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An Early-Time Model for Well Testing of a Hydrate-Capped Gas Reservoir

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Abstract

Natural gas hydrate have been estimated to make up the largest component of fossil fuel resource worldwide. Hydrate reservoirs may be found in different geologic settings including deep ocean sediments and arctic areas. Some reservoirs include a free-gas zone beneath the hydrate, and such a situation is referred to as a hydrate-capped gas reservoir. Gas production from such a reservoir could result in pressure reduction in the hydrate cap and endothermic decomposition of hydrates.

Well testing in a hydrate-capped gas reservoir is a developing art; development of a new model, incorporating the dynamic effects of gas hydrate decomposition, is necessary for realistic and accurate predictions. This paper presents a two-dimensional (*r,z*) mathematical model for a constant rate drawdown test performed in a well completed in the free gas zone of a hydrate-capped gas reservoir during the early-time period of production. Using energy and material balance equations, the effect of endothermic hydrate decomposition appears as an increased compressibility in the resulting governing equation. The Laplace-domain solution for the dimensionless wellbore pressure is derived using Laplace and finite Fourier cosine transforms. The solution to the analytical model was compared with a numerical hydrate reservoir simulator over some range of hydrate reservoir parameters.

The results show that the effect of decomposition on wellbore pressure is substantial. The analytical model can be used for analysis of drawdown tests in hydrate-capped gas reservoirs. Furthermore, it may be used to quantify the contribution of hydrate decomposition on production performance.

Introduction

In recent years, demands for energy have stimulated the development of unconventional gas resources which are available in enormous quantities around the world. Gas hydrate as an unconventional gas resource tends to form in two geologic settings[1]: (1) on land in permafrost regions, and (2) in the ocean sediments of continental margins. During the last decade, extensive efforts consisting of detection of the hydrate-bearing areas, drilling, logging, coring of the intervals, production pilot-testing, and mathematical modeling of hydrate reservoirs have been pursued to evaluate the potential of gas production from these gas hydrate resources.

A number of recovery processes have been suggested for producing gas from hydrates in sediments. Among others, Pooladi-Darvish[2] has presented a review of the important conceptual production methods including depressurization, thermal stimulation, and inhibitor injection.

A typical form of depressurization technique is illustrated in Figure 1. A hydrate-capped gas reservoir is defined here as a gas reservoir capped with a partially saturated hydrate interval. The intercept of the hydrate-water-gas equilibrium curve and the geothermal depth-temperature curve identifies the base of the hydrate stability zone. Above this base-line, hydrates are expected to be stable. A well is drilled through the hydrate layer and is completed in the free gas zone. Gas production from the well causes pressure reduction, which propagates into the reservoir and provides the driving force for the decomposition of the hydrate within the hydrate cap. The endothermic decomposition of hydrate has two effects: (i) cooling of the decomposed zone, and (ii) generation of gas and water according to Equation (1). The cooling effect creates a temperature gradient in the reservoir system. This leads to the initiation of conductive heat flow towards the cooled zone that provides part of the necessary energy for further decomposition. Another part of the heat of decomposition is provided from the sensible heat of the hydrate cap itself. The second effect (the generation of gas and water) promotes the two-phase fluid flow and convective heat transfer in the reservoir.

$$Hydrate + Energy \longrightarrow CH_4 + N_H \cdot H_2O \qquad (1)$$