We SP3 02

Using Multiple Linear Models for Permeability Estimation and Modeling in a Well of Sandstone Reservoir

W.J.M. Al-Mudhafer (Louisiana State University) & Y. Gebrai* (Louisiana State University)

SUMMARY

In this paper, we present the multiple linear model to estimate the formation permeability at non-cored intervals as function of well logs and core measurements for a well in sandstone formation in West Africa. In Linear model, the least-squared function is used to generate the relationship between core permeability and the explanatory variables such as caliper (CCL), deep induction, gamma rays, neutron porosity, core porosity, deep resistivity, spontaneous potential (SP), corrected density, and rock facies. The resulted permeability equation has different intercept for each rock types. The linear model has been done three different ways to ensure the normal distribution for the response factor (permeability) and achieving the statistical tests. The first one is the full model that has all the independent variables with the original data. In the second one, a stepwise elimination has been used to delete the variables that don't have a significant effect on the model. A log transformation was applied in the third model to get an approximate normal transformation. To validate the linear model, t-test and ANOVA table have been considered to choose the optimal model that performs null hypothesis rejection for all the variables and the confidence interval to be greater than 95%.

Introduction

Acquiring accurate estimates of permeability is crucial to the reservoir characterization process and increasing productivity. Since the permeability of a reservoir cannot be directly measured, methods such as core analysis, well logging, and well tests are commonly used to provide estimates of permeability (Ahmed et.al, 1991).

Petroleum reservoirs are very complex structures with many layers and varying petrophysical properties. One of the most important petrophysical properties needed to understand the layering in a reservoir is permeability (Yao et.al, 1993). More accurate permeability estimates result in more realistic simulations, better well designs, and it allows for better economic decisions.

Core analysis provides data on a very small scale of a few cubic inches. Well logs provide data of a few cubic feet and well tests provide data of thousands of cubic feet of the reservoir. The different scales of each method provide varying estimates of permeability; however, the data obtained from the different methods can be correlated with each other in the linear regression modelling.

Linear Regression Modeling

Linear regression is used to model the relationship between the dependent and independent variables by fitting a linear equation to observed data. The independent is considered to be an explanatory variable, and the other is considered to be a response variable. The least squared function is used to estimate the coefficients in the regression model (Abraham and Ledolter, 2006). This function calculates the best-fitting line for the observed data by minimizing the sum of the squares of the vertical deviations (variance) from each data point to the line leading to optimal fit (Chatterjee and Hadi).

In this study, statistical approach was used to generate the relationship between core permeability and the explanatory variables such as calliper (CCL), deep induction, gamma rays, neutron porosity, core porosity, deep resistivity, spontaneous potential, corrected density and rock facies. This approach involves the use of multiple linear models and incorporates all the data acquired from a core analysis and a well test.

Results and Discussion

This study was conducted in the R statistical programming software environment and a linear model using the least squares approach was used to generate the relationship between the data from the core analysis and the well log that have been obtained from Karpur published dataset for a West Africa sandstone reservoir (Karpur et.al, 2000).

Three linear models were generated one using the full model, the next one included a stepwise elimination, and the final model was generated once a stepwise elimination and log transformation was applied to the full model. The aim was to produce an approximately normal distribution and the results were promising. This resulted in a permeability equation that has a different intercept for each rock type. Three steps were then taken in order to estimate the normal distribution for the response factor (permeability) and for running the statistical tests. The first step was to run the full model that included all the independent variables with the original data. In the second step, a stepwise elimination was used in order to delete the variables that do not have a significant effect on the model. This step was followed by a log transformation in order to produce an approximate normal distribution. To validate the linear model, a t-test and ANOVA table were considered in order to choose the optimal model that performed the null hypothesis rejection for all the variables and resulted in a confidence interval greater than 95%.

Conclusions

The linear regression models have been used to estimate and model the formation core permeability considering different types of well logs attributes and rock facies in addition to the core porosity. The stepwise elimination has been used to delete the non-influential variables in the linear model to optimize the model that performs the probability of t-test to be less than or equal 0.05 for all the parameters leading to assuring the confidence intervals to be greater than or equal to 95%.. This reflects the viability of the resulted model to give acceptable empirical equation to estimate the permeability in non-cored intervals.

Figure 1 Above the output after running the full model with the entire data set can be seen. This figure does not depict the desired normal distribution approximation. This can best be seen in the upper right image where there are significant deviations at both ends of the plot. It also shows the histogram of the initial model is depicted and it is clear that this model significantly differs from a normal distribution.

Figure 2 This figure shows the output when the stepwise elimination and the log transformation were both applied to the model. This plot is a much better approximation of a normal distribution. This is most evident in the upper right image where a strong correlation can be seen. It also shows the histogram of the response factor (permeability) that has approximate normal distribution.

References

- Ahmed, U., Crary, S.F. and Coates G.R. [1991] Permeability Estimation: The Various Sources and Their Interrelationships, *JPT*, 578-87.
- Yao, C.Y. and Holditch, S.A. [1993] Estimating Permeability Profiles Using Core and Log Data. Society of Petroleum Engineers.
- Abraham, B. and Ledolter, J. [2006] Introduction to Regression Modeling. Belmont, CA. Duxbury Press.
- Chatterjee, S. and Hadi, A.S. [2006] *Regression Analysis by Example*. New York, John Wiley & Sons, Inc.
- Karpur, L., Lake, L. and Sepehrnoori, K. [2000] Probability Logs for Facies Classification. *In Situ*, **24**(1), 57.