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A Review of Primary Drainage Techniques

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Abstract. In the field of special core analysis, the process of primary drainage is of significant importance, because it reproduces phenomena happening in the reservoir such as oil migration and CO_2 injection. This process involves the initial injection of a non-wetting fluid, which could be gas or oil, into a rock sample that is fully saturated with water. Generally, the main objectives of performing primary drainage in the lab are twofold. First, it involves the acquisition of several drainage petrophysical properties: (i) static properties such as capillary pressure and Resistivity Index, which are crucial to a better understanding of the oil initially in place; (ii) dynamic properties, such as primary drainage relative permeability, which aid in the understanding of CO_2 mobility and sequestration in aquifer injection studies and are useful for feeding hysteresis simulation models. Second, it involves the preparation of a specific sample for an imbibition experiment. The setting of initial fluids saturation and representative pore occupancy are key to the restoration of wettability, which in turn is crucial for the representativeness of the obtained imbibition relative permeability curves. However, there is a catch: the restoration of states and the acquisition of petrophysical properties during primary drainage are typically mutually exclusive. This means that a rock sample used for a primary drainage-related measurement is generally unable to proceed through a full cycle of a recovery experiment program. This paper aims to stimulate a discussion on the numerous incompatibilities between these two aspects of primary drainage. It highlights the challenges faced when trying to balance the need for wetting state restoration with the desire to obtain valuable petrophysical properties. Furthermore, it offers a best practice guide for restoring the initial states of reservoir rock samples.

1 Introduction

The primary drainage process in special core analysis represents the initial injection of a non-wetting fluid in a core sample fully-saturated with water. This step follows the conventional core analysis (CCA) steps, that aim at characterizing the core sample regarding porosity and permeability, and establishes the initial water saturation (Swi) in the core following an experimental technique appropriate to the goal of the study. In the restored state workflow, where initial fluids saturation, pore occupancy and wettability are supposed to mimic the reservoir, primary drainage represents the reproduction of the initial migration of hydrocarbons from the source rock to the reservoir [1].

When establishing Swi during primary drainage, there are several static and dynamic petrophysical properties that may be obtained simultaneously to the core desaturation. We can name the capillary pressure (Pc), Resistivity Index (RI), Archie's Law saturation exponent (n) [2], wetting and non-wetting phase drainage relative permeabilities (Kr) and the irreducible water saturation (Swirr), that is the lowermost value of water saturation obtainable in primary drainage and differs from Swi as the latter may be higher in the case of transition zone cores. These are key parameters to feed a hydrocarbon reservoir simulation model regarding fluids distribution, contacts, and height of the hydrocarbon column above the free water level. A lot of effort has been made through years of scientific research to obtain the majority of these data at once. Nonetheless, since the core samples have been used for these tests, their suitability to undergo a complete SCAL experimental cycle, where recovery or wettability experiments are performed, may be questionable. This situation is imposed because initial states restoration demands that the primary drainage process follow certain rules in order to preserve the representativity in terms of value of Swi, homogeneity of the water saturation (Sw) profile and correct fluid distribution in the pore space.

Reaching the value of Swi corresponding to the initial target is important, as wettability alteration is directly related to the oil saturation in the sample. Translating to the reservoir scale, this dependency describes the wettability gradient as a function of height above the initial water-oil contact [3-6]. The dependency of wettability alteration on Swi has been deeply discussed in the literature over a large range of Swi values and lithologies.

Precursor studies on this matter were performed on outcrop Berea sandstone set to Swi and aged with crude oil. A clear relationship was found between the Amott Harvey wettability index [7] and Swi [8, 9]. This was found to be true even for the quasi-asymptotic portion of the Pc(Sw) curve [10]. Other studies investigated the relationship between Swi and wettability alteration on outcrop chalks. Authors reached the same conclusion found on outcrop sandstone samples, that water-wetness decreases with decrease in initial water saturation [11, 12].

In addition, several other studies evaluated the effect of Swi on spontaneous water imbibition, as this may be considered as a fast and simple way to assess wettability to water. Besides, it is possible to investigate the spontaneous water imbibition rate. It was consistently found that

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spontaneous water imbibition rate decreases as Swi decreases [9, 13-15].

The importance of reaching the target value of Swi during primary drainage is as important as obtaining a homogeneous saturation profile, free from capillary end-effects (CEE). As core samples are expected to have uniform properties to undergo SCAL tests, a gradient in the saturation profile would result on a wettability gradient [16], thus hindering the uniform criterion.

Another topic that has been recently discussed is the impact that dopants added to the aqueous phase may have on the wettability alteration of core samples and their behavior during oil recovery experiments [17]. Adding dopants to one of the phases (water or oil) is necessary for appropriate phase segmentation on most of regular i*n situ* saturation monitoring (ISSM) devices. In this recent work, the authors showed that the addition of NaI to connate water can have an effect on oil recovery and wettability on outcrop sandstones, as Iw values, water wetness index of the Amott Harvey wettability index [7] increase with the increase in NaI concentration on connate brine. This conclusion raises a deep and important discussion over another important topic of the restored state approach, that is the use of appropriate fluids.

On the emerging subject of the application of SCAL techniques on the study of CO_2 injection in saline aquifers, the primary drainage phase may provide some important parameters. The stability of CO_2 injection in water saturated core samples [18], primary drainage relative permeability curves of CO_2-brine systems [19] and the dependency of the residual CO_2 saturation (Sco$_2$,r) on the initial CO_2 saturation (Sco$_2$,i) are some of them [20]. Understanding the onset of viscous fingering and the displacement process during CO_2 injection in a fully-water saturated core are key for the prediction of plume migration and early breakthrough in geological CO2 storage sites. In addition, the relation between Sco$_2$,r and Sco$_2$,i shall indicate the performance of CO_2 trapping in porous media.

This paper proposes a review of the most commonly used primary drainage techniques, their advantages and drawbacks, the measurements that may be obtained during this important step of the SCAL program and the incompatibility between the methods used to obtain such data and proper initial states restoration in a restored state approach. In addition, a presentation of the technological advances proposed by different authors to tackle the challenges of representativity of the reservoir behaviour during fluids migration in the reservoir in the core scale will be discussed. It is important to state that the considerations of this paper are related to core samples departing from a water-wet state after an appropriate cleaning process [21, 22].

2 Classic Primary Drainage techniques

There are several methods to decrease water saturation down to a target value of Swi. The choice of the method to be used is usually driven by operational constraints and laboratory capabilities, even though significant differences has long been reported following the adopted primary drainage technique [23].

The most commonly used primary drainage techniques are [22]: viscous oil flood, centrifugation and porous plate.

2.1 Viscous Oil Flood

The viscous oil flood (VOF) method consists in injecting oil at either constant flowrate or pressure steps in an initially fully water-saturated sample, while measuring the pressure drop between inlet and outlet as well as fluid production (oil flowrate in the outlet in the case of constant pressure injection) [24]. This method may be performed whether by injection of both phases (steady-state) at different flowrate ratios or by injection of only one phase (unsteady-state). During the primary drainage step of a SCAL experimental cycle where the viscous oil flood technique is used, the unsteady-state method is preferred over steady-state, as it is faster and simpler to set up.

Until oil breakthrough, only water will be produced as oil percolates in the sample. After oil breakthrough, a production of both phases will be observed until brine production ceases, in the unsteady-state case. This is a fast technique that does not require a particular setup, being possible to be carried out in the same cell used for the following steps of SCAL (ageing and flooding) and by a simple injection rig.

This method allows the direct measurement of end-point effective permeability from simple application of the multiphase Darcy's Law [25]. To perform the measurement of the effective permeability ($k_o(S_w)$), a steady flow of both the injected and produced phases, and a constant ΔP, must be attained. For this reason, in the case of unsteady-state experiments, only the measurement of the injected phase k_{eff} is possible, as only the injected phase may reach a steady flow. Alternatively, in the case of the steady-state method, both phases effective permeability measurement is possible, as a steady flow of both phases is reached at each flowrate ratio.

Nonetheless, the viscous oil flood technique generates a saturation gradient along the injection axis, known as the capillary end effect, that was initially noticed by Leverett & Lewis [26]. Its generation is originated by trapping of the wetting phase due to a discontinuity in capillary forces. This leaves a higher saturation of the wetting phase close to the outlet thus reducing the non-wetting phase permeability. Therefore, the effective permeability values experimentally obtained by the unsteady or steady-state methods are distorted, as CEE represent an experimental artifact.

In order to obtain corrected relative permeability and capillary pressure curves from the viscous oil flood technique, a deconvolution of experimental data, typically ΔP, water production and flowrate *versus* time, must be performed through numerical simulation [27-31]. Moreover, ISSM is recommended to provide information about saturation profiles and the extent of capillary end-effects [22]. It helps the deconvolution of the impact between capillary pressure and relative permeability to production history by numerical simulations.

Regarding the direct definition of the capillary pressure *versus* water saturation curve from the viscous oil flood, the Semi-Dynamic Method represented a remarkable step [32]. By using this technique, it is possible to obtain the Pc(Sw) relation without the need of numerical simulation for deconvolution of the experimental data. The principle of this method is to deduce the capillary pressure from the local balance between viscous and capillary forces in the sample. For this matter, the sample is flooded with oil at constant flowrate while the outlet face is continuously washed by water, which makes the water phase continuous throughout the sample, and so its pressure (Pw). By measuring the oil pressure (Po) at several points along the core, it is possible to discretely obtain the capillary pressure at each of these points following the definition of capillary pressure (Pc = Po – Pw), whereas the water saturation in such points are measured using ISSM.

Primary drainage relative permeability curves are useful in the description of hysteresis models, as some of them rely on the interpolation of drainage and imbibition relative permeability curves [33-35]. These models are largely used in reservoir modeling for hydrocarbon production prediction and the possession of primary drainage relative permeability curves allow the locus of initial fluid permeabilities at each location of the reservoir, especially the transition zone.

In addition to primary drainage relative permeability and capillary pressure, an interesting work was published to derive a one-dimensional absolute permeability measurement in the core scale from a miscible replacement of a low viscosity fluid by a high viscosity one [36]. As this method assumes a piston-like displacement of the resident phase, it may be extended to an unsteady-state viscous oil flood using a high viscosity oil in a cleaned core sample saturated with brine, thus representing another useful data that is obtainable during primary drainage.

Another important parameter that may be derived during a primary drainage step performed using the steady-state technique is the Resistivity Index (RI) [32, 37, 38]. For that, local resistivity measurements in the core and ISSM to monitor the portions of the core that have homogeneous saturation are needed. This method was initially proposed to improve the quality of RI data coming from Continuous Injection (CI) experiments (the CI method will be furtherly discussed in the sub-section dedicated to porous plate techniques). The explanation for the better results coming from the VOF, steady-state, approach is based on the fact that during this type of fluid displacement, the development of a Buckley-Leverett shock front [26] is better controlled than in the case of CI. Therefore, by applying several flowrate ratios, different water saturation levels may be achieved, allowing a good description of the RI *versus* water saturation curve.

When using the viscous oil flood technique for establishing Swi on samples that will undergo a complete recovery experimental cycle, CEE must be eliminated to obtain a homogeneous saturation profile. Some laboratories adopt approaches to reduce the presence of CEE by applying high flowrates during the oil flood. Nonetheless, this does not represent actual flow in the reservoir and may cause irreversible damage in the core, such as fines migration and additional pore volume creation, impacting further measurements once the rock matrix has been modified. In addition, Capillary End-Effects are anyway present in the outlet face of a sample submitted to viscous oil flood, even though routine ISSM devices are not able to capture it [39]. Notwithstanding, low values of Swi (close to Swirr) are often not reached by the viscous oil flood method, even though high flowrates are applied [22].

An effective solution to eliminate capillary end-effects is reversing the direction of oil injection at the end of primary drainage. Although this method may produce a homogeneous saturation profile, two major issues may outcome:

(i) Unwanted imbibition from the mobilization of the brine concentrated at the sample outlet. This brine will be displaced towards the initial inlet, increasing water saturation at these points.

(ii) Formation of disconnected oil clusters that will adversely affect wettability restoration and impact effective permeability measurements [40].

2.2 Centrifugation

Centrifugation is another widely used technique for setting initial water saturation [41]. It consists in placing a rock sample inside a centrifuge machine that will induce an injection pressure through centrifugal forces imposed by high-speed rotation. If we consider only a one-dimensional flow, the capillary pressure at a radius r is given by Eq. (1).

$$P_c(r) = \frac{1}{2} \cdot \Delta\rho \cdot \omega^2 \cdot (R^2 - r^2) \qquad (1)$$

where P_c is capillary pressure, $\Delta\rho$ is the difference between phases densities, ω is the rotational speed of the centrifuge, and R is the distance between the centrifuge central axis and the sample outlet.

Main information that is extracted from conventional core centrifugation is the capillary pressure curve *versus* water saturation during drainage and imbibition experiments. For an appropriate conversion of the experimental data into the correct Pc(Sw) curve, a correction must be applied, which takes into consideration the presence of the saturation gradient that is expected from the application of a non-uniform capillary pressure field in the core [42]. The relation between capillary pressure and water saturation is important to describe the hydrocarbon profile in reservoir modelling. Through the years, new approaches have been proposed in order to obtain the capillary pressure *versus* water saturation relation in reduced experimental duration, notably by applying magnetic resonance imaging (MRI) [43-44].

It is interesting to notice that, as this technique is capable of generating a discrete capillary pressure field over the core sample length, it proves that CEE are not always phenomena that need to be minimized as it contains considerable amount of information.

Besides obtaining the capillary pressure *versus* water saturation relation, the centrifugation method has benefited of technological developments to derive some other important features directly. In that way, it is important to reiterate the importance of combining the strength of MRI and centrifugation to obtain Archie m & n exponents and the Resistivity Index [45-46]. In addition, a recent work has presented a new way to measure the Pc(Sw) curve and the saturation exponent n without the need of MRI analysis or unloading the core from the centrifuge [47]. For that, it combines the saturation gradient generated from centrifugation, onboard resistivity measurements and numerical inversion to describe the totality of the Pc(Sw) curve.

Besides obtaining the capillary pressure curve from multi-step centrifugation, relative permeability of the invading phase (oil, in the case of oil/water primary drainage) may be measured during centrifugation from the transient phase of water production [48-50]. This approach requires numerical interpretation to deliver relative permeability curves, and provides irreducible water saturation, however it covers a small saturation range.

Regarding the establishment of initial water saturation in a complete SCAL workflow, the centrifugation is often chosen for time and cost constraints, as it is capable of generating very high capillary pressure on multiple cores at a time [22]. Nonetheless, this approach contains several warnings:

(i) High-speed centrifugation is not suitable for friable samples, that might be fractured during the process, thus invalidating its suitability for recovery experiments afterwards.

(ii) Initial water saturation establishment from high-speed centrifugation may lead to lower values than the initial Swi target value. It is important to highlight that in restored state tests, core saturation must be consistent with the log analysis results [22].

(iii) Even though a high capillary pressure is applied in the core, the saturation profile is non-uniform due to capillary end-effects.

Additionally to the issues related to very-high speed centrifugation, a reproduction of hydrocarbons initial migration in the reservoir by centrifugation is impossible, which may discredit this technique for states restoration. The issues of this technique are not only the presence of capillary end-effects (as seen in Figure 1 [51]), but also the possibility of not desaturating the outlet face of the sample. This effect comes from the boundary condition when r is equal to R in Eq. (1), which gives $P_c = 0$, thus, $S_w = 1$.

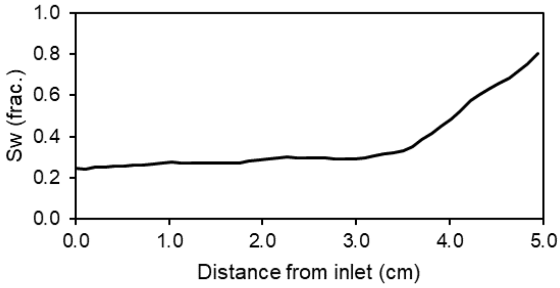

Fig. 1. Water saturation profile acquired by NMR after a centrifuge primary drainage of a Bentheimer sandstone (from Fernandes, 2023).

The solution for these problems is to reverse the injection direction, such as in the viscous oil flood case. However, this approach leads to the same issues as seen in section 2.1, with an aggravating factor: by imposing a gradient in capillary pressure in the other direction, the control of the homogeneity of the saturation profile is extremely difficult, especially because centrifugation ISSM is not available. A mislead in the control of the homogenization of the saturation profile may generate a situation such as the one presented in Figure 2 [51].

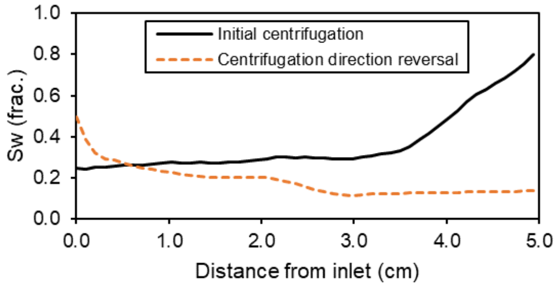

Fig. 2. Centrifugation primary drainage of a Bentheimer sandstone, imaged by NMR. The black solid line represents the water saturation profile following the first injection direction. The orange dashed line represents the saturation profile after injection direction reversal (from Fernandes, 2023).

In addition, the centrifugation method limits sample size and manipulation is generally needed to unload the sample from the centrifuge machine and load it into the coreflooding cell, where further displacements will be performed.

2.3 Porous Plate

The semi-permeable membrane method or the porous plate, as it is largely known, consists of placing a water-wet semi-permeable ceramic in the outlet face of the sample and injecting oil at successive constant pressure steps. The porous plate technique was first introduced to measure capillary pressure *versus* water saturation in a water/gas system [52], being further extended to water/oil systems. This process can be done individually by using special coreholders or on a batch basis, by using a specific apparatus. Nonetheless, the use of individual coreholders at reservoir confining stress is recommended [22]. Water production monitoring by material balance throughout the experiment allow the direct determination of the Pc(Sw) relation at the end of the experiment.

For performing this technique, a water-saturated semi-permeable ceramic plate is placed at the outlet of the sample, in which oil will be injected at constant pressure steps (in the case of an oil/water test). The ceramic has a high entry-pressure threshold to the non-wetting phase due to its small pores and for being strongly water-wet. The oil phase is considered to be connected along the sample, which generates homogeneous capillary pressure, thus a homogeneous saturation profile, such as the one shown in Figure 3 [51], where the resulting saturation profile of a Bentheimer sandstone at the end of a Porous Plate experiment is presented.

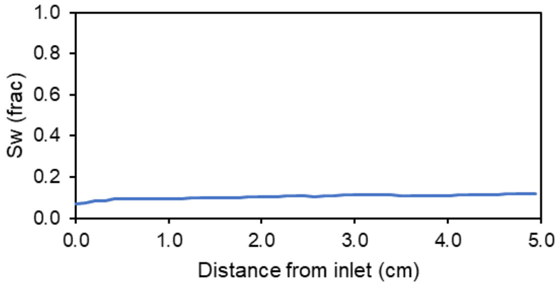

Fig. 3. Water saturation profile of a Bentheimer sandstone after porous plate primary drainage, imaged by NMR (from Fernandes, 2023).

The Porous Plate technique is considered as the reference method for establishing Swi, as it better reproduces what happens during petroleum migration in terms of fluid motion [22]. In addition, pore-scale analysis of primary drainage by the porous plate technique showed that this is the best option in terms of pore occupancy and fluids connectivity for either low or high Swi target values, as it does not induce experimental artifacts while eliminating CEE, as it is the case for VOF and centrifugation [40]. The main issue of this technique is the experimental time needed for pressure equilibrium to reach the target Swi. This is due to the extremely low permeability of the porous plate. Another drawback is the need to unload the porous plate from the overburden cell to perform further SCAL steps.

As for the other classic primary drainage techniques, the porous plate has benefited from diverse technological developments to maximize the information that may be obtained during the Swi establishment and to reduce experimental duration. An important parameter that may be obtained is the Resistivity Index, from which the saturation exponent n may be extracted. For that, resistivity measurements are performed while the core is desaturated by the porous plate method. The first publication of an experimental cell capable of performing onboard resistivity measurement while desaturating a core by the porous plate technique was presented in 1972 [53]. One proposed solution to reduce the delay to obtain the Pc(Sw) relation from porous plate experiments was performing batch porous plate primary drainage using a pressure chamber. However, this solution was quickly discredited by the several issues incoming from the batch approach [54].

To deal with the long duration constraint of the porous plate method, authors worked on different solutions to obtain capillary pressure and resistivity measurements in reduced duration. The Continuous Injection (CI) method [54] consists of injecting oil at a very low, constant, flowrate in a sample fully water saturated and in contact with a semi-permeable porous plate at the outlet. This approach was a good solution for obtaining RI in reduced time compared to the classic porous plate (also called equilibrium method), as several data points are obtained in the plateau region of the capillary pressure curve. On the other hand, this technique does not provide reliable oil/water capillary pressure curve, because a non-equilibrium condition prevails during the experiment, therefore no precise point of capillary pressure *versus* water saturation is possible to be obtained.

Another important example of an attempt to reduce the experimental duration to obtain RI data is the FRIM method [55]. This method has similarities with CI but differs in how resistivity is measured. While CI measures resistivity between the core end-faces, FRIM counts on a radial resistivity measurement, which is much less sensitive to non-uniform saturation profiles and investigates the entire sample during the electrical measurement. Nevertheless, the acquisition of a reliable capillary pressure *versus* water saturation relation is not addressed by this technique as well.

This does not mean that developments in this direction were not achieved. Modeling of water production during the transient phase of capillary pressure application with exponential functions allowed a prediction of asymptotic production [56, 57]. This approach reduces experimental duration while improving the accuracy of the Pc(Sw) data obtained. Using a similar approach, reliable and fast simultaneous measurements of RI and Pc(Sw) were obtained by interrupting intermediate capillary displacement pressures before equilibrium and applying a non-linear regression to fit the saturation data to an exponential-decay model. This solution allowed capillary pressure curves to be obtained from short-wait porous plate measurements. [58].

As the porous plate technique is well-suited for a direct definition of the capillary pressure curve, some authors have worked on a way to derive relative permeability simultaneously to Pc description. As previously discussed in the sub-section dedicated to viscous oil flood, Kr information may be derived using the transient part of fluid production during coreflood. Therefore, attempts to combine the Continuous Injection method and the membrane method were proposed [59, 60]. Nonetheless, it was lately shown that good accuracy determination of the relative permeability functions using this method is not possible, given that uncertainty increases with membrane hydraulic resistance and the presence of the second fluid in the system [61].

Nevertheless, even though the experimental duration was addressed by several authors, in a recovery experiment SCAL workflow, the necessity of unloading the core at the end of Swi establishment is a problem. Handling to unload core from the porous plate set-up to the coreflood rig represents a major risk for poorly consolidated cores and preventing gas to enter the system when mounting the core in the coreflooding cell demands very careful operation. To tackle these issues, the Toroidal Porous Plate was proposed [62], which allowed performing porous plate primary drainage and subsequent coreflood within the same experimental cell. Nonetheless, the long experimental duration of the porous plate method was not solved by this technology.

2.4 Partial conclusion

As discussed in the previous sub-sections dedicated to the classic primary drainage techniques, decades of experimental research provided massive technological development to extract precious information during this SCAL experimental step.

Meanwhile, none of these works provide an optimized alternative for preparing a core at the correct target Swi value, a homogeneous saturation profile, on an industry-standard experimental duration, without imposing experimental artifacts by reversing flow direction and without need to unload the core after Swi establishment.

In the next section we will present and discuss the works that searched for a solution for these challenges. After a quick first look, it seems clear that the solution to tackle the several challenges of performing a proper initial states restoration is on the hybridization of the classic primary drainage techniques.

3 Hybridization

The hybridization of the primary drainage techniques seems like a logical approach to take advantage of the benefits of the classic techniques and avoid the associated drawbacks.

A cutting-edge project was developed to combine centrifugation and porous plate techniques. The Spinning Porous Plate [63] was presented as a solution to obtain a homogeneous saturation profile at a desired capillary pressure and at reduced experimental time. As presented in Figure 4

[63], the technique consists of placing a sample on a porous plate and this assembly is put in a high-speed centrifuge for desaturation. For the validation of this method, sandstone and carbonate samples were submitted to primary drainage centrifugation with and without the porous plate and X-Ray CT imaging allowed the visualization of the extent of capillary end-effects on each case. Although the presence of the porous plate seems to reduce CEE, this method has proven to be unsuccessful to obtain a homogeneous saturation profile at high values of Swi targets and for low permeability samples. In addition, the problems of sample size limitation and the necessity of core handling and loading in the coreflooding cell for the subsequent steps of a recovery experimental program are still present.

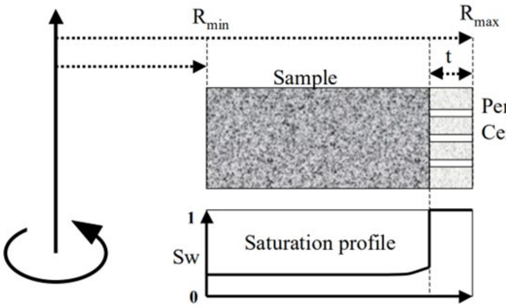

Fig. 4. Schematic draw of the Spinning Porous Plate principle (from Fleury *et al.*, 2009).

Inspired by the previous developments in SCAL and aiming to tackle the issues presented above, the Hybrid Drainage Technique (HDT) was proposed [64]. It consists of coupling viscous oil flood and porous plate methods for performing a fast, capillary-driven primary drainage, free from capillary end-effects. This technique was validated on both sandstone and limestone outcrop samples in a large permeability range and on a carbonate reservoir core [51].

The principle of the HDT is quite simple: take advantage of the viscous oil flood technique to perform a quick desaturation of the core (Phase 1) and eliminate the capillary end-effects generated by an application of homogeneous capillary pressure in the sample using the porous plate method. In practice, the rock sample is loaded in an overburden cell together with a mono-perforated porous plate placed at the sample's outlet. This perforated porous plate is then mounted on a base-plate constituted of two isolated outlets: one directly connected to the porous plate perforation (outlet 1), and one positioned immediately behind the porous plate (outlet 2). The presence of an O-ring ensures the isolation between both outlets, that are connected to valves out of the cell. As this porous plate counts with an integrated by-pass, it may be mounted together with the core at a dry state and remain in place through the whole experimental cycle, without need of removal. A schematic representation of the method is presented in Figure 5.

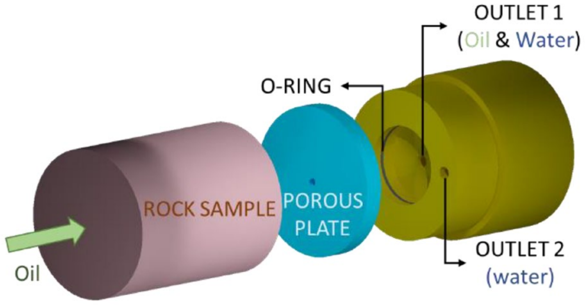

Fig. 5. Schematic draw of the Hybrid Drainage Technique setup (from Fernandes *et al.* 2022).

The main benefits of this technique are experimental time reduction and a homogenous saturation profile generation. The time reduction is due to fast water production from viscous oil flood while the latter results from a very quick transition to porous plate drainage without cell unloading, which makes this technique suitable for any sample size. In addition, the sample is immediately ready for further testing after Swi establishment, as the overburden cell is adapted to further steps of a recovery experiment.

4 Discussion/Conclusion

It is quite clear that the primary drainage step of a SCAL experimental workflow holds a huge amount of information that may be accurately acquired thanks to several technological developments reached through decades of scientific research. These data are of some importance for a good reservoir description and modeling, as well as to obtain reliable production forecast. However, many of the developed techniques are based on the generation of saturation gradients during Swi establishment for properties definition. In addition, core handling during unloading/loading processes may damage fragile samples or hinder fluids occupancy in the case of samples initialized at high Swi target values. These issues represent an incompatibility of these methods with proper cores states restoration for subsequent steps of coreflooding in recovery or wettability experiments.

As initially stated, the best solution for establishment of initial fluid saturations among the classic techniques is porous plate. Besides respecting reservoir flow, it generates a homogeneous saturation profile at the targeted capillary pressure (that is directly associated to water saturation) without generating detrimental experimental artifacts. Nonetheless, the necessity of unloading the sample to continue a coreflooding workflow is a major issue of this technique. The Toroidal Porous Plate [62] proposes a solution to this problem, as a bypass in the porous plate allows further injections to be carried on without handling. Nevertheless, it does not tackle the experimental duration issue, which limits the application of this technique to very small core samples, as performing primary drainage by porous plate on full size cores in a reasonable duration is impossible. Finally, the only primary drainage technique capable of generating a homogeneous saturation profile, at a targeted Swi value, without flow reversal and not demanding sample unloading from the experimental cell to perform further corefloods is the Hybrid Drainage Technique [64].

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