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Combination of Geological, Geophysical and Reservoir Engineering Analyses in Field Development: A Case Study

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***Abstract*—**A sequence of different Reservoir Engineering methods and tools in reservoir characterization and field development are presented in this paper. The real data of Jin Gas Field of L-Basin of Pakistan is used. The basic concept behind this work is to enlighten the importance of well test analysis in a broader way (i.e. reservoir characterization and field development) unlike to just determine the permeability and skin parameters. Normally in the case of reservoir characterization we rely on well test analysis to some extent but for field development plan, the well test analysis has become a forgotten tool specifically for locations of new development wells. This paper describes the successful implementation of well test analysis in Jin Gas Field where the main uncertainties are identified during initial stage of field development when location of new development well was marked only on the basis of G&G (Geologic and Geophysical) data. The seismic interpretation could not encounter one of the boundary (fault, sub-seismic fault, heterogeneity) near the main and only producing well of Jin Gas Field whereas the results of the model from the well test analysis played a very crucial rule in order to propose the location of second well of the newly discovered field. The results from different methods of well test analysis of Jin Gas Field are also integrated with and supported by other tools of Reservoir Engineering i.e. Material Balance Method and Volumetric Method. In this way, a comprehensive way out and algorithm is obtained in order to integrate the well test analyses with Geological and Geophysical analyses for reservoir characterization and field development. On the strong basis of this working and algorithm, it was successfully evaluated that the proposed location of new development well was not justified and it must be somewhere else except South direction.

***Keywords*—**Field development, reservoir characterization, reservoir engineering, well test analysis.

I. Introduction

THE Jin concession lies in the L-Basin of Pakistan and in a highly prospective area where the large gas fields of Pakistan are found. The structure was interpreted as a North-South trending fault block closed on the west by a down thrown wrench fault. The total area on the lowest closed contour was 17 Km². However, after acquisition of new seismic data and reprocessing of the vintage seismic data, the quality of seismic data improved considerably. Based on this, new map has been prepared (Fig. 1) which shows that the structure is much larger (29 Km²). It is also confirmed that the structure is a four way dip closure and not a fault closure as inferred previously. The primary objective in this area is the M-Limestone; the secondary objective was the U-Limestone. Both are of early Eocene age. The Late Cretaceous Sandstone provided a tertiary objective. The source rock for the gas is the Lower Cretaceous Shales. Seal for the M-Limestone is provided by the S-Shale, for the U- Limestone, seal is provided by the G-shale.

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Jin gas field was brought on production in April 2010 with an initial production rate of 16.5 MMscfd gas. Presently (December 2015), the well is producing 14 MMscfd gas, thus showing a decline of 3.24% per year whereas initially a decline rate of 13% per year was estimated and the well was projected to produce only 6 MMscfd gas in the 5th year whereas, the well is producing 14 MMscfd. The reasons of difference of decline rates between predicted and actual are also investigated in this study. The reasons of deviation of decline rate will also help in good reservoir evaluation and characterization. Fig. 2 shows the production history of JinX-1 well since April 2010 till end December 2015 where it is observed that JinX-1 well has been producing gas steadily over almost five years.

After production of more than five years of JinX-1 well, the reservoir has been appraised and level of confidence has been increased on initial gas in place estimated through different methods. For further field development, the second well (Jin-2) was proposed on the south of the JinX-1 well on the basis of G&G Data as shown in Fig. 3.

The location for Jin-2 well was proposed on the basis of some relatively high top of reservoir. Top of reservoir in JinX-1 is 1290 m whereas in proposed Jin-2 well top of reservoir is 1285 m. It indicates additional 5 m of reservoir in proposed Jin-2 well. But well test analysis was not in fully agreement about this proposal. So, the aim of this study was to integrate the pressure transient analysis to recheck and validate the direction of location of proposed well with strong basis.

II. Methodology

Globally two methods of pressure build up test interpretation are widely used, one is Log-Log method and second one is Semi-Log method [7]. Log-Log method indicates reservoir characteristics, near wellbore reservoir permeability & skin, and initial reservoir pressure (Pi) at tp = 0 i.e. the pressure is extrapolated backward to start of production after the last pressure build up, on the contrary Semi-Log method extrapolates the currently recorded reservoir pressure to infinity to give recent reservoir pressure, near wellbore permeability & skin factor. No-flow boundaries can be identified by both methods.

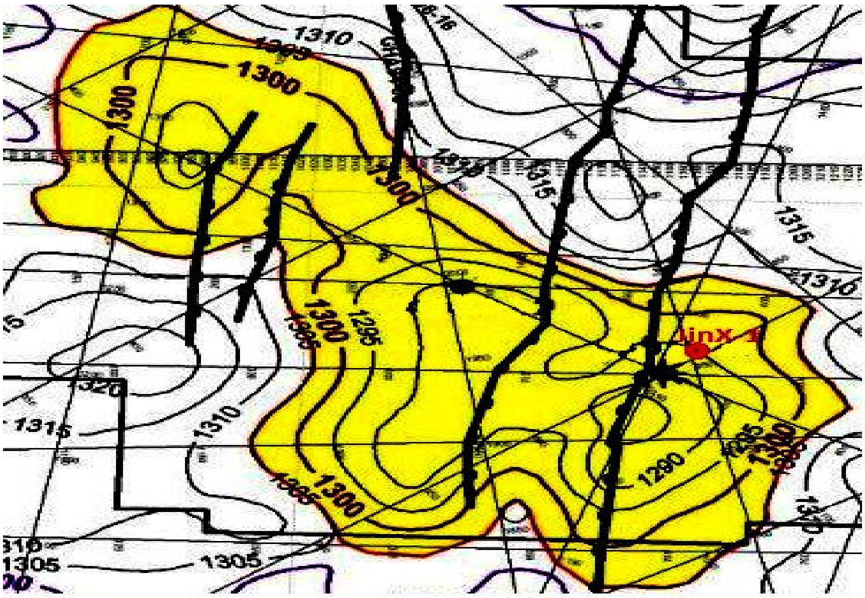

Fig. 1 Depth Structure Map of Jin Gas Field

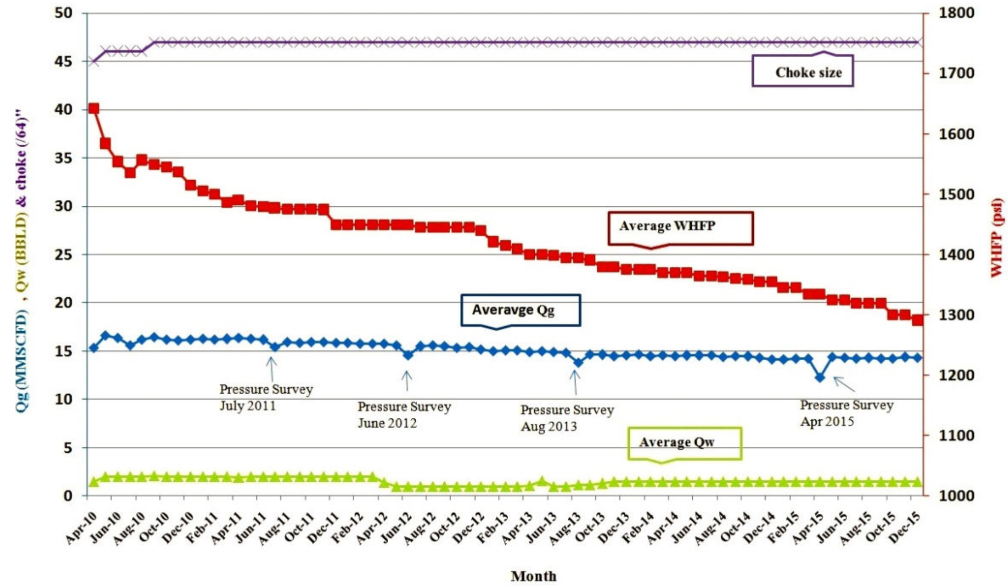

Fig. 2 Production History Graph of JinX-1 Well

To investigate the best direction for location of new development well first of all, all four pressure surveys (year 2011 to 2015) are interpreted. The analyses were not limited to classical approach of determining the permeability and skin parameters, various parameters in the model including boundary distances were adjusted to get a best match in the pressure derivative log-log curve and downhole pressure history. After the analytical modeling, a numerical model was build which allowed geological elements to be incorporated and again a best fit curve matching was achieved in pressure derivative log-log curve and downhole pressure history.

Secondly, validation of well test models and their results through material balance method by history matching was carried out and the initial gas in place, using the results of well test analysis, was estimated. Thirdly, initial gas in place of Jin Gas Field has also been estimated through Volumetric Method to provide checks on result from material balance method. The validation of results from one tool by the other tool always increases the level of confidence on the final results [9].

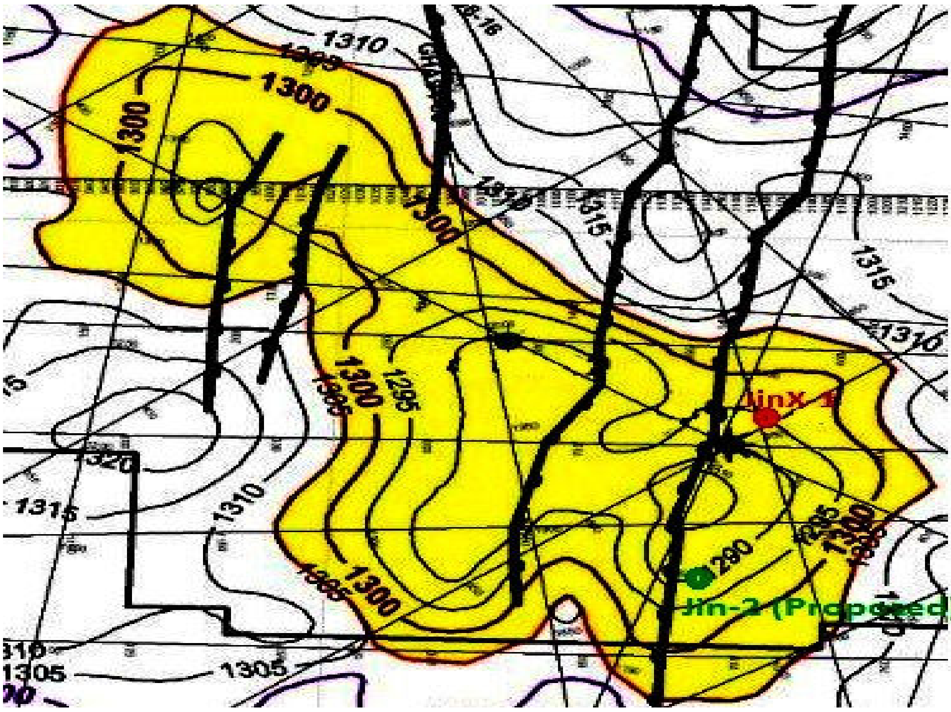

Fig. 3 Depth Structure Map of Jin Gas Field with proposed location of Jin-2 Well

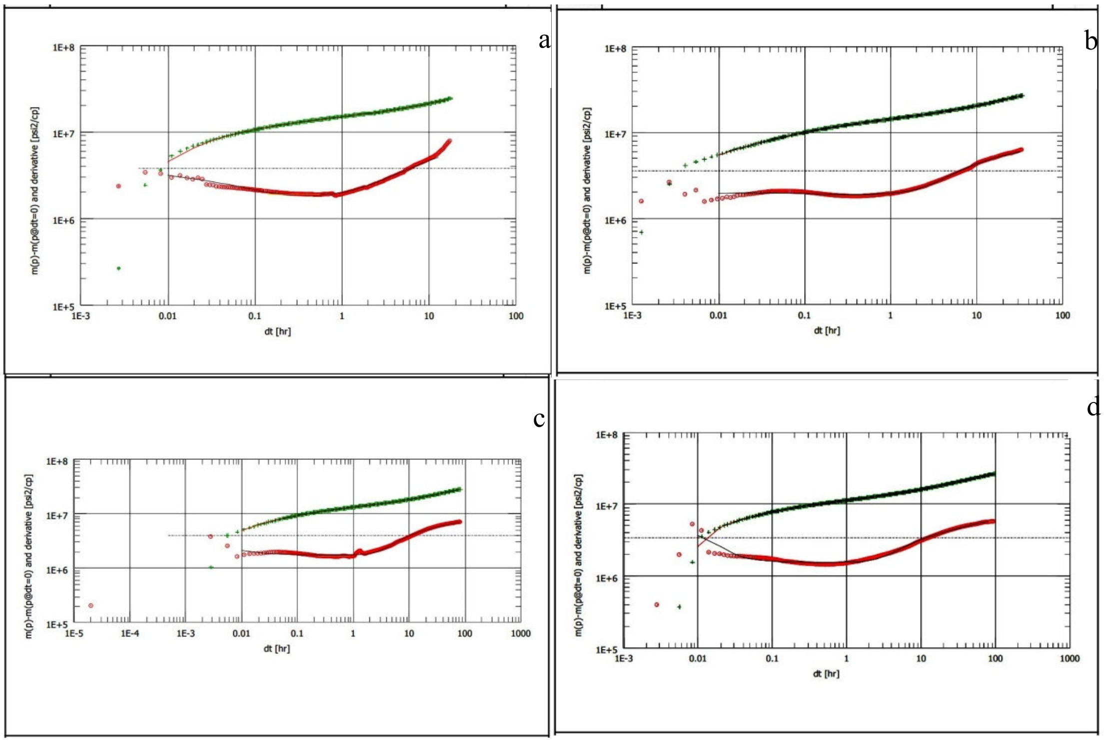

Fig. 4 Pressure Derivative Log-Log Plots of pressure surveys of the years 2011, 2012, 2013 and 2015 as (a), (b), (c) and (d) respectively

III. Results and Discussions

As mentioned earlier, for further field development the second well (Jin-2) was proposed on the south of the JinX-1 well on the basis of G&G data due to a larger area of reservoir in that direction but one of well test analysis showed boundary between currently producing JinX-1 well and proposed Jin-2 well. Since this boundary has no evidence on seismic cross section due to probably noisy data, sub-seismic fault or some heterogeneity. Therefore, this study was focused to model fault/boundary distances from the currently producing JinX-1 well and to verify the results of these well test analyses through the other tools of Reservoir Engineering.

JinX-1 well was put on production in April 2010 and since then five pressure surveys have been carried out including DST in 2006 and annual pressure surveys in year 2011, 2012, 2013 and 2015 periodically.

Figs. 4 (a)-(d) show good match of pressure derivative log-log plot of pressure surveys of the years 2011, 2012, 2013 and 2015 respectively. Linear derivative analysis was performed in the log-log plot to identify and separate reservoir effects from wellbore effects. Normally reservoir effects do not show an increase in the primary pressure derivative. A method used to differentiate between reservoir and wellbore effects was the first derivative theory that states that the slope of this derivative is going to go down, always we had a reservoir effect and up with a wellbore effect. The pressure derivative application to gas well test analysis involves the combined use of existing type curves in both the conventional dimensionless pressure form and the new dimensionless pressure derivative grouping. Thus, this new approach has combined the most powerful aspects of the two previously distinct methods into a single-stage interpretive plot. Use of the pressure derivative with pressure-behavior type curves reduces the uniqueness problem in type curve matching and gives greater confidence in the results [6]. Features that are hardly visible on the Horner plot or are hard to distinguish because of similarities between are reservoir system and another are easier to recognize on the pressure-derivative plot.

The results were calculated using log-log method are validated with semi-log method having good match as shown in Fig. 5. Figs. 5 (a)-(d) are semi-log plots (straight line analysis) belong to years 2011, 2012, 2013 and 2015 respectively.

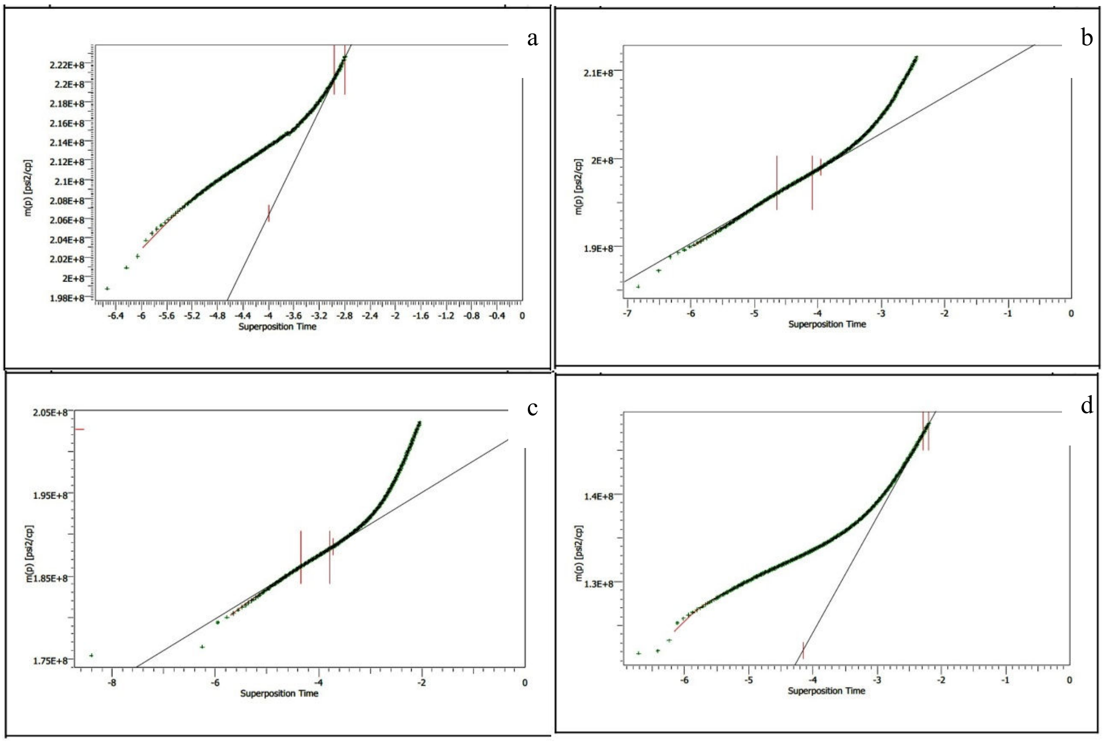

Fig. 5 Semi Log Plots of pressure surveys of the years 2011, 2012, 2013 and 2015 as (a), (b), (c) and (d) respectively

It is necessary to use numerical simulation techniques to extend well test analysis to complex geometries [3]. This is the main aim of the Numerical Linear Model together with the ability to add any number of interfering wells and fault patterns. Figs. 6 (a)-(d) show the numerical simulation model of pressure surveys of the year 2011, 2012, 2013 and 2015 of Jin Gas Field respectively.

Summary of results of the pressure surveys are shown in Tables I and II. First column of both the tables comprises of Initial reservoir pressure, extrapolated pressure, permeability thickness, skin factor, distance of No Flow boundaries in South, East, North and West directions whereas further columns show calculated values of these parameters of different years through different methods. These Well Test Analyses showed reasonable outputs. All the results are in agreement to each other but to further verify these results, Material Balance with aquifer modeling was also carried out by using these results of Tables I and II. This gave a high confidence level on result of well test interpretation of Jin Gas Field because Material Balance estimation with aquifer modeling is also validated by history matching process. Only after history matching, an accurate aquifer model and correct estimation of Initial Gas In-Place can be achieved. Hence this study also provides a methodology and algorithm in order to evaluate an oil and gas field on the basis of well test analyses.

The main purpose of way out provided in this study to verify and validate the results of each tool of reservoir engineering on the basis of other tool in order to obtain more accurate results.

The graphical representation of Material Balance Equation can be used to detect the presence of water influx, as shown in Fig. 7 (a). When the plot of p/Z vs. Gp deviates from the linear relationship, it indicates the presence of water encroachment. The Cole plot as shown in Fig. 7 (b) is a useful tool for distinguishing between water drive and depletion drive reservoirs [4]. The plot is derived from the generalized MBE as given in an expanded form by (1) as:

$$\frac{G_p B_g + W_p B_w}{B_g - B_{gi}} = G + \frac{W_e}{B_g - B_{gi}} \quad (1)$$

Or in a compact form by (2) as:

$$\frac{F}{E_G} = G + \frac{W_e}{E_G} \quad (2)$$

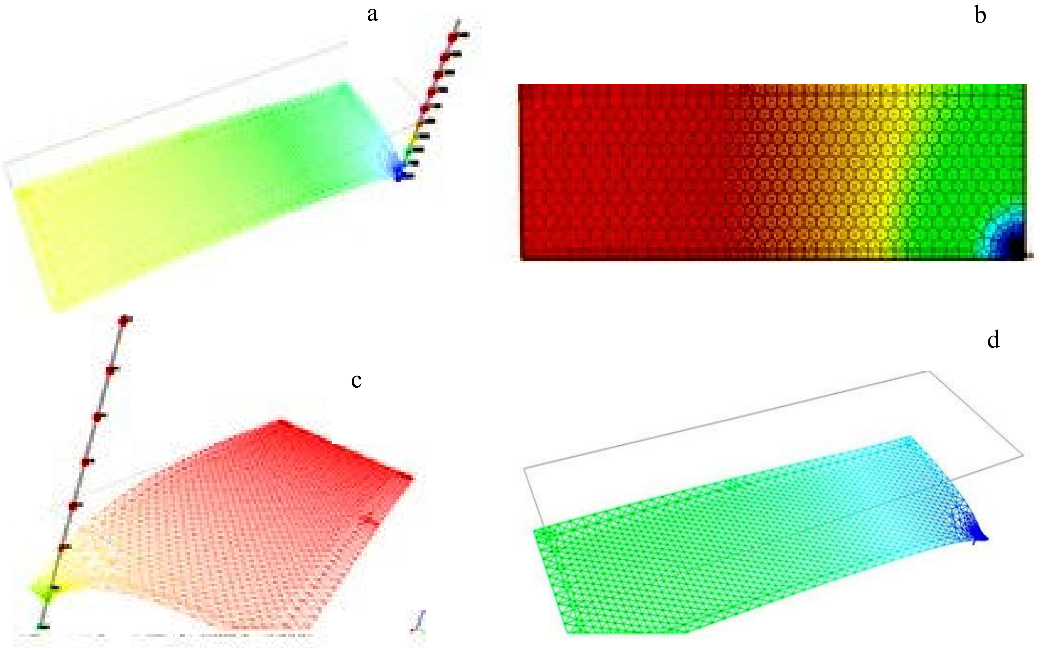

Fig. 6 Numerical Simulation Models of pressure surveys of the years 2011, 2012, 2013 and 2015 as (a), (b), (c) and (d) respectively

TABLE I
SUMMARY OF WELL TEST INTERPRETATION RESULTS OF YEARS 2011 AND 2012

Properties		Year 2011			Year 2012		
		Log-Log Method	Semi-log Method	Numerical Model	Log-Log Method	Semi-log Method	Numerical Model
Pi	Psia	2002	-	1995	1926	-	1900
P*	Psia	-	1968	-	-	1911	-
k.h	md-ft	3220	3350	3600	3550	3880	3490
Skin	-	-2.0	-2.8	-2.2	-2.8	-3.0	-2.9
S – No Flow	ft	610	570	595	550	590	513
E– No Flow	ft	380	312	390	419	375	395
N– No Flow	ft	7400	7390	7220	7500	7420	7600
W–No Flow	ft	23000	22000	22500	21500	23000	22200

TABLE II
SUMMARY OF WELL TEST INTERPRETATION RESULTS OF YEARS 2013 AND 2015

Properties		Year 2013			Year 2015		
		Log-Log Method	Semi-log Method	Numerical Model	Log-Log Method	Semi-log Method	Numerical Model
Pi	Psia	1882	-	1880	1812	-	1816
P*	Psia	-	1866	-	-	1825	-
k.h	md-ft	3800	3670	4000	3500	3490	3420
Skin	-	-2.1	-3.6	-2.8	-2.47	-2.9	-2.3
S – No Flow	ft	610	535	518	533	590	566
E– No Flow	ft	405	380	390	340	400	375
N– No Flow	ft	7400	7480	7500	7500	7490	7200
W–No Flow	ft	22500	22000	22200	22000	21525	21000

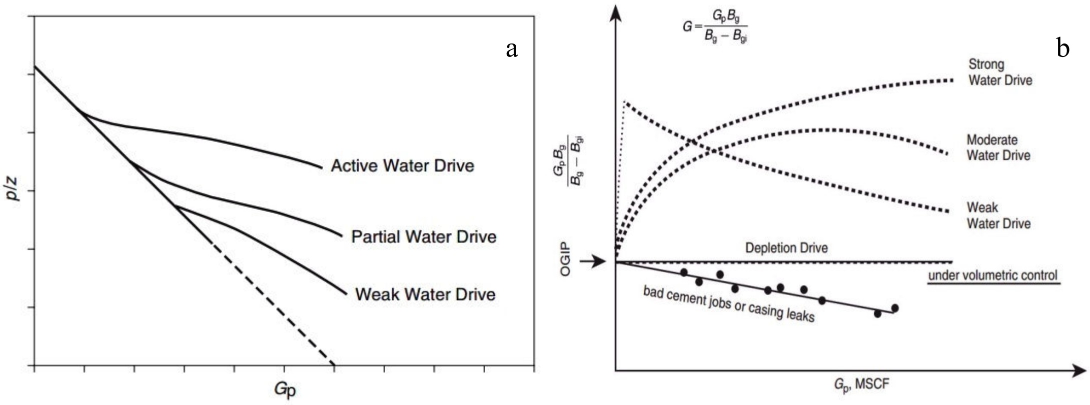

Fig. 7 Reservoir Drive Mechanism Diagnostic Plot, MBE Plot (a), Cole Plot (b), Extracted from Reservoir Engineering Handbook by Ahmed Tarek

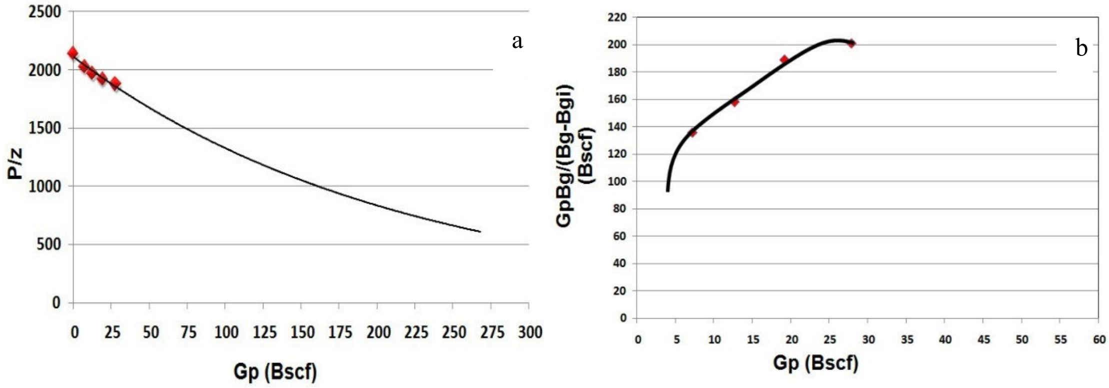

Fig. 8 Reservoir Drive Mechanism Diagnostic Plot of Jin Gas Field, (a) MBE Plot, (b) Cole Plot

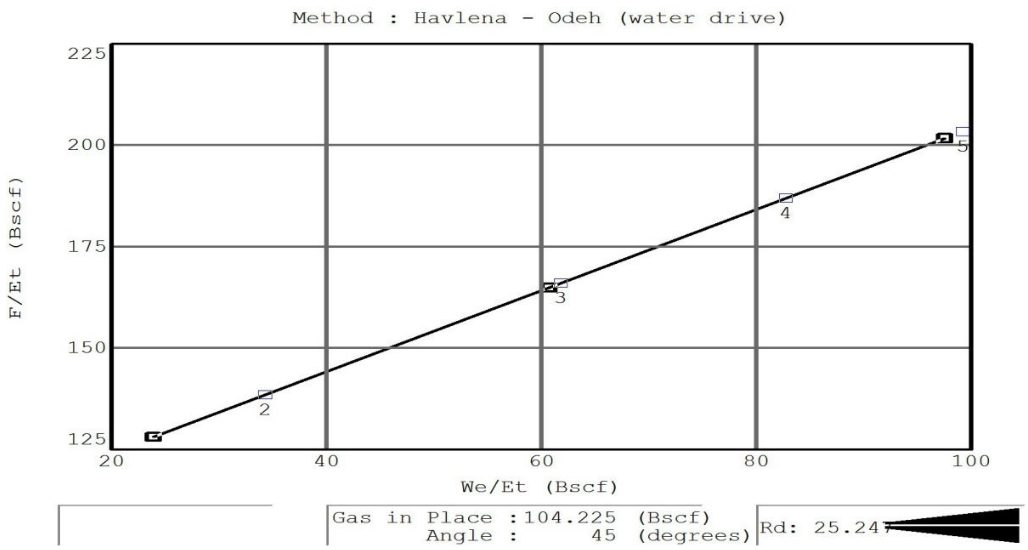

Fig. 9 Havlena–Odeh Plot of Jin Gas Field

To investigate the reservoir drive mechanism, diagnostic plot was generated first. i.e. P/Z Vs Gp and Cole Plot of Jin Gas Field as shown in Fig. 8 (a) and (b) respectively).

The reservoir drive mechanism diagnostic plot of Jin Gas Field indicates external support of energy to the reservoir or in other words presence of water drive mechanism. The degree of pressure maintenance through aquifer support can be predicted through shape of Cole plot (Fig. 8 (b)) which translates strong to moderate water drive. But there is no water production on surface since the well come on production before five years. Only a very little volume of water has been produced which is condensed water as per laboratory analysis reports. Hence Material Balance with accurate aquifer modeling was necessary to know the strength and geometry of aquifer in order to propose direction of well location correctly [8].

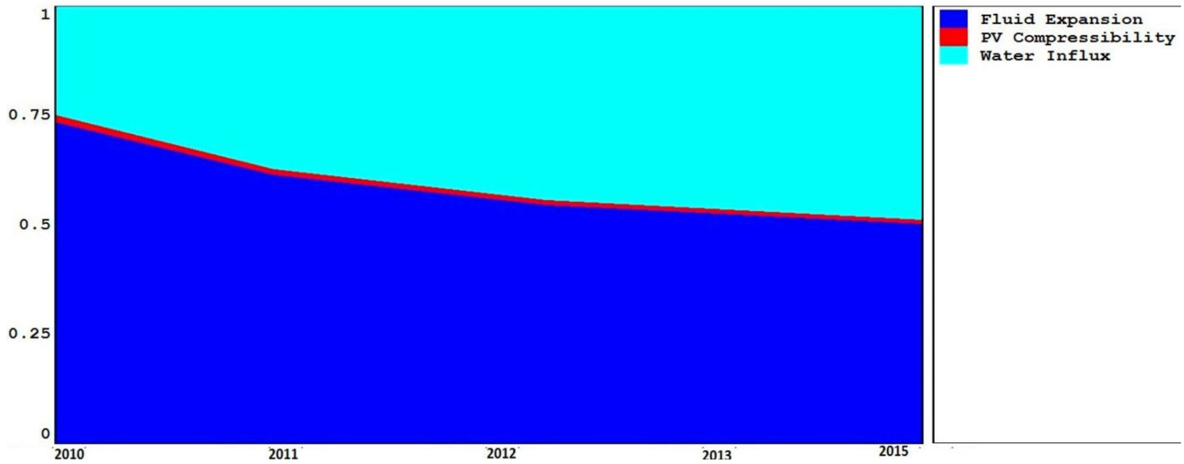

Fig. 10 Drive Indices Plot of Jin Gas Field

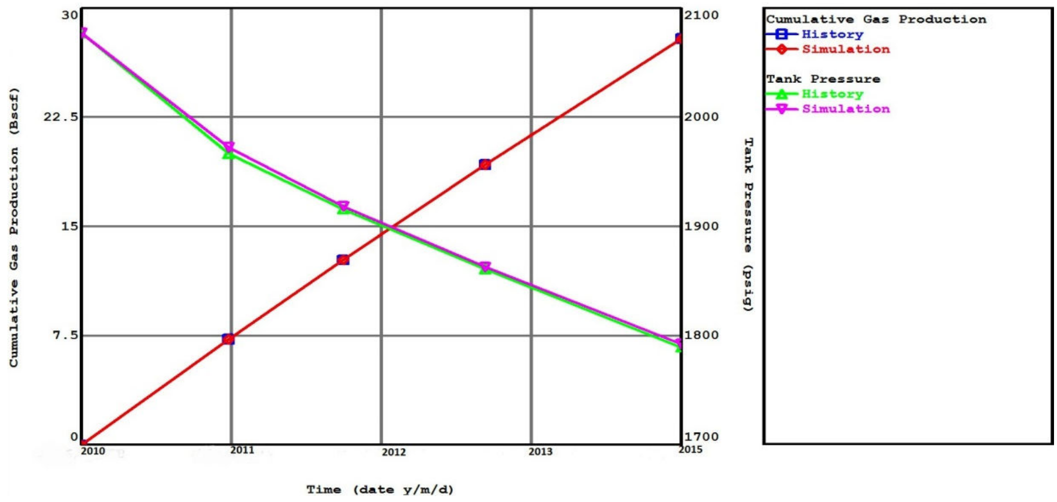

Fig. 11 History Matching Plot of Jin Gas Field

Fig. 10 confirms the water drive mechanism with the drive indices. Figs. 9 and 11 show good match whereas in Fig. 12, the calculated pressure and water influx are also plotted which verified our results and outputs and increased the level of confidence on well test results.

The Initial Gas In-Place calculated by Material Balance is also verified by Volumetric Reserve Estimation Method which gave the same result as MBE. Volumetric Method uses static properties of the reservoir and Material Balance Method is the dynamic model of the reservoir [2]. The results from both methods are in agreement which indicates the Well Test results of Jin Gas Field are accurate so if there is missing in seismic data processing or interpretation then we should also integrate the well test analyses in decision making in field development specially in marking the well location for development wells. After going through this working algorithm, we can add one more boundary (which may be fault or any properties bearer) in South direction near the well JinX-1 as shown in Fig. 13. This fault/boundary was absent in seismic interpretation due to may be of some noisy data [1], [5]. That is why no boundary or fault was mentioned on depth structure map of Jin Gas Field (Fig. 1).

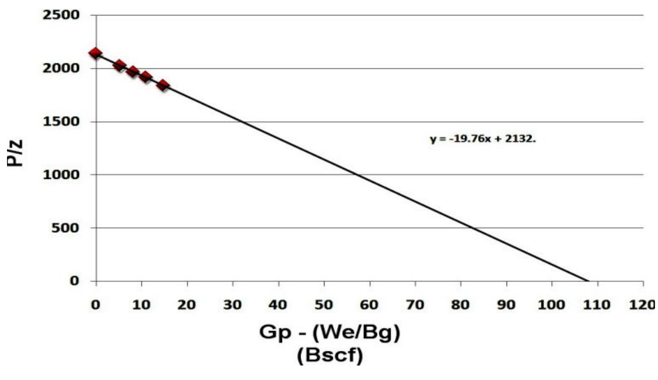

Fig. 12 MBE Plot (after incorporating water influx) of Jin Gas Field

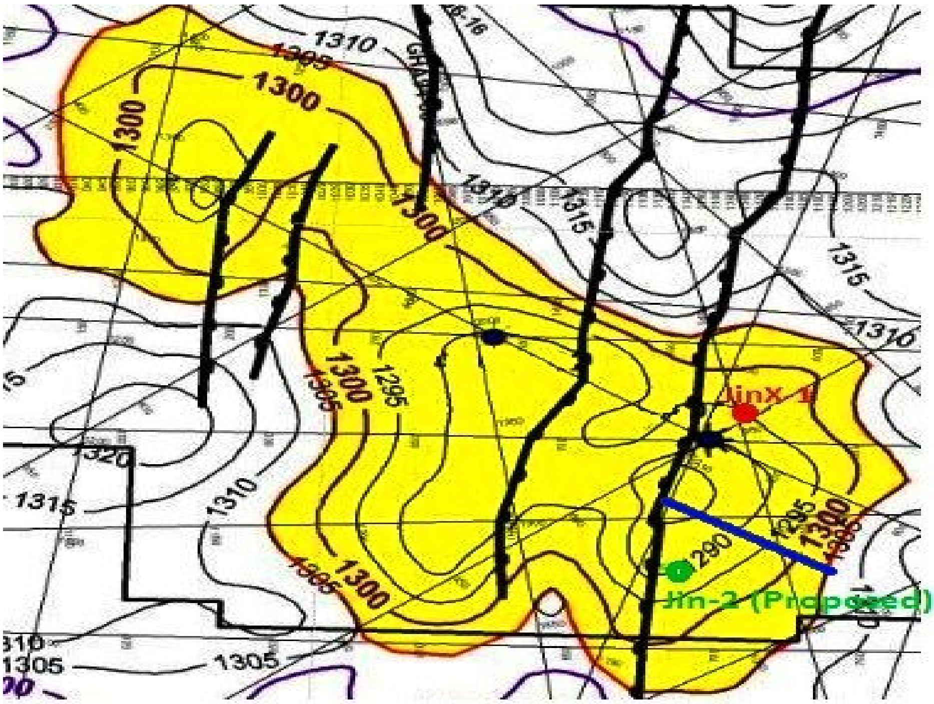

Fig. 13 Depth Structure Map of Jin Gas Field with proposed location of Jin-2 Well and boundary in South direction (highlighted in Blue color) after well test analyses

IV. Conclusion

Hence the ambiguity regarding well location which was marked only on Geological and Geophysical data can be cleared now by looking at the well test analyses which are verified by Material Balance and History Matching. As Per Well Test Interpretations of Jin Gas Field South no flow boundary is being detected repeatedly along with another boundary in the East. The distances of the boundaries from the well bore are in the range of 500ft to 610ft for South and 300ft to 405ft for East (Tables I, II). If we did not integrate the results of well test with G&G Interpretation, the proposed location in the South direction remained valid. The one of the reason of going towards South was the structural high. In Fig. 1, can be seen that present Well (JinX-1) has top of the reservoir at 1290m whereas proposed location of Jin-2 at South was at 1285 m means 5m additional reservoir thickness. But the presence of boundary between the present well and new proposed well would be resulted in different results from the current well. Since this proposed well Jin-2 is a development well so it should be in the same pool like the present well (JinX-1). If the development well Jin-2 is drilled beyond the no flow boundary it might be a dry well. Therefore, well testing played a crucial role in development of Jin Gas field. Integration of well test interpretation results with the G&G results gave a clearer picture of the reservoir.

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