



Estimation of T₂ cut-off and NMR permeability to characterise complex carbonate reservoir in Bassein formation, North of Mukta field

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Keywords

Low porosity carbonates, Micrite, NMR, T₂ cut-off

Abstract

The objective of this case study is to establish suitable NMR T₂ cut-off which helps to differentiate between producible and non-producible hydrocarbons in the heterogeneous low porosity carbonate reservoir of Bassein formation, North of Mukta field. It also involves calibration of permeability by determining formation permeability coefficients of the reservoir.

Low porosity carbonate reservoirs are developed as a result of combination of primary and secondary pore types affecting permeability of rocks and most of these carbonates produce hydrocarbon from low porous reservoirs after suitable activation job. Thus, an integrated study has been carried out to characterize low porosity carbonate involving integration of mineralogy specially SEM and thin section, Capillary, XRD, NMR and production data.

27 representative samples were selected after analyzing conventional and advanced log-data in reservoir section of Bassein formations of well X, Y & Z for different studies. The core determined T₂ cut-off for these carbonate reservoir has given precise data, which is vital for pore characterization, permeability prediction and irreducible water saturation estimation in Bassein formation.

Introduction

The study area (Fig-1) has a sedimentary succession ranging from paleocene to recent, resting on the Basement of Deccan trap basalt flows of late cretaceous age. The basement is uncomformably overlain by the sequence of trapwash and clastics sequence which together constitute the Panna

formation of paleocene to early eocene age. The association of fine sediments indicates that the initial supply of sediments was from basaltic provenance. As the basalt underwent extensive erosion, the underlying metamorphic/granitic rocks got exposed as inliers and subsequently they also supplied coarser sediments. The increase in sand content together with its improved quality in the younger units of Panna formation is probably due to this factor. The clastic unit of Panna formation is overlain by a very thick platform limestone sequence, designated as Bassein formation of middle to late eocene in age. Top of Bassein formation is an unconformity, and it corresponds to seismic marker H3B.

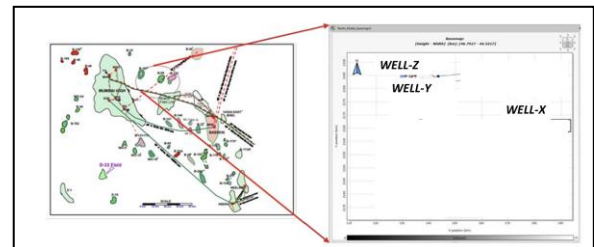
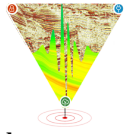


Fig-1: Location of Study area.

In a porous rock system, there will be a continuous range of pore sizes. This means that the CPMG echo-train comprises of a continuous range of relaxation times. The total NMR signal is summation of the exponentially decay signal that corresponds to particular pore-size. The initial amplitude of the spin echo train is proportional to the number of hydrogen nuclei associated with the fluids in the pores within the sensitive volume. This amplitude is calibrated in porosity units. Raw data is measured in time domain. This raw data is then converted to T₂ domain by applying Inverse Laplace Transform. T₂ distribution curve is used for porosity partitioning and also in



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permeability computation. The NMR estimated producible porosity is called the free-fluid index (FFI). However the estimation of bound and free fluid is dependent on T₂ cut-off value. The generalized T₂ cut-off values used for clastic (33 ms) and carbonates (90-100 ms) are frequently found to be unrealistic for log interpretation, due to mineralogy-dependent surface relaxivity effects which shift the T₂ spectra. Thus, it is often desirable to calibrate T₂ cut-off values with core NMR measurements.

Study approach:

The present study focusses on low porosity carbonate reservoir of Bassein formation of North of Mukta field. For this study, a total of 27 samples from Bassein formation representing three different wells were selected for NMR laboratory study. Final T₂ cut-off have been estimated on 20 samples off that formation as rest of the plugs got internally damaged during desaturation although T₂ relaxation study for the same had been carried out successfully at 100%. Plugs under study have fair to good porosity of the order 2.39-20.97p.u. and permeability ranging from 0.02-10.74mD.

NMR analysis was performed using 2 MHz low field Geospec 2/75 NMR spectrometer. The spectrometer operates at a magnet strength of ~550 Gauss. Prior to the NMR measurements, the samples were methodically cleaned and dried. Subsequent to routine petrophysical analysis and dry state NMR T₂ relaxation measurements, the samples were next saturated with NaCl brine of Formation water salinity. Later an irreducible state had to be attained to identify the T₂ cut-off for free fluid fraction (via Centrifuge). All measurements were performed at room temperature and normal atmospheric pressure.

Furthermore, mineralogical studies were carried out to decipher mineral compositions and presence of magnetic materials. Capillary pressure studies were also done to find the irreducible water saturation. Final integration of all available data was performed and an analysis was done.

The workflow of Routine core and NMR measurement is explained briefly through the following table:

Stage	Analysis/Measurement
1	Core sample preparation (Soxhlation & drying)
2	Determination of permeability, porosity and grain density (along with mass/weight measurements in dry, saturated and suspended/immersed state samples).
3	NMR T ₂ measurement on dry core
4	Brine synthesis and saturation with simulated formation brine
5	NMR T ₂ relaxation spectra measurements at Sw = 1 (inter-echo spacing 100 μs).
6	Desaturation (in stages) by spinning in centrifuge; NMR T ₂ measurement on desaturated samples at TE=100 μs
7	NMR data Analysis for T ₂ cut-off and Permeability modeling/ calibration of Permeability co-efficient

Table-1: Work flow for NMR measurement

Routine Core & NMR measurement:

1 inch diameter core plug samples were prepared by cleaning (using Toluene and Methanol as solvent) and drying (Humidity Controlled Oven). Porosity and permeability for the core plugs were determined by use of a KEY-PHI Helium Porosi-Permeameter. After the physical measurement of the oven dried plugs were made they were sent to Rock core analyzer for the dry state NMR measurements which in turn helped in finding the clay cut off later. Now the samples were saturated with a simulated formation brine at 100%. NMR experiments were performed on Rock Core Analyzer later an irreducible state had to be attained to identify the T₂ cut-off for free fluid fraction (via Centrifuge). All measurements were performed at room temperature and normal atmospheric pressure. All the NMR data has been ensured to be of good quality and the samples have a signal to-noise ratio greater than 100.

NMR T₂ Distribution:

Area under T₂ distribution curve is NMR total porosity. Long T₂s come from large pores and short T₂s from small pores, so this T₂ distribution curve represents pore size distribution of the core

NMR T₂ distributions were measured on 20 core plugs. The combined T₂ distributions of all the plugs (Bassein formation samples) are presented in Fig-2. T₂ relaxation curves (from 100% saturated sample) shows distribution in the bound water region from Bassein formation. i.e., T₂s are short to medium. Short T₂ represents small pores/micro-porosity, the

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medium T₂ represents medium sized pores and the larger T₂ represents macro-pores.

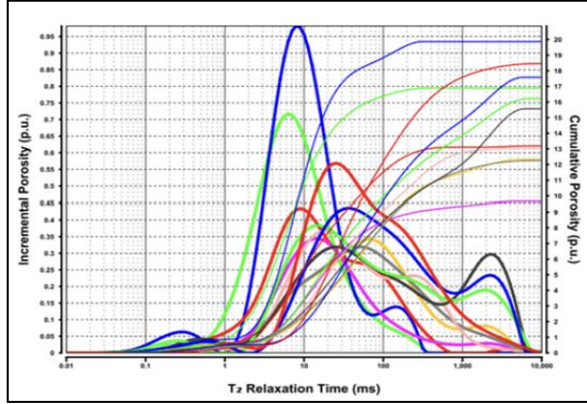


Fig-2 Combined T₂ distribution at 100% water saturation for 20 samples of Bassein formation

Sedimentological studies

1-XRD studies

13 samples representing 03 wells were considered for mineralogical studies (XRD) study from the formation, result of which is as following. According to the data, the bulk mineralogical study of the rock samples indicates Calcite as the main mineral along with significant presence of Dolomite in almost all the samples. Minor traces of Quartz and Kaolinite was also observed in some of the samples (Fig-3).

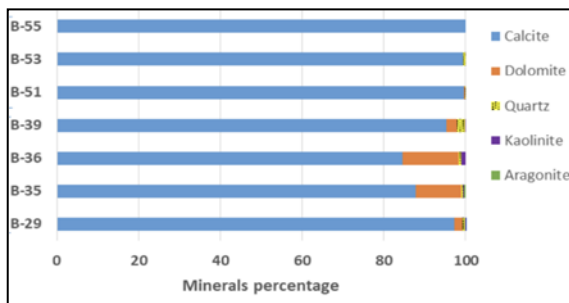


Fig-3 Graphical representation of the mineralogical analysis of Bassein formation samples, North of Mukta field.

2- Thin section & SEM

Ten (10) samples under the present study were taken from the conventional cores of the wells X, Y and Z which represents Bassein Formation. The carbonates of Bassein Formations were mostly packstone to rudstone with micrite matrix and dolomite. SEM was also carried on two samples.

Well: Z (Sample: B-22 & B-25) – Packstone/Grainstone (Fig-4): The rock is grain supported with carbonate mud matrix in interparticle pore spaces between skeletal fragments. Allochems are mainly broken part of larger benthic foraminifera. Interbioclastic spaces are occupied by fine crystals of dolomite and calcite and smaller planktonic forams and corals. These dolomites are product of neomorphism of from micritic muds. Moldic porosity is also evident. Grain supported, diagenetic texture due to compaction and pressure solution with partial grain suturing, some grain contacts are microstylolite.

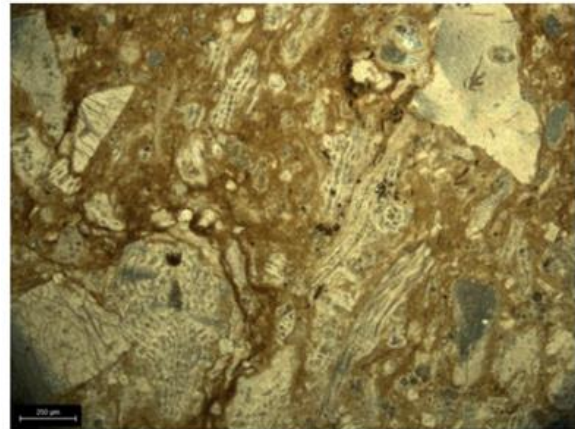


Fig-4: B-22 – Packstone XPL: 5X (XPL)

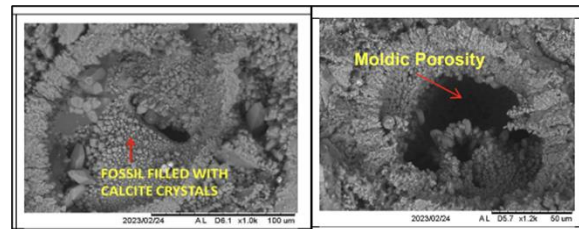
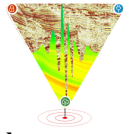


Fig-5: SEM Image: Moldic porosity and calcite crystal

SEM –EDS image shows the fossils and calcite grains, dolomite in sample of Well Y. Filling of



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porosity is also shown in the image. Presence of kaolinite clay depicted. Well-developed moldic porosity is also observed (Fig-5).

3-Capillary Pressure Studies:

A total of 8 core plug samples of all three Wells in North of Mukta field were selected for capillary pressure studies using centrifuge method. Based on capillary pressure measurements carried out using Ultrahigh rock core centrifuge on 8 core plug samples of Wells X, Y and Z in North of Mukta field, 4 distinct rock facies were identified. Behaviour of Capillary pressure curves also validated porosity permeability results of core plug samples. Irreducible water saturation (Swirr) for core plugs varied from 24.44% to 97.40% which signifies variation of Bassein formation in terms of quality of reservoir (Fig-6).

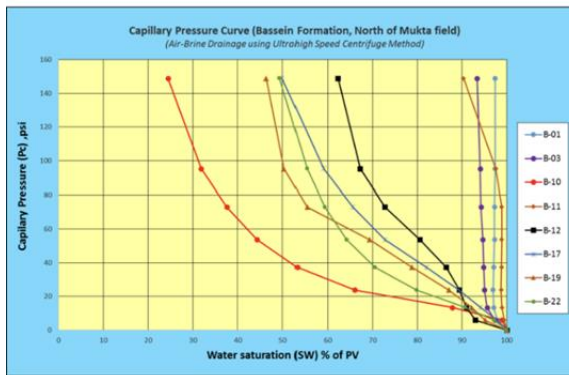


Fig-6: Capillary pressure curves for 8 core plug samples of Bassein Formation, North of Mukta Field

Discussions

T₂ cut off: Bassein formation, North of Mukta field:

In North of Mukta field, a total of 27 samples from three wells X, Y & Z representing Bassein formation were studied for the T₂ cutoff estimation. Determined T₂ cut-offs for Bassein formation were observed 99ms for well X, while lower T₂ cut off were observed in the range of 70-87 ms for the wells Y and Z. Lower T₂ cut-offs (70-87ms) were observed

in all the samples for the wells Y and Z compared to default T₂ cut-off of Carbonates (~90-100 ms) (Fig-7). The reason for the lower T₂ cut-off in Bassein formation of these two wells was the presence of micritic mud matrix in most of the samples and abundant microstylolites along with stylolites, vugs.

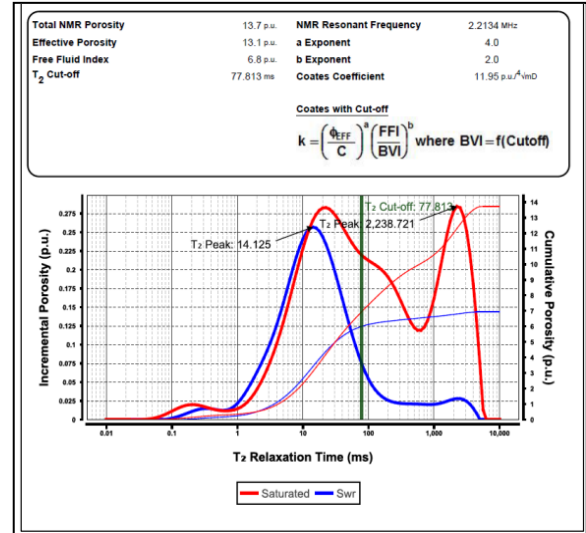
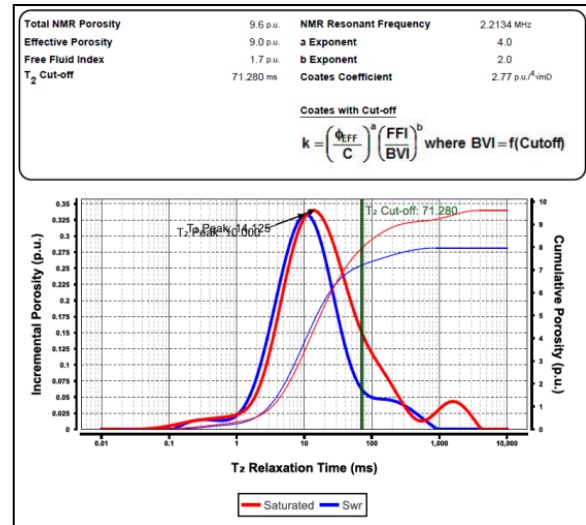
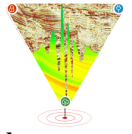


Fig-7: T₂ cut-offs for Bassein formation were observed 71-77 ms for well X.

The estimated T₂ cut off for Bassein formation in North of Mukta field is tabulated below:



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Petrophysical Study results			NMR Study Results						
Helium Porosity (p.u.)	Gas Permeability (mD)	Brine permeability (mD)	Total NMR Porosity (p.u.)	Effective porosity (p.u.)	Free Fluid Porosity (p.u.)	T2 Cut-off (ms)	NMR Perm. (Costes) (mD)	(Timus mean or SDN) (mD)	(Log MS)
6.70	0.04	0.03	8.10	7.30	1.40	99.51	0.05	0.04	
6.50	0.30	0.18	6.50	6.10	0.44	99.81	0.32	0.29	
9.40	4.64	3.68	9.70	9.00	5.50	74.56	5.14	4.62	
5.90	0.03	0.02	5.20	4.70	2.80	76.43	0.03	0.03	
21.00	9.90	8.22	22.20	21.60	17.30	77.01	13.58	9.90	
8.80	0.15	0.07	9.20	8.40	1.30	84.29	0.17	0.15	
6.40	0.34	0.22	7.00	6.40	4.30	76.48	0.40	0.34	
10.30	1.27	0.96	8.20	8.30	5.30	84.35	1.54	1.27	
8.40	5.99	5.54	7.70	7.30	5.80	70.37	7.55	6.01	
18.10	0.72	0.43	18.50	17.40	7.50	72.18	0.75	0.72	
16.70	1.01	0.69	17.10	16.10	8.40	84.17	1.10	1.01	
10.50	0.94	0.56	10.90	10.30	7.10	82.47	0.98	0.84	
12.90	1.68	1.30	13.70	12.70	7.00	77.81	1.88	1.68	
11.70	0.93	0.63	12.90	12.00	4.10	87.35	1.11	0.92	
12.00	10.74	9.80	12.00	11.40	4.40	87.31	12.95	10.74	
12.30	2.02	1.63	12.40	11.50	5.20	78.16	2.46	2.02	
10.10	5.64	4.52	9.60	8.50	1.70	71.28	5.86	5.63	
13.00	0.67	0.48	13.00	11.70	2.40	75.10	0.80	0.67	
16.50	0.43	0.23	18.60	17.50	1.40	74.63	0.49	0.42	
13.60	3.82	3.24	15.70	14.30	0.79	77.24	4.90	3.81	

Table-2: Estimated T2 cut off and permeability

Well testing results and Secondary porosity features in well Y of Bassein formation

The well Y penetrated Upper Bassein carbonate and flowed oil @ 1085 BPD and gas @ 1, 71,737 m3/d through ¾ bean from the low porosity interval XX29-XX50m. In this well FMI log was recorded in the interval XX32- XX63m. Processed FMI logs showed the presence of pressure solution features/fractures in Bassein formation, North of Mukta field (Fig-8). Good visual porosities were present with micritic mud matrix in most of the current studied samples of Bassein Formation. Vugs and pressure solution features like stylolite and microstylolites were abundant in Bassein Formation.

Tri-modal NMR distribution was observed in Bassein formation of well B-127NE-1, which implies the existence of secondary porosity. Presence of pressure solution features along with lower T2 cut-off in hydrocarbon-bearing zones are very likely to contribute to production after suitable activation job.

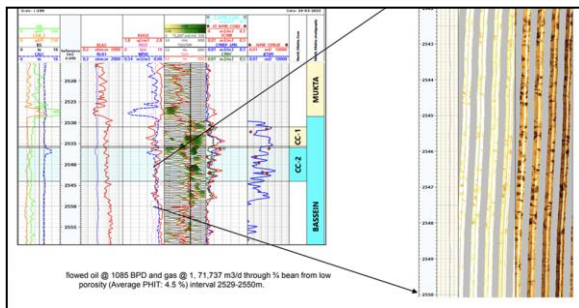


Fig-8: Log Motif and processed FMI: North of Mukta field, Bassein formation

Conclusion:

The generalized T2 cut-off values used for carbonates (90-100 ms) are frequently found to be unrealistic for log interpretation, due to mineralogy-dependent surface relaxivity effects which shift the T2 spectra. Thus, it is often desirable to calibrate T2 cut-off values with core NMR measurements.

North of Mukta field, estimated T2 cut-offs for Bassein formation were observed 99ms for well-X, while lower T2 cut off were observed in the range of 70-87 ms for the well-Y and Z. Petrographic studies show the presence of micritic mud matrix in most of the samples and abundant microstylolites along with stylolites, vugs which were the primary causatives for the variations in computed T2 cut-off.

NMR determined T2 cut-off in low porosity carbonate reservoir has given precise data, which is vital for pore characterization, permeability prediction and irreducible water saturation estimation in Bassein formation of North of Mukta field.

Tri-modal NMR distribution is observed in Bassein formation of well Z, which implies the existence of secondary porosity. Presence of pressure solution features along with lower T2 cut-off in hydrocarbon-bearing zones are very likely to contribute to production after suitable activation job.

References:

1. "Recommended Practices for Core Analysis: RP40"; American Petroleum Institute.
2. All Manuals and documents related to the Rock Core Analyser facility (Hardware as well as Software) by M/s Oxford Instruments & GIT (Canada).

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