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Assessment of Water Saturation Using Archie's Formula, Indonesia Equation and Simandoux Model of Shahbazpur Gas Field (SBZ 01)

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ABSTRACT

Reservoir quality assessment is a process for quantitatively assigning reservoir properties, recognizing geologic information and uncertainties in spatial variability. A petroleum reservoir is a heterogeneous system with large intrinsic complexity. A good reservoir is one that is commercially productive; it produces enough oil or gas to pay back its investors for the cost of drilling and leaves a profit. The improvement of reservoir performance analysis is one of the most important existing and emerging challenges to geoscientists and engineers. The aim of this study is to use an integrated technique in computing an essential parameter - water saturation of Shahbazpur gas field (SBZ 01). This study shows the assessment of water saturation using Archie's formula, Indonesia equation and Simandoux model with the help of wireline log data. Well logging plays an essential role in the determination of the production potential of a reservoir. The process involves lowering a number of instruments into a borehole with the purpose of collecting data at different depth intervals. The assessment of water saturation is undertaken to determine the reservoir's capability to both store and transmit fluid. According to wireline log data analysis, the average water saturation found from Archie's formula is 17.30 percent, by Indonesia equation 40.00 percent and by Simandoux model 52.14 percent. This analysis is very important to predict the overall performance of a reservoir as well as to enhance the production and life of the reservoir. The aforementioned analyzed results can be used for further reservoir evaluation and reservoir properties analysis.

Keywords: Water Saturation, Reservoir Quality, Archie's Formula, Indonesia Equation, Simandoux Model

1. Introduction

The quality of a reservoir is defined by its hydrocarbon storage capacity and deliverability. A reservoir rock is a subsurface rock that has effective porosity and permeability which usually contains commercially exploitable quantity of hydrocarbon or fluid. [1]

One of the key issues in reservoir quality assessment using well log data is the prediction of petrophysical properties such as porosity and water saturation. Over the life of the reservoir, many crucial decisions depend on the ability to accurately estimate the formation permeability and water saturation.

However, the prediction of such properties is complex, as the measurement sites available are limited to isolated well locations. This requires an integrated knowledge of the tool responses and understanding of the geology of the region, together with various mathematical techniques in order to derive interpretation model that relates the log data to the petro physical properties. Establishment of an accurate well log interpretation model is not an easy task due to the complexity of different factors that influence the log responses. [2]

2. Overview of Shahbazpur Gas Field

The principal objective of drilling Shahbazpur well no. 1 was to investigate hydrocarbon potentiality, specially the gas play in the sandstone of Miocene age and to collect detail Geological information of the southern platform of Bengal fore deep which has not yet been studied due to the lack of sufficient well. [3]

Moreover, drilling of Shahbazpur well 1 would be considered to study the stratigraphy, structure, sedimentation, condition of deposition, identification of the onset of overpressure, source rock potential of the sediments and the migration and accumulation of Hydrocarbons. In this regards all available previous Geological and other related information were re-evaluated and it was observed that the best structure to be taken for immediate exploration was the Shahbazpur structure. [3]

3. Location of the Study

The Shahbazpur Gas Field lies in the Bhola District in the South part of Bangladesh. Shahbazpur gas field was discovered in 1994 with an estimated reserve of 0.465 trillion cubic feet of gas, out of which 0.35 trillion cubic feet is extractable from the first and second well. [4]

Name of the well	: Shahbazpur
Classification	: Exploratory
Proposed depth	: 3750 m
Location	: 90^{o} 45' 13.8'' 22^{o} 27' 55.7''
Ground elevation	: 3.3 m MSL
Type of trap	: Anticlinal

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Primary objective : Hydrocarbon prospect in Miocene

The entire area is a deltaic flat land and composed of recent sand, silt and clay. The surface topography of the area is represented by crops field with river canals. [4]

The highest elevation is 3.3m in central part of the island and gradually decreased towards the margin of the island. The area is surrounded by the Bay of Bengal in the south, Tetulia river in the west, Shahbazpur river in the east and Ganeshpura river in the north. [4]

4. Research Methodology

Water saturation is the ratio of water volume to pore volume. Water bound to the shale is not included, so shale corrections must be performed if shale is present. We calculate water saturation from the effective porosity and the resistivity log. [5]

The Archie equation was the first empirical model built (1942) to estimate the water saturation in non-conductive matrix rocks. It usually works well with clean clastic sandstones and carbonate rocks. The Indonesia equation works well with fresh formation water. The parameter Rshale (resistivity of shale) is usually taken from the resistivity reading of a nearby pure shale, assuming that the clay cements & silt, and the shale nature, are similar to those of the shaly sand. The Simandoux model for the resistivity log follows the classical form also, but it must be linearized, so the result does not often look similar to the usual response equation. [6]

Lithology has been identified with the help of spectral and gamma ray log. After that hydrocarbon bearing zone is detected by the interpretation of other logs-resistivity, density-neutron. Shale volume has been calculated by using gamma ray log as well as true resistivity method and then the results have been compared and then reservoir thickness has been determined by using the gamma ray log data. The interpretation is also continued by comparing with resistivity and porosity logs. Reservoir area has been determined by seismic data. Then the formation water resistivity has been generated by interpretation of resistivity log. Inverse Archie's method has been used in this study.

4.1 Determination of Water Saturation

Water saturation has been determined using three method- Archie's formula, Indonesia equation as well as Simandoux model.

Archie Equation to calculate the water saturation is as follows:

$$S_w = \sqrt[n]{(a \times R_w)/(\Phi^m \times R_t)} \quad (1)$$

Simandoux model for calculating water saturation is:

$$S_w = \{(0.4R_w/\ \Phi_e^2)\} \times [\sqrt{\{(V_{sh}/R_{sh})^2 + (5\Phi_e^2)/\ (R_w \times R_t)\}} - (V_{sh}/R_{sh})] \quad (2)$$

Indonesia equation for estimation of water saturation:
By using Indonesia model water saturation in both the uninvaded zone and the flushed zone can be calculated. Water saturation for un-invaded zones,

$$S_w = (1/R_t)[\{V_{cl}^{\ (1-0.5Vcl)}/(R_{cl})^{\ 0.5}\} + \{\Phi_e^{\ 0.5m}/(aR_w)^{0.5}\}] \quad (3)$$

Water saturation for flushed zone,

$$S_{xo} = (1/R_{xo})[\{V_{cl}^{\ (1-0.5Vcl)}/(R_{cl})^{\ 0.5}\} + \{\Phi e^{\ 0.5m}/(aR_{mf})^{0.5}\}] \quad (4)$$

5. Estimation of Water Saturation

Water saturation is calculated using three different methods. The value of average water saturation estimated from Archie, Indonesia and Simandoux model are 17.3%, 40%, 52.14% respectively.

Values of derived water saturation are shown in Table 1 and details calculation of estimating water saturation using Archie's formula is shown at Appendix 1.

The maximum water satuation using Archie's formula is determined at depth of 2599 m. The maximum value is 0.215. And the minimum value is 0.126 at depth of 2592 m. Value of Archie's exponent is taken as 1.4 and the value of cementation factor is taken as 1.54. The determined water saturation from Archie's formula are shown in Fig. 1.

Table 1 Values of estimated water saturation

Depth	S_w (Archie's)	S_w (Indonesia)	S_w (Simandoux)
2588	0.195	0.39	0.49
2589	0.165	0.39	0.52
2590	0.204	0.43	0.56
2591	0.198	0.40	0.52
2592	0.126	0.37	0.54
2593	0.141	0.34	0.43
2594	0.148	0.34	0.43
2595	0.154	0.38	0.47
2596	0.165	0.40	0.52
2597	0.164	0.38	0.47
2598	0.198	0.41	0.53
2599	0.215	0.51	0.69

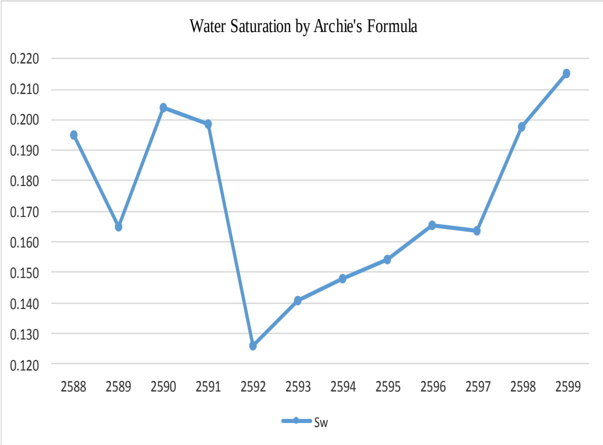

Fig.1 Water saturation (Y axis) vs. depth (X axis) using Archie's formulae

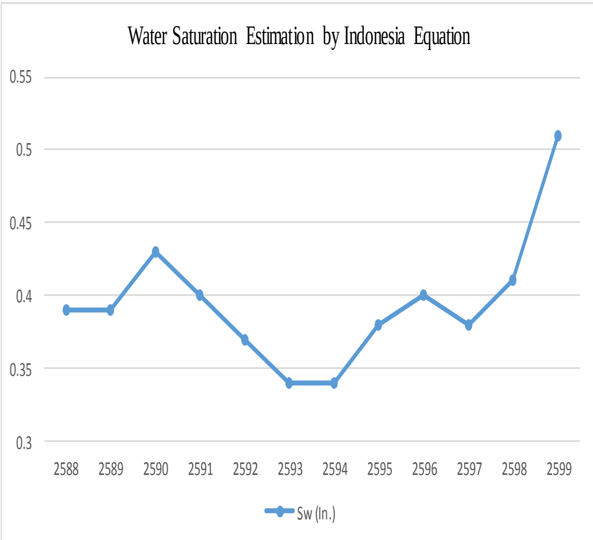

Fig. 2 Water saturation (Y axis) vs. depth (X axis) using Indonesia Equation

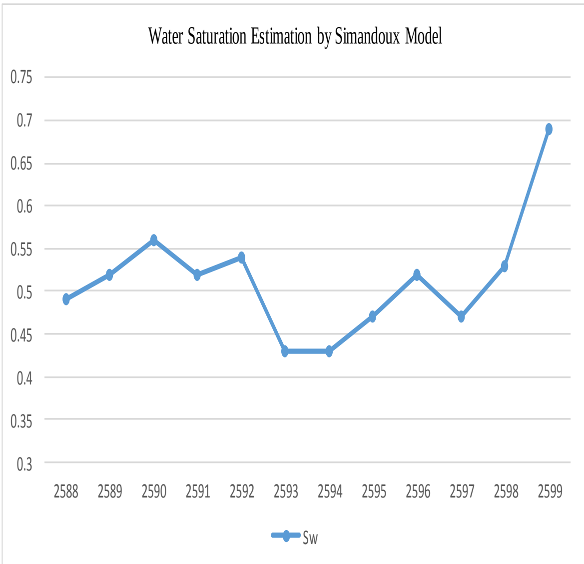

Fig.3 Water saturation (Y axis) vs. depth (X axis) using Simandoux Model

Appendix 2 shows the estimation of water saturation using Indonesia equation and Appendix 3 shows the estimation of water saturatiuon by Simandoux model. The maximum water satuation using Indonesia equation is determined at depth of 2599 m. The maximum value is 0.51. And the minimum value is 0.34 at depth of 2593 as well as 2594 m.

The maximum water satuation using Simandoux model is determined at depth of 2599 m. The maximum value is 0.69. And the minimum value is 0.43 at depth of 2593 as well as 2594 m. Estimated water saturation by Indonesia and Simandoux model are graphically represented at Fig. 2 and Fig. 3.

6. Conclusion & Recommendation

This work has introduced the practical application of wireline log and water saturation. All calculation in this work has been done without consideration of mud composition, mud temperature plus other sophisticated parameter. After the analysis of different logs it is detected that the value of average water saturation found from Archie's formula, Indonesia equation and Simandoux model are 17.3%, 40%, 52.14% respectively.

To estimate the water saturation of any reservoir more accurately, the special or routine core analysis is required. The estimated formation water resistivity may change depending upon the values of Archie's exponent and cementation factor.

To assess the quality of the gas reservoirs of Bangladesh more accurately, special logging tools such as Nuclear Magnetic Resonance (NMR) and Formation Micro-Scanner (FMS) logs can be run.

NOMENCLATURE

R_t : True Resistivity
R_w : Water resistivity
Φ : Porosity
S_w : Water saturation
a : Archie's exponent
m : cementation factor
n : Saturation exponent, it is the gradient of the line defined on the plot.
V_{sh} : Shale volume
Φ_e : Effective porosity
R_{cl} : Clay zone resistivity
R_{xo} : Flushed zone resistivity
R_{mf} : Mud filtrate resistivity

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Appendix 1 Water saturation estimation by Archie's formula

Base, m	Log values		Calculated			Constants		Calculated			
	Rt	Rxo	Porosity	Rw	Rmf	a	m	Sw	Sxo	BVW	MHI
2588	8.0	10.0	16.87	0.100	0.436	1.4	1.54	0.195	0.760	0.033	0.256
2589	10.0	15.0	18.13	0.100	0.436	1.4	1.54	0.165	0.587	0.030	0.281
2590	8.0	12.0	15.92	0.100	0.436	1.4	1.54	0.204	0.725	0.032	0.281
2591	8.0	10.0	16.48	0.100	0.436	1.4	1.54	0.198	0.774	0.033	0.256
2592	15.0	18.0	19.73	0.100	0.436	1.4	1.54	0.126	0.502	0.025	0.251
2593	12.0	12.0	19.74	0.100	0.436	1.4	1.54	0.141	0.615	0.028	0.229
2594	10.0	15.0	20.89	0.100	0.436	1.4	1.54	0.148	0.526	0.031	0.281
2595	9.0	15.0	21.21	0.100	0.436	1.4	1.54	0.154	0.520	0.033	0.296
2596	8.0	13.0	20.86	0.100	0.436	1.4	1.54	0.165	0.566	0.035	0.292
2597	9.0	14.0	19.58	0.100	0.436	1.4	1.54	0.164	0.573	0.032	0.286
2598	8.0	13.0	16.56	0.100	0.436	1.4	1.54	0.198	0.676	0.033	0.292
2599	6.0	8.0	17.88	0.100	0.436	1.4	1.54	0.215	0.812	0.038	0.265
Average	**9.25**	**12.92**	**18.65**					**0.173**	**0.636**	**0.032**	**0.271**

Calculation:
Formation depth: 2595m

Water saturation, Sw =[(FRw/Rt)]0.5 for uninvaded zone by Archie's formula

Sw =[(aRw)/(Φm×Rt)]0.5 = [(1.4×0.1)/(0.211.54×9)]0.5 = 0.154 for un-invaded zone

Sxo =[(aRmf)/(Φm×Rxo)]0.5 = [(1.4×0.436)/(0.211.54×15)]0.5 = 0.520 for flushed zone

Bulk Volume Water (BVW) = Water saturation × Porosity = 0.154×0.21 = 0.033

Moveable Hydrocarbon Index, MHI = Sw/Sxo = 0.154/0.520 = 0.296

Appendix 2 Water saturation estimation by Indonesia equation

TVD	Vcl	Log values, ohm-m			Calculated			Constants		Calculated			
meter		Rcl	Rxo	Rt	Φe	Rw	Rmf	a	m	Sw	Sxo	MHI	BVW
2588	18.52	3	10.0	8.0	20.19	0.10	0.436	1.4	1.54	0.39	2.06	0.19	0.08
2589	18.52	3	15.0	10.0	17.04	0.10	0.436	1.4	1.54	0.39	1.92	0.20	0.07
2590	18.52	3	12.0	8.0	17.57	0.10	0.436	1.4	1.54	0.43	2.10	0.20	0.08
2591	18.52	3	10.0	8.0	19.14	0.10	0.436	1.4	1.54	0.40	2.15	0.19	0.08
2592	18.52	3	18.0	15.0	13.37	0.10	0.436	1.4	1.54	0.37	2.11	0.18	0.05
2593	18.52	3	12.0	12.0	18.61	0.10	0.436	1.4	1.54	0.34	2.01	0.17	0.06
2594	18.52	3	15.0	10.0	20.71	0.10	0.436	1.4	1.54	0.34	1.65	0.21	0.07
2595	18.52	3	15.0	9.0	19.66	0.10	0.436	1.4	1.54	0.38	1.72	0.22	0.07
2596	18.52	3	13.0	8.0	19.14	0.10	0.436	1.4	1.54	0.40	1.89	0.21	0.08
2597	18.52	3	14.0	9.0	19.66	0.10	0.436	1.4	1.54	0.38	1.78	0.21	0.07
2598	18.52	3	13.0	8.0	18.61	0.10	0.436	1.4	1.54	0.41	1.93	0.21	0.08
2599	18.52	3	8.0	6.0	16.52	0.10	0.436	1.4	1.54	0.51	2.69	0.19	0.09
Average			**12.9**	**9.3**	**18.65**					**0.40**	**2.00**	**0.20**	**0.07**

Calculation:
Formation depth: 2595m
Water saturation for un-invaded zones, Sw = (1/Rt)[{Vcl (1-0.5Vcl)/(Rcl) 0.5}+{Φe 0.5m/(aRw)0.5}]

Sw = (1/9)[{0.167 (1-0.5×0.167)/3 0.5}+{0.196 0.5×1.54/(1.4×0.10)0.5}] = 0.38

Water saturation for flushed zones, Sxo = (1/Rxo)[{Vcl (1-0.5Vcl)/(Rcl) 0.5}+{Φe 0.5m/(aRmf)0.5}]

Sxo = (1/15)[{0.167 (1-0.5×0.167)/30.5}+{0.196 (0.5×1.54)/(1×0.436)0.5}] = 1.72

Bulk Volume Water (BVW) = Water saturation × porosity = 0.38×0.196 = 0.07
Moveable Hydeocarbon Index, MHI = Sw/Sxo = 0.38/1.72 = 0.22

Appendix 3 Water saturation estimation by Indonesia equation

TVD	Resistivity, ohm-m			Calculated (%)			BVW
meter	Rt	Rcl	Rw	Vsh	Φe	Sw	
2588	8.0	3.0	0.10	24.65	20.19	49.45	0.100
2589	10.0	3.0	0.10	20.41	17.04	52.40	0.089
2590	8.0	3.0	0.10	29.53	17.57	56.79	0.100
2591	8.0	3.0	0.10	20.41	19.14	52.17	0.100
2592	15.0	3.0	0.10	10.68	13.37	54.54	0.073
2593	12.0	3.0	0.10	20.41	18.61	43.80	0.082
2594	10.0	3.0	0.10	13.49	20.71	43.15	0.089
2595	9.0	3.0	0.10	14.73	19.66	47.90	0.094
2596	8.0	3.0	0.10	13.49	19.14	52.20	0.100
2597	9.0	3.0	0.10	13.49	19.66	47.91	0.094
2598	8.0	3.0	0.10	27.50	18.61	53.63	0.100
2599	6.0	3.0	0.10	13.49	16.52	69.83	0.115
Average				**18.52**	**18.35**	**51.98**	**0.095**

Calculation:

Formation depth: 2595m

Water saturation, Sw ={(0.4Rw/ Φe2)}×[√{(Vsh/Rsh)2+ (5Φe2)/ (Rw×Rt)}-(Vsh/Rsh)]

Sw ={(0.4×0.10/ 0.1962)}×[√{(0.147/3)2 + (5×0.1962)/ (0.10×9)}-(0.147/3)] = 0.479

Gas saturation, Sg= 1-0.479=0.521

Bulk Volume Water (BVW) = Water saturation × porosity = 0.479×0.196 = 0.094