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Modeling of Ice Formation in Gas Hydrate Reservoirs

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Summary

A number of numerical simulation studies of gas hydrate reservoirs have indicated that the pressure reduction method known as *depressurization* is a promising technique to produce gas from hydrate reservoirs. In some cases, severe ice formation has been observed, leading to plugging and termination of gas production. Some researchers have suggested that if the flowing bottomhole pressure is not lowered beyond the equilibrium pressure corresponding to the freezing point of water, then ice formation may be avoided. This argument is based on the premise that the lowest temperature would occur at the wellbore. If temperature can be controlled to above zero by controlling the bottomhole pressure, then freezing should not occur. The objective of this work is to explore under what conditions ice particles form. Various cooling mechanism (cooling because of decomposition, gas expansion, etc) are studied in detail.

For this purpose, a 3D mathematical model for gas production from hydrate reservoirs is introduced which incorporates energy balance, fluid flow and kinetics of the hydrate decomposition along with the ability to predict the formation of ice particles. This model is developed by modifying the GPRS (General Purpose Reservoir Simulator) platform to account for a number of mechanisms including hydrate decomposition and ice formation. GPRS is an object oriented reservoir simulator code developed at Stanford University. We will then apply this simulator to model large-scale hydrate decomposition process in porous media, and demonstrate the effect of ice formation on gas production behavior. Through some case studies we investigate the conditions in which ice forms and becomes an issue. The learning for these studied are then used to suggest practical ways of avoiding ice formation.

Keywords: Gas Hydrate Reservoirs, Ice Formation, Reservoir Simulation, GPRS, Joule-Thomson Effect

Introduction

Hydrate particles are made up of natural gas molecules trapped in water molecule structures, and are considered as a potential resource for clean energy. Enormous quantities of methane gas exist in the form of hydrate in the permafrost and offshore environments. Large resources of hydrate have been explored worldwide including the North West Territories of Canada, Siberia, Alaska and Japan. In the last two decades much interest and research has been devoted towards the mathematical modeling of gas production from hydrate reservoirs. Three general techniques have been suggested to recover gas from hydrate reservoirs which are all based on breaking the stability conditions of hydrate leading to generation of gas; Depressurization, Thermal Stimulation and Inhibitor Injection. While depressurization does not require an external source of energy and is based on propagation of pressure drop from the wellbore to the hydrate decomposition zone, the thermal stimulation technique needs an external source of energy, not unlike those applied in the thermal recovery of heavy oils. The first attempts to model hydrate formation and decomposition go back to the works done in the first decades of 1900's which aimed at preventing hydrate formation in the gas transportation pipes. Exploration of hydrate reservoirs and their potential as a new resource for energy has resulted in more research activities in the last two decades. The existing analytical models (Selim and Sloan (1985), Selim and Sloan (1990), Tsypkin (2000), Hong et al (2002), and Gerami and Pooladi-Darvish (2006) and (2007)) have been used as a tool for mechanistic studies and understanding of the behavior of the decomposition process. However the limitations and assumptions involved in the analytical models limits their application. Numerical models (Holder and Angert (1982), Burshears at al (1986), Yousif at al (1991), Moridis (2002), Hong and Pooladi-Darvish (2003), Moridis et al (2005), and Sun and Mohanty (2005)) are based on a more general form of the mathematical model of the process and can be easily extended to include real-life conditions such as heterogeneity and variable operating conditions. A number of these simulation studies have indicated that hydrate decomposition applying depressurization technique could lead to drop the temperature below the water freezing point. Model developed by Kowalsky at el (2007) had the ability to predict ice formation. While ice formation was prevented applying thermal stimulation technique the endothermic nature of the decomposition process cooled down the media during depressurization, which led to ice formation and reduced the permeability of the media. Four components (hydrate, methane, water and salt) and five phases (hydrate, gas, aqueous-phase, ice and salt precipitate) 3-D kinetic simulator developed by Sun and Mohanty (2005) can track water freezing and ice melting with PVSM (Primary Variable Switching Method) by assuming equilibrium phase transition.

Theory and/or Method

The process of gas production from hydrate reservoir involves three major mechanisms; heat transfer by conduction and convection, endothermic reaction that convert hydrate structure to gas and water molecules and flow of products within the reservoir. In order to decompose the hydrate structure either the pressure at the bulk phase should be reduced (depressurization) or the temperature (equilibrium pressure) should be increased (Thermal Stimulation). In the depressurization method the pressure at the wellbore drops below the equilibrium pressure, the decomposition of hydrate commences. Upon the propagation of the pressure reduction, the decomposition moves deep into the hydrate layer. The endothermic nature of the decomposition process leads to the reduction of the temperature at the decomposing zone and results in transferring heat from warmer parts of the porous medium towards the decomposition zone. A 3-D, four phases; Gas, Hydrate, Ice and Water (G,H,I,W) and four components (g,h,i,w) model which accounts for multiphase flow, heat transfer (convection and conduction) and kinetics is developed based on recently introduced GPRS- Thermal (2005) model. In this work it has been suggested that if the pressure of the wellbore kept above the equilibrium pressure corresponds to freezing temperature, ice will not form. The bottomhole pressure (BHP) for which ice formation will be prevented is defined as: $BHP \geq p_{eq}(T_f(BHP))$. Upon solving this equation, the minimum BHP is calculated as 2.2512 MPa. The following example shows that any value of BHP below the minimum BHP will results in formation of ice.

Examples

A 1-D hydrate reservoir initially at $p_i = 10 \ MPa$, $T_i = 279.15 \ K$, $S_G = 0$, $S_H = 0.5$, $S_I = 0$ and $S_W = 0.5$ is considered for gas production under depressurization technique. Two different cases with BHP=2.2512 MPa (fig 1- right) and 1 MPa (left) have been simulated to see the condition under which ice particles will form.

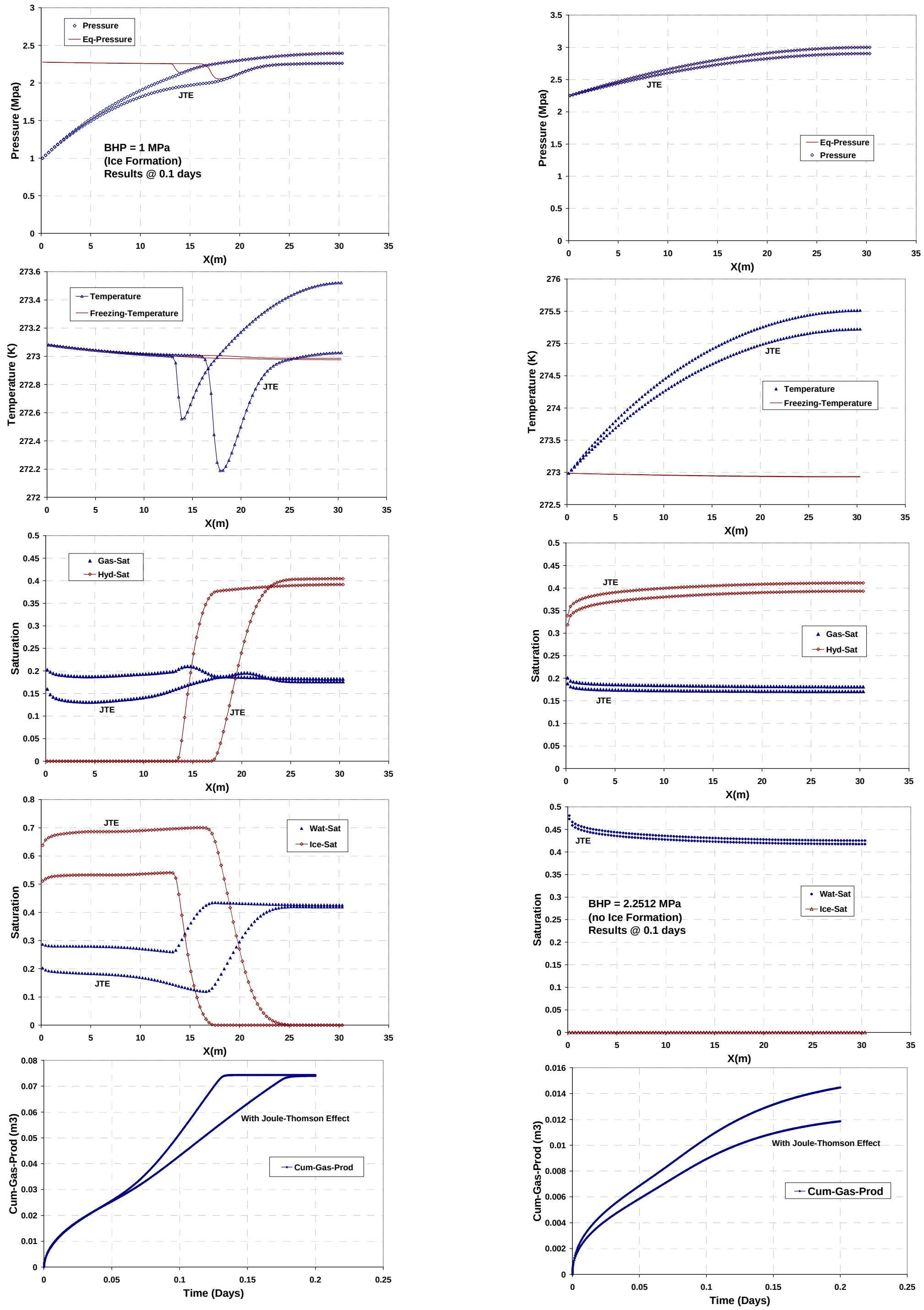

Figure 1: pressure, temperature and saturation profiles for both cases in time=0.1 days, cumulative gas production is shown in time=0.2 days.

Conclusions

A 3-D four phases four components simulator was developed based on CVFD method to model hydrate decomposition and formation along with ice formation and fusion. Two mechanisms of cooling were investigated; the endothermic decomposition of hydrate particles and the Joule-Thomson effect. Ice formation was detected in the case where bottom-hole pressure dropped below the equilibrium pressure corresponds to the freezing temperature; however it was prevented with BHP larger than this value. One may conclude that the minimum temperature across the media will be above the freezing temperature if the minimum pressure (BHP) kept above the equilibrium pressure of the freezing temperature therefore ice formation may be prevented. If this condition honored the Joule-Thomson effect can not drop the temperature further. Although ice formation releases heat and leads to more decomposition of hydrate particles, its blockage effect could results in decreasing the permeability drastically. Further investigation required to see the effect of ice formation on the total gas production (hydrate decomposition).

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