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Identifying Average Reservoir Pressure in Multilayered Oil Wells Using Selective Inflow Performance (SIP) Method

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Abstract

The downhole flow profiles of the wells with single production tubes and mixed flow from more than one layer can be complicated, making it challenging to obtain the average pressure of each layer independently. Production log data can be used to monitor the impacts of pressure depletion over time and to determine average pressure with the use of Selective Inflow Performance (SIP). The SIP technique provides a method of determining the steady state of inflow relationship for each individual layer. The well flows at different stabilized surface rates, and for each rate, a production log is run throughout the producing interval to record both downhole flow rates and flowing pressure. PVT data can be used to convert measured in-situ rates to surface conditions. Different types of Inflow Performance Relationship (IPR) equations can be used for SIP interpretation, including the Straight-line method, Fetkovitch method, and Laminar Internal Turbulent (LIT) relations. Although the SIP method can be used for single-phase flow, the interpreter can restrict the IPR's calculations to a particular phase. This research discusses the difficulties in estimating the average reservoir pressure in multilayered reservoir completed wells over their production life. The SIP technique has been applied to some producing wells in the south of Iraq, which are completed in multiple producing reservoirs previously tested with a formation tester to estimate reservoir pressure and other parameters. Two wells are taken in the south of Iraq region, Zubair Oil Field, one with cross flow between perforations and the other well with no cross flow. An average pressure is not calculated for layer A in Well-1, because there is no contribution rate. While the average pressure for Well-1, layer B is 3414.49 psia. Also, the average pressure for Well-2, layer H is not calculated because there is no rate contribution from this layer, and the maximum average pressure was calculated in layer G, which is about 2606.26 psia. It is also found that the presence of cross flow has no effect on SIP calculations.

Keywords: average reservoir pressure, multilayered reservoir, selective inflow performance, SIP, production logging tool, South of Iraq.

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1- Introduction

Production logging is the most common method to evaluate the production profile of a well with various production zones. This production profile assumes a single surface production rate and a single downhole flowing pressure. However, much more data can be obtained from the production log. The productive index, PI, and reservoir pressure for each of the producing layers can also be obtained. It is impossible to determine this information using a pressure buildup or drawdown test when more than one zone is mixed in a single production string [1]. Layered reservoirs are usually divided into two parts; First, layered formation with cross-flow, where layers communicate at contact planes throughout the reservoir. Second, layered reservoir without cross flow (commingled system) where layers are communicated only through well-bore (which is our case) [2]. In most multi-reservoirs, individual productive layers usually develop different thicknesses, porosity, permeability, skin factor, and average pressure. An evaluation of multilayer formation properties will benefit in well performance and simulation design. [3]. The reservoir pressure determination of each producing zone can be determined if different reservoirs are in communication with each other. It can also be determined if parts of the producing intervals are being supported by some type of pressure support such as a water drive, this information is then used to improve the recovery factor for each of the wells [4]. Cased hole formation tester, multilayer testing (MLT) and SIP are examples of these tests. Individual reservoirs are examined using a Drill Steam Tester (DST) and open-hole logging data to overcome the limitation for this procedure. This provides fundamental information about the reservoir properties. Then Production Logging Tool (PLT) is utilized to collect data in these wells on a regular basis. Essentially there is two types of production logging tool string for production wells and for water injection wells. They are the same except that the injection well tool string doesn't need fluid identification. The choice of tools is dictated by the completion type and size of tubing. This is primarily the outside diameter of the tool string the size of the spinner flowmeter and whether or not the well completed 'barefoot' [5]. In this method vertical wells data are established, also the productivity index for each

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layer can be calculated. On the other hand, the performance of horizontal wells can be strongly be influenced by the anisotropy of horizontal to vertical permeability. Thus, modeling of horizontal wells is much more complex than modeling the vertical wells [6]. To meet productivity objectives, matrix simulation should provide a skin effect of 10% of the initial damage skin effect for sandstones and 2 to 3 % for carbonates [7]. Wells are logged periodically to get the update for flow profiles and contributing formation pressure using the SIP method which provides a means of establishing the IPR for each rate-producing layer [8]. Well life has been challenged due to the long production period, and the wells have been affected and lost their original properties, suffering from problems such as wellhead pressure, casing integrity problems, and oil flow rate that is directly related to the area of the pay zone [9].

In this study, two scenarios are investigated to illustrate SIP methodologies, benefits over alternative methods, and critical considerations that may affect the final result. At various surface production rates, the production log data, spinner and pressure are collected. The Zubair Oil Field in the southern part of Iraq region is where this research is applied, and it is considered the only study for the field. The main objective of this study is to estimate the average reservoir pressure of each layer, to demonstrate that SIP in the case of cross flow in the comingled system is a valid technique similar to the equilibrium system.

2- Selective Inflow Performance (SIP) Method

It is a technique used to determine individual contribution zone average pressure. This method was established in around 1981. since then it has been established around the world. SIP test is performed under stable conditions and is suitable for medium to high permeability layers. In this method, well is logged with production logging tools at different chock sizes. From PLT measurement, a rate for individual layer and bottom hole flowing pressure can be obtained and to be plotted (rate versus bottom hole flowing pressure). According to SIP method, IPR is generated for each layer independently and then used to estimate layer pressure [8]. It is well known that water injection is the most common method for increasing oil recovery and pressure maintenance applications, where water injection is often used as a recovery method for light oil reservoirs, then later was used for viscous oil [10, 11]. Therefore, it is important to take in consideration the well status during average pressure calculation with the SIP technique.

There are different IPR equations can be used [7, 13]:

a. Straight line method

$$Q = PI \times (P\_avg-P) \tag{1}$$

Where: $P_{avg,}$= the calculated average pressure, psia . PI= productivity index, STB/day-psi. P = bottom hole flowing pressure, psia. Q = oil production rate STB/day

Corresponding of the straight-line fit of (P vs. Q) gives PI as the inverse of the slope [12]. This option required at least two valid data points and accepted negative rates for the regression typically for shut-in surveys with cross flow or for injection wells. This method is valid for single (liquid) phase reservoirs.

b. Laminar-Internal-Turbulent (LIT)

$$-2P_{avg.}^2 - P^2 = a \times Q + b \times Q^2 \tag{2}$$

Where: $P_{avg.}$ = the calculated average reservoir pressure, psia. P = bottom hole flowing pressure. Psia. a = the Darcy term, must be ≥ 0. b = the turbulence flow term, must be ≥ 0

Corresponding of the straight line fit of (P / Q) Vs. (Q) gives “a” as the intercept and “b “as the slop of the line. This option requires at least two valid data points and accepts negative rates.

c. Fetkovitch method

$$Q = \left(P_{avg}^2 - P^2\right)^n \tag{3}$$

Q = oil production rate, STB/day. C = flow coefficient. P_{avg}= the calculated average reservoir pressure, psia. P = bottom hole flowing pressure, psia. n = exponent depending on well characteristics.

It corresponds to the straight line fit of log (P) Vs. log (Q) which gives C as the intercept and n as the slop of the line. This option requires at least two valid data point and accept negative rates. In this research Straight Line Method have been used to perform calculation.

The reservoir fluid properties are very important in reservoir engineering computations such as material balance calculations, well test analysis, reservoir estimates and numerical reservoir simulations. Ideally, these properties should be obtained from actual measurements [14, 15].

2.1. Datum Correction

SIP is generated without pressure adjustments to a common datum by default. However, as a part of the interpretation process, these pressures can be corrected to a reference depth by specifying pressure and temperature. The average pressure of each layer remains the same and these modifications have no effect on results. For correction of hydrostatic gradient, a reference pressure channel, preferably the shut-in pressure is applied and the shift is then calculated as follows:

$$\Delta P_{IPR} = P_{ref.\,(shut\text{-}in)} @ \text{ datum depth} - P_{ref.\,(shut\text{-}in)} @ \text{ IPR depth} \tag{4}$$

The IPR depth is taken as IPR zone. All the potential within the same IPR will be shifted by the same amount of ΔP_{IPR} [16].

3- Field Study

Job procedure, data gathering, data quality control, and two case histories are described below which explain the use of SIP. The straight line method was used for establishing calculation and the interpretation was done by Emeraude software.

3.1. Job Procedure

The sequence of the testing operation for PLT job is:

1. Clean the well up
2. Shut-in
3. Wire line correlation
4. 1st draw down + PLT dynamic passes + stations
5. 2nd draw down + PLT dynamic passes + stations
6. Main build up + PLT static passes
7. Clean the well up
8. Shut-in
9. Wire line correlation
10. 1st draw down + PLT dynamic passes + stations
11. 2nd draw down + PLT dynamic passes + stations
12. Main build up + PLT static passes

The parking depth is 10 m above the first perforation. The parking depth is usually 10 meters above the first perforation. And the correlation log which is used for depth correlation is open hole gamma ray GR.

3.2. Production log interpretation flowchart

The methodology of production log analysis is essentially the same from one interpretation package to another, except for statistical analysis packages. However, interpretation packages are more rigorous, allowing for a more accurate analysis and enabling the interpreter to spend more time on analysis and less time on manipulating the data. A flowchart of the production log interpretation process is shown in Fig. 1.

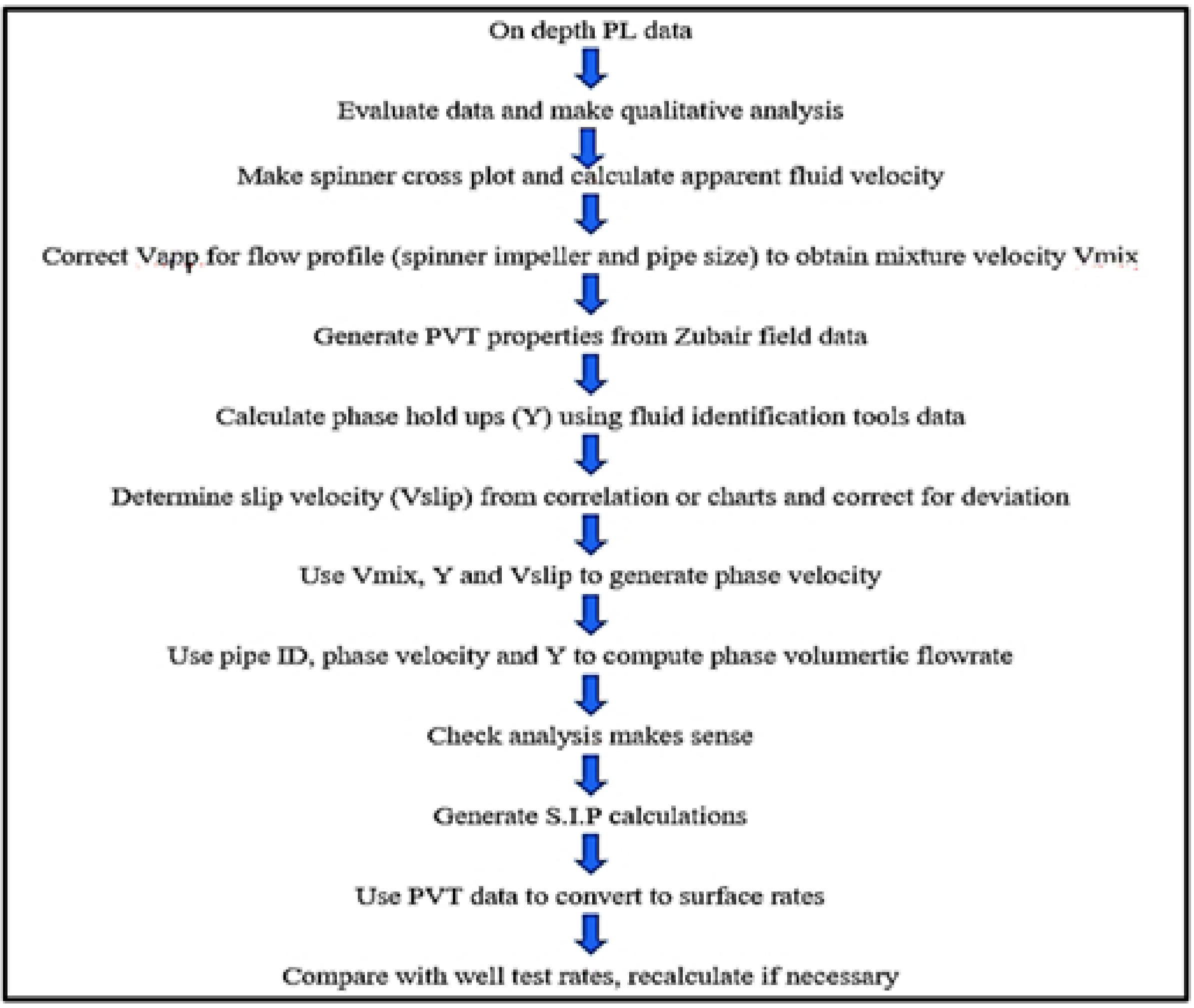


Fig. 1. Production Log Interpretation Flowchart

3.3. Requirement for Application of SIP Technique

1. Wells requires logging at multiple rates in order to generate a valid IPR.
2. Well should be open to flow at different chock sizes and stabilized, before data is acquired.
3. Data should be available in front of perforation to measure flow rate and flowing pressure.
4. For spinner calibration, logging speeds must be selected properly to make a distinct and clear line.

4- Case Study-1

Well-1 is part of the X field in which this technique was applied. Before completion of the well, conventional open hole logs were used for reservoir testing, and as a result, the pressure point tool was not run due to well conditions. The drilling was completed in may 2018 and well-1 was completed with a single selective completion in two layers, A and B, when reservoir A being the shallowest. Both layers were completed with a 9 5/8 " casing size. Fig. 2 shows a completion diagram for Well-1. The plan was to conduct a production log test (PLT) after perforation extension in layer B to monitor the production trend and contribution of each individual layer. The job was initiated in August 2018 and further refined to ensure good data quality under safe operating conditions. Six up and down passes were performed with cable speeds of 10, 20 and 30 m/min for flowing passes. While during shut-in, the passes were recorded with cable speed of 35, 40 and 50 m/min. Data interpretation indicated no cross flow in shut-in conditions among the two layers. Well flow profile showed during the first and second draw down that layer B (which consists of two perforation intervals) was the most contributor layer and flow came from the deepest two perforations while there was no flow from layer A. Fig. 3 indicates the flow profile inside 9 5/8" casing size during the first draw down and no water production was detected. From a quantitative stand point there is a good match with surface well test data as shown in Fig. 4.

Petrophysical interpretation can be summarized as follows:

- The main lithology for the reservoir is Limestone.
- For layer A, the porosity value was good, at about 19.4%, with good oil content.
- Layer B has an oil-bearing interval with good properties, and no fringe is visible. The free water level is at 2390 m MD, and the porosity range is 23%-22%.

From Fig. 3, the following interpretation can be concluded for flowing (28/64")

- The upper perforation in layer A doesn't contribute to the Production.
- The borehole OWC is about 2384,5mMD.
- Third perforation in layer B is producing water/brine.
- The salinity value of the brine used in the interpretation is 200ppk.
- Good match between fluid rates from PLT and separator test.

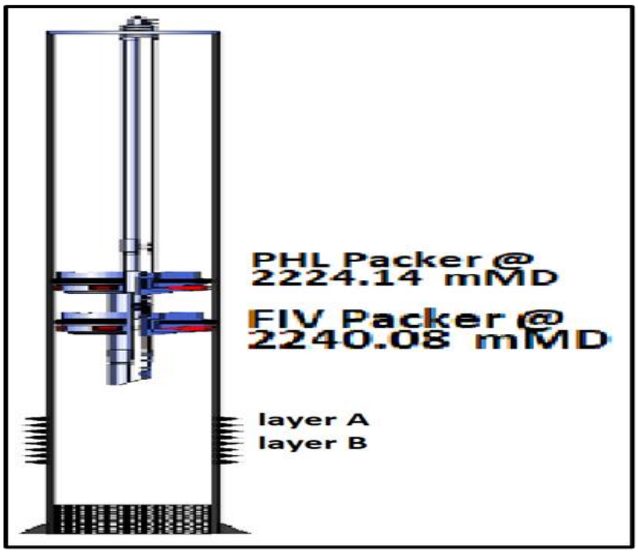


Fig. 2. Well-1 Completion

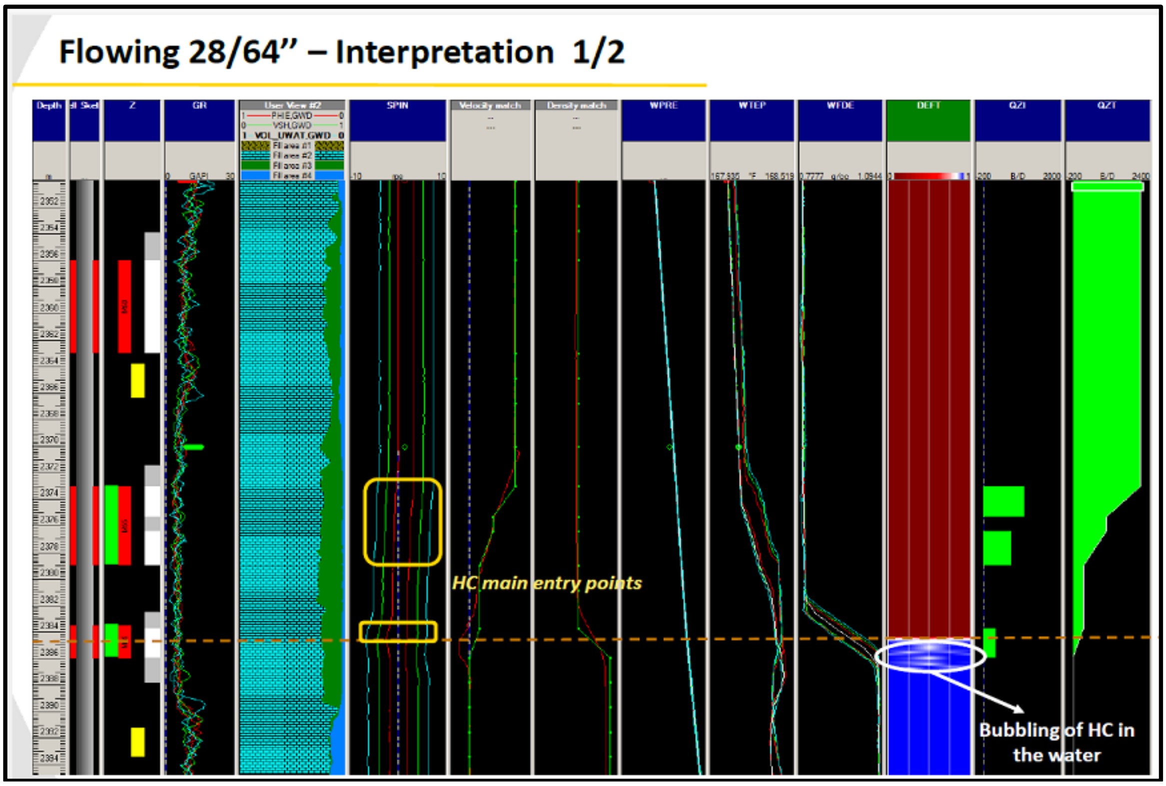


Fig. 3. Well-1 First Drawdown Flow Profile

For the first draw down, Fig. 4 shows a good match between fluid rates from PLT and surface separator test.

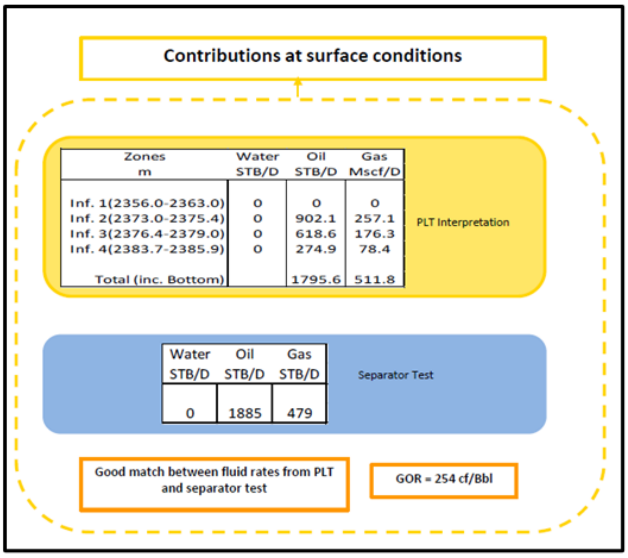


Fig. 4. Contribution at Surface Conditions and Well Test for First Draw Down

This technology is in a non-slandered format for various purpose including multi-layer testing to obtain layer wise permeability and skin factor using pressure and flow rate transient data acquired with production logging tools [17]. In some cases, the effect of total layer pressure distributions could result in a 100% difference in individual layer estimation, the SIP reduces them by estimating individual layer average pressure. The challenge in characterizing layered reservoirs is the large number of unknown parameters reduces uncertainty and the selective inflow performance production logging techniques is used in order to reduce the uncertainty of MLT estimation [17]. Fig. 5 indicates the flow profile inside 9 5/8” casing size and during the second draw down and no water production was detected. From quantitative standpoint there was a good match with surface well test data as shown in Fig. 6. From Fig. 3, the following interpretation can be concluded for flowing (36/64) "

- Only the lower perforations 2-3 (layer B) produce. The upper perforation 1 doesn’t contribute to the production.
- Higher rates of hydrocarbon production passing from (28 to 36)/64” chock
- The bore hole OWC is about 2381 m MD.
- Perforation 3 is producing water/brine.
- The salinity value of the brine used in the interpretation is 200 ppk

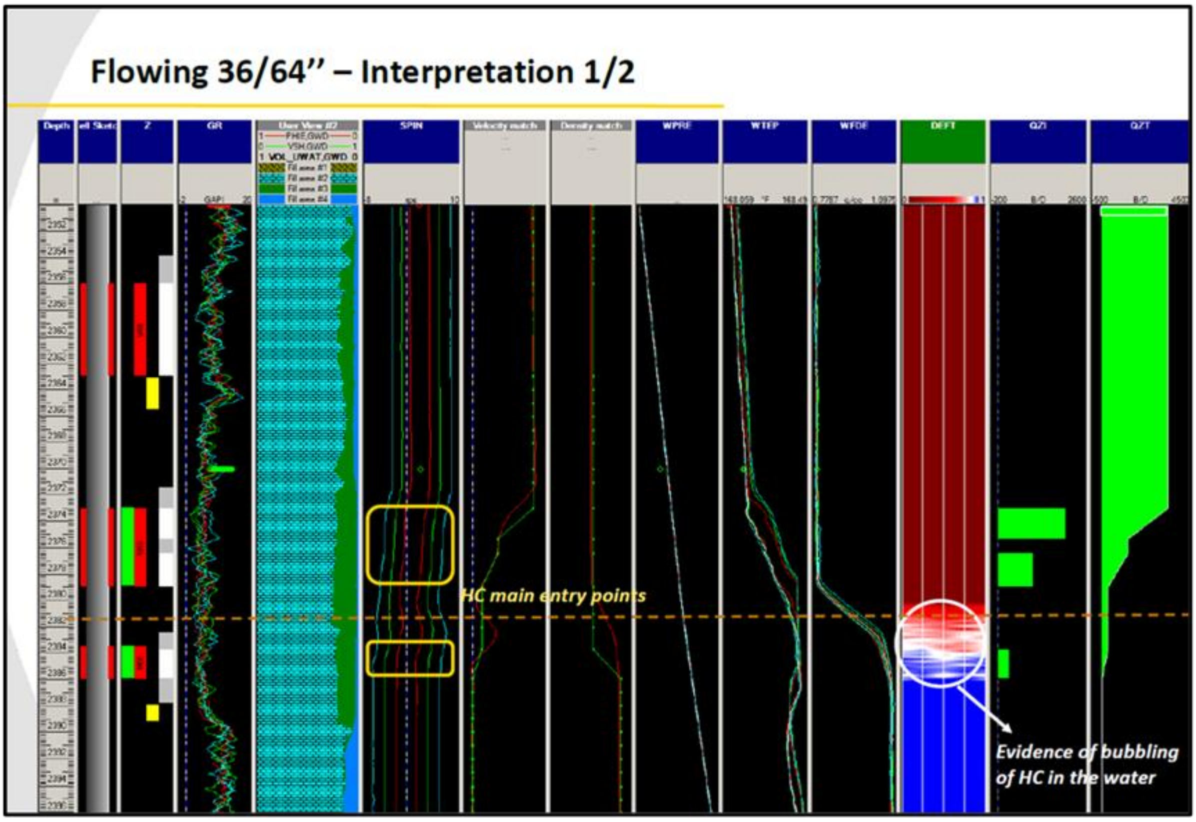


Fig. 5. Well-1 Second Drawdown Flow Profile

For the second draw down, Fig. 6 shows a good match between fluid rates from PLT and surface separator test.

SIP estimated pressure was performed and average pressure for layer B was 3414.49 psia. On the other hand, average pressure for layer A could not be calculated because there was no flow in this layer as shown in Fig. 7. So the average pressure was calculated for layer B only.

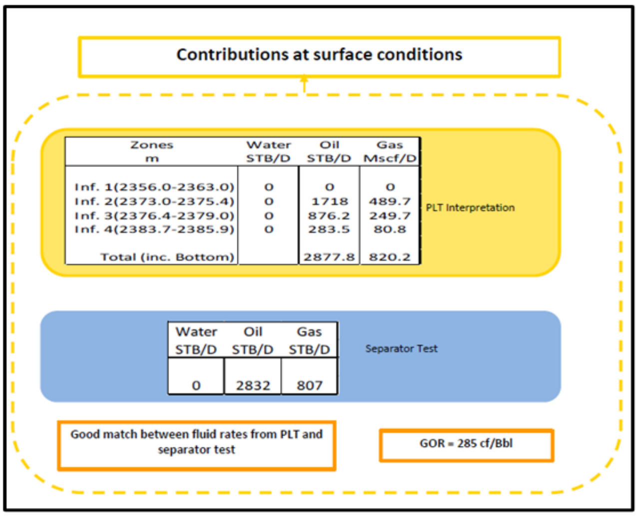


Fig. 6. Contribution at Surface Conditions and Well Test for the Second Draw Down

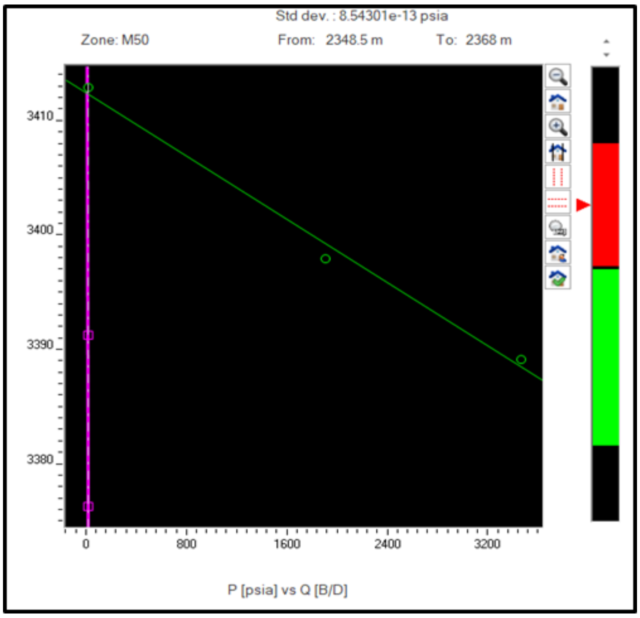


Fig. 7. SIP for Well-1

5- Case Study-2

Well-2 is a new well located in field X, drilling operation was finished at Apr. 2022 the well was completed as oil producer with single completion string as shown in Fig. 8. All layers were completed with 7 " linear. Before the completion was initiated, an open hole measurement and data point were taken. The reservoir consists from six layers (C, D, E, F, G and H) where layer C is the shallowest and layer H is the deepest. PLT job was established at Jul. 2022 to evaluate production rate across the perforated intervals. The job was planned with the same steps as Well-1. Data quality check was done before starting interpretation, the interpretation indicated there is a cross flow observed during build up period from layer H to layer D as shown in Fig. 9.

Most contribution was coming from layer G, layer D and layer C which have two perforations interval, also there was no water production was detected, as shown in Fig. 10 and Fig. 11.

For two flowing periods. Contribution at surface conditions and well test was in a good agreement as shown in Fig. 12 and Fig. 13.

SIP was performed and the average pressure was calculated for five layers. H layer have no production during first flowing period therefore the average pressure cannot be calculated as shown in Fig. 14. The values of average pressure for other layers are listed in Table 1.

From the petrophysical interpretation, the lithology of the reservoir is sandstone with good petrophysical characteristics, the porosity ranging between (15-19) %. The lower average pressure was in layers D and E, it is may be due to the nature of the lithology matrix in these formations which depends on the inclusion amount of Shale and siltstone in the sand formation as shown in Fig. 15.

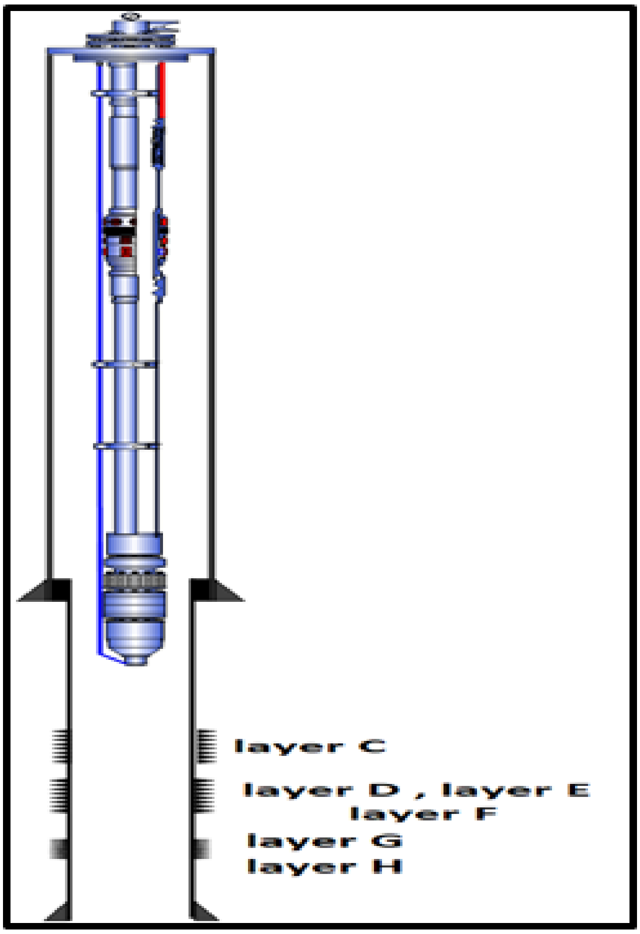


Fig. 8. Well-2 Completions

Combining SIP results with other well information (such as initial reservoir pressure and total well production) allows the allocation of production to individual zones. The influence on uncertainty of PL interpretation may be due to the probable existence of water drive and production from offset wells therefore it must be considered when assessing the reliability of results obtained through application of the technique [18, 19, 20].

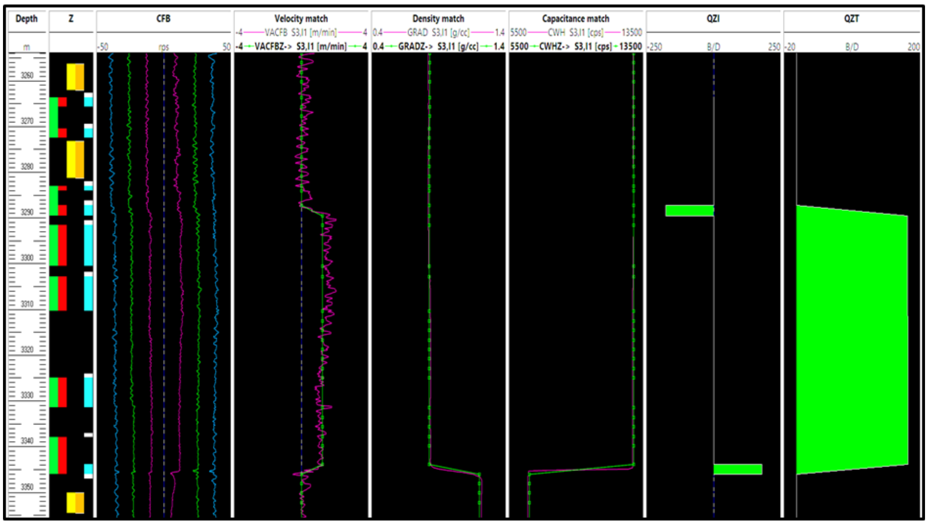


Fig. 9. Well-2 Shut-in Period Which Indicated Cross Flow Presence

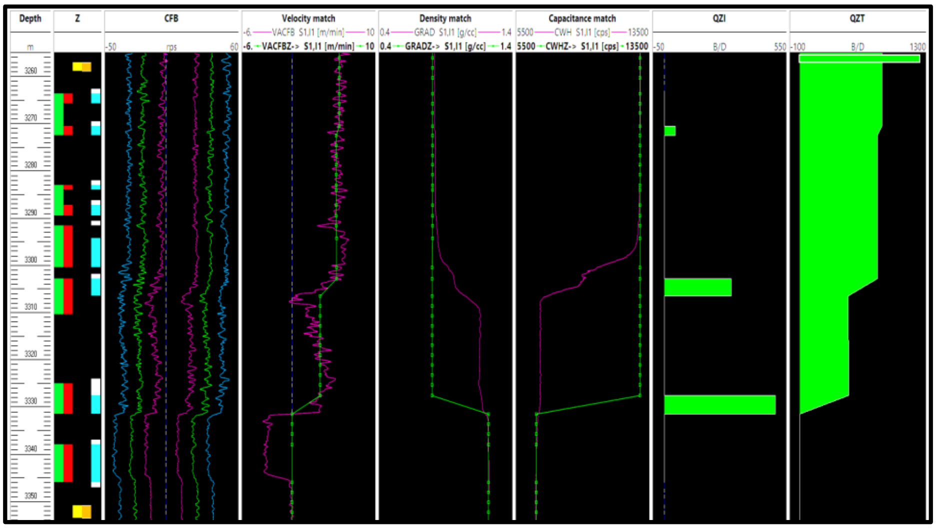


Fig. 10. Well-2 First Flowing Period

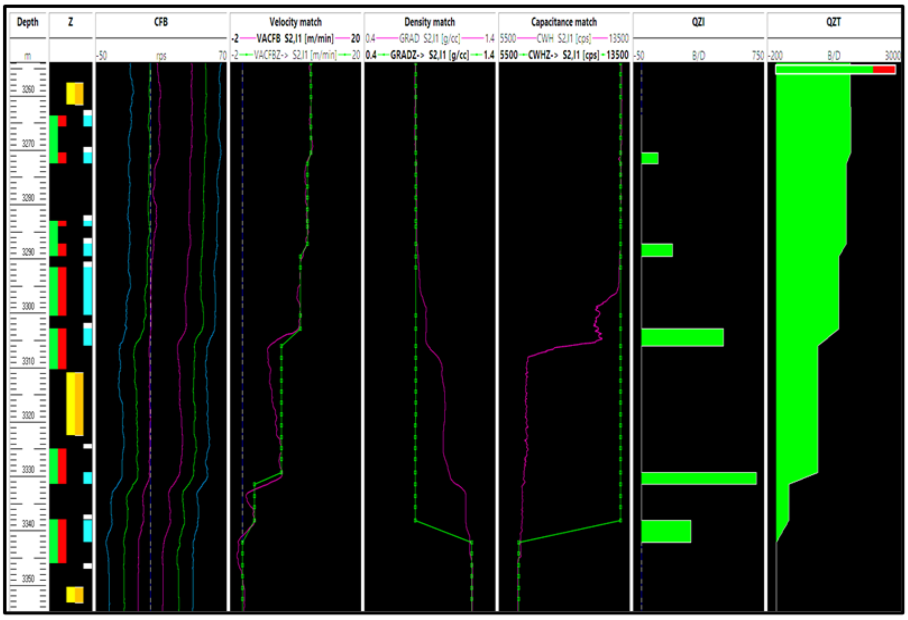
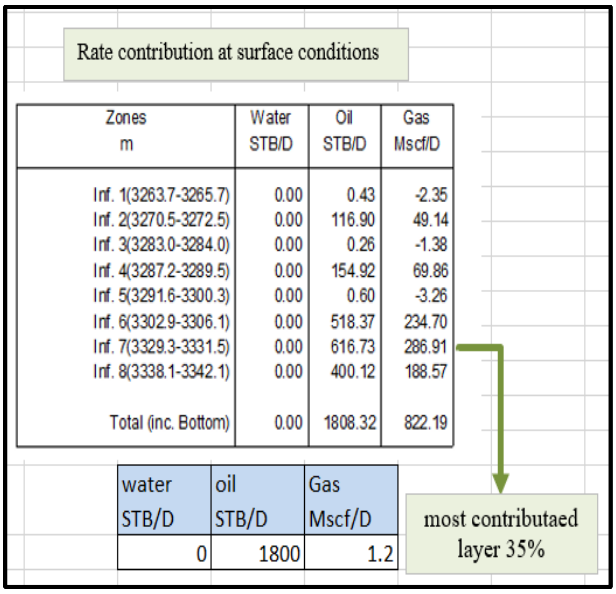


Fig. 11. Well-2 Second Flowing Period

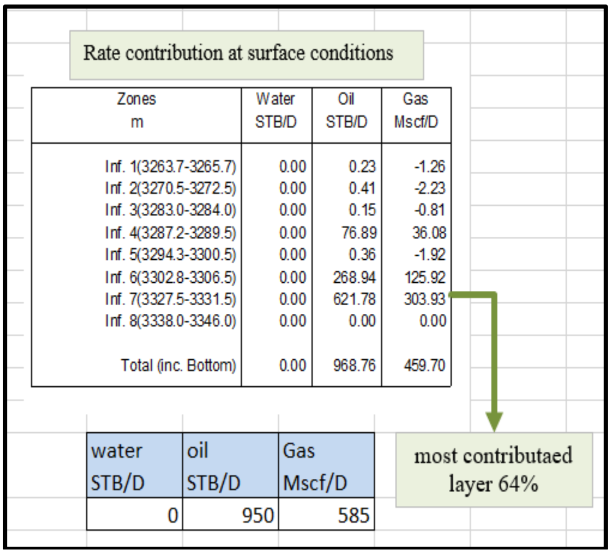


Rate contribution at surface conditions

Zones m	Water STB/D	Oil STB/D	Gas Mscf/D
Inf. 1(3263.7-3265.7)	0.00	0.43	-2.35
Inf. 2(3270.5-3272.5)	0.00	116.90	49.14
Inf. 3(3283.0-3284.0)	0.00	0.26	-1.38
Inf. 4(3287.2-3289.5)	0.00	154.92	69.86
Inf. 5(3291.6-3300.3)	0.00	0.60	-3.26
Inf. 6(3302.9-3306.1)	0.00	518.37	234.70
Inf. 7(3329.3-3331.5)	0.00	616.73	286.91
Inf. 8(3338.1-3342.1)	0.00	400.12	188.57
Total (inc. Bottom)	0.00	1808.32	822.19

water STB/D	oil STB/D	Gas Mscf/D
0	1800	1.2

Fig. 12. Well-2 Surface Contribution and Well Test Rates for First Draw Down



Rate contribution at surface conditions

Zones m	Water STB/D	Oil STB/D	Gas Mscf/D
Inf. 1(3263.7-3265.7)	0.00	0.23	-1.26
Inf. 2(3270.5-3272.5)	0.00	0.41	-2.23
Inf. 3(3283.0-3284.0)	0.00	0.15	-0.81
Inf. 4(3287.2-3289.5)	0.00	76.89	36.08
Inf. 5(3294.3-3300.5)	0.00	0.36	-1.92
Inf. 6(3302.8-3306.5)	0.00	268.94	125.92
Inf. 7(3327.5-3331.5)	0.00	621.78	303.93
Inf. 8(3338.0-3346.0)	0.00	0.00	0.00
Total (inc. Bottom)	0.00	968.76	459.70

water STB/D	oil STB/D	Gas Mscf/D
0	950	585

Fig. 13. Well-2 Surface Contribution and Well Test Rates for Second Draw Down

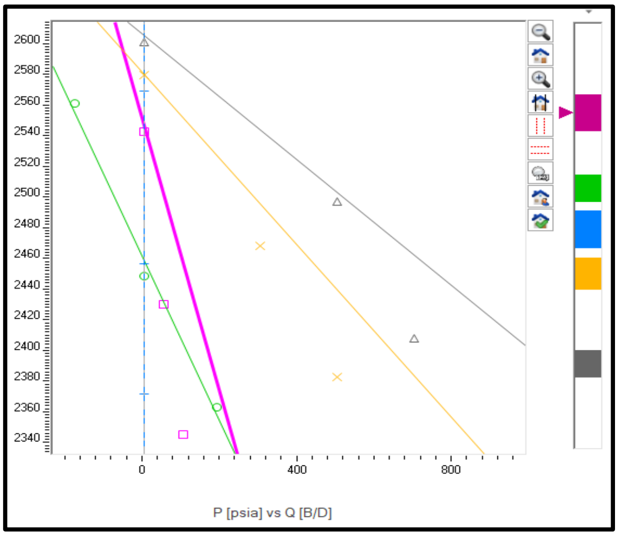


Fig. 14. Selective Inflow Performance for Well-2

The most important advantage of SIP method is to minimize cost and time during the operational sequence. SIP technique requires stable flow rates and well bore pressure to plot a representative IPR. For Well-1 the well was under equilibrium, while in Well-2 there was cross flow between layer D and H during shut-in around 180 bbl/day, and layer D was considered a thief zone. SIP couldn't be implemented for layers A and H because the contribution rate wasn't excited. Although the two cases were different in regard to flow equilibrium inside the well bore, the SIP technique was valid and done with the same procedure in both cases.

Table 1. Values of Average Pressure from SIP

Layers	Pavg from SIP, psia
C	2548.42
D	2460.24
E	2520.83
F	2580.9
G	2606.26

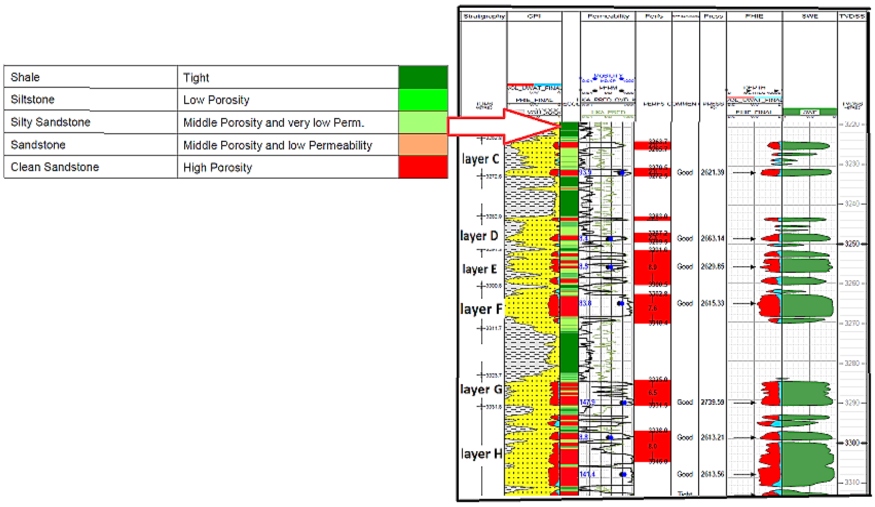


Fig. 15. Lithology Identification for Well-2

6- Conclusion

Production logging extends beyond the conventional scope of zonal qualification, offering valuable insights into hydrocarbon entry and facilitating the computation of rates. It enables the estimation of selective inflow performance (SIP) for individual layers in a commingled system. In the case of layer B, the average pressure is approximately 3414.49 psi, with a contribution rate of 100% from layer B. For well-2, layer G emerges as the most significant contributor, with contribution rates of 64% and 35% during the first and second drawdown, respectively. SIP provides reliable estimates for average reservoir pressure in wells with very low gas-oil ratio (GOR) and single-phase flow. The SIP methodology follows the same steps as for flow equilibrium in a commingled system. The accuracy of SIP is directly proportional to the production potential of the layer, with higher production leading to better accuracy. It is important to note that SIP cannot be created for inactive layers. To calculate SIP, two flow periods are required, and a shut-in period is not mandatory. However, if a shut-in duration exists, it is recommended to utilize it as input pressure data in the pressure channel order within the Emeraude software.

Nomenclature

a: Darcy term
b: Turbulence flow term
C: Flow coefficient
IPR: Inflow performance relationship.
n: Exponent depending on well characteristics
P_{avg}:: The calculated average pressure
PI: Productivity index
P: Bottom hole flowing pressure
Q: Oil production rate
ΔP_{IPR}: Pressure difference between datum depth and IPR deference

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تحديد متوسط الضغط في الابار النفطية متعددة الطبقات بأستخدام طريقة أداء التدفق الأنتقائي

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الخلاصة

في هذا البحث تمت مناقشة التحديدات في تقدير متوسط الضغط المكمني للأبار المتعددة الطبقات خلال مدى عمرها الأنتاجي. كانت في السابق تقنية تحديد نمط جريان الموائع للأبار المتعددة الطبقات وذات انبوب فردي للأنتاج عملية معقدة. و لغرض مراقبة هبوط الضغوط بمرور الزمن وكذلك لتحديد معدل ضغط كل طبقة بصورة منفردة يتم أستخدام بيانات الفحص الأنتاجي التي من خلالها يتم تطبيق تقنية أداء التدفق (SIP)الأنتقائي. تعتبر طريقة ادائية التدفق ألأنتقائي هي أحدى الطرق المستخدمة في تحديد أدائية الجريان لكل طبقة منفردة. حيث يتدفق البئر بمعدلات جريان سطحية مستقرة و مختلفة, ولكل معدل جريان تقوم مجسات الانتاج (PLT) بتسجيل ضغط جريان قاع البئر و معدل الانتاج لكل طبقة موجودة في المكمن و المطلوب فحصها خلال فترة الانتاج. ومن الجدير بالذكر ان بيانات ال (PVT) يتم أستخدامها لتحويل البيانات المقاسة عند الظروف المكمنية الى ظروف سطحية. كذلك يمكن أستخدام انواع مختلفة من معادلات ال (IPR) في تقنية ادائية التدفق الأنتقائي منها طريقة الخط المستقيم, وطريقة Fetkovitch وطريقة LIT.

بالرغم من أستخدام هذه التقنية للموائع ذات الطور الواحد إلا انه بالأمكان التحكم بالطور المراد أجراء الحسابات له. لقد تم أسخدام هذه التقنية لأبار منتجة تقع في جنوب العراق حيث تم أكمال هذه الأبار لعدة طبقات منتجة و لمكمن واحد والذي تم فحصة سابقا بمجسات الفحص الطبقي لغرض تخمين الضغط المكمني ومتغيرات أخرى. تم أخذ بئرين في حقل الزبير النفطي الواقع جنوبي العراق, حيث أن البئر الأول يوجد فيه Cross flow بين منطقتي التثقيب أما بالنسبة للبئر الثاني فأنه في حالة اتزان, بالتالي تم حساب معدل الضغط لكل طبقة منفردة ولكلا البئرين ألا أن الطبقة A في البئر الأول لم يتم حساب معدل الضغط لها حيث لم يكن فيها معدل جريان بينما معدل الضغط للطبقة B يعادل ٣٤١٤,٤٩ باوند/انج تربيع. بينما للبئر الثاني تم حساب الضغط لجميع الطبقات ماعدا الطبقة H حيث لم يكن بالأمكان حسابة بسبب عدم توفر الجريان في هذه الطبقة وكان أعلى معدل ضغط في الطبقة G يعادل ٢٦٠٦,٢٦ باوند/انج تربيع, بالتالي تم التوصل الى ان طريقة أداء التدفق الأنتقائي يمكن أستخدامها في كلتا الحالتين أي في حالة Cross flow وفي حالة كون البئر متزن.

الكلمات الدالة: متوسط الضغط المكمني، طبقات متعددة، مجسات انتاجية، أداء التدفق الأنتقائي، جنوب العراق.