[PS]Wireline-Log-Derived Indices for Miscible Light-Hydrocarbon-Injection Recovery in Bakken Petroleum System*

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Abstract

Bakken Petroleum System (BPS) has a great potential for enhanced oil recovery (EOR) because of the high original oil-in-place estimates accompanied by low primary recovery potential. BPS is composed of both conventional and unconventional units exhibiting significant variations in lithology, rock texture, clay content, porosity, and total organic carbon. Two wireline-log-derived EOR-efficiency indices are generated for a 200-feet depth interval in the BPS to identify flow units suitable for EOR using light, miscible hydrocarbon injection. The Microscopic Displacement (MD) Index exhibits higher resolution compared to the Ranking (R) Index. MD index relies on a novel method to calculate the miscible free-oil volume from subsurface NMR T2-distribution logs by accounting for alteration in MMP due to pore confinement effect. At a resolution of 1-foot depth interval, several flow units were successfully identified in the Middle Bakken Formation that exhibit high miscible-gas-injection recovery potential.

In-situ wireline-log-derived EOR indices provide an economical screening method to identify flow units in the Bakken Petroleum System suitable for light, miscible hydrocarbon injection. In addition, factor analysis was performed on NMR T2 distribution to estimate free-waterfilled and bound-fluid-filled porosities. The indices predict that 50% and 20% of the Middle Bakken Formation should exhibit high and intermediate recovery potentials, respectively, for miscible, light hydrocarbon injection. Indices show that the recovery potentials of the Upper and Lower Bakken formations are approximately 60% lower than that of the Middle Bakken.

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Wireline-Log-Derived Indices for Miscible Light-Hydrocarbon-Injection Recovery in Bakken Petroleum System

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Abstract

Three wireline-log-derived EOR-efficiency indices are generated for a 200-feet depth interval in the Bakken Petroleum System (BPS) to identify flow units suitable for EOR using light, miscible hydrocarbon injection. R-index is calculated using kerogen content, water saturation, permeability, principal pore throat diameter, and porosity. MD Index computes the microscopic displacement efficiency for the miscible gas injection in the presence of pore confinement effect. An important step in computing MD-index is to decompose NMR T2 distribution at each depth using factor analysis to compute the free oil, movable water and bound fluid volumes. Lastly, k-means clustering method was used to generate KC-Index, which partitions the entire BPS into four groups, representing miscible-gas-injection recovery potentials at four levels. The proposed log-derived EOR-efficiency indices generate consistent predictions of miscible light-hydrocarbon injection performance at various resolutions. Indices indicate that several units in the Middle Bakken of the BPS will have much higher recovery potential in comparison to the Upper and Lower Bakken.

MD-Index

MD-index is a measure of pore-scale displacement efficiency in gas-displaced hydrocarbon-bearing zone. MD-index incorporates volume fraction of miscible free oil, bound fluid, movable water, and kerogen. MD-index is formulated as a simple ratio of positively affecting parameters to the adversely influencing parameters expressed as

$$I_{MD} = \frac{V_o}{(V_w + V_b) \times V_k}$$

where V_o, V_b, V_w are the pore volume fractions of miscible free oil, bound fluid, and movable water with respect to bulk volume, and V_k is the kerogen volume fraction with respect to bulk volume.

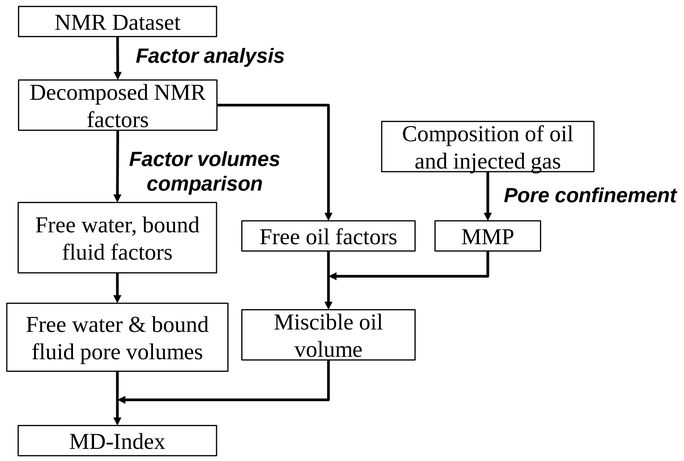

Figure 1: Flow chart of the MD-index calculation process

Steps Involved in MD-Index

1. NMR Decomposition using Factor Analysis

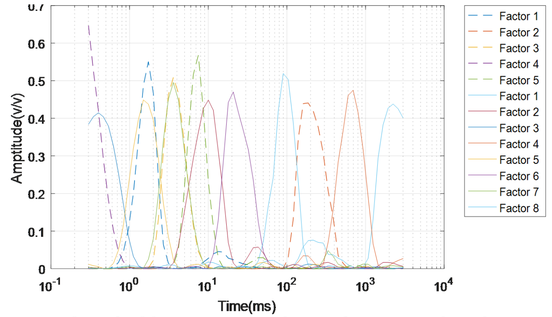

Figure 2: Factors identified by Factor Analysis of NMR T2 distribution for Middle Bakken (Solid line) and Upper and Lower Bakken (dashed line).

2. Determination of Pore Volumes of Various Fluid Phases Represented by the Decomposed Factors

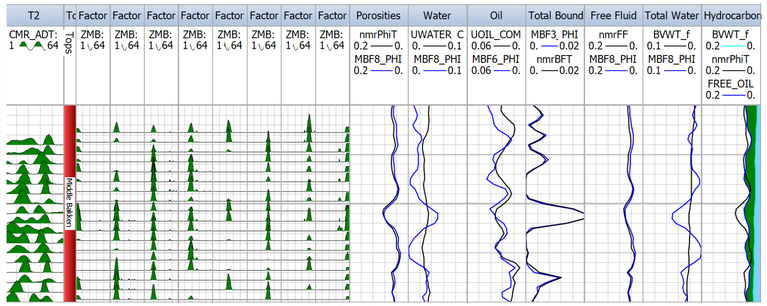

Figure 3: Original NMR T2 (Track 1), Decomposed factors (Tracks 3-10) and comparison (Tracks 10-16) of the inverted factor volumes with fluid volumes from T2 cutoff. Factors 1,2,4,6,7 are identified as free hydrocarbon.

3. Correction of Miscible, Free-Oil Volume for Pore Confinement Effect

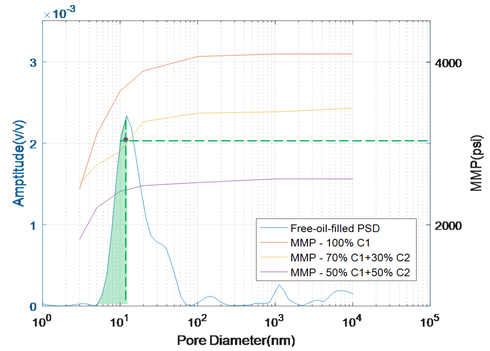

Figure 4: Free-oil-filled PSD of Middle Bakken formation and MMP of injected gas and Bakken oil mixture with pore confinement effect

Log-Derived Indices of Recovery Potential

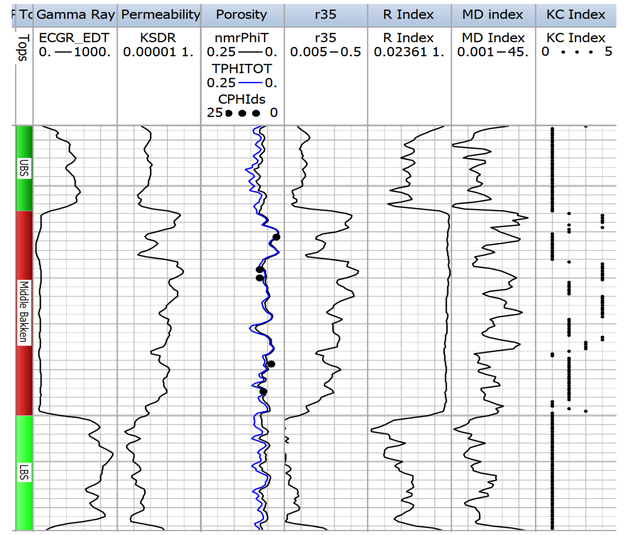

Figure 5: R, MD, and KC Indices indicating recovery efficiency for light hydrocarbon injection in the Bakken Petroleum System

Ravis et al. (1994) developed ranking characteristic parameter to rank several reservoirs for gas injection. R-index shown in figure 5 is generated using a modification of Ravis's ranking parameter. Actual reservoir parameters at a specific depth are compared with the best and worst reservoir parameters across the BPS and the depth is ranked using a exponentially varying function that generates the R-Index. On the other hand, KC-index clusters all the depths into 4 groups, indicating low, low-intermediate, high-intermediate, and high recovery efficiencies. KC-index is based on popular cluster analysis technique in data mining. Input logs from a single depth are arranged as *n* coordinates representing a point in an *n*-dimensional space. By clustering the depths in the BPS into groups, we can generate the KC-index that compares the center points of clusters to qualitatively predict/rank the recovery efficiency during the gas injection for each depth.

Conclusions

- In-situ wireline-log-derived EOR indices provide an economical screening method to identify flow units in BPS suitable for light hydrocarbon injection.
- MD-Index has the highest resolution among the three indices.
- MD-Index incorporates miscible free-oil volume by accounting for the alteration in minimum miscibility pressure due to pore confinement effects.
- The three indices consistently predict 50% of the Middle Bakken formation to exhibit high recovery potentials for miscible light hydrocarbon injection.
- Indices show that the recovery potentials of the Upper and Lower Bakken formations are approximately 60% lower than that of the Middle Bakken.

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References

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