Volume Estimation by Monte-Carlo Simulation using Customized Distribution Functions: A Comparative Study

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Keywords

Uncertainty; Volume estimation; Monte-Carlo Simulation; Distribution function; Stochastic method

Summary

High risk is associated with each exploration and production (E&P) asset due to uncertainties related to various geologic and financial factors. The reservoir properties (porosity (Φ), water saturation (Sw) etc.) describing the hydrocarbon resources in place are uncertain and accurate determination of these properties is essential to assess the economic viability of any E&P asset.

In general, standard distribution functions (normal, log normal, gamma etc.) of reservoir properties (porosity (Φ), water saturation (Sw), net pay (h) etc.) are taken as inputs in Monte-Carlo Simulation for volume estimation. Though this method takes care of the variability in input data set, it is likely that assumed standard distribution functions will not always fit to the actual variation of data. Therefore a customized distribution function which fits to the actual variation of reservoir properties is crucial for better accuracy in volume estimation.

In this paper, a modified statistical approach has been adopted and a comparative study has been carried out to provide the difference between the volume estimates derived from standard distribution functions as well as customized distribution functions for input parameters in Monte-Carlo Simulation. These customized distribution functions for reservoir properties are well log data driven.

The volume estimates derived in two cases show a measureable difference. Hence it is recommended to use the proposed approach on routine basis for better accuracy of results.

Introduction

Resource/Reserve estimation for a prospect depends upon a number of reservoir properties. There are a number of methods available in the industry for volume estimation. Stochastic method based on Monte-Carlo Simulation is one of the most useful methods (Thander et. al., 2014). In stochastic approach multiple values for each parameter are considered resulting in multiple values of output honoring variation/uncertainty of the data.

Monte-Carlo Simulations are computational algorithms that depend on repeated random sampling to obtain numerical results. These techniques help in estimation of uncertainty in quantitative analysis and decision making. In principle, Monte-Carlo Methods can be used to solve any problem having a probabilistic explanation.

Monte-Carlo Simulation method simulates a test which results in a probabilistic distribution of a random variable using a mathematical function of a number of input random variables. In this method each random variable is assigned with a probability distribution function which generates a number of possible values for each input variable. A deterministic calculation based up on the mathematical relationship between the output and input random variables is performed which results in the probability distribution function for the output (Yashrakshita, 2013)

A number of standard probability distribution functions (uniform, triangular, normal, gamma distribution etc.) are possible for each input variables. The selection of these distribution functions depends upon the input data variability. In practical cases it is likely that the assumed standard distribution function is not fitting the actual data which affects the accuracy level.

Therefore, it is required to have a customized distribution function of input variables. In the present paper a comparative analysis has been carried out using Monte-Carlo Simulation taking standard as well customized distribution functions for input variables.

Methodology

As per the American Association of Petroleum Geologists (AAPG) guidelines the petroleum initial in place (PIIP) is defined as

$$(PIIP\ STB\ or\ scf) = A*h*\Phi*(1-Sw)/FVF \quad (1)$$

Where,
PIIP = Petroleum initially in-place (for oil OIIP and for gas GIIP)

A = Areal extent of the reservoir pool (m^2)
h = Net pay (m)
Φ = Porosity (fraction)
S_w = Water saturation
FVF = Formation volume factor [for oil (RB/STB) or gas (Rcf/scf)]
Oil initially in-place or Gas initially in-place is measured in barrels or cubic feet.

Stochastic Method

In this method each parameters (A, h, Sw, Φ and FVF) is assigned with a probability distribution function which generates a number of possible values for each input parameter.

In conventional approach standard distribution functions (normal distribution, uniform distribution, log normal distribution etc.) are used for populating the parameters. Distribution properties (mean, variance etc.) for these functions are determined from the input data set (Lipschutz and Schiller, 2005)

It is likely that the resulting standard distribution curve whose distribution properties (mean, variance etc.) are derived from the input data set is not representing the actual variation in data.

In the modified approach a customized distribution function is used which is derived from the actual data distribution.

In the present study Monte-Carlo Simulation using standard as well as customized distribution functions has been run for multiple realizations. The process flow chart is shown in figure 1. One representative well data (Well A) has been utilized for volume estimation. The basic data input for this process is derived from open hole well log data sets. Gamma ray (GR), Neutron Porosity (NPHI), Bulk Density (RHOB) & Laterolog Deep (LLD) logs have been used for estimation of reservoir properties (Glower, 2001): porosity (Φ), water saturation (Sw) and net pay (h). The flow chart for determination of these parameters is shown in figure 2**.**

Three logs namely effective porosity (Φ_e) water saturation (Sw) and net pay (h) are generated from input logs.

All the input parameters (A, h, S_w, FVF and Φ) for volume estimation are discussed in details below:

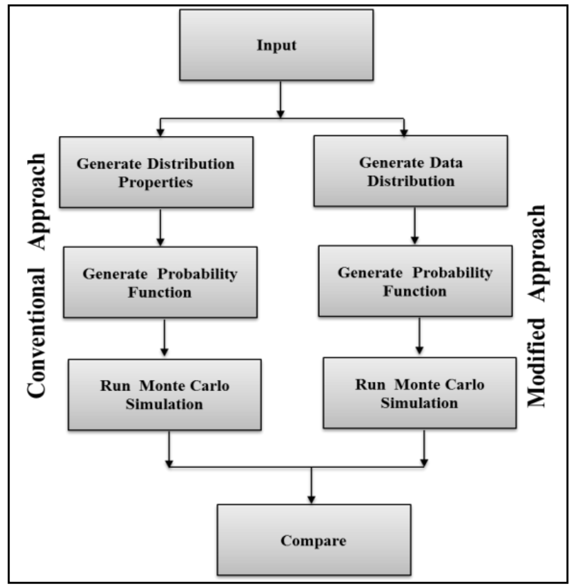

Figure 1: Flow chart for Monte-Carlo Simulation

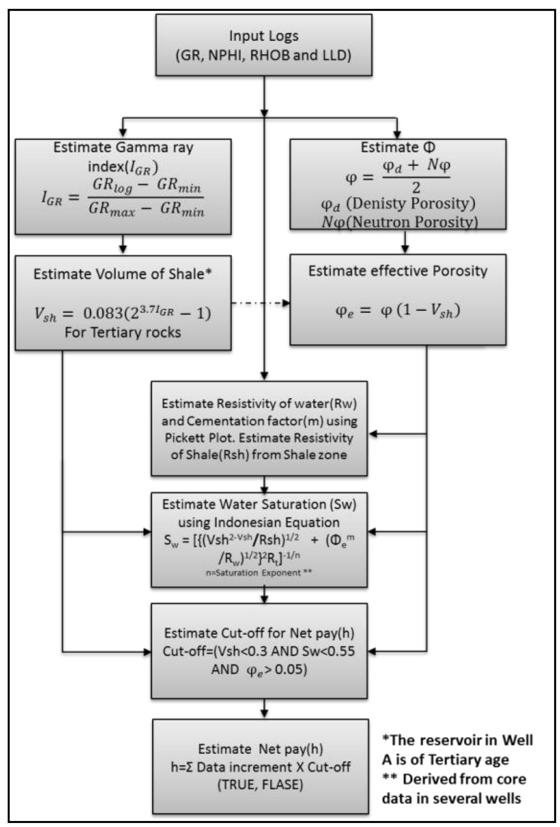

Figure 2: Flow chart for determining reservoir properties

1.) Porosity(Φe)

Porosity has been estimated for the following two cases:

- using standard distribution function and
- using customized distribution functions.

In first case, a log normal probablity distribution function is assumed for porosity with mean (μ) value equals to 0.20 and standard deviation(σ) of 0.07. The distribution function for this case is shown in figure 3.

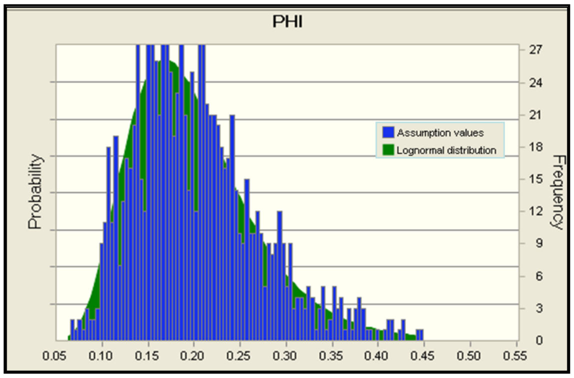

Figure 3: Log normal porosity distribution curve

In second case, a customized probablity distribution function is created from the data distribution of porosity log. In this case histrogram for porosity log for the range 0.0- 0.40 is created and then frquency for each data point is normalized which resulted in a customized probablity distribution function for porosity. The function generated is shown in figure 4.

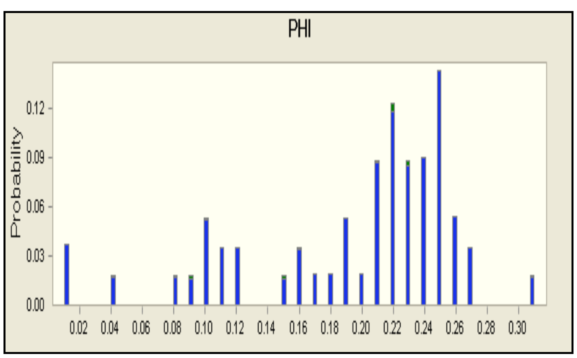

Figure 4: Customized porosity distribution curve

2.) Water Saturation (Sw)

Water saturation has also been estimated for two cases following the same method as used for estimating the porosity.

In first case, a log normal probablity distribution function is assumed for S_w with mean (μ) value equals to 0.30 and standard deviation(σ) of 0.1. The distribution function for this case is shown in figure 5.

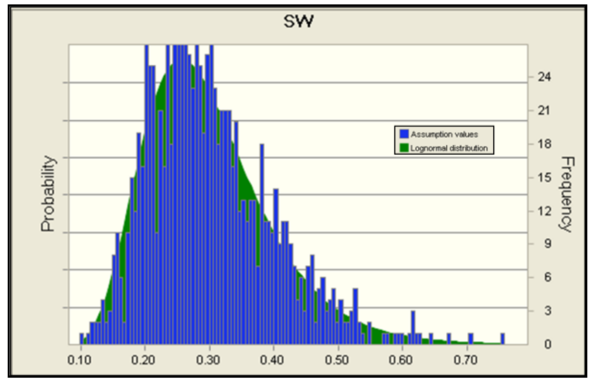

Figure 5: Log normal Sw distribution curve

In second case, the customized probablity distribution function is created from the data distribution of S_w log for the range 0.0- 1.0 The function generated is shown in figure 6.

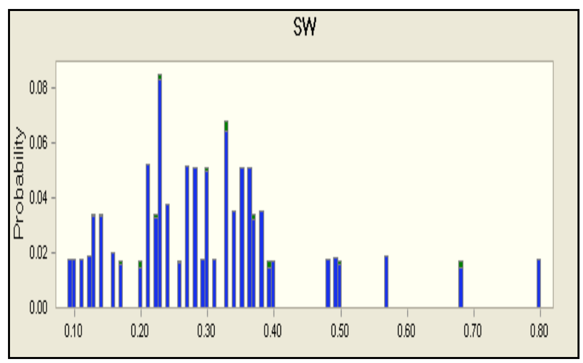

Figure 6: Customized Sw distribution curve

3.) Net pay (h)

The net pay for the reservoir zone in Well A is estimated using the cut-off equation as discussed in flow chart (figure 2). The estimated net pay after applying the cut-offs is of the order of 7m.

The thickness for detrmining the net pay is dervided from the thickness of reservoir zone encountered in the well which may not be the true stratigraphic thickness of reservoir. Moreover since the net pay is derived from the cut-offs for V_{sh}, S_w and Φ_e which are user defined; the value for net pay will differ for different cut-offs.

Considering above, uncertainity in the value of net pay has been taken into account rather then considering a single value.

A uniform distribution function ranging from 6-8m is considered for the present computation. The distribution curve for net pay is shown in figure 7.

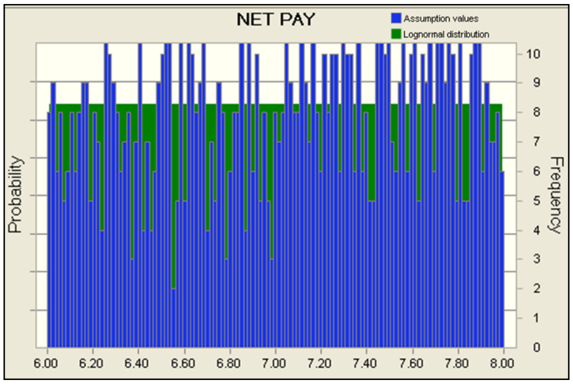

Figure 7: Uniform net pay distribution curve

4.) Area(A)

In the present computation an assumed value equals to 6 SKM of area is considered.

The area for a structural closure is estimated from the last closing contour of the structure or from the oil water contact (OWC). It is observed in general that there exist a transition zone between base of clean oil bearing zone and oil water contact (OWC) or free water level. Part of the area which is present in the transition zone in the sub surface will contribute to water production with oil.

Therfore the area above the base of clean oil bearing zone should be considered for volume estimation. However top of trasition zone may not always be known accurately which imposes an uncertainty on area estimation.

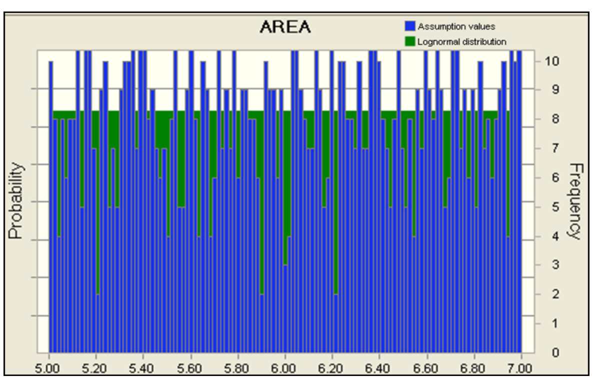

Figure 8: Uniform area distribution curve

Considering above, uncertainity in the value of area has been taken into account. A uniform ditrbution function ranging from 5-7 SKM is assumed. The distribution function for area is shown in figure 8.

5.) Formation volume factor (FVF)

Values for formation volume factor typically range from approximately 1.0 bbl/STB for crude oil containing little or no solution gas to nearly 3.0 bbl/STB for highly volatile oils (Al-Marhoun, 1992). In the present study a uniform distribution taking into account all possible values of FVF between 1 and 3 are considered. The distribution curve for FVF is shown in figure 9.

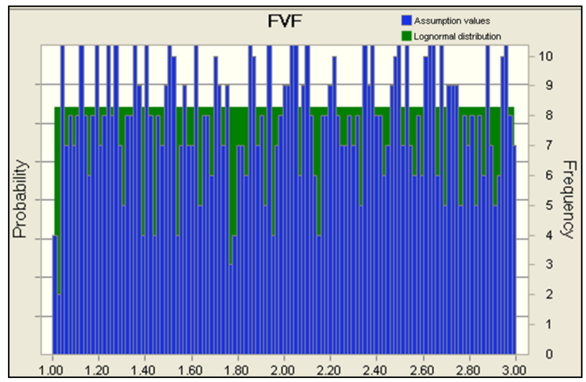

Figure 9: Uniform FVF distribution curve

Results

Volumetric estimation (PIIP in million barrels) has been carried out using Monte-Carlo Simulation for the two cases with 1000 trials. The results are discussed below:

1.) Stochastic estimation using standard distribution function:

In first case, the stochastic volumetric estimation by Monte-Carlo Simulation is carried out using standard distribution functions. The PIIP (MMBBLS) probability and cumulative probability distribution plots are shown in figure 10.

2.) Stochastic estimation using customized distribution function:

In second case, the stochastic volumetric estimation by Monte-Carlo Simulation is carried out using customized distribution functions. The PIIP (MMBBLS) probability and cumulative probability distribution plots are shown in figure 11.

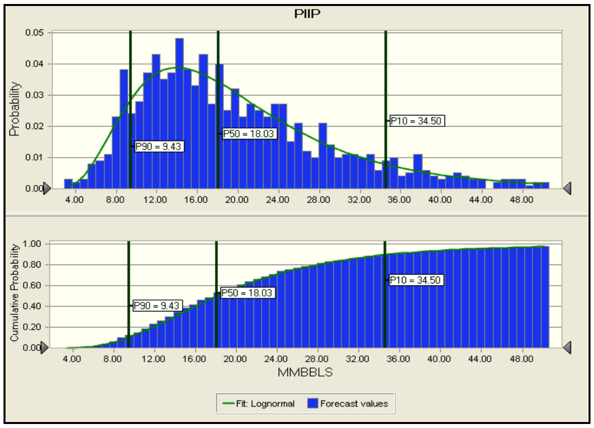

Figure 10: PIIP (MMBBLS) probability and cumulative distribution plots using standard distribution functions

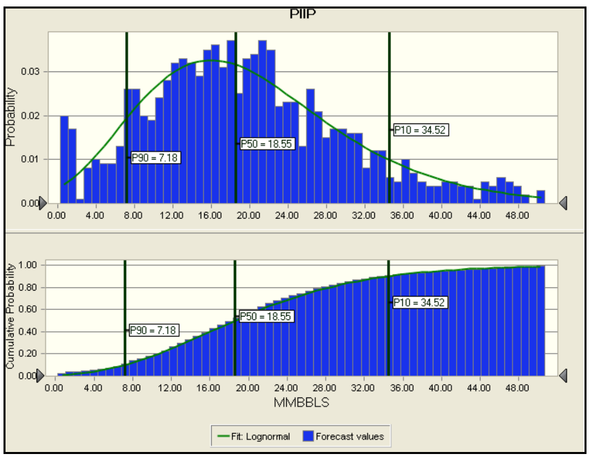

Figure 11: PIIP (MMBBLS) probability and cumulative distribution plots using customized distribution functions

The percentile values (P10-P90) along with absolute values of difference between two estimates are plotted in order to draw a comparison between two cases (figure 12). It can be observed from plot that there is a measureable difference in two cases.

Conclusions

- Accurate determination of volume estimation is essential to assess the economic viability of any E&P asset.
- Reservoir properties (porosity, water saturation etc.) are not single valued function rather a range of values exist for each of these parameters.

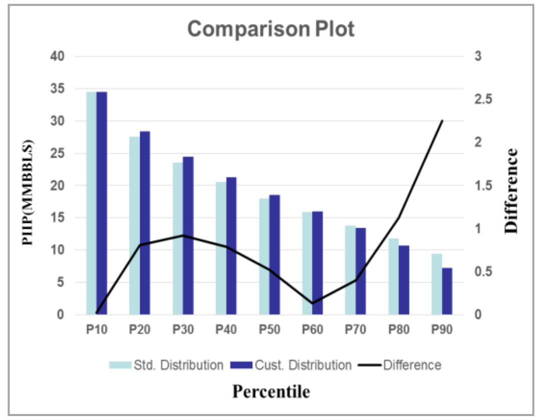

Figure 12: Comparison plot showing differences in percentiles in two stochastic cases

- In conventional method of volume estimation by Monte-Carlo Simulation, assumed standard distribution function (normal, gamma etc.) may not always consider the actual variation of reservoir properties i.e. the standard distribution function assumed may not fit the actual data.
- The present study reflect that there is a measureable difference in volume estimates by Monte-Carlo Simulation using both standard as well as customized distribution function for reservoir properties.
- The difference in percentile values for two stochastic cases observed with present data set is as large as 2.25 MMBBLS (P90).
- A customized distribution function which fits the actual variation in the values of reservoir properties is recommended for better accuracy in volume estimation by Monte-Carlo Simulation.

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