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Reservoir Characterization and Reserve Estimation of Shahjadpur-Sundalpur Gas Field Using Wireline Log Data

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Abstract— Reservoir characterization is a detailed description of a reservoir using all available data. The hydrocarbon storage capacity is characterized by the effective porosity and size of the reservoir, whereas the deliverability is a function of permeability. Porosity and permeability are key parameters that are readily measured on rock samples and from well log analysis. This study shows the determination of reservoir rock properties and volumetric reserve estimation of Shahjadpur-Sundalpur gas field (well-2) using wireline log data. Hydrocarbon bearing zone of a reservoir is detected by Resistivity log, Porosity logs and Lithology logs. Porosity has been determined by using Sonic, Density and Neutron logs. Effective porosity has been calculated from neutron-density combination formulae. Log derived permeability is estimated using Wyllie & Rose equation. Water saturation has been estimated from Archie formulae, Indonesia equation and Simandoux model with the help of resistivity log data. At last reserve is estimated using volumetric method.

Index Terms— Porosity, Permeability, Shale Volume, Water Saturation, Resistivity, Density log, Neutron log.

1 Introduction

A reservoir rock may be defined as any rock that has sufficient porosity and permeability to allow oil and gas to accumulate and be produced in commercial quantities. Porosity and permeability are the most significant rock properties which depend on the lithological, structural and compositional behavior of reservoir rock. [1]

Reservoir characterization is a term which integrates all available data to define the geometry, distribution of physical parameters, and flow properties of a petroleum reservoir. Well logs is one of the most significant method, used in oil and gas industry for reservoir characterization. Well logging is performed in the boreholes which are drilled for the oil and gas, mineral, groundwater and geo-thermal exploration. This method provide insight into the formations and conditions in the subsurface , aimed primarily at detection and evaluation of possibly production horizons and calculate the hydrocarbon volume, and many others. By using wireline log data, one may be able to calculate Shale volume (Vsh), Water saturation (Sw), Porosity (φ), Permeability (k). [2]

To get a clear idea about a formation it must be evaluated. Formation evaluation is the process that characterizes rock and fluid properties based on downhole measurements, formation testing, and laboratory analysis services. Petrophysical analysis uses a wide variety of measurements which leads to an understanding of the reservoir and its detailed characteristics. This process also determines the best means for their recovery. [3]

The main objectives of reservoir characterization are the description and the characterization of the reservoir heterogeneities that control the fluid flow combined with geological and structural model of the reservoir. This study is also to demonstrate the understanding of the petrophyiscal application of wireline logs in hydrocarbon evaluation and its significance in gas exploration and exploitation in regions similar to the study area.

2 Location of The Field

Shahjadpur-Sundalpur gas field is located in Companygonj upazila of Noakhali district about 14 km East of Noakhali town (Fig.-1). Sundalpur gas field was discovered by BAPEX in 2011. This structure is considered as southern extension of Begumganj structure. BAPEX has completed 200 km seismic and after interpretation of the data has finalized the well location. [4]

Figure 1: Location Map of Shahjadpur-Sundalpur Well # 2. [4]

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3. Final Stage Reservoir Characterization

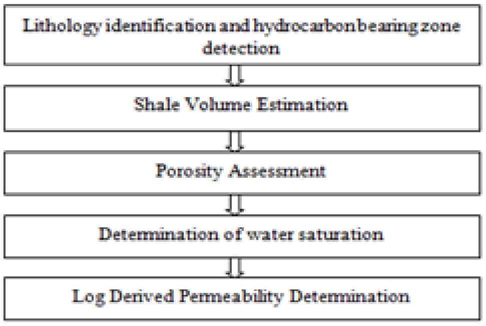

Figure 2: Procedure of Reservoir Characterization.

3.1 Lithology and Hydrocarbon Bearing Zones Detection

Understanding reservoir lithology is the foundation from which all other petrophysical calculations are made. The lithology of the formation has been identified by the analysis of SP log and Gamma Ray log. Calipar log is also used for the purpose of lithology identification. Hydrocarbon bearing zone is detected by Resistivity log and Porosity log comparing with Gamma Ray log response.

3.2 Shale Volume Estimation

A high gamma ray response implies the presence of shale, while a low response implies the presence of clean sands or carbonates. Shale is usually more radioactive than sand or carbonate. Shale volume in porous reservoirs is calculated by using this log. Calculation of the gamma ray index is the first step needed to determine the volume of shale from gamma ray log. The gamma ray log has several nonlinear responses and linear responses. The nonlinear responses are based on geographic area or formation age.

$$V_{sh} = I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$$

Nonlinear response: Larionov (1969) for Tertiary rocks: [5]

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

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Where, V_{sh} = shale volume, I_{GR} = Gamma Ray index

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3.3 Porosity Assessment

Porosity of the formation has been determined using three different types of logs such as:

- Density Log.
- Neutron Log.
- Sonic Log.

A density-logging tool sends gamma rays into a formation and detects those that are scattered back. When gamma rays enter the surrounding rocks where some are absorbed. Some gamma rays survive to reach scintillation counters mounted above the source. The number of gamma rays arriving at the far detector is inversely proportional to the electron density of the rock, which in turn is proportional to the actual rock density. Density porosity can be determined by using the following formula: [5],[6]

$$\varnothing_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}}$$

Where, $\varnothing_D$ = desity derived porosity, ρ_{ma} = matrix density, ρ_{fl} = fluid density.

Neutron logs are based on particle physics concepts. Neutron logs all emit neutrons from a source at the bottom of the tool. In older tools, fast thermal neutrons are sent out, which are captured by hydrogen atoms. Gamma rays of capture are emitted to balance the energy. The number of gamma rays returning to the detector is inversely proportional to the number of hydrogen atoms, which is highly related to the porosity of the rock. [6]

The true porosity may be estimated either by taking an average of the two log readings or by applying the equation: [5]

$$\varnothing_{N\text{-}D} = \left(\frac{\varnothing_N^2 + \varnothing_D^2}{2}\right)^{0.5}$$

Where, $\varnothing_N$ = neutron derived porosity, $\varnothing_{N-D}$ = neutron-density combination.

3.4 Water Saturation Estimation

Water saturation (S_w) of a reservoir's uninvaded zone is calculated by Archie (1942) formula [5]

$$S_w = \left(\frac{a * R_w}{R_t * \varnothing^m}\right)^{1/n}$$

Where, S_w = Water saturation, R_w= Formation water resistivity, R_t= True resistivity of formation, ϕ= Porosity, m= cementation factor, n= saturation exponent.

Simandoux Equation: [5]

$$S_w = \frac{0.4 * R_w}{\phi_e^2} * \left(\sqrt{\frac{\left(\frac{V_{sh}}{R_{sh}}\right)^2 + 5\phi_e^2}{R_w * R_t}} - \frac{V_{sh}}{R_{sh}} \right)$$

Where, S_w = Water saturation, R_w = Formation water resistivity, R_t = True resistivity of formation, V_{sh} = Shale volume, ϕ_e= Effective porosity.

Indonesia Method: [5]

Water saturation for un-invaded zones,

$$S_w = \left(\frac{1}{R_t}\right) * \left(\frac{V_{cl}^{\,1 - 0.5V_{cl}}}{R_{cl}^{0.5}} + \frac{\phi_e^{0.5m}}{a^* R_w^{0.5}} \right)$$

Water saturation for flushed zones,

$$S_w = \left(\frac{1}{R_{xo}}\right) * \left(\frac{V_{cl}^{\,1 - 0.5V_{cl}}}{R_{cl}^{0.5}} + \frac{\phi_e^{0.5m}}{a^* R_{mf}^{0.5}} \right)$$

Where, R_w = Formation water resistivity, R_t = True resistivity of formation, ϕ_e= Effective porosity, R_{cl} = Clay zone resistivity, R_{xo} = Flushed zone resistivity, R_{mf} = Mud filtrate resistivity, m = cementation factor.

3.5 Permeability from Logs

Log-derived permeability formulas are only valid for estimating permeability in formations at irreducible water saturation (schlumberger, 1977). Wyllie and Rose (1950) give two formulas for determining permeability. The following formulas are [5]

$$K = \left(79 * \frac{\Phi^3}{S_{w\,irr}}\right)^2 \qquad (dry\ gas)$$

Where, K = permeability in millidarcys, ϕ = Porosity, S_{wirr}=Water saturation of a zone at irreducible water saturation.

4 Reserve Estimation

The volumetric method determines the areal extent of the reservoir, the rock pore volume, and the fluid content within the pore volume. This provides an estimate of the amount of hydrocarbons-in-place in that rock volume. Then the ultimate recovery can be estimated by using an appropriate recovery factor. [7]

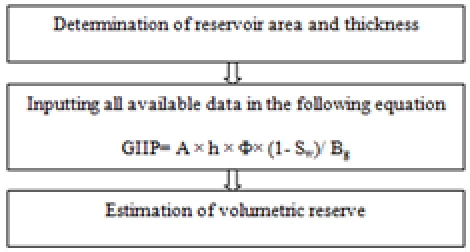

Figure 3: Procedure of Volumetric Reserve Estimation.

Recovery factor, converts hydrocarbon in place to reserves or recoverable hydrocarbon, are also average values over the hydrocarbon pore volume. A general formula for the calculation of the volume of hydrocarbons in a reservoir is represented as: [7]

$$GIIP = \frac{A^* h^* \phi^* (1-S_w)}{B_g}$$

Where, GIIP = intial gas in place, A = hydrocarbon-bearing area of the reservoir, h = net productive thickness or pay of the reservoir, ϕ= porosity, S_w = water saturation, B_g = Gas formation volume factor.

5 Results and Discussions

5.1 Lithology and Hydrocarbon Bearing Zones Detection

By the analysis of Gamma Ray log and SP log the formation lithology was interpreted. After interpreting lithology, the Gamma Ray log and SP log were analyzed further and the hydrocarbon bearing zone was detected. From the analysis of different logs, for well-2, a gas bearing sand zone was found between 1395-1407m depth. Water bearing sand zone was detected between 906-950m, 987-1014m and 1375-1393m. Shale volume was calculated by using Gamma Ray log values and True resistivity method. For well-2, the average shale volume calculated using Gamma Ray log was 26.12% and the average shale volume estimated using true resistivity method was 32.76%.

5.2 Porosity Assessment

Three different methods were used to determine porosity. Porosity was calculated for different depths using density and neutron logs at well-2. Effective porosity was determined from Neutron-Density combination formula. At well-2, the average porosity calculated using neutron and density porosity method were 9.15% and 18.68% respectively. After that the average effective porosity estimated using neutron-density combination formulae was 21.99%.

Table 1

Different values of porosity obtained by several methods at different depths

Depth, m TVD	PHIN (%)	PHID (%)	PHIND (%)
1395	13.18	28.92	22.47
1396	2.86	-19.74	14.10
1397	4.72	39.9	28.41
1398	4.06	-21.56	15.51
1399	2.85	34.37	24.39
1400	8.00	33.14	24.11
1401	17.38	19.82	18.64
1403	7.40	38.6	27.79
1404	8.32	-20.71	15.78
1405	5.20	35.35	25.26
1406	14.98	31.95	24.95
1407	20.85	24.07	22.52

Plotting the different values of porosity obtained from sonic log with respect to depth change which can be shown below:

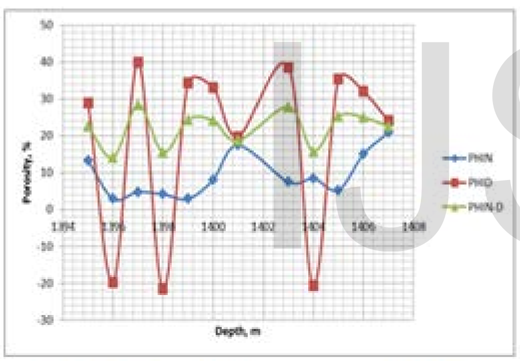

Figure 4: A curve showing relation between porosity and depth change (Well-2).

5.3 Resistivity Calculation

Formation water resistivity was determined from formula and taken as 0.102 ohm.m and mud filtrate resistivity was found 0.6 ohm.m for well-2. Formation true resistivity R_t was estimated directly from True resistivity log. The average value of R_t was 13.23ohm.m. Flushed zone resistivity R_{xo} is calculated from RFOC log directly.

5.4 Water Saturation Estimation

Water saturation was calculated using three different methods. For well-2, the value of average water saturation found from Archie, Indonesia and Simandoux model were 14.6%, 37%, 40.68% respectively.

Table 2

Water Saturation estimation Archie, Indonesia and Simandoux method

Depth, m	Sw (Archie)	Sw (Indonesia)	Sw (Simandoux)
1395	0.169	0.43	47.32
1396	0.171	0.39	47.63
1397	0.079	0.21	21.92
1398	0.147	0.35	41.08
1399	0.092	0.24	25.81
1400	0.103	0.27	28.70
1401	0.165	0.41	46.12
1403	0.098	0.26	27.44
1404	0.187	0.44	52.19
1405	0.143	0.37	39.94
1406	0.167	0.44	46.69
1407	0.226	0.58	63.35

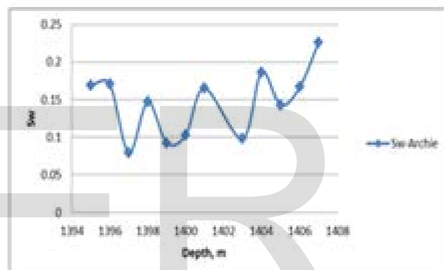

Figure 5: Depth vs Water Saturation calculated using Archie formula (Well-2).

In this figure, the values of water saturation using Archie's formula are ranging from 8-22%.

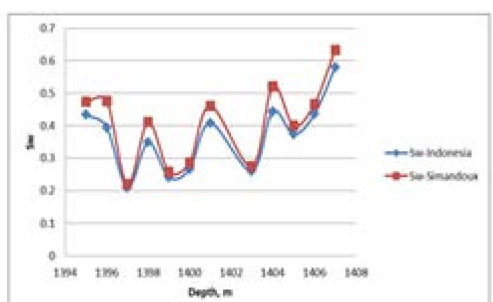

Figure 6: Depth vs Water Saturation calculated using Indonesia and Simandoux method.

It is seen that the value of water saturation obtained by Archie formulae is less than the value of water saturation obtained by Indonesia and Simandoux model. But the values obtained by Indonesia and Simandoux model are more close.

5.5 Log Derived Permeability

The log derived permeability of the gas zone has been calculated using Wyllie & Rose equation. Irreducible water saturation was taken as .079. The average log derived permeability for gas zone at well-2 is 110 mD.

5.6 Volumetric Reserve Estimation

For the gas bearing sand zone at well-2 between 1395-1407 m depth, the Gas Initial In Place is 0.0105 TCF.

6 Conclusions

Estimation of a hydrocarbon reserve is a complex process because it involves integrating geological and engineering data. In this paper, Volumetric reserve estimation method is used for estimating the reserve of Sundalpur well-2. Volumetric method of reserve estimation is much more dependent on quality of reservoir description. This method of reserves estimation often results in high amount because this method does not consider problems of reservoir heterogeneity.

In this paper, water saturation was estimated by three different models as Archie, Indonesia and Simandoux method respectively. Results showed that the water saturation obtained from Archie formulae was lower than the value of Indonesia and Simandoux model. Although, the average value of Archie water saturation was taken for reserve estimation.

The total amount of reserve may vary with respect to time due to accumulation or migration of gas. In this research, the total estimated reserve is actually poor because it includes both probable and proven reserve. Sundalpur-2 is still in production.

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