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PRODUCTION STRATEGIES FOR MARINE HYDRATE RESERVOIRS

J. Phirani and K. K. Mohanty
Department of Chemical & Biomolecular Engineering
University of Houston
4800 Calhoun Road, Houston, TX 77204-4004, USA

ABSTRACT

Large quantities of natural gas hydrate are present in marine sediments along the coastlines of many countries as well as in arctic regions. This research is aimed at assessing production of natural gas from the marine deposits. We had developed a multiphase, multicomponent, thermal, 3D simulator in the past, which can simulate production of hydrates both in equilibrium and kinetic modes. Four components (hydrate, methane, water and salt) and five phases (hydrate, gas, aqueous-phase, ice and salt precipitate) are considered in the simulator. In this work, we simulate depressurization and warm water flooding for hydrate production in a hydrate reservoir underlain by a water layer. Water flooding has been studied as a function of injection temperature, injection pressure and production pressure. For high injection temperature, the higher pressure increases the flow of warm water (heat) in the reservoir making the production rate faster, but if injection temperature is not high then only depressurization is the best method of production. At intermediate injection temperature, the production rate changes non-monotonically with the injection pressure.

Keywords: Gas hydrates, Injection Temperature, Injection Pressure, Production Pressure

NOMENCLATURE

SA = aqueous saturation
SH = hydrate saturation

INTRODUCTION

Gas hydrates are ice-like compounds formed by trapping of gas molecules in clathrates of water molecules under high pressure and low temperature [1]. Three types of crystalline structure of gas hydrates have been found so far, Structure I (SI), Structure II (SII), Structure H (SH), in the order of increasing clathrate size. The properties associated with the crystalline structures have been studied in details by Sloan [1]. SI methane hydrate is very common and will be the focus of present study. The hydrate reservoirs can be classified into 3 types [2]: Class 1 reservoirs have a hydrate layer overlying a free gas layer, Class 2 reservoirs have hydrates overlying a water saturated layer and Class 3 reservoirs have a single layer containing hydrates bounded by two impermeable shale layers. Class 2 reservoirs are studied in the present work.

Four methods and their combinations have been proposed to produce gas from hydrate reservoirs: depressurization, thermal stimulation, inhibitor injection, and CO2 injection [1,3]. In depressurization, the pressure is lowered at the production well below the hydrate stability pressure and the dissociated gas flows into the production well. In thermal stimulation either wells are heated or warm water or steam is injected raising the temperature above the hydrate stability temperature. In the inhibitor process, chemicals that inhibit hydrate injection are injected along with water in injection wells. In the CO2 process, CO2 replaces methane in clathrate cages giving rise to methane production and simultaneous CO2 sequestration.

In this work, we are considering injection of warm water and depressurization for production from Class 2 hydrate reservoirs. The source of warm water could be a nearby oil reservoir or an underlying water aquifer. Gas production from a hydrate reservoir is studied through numerical simulation.

The numerical model used is a finite-volume simulator that takes into account heat transfer, multiphase fluid flow and equilibrium thermodynamics of hydrates [4]. Four components (hydrate, methane, water and salt) and five phases (hydrate, gas, aqueous-phase, ice and salt precipitate) are considered in the simulator. Water freezing and ice melting are tracked with primary variable switch method (PVSM) by assuming equilibrium phase transition. Equilibrium simulation method is used here because kinetics of hydrate formation and dissociation are relatively fast in the field-scale. This simulator has been validated against several other simulators for the problems in the code comparison study conducted by US DOE.

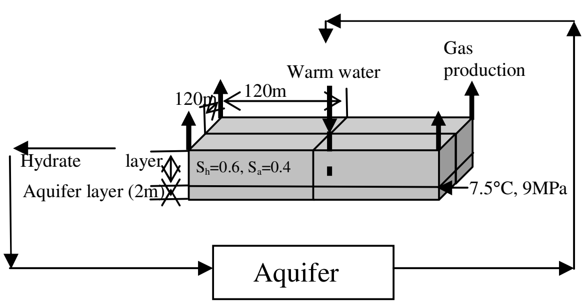

Figure 1: Domain considered for the base case

The objective of this study is to identify optimum production strategies for gas production from Class 2 hydrate reservoirs through numerical simulation. The domain selected as the base case is a quarter five-spot of size 120m x120m x10m (Figure 1). Initial temperature and pressure are assumed to be 7.5°C and 9MPa, respectively, which lie in the hydrate stable zone. The bottom 2m of the domain is an aquifer layer (S_A=1.0) and the top 8m is a hydrate layer with a hydrate saturation, S_H of 0.6 and aqueous saturation, S_A of 0.4. There is no heat and mass transfer though the side boundaries due to symmetry. There is only heat transfer, but no mass flow through the top and bottom boundaries due to impermeable shale layers. The effect of injection temperature, injection pressure and production well pressure on gas and water production is studied.

RESULTS

Simulations were run for different injection pressures, injection temperatures and production pressures for 3000 days and total production of gas was compared for the above parameters.

For the case of no injection, the dissociation is due to pressure falling below the hydrate stable pressure due to depressurization at the production well. The heat of dissociation comes from surroundings, decreasing the temperature of the reservoir. Ice starts forming if the pressure goes below quadruple point pressure. After all the hydrates dissociate, the temperature again starts rising by the heat from surroundings.

For the case of warm water injection, the pressure of injection has to be higher than the reservoir pressure for the hot water to go in. The temperature rise is higher for higher temperature and higher injection pressure (injection flow rate increases). But if injection pressure is high the average pressure in the reservoir increases, slowing the dissociation of hydrates (and even formation of additional hydrates) before the warm water reaches a certain region. If production pressure and temperature are both high, the rate of production of gas increases. The total production of gas also depends on the production pressure, and for different production pressure the optimum injection conditions vary.

Figure 2 shows total production for the production well pressure of 2MPa. The injection temperature was kept constant at 20C and injection pressure was varied. The results were compared against the no injection or depressurization only case. When warm water is injected at a higher pressure but at a relatively low temperature (20C in the present case) the gas production rate decreases with increasing injection pressure. This is because the average pressure of the reservoir domain increases; dissociation of hydrate slows down. In case of 5MPa of injection pressure, the total production of gas increases because water occupies some pore space that would have been occupied by gas during depressurization. At higher injection pressure the hydrate dissociation is not complete in 3000 days. For low temperature water injection, only depressurization seems to be better than warm water injection.

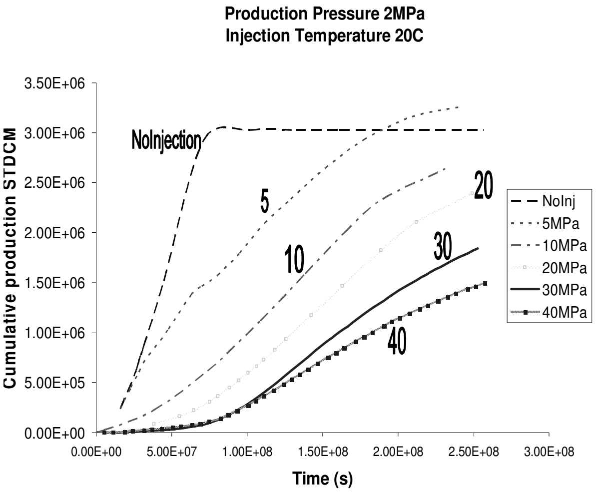

Figure 2: Cumulative production of gas with varying injection pressure, 20°C of injection temperature and 2MPa of production pressure

Figure 3 shows the cumulative production of gas when production well pressure is kept at 4MPa and injection temperature is 80°C. The injection pressure is varied. In this case, only depressurization is slow and does not dissociate all the hydrates present in 3000 days. With increasing injection pressure the gas production rate increases. With an injection water of 80°C, as the injection pressure increases more of the reservoir gets to this high temperature which helps in hydrate dissociation.

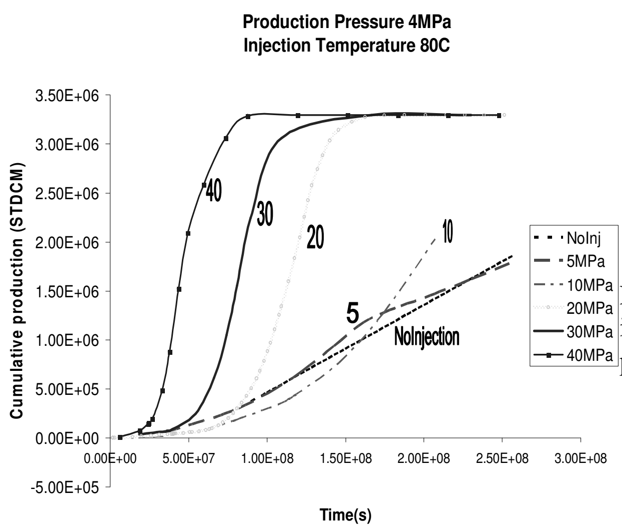

Figure 3: Cumulative production of gas with varying injection pressure at 80°C of injection temperature and 4MPa of production pressure.

If injection temperature is in medium range (50°C) then injection pressure and production pressure play an important role. Figure 4 and 5 are plots for 2MPa and 4MPa of production pressure, respectively, at 50°C of injection temperature with varying injection well pressures. If Injection pressure rises from 5MPa to 10MPa the production almost remains same for the case of production pressure 2MPa but decreases drastically in the case of production pressure 4MPa. This can be attributed to higher average pressure in the reservoir domain which hinders hydrate dissociation. In case of injection pressure of 30MPa and 40MPa the total production and rate of production increases (Figure 4 and 5), though initial rate of production falls due to increase in average reservoir pressure which assists hydrate formation while temperature is still not high. The gas production rate is non-monotonic with the increase in injection pressure.

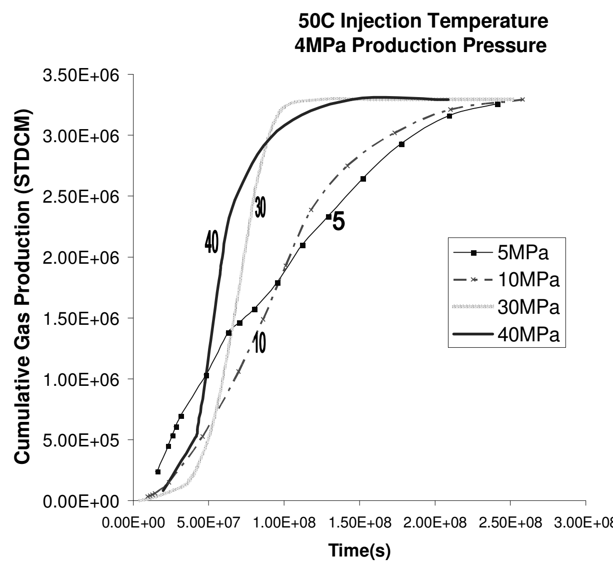

Figure 4: Cumulative gas production with varying injection pressure and 2MPa of production pressure and 50°C of injection temperature.

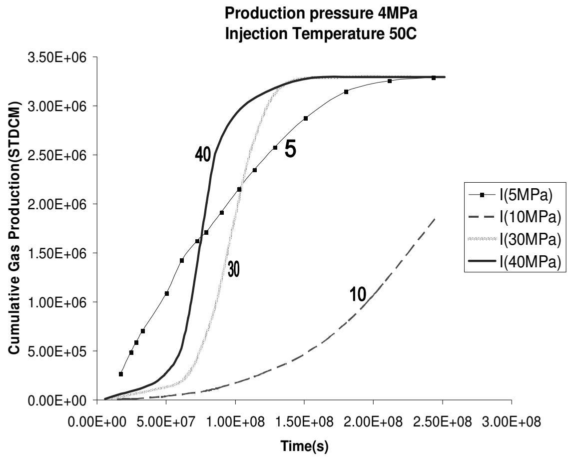

Figure 5: Cumulative gas production with varying injection pressure and 4MPa of production pressure and 50°C of injection temperature.

CONCLUSIONS

The production well pressure, injection temperature and pressure play an important role in the production of gas from hydrate deposits. For high injection temperature, the higher pressure increases the flow of warm water (heat) in the reservoir making the production rate faster, but if injection temperature is not high then only depressurization is the best method of production. At intermediate injection temperature, the production rate changes non-monotonically with the injection pressure. These parameters should be chosen carefully to optimize recovery and recovery rate of gas. This paper addresses a very simple homogeneous domain. Realistic reservoirs would have heterogeneity in sediments as well as hydrate distribution, which need to be taken into account. Models are being developed to address the variation in hydrate saturation in marine sediments [5].

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