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Estimation of wettability in gas–liquid–rock systems

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Abstract

The wettability in gas–liquid–rock systems, including geothermal (steam–water–rock) systems, is central to defining the relative permeability and capillary pressure, which govern the forecasts of future production and reinjection performance. Since the frequently used Amott and USBM approaches are appropriate only for specific liquid–liquid–rock systems, we developed a model to evaluate the wettability in gas–liquid–rock systems. The method can be applied to determine the wettability at specific wetting-phase saturation if the capillary pressure and relative permeability at this fluid saturation are known. The proposed model can also be used in liquid–liquid–rock systems. The validity of the technique was tested qualitatively and quantitatively using experimental data from different rock–fluid systems. The calculated wettability indices in gas–liquid–rock systems were higher than in liquid–liquid–rock systems, as expected. Results also show that the wettability index calculated using the new method may or may not be independent of fluid saturation in the cases studied. In addition, the wettability index in drainage was seen to be greater than that in imbibition, a wettability difference that is particularly important in steam–water–rock (geothermal) systems because of the impact on reinjection.

Keywords: Geothermal systems; Evaluation of wettability; Steam–water gas (steam)–liquid–rock systems; Liquid–liquid–rock systems; Capillary pressure; Relative permeability

1. Introduction

Wettability is defined as the tendency of a given fluid to spread on a solid surface when two immiscible liquids or a liquid and gas are present (Bear, 1972). This phenomenon influences multiphase flow in a geothermal reservoir and controls the fluid distribution, for example, steam

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Nomenclature

F	lithology factor
k	absolute permeability
k_{air}	air permeability
k_{rw}	relative permeability of the wetting phase
k_w	effective permeability of the wetting phase
P_c	capillary pressure
P_e	entry capillary pressure
S_{nwr}	residual saturation of the non-wetting phase
S_w	wetting-phase saturation
S_{wr}	residual wetting-phase saturation
S_w^*	normalized wetting-phase saturation
W_i	wettability index
W_{iw}	wettability index at the wetting-phase saturation of S_w
W_r	ratio of the wettability index of fluid pair 1 to fluid pair 2

Greek symbols

θ	apparent contact angle through the liquid phase
θ_w	apparent contact angle through the water phase at a wetting-phase saturation of S_w
λ	pore size distribution index
σ	interfacial tension
ϕ	porosity

Superscripts

n	for fluid pair n (=1, 2)

exists in the fractures while water exists in the matrix in many cases. Wettability also affects capillary pressure and relative permeability values and is important during fluid extraction (i.e. when the reservoir is produced or drained) and fluid recharge (i.e. when the reservoir is recharged). During reinjection, an important mechanism is for water to imbibe strongly into the rock matrix, which depends on the wettability of the steam–water–rock system.

It has been proven experimentally that wettability in gas–liquid–rock systems can be altered from strong preferential liquid-wetness to preferential neutral gas-wetness by chemical treatment (Li and Firoozabadi, 2000). A lot of attention has been paid to the study of this effect because of its importance in natural gas reservoirs. However, it still remains a challenge to evaluate the wettability alteration quantitatively in gas–liquid–rock systems. The difficulty is not limited only to the characterization of the steam–water–rock systems found in geothermal reservoirs, so many of our remarks are applicable also to gas–water–rock systems in general.

Wettability is often represented by contact angle or wettability index. Slobod and Blum (1952) developed a method to evaluate the wettability of reservoir rocks from the threshold capillary pressures measured in oil–water–rock and air–oil–rock systems. However, the semiquantitative method was based on the assumption that the contact angle through the liquid phase in gas–liquid–rock systems is zero. This assumption implies that there would be no differences among the wettabilities of gas–liquid–rock systems. This may not be true in certain cases, espe-