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Evaluation of Gas Reservoir of the Meghna Gas Field, Bangladesh Using Wireline Log Interpretation

Abu Reza Md. Towfiqul Islam[1,*], Md. Aminul Islam[2]

[1]Department of Disaster Management, Begum Rokeya University, Rangpur, 5400, Bangladesh
[2]Department of Petroleum Geoscience, Faculty of Science, Brunei Darussalam University, Gadong, 1410, Brunei
*Corresponding Author: gm_towfique_06@yahoo.com

Abstract The gas reservoir from the well Bakhrabad-09 of the Meghna Gas Field, Bangladesh was evaluated in this study in order to appraise the qualities of the reservoir based on quantitative analysis of petrophysical parameters. Among 24 permeable zones, two zones were gas-bearing and rests were water-bearing zones which identified in the study well. Relatively high resistivity, high SP log, low gamma ray log, very low neutron and low density log responses indicate hydrocarbon type might be gas-bearing zones than that of water-bearing zones. The shale volume of those zones ranged from average 21% to 22 % indicated that shaly sand dominating lithology and less affect the water saturation values in the gas reservoir. The average porosity of these zones ranged from 31% to 34 % which was within the limit for good hydrocarbon accumulation. Three saturation equations were used to evaluate the water saturation which was converted to gas saturation. The average gas saturation values of these zones were more than 60 % indicate high hydrocarbon accumulation. The average permeability of these zones ranged from 42.5 md to 50 md respectively which was within ranged for commercial gas accumulation. Average bulk volume of water ranged from 0.045 to 0.053 was shown that the reservoir consist of mainly fine to very fine grained sandstone and more or less at irreducible water state. It can be concluded that gas reservoir are good qualities for commercial hydrocarbon accumulation and production.

Keywords Wireline log, Meghna Gas Field, Well Bakhrabad-09, Reservoir quality and Hydrocarbon accumulation

1. Introduction

Wireline logs are helped to define physical characteristics of the reservoirs such as porosity saturation, hydrocarbon moveability and permeability [1]. Petrophysical evaluation has a unique opportunity to observe the relationship between porosity and saturation [2]. Well log data are used to give erroneous values for water saturation and porosity in the presence of shale effect. The determinations of reservoir quality and formation evaluation processes are largely depend on quantitative evaluation of petrophysical analysis. Petrophysical analysis of gas reservoir of different gas field was carried out by Islam et al. [3-7] in Bengal Basin, Bangladesh. Rahman et al. [8] was carried out the analysis of reservoir sand of Titas-15 well using well log interpretation.

In this regard, the study was focused on the gas reservoir evaluation in the well Bakhrabad-09 of Meghna Gas Field, Bangladesh using wireline log interpretation. The objective of the study is to identify the gas zones of reservoir using composite log responses and to determine petrophysical parameters of the gas reservoir of the Meghna Gas Field, Bangladesh. It is located in Bancharampur upzila under Brahmanbaria District some 40 km away of northern most east direction from capital city of Dhaka, Bangladesh. Meghna Gas Field was discovered by BAPEX in 1990 [9] (Figure 1).

2. Geologic Setting

Bengal Basin is a productive gas-bearing basin in Southeast Asia. It is bounded by the Indian Shield on the west, north by the Precambrian Shillong Massif, on the east by the Arakan Yoma folded system and in the south it plunges into the Bay of Bengal (Figure 2). Foredeep part of the Bengal Basin is further subdivided into Eastern Chittagong-Tripura folded belt and unfolded western region deep basinal area also known as platform flank [10]. The Greater Bakhrabad structure lies on the southern fringes of the Surma Basin. The Surma Basin is the northeastern extension of the Bengal Fore deep [11]. Geologically, Morichakandi structure is situated in the western most part of the Chittagong-Tripura folded belt and a sub-structure of the Greater Bakhrabad, which lies on the north western part of the Bakhrabad (Figure 2). Titas Structure is present in the north and Kamta Structure lies in the west. Morichakandi structure is a symmetrical anticline with SE-NNE [12].

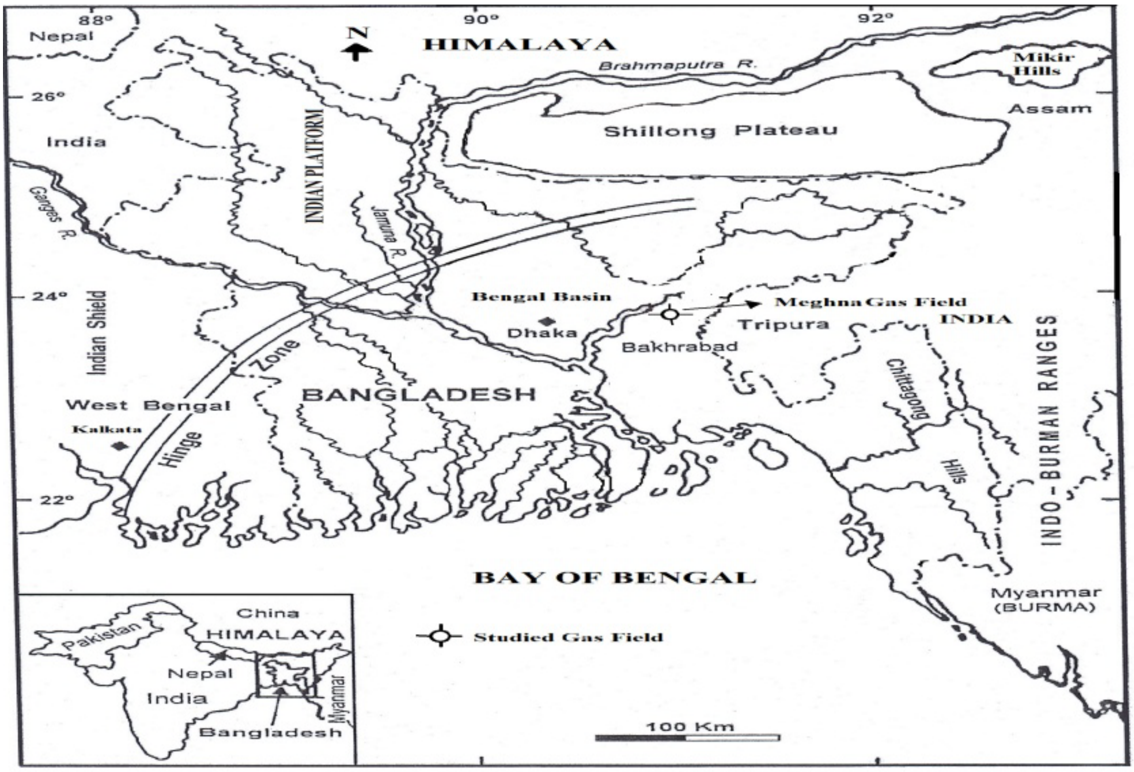

Figure 1. Map showing the location of the Meghna Gas Field (modified after Alam et at., [15])

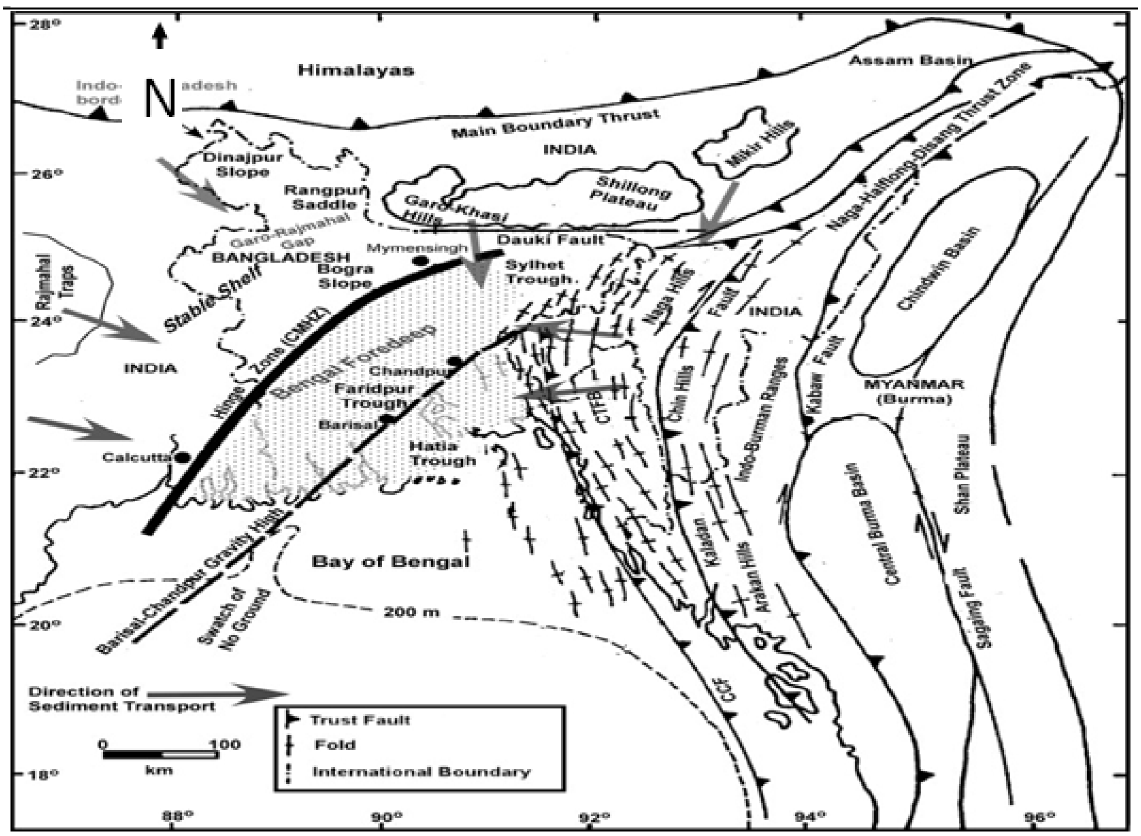

Figure 2. Regional map showing the tectonics elements of the Bengal Basin and surrounding areas (modified from [13-15]

3. Materials and Methods

The wireline log from the well Bakhrabad-09 of the Meghna Gas Field was used for the study and data collected from Data Centre of the Bangladesh Petroleum Exploration and Production Company (BAPEX), Petrobangla. The wireline log includes resistivity logs (ILD and MSFL), density log, neutron log, gamma ray (GR) log, self potential (SP) log etc. Description and evaluation of gas-bearing zones of the study well using wireline log. Digital data were analyzed by Excel software. Petrophysical parameters of the gas reservoir were determined by the following procedure:

At first step, the shale volume was calculated using Schlumberger equation [16]. Calculation of shale volume from gamma ray log using gamma ray index (I_{GR}) for tertiary rocks [17].

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{mix} - GR_{min}} \quad (1)$$

$$V_{sh} = 0.083[2^{3.7\times I_{GR}} - 1.0] \quad (2)$$

After computation of the volume of shale (V_{sh}), computation of porosity and shale corrected from neutron-density logs. The following formula was proposed by Dresser Atlas [17] to calculate porosity from neutron and density logs:

$$\emptyset_{Den} = \left(\frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}\right) - V_{sh}\left(\frac{\rho_{ma} - \rho_{sh}}{\rho_{ma} - \rho_f}\right) \quad (3)$$

$$\emptyset_{Ncorr} = \emptyset_N - [(\frac{\emptyset_{Ncl}}{0.45}) \times 0.30 \times V_{sh}] \quad (4)$$

Estimation of porosity ($\emptyset$) was also calculated by Neutron-Density logs using Schlumberger [18].

$$\emptyset_{Dcorr} = \emptyset_D - [(\frac{\emptyset_{Ncl}}{0.45}) \times 0.13 \times V_{sh}] \quad (5)$$

$$\emptyset_{N\text{-}D} = \sqrt{\frac{\emptyset_{N corr}{}^2 + \emptyset_{Dcorr}{}^2}{2.0}} \quad (6)$$

Where, $\emptyset_D$ = density porosity, $\emptyset_N$ = neutron porosity, ρ_{ma} = matrix density (sandstone) 2.6 g/cm^3, ρ_b =bulk density (log reading), ρ_f =fluid density (for water= 1.0g/m, for gas=0.7 g/m), ρ_{sh} =shale density.

After computation of porosity, the water saturation (S_w) was calculated in the study. The following three formulas were commonly used to calculate water saturation of gas reservoir:

$$S_w = (\frac{0.4\times R_w}{\emptyset^2})\left[\frac{V_{sh}}{R_{sh}}\sqrt{\left(\frac{V_{sh}}{R_{sh}}\right)^2 + \frac{5\emptyset^2}{R_t\times R_w}}\right] \quad (7)$$

$$S_w = \frac{1}{\emptyset}\times\left[\sqrt{\frac{R_w}{R_t} + \left(\frac{a\times V_{sh}}{2}\right)^2} - \frac{a\times V_{sh}}{2}\right] \quad (8)$$

$$S_w = \frac{\frac{V_{sh}}{R_{sh}} + \sqrt{\left(\frac{V_{sh}}{R_{sh}}\right)^2 + \frac{\emptyset^2}{0.2\times R_w\times(1.0 - V_{sh})\times R_t}}}{\frac{\emptyset^2}{0.4\times R_w\times(1.0 - V_{sh})\times R_t}} \quad (9)$$

Where, S_h = Hydrocarbon saturation, R_{sh} =Shale resistivity, R_w =formation water resistivity, R_t =true resistivity from the deep resistivity log, a= 1 (tortusity factor)

Equation (7), (8) and (9) were introduced by Simandoux [19], Fertl [20] and Schlumberger [21] respectively. Formation water resistivity (R_w) was calculated by Bateman and Konen [22] equation.

$$R_w = 10^{\left\{\frac{SSP}{K} + Log\, R_w\right\}} \quad (10)$$

$$S_h = 1 - S_w \quad (11)$$

Determination of permeability (K) was done by the following by Coates and Dumanoir [23] equation.

$$k = \left(\frac{c\times\emptyset^{2w}}{W^4\times(R_w/R_{tirr})}\right)^2 \quad (12)$$

Where, $W = \left[(3.75 - \varphi) + \{\frac{\left[\log\left(\frac{R_w}{R_{tirr}}\right) + 2.2\right]^2}{2}\}\right]^{½}$

$$c = 23 + 465\rho_h - 188\rho_h^2$$

Permeability was also calculated by using Wyllie and Rose [24] equation:

$$K = (79\times\emptyset^3/S_{wirr})^2 \quad (13)$$

Where, S_{wirr} = saturation at irreducible water saturation, R_{tirr} = deep resistivity at irreducible water resistivity, SSP= Static Self Potential, w and c =constant on hydrocarbon density, ρ_h =hydrocarbon density (0.7 for gas)

Hydrocarbon moveability index is the ratio of the uninvaded zone and flushed zone and expression of the following Archie [25] equation:

$$\frac{S_w}{S_{xo}} = [\frac{R_{xo}\times R_w}{R_t\times R_{mf}}]^{1/2} \quad (14)$$

Where, S_{xo} =flushed zone water saturation, R_{mf} =mud filtrate resistivity, R_{xo} =formation shallow resistivity.

The bulk volume of water (BVW) of the hydrocarbon-bearing zones in the studied well Bakhrabad-09 was computed using Moris and Biggs [26] equation:

$$BVW = S_w \times \emptyset \quad (15)$$

4. Results

Petrophysical analysis determines different geometric properties of the reservoir such as lithology, shale volume, porosity, permeability, hydrocarbon saturation and bulk volume of water using available wireline logs. In the well Bakhrabad-09, 24 permeable zones were identified from the composite log responses (Table 1). Among these permeable zones, two zones were identified as hydrocarbon-bearing while remaining was water-bearing.

Table 1. Permeable zones in the well Bakhrabad-09 of the Meghna Gas Field

Zone No.	Zone Type	Depth Range (m)	Thickness (m)
1	Water-bearing	952-1004	50
2	Water-bearing	1006-1060	54
3	Water-bearing	1074-1097	23
4	Water-bearing	1304-1327	23
5	Water-bearing	1433-1454	21
6	Water-bearing	1524-1541	17
7	Water-bearing	1661-1690	29
8	Water-bearing	1765-1783	18
9	Water-bearing	1817-1847	30
10	Water-bearing	2054-2073	19
11	Water-bearing	2094-2131	37
12	Water-bearing	2149-2191	42
13	Water-bearing	2191-2204	13
14	Water-bearing	2323-2353	30
15	Water-bearing	2398-2453	55
16	Water-bearing	2460-2478	18
17	Water-bearing	2560-2563	3
18	Hydrocarbon-bearing	2665-2676	11
19	Water-bearing	2753-2765	10
20	Water-bearing	2774-2792	18
21	Water-bearing	2837-2865	21
22	Water-bearing	2874-2890	16
23	Hydrocarbon-bearing	2935-2941	6
24	Water-bearing	2945-2955	10

Hydrocarbon-bearing zones in the well BaKhrabad-09 were identified with the help of SP, GR, resistivity, (ILD & MSFL), neutron and density log responses. For this purpose, resistivity logs are the best option to detect gas-bearing zones. In these gas-bearing zones, gamma ray log shows low response and SP log shows high values as these deflects from shale base line. The resistivity log response in the gas-bearing zones is very high. Generally, gas-bearing zones deep resistivity log (ILD) value is higher than the shallow resistivity log (MSFL). Very low neutron and low density log responses support that hydrocarbon are gas type [27]. Composite log responses of the individual zones are shown in the figure 3 and 4.

Shale volume (V_{sh}) is used to calculate the shale distribution in the reservoir. It also affects the water saturation in the study well. Shale volume was calculated by using Schlumberger equation [16]. The average shale volumes of these zones are 21% and 22 % respectively which graphically presented in figure 5 & 6 and table 4. The determination of porosity and permeability are a very important step for calculating fluid saturation in reservoir evaluation [28]. In this study, density and neutron log were only used for porosity determination. Permeability (K) was calculated by Coates and Dumanoir [23] and Wyllie and Rose [24] equation. Wyllie and Rose [24] equation was found better result for reservoir evaluation of the gas zones than Coates and Dumanoir equation. The calculate values of these zones are graphically presented in the figure 5 & 6 and table 2. Water saturation of the hydrocarbon-bearing zones has not calculated using Archie [25] equation because it is only valid for clean sandstone. The permeable zone with more than 60 % hydrocarbon saturation is commonly treated as hydrocarbon-bearing [1].The value of water saturation is less affected by incursion of shale and porosity. Three saturation equations were used to get more reliable saturation values. Three most used equations were proposed by Simondoux[19] , Fertl [20] and Schlumberger [21] used for calculating water saturation as well as hydrocarbon saturation which graphically presented in the figure 5 & 6 and table 3. Simandaux [19] equation was found better suited for water saturation calculation than the equation of Fertl [20] and Schlumberger [21] in the zone-1. Schlumberger equation [21] was considered as a suitable for water saturation calculation and conversely for the calculation of hydrocarbon saturation than the equation of Simandoux [19] and Fertl [20] in the zone-2.

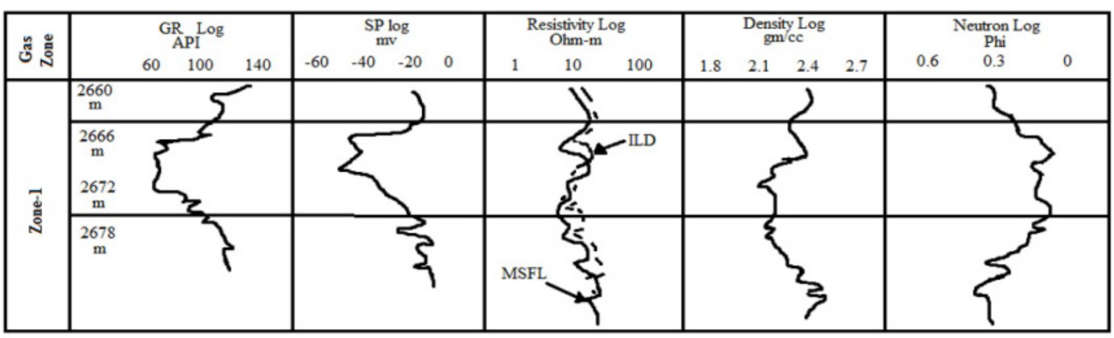

Figure 3. Composite log responses of the hydrocarbon bearing zone-1 in the the well Bakhrabad-09.

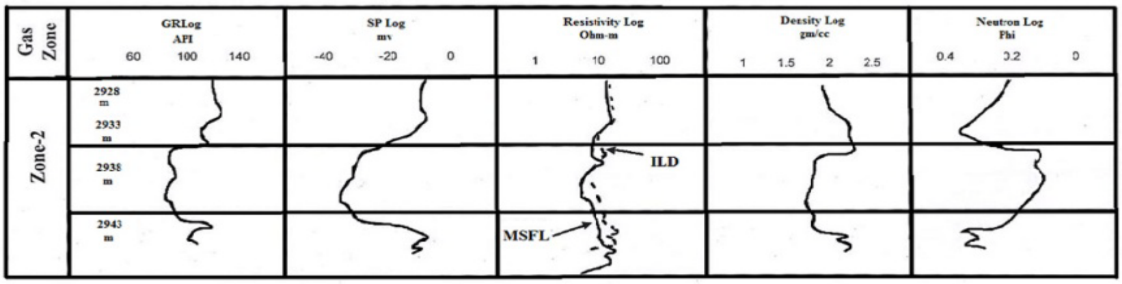

Figure 4. Composite log responses of the hydrocarbon bearing zone-2 in the well Bakhrabad-09.

Table 2. Distribution of permeability and porosity values of hydrocarbon-bearing zones in the well Bakhrabad-09.

Zone No.	Depth Range (m)	Thickness (m)	Permeability (Millidarcy)				Porosity (%)	
			Coates [23]		Wyllie [24]			
			Range	Average	Range	Average	Range	Average
1	2665-2676	11	20-70	45	20-90	55	33-35	34
2	2935-2941	6	16-60	33	25-75	50	23-28	31

Table 3. Distribution of hydrocarbon saturation values of gas-bearing zones in the well Bakhrabad-09.

			Hydrocarbon Saturation (S_h) %					
Zone No.	Depth Range (m)	Thickness (m)	S_h Simandoux [19]		S_h Fertl [20]		S_h Schlumberger [21]	
			Range	Average	Range	Average	Range	Average
1	2665-2676	11	70-75	73	65-70	66	67-77	71
2	2935-2941	6	60-65	62	80-85	82	86-88	87

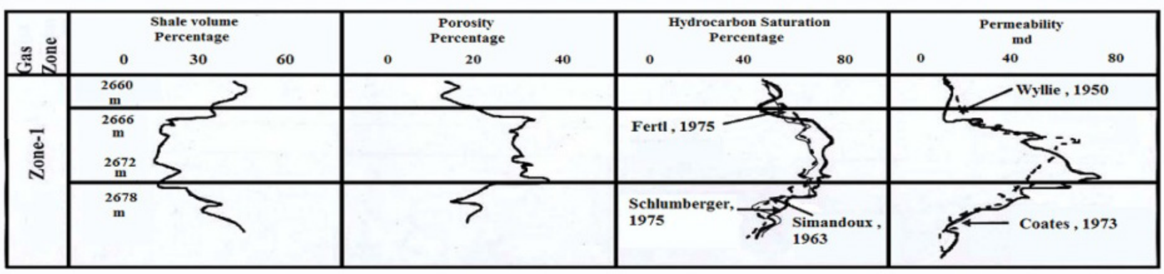

Figure 5. Graphical representation of petrophysical parameters (Shale volume, Porosity, Hydrocarbon distribution and Permeability) of the hydrocarbon bearing zone-1 in the well Bakhrabad-09.

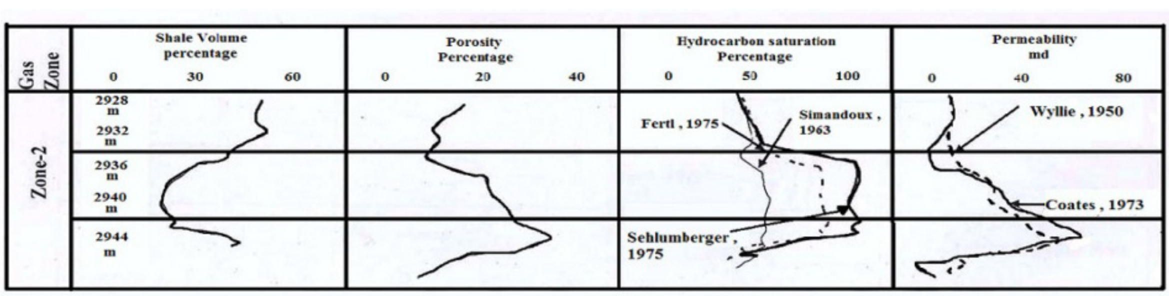

Figure 6. Graphical representation of petrophysical parameters (Shale volume, Porosity, Hydrocarbon distribution and Permeability) of the hydrocarbon bearing zone-2 in the well Bakhrabad-09

Table 4. Distribution of hydrocarbon moveability index, BVW and volume of shale values in the hydrocarbon-bearing zones in the well Bakhrabad-09.

Zone no.	Depth ranges(m)	Thickness (m)	Hydrocarbon Moveability Index (S_w/S_{xo})		Bulk Volume of Water (BVW)		Volume of Shale (%)	
			Range	Average	Range	Average	Ranges	Average
1	2665-2676	11	0.14-0.27	0.19	0.052-0.055	0.053	12-30	21
2	2935-2941	6	0.11-0.55	0.29	0.04-0.049	0.045	10-34	22

Hydrocarbon moveability index is the ratio between water saturation of uninvaded zone (S_w) to the water saturation of flushed zone (S_{xo}). If the ratio of S_w and S_{xo} is equal to or greater than 1.0, then hydrocarbon will not move within the well. If the saturation index is less than 0.7 (for sandstone), hydrocarbon is moveable [29]. Hydrocarbons are moveable in the study well because all the calculated values are less than 0.7. It is important to know that BVW whether the formation is at irreducible water saturation or not using Morris and Biggs [26] equation. If The BVW ranges from 0.035 to 0.07, the grain size is fine to very fine-grained sand [30]. Bulk volume of water is nearly constant with some minor scattering in the hydrocarbon-bearing zones which indicate that the water free hydrocarbon (Table 4).

5. Discussions

The quantitative analysis of wireline log data gives the clue that whether the well would be commercially viable or not. In well Bakhrabad-09, two hydrocarbon-bearing zones were identified with depth ranges of 2665-2676 m and 2945-2955 m having average thickness of 11 m and 6 m. (Table 1). GR log value of these zones were average 60 API indicate the value below it were shown to be gas sand reservoir while the value above it were shown to be shale. SP log values were average -40 mv indicate gas sand reservoir. The true resistivity (R_t) values of these zones were greater than the water bearing resistivity (R_0) value [31]. The average true resistivity ranged from 10 to 50 Ωm suggest gas reservoir with higher average true resistivity values have lower water bearing resistivity and vice versa. The density and neutron log value of these zones were average 1.95 g/cm^3 and 0.15 phi respectively. Both the density and neutron log responses through gas reservoir support that hydrocarbon types are gas (Figure 3 and 4).

The average shale volume of these zones were ranged from 21-22 % which converted to sand volume 81-82 % support that gas reservoir consist of shaly sand dominating lithology (Table 4). The average shale values in the well Bakhrabad-09 are relatively low sufficient to allow for free fluid flow of hydrocarbon. The average shale volumes are within the ranges (21 %) which show that less affects the water saturation values in the reservoir (Figure 5 and 6). It indicates that the reservoir is evidence of sand development [32]. The average log derived porosity values of these zones ranges from 31 % to 34 % which indicates very good porosity in the gas reservoir. Similar observation of porosity value was made by Ajisafe [33] in “Y” Field Niger Delta. The average permeability of these zones ranges from 42.5 md to 50 md shows good enough to accumulate hydrocarbon. The average porosity/permeability values 33 %/ 45 md are good average to permit free fluid flow of hydrocarbon in the gas reservoir (Table 2 and figure 5 & 6). The average hydrocarbon saturation values of the two gas zones were 68 % by using Simandoux [19], 74 % following by Fertl [20] and 79% following by Schlumberger equation [21] (Figure 5 & 6 and table 3). Higher average hydrocarbon saturation values suggest that gas reservoir is built up very high hydrocarbon accumulation. Same observation was made elsewhere in Bengal Basin by Islam et al. [4] [7]. Average hydrocarbon moveability index of the zones ranges form 0.19-0.29 indicate that hydrocarbon is moveable in the study well. Bulk volume of water values are average ranges from 0.045-0.053 suggests gas reservoir consist of mainly fine to very fine grained sandstone (Table 4). Islam et al. [5-6] made also similar result in Kailas Tila and Shahbazpur Gas Field of the Bengal Basin.

6. Conclusions

The reservoir quality of the well Bakhrabad-09 was studied using wireline log interpretation. Out of 24 permeable zones, two gas-bearing zones were identified in the study well on the basis of available composite log responses. The comparatively high resistivity log, log GR log, high SP log, very low neutron and low density log responses indicate that hydrocarbon might be gas-bearing. The mean shale volumes of those zones are low values show that shaly sand dominating lithology and less affect the water saturation values in the gas reservoir. The porosity value ranges between 23 % -38% indicate good porosity of the reservoir. The permeability value ranges between 33 md- 55 md show that potential reservoir for hydrocarbon accumulation. The average water saturation value ranges between 13 %-38 % which convert to average gas saturation value ranges between 62 %-87 % indicate very high hydrocarbon accumulation. Bulk volumes of water (BVW) of these zones ranges between 0.04-0.055 reveal that fine to very fine grain sandstone develop in the gas reservoir. Hydrocarbon is moveable which support by the calculated values in the study well. It suggests that the gas reservoir in the well Bakhrabad-09 have very good qualities with average 33 % porosity, average 21 % shale volume, hydrocarbon saturation values as high as more than 60 % and average permeability 46 md. The study also suggests that the gas-bearing zones of the reservoirs are prospective for commercial hydrocarbon accumulation and production.

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