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Development of a Response Surface Based Model for Minimum Miscibility Pressure (MMP) Correlation of CO_2 Flooding

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Abstract

Correlations are commonly used to predict CO_2 multiple contact miscibility (MMP) since such correlations are generally inexpensive and easy to use. In this study, we used a novel approach based upon four dimensionless scaling groups commonly used for hydrocarbon phase behavior modeling (reduced temperature and acentric factors for light and heavy pseudo components) as well as multivariate regression analysis based on response surface methodology to develop an MMP correlation for a broad range of reservoir oils. Applying the response surface method and multivariate regression analysis made it possible to quantify and rank the effect of each one of the mentioned dimensionless groups on the predicted MMP value. Since reservoir temperature is one of the main parameters, slim tube simulations were performed at four different reservoir temperatures (90, 150, 180, and 220 °F) for all of the fluid models. Based on the results from these simulations, and by performing multi-variate regression analysis, MMP values were correlated using a response surface based on linear, quadratic, and third degree equations. Our new MMP correlation takes into account the important equation-of-state properties for heavy- and light-oil components as well as temperature. Predicted MMP values from the new correlation were compared with previously published MMP correlations and found to have a lower average error.

Introduction

Miscible CO_2 flooding is one of the most efficient displacement processes among tertiary oil recovery methods. Based on a study by Stosur *et al*. (1990), on future potential of Enhanced Oil Recovery (EOR) methods in the US, miscible CO_2 gas injection is gaining more popularity and eventually will be more attractive than any other EOR techniques. This can be related to higher oil prices as well as availability of more CO_2 sources considering the global regulations and restrictions on CO_2 emissions. In a CO_2 displacement project, when full miscibility between injected CO_2 and reservoir fluid is reached, capillary forces are eliminated from displacement process which ideally results in no oil trapping and consequently higher recovery values. Difference between reservoir pressure (or displacement pressure) and Minimum Miscibility Pressure (MMP) is the most important factor to determine whether miscibility has been achieved in the reservoir. Displacement pressure should be higher than MMP in order to achieve miscibility in the reservoir.

Miscibility in reservoir conditions is generally achieved by two different mechanisms. When the injected fluid and reservoir crude become fully miscible, or in other words, First Contact Miscible (FCM) conditions are achieved, a single phase fluid is created and therefore, injected fluid completely displaces the reservoir fluid. One of the most obvious cases for this type of miscibility condition is FCM of Butane with some crude oils at reservoir conditions. Another type of miscibility mechanism is called multiple contact miscible displacement. Carbon dioxide generally makes multiple contact miscibility with crude oils at some reservoir conditions. This means that many contacts are necessary (in the form of mass transfer) for crude oil components and CO_2 to be mixed with each other. In these contacts, CO_2 first starts to be condensed into the reservoir oil, and then light oil components are vaporized into the CO_2-rich phases. This continues until there is no interfacial tension between these two new phases and a single hydrocarbon phase is being produced. This process mainly depends on reservoir pressure since reservoir temperature is considered constant in the CO_2 flooding processes. As reservoir pressure increases, more CO_2 is dissolved in the oil and more oil components are vaporized by oil. It is known that the extraction of hydrocarbons depends greatly on the density of CO_2 (Lake, 1989). As CO_2 density increases, more hydrocarbon components are vaporized from crude. In general, higher reservoir pressure results in higher CO_2 density. The pressure at which reservoir oil and CO_2 are in extremely close contact is called MMP.

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