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Review

A comprehensive review on characterization and modeling of thick capillary transition zones in carbonate reservoirs

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ABSTRACT

Tight carbonate reservoirs exhibiting thick transition zones usually contain a large quantity of oil. Therefore, significant reserves might be left after secondary recovery by waterflooding not only due to the being in transition zones but also more due to the rock quality, tightness, pore throat and geometry, mineralogy, and wettability etc. Proper characterization and modeling of oil reservoirs are the key factors to predict their production performances, improve oil recovery and optimize the reservoir management. The development of saturation functions for transition zones, especially, of carbonate reservoirs is vital and challenging to address the multiphase flow and initial water saturation distribution in both static and dynamic modes.

In this paper, a complete overview of the available experimental, modeling and simulation research works on transition zones in carbonate reservoirs is presented systematically. It is necessary to obtain a review of the past and present works so that the future researchers will get a clear idea of the approach on characterization and modeling of transition zones in carbonate reservoirs. Initial water saturation, hysteresis behaviors of relative permeability and capillary pressure, wettability alteration modeling and reserve estimation has been discussed in this paper. Petrographic and diagenesis study has also been discussed with the help of a few laboratory works from our research group. It is expected that this review will open new doors to the forthcoming researchers in this field. New thoughts and future works on transition zone characterization and modeling are also provided in this review as future developments and challenges.

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1. Introduction

The capillary transition zone of carbonate reservoir is traditionally defined as the reservoir interval that extends from the oil-water contact (OWC) up to the reservoir level where water saturation reaches its irreducible level, Swirr as shown in Fig. 1. The transition zone, therefore, may vary in thickness from a few feet in high permeability reservoirs to over hundreds of feet in some low permeability, thick and tight carbonate reservoirs. Transition zones may then contain a significant portion of the reservoir's oil in place.

The extent of transition zones in carbonate reservoirs is essentially governed by the heterogeneity of the reservoir layering and the capillarity of the reservoir rocks, driven by drainage capillary pressure as shown in Fig. 2 more clearly. Wettability studies of many thick carbonate reservoirs show that reservoir wettability may differ as a function of the water saturation level from being strongly water wet at the OWC levels where Sw equals to 100% to being oil wet at the top of the transition zone where Sw equals to Swirr. The original water wet rock may change to oil wet (fraction of oil wet pores may increase) as the oil saturation increases with height above the free water level (HAFWL).

During the oil production from carbonate reservoirs, it is assumed that perforation of the transition zone is noneconomic. Currently, extensive research works on characterization and performance prediction of carbonate reservoir transition zones are in progress. From the findings, the main research topics include behaviors of relative permeability, capillary pressure, and residual oil saturations with initial water saturation. To characterize the transition zone behavior, it is necessary to perform different laboratory experiments and develop and implement static and dynamic models. For this purpose, Spearing et al. (2014) studied the transition zone behavior with the measurements of bounding and scanning curves for capillary pressure and relative permeability at reservoir conditions for a giant Abu Dhabi carbonate reservoir.

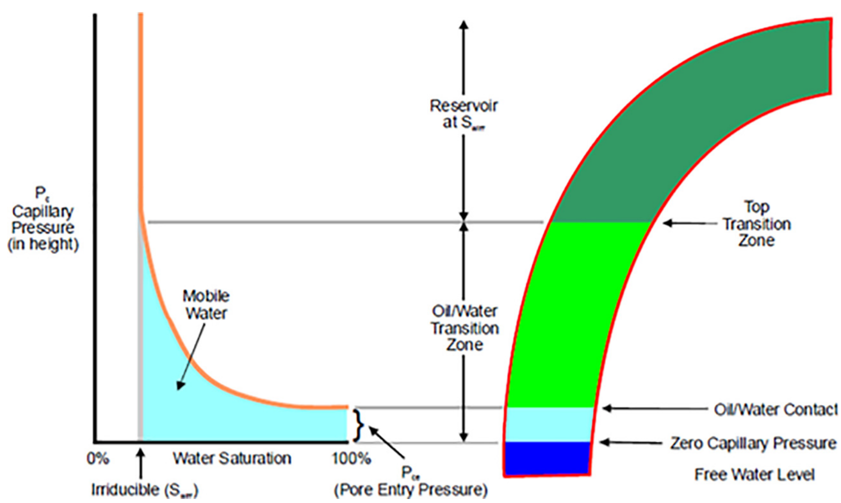

Fig. 1. Schematic diagram of the oil-water capillary transition zone with a variation of water saturation and capillary pressure (Holmes, 2002).

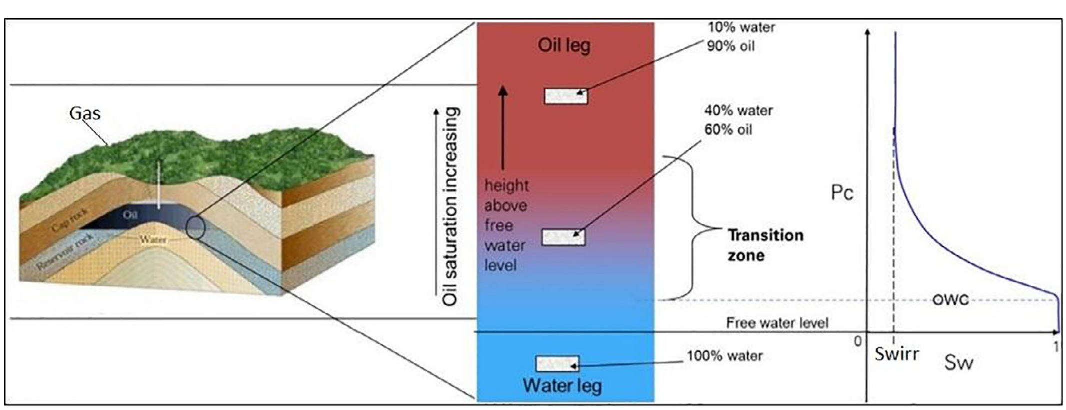

Fig. 2. Oil saturation, free water level, and capillary pressure behaviors in the transition zone (Spearing et al., 2014).