Reservoir Rock Properties Estimation of Habiganj Gas Field Using Core Analysis

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Abstract— This Study has been undertaken with a view to characterizing a hydrocarbon reservoir by qualitative core analysis of petrophysical properties of the hydrocarbon reservoir of interest along with the delineation of hydrocarbon and water bearing zone. The quality of a hydrocarbon reservoir has been described by its hydrocarbon storage capacity and deliverability which are function of effective porosity, reservoir size and permeability. Porosity and permeability are, the most important parameters to have a vivid idea of the reservoir.

Index Terms— Core Analysis, Sampling, Grain Density, Porosity, Permeability, Fluid Saturation, Electical Resistivity.

1 Introduction

CORE analysis is one of the most elementary processes for reservoir characterization, in oil and gas industry. It is very essential for petroleum geologist to acquire more knowledge about the condition below the surface by using petrophysical properties of rocks. This method is very useful to detect hydrocarbon bearing zone, evaluate the hydrocarbon volume, and many others. Some approaches are needed to characterize reservoir, by using core analysis data, one can calculate: Shale Volume (Vsh), Water Saturation (Sw), Porosity (φ) and Permeability (k). Core analysis must be done following all necessary steps included in the process and it should not be analyzed randomly because, the result might be a total error.

Reservoir is the most important geologic information which can be termed as a subsurface volume of rock having enough porosity and permeability to store hydrocarbon under adequate seals and traps. Whereas Reservoir Characterization is influentially known as a term which integrates all available data to define the geometry, distribution of physical parameters, and flow properties of a petroleum reservoir. Basically petrophysical properties are used in reservoir characterization, which are mostly based on geology. [1]

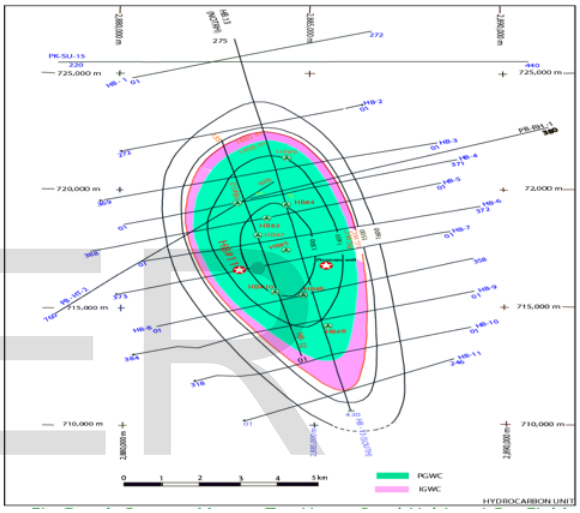

Fig. 1. Depth Contour Map on TOP Upper Sand in Habiganj Gas Field [3]

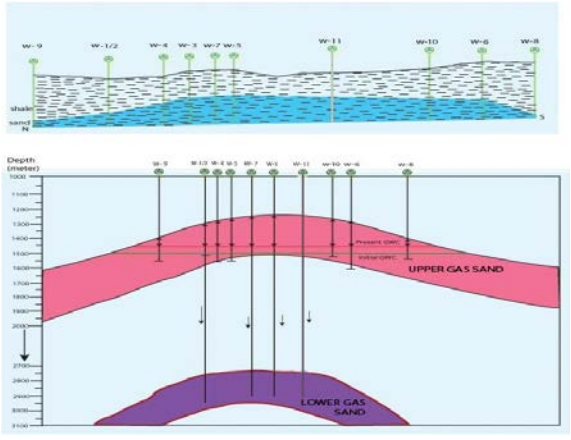

Fig. 2. Cross-sectional view of the subsurface of Habiganj gas field, Bangladesh [3]

2 Location Of The Field

The Habiganj gas field is located in Habiganj district and lies 32 km northeast of Titas gas field. The gas field was discovered by Shell Oil Company in 1963 and has been one of the major gas producers in the country. The reservoirs are sandstones belonging to the Surma Group (Bhuban and Bokabil Formations) of Miocene-Pliocene age. There are two gas zones known as upper gas sand (UGS) and lower gas sand (LGS). The upper gas sand lies at a depth of 1320 meter below surface and has a maximum gross pay 230 meter thick. These gas sand is medium to fine grained, well sorted, clean, and unconsolidated. The lower sand lies at a depth of about 3000 meter below surface and is thinner and has lesser areal extent than upper gas sand and the gross pay of the lower sand is 15 meter thick. [2]

3 Literature Review

3.1 Core Analysis

Laboratory study of a sample of a geologic formation, usually reservoir rock, taken during or after drilling a well. Petrophysical measurements are made in the borehole and on cores in the laboratory to determine the major reservoir properties: porosity, permeability, fluid saturations and resistivity by log or core analysis technique. Core analysis is especially important in shale reservoirs because of the vertical and lateral heterogeneity of the rocks. Core analysis can include evaluation of rock properties and anisotrophy; organic matter content, maturity, and type; fluid content; fluid sesitivity; and geomechanical properties. This information can be used to calibrate log and seismic measurements and to help in well and completion design, well placement, and other aspects of reservoir production. [4]

3.2 Petrophysical Properties

3.2.1 Porosity

Porosity is the ratio of pore volume and bulk volume. A number of techniques are employed for the measurement of porosity in consolidated rocks. Boyle's-law helium-expansion is a standard method for measuring either pore volume or grain volume. Bulk-volume measurements are generally determined by fluid displacement (Archimedes principle) or by callipering plug samples. With Boyle's-law and bulk-volume data, bulk and grain densities can be determined by also weighing the sample.

3.2.2 Permeability

The ability, or measurement of a rocks ability, to transmit fluids, typically measured in Darcies or milliDarcies. Absolute permeability is the measurement of the permeability conducted when a single fluid, or phase, is present in the rock. Effective permeability is the ability to preferentially flow or transmit a particular fluid through a rock when other immiscible fluids are present in the reservoir (for example, effective permeability of gas in a gas-water reservoir). Relative permeability is the ratio of effective permeability of a particular fluid at a particular saturation to absolute permeability of that fluid at total saturation. Calculation of relative permeability allows for comparison of the different abilities of fluids to flow in the presence of each other, since the presence of more than one fluid generally inhibits flow. [5]

3.2.3 Fluid Saturation

Saturation is the measure of the fluid volume present in the pore volume of a porous medium. By definition, the saturation of a fluid is the ratio of the fluid volume to the pore volume or the rock. Hence, considering the fluids typically present in a reservoir rock: $S_w + S_o + S_g = 1$

Where S_i and = w, o, g are the saturations and volumes of water, oil, and gas. The sum of saturation of each fluid phase is equal to unity since the pore space is completely filled with fluids (or at least the effective pore volume). Because the fluids and their saturations in the pore space may vary from point to point and pore to pore, the values of saturation are meaningful only for samples large enough for the porous medium to be considered a continuum. [6]

4 Procedure And Core Data Analysis

The petrophysical parameters determination processes are followed by three stages:

- Procedures for Sampling.
- Routine Core Analysis.
- Special Core Analysis

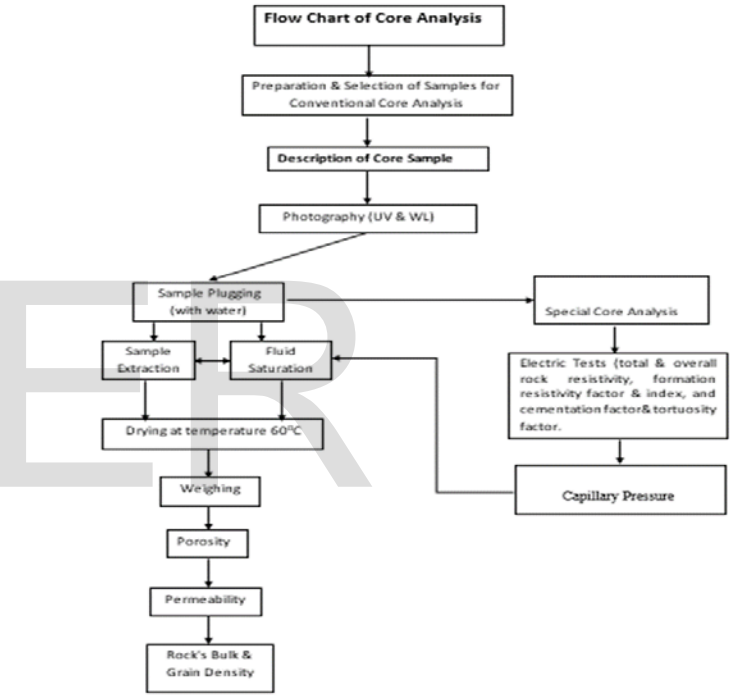

Fig. 3. Flow Diagram of Core Analysis

4.1 Procedures For Sampling

Measure depth of sample collection. Frequency of sample selection is about 1' or 1 m (depends on the core owner request). Note depth, sample no. & orientation of core by, for example, an Arran& hammer out a piece of stone about 3" (5-10 cm) long. One sample (30-40 g) is selected for fluid saturation measurement (protection from fluid evaporation is necessary; if not proceeding immediately to the distillation apparatus). [7}

- Horizontal &/or vertical plugs or samples are drilled separately.
- Return core sample to the exact same place & orientation.
- For accommodating laboratory equipment, plugs must be sawn to practical lengths (viz, 1" to 4"). Re-

turn plugs trimmings to holes where plugs were drilled in the core.

- Before cleaning in extractor, plugs are washed in water to remove saw dust or mud. Dry plugs slightly to allow permanent marking of plug or sample no. with a felt pen.
- After marking, they are placed in a soxhlet extractor and cleaned using methanol, then toluene and again with methanol in that order (1 day 7-8 hrs for 1st methanol wash, 2 days 14-16 hrs for toluene wash, final methanol wash to last about 4-6 hrs).
- When clean, the plugs must be dried at 30-60˚C (average 50˚C) overnight; and then plugs must be cooled to ambient conditions before petrophysical analysis.

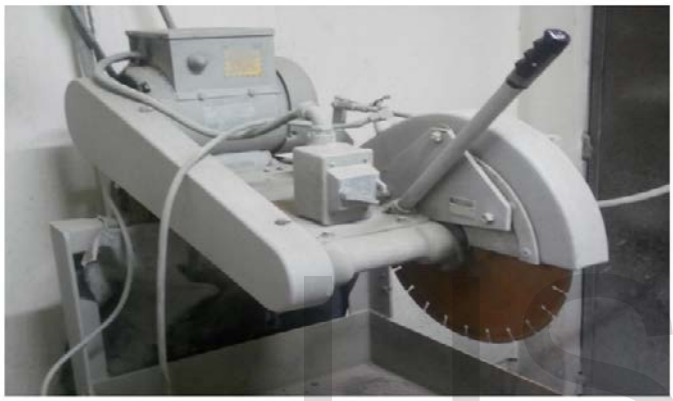

Fig. 4. Core Cutting Machine [8]

Fig. 5. Core extraction instrument. [8]

4.2 Routine Core Analysis

After procedures for sampling, the following parameters are estimated accordingly.

4.2.1 Core Photography

The fully automated core photography system is designed for complete core photography and archiving purposes, producing high quality white & UV color images of full diameter whole or slabbed cores. The lights are oriented at a 45° angle for maximum coverage from each side of the core material being photographed without having to place the lights directly over the material to be photographed. Oil show indicators are found by examination of the rock samples for oil stain, bleeding, fluorescence or cut. Stain is the trace of asphaltic material left behind on drill cuttings after the oil has been washed off during drilling. Stain left by high quality oil has a typical iridescent sheen, visible in normal light. Bleeding is the exudation of oil from the pores due to pressure release as the sample is brought to the surface. Fluorescence represents oil's distinctive ability of emitting light in the visible range when exposed to UV light. Unfortunately, quite a number of minerals and many refined products are fluorescent, so there is a certain amount of technique involved in distinguishing between primary HC's and refined products or fluorescent minerals. However, if HC's are present in the rock, they will disseminate into the solvent, giving the entire solvent a distinctive color under UV light. This sheen under UV light is called cut and the color of the cut indicates the quality of the oil. For oil shows to note the amount, intensity & color of the fluorescence due to HC's, core analysts note the present of fluorescence (under UV light) in the total representative sample, the intensity of fluorescence (weak, fair, or strong) and the color of the fluorescence (brown, yellow-brown, yellow-orange, blue-white etc.). (i) Darker color (orange-brown) - associated with low gravity crudes (ii) Yellow color - is medium gravity oils (iii) Lighter color (yellow-white or pale blue-white) - indicative of high gravity oils. Typically, slabbed core sections are photographed under white as well as under UV light to capture the oil (if present) fluorescence. The operator positions the core samples on a four rows rack and a digital camera mounted above the core samples under white or UV lighting takes a high resolution picture. The images are then automatically digitized, displayed & recorded in the high speed computer. [7]

Fig .6. Instrument of core photography. [8]

4.2.2 Porosity Assessment

The considered composition of a core sample is three volumes: pore volume (Vp), grain or matrix volume (Vg) & bulk volume (Vb); where bulk volume (Vb) = grain volume (Vg) + pore volume (Vp). Hence, porosity may be determined in one of the following ways:

$$\phi = \frac{V_p}{V_b} \times 100\%$$

$$\phi = \frac{V_b - V_g}{V_b} \times 100\%$$

$$\phi = \frac{V_p}{V_p + V_g} \times 100\%$$

The above considered composition of a core sample is measured in following determinations ways: [7]

(a) Bulk volume measurement or determinations by i. Physical caliphering of the length & diameter of a core sample and then calculating the volume, ii. Actual measurement if sample is regular, iii. Mercury pycnometer method.

(b) Grain Volume Measurements may be made by i. Direct measurement with the Porosimeter while the core sample is contained in a matrix cup, or ii. Calculation from known grain density, iii. Archimedes' Principle.

(c) Pore volume measurement by i. Boyle's Law Porosimeter, ii. Mercury Injection Method, iii. Fluid saturation method.

So, the porosity is measured by one of several methods depending on the type of samples.

After analyzing the core data of the Habiganj Gas Field we derieved following results.

Table 1

Porosity of the formation in Habiganj well No. 11

S/N	Depth (m) point in succession	Sample No. in random	Porosity, Φ in %
1	3086.7	6	6.16
2	3087	8,8e	10.84
3	3087.5	9	11.6
4	3087.7	3	10.56
5	3087.9	4,4e	6.82
6	3088	10	9.82
7	3088.5	11	12.32
8	3088.6	12	13.31
9	3088.9	7,7e	12.2
10	3089	2	10.73

4.2.3 Grain Density Measurement

Grain Density of samples is the ratio of the sample's dry weight to grain volume, D_g or $\rho_{ma} = W_d/V_g$, gm/cc.

It is determined by Helium Porosimeter in the following equation: [7]

$$\text{Grain density } (\rho_{ma}) = \frac{Dry\ wt. - (sp.\ gr.\ of\ oil \times bulk\ volume \times oil\ bulk)}{Bulk\ volume\ (1 - 0.01 \times porosity)} \times 100$$

$$\text{Grain density } (\rho_{ma}) = \frac{Dry\ wt. - (sp.\ gr.\ of\ oil \times bulk\ volume \times oil\ bulk)}{Grain\ volume} \times 100$$

In this case, first weight of each sample taken after it has been extracted and dried and then grain volume is determined by porosimeter. The results of the analysis is shown below.

Table 2

Grain Density of the formation in Habiganj well No. 11

S/N	Depth (m) point in succession	Sample No. in random	Grain Density (D_g) gm/cc
1	3086.7	6	2.7
2	3087	8,8e	2.7
3	3087.5	9	2.7
4	3087.7	3	2.7
5	3087.9	4,4e	2.7
6	3088	10	2.7
7	3088.5	11	2.7
8	3088.6	12	2.7
9	3088.9	7,7e	2.7
10	3089	2	2.7

4.2.4 Permeability Determination

The air permeabilities are determined by using an Air permeameter with high accuracy ensured by calibrated orifices and differential pressure manometers which are built-in at digital equipment. Here compressed dry air uses as fluid to flowing medium, implementing a hassler confining pressure of 200 psig. Hence, Darcy's equation is used to calculate core sample permeability using the data obtained from Air Permeameter.

$$\text{Permeability, } k = C \times Q_a \times \frac{L}{A}$$

Where,

$$C \text{ Value} = \text{Mercury Column} = \frac{P_a \mu (1000)}{(MP)(DP)},\ Q_a = \text{Flow rate, cc/sec} = \frac{O \times W}{200},$$

k = Permeability, mD, Pa = Atmospheric pressure, mmHg/760, μ = Air viscosity, cp, MP = (P1+ P2)/2 = Mean pressure, psia, DP = (P1– P2) = Differential pressure (Inlet-Outlet), psia, 200 = Net Over burden (NOB) Pressure (psi), O = Orifice reading = Orifice Q Value, W = Water Column = Orifice Water, L = Sample length, cm, A = End section area (cm²) of the sample.

Or,

The length of the sample, upstream & downstream pressures, flow rate, viscosity of nitrogen, barometric pressure & temperature are entered into Darcy's equation for gas permeability, and the permeability of the sample calculated as follows: [9]

$$k_g = 2.2\frac{\mu_g L Q_g P_b}{A(P_1^2 - P_2^2)}$$

Where: Kg = Gas permeability, mD, µg = Gas viscosity, cp, Qg = Gas flow rate, ft3/sec, L = Sample length, ft, A = Cross-sectional area, ft2, Pb = Barometric pressure, psi, P1 = Upstream pressure, psi, P2 = Downstream pressure, psi.

The following results show the permeability variation of Habiganj Gas Field, well No. 11.

Table 3

Permeability of the formation in Habiganj well No. 11

S/N	Depth (m) point in succession	Sample No. in random	Permeability (k) in md	
			Horizontal	Vertical
1	3086.7	6	25.04	-
2	3087	8,8e	25.49	35.85
3	3087.5	9	38.36	-
4	3087.7	3	-	-
5	3087.9	4,4e	37.78	16.24
6	3088	10	-	-
7	3088.5	11	63.38	-
8	3088.6	12	-	-
9	3088.9	7,7e	40.38	32.32
10	3089	2	-	-

4.2.5 Fluid Saturation Estimation

Fluid saturation is fraction of the effective porosity which is occupied by reservoir fluid remaining in the pores when brought to the surface and at the time of extraction or retorting in suitable apparatus. This is done by two methods: i) Dean Stark Distillation. ii) Retort Method. [7]

$$S_f = \frac{Fluid\ Volume\ (V_f)}{Pore\ Volume\ (V_p)} \times 100\%$$

The method of determining fluid saturation is by extraction with a solvent (e.g., toluene) using the Dean Stark distillation apparatus. The water saturation (Sw) can be determined directly using this method, i.e.

$$S_w = \frac{Water\ volume}{Pore\ Volume} \times 100\%$$

The oil saturation (So) is an indirect determination as percent of pore volume,

$$S_o = \frac{(Wet\ samples\ weight\ -\ dry\ sample\ weight\ -\ water\ weight)}{(Pore\ volume).(oil\ density)} \times 100\%$$

Sg = 1 – Sw – So

The results of the fluid saturation analysis is given below.

Table 4

Fluid Saturation of the formation in Habiganj well No. 11

S/N	Depth (m) point in succession	Sample No. in random	Fluid Saturation (S_f),in %		
			Water, S_w	Oil, S_o	Gas, S_g
1	3086.7	6			
2	3087	8,8e	52.30	10.70	37.00
3	3087.5	9	50.00	-	-
4	3087.7	3	56.15	-	-
5	3087.9	4,4e	66.70	10.30	23.00
6	3088	10	58.60	-	-
7	3088.5	11	46.90	-	-
8	3088.6	12	43.50	10.00	46.50
9	3088.9	7,7e	50.50	20.50	29.00
10	3089	2	49.10	29.90	21.00

4.3 Special Core Analysis

4.3.1 Rock Electrical Resistivity

Method used for this measurement is the direct measurement of resistivity of a 100% or partially brine-saturated core. The electrical properties of reservoir rocks are studied by 4-electrodes Resistivity Meter at ambient temperature & pressure. All core plugs (for overall rock resistivity determination) are thoroughly saturated by prepared brine of 15,000 - 30,000ppm concentration (or the samples were previously brine saturated with imitating formation water; salinity NaCl: 15,000 - 30,000ppm). Brine solution with 30,000 ppm concentration has been used for all rock samples brine saturation which reflects formation water properties most.

$$R_c = C_r \times \frac{A}{L} \times \frac{1}{100}$$

Where, Rc = Resistivity in Ohm-meter (Ω-m), Cr = Measured resistance of partially/brine saturated sample in ohm (Ω), A = Cross sectional/cube face area of the sample in cubic centimeter, L = Length of the sample in centimeter.
Resistivity of brine (Rw) used in the test is also directly measured by the resistivity meter using four (4) cell electrodes.

$$Rw = Wr \times C$$

Where, Wr = Measured brine water resistance, C = Dipcell constant (0.001 m).
As the tests are fulfilled at different times and various ambient temperature T1, the results are calculated by the following formula at one symbolic temperature T2 = 250C, R25 = (measured Rc,w at T10C) . (T1 + 21.50C) / (250C + 21.50C). [10]

The electrical resistivity analysis of this zone is as follows.

Table 5
Resistivity of the formation in Habiganj well No. 11

S/N	Depth (m) point in succession	Sample No. in random	Electrical Resistivity Analysis	
			Total Rock Resistivity, R_t, in Ω -m	Overall Rock Resistivity, R_0, In Ω -m(R_w = .09)
1	3086.7	6	10.87	14.22
2	3087	8,8e	21.01	5.74
3	3087.5	9	20.14	5.06
4	3087.7	3	20.44	6.44
5	3087.9	4,4e	29.89	13.31
6	3088	10	20.12	6.91
7	3088.5	11	20.11	4.42
8	3088.6	12	20.13	3.84
9	3088.9	7,7e	15.40	4.62
10	3089	2	32.31	7.85

6 Conclusions

Reservoir properties estimation is very important and crucial for a reserve to make decisions. Estimation provides the confidence about economic feasibility to produce from a reservoir; whether it is cost worthy or not. These core samples used in this experimental study is from the depth of 3086m to 3089m. Average Porosity of this zone is around (6 - 12.5)% and grain density is almost 2.70 gm/cc. Results showed that the water saturation, oil saturation and gas saturation are around (43.5 – 59)%, (10-30)%, (21-46.5)% respectively. Both the horizontal and vertical permeability is around 25 - 63.5 md. The average total resistivity and overall resistivity of the rock is found 21 Ω-m and 7.25 Ω-m respectively. Reservoir net thickness may be changing through the formation causes for reservoir geometrically shape and shalyness. From the study it is clear that the Habiganj gas field is very prospective in respect of Bangladesh.

6 Recommendations

There is a huge uncertainty in the estimation process these petrophysical properties due to erroneous impact of human resource involvement.

- Coring should be done at proper target depth interval.
- Ending (bottom & top) part of core boxes should preserved properly by plastic cover and scotch tape to preserve reservoir fluids, So that the fluid saturation and electrical resistivity analysis could be done accordingly.
- If experts are present at the well site during the coring time, this could be maintained properly.
- In this core may be involved the use of hazardous materials, operations, and equipment. This core does not address all of the safety problems associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

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