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Conditioning of Effective Permeability with Well Test Permeability Improves the Geostatistical Reservoir Characterization: Real Test Case Evaluation.

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Abstract-*Geostatistical Reservoir Characterization is nothing but the realistic modeling of petrophysical properties using different sources of data such as well test and well log permeability. Well test cast information at dynamic conditions for a large volume. However, well log estimates at static condition for a small volume but provides high resolution. A series of petrophysical realization is generated using only well log data of a Norwegian Oil field. Integrating well test and well log information, several petrophysical realization suites have been modeled. The conditioning method uses an inverse block co-kriging of both log and well test data, and a Fast Fourier Transform to speed up the calculations. The dynamic responses of realizations are evaluated with the buildup pressure and layer's rate profile recorded by Production Logging Tool (PLT) of the three real wells of the oil field. Each of the realization is input into the full field simulation model followed by inserted into the three six layered numerical well test models to simulate drawdown rate and buildup pressure responses as actual test. All pressure responses are matched with the real pressure profile for primary screening. Following, layers' inflow profiles of the pressure matched realizations are examined with the real layers' inflow profile. The average success rates are 72.22% and 27.22% for the well test and well log conditioned models respectively. Well test suite achieved 30.56% average improvement in layers' inflow over the well log suite. Well test conditioned permeability model results realistic and reliable performance, hence capable of predicting real like and worthy reservoir characteristics.*

Keywords: Reservoir Characteristics, Co- Kriging, Petrophysical realizations, Pressure signature, Inflow.

1. INTRODUCTION

Dynamic data such as well test is included along with static data such as well log and core analysis for modeling petrophysical properties of petroleum reservoir in order to the precise history matching which indicates the improve reservoir characterization and accuracy level in forecasting will be high. Well testing provides information regarding the effective permeability of flowing fluids within the established large drainage volume around the well being tested in reservoir. In addition well log estimates permeability for small volumes of formation in the well test drainage regions yielding high resolution data. Therefore, well test interpreted permeability is considered as average of all well log permeability data within the well test investigated zone.

Including well test effective permeability in geostatistical modeling of petroleum reservoirs means combining data from different sources in order to improve the quality of the geological representation of the reservoir. All data contain some error measurements. Consequently, data used to condition geological models of petroleum reservoirs should be associated with an uncertainty. This is necessary when combining different sources of information since the different data may be in conflict with each other. This is important to consider when the permeability data from well tests and well logs are used concurrently in the geostatistical conditioning of the permeability field.

In the real case test described here, the uncertainty levels are estimated and assigned the well log and well test data. Various levels of this parameter uncertainty are chosen to investigate the sensitivity on the resulting flow simulation responses. By comparing the dynamic flow simulation response from the geostatistical realizations with and without conditioning on the well test effective permeability, the effect of the well test permeability conditioning is evaluated.

2. PERMEABILITY CONDITIONING METHOD

If a permeability field k is defined on a grid cell of location u, a Gaussian random permeability field $k(u)$ honoring only well log data can be obtained by kriging on the observed well log measurements.

Well test investigation measures the effective permeability field around the well which can be denoted $K(u)$. It is an averaged, or convolved, version of the permeability field k(u) since it measures the true effective permeability over several grid cells in the vicinity of location u in investigated zone for a convolution filter f. Then,

$$K(u) = \int f(u-v)k(v)dv \text{..............................(1)}$$

Since the horizontal permeability normally is much higher than the vertical permeability and infinite acting radial flow develops during the well testing, then the filter is proportional to $1/|u - r|$ for the radial distance r from the well location u.

When there are n permeability log observations in vector k_{obs} and p well test effective permeability in vector K_{obs}, the inverse block kriging equation can be used to ensure that a simulated realization honors both well data.

$$k^*(u) = \hat{m}(u) + \left[c_{obs}(u)\ \bar{c}_{obs}(u)\right] \begin{bmatrix} C_{obs} & \bar{C}_{obs} \\ \bar{C}^T_{obs} & \bar{\bar{C}}_{obs} \end{bmatrix}^{-1} \begin{bmatrix} k_{obs} - \hat{m} \\ K_{obs} - \hat{M} \end{bmatrix} \text{....(2)}$$

Where $\hat{m}, \hat{M}$ are vectors of the expected permeability *(E[k(u)])* in the n permeability log locations, and expected effective permeability *(E[K(u)])* in the p well test observation locations respectively. The covariance vectors are defined as

$$c_{obs}(u) = Cov(k(u), k_{obs})\ and\ \bar{c}_{obs}(u) = Cov(k(u), K_{obs})$$

while the covariance matrices of the observation data are

$$C_{obs} = Cov(k_{obs}), \bar{C}_{obs} = Cov(k_{obs}, K_{obs}), \bar{\bar{C}}_{obs} = Cov(K_{obs})$$

If the standard deviation of the permeability field in the well test region $\sigma(u)$ can be approximated by the standard deviations in the center cell of the convolution, a significant decrease in the number of computations is obtained. Then,

$$\bar{C}(u,v) \approx \sigma(u)\sigma(v) f(u) * \rho(\|u-v\|) \quad \text{and}$$

$$\bar{\bar{C}}(u,v) \approx \sigma(u)\sigma(v) f(u) * f(v) * \rho(\|u-v\|)$$

Where $\rho(u)$ is the correlation function. To simplify further, the kriging equation is transformed into the Fourier domain where the convolutions are reduced to computational much faster multiplications. More details are found in Skorstad[2] *et al*. (2008).

3. CASE STUDY

In Norwegian Sea most of the oil and gas fields consist of several geological formations for instance 'Kritt', 'Viking', 'Garn', 'Ile', 'Tilje ', of which the 'Ile' formation has been selected for this study. A oil field of Norwegian Sea has six layers of 'Ile' formation, Ile-6, Ile-5, Ile-4, Ile-3, Ile-2 and Ile-2.1 which are found suitable as a real test case for the proposed methodology. The area under study has 26 wells with porosity and permeability logs. Three of these wells also have effective permeability extracted from the kh-product of the well test interpretation, see Figure 1 for their locations on an outline picture of the reservoir.

The oil field provided an existing petrophysical model used to generate a benchmark suite of dynamic responses. Each suite consists of twenty (20) stochastic porosity and permeability realizations conditioned on the well log data only. The petrophysical model was then augmented with the proposed well test permeability conditioning to generate new six (06) suites; each has twenty (20) stochastic realizations. All realizations were fed into the full field simulation model in order to compare the dynamic responses of the petrophysical realizations.

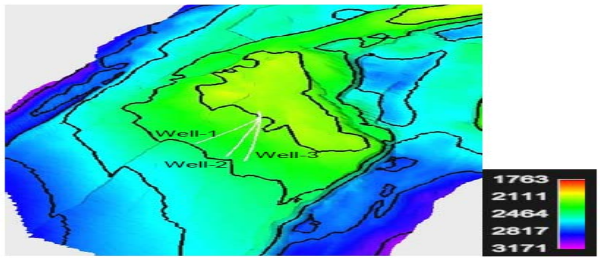

Fig.1: Top map of Ile formation with wells extending 8.00 km in E-W and 10.00 in N-S direction.

3.1 Parameter Settings

Since the well test and the well log permeability are co-located along the well trajectory, and both are used to condition the reservoir description on the geomodeling, they must be understood as data with uncertainties, see also Ringrose[1] . The well test data is on a coarser scale, and the well log data is from a more detailed resolution, although they are routinely taken as exact data on the scale of geomodeling. The well test scale can be understood as the size of the radius of investigation of the well test. This corresponds to the range of the variogram when conditioning the well test permeability in the kriging equation. To investigate how sensitive the algorithm is to these quantities several suites with varying well test permeability parameters were tested. Based on the input data, both a default range and a default uncertainty of the well test permeability were estimated. The coefficient of variation (standard deviation/average) was used as the uncertainty measure. Thereby, the internal, relative changes within a layer are emphasized. This dimensionless measure is convenient since the geostatistical conditioning is done in the Gaussian domain, after a transformation sequence from the actual permeability distribution. To investigate the sensitivities of the well test parameters, also a higher and a lower parameter value were included in the tests. The high and low uncertainties were taken as twice, and half the default values, respectively, while the low and high ranges were chosen to be two standard deviations lower and six standard deviations higher, respectively. All estimated uncertainty and range parameters are found in Table 1 and Table 2. The well log permeability uncertainties estimated from all 26 wells were kept fixed in the test suites as the focus here was primarily to test the well test permeability sensitivity.

Table 1: Uncertainty in well log & well test permeability in Ile formation layers.

Layers	Uncertainty in Well test permeability			Uncertainty in Well log permeability
	Low	Default	High	
Ile-6	0.18	0.36	0.71	0.64
Ile-5	0.14	0.27	0.55	0.68
Ile-4	0.11	0.22	0.44	0.84
Ile-3	0.28	0.57	1.13	1.91
Ile-2	0.23	0.46	0.92	1.29
Ile-2.1	0.42	0.85	1.69	1.42

Table 2: Range in well log & well test permeability.

Layers	Range in Well test permeability			Range in Well log permeability (meter)
	Short (meter)	Default (meter)	High (meter)	
Ile-6	475	773	1668	1500
Ile-5	446	587	1011	1500
Ile-4	289	369	610	1500
Ile-3	249	249	366	1500
Ile-2	409	800	1974	1500
Ile-2.1	249	251	1237	1500

Since the radius of investigation will be larger for high permeable layers, the extent of the conditioning area of such layers will also be larger. To isolate the effect of the well test conditioning, all stochastic realization suites were initiated with the same seed. This means that the simulated noise field is the same in corresponding realizations across the suites, and that the only difference is the kriging.

3.2 The Petrophysical Realizations

Combining different setting of uncertainty and range in Permeability seven suits of petrophysical realizations has been developed shown in Table 3, each group contains twenty permeability fields.

Table 3: The Modeled Petrophysical Realization Suites.

Realization No.	Suite Name	Conditioned Data	Uncertainty in Permeability	Range in Permeability
1-20	Benchmark Suite	Well log	Well log	Well log
21-40	Mean Value	Well log & Well Test	Default	Default
41-60	Small Uncertainty	Well log & Well Test	Low	Default
61-80	High Uncertainty	Well log & Well Test	High	Default
81-100	Short Range	Well log & Well Test	Default	Short
101-120	Long Range	Well log & Well Test	Default	Long
121-140	Serial Simulation	Well log & Well Test	High	Long

The effect of the well test conditioning is shown in figure 2 at Ile-6. The change in permeability is large in the near well regions, but notice that the effect is not as large in the cells containing the well trajectory, since the realization also is conditioned to the well log data there. On average the permeability is reduced, since the well test permeability is lower than the well log data.

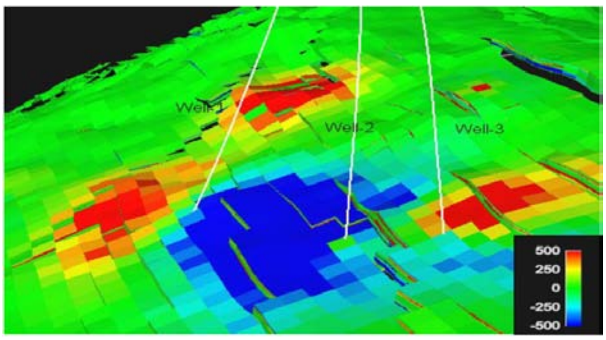

Fig.2: Changes in permeability after well test conditioned at Ile-6.

Note the effect north of the three shown wells. The permeability in and around another well location is also changed since the well log permeability data now are associated with an uncertainty.

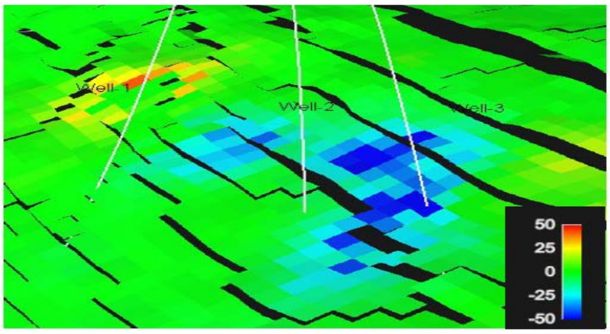

Fig.3: Changes in permeability after well test conditioned at Ile-3 formation around the wells.

Figure 3 shows the permeability change due to the well test conditioning in the low permeable Ile 3 formation. The well log and well test permeability in Well-1 are in good correspondence. A detailed look at the well log permeability reveals that the well log in this layer is considerably higher than the adjacent well log values above and below, and also higher than the well test permeability. Consequently, when the stochastic realization is generated, the uncertainty on the data in this layer leads to a decreased permeability, both in and around the well.

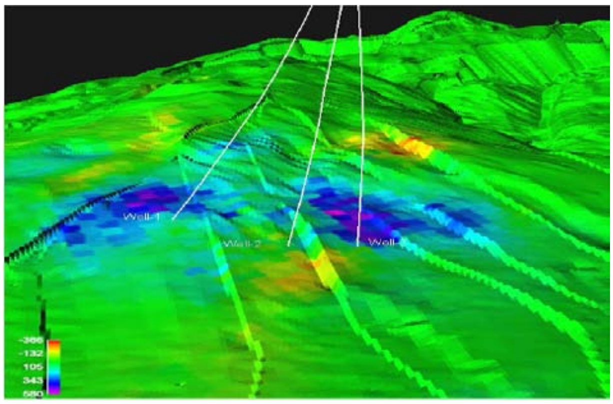

Fig.4: Average changes in permeability after well test conditioned at top of structure around the wells.

4. EVALUATION METHODOLOGY

Altogether one hundred forty (140) realizations will be examined by matching of simulated well test pressure and inflow profiles with real well test pressure and inflow profiles. The realizations contain PERMX, PERMY, PERMZ and PORO data for the grid cells around the investigated wells zone of the full field dynamic model which has been run including the realizations to generate initial properties of the grid blocks of the field. The initial grid properties, layers and wells trajectory information are integrated to model Perm-X, Perm-Y, Perm-Z and Porosity map for the six layers numerical PEBI (Perpendicular Bisector) well test models in figure 5. for the each of three wells.

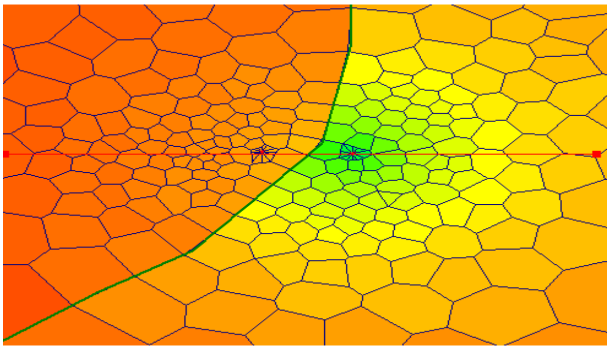

Fig.5: Numerical PEBI well test model.

4.1 Pressure & Inflow Profile Evaluation

In petroleum industries, two major types of field data such as i) Pressure Profile and ii) Rate Profile are highly considered as evaluating parameter for properties and full field simulation models in terms of representing real filed. A complete well test investigation data of three wells is available for this evaluation. In all test a drawdown period followed by a pressure build up period has been performed. The recorded rate profile in each layer during drawdown period and the interpreted pressure signature during build up period has been selected as matching parameters. The interpreted pressure build up test generates full test, linear plot, Horner plot and diagnostic plot. As per the real reservoir structure, a the six layers PEBI numerical well test simulation Model of 1500 meter radius has been constructed for each of the concerned three wells. The permeability maps are input into the layers of the numerical well test models and simulate well test as per the real well test to generate the rate and pressure profiles curves.

Altogether four hundred twenty (420) well test runs have been completed on three modelled wells using one hundred twenty (120) realizations. The simulated pressure profiles are matched with real pressure build up test curves to illustrate the comparison in terms of well test permeability between the only well log conditioned suite and well test conditioned suites. The simulated well test permeability of three wells for one hundred forty (140) realizations has been normalized with corresponding well test interpreted permeability.

$$K_{nor} = \frac{K_{actual\ well\ test\ permeability}}{K_{simulation\ well\ test\ permeability}} \quad (3)$$

Unit value of K_{nor} provides the best match with the real field data yielding more realistic petrophysical properties models describing accurate reservoir characteristics. When K_{nor}<1.0, it describes the simulated permeability field has over value and when K_{nor}>1.0 it describes the simulated permeability field has under value, both cases present poor reservoir characteristics.

Uncertainty is inherent nature of data sources using for modelling realizations, naturally some pressure profiles of realizations perfectly matched i.e. normalized permeability is unit and some will deviate. Afterwards, the realizations yielding perfectly matched pressure response become candidates for next screening by real inflow profile in layers recorded by PLT during drawdown period of well test.

In the concern zone of well-1 the simulated well test permeability is normalized by real well test interpreted permeability 1315 mD. The normalized permeability is plotted against realizations shown in figure 6.

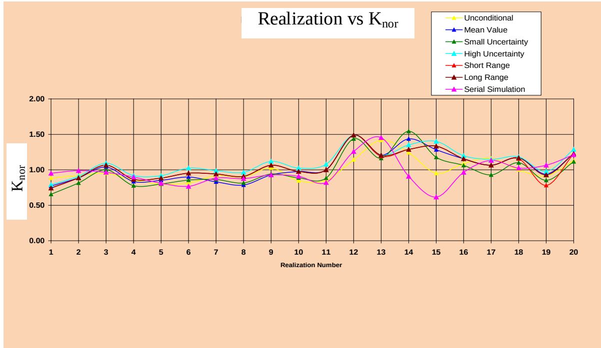

Fig.6: Normalized Permeability vs Realizations ;well 1.

The normalized permeability of realizations 18, 31, 43, 91&111 show unit value in figure 6. The simulated diagnostic plot of these realizations perfectly matched with the field curve in figure 7.

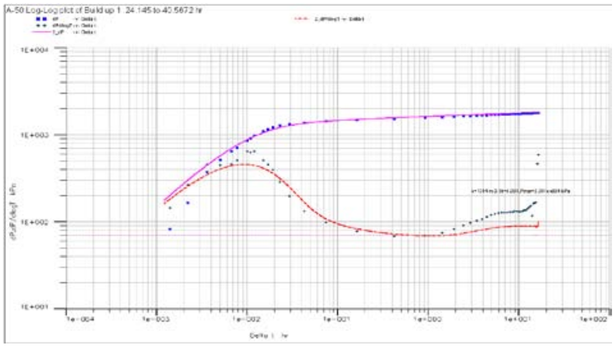

Fig.7: Simulated diagnostic plot with field curve of well-1 for realization no. 18,31,43,91&111.

The matched permeability models are treated as the representative of the real field. However, only pressure responses matched model may yield large uncertainties in future decisions. In light of making more accurate reservoir characterization, it will be good practice, if the pressure responses matched models are crosschecked with the rate responses if data is available.

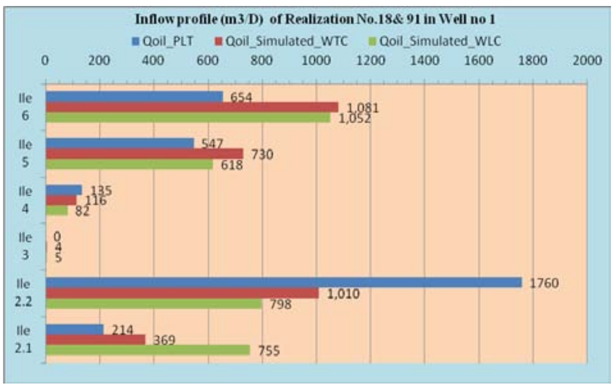

Fig. 8: Layer's Inflow Profiles in well 1:Observed and Realization no. 18 & 91.

Among 140 realizations, only one well log conditioned permeability field and four well test conditioned permeability models matched with field pressure curve. Individual layer's rate profile is available for further examination. The observed inflow profile is recorded for each of the layers using PLT during drawdown period before buildup, accordingly the well test simulated inflow profile of realization no. 18 & 91 in figure 8.
Although, the total flow rate, 3310 m^3/d at 14.4 hrs, is the same for the observed, well test conditioned and well log conditioned realizations cases. Different happenes in individual layer's infolw profile indicating the properties models quality. In Ile-4, Ile-3, Ile-2.2 and Ile-2.1 layers the well test condition inflow responses provides better matching than the well log consitiones profile with the observed rate. However, well test condition profile shows poor match in Ile-6, Ile-5 layers. Overall success for well test conditioned suite is 66.66%, where as 33.33% success is achieved by the well log conditioned suite. From this analysis for the case of well-1, incorporating well test data along with well log information in petrophysical properties modeling yields more realstic models which represents accurate reservoir characterstics.
The well test interpretation of well-2 results 800.6 mD permeability in the volume around the well. The numerical well test permeability is normalized with real permeability where only one well test conditioned realization shows unit value in figure 9 and perfectly matched with the real pressure responses in figure 10.

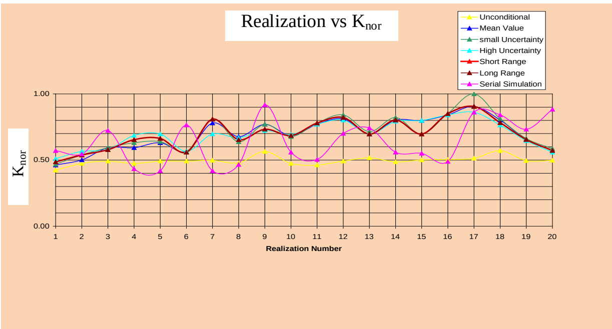

Fig.9:Normalized Permeability vs Realizations; well 2.

All realizations are modelled using over value reflected in figure 9, accept a well test conditioned realization. The reflection is continued in diagnostic plot. Further examination on realizations has been carried out by layers inflow profile information, figure 11.

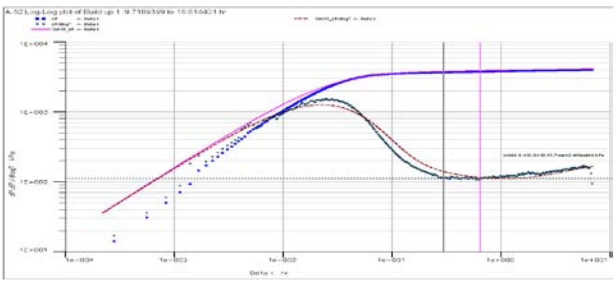

Fig.10: Simulated diagnostic plot with field curve of well-2 for realization no. 57

The well test conditioned suite improves in Ile-5, Ile-4, Ile-3 and Ile-2.1 layers out of six layers, here also the success rate is the same as the well-1. In Ile-3 the well log suite simulates a unrealstic inflow profile which is statistically treated as noice in data. Conditioning with well test data during permeability field modeling will eliminate noice.

Fig. 11: Layer's Inflow Profiles in well 2: Observed and Realization no. 01 & 81.

However, 30% over rate is simulated by the well test conditioned permeability model with respect to the observed rate in Ile-2.2 layer but this deviation is within the tolerable limit. In well-2 case the overall performance of well test information is unlikely well-1 but comparatively improve the characterization over the well log information. Further analysis with other wells in the field will provide more comparative scenarios.

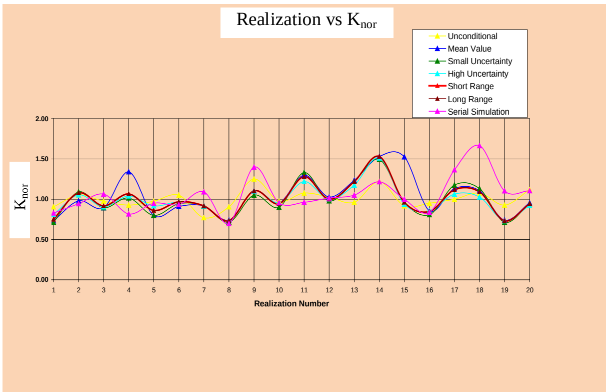

Fig.12:Normalized Permeability vs Realizations ;well 3.

In light of previous analysis, the result of well-3 is shown in figure 12. Only one well log conditioned realization and two well test conditioned realization yield unit value in terms of normalized permeability determined by real well test estimated permeability 1033 mD. The simulated derivative plots of these realizations precisely matched with the field diagnostic plot in figure 13.
In the diagnostic plot the derivative curve becomes flat at infinite acting period when a full radial flow pattern is developed into the drainage volume around the testing well. At that moment the pressure signature cast the permeability information of the drainage volume.

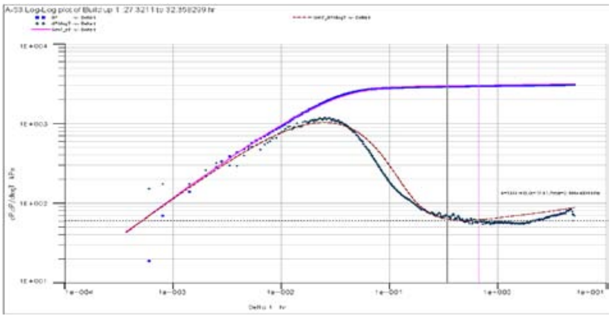

Fig. 13: Simulated diagnostic plot with field curve of well-3 for realization no. 17, 92&112

The numerical well test model performed the same function as the real test and simulated well test permeability. The above permeability fields in the well test model yielded the exact well test permeability as the real; hence these realizations may be considered as reliable models to describe the formation characteristics. However, a single parameter matching provides less reliability than the multiple parameters matching. The pressure responses screened realizations are further examined with the rate signature to find out the real representative models of the reservoir. The rate responses screening is illustrated in figure 14.

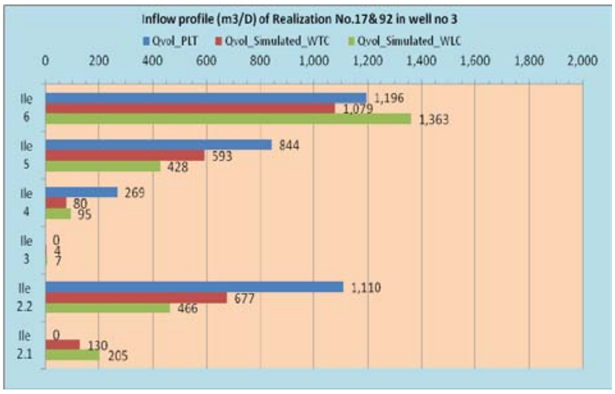

Fig. 14: Layer's Inflow Profiles in well 3: Observed and Realization no. 17 & 92.

After pressure profile evaluation, in the rate profile screening the scenario of well test realization performed better results than the past two cases. Inflow profile of well test condition model improves in Ile -6, Ile-5, Ile-3, Ile-2.2 and Ile-2.1layers except Ile-4 where a small deviation is observed over well log conditioned model. Overall success for the well test condition permeability field is 83.33%, whereas well log permeability field scores only 16.66%. Well-3 continues with the same trend as previous but obtained more improvement.

5. RESULTS & DISCUSSION

The inherent characterstics of nature is that, incorporation of additional consistent information in any model will improve the quality of model in terms of reality and reliability, which has been achieved in this study by including the real well test permeability information in the modeling of the permeability field of the reservoir. Statistical analysis of the three wells on the six layers' inflow profile matching estimates the average success rates are 72.22% and 27.22% for the well test conditioned model and well log conditioned model respectively. The average improvement rate in layers' inflow responses is 30.56% in the case of well test suite over the well log suite. Permeability field modeling plays major role in geostatistical reservoir characterization. A precise permeability map able to forecast the real behavoirs of reservoir accurately. The analysis of real presure and rate profile of three wells of the real reservoir with the sumilated presure and rate profile of three model wells of the model reservoir has established that well test conditioned suite is capable to simulate the real reservoir characteristics than the well log conditioned suite; hence improve the geostatistical reservoir characterization.

6. CONCLUSION

Reservoir characteristics is dominated by the petrophysical properties of reservoir, therefore a good petrophysical properties model exhibites reservoir behavior accuratly. A properties model will be precise if multiple relevent sources of data is included in the model rather than a single source. Here, well test realization serises are conditioned on well test & well log permeability, where only well log permeability is conditioned on well log realization serises and both are examined by dynamic behavoir. In this evaluation, the dynamic responses of both realization serises are compared with the real reservoir's dynamic profiles, obeying natural trend, the well test serises generate much better performance, approximately similar to the real performance over the well log serises.In light of well test serises performance in this study, it can be awarded to the well test realizations that these serises are capable for representing real like and reliable reservoir characteristics.

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8. REFERENCES

[1] Ringrose, P. (2008): Total-Property Modeling: Dispelling the Net-to-Gross Myth. SPE Reservoir Evaluation & Engineering, Vol 11, No. 5. SPE-106620.

[2] Skorstad, A., Georgsen, F., Abrahamsen, A. and Smørgrav, E. (2008): *Reservoir Characterization Improvement by Accounting for Well Test Extracted Effective Permeabilities.* Presented at the ECMOR XI, September 8-11, Bergen, Norway.

8. NOMENCLATURE

Symbol	Meaning	Unit
K	Well test permeability	(mD)
k	Well log permeability	(mD)
$c_{obs}(u)$	Covariance vectors	Dimensionless
C_{obs}	Covariance matrices	Dimensionless
$\sigma(u)$	standard deviation	Dimensionless
		Dimensionless