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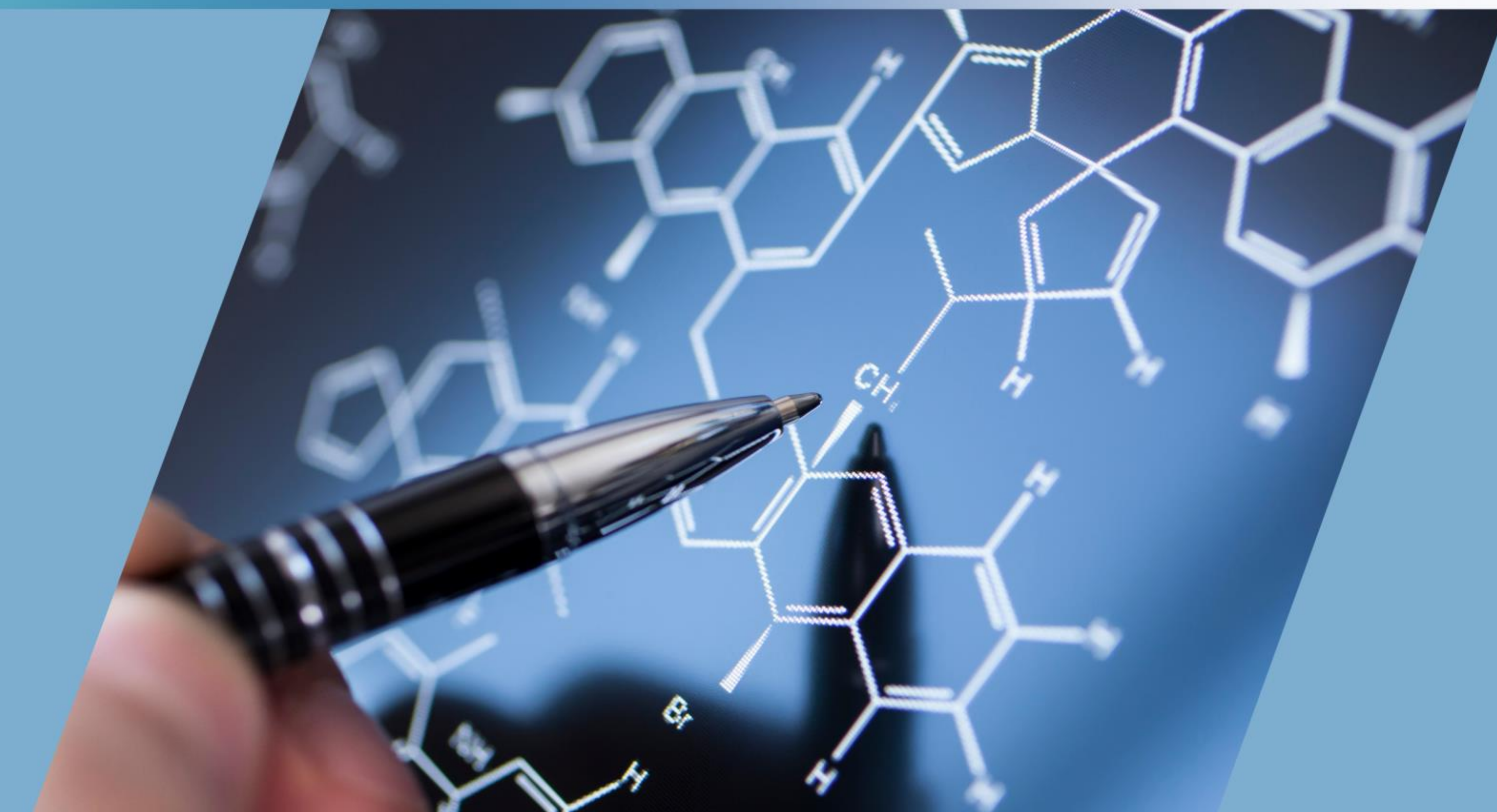

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# Bahr Essalam Gas Wells Production Evaluation Using Theoretical Method

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**A B S T R A C T**

The production flow phenomenon potential of the Bahr Essalam's natural gas wells surveillance can be determined. However, it is one of the most important challenges for implemented operations to be accomplished at the location. On the other hand, the deliverability test application is a reliable fundamental operation in order to evaluate the reservoir productive capability at the current reservoir conditions. Consequently, the flow-after-flow test has been implemented for three wells of XX-02, XX-14, and XX-15, the pseudo-gas potential and inflow performance relationship have been used to evaluate the test. Therefore, the collected information has been analyzed using theoretical method which is considered an accurate method for the natural gas production flow rate assessment. The data analysis demonstrated that the absolute open flow potentials (AOFP) which mathematically represent the maximum gas flow rate at bottom hole flowing pressure equal to atmospheric pressure for the wells of XX-02, XX-14, and XX-15 are 66.6, 68.97, and 74.5 MMscf/day respectively. Additionally, the prediction of gas production flow rate at bottom hole flowing pressure of 1000 psi for the wells is 63, 65, and 70 MMscf/day respectively. Moreover, the group of IPR curves that belong to three wells depicted no substantially significance change in the delivered gas at the given bottom hole flowing pressure of the reservoir, which provides an average gas flow rate of approximately 41 MM scf/day. In conclusion, the IPR curves are essential study to evaluate the wells capability to deliver the gas to the wells and the gas amount that may actually be delivered up to the separators.

## 1. Introduction

Therefore, in this paper work, the Flow-After-Flow test will be analyzed using theoretical method to evaluate the Bahr Essalam natural gas field according to obtained data from Mellitah Oil & Gas Company. It is located within Block NC41 in the Mediterranean Sea, approximately 120 km northwest of Tripoli. The offshore gas and condensate field is owned and operated by Mellitah Oil & Gas (MOG), an equal joint venture (JV) between Eni and National Oil Corporation (NOC), a Libyan state-owned oil company. Production started in 2005 as part of the Bahr Essalam Phase I project.

In the natural gas fields, the well testing can be parted into three sections which are transient pressure analysis, production analysis and deliverability analysis. The deliverability testing may be conducted by producing the natural gas well at usually four different gas flow rates (İŞÇAN, 2021). The deliverability conventional back pressure test which known as flow-after-flow test analysis can be used as an analysis technique to define a regular inflow performance relationship (IPR). This practical analysis is a relationship between the bottom hole flowing pressure or tubing well head pressure and natural gas flow rate that may substantially be utilized to



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forecast the gas production rate at any gas reservoir pressure. In other words, the flow-after-flow test run to evaluate the capability of gas well production at a certain reservoir conditions (Brown,1984). Prior to the achievement of gas flow rate, the stabilization of reservoir pressure needs a particular time which is not practical for long period (Lee et. al., 2003), because it is attributed to low permeability reservoir. Therefore, the low permeability gas reservoir can be subjected for deliverability testing such as flow-after-flow test as a result of long time required for reaching reservoir pressure stabilization condition. Additionally, it can be named four-point tests as well. It is carried out by producing the gas well at different stabilized gas flow rates following with measured bottom hole flowing pressure. Usually, conventional flow-after- flow tests are carried out with a succession of increasing flow rates (Smith, 1990). The required time to create the reservoir pressure before the achievement of flow is not practical, because shut in wells leads to reduce the gas production system (Lee et. al., 2003). Rawlins and Schellhardt provided a method to measure the productive capability of the wells. It is a reasonable test that can be conducted to control gas flow rates (Rawlins and Schellhardt, 1935; Smith, 1990). Therefore, this method became standard practice and became known as the conventional multi point or back pressure test. Besides, this practical test is pointed to such the flow-after-flow back pressure test. Moreover, the gas flow rate measurement can be accomplished using an inflow performance formula. This formula could be assessed according to original field data. The theoretical method is used for natural gas production evaluation. It requires extra work that depends on the pseudo-gas potential integral prior to Flow-After-Flow analysis.

In addition, this formula relies on the coefficients A and B of pseudo pressure approach which are essentially independent parameters of the reservoir pressure (Lee, 1982; Ahmed and McKinney, 2011). In addition, it is necessary to mention the most essential phenomena which gas flow rate stabilization. So, it is caused by liquid accumulation in bottom hole, liquid removal or unsteady state action of the gas well. In fact, it is possibly due to a combination of the all previous mentioned phenomena. Typically, previous study by Cullender demonstrated that the stabilization can be achieved. The flowing pressure of the wellhead variation may be no more than a specific number of psia in short duration of about fifteen minutes (Cullender, 1955; Smith, 1990). To evaluate the natural gas well performance, the inflow performance relationship (IPR) curve may be suggested for this purpose. Moreover, the empirical method is one of the most important approach for interpreting and evaluating the deliverability tests analysis of gas wells performance (AL-Attar H and Al-Zuhair, 2009). Consequently, the main target of the deliverability test such as flow after flow test is to foretell the manner in which the gas flow rate is going to decline simultaneously with reservoir pressure depletion (Aluhwal, et. al., 2017). Moreover, absolute open flow potential (AOFP) may be defined as the gas flow rate at which the gas well produces contra a zero-value at sand face. It is impossible to be measured directly but might be procured from deliverability tests. So, it is usually utilized by regulatory authorities as a index in setting maximum allowable production gas flow rate (Nguyen and Sergeev, 2015). The gas well flow performance evaluation of inflow performance relation (IPR) technique was used by Bakyani (Bakyani, et. al., 2018). A case study has been conducted for a gas well to evaluate natural gas production (Igwilo, et. al. 2018). A research study about normalized pseudo variables in gas well testing was carried out in order to estimate well deliverability, skin, permeability, mechanical skin (Meunieur, et. al., 1987). A similar research was run to facilitate the early assessment of natural gas well deliverability in a strong heterogeneity and complex low permeability reservoir (Xi, et. al., 2020; Sergeev et. al., 2017). Therefore, the multipoint back-pressure test results is a very reliable deliverability operation. A limited number of about four points tests are often run for a single gas well (Brar and Aziz, 1978).

## 2. Methodology

The real data of deliverability test is acquired from the Bahr Essalam gas field. The pseudo gas potential and analytical mode suggested for back pressure test interpretation. The one of the important modes to be used is empirical method for data interpretation.

### 2.1 Flow-After-Flow Test

Flow-After-Flow test may be named as Back Pressure Test. It can be defined as a simple inflow performance relationship between bottom hole flowing pressure or tubing well head pressure and gas flow rate. Moreover, it could be forecast the production gas flow rate at any given bottom hole pressure. The pressure history and gas flow rate of typical multi point test can be shown in Figure 1. It illustrates a typical sequence of rate varies in which the gas flow rate increases throughout the test. Besides the test can be run in a reverse sequence as well.

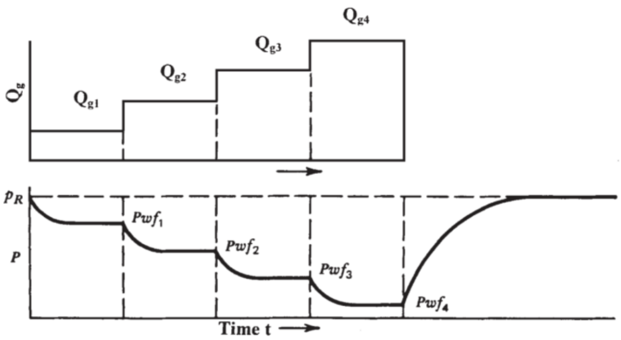


**Figure (1)** Conventional multi point test (Smith, 1990).

### 2.2 Collected data

The data of Flow-After-Flow test has been collected from three different gas wells (Well XX-02, Well XX-14 and Well XX-15) that located within Baher Esslam gas field is shown in the Table 1**.** Additionally, the gas sample was collected from this gas reservoir for PVT analysis (hydrocarbon compositions). So, the supplement Table 2 depicts the compositional analysis data. Moreover, the reservoir pressure is 3550 psi, temperature is 279 $^oF$, 51 $^oAPI$ condensate, heptane plus $P_{pc}$ and $T_{pc}$ are 352.22 psi and 1012.695 $^oR$, respectively.

**Table (1)** Gas test data

| Test | $P_{wf}$, psi | Gas flow rate, scf/D | $Q_o$, STB/D |
|---|---|---|---|
| Well_XX-02 | | | |
| 1 | 2890 | 33,176,354 | 993 |
| 2 | 2700 | 38,768,432 | 1078 |
| 3 | 2460 | 42,832,109 | 1183 |
| 4 | 2200 | 48,043,283 | 1202 |
| Well_XX-14 | | | |
| 1 | 2922 | 31,990,123 | 1121 |
| 2 | 2650 | 40,112,879 | 1163 |
| 3 | 2490 | 43,123,657 | 1204 |
| 4 | 2188 | 49,002,436 | 1213 |
| Well_XX-15 | | | |
| 1 | 3030 | 29,990,102 | 781 |
| 2 | 2733 | 39,856,732 | 793 |
| 3 | 2570 | 44,109,834 | 818 |
| 4 | 2311 | 50,111,232 | 983 |

**Table (2)** Gas compounds

| | Mole fraction (Xi) | | |
|---|---|---|---|
| | Well No. | | |
| | XX-02 | XX-14 | XX-15 |
| Comp. | Xi | Xi | Xi |
| C1 | 0.714250 | 0.7269 | 0.76310 |
| C2 | 0.041720 | 0.0409 | 0.04280 |
| C3 | 0.027000 | 0.0194 | 0.02040 |
| i-C4 | 0.003700 | 0.0060 | 0.00330 |
| n-C4 | 0.010505 | 0.0052 | 0.00260 |
| i-C5 | 0.001575 | 0.0027 | 0.00211 |
| n-C5 | 0.001230 | 0.0028 | 0.00957 |
| C6 | 0.006940 | 0.0068 | 0.00710 |
| C7+ | 0.019480 | 0.0191 | 0.02010 |
| $H_2S$ | 0.018460 | 0.0181 | 0.01901 |
| $N_2$ | 0.029580 | 0.0290 | 0.03040 |
| $CO_2$ | 0.125560 | 0.1231 | 0.07951 |

### 2.3 Theoretical Method

The theoretical method is substantially based on the main pseudo steady state inflow performance equation (Lee, 1982; Ahmed and McKinney, 2011) which can be written as following simplified formula:

$$\psi(\bar{P}) - \psi(P_{wf}) = A.Q_g + B.Q_g^2$$

Where A and B are constants, $\psi(P)$ is called pseudo gas potential, psi$^2$/cp which can be defined at any pressure (P) as the next form:

$$\psi(P) = 2\int_{14.7}^{P} \frac{P}{\mu.z}\,dP$$

Where $\mu$ is gas viscosity, cp and $z$ is the gas deviation factor, $Q_g$ stand for gas flow rate, scf/day, $P_{wf}$ is bottom hole flowing pressure, psi, $\bar{P}$ is average reservoir pressure of the drainage area, psi.

### 2.4 Corrected Gas Flow Rate

The natural gas production flow rates are corrected according to the gas equivalent of the hydrocarbon condensate simplified formula (Cragoe, 1929) which as following:

$$Q_{gc} = Q_g + 3003(1.03 - \gamma_o).Q_{con}$$

$Q_{gc}$ stand for corrected gas flow rate, scf/d, $\gamma_o$ is liquid condensate specific gravity and $Q_{con}$ liquid condensate rate, STB/day.

## 3. Inflow Performance Relationship

A plot of gas production flow rate against bottom hole flowing pressure is termed the gas well or reservoir inflow performance relationship (IPR) that proposed as a method of interpretation of flowing and natural gas reservoir potential. Additionally, the absolute open flow potential (AOF) is the major parameter which could be estimated using theoretical approach that common method is used in the natural gas industry.

## 4. Results and discussion

The theoretical method is considered the best method that used for gas production assessment. It is a reliable method to analyze the back-pressure test in the natural gas industry, because it is more accurate and rigorous than the other methods (Al-Hussainy, *et. al.*, 1966) which is attributed to the pseudo gas potential calculation. Therefore, based on this deduction, the obtained results of deliverability test analysis can be show in Figure 2**.**

The pseudo steady state inflow performance equation that mentioned above demonstrates that the coefficients A and B of pseudo pressure approach for each well are essentially independent variables of the reservoir pressure. These variables can be treated as fixed parameters. A and B might be determined from the individually regression of the straight line for each single gas well.

The obtained results displayed that A is 1.035 and B is 0.00000014567 for Well XX-02 in which A is represent the intercept and B is represent the slope of the fitted line. Secondly, A is 1.861 and B is 0.0000001233 for Well XX-14. Finally, A is 2.4869 and B is 0.00000009587 for Well XX-15. The absolute open flow potential (AOFP) can be calculated from the fitted straight line. AOFP mathematically acts the maximum gas flow rate at bottom hole flowing pressure equal to atmospheric pressure. The AOFPs for the wells of XX-02, XX-14 and XX-15 are 66.6, 68.97 and 74.5 MMscf/day respectively. The pseudo-gas potential ψ(P), at initial reservoir pressure is 714.9 MMpsi$^2$/cp, because the three wells are located in the same reservoir. Table 3 demonstrates the Pseudo-gas potential results at each pressure data. According to the obtained results, the prediction of gas production flow rate at bottom hole flowing pressure equal to 1000 psi for the well of XX-02, XX-14 and XX-15 are 63, 65 and 70 MMscf/day. Additionally, the inflow performance relationships curves (IPR) for all conducted deliverability tests. It is clearly the IPR curves show no a remarkable significant difference between delivered natural gases for all the wells. It can be noticeable that the average bottom hole flowing pressure of 2595 psi is the average bottom hole flowing pressure of the all wells which reflexes the average gas production flow rate of approximately 41 MM scf/day. This estimated average is obtained from the flow-after-flow test data as displayed in Figure 3. In addition, the Figure 4 illustrates the pseudo gas potential as a function of gas viscosity (μ), cp and gas deviation factor (z) for the natural gas compounds. Finally, it is important to mention that various wells flow-after-flow tests and IPR curves that discussed above are the reliable indicators to assess the pay zone capacity to deliver the natural gas to the wells. Moreover, the test evaluates the capability of the wells to deliver the gas volume to the ground surface at average reservoir pressure of 3550 psi and average flowing bottom hole pressure of 2595 psi.

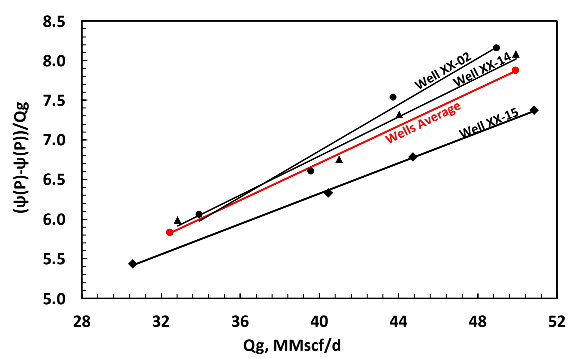


**Figure (2)** Deliverability test analysis using pseudo gas potential

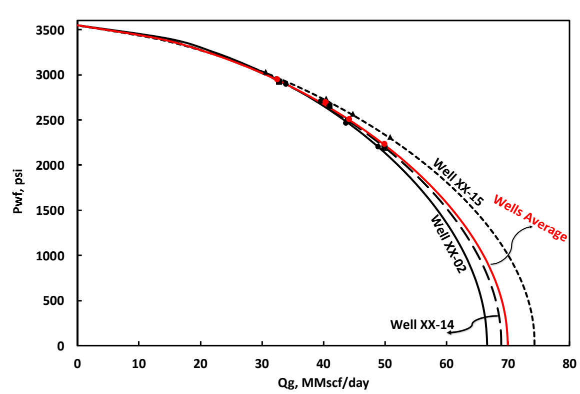


**Figure (3)** IPR curves for the wells and their average

**Table (3)** Pseudo-gas potential results

| P, psi | Qgc, scf/d | ψ(P), psi²/cp | [(ψ(P)-ψ(Pwf)]/ Qgc |
|---|---|---|---|
| Well XX-02 | | | |
| 3550 | 0.000 | 714,942,893 | - |
| 2890 | 33,935,737 | 509,463,548 | 6.0550 |
| 2700 | 39,592,818 | 453,375,673 | 6.6064 |
| 2460 | 43,736,792 | 385,285,164 | 7.5373 |
| 2200 | 48,962,496 | 315,630,649 | 8.1555 |
| Well XX-14 | | | |
| 3550 | 0.000 | 715,144,205 | - |
| 2922 | 32,847,393 | 518,432,228 | 5.9887 |
| 2650 | 41,002,268 | 438,123,379 | 6.7562 |
| 2490 | 44,044,400 | 392,772,087 | 7.3193 |
| 2188 | 49,930,061 | 311,695,307 | 8.0803 |
| Well XX-15 | | | |
| 3550 | 0.000 | 718,202,608 | - |
| 3030 | 30,587,361 | 551,949,839 | 5.4353 |
| 2733 | 40,463,168 | 462,036,687 | 6.3308 |
| 2570 | 44,735,389 | 414,734,421 | 6.7836 |
| 2311 | 50,862,968 | 343,072,211 | 7.3753 |

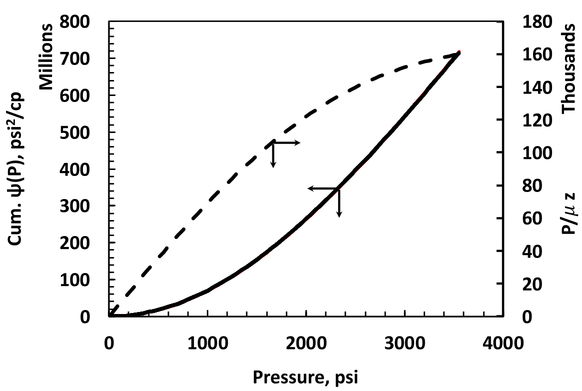


Figure 4: Pseudo-gas potential vs. pressure

## 5. Conclusion

The flow-after-flow test was analyzed by theoretical method in order to assess the Bahr Essalam's natural gas wells production such as Well XX-02, XX-14 and XX-15. The natural gas production flow rates of these wells are corrected according to the gas equivalent of the hydrocarbon condensate. The main indicator of production potential is the pseudo steady state inflow performance relationship. The analysis has shown that the wells have a productive capability at the current reservoir pressure of 3550 psi and average gas production of 41 MM scf/day at average bottom hole flowing pressure of 2595 psi as can be shown in the average IPR curve of three wells. The forecasting of gas production flow rates of the wells XX-02, XX-14 and XX-15 are 63, 65 and 70 MMscf/day respectively, when the pressure is dropped to1000 psi.

**Conflict of Interest**: The author declares that there are no conflicts of interest.

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