Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2017
(ICMERE2017) 18 – 20 December 2017, Chittagong, Bangladesh

ICMERE2017-PI-101

WIRELINE LOG BASED ASSESSMENT OF SHALE VOLUME AND POROSITY: A CASE STUDY

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Abstract*-Wireline log is one of the most popular method for reservoir characterization as well as reservoir quality assessment in oil and gas industry. This study shows the assessment of shale volume and reservoir porosity using wireline log data of anonymous field (well no. X). The reservoir lithology, resistivity and porosity have been estimated using lithology log, resistivity logs, and porosity logs such as sonic log and density-neutron logs. The shale volume is calculated from gamma ray and true resistivity methods. The effective porosity is estimated from neutron-density logs considering clay content. Based on log data analysis, lithology is mainly sand, and several hydrocarbon (gas) bearing zones are detected. Among them, one of the major hydrocarbon bearing zone is in the depth of 2588 to 2599 meter in this field. Shale volume ranges from 18.52 to 21.46 API. The average value of true resistivity is 9.17 ohm-m. The effective porosity (average) estimated using neutron-density combination formula is 18.65% and corrected sonic porosity is 18.35%. Results shows that the quality of reservoir porosity is good. The analyzed results may be used for reservoir pore fluid estimation, further reserve estimation and geo-statistical reservoir properties analysis.*

Keywords: Well Logs, Lithology, Rock Resistivity, Effective Porosity and Reservoir Quality

1. INTRODUCTION

Reservoir characterization covers the understanding and approaches to describe the behavior of reservoir rock and fluid properties in a porous medium. Several methods and advanced technologies have been used in clastic and carbonate reservoirs to characterize the reservoir properly. It is a continuous process and integrated task that can be accomplished using several methods [1]. In the petroleum industry, the widest techniques for reservoir characterization are core analysis, well-logging [2-6], geophysics [7], geostatistics [8], well testing [9] and soft computing (i.e. artificial networks, fuzzy logic, and evolutionary computing [10-12].

Wireline log is one of the most widely used methods for reservoir characterization in oil and gas industry. It is very important for petroleum reservoir engineer as well as geologist to get more information about the condition of reservoir by using petrophysical properties of rocks (i.e. rock resistivity, shale content, porosity, permeability, and fluid saturation). Those properties are not uniform throughout the world hydrocarbon reservoir and formation due to the heterogeneity nature of sandstone and carbonate reservoirs deposition system. Besides, this method is very useful to detect water and hydrocarbon bearing zones, evaluate the shale (clay) content, hydrocarbon volume and so on. Therefore, reservoir characterization and fluid flow modelling in porous media is a crucial task to generate the realistic dynamic model of the heterogeneous reservoir that can be used to forecast ultimate hydrocarbon recovery as well as economic project feasibility. Besides, it can be assisted by making lots of decisions such as the development of fields, economic analysis, and reservoir management scenarios. Lithology interpretation is very significant in reservoir characterization because of wrong interpretation of lithology type which affects the other steps consequently such as shale volume (shalyness), effective porosity and water saturation assessment [13]. In addition, the shale volume and effective porosity can be used for integrated reservoir characterization and sensitivity analysis of this reservoir using different approach such as factor analysis and soft computing system [5-6, 10-11, 14-15]

The main objective of this paper is the assessment of shale volume and effective porosity using wireline log data of a reservoir in Bengal Basin.

2. LOCATION OF THE STUDIED AREA

The field is located in the eastern folded belt in the Hatia Trough of the Bengal Basin and has been drilled to a depth of 3750 m. Tectonically, the area is gently deformed and existing structures are mainly large and gentle NNW-SSE trending anticlinal forms. The age of the reservoirs extends from Late Miocene to Early Pliocene. The sediments of the Neogene Surma Group are subdivided into the Bhuban and Bokabil formations with a thickness of 4 to 5 km. This sediment deposited deposited under marine-deltaic to fluvial-deltaic conditions. The lower Bhuban Formation consists of fine grained, well indurated, massive to thick-bedded sandstones, shales, claystones and siltstones. The upper BokaBil Formation is composed of fine- to medium-grained moderately indurated sandstones with shales, silty shales and siltstones. Characteristic lithofacies include ripple-laminated sandstones, partly with flaser bedding, parallel-laminated sandstones, cross-bedded sandstones, cross-bedded sandstones with lags of mud clasts and apparently massive sandstones [16-17].

3. MATERIALS AND METHODS

Lithology has been identified with the help of spectral gamma ray (GR) log. After that, hydrocarbon bearing zone as well as reservoir thickness is detected by the interpretation of GR log comparing with resistivity, density, neutron and porosity logs of the well no. X of Bengal Basin.

3.1 Assessment of Shale Volume and Porosity

Shale Index (I_{GR}) as well as Shale volume (V_{sh}) has been calculated using the value of GR and true resistivity (R_t) responses oven the entire log. The shale volume can be estimated using different techniques and methods [3, 18-24]. The GR log is used to estimate the volume of shale in a permeable zone. This volume (clay content) is used in evaluating shaly sand reservoirs. Shale volume has been calculated by using gamma ray (GR) method and True Resistivity (TR) method [18, 20, 24] and then the results have been compared. Total porosity has been calculated from porosity logs such as sonic, density, neutron and neutron-density combination formula [3, 24]. Further, the estimated shale volume from GR method is also used to assess the effective porosity of the reservoir. The required equations of this study are listed as the followings [3]

$$I_{GR}=\frac{GR_{log}-GR_{min}}{GR_{max}-GR_{min}} \tag{1}$$

V_{sh} for Tertiary rocks of Non-linear response [18]:

$$V_{sh}=0.083(2^{3.7I_{GR}}-1) \tag{2}$$

Density porosity,

$$\phi_D=\frac{\rho_{ma}-\rho_b}{\rho_{ma}-\rho_{fl}} \tag{3}$$

Effective porosity with clay correction (PHIDe),

$$\phi_{D,e}=\frac{\rho_{ma}-\rho_{b.c}}{\rho_{ma}-\rho_{fl}} \quad and \rho_{b.c}=\rho_b+V_{sh}\,(\rho_{ma}-\rho_{cl}) \tag{4}$$

Effective neutron porosity (PHINe),

$$\phi_{N,e}=\phi_N-V_{sh}*\phi_{N,sh} \tag{5}$$

Effective porosity using Neutron-Density combination formula (PHINDe) for gas reservoir,

$$\phi_{N\text{-}D,e} = \left(\frac{\phi_{D,e}^{2} + \phi_{N,e}^{2}}{2}\right)^{0.5} \quad (6)$$

Effective porosity from sonic logs for gas reservoir, PHISe,

$$\phi_{s,e} = \left(\frac{\Delta t_{log} - \Delta t_{ma}}{\Delta t_{fl} - \Delta t_{ma}}\right) * 0.7 \quad (7)$$

All symbols are mentioned in nomenclature (section 8).

4. RESULTS AND DISCUSSIONS

The lithology of the studied reservoir is mainly sand or shaly sand based on gamma ray (GR) and resistivity log data analysis. The water bearing sandstone is detected between 2755-3105 m. There are several shale zones also found at depth 1665-1690, 1905-2020 and 2445-2588m. The major lithology of reservoir is shaly sand from 2588-2599m depth which is porous and permeable with 12 m thickness. Besides, other gas zones also detected between 3154-3212, 3227-3307, 3332-3377 and 3397 -3453 m. The average reservoir true resistivity (R_t) is 9.17 ohm-m which estimated directly from deep induction log (ILD) for 2588-2599m.

4.1 Shale Volume Estimation

The maximum and minimum value of GR log of the studied well is 138 and 45 API respectively, where average is about 87 API for the major hydrocarbon bearing zone. The calculated shale index (average) and shale content (shale volume) is 45 and 18.52% respectively based on GR method. On the other hand, average shale volume is 21.46% based on true resistivity method when maximum and minimum true resistivity is 15 and 3 ohm-m for clean sand and clay zone, respectively. Detailed results of shale volume estimation are shown in Table 1.

Depth	Vsh from GR method			Vsh from TR method	
(meter)	GR_{log} (API)	I_{sh} (fraction)	V_{sh} (%)	R_t (Ohm-m)	V_{sh} (%)
2588	95	0.538	24.65	8	26.18
2589	90	0.484	20.41	10	16.74
2590	100	0.591	29.53	8	26.18
2591	90	0.484	20.41	8	26.18
2592	75	0.323	10.68	15	0.00
2593	90	0.484	20.41	12	9.92
2594	80	0.376	13.49	10	16.74
2595	82	0.398	14.73	9	21.00
2596	80	0.376	13.49	8	26.18
2597	80	0.376	13.49	9	21.00
2598	98	0.570	27.50	8	26.18
2599	80	0.376	13.49	6	41.27
Avg.	86.67	0.45	18.52	9.25	21.46

4.2 Assessment of Porosity

The average neutron porosity is 23.55% for the interval of 2588-2599m depth. The clay corrected neutron porosity (PHINe) is 18.89% where the adjacent shale neutron porosity (PHIN,sh) is 26% using GR method. Besides, matrix density (ρma) and fluid density (ρf) of 2.65 gm/cc and fluid density (ρf) of 1.0 gm/cc have been used to estimate the density porosity for fresh water based mud [2-12]. On the other hand, matrix travel time (Δt) of 55.5µs/ft, and fluid travel time of 189µs/ft used to calculate total sonic porosity for the same drilling fluid [2, 12]. Based on the log interpretation, average bulk density (ρb) of the hydrocarbon bearing sand and shale are found from the density log reading is 2.3 and 2.35 gm/cc respectively. The total density porosity (average) percentage is 21.52 which ranges from 13.94 to 26.06 without clay correction while effective porosity (PHIDe) percentage is 18.18 which ranges from 11.49 to 23.00 with clay corrected using GR method. On the other hand, average sonic transit time and total porosity is 90.50 µs/ft and 26.22% for the studied interval. Besides, the effective sonic porosity (average) is 18.35% based on Hilchie formula [8] correction for hydrocarbon (gas) effect which ranges from 13.37% to 20.71% at 2552m and 2591m respectively. Summarized results of estimated density and neutron porosity with and without clay correction have been shown in Table 2.

Table 2: Different values of porosity (percentage) obtained by several methods at different depths.

Depth (m)	PHINe	PHIDe	PHINDe	PHISe
2588	18.63	14.91	16.87	20.19
2589	18.73	17.50	18.13	17.04
2590	15.36	16.44	15.92	17.56
2591	18.73	13.86	16.47	19.14
2592	21.26	18.06	19.72	13.37
2593	16.73	22.35	19.74	18.61
2594	18.53	23.02	20.89	20.71
2595	20.21	22.17	21.21	19.66
2596	20.53	21.18	20.86	19.14
2597	18.53	20.58	19.58	19.66
2598	16.89	16.21	16.55	18.61
2599	22.53	11.49	17.88	16.52
Avg.	18.89	18.15	18.65	18.35

The maximum and minimum values of porosity are varying for different methods at the same depth of reservoir. The heterogeneity of porosity by different methods with respect to reservoir depth is shown graphically in Figure 2.

Estimated porosity is not same for all depth as well as different estimation techniques of this reservoir due to the variation of clay minerals (shalyness) as well as distribution of pore channels, grain size and shape, sorting and packing.

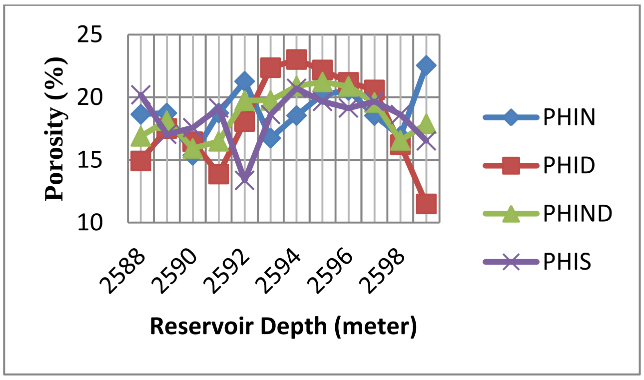

Figure 2: A curve showing relation between porosity and depth change of reservoir

In addition, matrix density and transit time can be changed due to the heterogeneity of the reservoir and can be altered the quality of porosity. The estimated porosity of this reservoir is about 18.5% which almost agreement with the core porosity (18-24%) of this field and close to nearest field of the basin [22].

5. CONCLUSIONS

The lithology of the reservoir is mainly sand and shale alteration unit. In this study, there are five hydrocarbon (gas) bearing zone detected which contain clean or shaly sand permeable rocks with low resistivity reservoir. The shale volume (shalyness) of the depth interval between 2588-2599m of studied zone is 18.52% and 21.46% using Gamma Ray and True Resistivity method, respectively. The estimated shalyness and porosity values can be used for further reservoir quality analysis as well as fluid saturation and permeability prediction. Besides, these results can be utilized for sensitivity analysis using different approach such as factor analysis and soft computing system.

6. ACKOWLEDGEMENT

The authors are thankful to the Memorial University of Newfoundland (MUN), Canada and Dept. of Petroleum & Mining Engineering (PME), Chittagong University of Engineering and Technology (CUET), Bangladesh for providing different facilities for this research.

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8. NOMENCLATURE

Symbol	Meaning	Unit
API	American Petroleum Institute	-
Avg.	Average	-
GR	Gamma Ray	API
GR_{log}	GR value of the zone of interest	API
GR_{min}	GR value of the clean zone	API
GR_{max}	GR value of the clay (shale) zone	API
Rt	True resistivity of the reservoir	Ohm-m
I_{GR}	Shale Index	Dimensionless
V_{sh}	Shale volume (Clay content)	Dimensionless
ϕ_D	Density porosity	Percentage
$\phi_{D,e}$	Effective density porosity	Percentage
ϕ_N	Neutron porosity	Percentage
$\phi_{N,e}$	Effective neutron porosity	Percentage
$\phi_{N,sh}$	Adjacent shale porosity	Percentage
$\phi_{N\text{-}D,e}$	Effective porosity from neutron-density combination formula	Percentage
$\phi_{s,e}$	Effective sonic porosity	Percentage
ρ_{ma}	Matrix density of rock	gram/cc
ρ_b	Bulk density of the formation (reservoir)	gram/cc
ρ_{fl}	Mud fluid density	gram/cc
Δt_{log}	Sonic transit time of the zone of interest	μs/ft
Δt_{ma}	Matrix transit time of rock	μs/ft
Δt_{fl}	Fluid transit time	μs/ft