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RESEARCH PAPER

# A review of reservoir oil-water transition zone characterization and potential recovery methods

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**Abstract**
The transition zone (TZ) in an oil reservoir has traditionally been a volume of lesser interest compared to the oil-saturated zone. Researchers have suggested that it can contain commercial hydrocarbon volumes. Therefore, this paper seeks to summarize the characterization methods of TZs for the assessment of oil production opportunities. Another goal is to summarize the potential methods of oil production from TZs. It is conceivable that TZs will produce both water and oil together. However, some surprising instances of dry oil (i.e., 100% oil, with no associated connate water) production, due to the formation of water clusters, have also been observed earlier. Also, oil can possibly be found below the current free water level. Characterizing TZs is more complicated compared to the oil-saturated (irreducible water saturation) zone. TZs can show variable wettability and permeability characteristics due to several complex phenomena related to buoyancy, capillarity, diagenesis, cementation, and reservoir tilting. Careful TZ core characterization followed by reservoir simulation and oil production can increase the overall reserves. Methods for TZ characterization include petrophysical logs (resistivity and NMR), geophysical analysis (AVO and P-wave absorption), and reservoir modeling (saturation height functions and wettability). Analysis of core obtained from TZs using the centrifuge method can reveal the residual oil saturation and relative permeabilities, which can aid the prediction of future oil production. More complicated analyses include structure and stratigraphic geological models and basin modeling for hydrocarbon migration history. Possible oil production methods from TZs include $CO_2$ injection, surfactant flooding, combined carbonated water and surfactant flooding, and smart well placement. We recommend including TZs that span several meters in depth as part of reserves calculation.

**Keywords:** Transition Zone, Wedge Zone, Recovery, Dry Oil, Water Cluster.

## Introduction

Transition Zone (TZ) is defined as the zone in the subsurface where water saturation changes from 100% to irreducible in the upward direction (Xian et al., 2006; Akbar & Permadi, 2016; Abiola & Obasuyi, 2020) (Figure 1). The TZ produces at different oil and water rates depending on the height above the Free Water Level (FWL). FWL is the level below the oil-water contact

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(OWC) characterized by zero capillary pressure and 100% water saturation. Several researchers have attempted to characterize the TZ based on various reservoir and fluid properties.

The wettability in TZs change with depth. Usually, most water-wet conditions are at the bottom, while most oil-wet conditions are at the top (Jackson et al., 2005). The wettability properties of the crude oil/water/rock systems get influenced by several variables, including temperature, composition of the water and oil, and initial water saturation. The increase in water saturation with an increase in depth is the primary determinant of wettability changes within a TZ (Kassa et al., 2021). In case of oil comprised of surface-active components, such as asphaltene, the pores and throats can become oil-wet due adsorption of surface-active components on the mineral surfaces. However, the bottom of the TZ will still be water-wet due to the absence of oil at this depth (Aleidan et al., 2017). Owing to rock heterogeneity, carbonate reservoirs can contain long TZs (Khan & Mandal, 2022).

Christiansen et al. (2000) experimentally examined the variation of oil saturation with height and the link between trapped oil in TZs using strongly water-wet glass beads and proppants. They demonstrated a considerable possibility for oil recovery from the TZs. They also mentioned that the centrifuge technology can be implemented to assess the trapped hydrocarbon relationships and their respective relative permeabilities. Additionally, according to Christiansen et al. (2000), permeability variations and hydrocarbon migration history in the geologic model, having structural and stratigraphic elements, can provide insight into the saturation distribution and hydrocarbon mobility in a TZ.

Jackson et al. (2005) used a 3D pore-scale network model, in conjunction with conventional reservoir-scale simulation, to predict the variation of wettability within an oil/water TZ and its impact on production. This model involves a variety of wettability values with varying degrees of advancing contact angles for water-wet and mixed-wet Berea sandstone. They demonstrated that the model with variable wettability and relative permeability within the TZ has a significantly higher recovery than the model with uniform TZ properties. Additionally, they recommend using a pore-scale network model made of actual rock structure and displacement processes to replicate wettability variation and fluid flow characterization at the reservoir scale.

Buiting (2011) proposed an upscaling saturation-height technique to improve TZ characterization for Arab carbonates. The study included upscaling of capillary pressure data and statistical analysis for developing a closed-form analytical expression for upscaling phenomena. The implementation of the analytical expression showed better accuracy in the estimation of TZ hydrocarbon volume in comparison to the traditional models.

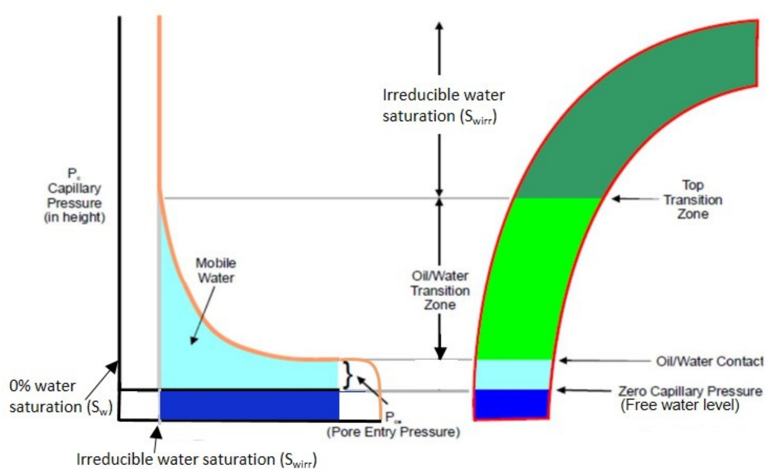


**Figure 1.** Water saturation profile depicting 100% water zone, transition zone, and oil pay zone ($S_{wirr}$) from bottom to top. These zones are commonly encountered in hydrocarbon reservoirs. Figure modified from Haddad (2011)

The concept of 'Paleo-Oil' is crucial in the study of TZs (e.g., Aleidan et al., 2017). Considerable amount of paleo oil is widely assumed to be present in the naturally/geologically water-flooded zone or residual oil zone (ROZ) below the FWL for both sandstone and carbonate reservoirs around the world. This type of oil requires enhanced oil recovery methods to mobilize because the primary or secondary recovery methods are ineffective in such conditions. Aleidan et al. (2017) compared the physical samples of main-play-zone oils with the paleo-oils (located below FWL) for characteristics, such as the geologic background of TZ fill, compositions, API, fingerprinting, Nuclear Magnetic Resonance (NMR), and gas chromatography. Their results suggest that the paleo-oil global composition and quality are significantly similar to the main-play-zone oil. Some variations in aromaticity, sulfur, and disulfur compounds were only evident through Fourier transform ion cyclotron resonance (FT-ICR) test.

Wedge zone, on the other hand, is a newly coined term by Efnik et al. (2006). This word carries a slightly different connotation compared to TZ. Like the TZ, the water saturation increases as we approach the Oil Water Contact (OWC) in a wedge zone. However, contrary to TZs, where capillary and buoyancy forces control saturation, the relative change in water and hydrocarbon volume in a wedge zone can be related to an increase in the number of micropores in the downward direction, i.e., toward the OWC. More micropores promote greater bound water volume, which aids in cementation and diagenesis (Efnik et al., 2006). This phenomenon causes downwards reductions in porosity and permeability. Oil entrapment, on the other hand, happens away from the OWC, i.e., towards the top, where cementation-induced diagenesis is minimized. This phenomenon occurs over distinct phases in the reservoir oil entrapment history.

Apart from the wedge zone, which explains the higher water saturation towards the base of the transition zone, there is an alternate understanding of this phenomenon. This hypothesis invokes the presence of water clusters. This hypothesis states that the reservoir rocks are water wet prior to oil migration. With reservoir charging, oil enters the largest pore throats accessible. This phenomenon is known as drainage. The buoyancy force grows as oil charging continues, and smaller pores begin to allow oil intrusion during drainage. This phenomenon results in wettability alteration. The efficiency of this process increases with decreasing water pore volume saturation. Eventually, the large pores become oil wet, while the small pores are still water wet. With continual oil accumulation, the oil-wet large pores start ejecting water under the process called imbibition, while the water-wet pores small pores continue with the drainage process. Due to the random interconnectivity of pores, pockets of water-wet pores become isolated. This phenomenon is known as percolation (Figure 2). Once oil bypasses a collection of pores, the cluster becomes part of an oil-wet pore system that progressively isolates the water-filled cluster by the process of "capillary holdup" (Parker & Rudd, 2000). The number of such water-wet pockets decreases upwards in the oil transition zone due to higher buoyancy force which increases the drainage of smaller pores and counteracts "capillary holdup."

This interplay of capillary hold-up and buoyancy force may result in the genesis of immobile water due to the presence of discontinuous water phase. This immobile water can be quantified in terms of effective irreducible water saturation ($S_w^{eirr}$). This irreducible water saturation increases with depth till the water-wet pores become interconnected, and water becomes mobile at critical water saturation ($S_w^{crit}$). In the TZ, the oil production will be dominant till the effective irreducible water saturation is greater than the critical water saturation. The moment the irreducible water saturation reaches the critical water saturation, oil and water are produced simultaneously (Parker & Rudd, 2000). Normally, wells drilled in the TZ produce a finite water cut.

Finally, the counterintuitive concepts of the occurrence of residual oil below the current-day OWC and tilted OWC deserve mention. The reservoir tilting mechanism is often encountered in onshore and offshore fields. Kirkham et al. (1996) reported the occurrence of the north-to-northeast downward tilting of the entire basin containing the Thamama group rocks in offshore Abu Dhabi during the Late Miocene to recent Zagros Orogeny. This process led to the change of equilibrium of the structures and the fluid content, impacting the existing hydrocarbons in the reservoir. It resulted in the depression of the paleo-oil contact over half of the north-eastern part of the structure and elevation of the paleo-oil contact in the south-western portion (Figures 3a, 3b). This symmetric depression and elevation led to higher porosity and permeability beneath the new OWC in the depression zone and lower porosity and permeability in the elevated zone. The imbibition resulted in the partial flushing of migrated and accumulated oil, leading to the genesis of a ROZ between the present-day FWL and OWC. The tilting phenomenon also led to creation of a variable or tilted OWC.

**Methods for identification of oil production opportunities from transition zones**

Various researchers have attempted to understand hydrocarbon production from transition zones using the following approaches:

- Petrophysical approach
- Geophysical approach
- Reservoir modeling approach

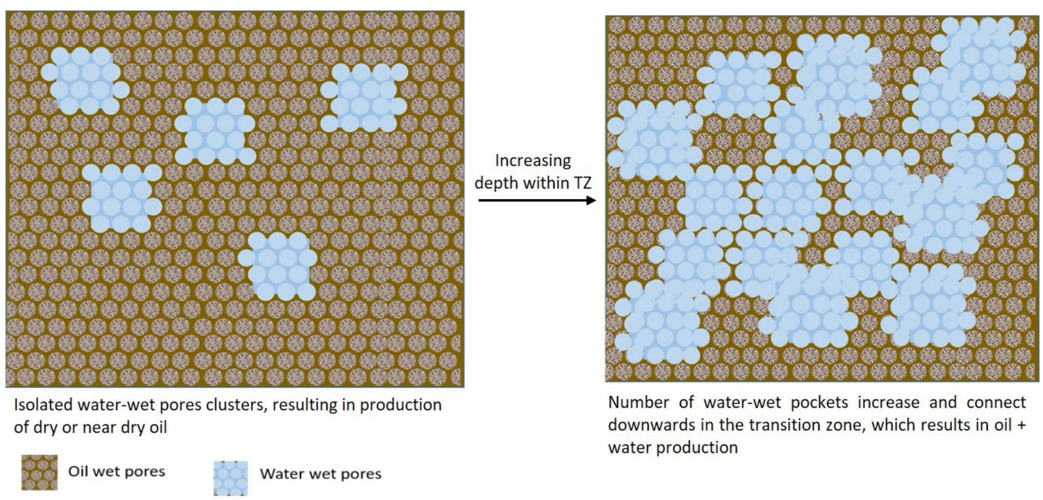


**Figure 2**. Isolated pore cluster formation during the percolation process. Notes: 1) Figures depict conditions after wettability alteration. 2) Figure does not depict pore size distribution

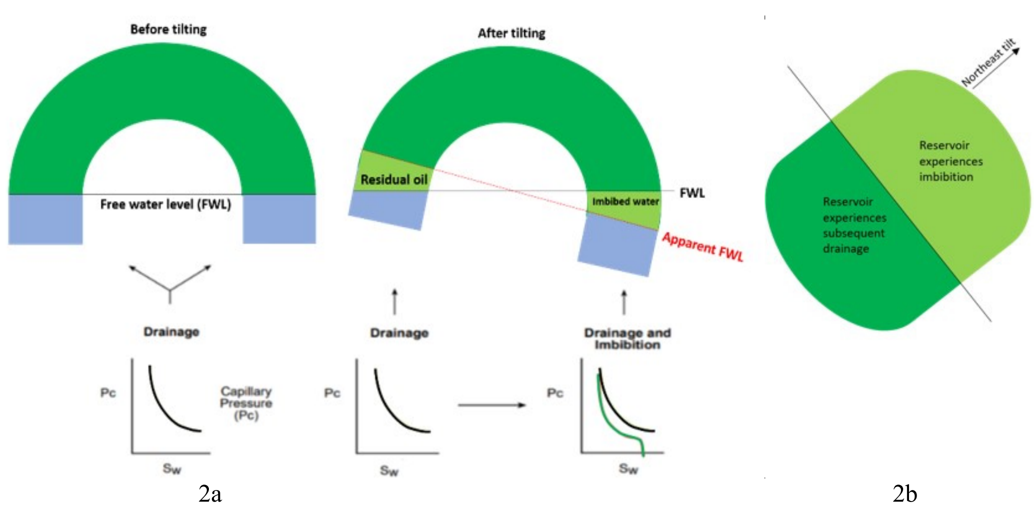


**Figure 3.** Thamama reservoir tilting. (a) Effect of tilting on saturation and capillary pressure, (b) Sections of reservoir undergoing imbibition and drainage. Figure modified from Kirkham et al. (1996)

These approaches can also be combined for better results.

*Petrophysical approach*

The petrophysical approaches to estimate the saturation profile of TZ of a reservoir employ resistivity and NMR logs.

Resistivity logs

The saturation profile of TZs can be used to estimate oil production. A widely used method on that end is Archie's equation which uses the resistivity log data. The Archie's equation defines the relationship between water saturation, porosity, true resistivity, and 100% formation water resistivity. This equation can be expressed as shown in Equation 1:

$$S_w^n = (aR_w)/ \Phi^m R_t \qquad \text{…………… Eq. 1}$$

Where,

$S_w$ = Water saturation
$R_w$ = Formation water resistivity
$R_t$ = Formation true resistivity
$\Phi$ = Porosity

In this equation, n, a, and m are empirical constants representing saturation exponent, cementation exponent, and cementation factor respectively. For carbonates, the value of n, a, and m are 2, 1, and 2 respectively.

Although this method seems intuitively simple, using resistivity logs has limitations. Resistivity logs can precisely quantify hydrocarbon and water-bearing formations due to high contrast in values. However, TZs may have similar volumes of oil and water. In such cases, the resistivity data may lead to erroneous results in the determination of hydrocarbon and water saturation (Al Harbi et al., 2018). Additionally, low resistivity pay characteristics may exhibit high water saturation in the logging data, while the production may manifest little or no water. Similarly, microporous carbonates may have significant dry oil (i.e., no associated connate water) or nearly-dry oil, but the resistivity log analysis may indicate significant connate water. Such insensitivity of resistivity logs has a significant impact on the reservoir development.

NMR logs

NMR logs solve difficult formation evaluation problems, such as characterization of pore structure, movable fluid saturation, and residual oil saturation (Liu et al., 2016; Zhang et al., 2020). The NMR tool furnishes information on porosity and pore size distribution. This logging tool is better equipped to distinguish oil, water, and gas along with wettability and residual oil saturation (Kenyon, 1997). Some of the paramount features of NMR logs are shown in Figure 4. Predominantly small pore group is indicated between 1-10 ms and larger pore group is indicated between 30-2000 ms T2. Irreducible water saturation is mainly contained within small pores. Additionally, gas and water are clearly distinguishable. These characteristics of NMR technology place it on a higher pedestal in TZ characterization compared to resistivity logs.

Another example of an NMR log pre-empting the misinterpretation of resistivity logs is shown in Figure 5. The depth 4330-4400 m based on the resistivity log readings looks akin to an oil saturated zone, and between 4400-4460 m looks like a transition zone. However, the NMR log does not indicate any changes in bound volume or free fluid between 4330-4460 m.

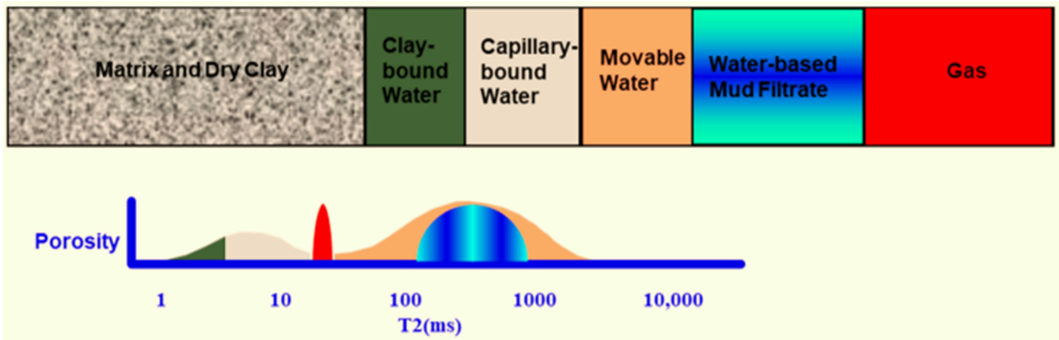


**Figure 4**. NMR T2 times can be used to differentiate clay-bound water, capillary-bound water, and movable water. Gas and water have different T2 times. Figure modified from Sun et al. (2021)

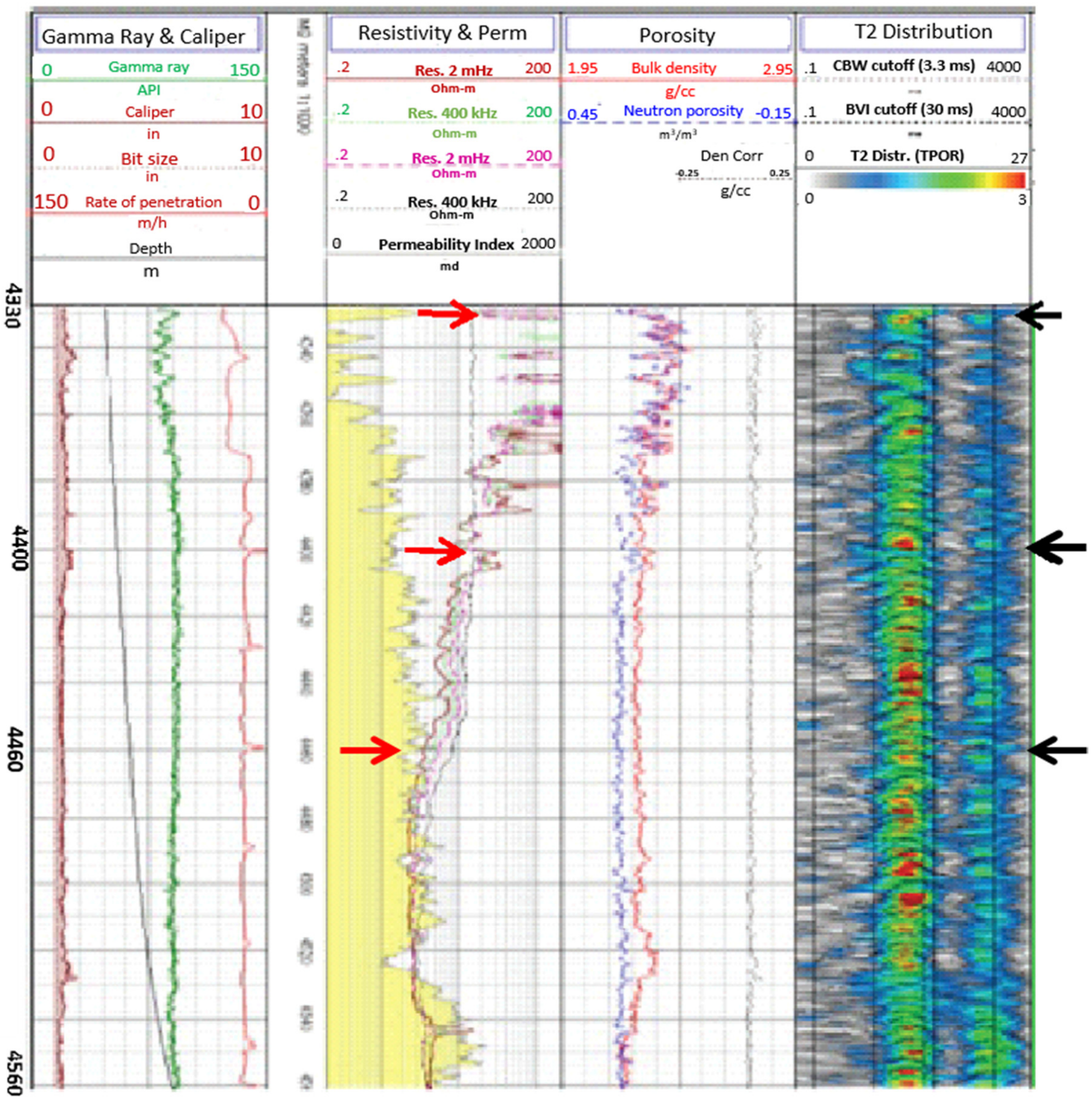


**Figure 5.** Gamma Ray, Caliper, Resistivity, Permeability, Porosity, and T2 distribution logs for a sub-horizontal well drilled in the North Sea. Red and black arrows depict readings of the resistivity and NMR T2 logs for 4330, 4400, and 4460 m depths. Not much difference is visible in the NMR T2 log between 4330-4460 m, while the resistivity log shows large differences between these depths. Figure modified from Pajchel et al. (2011) and Ghosh (2022)

BVI from the NMR log shows the same trend throughout. This observation leads to the conclusion that the resistivity log interpretation of an oil zone and a transition zone is incorrect. Therefore, the NMR log is providing the correct impression of fluid and pore type because it “sees” near the wellbore. However, the resistivity log “sees” lithology away from the wellbore (Pajchel et al., 2011).

*Geophysical Approach*

The geophysical approaches discussed in this paper consist of the AVO method and the P-wave absorption method.

AVO method

The Amplitude Versus Offset (AVO) attributes are highly desirable for evaluating the hydrocarbon anomalies in the reservoir. These attributes include angle versus reflection amplitude gradient curve, intercept versus gradient plot, synthetic gathers, intercept, and gradient standard-deviation crossplots (Lanning & Cambois, 1998; Cambois, 2000; Hoversten et al., 2006). These AVO signatures come from the seismic data and well logs, calibrated to identify the hydrocarbon abnormalities. This calibration scheme is the primary objective of seismic inversion for the identification of similar reservoir seismic signatures. The correlation between water saturation and seismic properties, such as amplitude, impedance, and instantaneous amplitude comes out strong. Researchers have a consensus on the applicability of seismic data. Especially, the AVO technique has provided reliable information about reservoir liquids and their identities (Varela et al., 2003). Iwaki et al. (2014) discussed a method of identification of the thickness of a transition zone above a gas-water contact. Plotting amplitude vs. incident angle (Figure 6), they found that the amplitude changes at most 7% for a 10 m thick and 35% for a 40 m thick transition zone when compared to a no transition zone model.

Though not directly related to the estimation of hydrocarbon saturation in the TZ, AVO has nevertheless been used to estimate the presence of hydrocarbons. The assessment of AVO behavior in the pre-stack seismic data may result in a direct hydrocarbon indication (DHI).

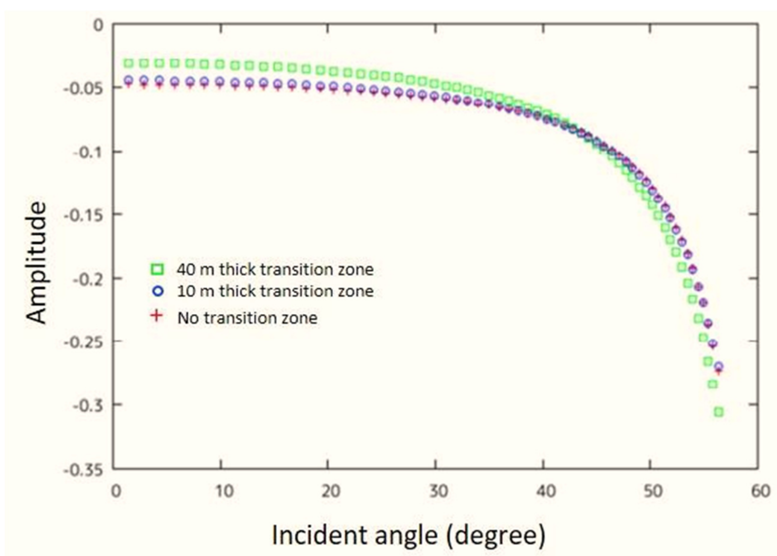


**Figure 6**. Amplitude changes with offset for no transition zone, 10 m thickness transition zone, and 40 m thickness transition zone. Figure modified from Iwaki et al. (2014)

This indicator principle is based on the change in the amplitude of seismic reflection data with the change in the lithology or presence of fluid (Fahmy & Reilly, 2006; Feng et al., 2007). Researchers have used these parameters to identify the lithology in various basins (Ogbamikhumi & Igbinigie, 2020; Nanda, 2021). Ogbamikhumi & Igbinigie (2020) performed the cross-plot feasibility analysis on various parameters, such as Poisson ratio, lambda-rho, and lambda-rho/Mu-rho for the identification of fluid and lithology indicators in the Eva field of onshore Niger Delta Basin.

Pan et al. (1997) used 3D seismic data to investigate oil saturation in a sandstone deposit in China. They used actual values of oil saturation from three wells and 3D seismic data interpolation throughout the reservoir to obtain their results. Balch et al. (1999) used artificial intelligence and seismic data to predict the water saturation distribution in a sandstone reservoir in Mexico. Additionally, four-dimensional (4D) seismic is a crucial tool for identifying fluid movement patterns, which can be used both in and above the transition zone. 4D data is qualitatively used for identifying undrained or inadequately drained areas in the reservoir and as a lithology indicator (Berle et al., 2010).

P-wave absorption method

The applicability of this method was demonstrated by Mu & Cao (2004) in the laboratory. They performed experiments using water, oil, sandstone, and gases in a physical reservoir model. They used an automatic acquisition system and transducers with a primary frequency of 150 kHz and wavelength of 14 mm. A common offset observation system was employed. The researchers vacuumed the sandstone sample and injected varying percentages of oil, water, or gas (i.e., 10%, 20%, and so on). Following that, the common offset records were obtained. Especially, reflected P waves from the top of the sandstone bed were observed. Figure 7 shows the correlation between the fluid content in the sandstone layer and the absorption coefficient of the P-wave reflection. It is evident that the absorption coefficient in the layer with oil sharply increases with increasing oil content, especially between 30-60% saturation, and is comparatively larger than that of gas containing layer. The water-containing layer has a significantly lower absorption coefficient and remains constant with increasing saturation.

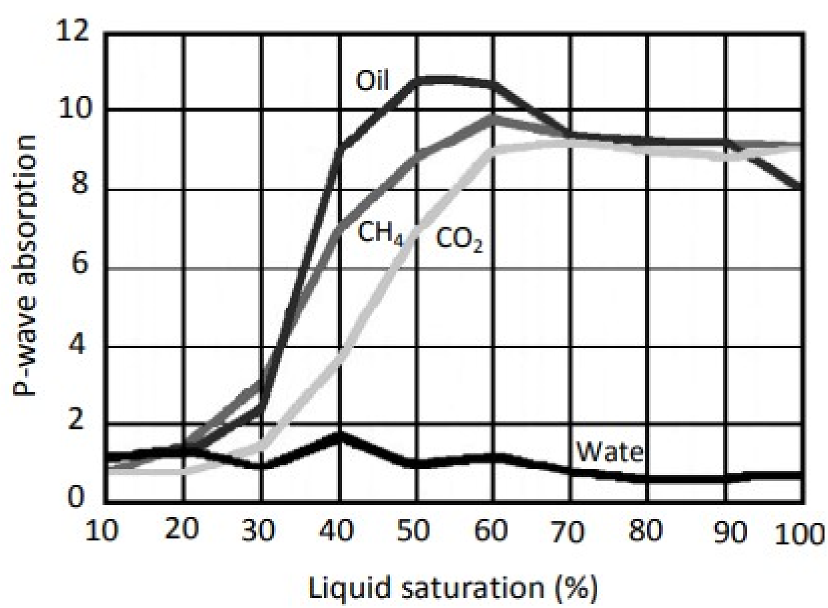


**Figure 7.** Relationship between P wave absorption and the fluid content in the sandstone layer (reproduced with permission from Elsevier). Figure from Mu & Cao (2004)

*Reservoir modeling approach*

The reservoir modeling approaches discussed in this paper include saturation height methods and wettability alteration approaches.

Saturation height methods

The interaction between water saturation and capillary pressure is primarily described by two approaches for calculating saturation-height in the oil and gas (O&G) sector.

The first method is the Corey-Brooks method which is fit for heterogeneous reservoirs where it is difficult to characterize water saturation (Lian et al., 2016). This method can be used to represent long and short TZs and aptly correlate with the capillary curves. Lu et al. (2020) used this method to identify the isolated oil clusters and concluded that no correlation exists between the irreducible saturation and network pore/throat size. However, the results suggested that the irreducible saturation can be correlated with the pore connectivity, the ratio of standard deviation to mean of radius, and pore radius to throat length ratios.

Another method for the estimation of saturation height includes the classical Leverett J. function method based on the detailed sedimentological evaluation. This evaluation can be used for the main reservoir rock type identification, which can be further used for pore throat analyses and capillary pressure (Pc) determination (Wiltgen et al., 2003; Behrenbruch et al., 2016; Arifianto et al., 2018). Following pore throat analysis and capillary pressure measurement, the function based on capillary pressure and saturation is averaged for each type of rock (Harrison & Jing, 2001; Lalanne & Rebelle, 2014; Filippi et al., 2015; Ghosh et al., 2022). It is noteworthy that the clarity of the reservoir's FWL depth is crucial for successful implementation of this method. This method can be further extended to identify the isolated oil clusters (Larson et al., 1981).

Capillary pressure vs. water saturation for different rock types ranging between high permeable and low permeable are shown in Figure 8.

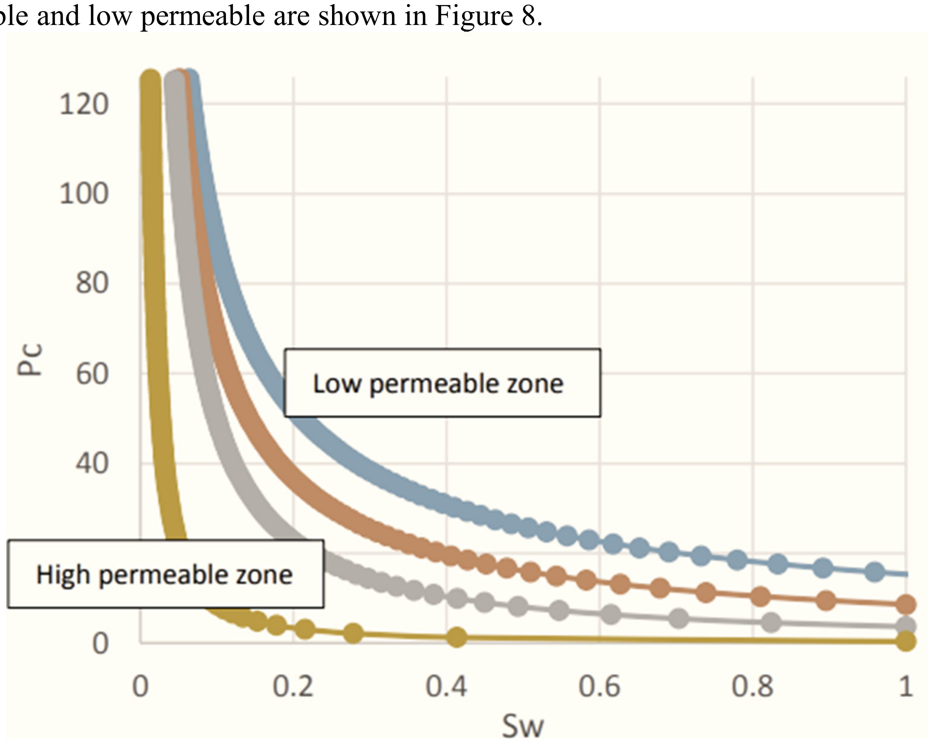


**Figure 8.** Capillary pressure ($P_c$) vs. water saturation ($S_w$) for four different rock types. Figure modified from Nasr (2015)

Based on Figure 1 discussed earlier, it is observable that a reservoir consisting of high permeability rocks will have shorter transition zones compared to reservoirs consisting of comparatively lower permeability rocks. The saturation-height behavior of the low permeability rock type is also similar to that observed in reservoirs with comparatively wide pore-size distribution. Therefore, considering the transition zone as part of the reserves is more important for reservoirs with wide pore size distributions (such as carbonates) and relatively low permeability reservoirs.

Wettability

Case 1- If no injection of water into the reservoir is taking place, i.e., the initial water saturation is only controlled by primary drainage, then the initial production behavior of the reservoir does not depend on wettability variations in the region (Jackson et al., 2005).
Case 2- If the initial water saturation is modified by injection water or movement of free water level, then the production is dependent on the wettability. In this situation, the wettability of a reservoir is calculated using in-situ measurements, for instance, in-situ measurements of the FWL, SOR (the maximum depth at which oil is still mobile), and SWI (the minimum depth at which water is still mobile) using wireline equipment (Causin & Bona, 1994).
Anomalous dry oil production from the transition zone may be observed if the initial water saturation has been modified by the movement of the FWL following reservoir filling and wettability alteration (Case 2). If wettability fluctuates with height through the TZ, there may be a substantial interval of mobile oil below the FWL from which dry oil may be produced.

**Methods for oil production from transition zones**

There are various methods for oil production from the TZs. Efnik et al. (2006) suggested the installation of more wells for increasing production from TZs based on the simulation studies. The studies showed that the installation of four wells led to extended production from near TZs.

Another method includes the injection of $CO_2$ to extract oil from the TZs. Koperna et al. (2006) presented a modeling case study to recover residual oil from TZ/ROZ in two fields (Wasson oil field and Salt Creek) using two $CO_2$-EOR methods. The simulation studies were conducted using the $CO_2$-PROPHET with a full-scale reservoir simulator. According to the findings, the five oil plays in the Permian Basin can recover about 40% of the oil from the TZ/ROZ. In four of these wells, it was discovered that the water saturation was steadily rising toward FWL, which might be attributable to the reservoir's history of entrapment and changes in the rock's quality brought on by diagenesis. Skauge & Surguchev (2000) simulated the scenarios for oil recovery based on immiscible or developed miscibility liquid $CO_2$ injection into the transition paleo zone and obtained a high recovery factor. Results of $CO_2$ injection showed up-dip oil displacement along with a tertiary oil bank formation and a significant reduction in the mobile oil viscosity.

Besides the $CO_2$ injection, waterflooding can be a viable candidate for oil production from TZ (Jackson et al., 2005). Their study suggests high displacement efficiency due to wettability variation during waterflooding over a long production time. From laboratory studies, Masalmeh (2000) suggested that water flooding did not have any influence on initial oil saturation. However, the oil mobility increases as initial oil saturation decrease in TZs during water flooding. They found that the oil mobility in a transition zone is much higher than suggested by conventional analysis.

$CO_2$-EOR is the technique most appropriate for TZ oil recovery out of those described above. It involves the injection of $CO_2$ to enhance the reservoir sweep efficiency and to manipulate the existing crude oil characteristics. It can induce oil swelling, reduce oil viscosity, and consequently help in recovering intermediate and some heavy oil components. Field case studies suggest that $CO_2$ can modify rock characteristics in carbonate reservoirs. It has also been witnessed that $CO_2$ injection has the potential for extra oil recovery of 14%-19% in comparison to water flooding (Luis et al., 2016). In the current scenario of global warming and emphasis on greenhouse gas emission, the utilization of $CO_2$ as the recovery agent has multi-fold consequences, which will be the main driving factor for field implementation. It can help reduce the carbon footprint, achieve sustainable production, and increase oil recovery (Luis et al., 2016).

Nowrouzi et al. (2020a) mentioned that in the field of chemical EOR, herbal extracts such as Anabasis Setifera are now being investigated as a replacement to traditional surfactants that are expensive and potentially harmful for the environment. Additionally, a mix of carbonated water and organic surfactants such Rapeseed oil (Nowrouzi et al., 2021), a mix of acetone+methanol with carbonated water (Nowrouzi et al., 2020b) are being investigated as a simultaneous $CO_2$ sequestering mechanism and EOR purposes. Future hydrocarbon recovery from TZs will be viable commercially and environmentally once these techniques are proven to work.

Apart from injecting water or $CO_2$ and increasing the number of wells, the positioning of horizontal wellbores is an important factor in maximizing the ultimate hydrocarbon recovery from transition zones. The factors responsible for dictating the optimum position of wellbores are – the thickness of the oil column, selected depletion method, fluid properties, lithological variations, and production history (Berle et al., 2010). The azimuthal propagation resistivity (APR) measurements along with omni directional multiple propagation resistivity (MPR) measurements can be used to identify horizontal well placement zones relative to the OWC. A development well per reservoir compartment can be used in combination with a pilot hole for the determination of reservoir properties and OWC positions. Subsequently, horizontal production branches can be drilled as sidetracks from the pilot hole (Berle et al., 2010).

## Conclusions and recommendations for future work

A comprehensive review was conducted on unlocking oil from TZs. Through this work, we have highlighted aspects of the complicated processes unfolding in the TZs. These processes involve the dynamically changing fluid and rock properties along with the reservoir characteristics. These dynamic behaviors dictate the methods to extract the oil present in the TZs. The methodology to characterize the TZs are multi-faceted. For instance, resistivity logs are used for water saturation estimation, but may require a complementary NMR log for accurate TZ characterization. Though it is impossible to uncover all mysteries of the TZ, our highlighted aspects serve new readers in understanding its basics and obtaining a useful overview.

Finally, futuristic research on TZs should focus on a) the application of methods commonly applied in enhanced oil recovery, such as surfactant flooding, polymer flooding, and others; b) exploration of $CO_2$ EOR and storage in transition zones to address the dual predicament of low oil recovery and global warming; c) increasing the number of field experiments (as opposed to lab experiments) for further investigating production of hydrocarbons (especially with zero connate water production) from TZs; d) Application of 4D seismic technology to gauge the effectiveness of the drainage efficiencies of various field recovery techniques.

## Abbreviations and Meanings

FWL: Free water level
OWC: Oil-water contact
ROZ: Residual oil zone

TZ: Transition zone
Dry oil: Oil production without connate water production

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