recently in Iran with uses of production logs to determine extra water production in Ahvaz oil field and sudden increase of pressure in the well in the Aghajari oil field have been used. Hoffman and his colleagues in 2010 used the production logs to determine the fracture properties. In this study, a specific

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algorithm was used to describe fractures. The result that was obtained from this study, the rate of flow from the similar fractures and there were very close to each other. Its error was less than one percent. Fractures with the highest fracture length had the most production (Hoffman and Narr 2012).

Work method the principal of production logs by means of a butterfly that move around an axis. Due to the moving tools and speed of rotating impeller, fluid motion speed can be achieved using Emeraude software, then determine the production flow profile. With a production flow profile to get the relationship of permeability with Darcy correlation, rock and fluid properties, reservoir pressure, skin factor and well pressure was be needed. In the carbonate reservoirs as the environment is heterogeneous for using of production logs, by relating Darcy correlation, the environment divided to a meter by a meter thus the environment was be considered to homogeneous. In carbonate reservoirs, it is suggested by the production logs method used with caution because it is assumed that the flow of single phase or water and oil viscosity was equal to each other that a certain viscosity is used. So, Because of these limitations, their application in multi-phase reservoirs with different viscosity, is not suitable. Also around the wells especially in gas wells that non-Darcy flow arises or also in the horizontal or high angle wells determination of permeability by logging production was impossible. Since production logs expressed by each area per one meter, which is assumed in the period of study, all features was true and the reservoir is homogeneous. For taking production logs the well must be stable and established flow in the well. After this, the flows in the well are shutting off and buildup Pressure Test was done. Flow profile was analyzed and flow in porous layers in throughput calculated. Production logs present, the fluid parameters for region to region and information about the type and how to produce and moving fluid into the well or near the wells. Using production logs, including temperature, pressure, fluid density, water flow fraction and velocity (flow rate) in a completed production or injection well can be driven and with the results, parameters such as porosity, saturation shrinkage, permeability, thickness and lithology of the formation is achieved. If logging using butterfly flow meter was done correctly, in the single-phase flow in a well with a fixed diameter should be taken to a safe flow profile. However, butterfly flow meter was able to create mechanical problems. So the obtained logs quality was highly depended to logging method and accuracy in the logging operation. If the cross-section area of the well was variable, like the wells that using any casing. To interpret and express logs that was obtained from butterfly flow meter, the caliper log was needed. In the multi-phase flow for complete analysis needed to other additional logs (Hill and Oolman 1982). Production log Tools sent into the well consist of the thirteen different episodes. Schlumberger Company has shown production tools schematically in Figure 1.

Tools in the time period of steady flow and closure of wells was driven into the well, record different electric pulses in each depth interval. Receivers converted these pulses to digital data addressing. Based on these data, various logs by using Emeraude software can be set drawn and in determination of permeability, can be used (ghasem askari and saeed mokhtari 2008). For each flow profile in each meter (h = 1), column flow was considered and permeability calculate by Equation 1.

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

in the equation parameter c was the constant of the equation, if the depth in feet and it is equal to 141.2 and if in meters it is equal to43.07. q_i That was flow that is achieved by Emeraude

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software. μ_o Viscosity, P_e external border pressure in terms of psi, Pwf internal well pressure in psi, S is skin factor. B_o Oil formation volume factor measured the ratio of oil to the measured oil in the reservoir in standard conditions, according to BBL / STB is. r_d The evacuation radius, r_w is the radius of the well. One important thing to have sufficient information about the terms of Darcy equation (Equation 1). Assumptions can be considered in the Darcy equation. Flow can be considered Stable and reliable. Assume that flow was completely (hundred percent) saturated. The chemical reaction between the fluid and rock doesn't happen. As temperatures rise, the viscosity does not change. Fluid is incompressible. Temperature is constant and flow is laminar. Software by considering all of these situations with Darcy equation to obtain the permeability "et al." (Sullivan et al. 2006).

Interpretation of butterfly flow meter because of the complexity of the multi-phase flow, sometimes all that was achieved from a multi-phase production logging in a well, is a qualitative view of the flow profile. Often the best and most reliable interpretation of a multiphase well is the use of temperature logs. So the engineer that interpret logs in the multiphase wells must use commentary instructions accurately and with the test of the accuracy of any logs, determine the described flow profile carefully "et al."(Leach et al.1974). Several factors caused the error in the production logs method such as: change in μ_o and B_o properties in very small variation in the range of about 5% in the calculations affect the permeability. Error in the draw down pressure due to an error in the calculation of relative permeability, this error maximum can cause ten percent difference in the amount of real permeability. Flow rate should be obtained from production logs. This method is not always possible and have limitations. The measured steady flow have about ten percent difference with the surface flow, which is the minimal amount in determining permeability. Skin Effect, which has a huge impact on the permeability because this factor affect from several wells "et al." (Sullivan et al. 2006). All of interpretation butterfly flow meter logs, is based on the response of flow meter, a linear function of the fluid velocity -Dale (1949)- .in the dynamic logging also an assuming done that the fluid velocity and velocity of moving tools are allowed to collect. In this case the flow meter to an effective velocity of response that v_e comes to having from corr.2 (ghasem askari and saeed mokhtari 2008).

$$v_e = v_f + v_T$$

Which, v_f is fluid velocity and v_T is tool velocity.it is assumed that the direction of flow v_f is always positive, though v_T in the opposite direction of v_f the sign is positive and otherwise it is considered negative. Negative effective velocity represents the flow meter velocity is upward. Butterfly flow meter response to the effective velocity considered as a linear function. At low velocities, the real response of butterfly flow meter dropped to quickly reach the threshold velocityv_t. At this velocity, butterfly flow meter doesn't turn (ghasem askari and saeed mokhtari 2008). Using Emeraude Software Emeraude Software was a series of petroleum engineering from Kappa company.it was used for analysis of production logging data and pulsed neutron Logs. Nowadays this software almost use in logging service companies, other owner companies and independent companies (ghasem askari and saeed mokhtari 2008). he software was able to analyze production logging data in the vertical to horizontal injection wells and also multi-phase production wells have a large deviation. This software provide facilities that data has obtained from all common tools and modern tools, are be analyzed. The

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software calculation of flow rate use the minimization problem and nonlinear regression is done. Non-linear regression with complete flexibility in the type and number of measurements that is controlled. In the Emeraude Software obtained flow rates, result of calculations was not by using the equations, but Those are the result of a process based on simulation and nonlinear regression.

For entering data in the software in load section, first five production when tools drive to the well and five production when tools come to the surface and entering one calibration production. Production that was done by tools include gamma, density, temperature, pressure logs, number of revolutions per second of the device, gamma ray log or casing connection log(CCL) and cable velocity. If the deviation of each measured parameter in the well consider as a function of E, the amount of deviation is the difference between the measured parameter and simulated parameter. Each specific statement in the function of E known as a remaining balance and can be assigned a specific weight to each remaining. Each remaining associated with a particular tool and add a new tool only correspond with one remaining objective was in the intention function. Particularly, this method can provide great flexibility, as the calculations can easily be adapted to any set of adequate measurements, although some of them create plasticizers additional information. Another noticeable difference in this approach is that any step required computational model can be easily applied until measurements simulated accurately. For example, when there are Gradio-manometer measurements, using models to make complete tools answer such as friction effects and well deviation effects. In other words, frictions are added to hydrostatic simulation, while conventional methods try to remove friction from measured gradients -Dale (1949)-. In the production logs by setting surface parameters such as gas flow rate, oil and water flow rate in the equations such as apparent velocity, etc. are simulated that from these simulated data obtained real data and if we can go return path through this way on production logs, a series of real data from well logs acquired production per each well area will be obtained.

Study case According to the supplementary report at the time of driving studied well tools that is located in the Persian Gulf. According to drilling data, there is any fault have been seen. The properties of the lithology of the drilled formations in the well-studied according to obtained cutting at drilling time and in some cases their compatibility with taken logs, were determined. For obtaining reservoir zones in the studied well, first perforated zones with using geology data and obtained logs from tools must be determined. According to the supplementary report at the studied well, reservoir zones are on the surmeh formation, which is equivalent with Arab formation in Saudi Arabia .lithology of this formation are often limestone, dolomite, Dolomitic limestone, anhydrite, Dolomitic anhydrite and thin clay layers. From the obtained lithology it has been found that the studied well can be carbonate. Assumptions using production log tools should be seen in carbonate reservoirs. After gaining the type of lithology using gamma ray logs, butterfly flow meter, temperature, density and pressure fluid reservoir zones in the well was achieved.

The first log is used to show reservoir areas, gamma ray log measured the natural radioactivity of rocks [figure 2]. Low radioactivity, shift the log to the left and high radioactivity shift the log to the right. Shale logs because of its radioactivity shift to the right. Sandstones and limestone rock as the reservoir rock shift the log to the left. The amount of shale in a limestone gravel can be calculated from the amount of radioactivity from gamma rays. Dolomitic rocks such as shale with highly gamma ray log. In order to separate these two stones from each other, should be used from temperature or pressure logs in the studied well because its lithology was

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limestone so reservoir area can be in depths that there is reduced amount of gamma radiation. so these areas should be identified by use of flow meter. Flow meter log (CFB), is one of the most important production logs with uses of this log: production areas, stimulation operations evaluation, enhanced oil recovery methods and calculation methods of (AOF) and (SIP) was done. Using this log to calculate the fluid velocity and butterfly flow meter rate [figure 3].

After data entry, tools specification, definition of perforated areas, and the characteristics of the well should be interpreted. For interpretation needed to provide the environment. This environment by using the first part of the interpretation window provides commentary. For different driving tools have different perceptions of the logs. With this window can be determined by any of the logs (pressure, temperature and density) in different drives, from which using the log obtained on software. After interpretation environment, after creating the interpretation environment to calibrate logs at the calibration, calibrated selected intervals for addressing [figure 4]. These sectors can't be selected in the perforation areas and must be selected above or below the selection. For the studied well, three intervals are selected for calibration addressing.

After selecting a calibration intervals based on the apparent speed based on the selection perforated areas, the reservoir area, draw the environment for interpretation and calibration intervals. To enter the rock and fluid properties from this section (PVT) used in the interpretation section. In the (Zone Rate) type of studied well model, including water and hydrocarbons as enter the flow of water, oil and hydrocarbon gases produced in the area. This amount of water 498 STB/D and 518 Stb/D for oil and 90 Mscf/D for gas. In the (LOG) section flow rate into the well, determined in any depth. In Figure 5 well flow rate obtained from a depth of 5983.53ft up to 6402.53ft.

required Parameters to obtain the permeability include external borders pressure, well pressure, the outer diameter of the well, the radius of the well, skin effect, viscosity, flow rate, software permeability, permeability multiplied the height. The amount of because the well is in the production is equal to zero. The amount of flow rate using software obtained through the logging method at the production time. Figure 5 show the amount of obtained flow rate from the software. The outer radius and inner radius, respectively, 4.5inches and 2.25 inches. Software calculated the viscosity. To calculate viscosity first we must set a specify base by multiplying permeability in height in the software while this amount for studied well is equal to 100. To get the well pressure from the beginning of the commentary from the PVT section the bubble point pressure was obtained. The pressure in the well is 1062.408 (psi). With using experience, well pressure always between 900 to 1300 psi was greater than the bubble point pressure. In This well pressure study, 1200 (psi) set greater than the bubble point pressure so the well pressure, is 2062.408 (psi) .To determine pressure (P_{avg}) that also has a great importance, you must first obtain (S.I.P). To enable this section, other commentary has been made in the previous interpretation.

Results and discussion Parameters affecting the permeability; P_{avg}: external reservoir borders at different depths, had several pressures. The average pressure was calledP_{avg}. The average pressure can be achieved by various statistical methods.one of this methods, flow was a selection that was based on determined experimental correlation with using selective flow, and productivity index can be achieved. Based on studies we have seen that in those areas that productivity index was low for example zone6 in the figure 6 It is be better not to use the permeability from the software. Well pressure: This pressure is a high impact on the

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permeability so with an increase of 200 (psi) the amount of permeability has doubled. To get this pressure from the bubble point pressure in the (PVT) section in the interpretation can be used that in this according to the experimental pressure was 1200 (psi) greater than the bubble point pressure.so the bubble point pressure was 1062.408 (psi) and we assume (P_{wf}) 2262.408 (psi).

Fluid properties and well properties (M_u,R_e,r_w,B_o): the effect of fluid properties on permeability is very low because the limit changes that made on the pressure was less than 5 percent. The radius of the well and the outer radius because of there was in the logarithm sentence can be effect in the permeability until with 20% increase in the outer radius, permeability increased by 1.08%. Flow rate (Q): production logs usually measured with a steady state flow with the accurate surface scale, with flow-rates in the surface match with a difference of less than 10%. Since the calculated flow rate is proportional to the permeability, this value has little effect on permeability. Ensure of the selective inflow pressure (SIP) Notice of the needed time to establish the high importance stability. Production log tools were above the perforations, when flow in the well, investigate flow rates and pressure for stability before starting a steady flow. In this case sudden pressure log was determined which in the logarithmic scale and use for evaluation of stability.

Logarithmic graph of detection pressure to ensure that get to the radial flow period with unlimited performance before the pressure build up is applied, then the flow rate and pressure data can be analyzed by transient pressure analysis software, with this procedure an interpretation model was built that can be extrapolated the stable well flowing pressure was used Fig. 6 ”et al.” (Sullivan et al. 2006).

In some wells with low permeability, pressure respect to time didn’t stabilized. In practice, flow paths within 8 to 12 hours after the opening of the well, was started [figure 8]. If the flow is stable until that time, it is unlikely that the past 12 hours, make a significant difference. After completion of the flow paths, the wells will be closed to build up the pressure. Logarithmic graph of detection pressure to ensure that get to the radial flow period with unlimited performance before the pressure build up, is applied. Then the flow rate and pressure data can be analyzed by transient pressure analysis software. Then according to figure 6 an interpretation model was built that can be extrapolated the stable well flowing pressure was used. With this model, pressure (S.I.P) is activated and for the (P_{avg}), (AOF) and (PI) superimposed in each specific zone. To determine pressure (P_{avg}) in each zone, the permeability of various distances in Table 1 was obtained.

Table 1. Obtained permeability from (PLT) software at the perforation intervals.

zone	perforation intervals(ft)	Obtained permeability from (PLT) software (milli darcy)
1	6054/42-6065/33	36/419
2	6104/62-6117/73	86/812
3	6151/82-6167/33	42/51
4	6200/21-6211/81	5/89
5	6244/59-6250/62	6/34
6	6289/34-6292/74	/434
7	6302/6-6306/2	10/855

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To validate core data is used. This data at several intervals to a depth of 1844/02 meters to 1950/6 meters. For better comparison, you can sort the core data. To do this, seven percent of high and low permeability results from the cores was removed and its average was determined in each period. In Figure 7 permeability obtained from both methods with logarithmic graph.

According to Figure 9 observed that permeability obtained in areas 1, 2, 3 and 5 are close to each other. Also the difference in 7 zone is very little but in areas 4 and 6 is the significant difference in permeability obtained from both methods. The cause of These differences can be derived by several factors, which may ultimately include: the use of production log tools, assume that the environment is single phase and study well is homogeneous, if that is possible in these two areas, the environment is out of single phase. The second reason is more possibility is that the height of production zones in these areas is much less than height of perforated zones. Therefore, since in the software two heights was the same, so the answer is not appropriate. Also in area 6, because of the oil production rate is very low, production log tools haven't been a good answer.

CONCLUSION

1 In areas where the production rate was low or in other words the productivity index was very low .it's better not to use production log methods and use direct methods such as coring. Rely to the results of production logs was better results when the flow rate is not very low and its velocity was quickly enough to be able to turn production log tools fin.

2. Permeability obtained from the software compared to the permeability obtained from core in such areas (1, 2, 3, 5) have close to each other, in some areas (4, 6) results obtained from the two methods are far from each other.

3. Average pressure (P_{avg}) is the parameter affecting the permeability so that with its increases, the permeability decreased so it's a very effective parameter. The best and most convenient way to get from the selective method.

4. In some areas of the software (Emeraude) flow rate has a negative output, which is the reason can be cross-currents that exist between the two production layers or fluid velocity is high enough that butterfly fin rotation is in the opposite direction.

5. To obtain The permeability from several different methods can be used that the most reliable method is the use of core, but due to the lack of measurement tools and as well as costly use of this method, the use of production log tools have introduced production because by using this method production profiles can be identified, achieved casing quality and the amount of permeability calculated and for around wells, it developed. And compared to the coring method has very low expenditure.

6. Using production log tools is possible in those wells that environment was homogeneous, single-phase flow, the system is stable and over the closing wells was done to achieve stability.

Nomenclature:

AOF = Specific productivity index, STB/day/psi/ft

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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 log 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

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APPENDIX

Figures and tables:

Figure 1. Production log tools

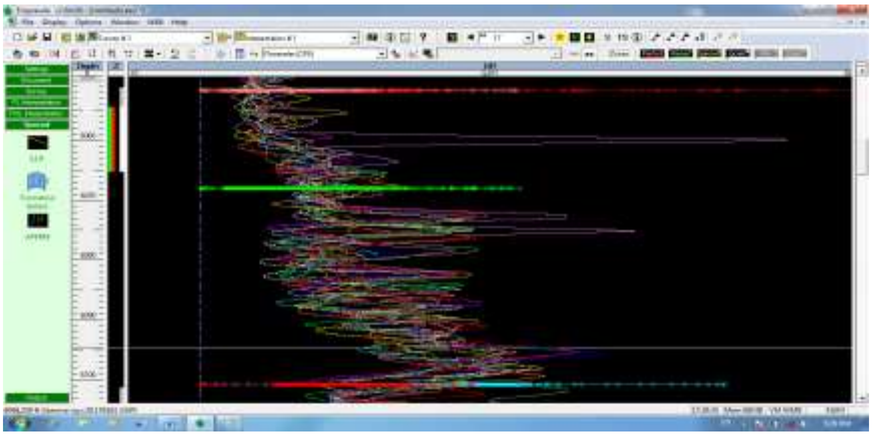

Figure 2 – reducing amount of gamma ray in reservoir area

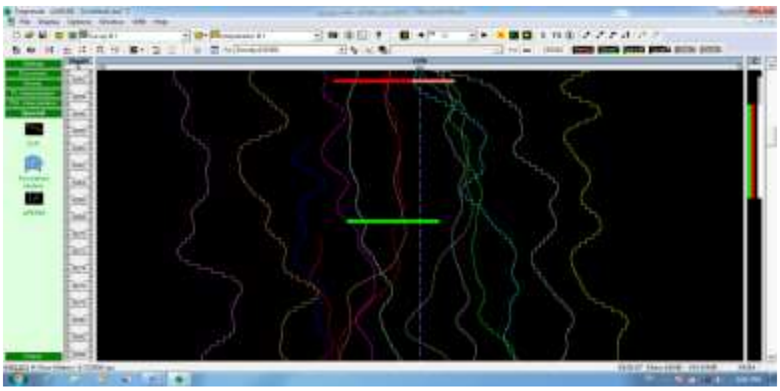

Figure 3 – butterfly flow meter log

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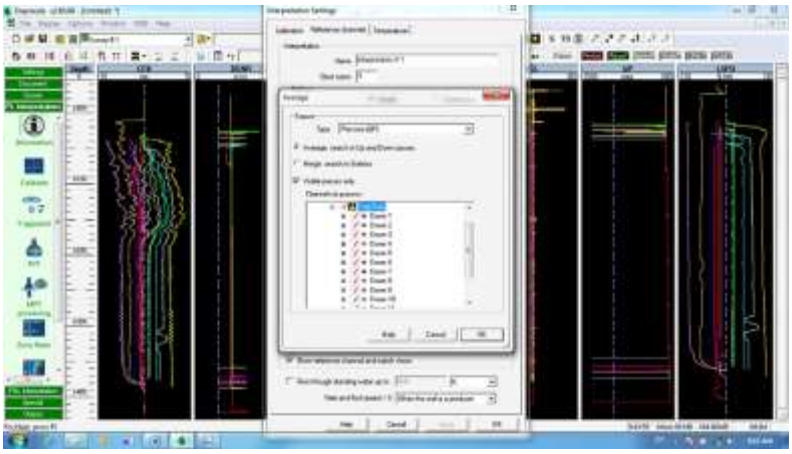

Figure 4 – making interpretation environment

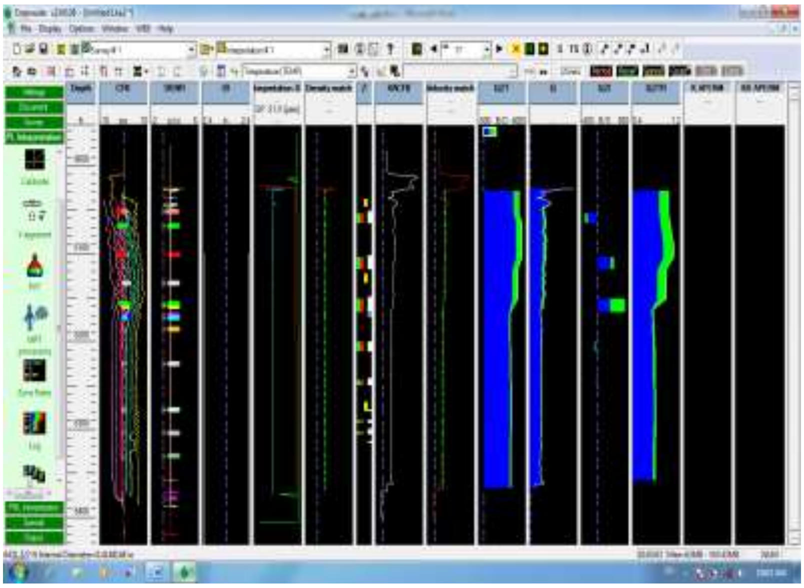

Figure 5 – obtained flow rate from PLT software

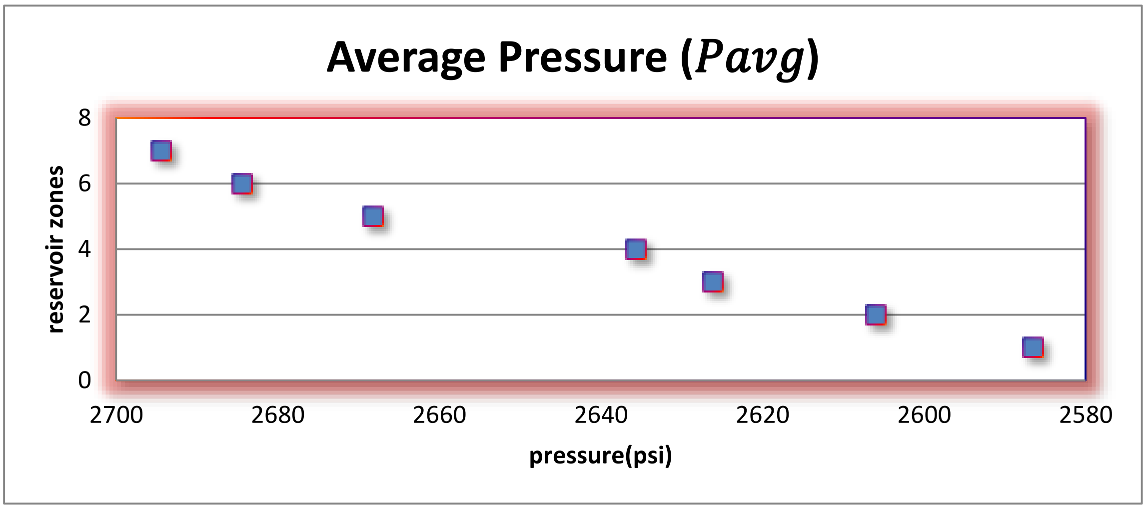

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Figure 6 – pressure results (SIP)

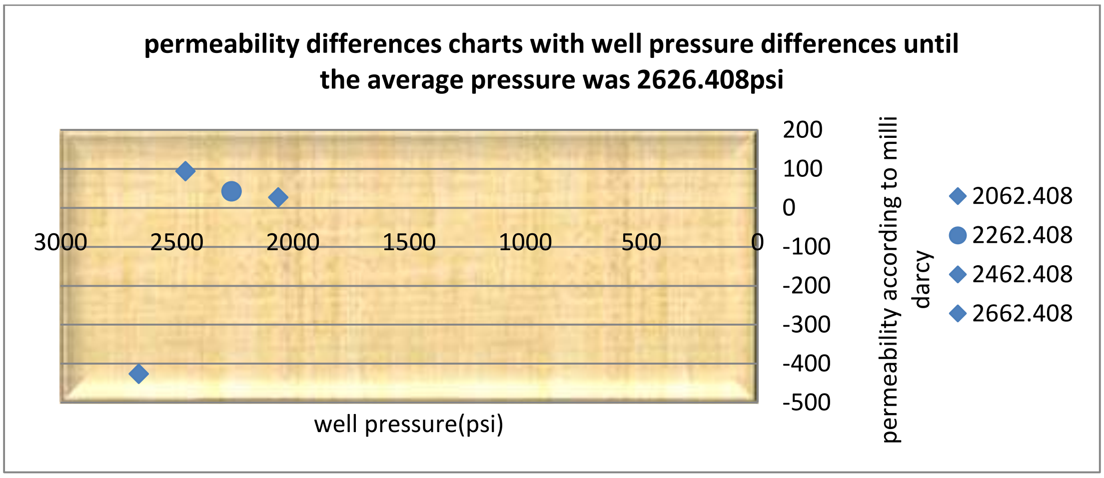

Figure 7 – well pressure impacts on the permeability

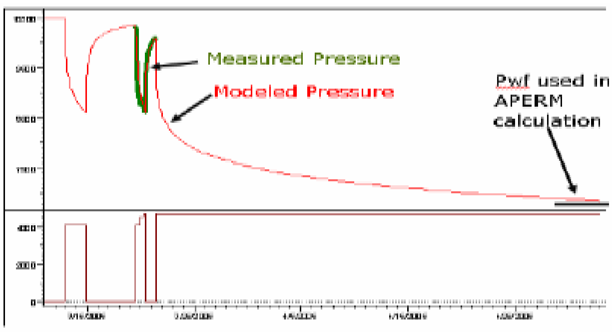

Figure 8. Well instability at the first time, with the passed necessary time to stabilize production logs ”et al.” (Sullivan et al. 2006).

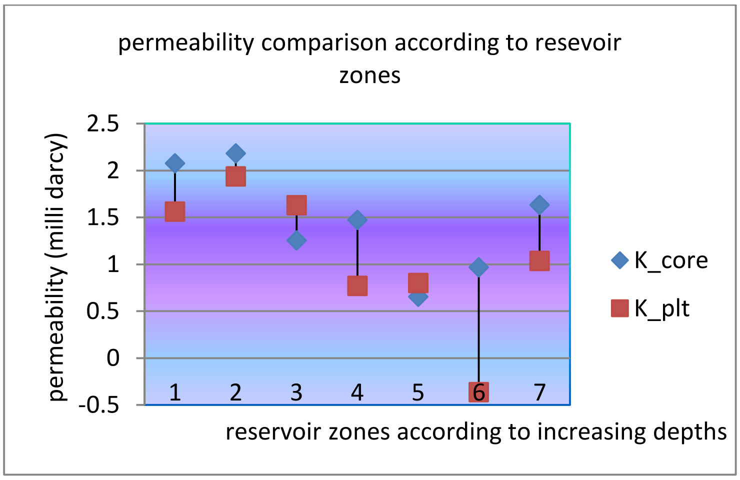

Figure 9- comparing permeability derived from core and software.

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4	6200/21-6211/81	5/89
5	6244/59-6250/62	6/34
6	6289/34-6292/74	/434
7	6302/6-6306/2	10/855

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