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Thermal Stimulation Based Methane Production from Hydrate Bearing Quartz Sediment

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ABSTRACT: Natural gas hydrates represent a potentially substantial unconventional natural gas resource and the recovery of permafrost hydrates has seen significant attention over the past decade. Laboratory study of different growth and dissociation methods is an important step in the development of gas hydrate production methods. The formation and dissociation behavior of gas hydrates in quartz sand sediment is investigated on a large laboratory scale reactor with a sample volume of 59.3 L. Hydrate saturations of 10% and 30% pore space volume are dissociated via a point source thermal stimulation method using both a low heating rate of 20 W and a high heating rate of 100 W. Hydrate growth via gas invasion method resulted in nonhomogenous hydrate formation. Secondary hydrate formation was observed during prolonged hydrate formation periods in a quasi-repeatable manner. Peak efficiency rates of gas production ranged from 91% to 72% and net “end of test” efficiencies from 86% to 41%. Higher initial hydrate saturations resulted in better production performance while greater heating rates resulted in higher peak efficiency rates. Higher hydrate saturations displayed heater temperature spikes followed by a transition zone where heater temperatures stabilized due to the onset of increased convective heat transport.

1. INTRODUCTION

Clathrates of natural gas, commonly referred to as methane hydrates, are nonstoichiometric compounds that form when methane and water coexist in environments of sufficiently low temperatures and high pressures. Clathrates form when small guest molecules, typically less than 0.9 nm, such as methane or carbon dioxide, become entrapped in hydrogen bonded water molecules forming cages stabilized by the entrapped molecules via van der Waals−London forces.[1,2] Methane hydrates are of interest for various reasons, including storage and transport of gases, use as a natural gas resource, flow assurance issues, and their role in climate and the environment. Methane in the hydrate phase occupies a volume roughly 164 times less than methane in the gas phase at STP.[3,2] This allows for the transport of natural gas in the hydrate phase at moderate temperatures of 258 K and atmospheric pressure[4] that are potentially more feasible than liquefied natural gas transport requiring temperatures as low as 110 K.[5] Hydrate deposits are typically found in one of two environments; arctic permafrost formations or oceanic sub seafloor sediments.[6] The vast amount of hydrates that are naturally occurring in permafrost and subseafloor formations on the continental shelf presents the possibility for distributed energy production. Although uncertain, the global estimate of methane hydrate is quite large and is on the order 21×10^{15} m^3 of CH_4.[7,8] Due to the cost and difficulties with deep ocean drilling the majority of field tests for methane production from hydrate bearing sediments have been performed in the permafrost region of the Mount Elebert site in the Alaskan north slope or the Mallik site in the Mackenzie Delta, Canada 2l and 5l production sites.[6]

There are three primary methods for inducing hydrate dissociation for gas production purposes, thermal stimulation, pressure reduction, and chemical inhibitor injection. Thermal stimulation causes hydrate dissociation by raising the temperature of the hydrates above the hydrate stability zone at system pressures, inducing dissociation. Depressurization methods promote dissociation by bringing the hydrate formation pressure below the hydrate stability zone at system temperatures. Chemical inhibitor injection causes hydrate dissociation by shifting the thermodynamic equilibrium such that the in situ pressures and temperatures are no longer within the hydrate stability zone, and thus dissociation occurs;[9] inhibitor methods can also function to promote dissociation by creating a chemical disequilibrium between the hydrate and gas/water phase causing competing reactions.[10] There has been much investigation in the thermal and depressurization methods in laboratory scale tests[11−13] and a few larger production scale tests at the Mallik site in the Beaufort Sea.[6] It is generally agreed that the depressurization method has been the more efficient method of gas production compared to current thermal methods. However, due to the endothermic nature of hydrate dissociation thermal energy is required during depressurization to maintain a stable temperature while the hydrate is decomposing. The majority of thermal stimulation tests have been conducted via the injection of steam or heated fluids[14] and thus must compensate for the inherent losses associated with transporting heated fluids through the overburden and down the well hole to the hydrate deposits. There has been some work on other methods of thermal stimulation such as microwave heating,[15] electro-magnetic,[16] and in situ combustion. Castaldi et al. presented the idea of in situ

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