# Investigating the Effect of Rock Pore Size Distribution on Reservoir Production Performance

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## Abstract

Rock pore size distribution is one of the most important parameter that can affect the reservoir depletion during the water flooding process. In this paper the effect of the pore size distribution from micro, to macro pore sizes on the capillary pressure curves, relative permeability curves and the remaining oil saturation is investigated.
Gaussian distribution was developed for micro, meso and macro pore sizes assuming that the pores are bundle of tubes with cylindrical shape for simplicity. The results from capillary pressure curves illustrate the invasion paths in pores while the relative permeability curves present the rock grain sorting. Purcell's correlation is used to calculate the data related to the relative permeability. The obtained fluid flow curves for different pore size distributions are then implemented in a simple reservoir model to evaluate the reservoir respond for water flooding. The results from simulation show that the oil recovery increases with increasing of the number of the macro pores follows by the meso and micro pore sizes. Moreover it is observed that the time of water breakthrough is highly dependent on the type of pores where the late water breakthrough time is obtained for the micro pores. This study concludes that the reservoir performances during water flooding and hence reservoir fluid production are highly dependent on the rock typing and the pore size distribution.

**Keywords:** Pore size distribution, Capillary pressure, Relative permeability, Residual oil saturation, Gaussian distribution.

## Introduction

Residual Oil Saturation or Remaining Oil Saturation (ROS) refers to the oil saturation left after the injection of a specific volume of displacement fluid (gas or water) into an oil bearing reservoir [1]. The assessment of ROS is necessary to determine whether an oil bearing reservoir has reached a limit beyond which production will not be economically possible. The proportion of ROS that can be moved with a required number of pore volumes of flooding fluid (gas or water) helps to determine the economic viability of production compared with the cost of fluid injection. The ROS is a function of the volume of fluid injected, wettability, heterogeneity of the reservoir and pore size distribution.

According to Shedid [2], pore-size distribution is considered critical to the displacement efficiency of oil bearing reservoirs. The pore-size distribution of rocks influences porosity and permeability of the reservoir, thereby affecting the ROS; hence it is important to study the pore-size distribution in rocks to understand the flow processes within a porous matrix and the performance of the reservoir in general. Beiranvand [3] explained that pore-size distribution is also related to a variation in the sorting and packing of grain size of rocks. Gaussian distributions were carried out to study variety of rock pore size distributions of macro, micro, and meso. The reservoir performance in respond to the aforementioned pore size distributions are then investigated using standard oil and gas reservoir software know as Eclipse 100.

**Methods and techniques**

In the oil and gas reservoirs, the link between permeability and hydrocarbon saturation is the distribution of pore channel sizes, represented by 1/r. More over the pore sizes govern the minimum threshold pressure which in turn results in wetting phase being displaced by non-wetting phase. To study the reservoir performance in term of hydrocarbon production and its dependency to pore size distribution following steps are deployed.

**Step 1:** Three well defined pore size distributions are considered namely micro, meso and macro.

$$P_C = \frac{2 \times \sigma \times \cos(\theta)}{r} \tag{1}$$

**Step 2:** Compute capillary pressure incrementally for the selected pore sizes from higher values to lower with an incremental value of 1μm assuming pores as bundle of tubes by applying the following equation:

**Step 3:** The pore size distributions are modelled with Gaussian Distribution Function (GDF).

**Step 4:** The total volume of invaded pores are computed by calculating of the volume of each single pore size multiplied by the number of pores invaded for three different chosen models.

**Step 5:** The developed porous models are used to compute the relative permeability using Purcell Equations

**Step 6:** The computed relative permeabilities for three sets of porous media are included into a simple Eclipse model to investigate the reservoir performance in response to the changes in pore size distribution.

The source of data to calculate capillary pressure, relative permeabilities as well as the pore volume are given in the following table.

**Table 1. Sources of the data used in this study**

| Parameters | Values | Source |
|---|---|---|
| Interfacial tension σ (dynes/cm) | 27 | Ling [4] |
| Contact angle θ in degrees | 0 | Ling [4] |
| Core Length (inch) | 2 | Ling [4] |
| Inter-particle pore size | Micro: [10-50µm] | Lønøy [5] |
| | Mesopres : [50-100µm] | Lønøy [5] |
| | Macro : >100µm | Lønøy [5] |

## Results and discussion

*Effect of pore size distribution on capillary pressure curves and relative permeability curves*

Fig.1a shows the capillary pressure curves for different ranges of inter-particles pore-size. It can be observed that the calculated Pc for macro size pores is the lowest at equal saturation with meso and micro. This indicates that a small pressure is required to invade the macro size pores compared to meso and micro. In line with the Pc, the required threshold pressure (entry pressure) for macro size pore is smaller than meso and micro which reveals that when there is an increase in permeability of the pore (macro), there would be subsequent decreases in capillary pressure.

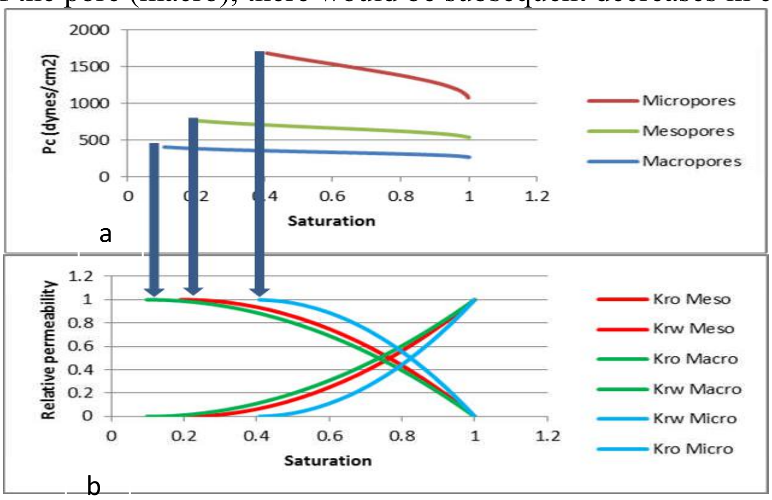


**Figure 1. Calculated capillary pressure (a) and relative permeability curves (b) for the three pre-defined pore size distribution models.**

For the defined rock models, the relative permeability curves are also calculated using Purcell approach and results are presented in Figure 1b. The different values of irreducible water saturation Swir (Swir micro =0.4, Swir meso=0.2 and swir macro 0.1) are shown in Fig.1b. It is obvious that micro represent the relative permeability with lower performance (shifted to the right). The change in position of Kro–Krw curve depends on the pore size distribution. Therefore, every pore type has a unique relative permeability signature.

*Reservoir performance to the pore size distribution (Simulation results)*

To study the influence of pore size distribution on hydrocarbon reservoir performance, a simplifiedreservoir models (Black Oil model built by using Eclipse 100) are built and the calculated capillary pressure and relative permeability as the main contributors are introduced to the model. The three models (micro, meso, and macro) were run successfully for and production were reported for 30 years. The main field performance parameters were extracted and results are presented in Fig.2 to Fig.5.

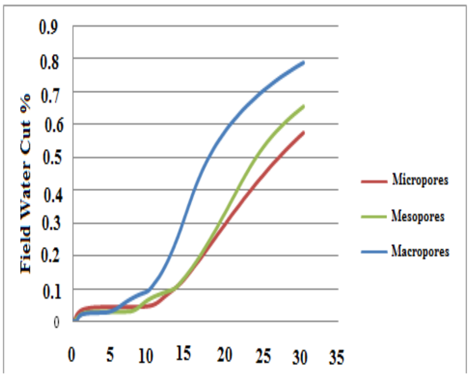


**Figure 2.Trend of water cut for three pore size distribution cases.**

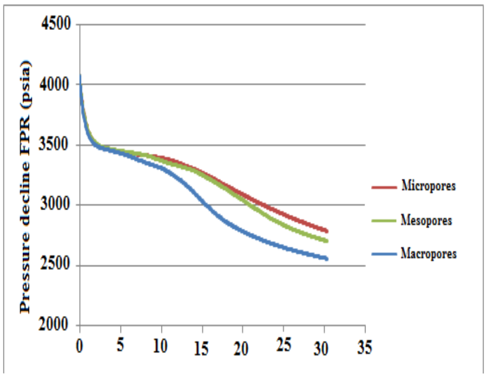


**Figure 3.Pressure decline curves for three pore size distribution cases.**

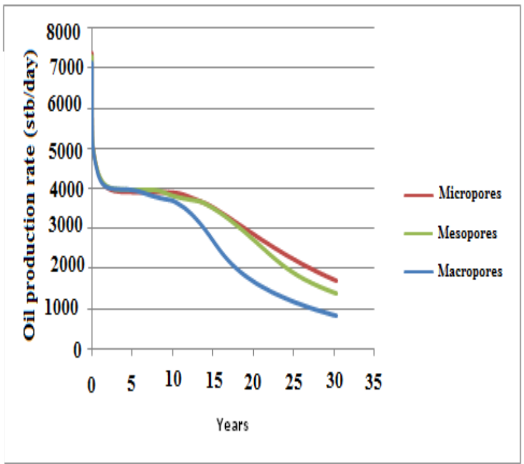


**Figure 4. Oil production rate for three pore size distribution cases**

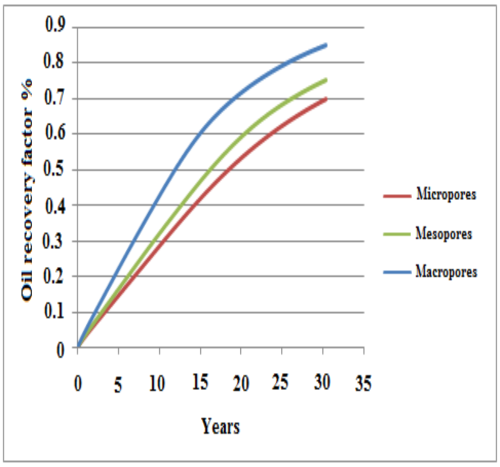


**Figure 5. Oil recovery factor for three pore size distribution cases**

From reservoir management consideration, water production has server impact on hydrocarbon production, hence on field development planning. Fig.2 shows the plot of field water cut for the cases owning three different rock pore size distribution. The Figure demonstrates a small increase in water cut for all three cases after which the trends remained steady till after about 7 years. Thereafter, there is a sharp increase in water cut for all cases with the macro case as the highest. The early water breakthrough event is observed for the macro pore size case, which means reservoir engineer should prepared for the intervention job at earlier stage compared to the other cases.

Fig.3 depicts the pressure decline during the production period. After the drastic drop in pressure caused by natural depletion, then the drop mainly governed by the rock pore size distribution where the pressure decline curve for microporous rock decreases further apart from the other curves followed by the average reservoir pressure is mesoporous and microporous. This result provides a guide to reservoir engineer to plan to maintain the reservoir pressure for macro case at early stage of reservoir production life.
It is also worth mentioning that any plan for water injection would be affected by the pore size distribution where the rate and injectivity of the injected water strongly affected by pore size distribution. This can be simply anticipated from the results in the Fig.3 where for macro case higher rate on injection is expected to depress the pressure decline.

The rate of oil production is also affected by the pore size distribution similar as pressure and water production and injection. Fig.4 shows the trend for the oil production rate for all cases. As it is demonstrated in this Figure, a sharp decrease in production rate in the early years is observed irrespective to the rock pore size. The production rate is maintained until the tenth year, after which it decreases sharply till 30 years. The initial decrease in oil production rate is due to the reduction in oil in the immediate production zone. The continuous flow of oil towards the producer causes the rates to sharply decrease further. There is a further decrease in the macro curve compared to othersbecause of the presence of large pores which can be attributed to the early water breakthrough presented in Fig.2.

Finally, the oil recoveries from the reservoirs having different pore size are evaluated using the following equation:

$$R_f = \frac{\overline{S_w} - S_{wir}}{1 - S_{wir}} \tag{2}$$

Where,

$\bar{S}_W$ is The average saturation behind the front calculated from the well know Buckley- Leverett equation [6], $S_{wir}$ is Irreducible water saturation, and $R_f$ is represents the recovery factor.

Fig.5 shows the plot of field oil efficiency for the three curves. It can be clearly seen that high oil recovery is associated with the macro pores despite the early time of breakthrough; this is because there is higher oil in place within macro (storage capacity) and hence sweep efficiency. The lower required capillary pressure and insignificant viscus and gravity forces are among other reason to ease the mobilization of oil in the macro-porous rocks than the other two studied cases.

## Conclusions

This study showed that the pore size distribution has a great influence on the number of invaded pores, the capillary pressure, the relative permeability, and the field performance.
The following conclusions were drawn from this work:

- The water invasion into the reservoir rock starts from zone with the highest population of macro pores followed by mesoporous, and microporous.
- The favourable relative permeability is associated with the macroporous rocks.
- The early time of water breakthrough is witnessed within macroporous.
- The highest oil recovery is obtained for macroporous sample which is associated to the highest storage capacity of the oil, even there is early time of water breakthrough.

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