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Research Article

Empirical and theoretical analysis of a modified isochronal test in a caspian region gas reservoir

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ABSTRACT

A deliverability test performed in a gas well is one of the fundamental steps to determine the flow potential of the wells in reservoir surveillance. Dynamic reservoir models need robust AOF (Absolute Open Flow), productivity index, permeability for calibration, history matching, and predictions. In this study, a gas well in a Pliocene sandstone gas reservoir was validated using the "Modified Isochronal Testing" method. This study aims to mitigate the efforts done to estimate the phenomenon of flow potential of the gas wells. Hence, the field development activities can be leveraged to a more efficient stage technically and economically. In this study, AOF, Productivity Index (PI), and the permeability of the tested interval were calculated. The validation of the permeability with log and core data increases the confidence level of the work done. AOF is the key performance indicator to define the gas well productivity at zero sand face pressure which is a measure of ranking the production potential of gas wells. The AOF values support the determination of the number of wells to be drilled and the design of the surface facilities. In this study, pressure and time data were obtained and they were analyzed by empirical and theoretical methods. These two methods used in analysis gave very close AOF values; 10.15MMSCF/D (empirical) and10.67 MMSCF/D (theoretical), respectively. The permeability was calculated as 3.42 md, which is in line with the log permeability of 3.70 md and core permeability of 3.40 md.

1. Introduction

Gas well testing is composed of three major schemes: pressure transient, deliverability, and production analysis. Although they are all related to each other, the most important data collection is the pressure by time at different flow rates. This study focuses on gas well deliverability tests. These deliverability tests were used to determine the production capability of a well under specific reservoir conditions as mentioned by Brown [1]. In this study, Absolute Open Flow (AOF), Inflow Performance Relation (IPR), productivity index (PI), and the permeability of the gas well were calculated using the theory described by Lee [2]. The calculated test permeability, log permeability, and the core of the tested interval matched with each other. The required time to create the reservoir pressure before the achievement of flow for a needed period of time is not practical as mentioned by Lee et al. [3]. Thus, an industry-accepted modification is needed to reduce test times. The aim of the modified isochronal test is to obtain similar data as in an isochronal test without longer stabilization periods to reach the reservoir pressure. The modified isochronal test is carried out similarly to an isochronal test except that the shut-in periods are of equal duration. The final stabilized flow point often is required after the final flow that will be used in the determination of the well performance coefficient (C).

Specifically, the modified isochronal test is a successive version of single-point tests planned to determine stabilized deliverability characteristics without forcing the well flow for the time required to reach the stabilized conditions as noted by Lee and Wattenberger [4]. The deliverability tests are described as flow-after-flow tests, single point tests, isochronal tests, and modified isochronal tests with and without a stabilized point. It is expected to enhance the deliverability evaluation of gas reservoirs in order to facilitate the early evaluation of gas well deliverability in complex gas reservoirs with low

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permeability and strong heterogeneity as well as calculation of the absolute open flow potential as mentioned by Xi et al. [5]. Shoaib et al. [6] stated that pulse tests which include the application of a cyclic sequence of alternating rates are the harmonic tests. They can be conducted during the ongoing production period. The isochronal test is carried out through the sequential production of the well without stabilization followed by shutting-in the well and allowing it to build-up to the average reservoir pressure before the beginning of the next production phase. In isochronal tests, each shut-in period needs to last until the stabilization time. However, this causes delays, and improper stabilization of the data leads to misinterpretations. On the other hand the modified isochronal test differs from the isochronal test in terms of the equal durations of each successive flow and shut-in periods. The modified isochronal test does not require the pressure to be stabilized at each flow and shut-in, except for the initial shut-in, to determine the reservoir pressure. Therefore, it is more practical and faster compared to isochronal test. As the permeability gets higher, the stabilization time gets shorter. Stabilization time is defined as the time needed to observe almost no change or very little change in pressure with respect to time. The determination of IPR (Inflow Performance), well performance coefficient (C), the inverse slope of gas deliverability curve (n), and AOF are the major parameters that can be calculated using the pseudo pressure approach which widely used in the industry as mentioned by Mohamd and Fatooh [7]. Although most of the gas reservoirs are clastic/sandstone as lithology, there are cases where tight carbonate reservoirs can be encountered as noted by Jiang et al. [8]. In such cases, similarly, conventional deliverability theory and equation in sandstone reservoirs are still used except for the coefficients of the equation which are sensitive to the reservoir data. Sergeev [9] emphasized that the adaptive interpretations of gas well deliverability tests facilitate the possibility of generating bottom-hole pressure and flow rate data at different test stages together with the IPR curve. In general, the idea is estimating the formation pressure and the flow coefficients. The modified isochronal and isochronal gas well testing techniques are often used in the industry. Especially, the modified isochronal deliverability method is generally in the unsteady state since it is not needed for the reservoir to reach the steady state during the test phase as stated by Aziz [10]. Having considered the basic concepts of modified isochronal test mentioned above, in this study, it was considered to implement a modified isochronal test analysis since the permeability of the reservoir is as low as 3-5 md. Otherwise, the successive shut-in stabilization periods would have been too long to be efficient if the isochronal test had been conducted here.

This paper aims to present a structured plan and the analysis of the test data using empirical and theoretical approaches based on the well-known textbook sources [1-4] and [28-30] . The analysis of the real field data revealed reasonable results which match the log and the core data. Therefore, this paper establishes a link between the theory and real field data application. When new gas wells are drilled, their potential needs to be determined for further field development activities. Deliverability gas well testing measures the production capabilities of a gas well under specific bottom-hole pressures and reservoir conditions. Although this study focuses on gas production techniques and reservoir approaches, it is also recommended to conduct calorific value and biomass analyses of the produced gas to be able to validate the gas for energy deliverability and quality aspects as a future activity as mentioned by Ozyuguran et al. [11].

In general, three-four month extended flow tests are costly and they cause time and money losses in terms of making a quick decision. However, the modified isochronal test, applied in this study, is relatively shorter up to a few days. The planning of the test is crucial, otherwise time and money losses emerge. Thus, successful or representative data cannot be obtained.

In this study, a pressure gauge which can acquire 2 data at 30 seconds (0.008333 hours) was used. This data resolution helps to visualize the pressure profile and the stabilization. Unless the resolution is planned carefully, the obtained data would not provide an opportunity to make a “sound” analysis. Moreover, since the electric power should not be interrupted during the test, a backup battery is recommended at the downhole gauge beside the electric power cable. This study focuses on the executed modified isochronal test which has five flow and three shut-in periods. Each of the four equal duration flow and three shut-in period durations is 15 hours. There is an extended flow period of 60 hours. The total duration of the test is 165 hours.

In general, it has been seen that the literature studies calculated the reservoir properties with dynamic testing. However, the calculated data have not been validated with log or core data. In this paper, the calculated permeability was validated with log and core, which increased the level of confidence. On the other hand, implementation of the textbook theory over the real field data rather than laboratory-driven data makes a significant difference in this paper compared to the literature.

Hashemi et al. [12] studied the well testing in horizontal wells. Near wellbore behaviors of gas and condensate wells were evaluated to find preliminary results throughout their study by means of different mobility zones stemming from condensate drop out. Wu et al. [13] investigated the multi - factor control for unconsolidated sandstone gas reservoir for productivity testing. They studied the combination of testing reservoir, pipe string type, sea area and the required minimum testing flow rate during cleaning up process. A test working system was designed based on critical flow test rates. Bakyani et al. [14] analyzed gas condensate wells. They aimed to optimize the flow performance by means of tubing equations and inflow performance relation (IPR). Igwilo et al. [15] reviewed a case study of horizontal well to optimize the gas production. In their study, it was aimed to evaluate the solution methods to identify the rates of the lift gas and the optimum gas production rates. Nodal analysis was applied to enhance the flow rate and to determine the constraints for the solution. Meunieur et al. [16] studied normalized pseudo variables in gas well testing. In their study, two methods were proposed to find rate-dependent skin, permeability, mechanical skin, and well deliverability.

The first method was the logarithmic convolution of pressure with flow rate. The second method was a transient flow-after-flow test with a short duration where they obtained close results. Solaimani et al. [17] analyzed the horizontal gas wells in tight formations. They investigated the sensitivity of the productivity to reservoir properties. A modified backpressure test method was used to identify the productivity of horizontal gas wells where pressure dependent viscosity and anisotropy exist. In their study, process conversion- flowing pressure correction was used to convert the modified backpressure test process into the isochronal test. The comparison of the productivity values before and after conversion yielded good productivity results. The benefit was gained especially in tight gas reservoirs. Gomaa et al. [18] studied the well testing analysis of unconventional gas reservoirs. They identified the Absolute Open Flow potential (AOF) and production performance coefficient (C) in a tight gas reservoir via flow-after-flow test. In their study, the improvement of permeability was emphasized after the fracturing operation. Brar and Aziz [19] investigated the utilization of the modified isochronal test to calculate the deliverability information without stabilized flow data. Their paper aimed to present two techniques to estimate stabilized deliverability output using isochronal data obtained from the modified isochronal test. They reported that reasonable permeability thickness product and skin factors were the outcomes of their research. Sarfraz and Tiab [20] studied the pressure build-up and drawdown in gas condensate reservoirs under two-phase flow conditions by a pseudo pressure approach integrated to changes of phases with pressure and physical properties. It was mentioned that the effective permeability could be used to estimate the well performance in pseudo-steady-state and Absolute Open Flow Potential. Franco et al. [21] studied optimized isochronal test. They applied multi rate well test to eliminate the shut-in time in gas well testing over transient and pseudo steady state flow. The edge point of their study is no stabilization time is required to reach the reservoir pressure. Instead, they developed a mathematical method using transient flow equation. Wjayanti et al. [22] utilized commercial software for the analysis of deliverability tests. They identified the (AOF) Absolute Open Flow potential , skin and permeability through the analysis of the Modified Isochronal Test. The delivered analysis graphs are similar to those which were generated in the in-house study. Putri et al.[23] investigated the production capability of a gas reservoir by means of modified isochronal gas deliverability test. The wells were flown to atmospheric pressure. They identified the Absolute Open Flow potential , well performance flow coefficient (C) and the inverse slope of gas deliverability curve (n). They aimed to estimate ability of a well to produce gas at surface by determining the (AOF) Absolute Open Flow potential.

This study contributes the literature through establishing a link between the oil and gas industry by using real field data and the textbook theory. The determination of the number of wells to be drilled and the design of the surface facilities for gas processing rely on the AOF data. Therefore, the study supports the economic planning. The confirmation of the calculated permeability through log and core data imposes the cross-check of the data by means of different sources in the literature. Moreover, dynamic reservoir models (reservoir simulations) of gas wells need the AOF, pay zone productivity, permeability for modeling calibration, history matching, and predictions. Especially, a low permeability well as depicted in this study needs a long time for stabilization. The modified isochronal test does not require stabilized pressure after each flow period. This time gain is a great advantage in terms of obtaining and analyzing data for a more practical and economical testing. The correct determination of the AOF, PI, and permeability help to estimate the flow potential of the gas wells for supporting the field development activities.

2. Basic Reservoir Information

The total hydrocarbon system is the Oligocene–Miocene Maykop/Diatom Total Petroleum System (TPS). The source rock is generally type-II and type-III kerogen. The reservoir is Pliocene which includes the Middle Pliocene Productive series referred to as the Red Bed Series. The Productive Series is composed of upper and lower conglomeratic Pereryva Suite.

The Red Bed Series constitutes the major reservoirs mentioned for the same reservoir by Iscan [24]. They are composed of highly fluvio-deltaic clastic sequences that include interbedded conglomerate to mudstones. The type log of the productive gas reservoir displays 43 m upper conglomerate and 5m siltstone and mudstone with relatively higher shale volume. The tested well in this study penetrates the reservoir at -5,412 ftss (5912ft MD). The average porosity is 17% and the average permeability is 3.7 md, while the highest permeability is up to 7 md (Figure 1).

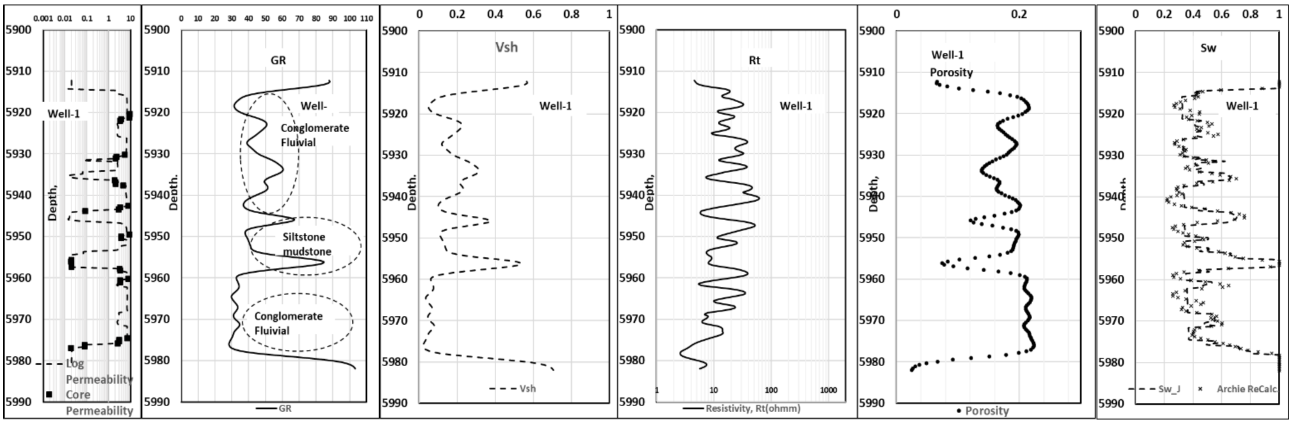

Figure 1. Type log of the reservoir

The core permeability was measured using flood experiments as per the methods by Iscan et al. [25]. These measurements revealed an average of 3.4 md which is in line with the log and the well testing permeabilities. This is a good and reliable argument that increases the confidence of the well-test data validated by means of log and cores as a major difference from most of the literature study so far.

The tested interval is 5,912-5,955 ft MD (43ft). There is a sharp reduction in porosity and permeability as well as resistivity towards 5,955 ft MD. The saturation log yields 100% water saturation at this depth. Although this behavior might be due to tightness, the bottom portion below 5,955 ft was not perforated and was not tested against the risk of a water zone. However, the reservoir properties get more prolific right after this depth. Therefore, it is planned to perforate this bottom zone in the future to further investigate the reservoir.

The top structural depth map of the reservoir is displayed in Figure 2. Based on laboratory MICP (Mercury Injection Capillary Pressure) data, the FWL is in a range of -5,481-5,530 ftss. Saturation data matches the saturation log better at a deeper FWL which is uncertain as this section was not tested.

3. Test Planning -Test Data and Data Analysis Method

This Section includes the real data which were acquired in the field. The analysis and the interpretation of these data were summarized in 3.1 Test Planning - Test Data, 3.2 Test Data Analysis Method, and 3.3 Permeability Calculation.

3.1 Test Planning - Test Data

To be able to proactive, the testing phase planning was initiated prior to the completion of the well. The power requirements, downhole temperatures, and most importantly the pressure-time recorders were supplied and brought to the well site. The well test rates and test durations were summarized together with end-point flowing and shut-in pressures (Table 1). The pressure-time data acquisition was planned as twice at 30 seconds. Therefore, thousands of pressure-time data were collected during the entire test phase of 165 hours.

The flowing bottom-hole pressure gradually decreases from 3,277 psi to 2,697 psi as the flow periods evolve. The successive flow and shut-in periods are 15 hours. There is an observed reduction in the successive shut-in periods after each of the interim flow periods which is a typical diagnostic of the modified isochronal testing. The initial reservoir pressure is 3,400 psi.

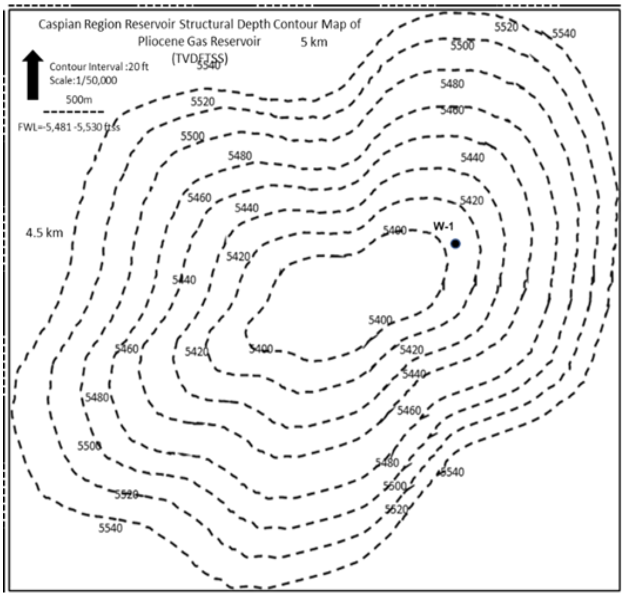

Figure 2. Top Structural Depth Map of the Gas Reservoir

Table 1. Modified isochronal test data summary

Test	Duration (hours)	P_{wf} or P_{ws} (psia)	q_g (MMscf/D)
First Flow	15	3,277	2.5
First shut-in	15	3,350	
Second Flow	15	3,178	3.1
Second shut-in	15	3,310	
Third flow	15	3,024	4.35
Third shut-in	15	3,275	
Fourth flow	15	2,783	6
Extended flow (stabilized)	60	2,697	5.2

The stabilized flow rate of 5.2 MMSCF/D was achieved by a flowing bottom-hole pressure of 2,697 psi at the end of a 60-hour testing period. The overall test rate profile by time data is summarized in Figure 3. It is planned to utilize the build-up data in another study to demonstrate the pressure build-up analysis by using the pseudo pressures concept. Each one of the flowing and shut-in periods is of 15 hours at flow rates ranging from 2.5 to 6 MMSCF/D (Figure 3). The rates are successively increased at each of the flow periods except for the stabilized extended flow. The extended flow data is used for the determination of the Well Performance Coefficient (C). The other four points are used to calculate the inverse slope of gas deliverability curve. The combination of all of these data lead to the calculation of the Absolute Open Flow Potential.

As it is seen the pressure does not stabilize at the end of each successive flow and shut-in period. This shows how the modified isochronal test differs from the isochronal one. There is a slight reduction in the pressure at the end of each of the 15-hour shut-in periods (Figure 4). If it was an isochronal test instead, pressure stabilization would have to be reached. However, in that case, the shut-in durations would have been different from each other and much longer waiting periods would have been unavoidable.

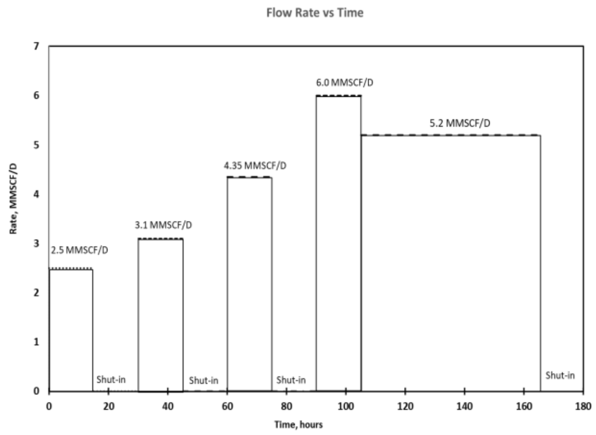

Figure 3. Rate vs time profile of the modified isochronal test

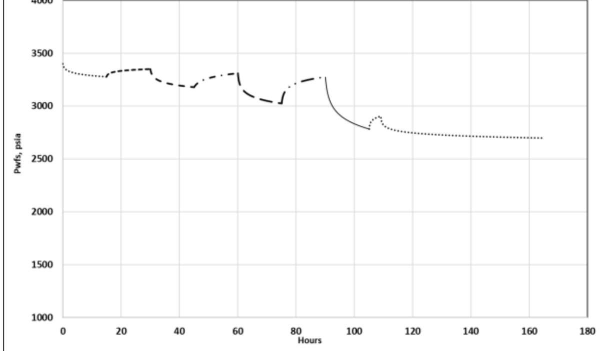

Figure 4. Pressure vs time profile of the modified isochronal test

3.2 Test Data Analysis Method

The data analysis was carried out using empirical and theoretical two methods based on well-known textbooks [1-4] and [28-30].

3.2.1 Empirical Method

The empirical method requires the plot of the square of delta pressure vs gas flow rate on a log-log paper. This plot provides an empirical correlation of the well test data. It is not recommended to extend the plot at a large distance beyond the obtained data to eliminate the risk of having misleading results. The empirical analysis relates flow rate with the square of the pressures as in Equation (1) which is known as back pressure equation. This equation is based on the empirical equation which was presented by Rawlins and Schellhardt [26].

$$q_{sg} = C(P_S^2 - P_{wf}^2)^n \tag{1}$$

As described in Brown [1] and Lee [2], the raw test data were processed by taking squares of the consecutive shut-in and flowing pressures as well as dividing the pressure difference by the corresponding flow rates (Table *2*). Therefore, (Table *2*) is the processing of the raw data which lead to the production of Figure *5* and Figure 6.

Lee [2] defined the theoretical rate at which the well could produce as the Absolute Open Flow Potential (AOF) if the flowing bottom-hole pressure was the atmospheric one.

$$slope = \frac{\left[log\left(P_4^2 - P_{wf4}^2\right) - log\left(P_2^2 - P_{wf2}^2\right)\right]}{\left[log\, q_4 - log\, q_2\right]} \tag{2}$$

$$slope = 1.48 = 1/n \tag{3}$$

$$n = 0.67 \tag{4}$$

The stabilized rate is 5.2 MMscf/D with a stabilized flowing bottom-hole pressure of 2,697 psi. The well performance coefficient C was calculated using this stabilized flow data and the reciprocal of the slope as "n" (Figure *5*). The value of the C was calculated as 1.77 x10^{-4} by using Equations (2)-(4).

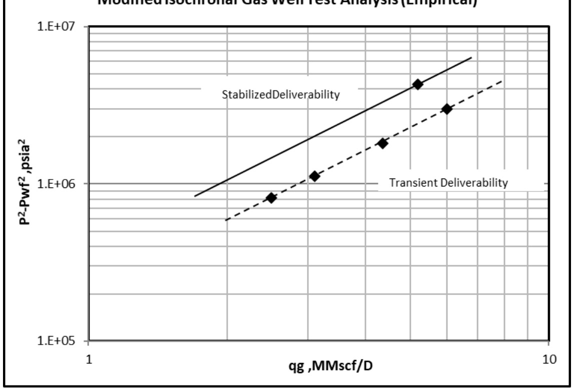

Figure 5. Empirical modified isochronal test deliverability

Donohue and Ertekin [28] utilized and presented this theory. In their study, they applied a case example with the utilization of the Equations (1) and (4). The typically characteristic test plots were also mentioned in their study which are similar to Figure 3, Figure 4 and Figure 5 of this paper. This proves the validity of the methodology which was applied in this study.

3.2.2 Theoretical method

The theoretical method is based on the background of Houpeurt [27] flow calculated using Equation (5) as described in Lee and Wattenberger [4]. The form of the equation in pseudo pressure terms is:

$$\Delta P_P = P_P(P_s) - P_P(P_{wf}) = a_t q + bq^2 \tag{5}$$

This form of Houpeurt's [27] equation is presented in pressure squared terms. The derivation is directly done from the diffusivity equation assuming that $\mu_g z$ is constant over the studied pressure interval. Equation (6) is presented for pseudo-steady flow as in the following:

$$\Delta P^2 = P_s^2 - P_{wf}^2 = aq + bq^2 \tag{6}$$

The solution of Equation (6) is done by dividing each side of the equation by gas flow rate (q) leading to Equation (7).

$$\frac{\Delta P^2}{q} = \frac{P_s^2 - P_{wf}^2}{q} = a + bq \tag{7}$$

Then, a graph of $(P_s^2 - P_{wf}^2)/q$ vs $a + bq$ is plotted linearly where slope of the equation is "b". The vertical intercept of the line is not directly "a" as in the isochronal test because the initial plot is made with the four points without the stabilization. Therefore, the $(P_s^2 - P_{wf}^2)/q$ vs $a + bq$ plot needs to be used for slope "b" calculation only. The "a" needed to be calculated using the stabilized point of q= 5.2 MMSCF/D and $(P_s^2 - P_{wf}^2)/q$= 823,798. Then, the vertical intercept "a" was calculated as 576,637 using the stabilized point (Figure 6). After the determination of "a" and "b", the Absolute Open Flow Potential (AOF) was calculated by setting the *Pwf* as atmospheric pressure. The calculated AOF values from the empirical and theoretical methods are compared with each other.

$$\Delta P^2 = P_s^2 - P_{wf}^2 = aq + bq^2 = 576637q + 47531q^2 \tag{8}$$

When the *Pwf* is set as 14.17 psi by definition of AOF, the flow rate q is solved as 10.67 MMSCF/D for the above quadratic Equation (8) as mentioned in Lee and Wattenberger [4]. Ikoku [29] described the Inflow performance curves as with the implementation of back pressure equation.

The theory and the applications of the deliverability equations of this study were validated with the deliverability testing and well production potential analysis methods as discussed by Chaudry [30] where a mathematical review of the deliverability concept was carried out.

3.3 Permeability Calculation

Permeability calculation requires the determination of the Productivity Index (PI). The PI is defined as the stabilized flow rate divided by the pseudo drawdown pressure Equation (9).

$$PI = \frac{q_{sg}}{\varphi_s - \varphi_{wf}} \tag{9}$$

The pseudo pressure term "φ" is defined as the pressure square divided by viscosity. Therefore, $P_s^2 - P_{wf}^2$ vs q_S was plotted as IPR (Inflow Performance Relation) (Figure 7). Then, the gas flow rate is calculated practically by the *PI* $x \left(P_s^2 - P_{wf}^2\right)/\mu_{gave}$ as detailed in Equation (10).

Table 2. Processing of the modified isochronal test data

q_g (MMscf/D)	P^2-P_{wf}^2 (psia)^2	(P^2-P_{wf}^2)/q_g	Test points
2.5	822,768	329,107	1
3.1	1,119,877	361,251	2
4.35	1,808,980	415,857	3
6	2,983,658	497,276	4
5.2	4,283,752	823,798	stabilized point

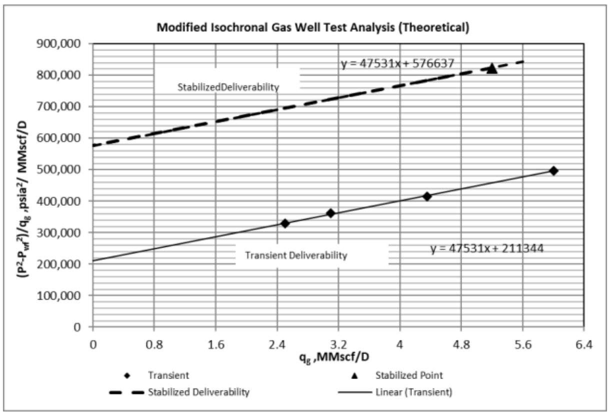

Figure 6. Theoretical deliverability of modified isochronal test

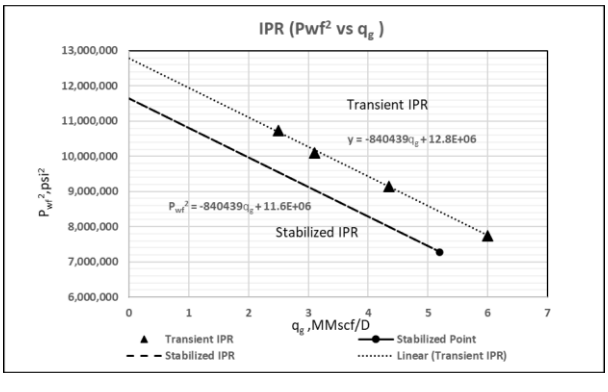

Figure 7. IPR curve for the gas well

Hence, the parameters except for the pressure square terms divided by average viscosity are the productivity index (PI). The slope obtained from Figure 7 is substituted into Equation (10) as applied in Brown [1]. Then, the corresponding permeability is calculated. The slope of the line was divided by average viscosity and its reciprocal was calculated as the PI (Figure 7). Then, the PI was calculated as 0.0227 scf/d/psi^2/cp.

$$q_{sc} = \frac{703x10^{-6}kh\left(P_s^2-P_{wf}^2\right)}{T\mu_{gave}Z_{ave}\left\{ln\left(\frac{r_e}{r_w}\right)-0.75+S+a`q\right\}} \tag{10}$$

All of the parameters which were used and calculated in the study were mentioned in section 8. The permeability was calculated as 3.42 md using the Equation (10) and the parameter in Table 3 (input parameters) which matched with the average log permeability of 3.70 md presented in Figure 1.

4. Conclusions

In this study, raw data was obtained and its analysis was carried out using the modified isochronal test. The entire test duration was 165 hours. The study provides a link between the theory and the real field application. In addition, economical and technical benefits are also provided regarding the field and facility development through the analysis of the data as well as the calibration and robustness of the dynamic simulation models. The conclusions of the study is presented under five items below.

- The Absolute Open Flow Potential (AOF) values were calculated using both empirical and theoretical approaches. The empirical method yielded an AOF value of 10.15 MMSCF/D, while the theoretical method resulted in 10.67 MMSCF/D. The percentage difference between the two methods was determined as 4.8%.
- The performance coefficient (C) of the deliverability equation was calculated as 1.77 x10^{-4}.
- The inverse of the slope of the gas deliverability curve was determined as 0.67. The stabilized rate was determined as 5.2 MMSCF/D at a stable flowing bottom-hole pressure of 2,697 psi.
- The productivity index (PI) of the well was calculated as 0.0227 scf/d/psi^2/cp. The permeability was calculated as 3.42 md through the tested interval of 43 ft. This test-driven permeability matched with the log permeability of 3.70 md and the core permeability of 3.4 md.
- The determination of AOF (Absolute Open Flow) by using two methods facilitated understanding the production potential of the gas wells in the fields for further technical and economic field development activities.

Table 3. Input reservoir parameters of the gas reservoir

Ps, psi	3,400
Phi	0.17
h, ft	43
T, F	180
rw, ft	0.3
q_{sg}, MSCF/D	5,200
P_{wfs}, psi	2,697
Sg	0.7
μ_g, cp	0.019
z	0.88
re, ft	2083
$a`q$	0
S	0

The tested interval is 5,912-5,955 ft MD (43 ft). There is a sharp reduction in porosity and permeability as well as resistivity towards 5,955 ft MD. The saturation log yields 100% water saturation at this depth. Although this behavior might be due to tightness, the bottom portion below 5,955 ft was not perforated and was not tested against the risk of a water zone. There is a plan to perforate the bottom portion of the well below 5,955 ft MD for testing the potential of this lower interval considering that hydrocarbon might have existed.

Declaration

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. The author also declared that this article is original, was prepared in accordance with international publication and research ethics, and ethical committee permission or any special permission is not required. This study is not a part of a graduate or undergraduate thesis study.

Author Contributions

A.G. İşçan is responsible for all sections of the study.

Nomenclature

AOF : Absolute Open Flow Potential, MMscf/d
MMscf/d: Million Standard Cubic Feet per Day
Mscf/d : Thousand Standard Cubic Feet per Day
P_s : Sandface Pressure, psi
P_{wf} : Flowing Bottom hole Pressure, psi
ΔP : Pressure Difference Between the Reservoir Pressure and Flowing Well Bottom Hole Pressure, psi
PI : Productivity Index , scf/d/psi^2/cp
q_{sg} : Stabilized Gas Flow Rate, MMscf/d
q_{sc} : Calculated Gas Flow Rate, MMscf/d
C : Well Performance Coefficient
n : The Inverse Slope of Gas Deliverability Curve
a or a_t : Theoretical Gas deliverability Vertical Intercept
b : Theoretical Gas Deliverability Slope

Phi : Porosity fraction
k : Permeability, md
h : Tested Interval Thickness, ft
T : Formation Temperature, R
r_w : Wellbore Radius, ft
r_e : Drainage Radius, ft
Sg : Gas Specific Gravity
μ_g : Average Gas viscosity, cp
z : Gas Compressibility Factor
S : Skin Factor
$a`q$: Non-Darcy Term
φ : Pseudo pressure term, psi^2/cp
P_p : Pseudo Pressure Term Identification

References

1. Brown, K., *The Technology of Artificial Lift Methods.* 1984, USA: PennWell Publiching Company.
2. Lee, J., *Well Testing*. 1982, USA: SPE AIME.
3. Lee, J., Rollins, J.B. and Spivey, J.P., *Pressure Transient Testing*. 2003, Richardson TX USA: SPE Textbook Series.
4. Lee, J. and Wattenberger, R., *Gas Reservoir Engineering*. 1996, Richardson TX, USA: Henry L. Doherty Memorial Fund of AIME.
5. Xi, F., X.Peng, Q. Li, X. Zhao, P. Zhang, and D. Pan, *A new method for evaluating the unstable deliverability of gas wells in gas formation testing phase*. Natural Gas Industry B, 2020. **7**(6): p. 614-623.
6. Shoaib,M., D.Viberti, S.B.Eloisa, and F.Verga, *Harmonic pulse testing for gas well deliverability Assessment.* Geoingegneria Ambientale e Mineraria, 2019. **158**(3): p. 53-60.
7. Mohamd,I.S. and S.K.,Fatooh,*Gas wells deliverability determination using flow after-flow test analysis.* Journal of Applied Science, 2020. **4**: p.26-43.
8. Jiang,L., C.Xiancaho, G. Ping, and Z. Jingchao,*Tight carbonate gas well deliverability evaluation and reasonable production proration analysis*.J Petrol Explor Prod Technol., 2021. **11**: p.2999-3009
9. Sergeev,V.L.,N.T.Phuonget,andA.I.Krainov, *Adaptive interpretation of gas well deliverability tests with generating data of the IPR curve.* J. Phys.,2017.: Conf. Ser. **803** (012136): p.1-6.
10. Aziz, K., *Theoretical basis of ısochronal and modified ısochronal back-pressure testing of gas wells.* Journal of Canadian Petroleum Technology, 2013. **6**(01): p. 20-22.
11. Özyuğuran, A., S.Yaman, and Küçükbayrak,S., *Prediction of calorific value of biomass based on elemental analysis*. International Advanced Researches and Engineering Journal. 2018; **2**(3): p. 254-260.
12. Hashemi, A., L. Nicolas, and C. Gringarten, *Well test analysis of horizontal wells in gas-condensate reservoirs.* SPE Res Eval & Eng , 2006. **9**(01): p. 86–99, SPE 89905-PA.
13. Wu, M., H. Liang, M. Zhang, D. Sun, and P. Zhong, *Productivity testing design method of multi-factor control for unconsolidated sandstone gas reservoir*. Engineering, 2016. **8**(11): p. 815-822.
14. Bakyani, A., A. Rasti, S. Qazvini, and F. Esmaeilzadeh, *Gas condensate wells simulation to optimize well flow performance using tubing equations coupled with ınflow-performance-relation (IPR) curve*. Open Access Library Journal, 2018. **5**(5): p. 1-17.
15. Igwilo, K., E. Okoro, A. Nwude, A. Mamudu, and C. Onuh, *A review on gas well optimization using production performance models:A case study of horizontal well*. Open Journal of Yangtze Oil and Gas,2018. **3**(1): p. 57-67.
16. Meunier,D.F., C.S.Kabir, and M.J. Wittmann, *Gas well test analysis: use of normalized pseudovariables*. SPE Form Eval, 1987. **2**(04): p. 629–636.SPE-13082-PA.
17. Soleimani, R.,Y. Jahanpeyma, and M. Salehian, *Analysis of horizontal well productivity in tight gas formations and its sensitivity to reservoir properties*. J Petrol Explor Prod Technol, September 2019. **9**: p. 1237–1244.
18. Gomaa, S., A. Attia, A. Abdelhady , S. Khaled, M. Elwageeh, A.N. Elhoshoudy, M. Omran, A. Essam, M.Osama , A. Ashraf, and C. Wagdy, *Well testing analysis of unconventional gas reservoirs: real case study of tight gas carbonate reservoir, apollonia formation, western desert, egypt*. International Journal of Petroleum and Petrochemical Engineering (IJPPE),2019. **5**(1): p. 1-5.
19. Brar, G.S. and K. Aziz, *Analysis of modified ısochronal tests to predict the stabilized deliverability potential of gas wells without using stabilized flow data*. Journal of Petroleum Technology (JPT) ,1978. **30**(02): p. 297-304, SPE-6134-PA.
20. Sarfraz, A.J. and T. Djebbar, *Pressure drawdown and buildup analysis in gas condensate reservoirs*. Paper presented at the SPE Western Regional/AAPG Pacific Section Joint Meeting, Anchorage, Alaska, May 2002. SPE-76780-MS.
21. Franco, F., A. Rinchon, and M.Useche, *Optimized isochronal testing*, Society of Petroleum Engineers - Abu Dhabi International Petroleum Exhibition and Conference 2018, ADIPEC 2018.
22. Wijayanti, P., L. Said, and P.J. Singh, *Analysis of determining deliverability test and ttransient pressure in the PW-02 well of Alpha fields by using Ecrin software*. Journal of Physics : Conference Series, 2019. **1402**(5): p.1-6.
23. Putri,N.A., A. Fattahanisa, A. Ristawati, and R. Setiati, *Production capability prediction of a reservoir gas by using gas deliverability analysis to supply gas energy in Indonesia.* IOP Conf. Series: Earth and Environmental Science 780. 2021: 012016.
24. Iscan, A.G., *Water saturation calculation using fractional flow and production logging data in a caspian region sandstone petroleum reservoir.* J. Petrol. Sci. Eng. 2021. **200**(05): p.108355
25. Iscan, A.G., F.Civan, M.V. Kok, *Alteration of permeability by drilling fluid invasion and flow reversal.* J. Petrol. Sci. Eng. 2007. **58** (1–2): p.272-244.
26. Rawlins, E.L. and Schellhardt, M.A., *Backpressure data on natural gas wells and their application to production Practices*. 1935 (7). Monograph Series, USBM.
27. Houpeurt, A., *On the flow of gases in porous media.* Revue de L' Institut Francais du Petrole, 1959. **15**(11): p. 1468-1684.
28. Donohue, D. and Ertrekin, T., *Gas Well Testing Theory, Practice & Regulation.* 1982, Springer Netherlands.
29. Ikoku, C.U., *Natural Gas Production Engineering*. 1992, Krieger Publishing Company.
30. Chaudry, A., *Gas Well Testing Handbook* 2003, Elsevier and Gulf Pulishing.