TECHNOLOGY STATUS ASSESSMENT

CHARACTERIZATION AND QUANTIFICATION OF THE METHANE HYDRATE RESOURCE POTENTIAL ASSOCIATED WITH THE BARROW GAS FIELDS

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Introduction

Naturally-occurring gas hydrates are widespread in subsea sediments and in permafrost regions and hold the promise of producing large volumes of methane gas (Collett, 2004). The U.S. Geological Survey (USGS) estimated that permafrost-associated gas hydrates on the Alaska North Slope (ANS) may contain up to 590 trillion cubic feet (TCF) of in-place gas (Collett, 1995), with the volume of gas within known gas hydrates of the Prudhoe Bay-Kuparuk River infrastructure area alone exceeding 100 TCF (Collett, 2004). If this assessment is valid, the amount of natural gas stored as gas hydrates in northern Alaska could be up to seven times larger than the estimated total remaining recoverable conventional natural gas resources in the entire United States (Collett, 1997). The U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) predicts that the gas hydrate resources closest to potential commercialization are those existing at high saturation within quality reservoir rocks under existing Arctic infrastructure. This assertion clearly points toward the hydrate accumulations overlying the Prudhoe Bay and Kuparuk Oil Fields as potential future commercial resources, although the only currently commercially produced gas fields on the North Slope, the Barrow Gas Fields, may also prove to be viable methane hydrate commercialization opportunities in the near future.

Occurrence of methane hydrate resources have been postulated in association with the Walakpa Gas Field, south of the village of Barrow, Alaska (Glenn and Allen, 1991 and Collett, 1992), and there is sufficient information available to model reservoir conditions to characterize and quantify the postulated methane hydrate resource. This project seeks to: establish the presence of a hydrate stability zone associated with the Barrow Gas Fields; fully and accurately characterize the methane hydrate resource; select an optimal location for drilling a dedicated hydrate test well; and model the gas and water production from a dedicated test well drilled in the free gas-charged reservoir directly beneath the methane hydrate/free gas interface. Results of recent research into hydrate occurrence, characterization, and producibility in the Alaskan, Canadian and Russian arctic regions have significantly advanced the understanding of this resource, and the current study will utilize and attempt to build on this advancing base of knowledge.

Current State of Information.

Significant effort has been undertaken to understand the character of natural gas hydrate accumulations in the Alaskan North Slope (ANS) since their existence was confirmed at the NW Eileen #2 well in 1972 (reviewed by Kvenvolden and McMenamin, 1980). A very significant milestone in the study of ANS methane occurred in February, 2007, when the first extensive core of hydrate-bearing sediment was recovered from the Mt. Elbert well at Milne Point Field on Alaska's North Slope (BP press release, 2007). The required elements necessary for the occurrence of methane hydrate are widespread across the ANS (Collett, 2004). So far, there is only inferential evidence for the presence of gas hydrate in the area of the Barrow Gas Fields, such as: presence of permafrost to a depth of 800-1300 ft. (Glenn and Allen, 1991, and Collett and others, 1989); free methane gas beneath the permafrost; hydrate formation in production wellbores; and material balance model results which indicate a reservoir energy source other than gas expansion. It is the goal of this study to integrate all available geoscience and production information available for the Barrow Gas Fields, in a framework supported by relevant ongoing and prior hydrate studies to quantify the methane hydrate resource potential in the Barrow area.

Occurrence of hydrates in the subsurface depends on a number of factors, including: appropriate reservoir pressure and temperature regime; suitable gas and formation water in a porous reservoir layer, which either has a geologic trapping mechanism, or is self-trapping by formation of hydrates; and critical timing of all the aforementioned elements.

Direct evidence for the presence of hydrates in the subsurface is obtained by collecting samples of the hydrate through coring. Indirect methods for detecting hydrates include interpretation of geological, geochemical and geophysical information (Paul, and Dillon, 2001).

Geologic evidence of gas hydrate presence is typically accomplished through interpretation of wireline logs, although these techniques are somewhat qualitative, and not optimized for hydrate analysis, but adapted from conventional oil and gas techniques (Collett, 1992). The USGS reports that the major issue in detecting gas hydrate from well logs is that gas hydrate and water ice permafrost have the same responses for the standard basic logs (Collett, 1998). Hole conditions for logging can also be poor due to thawing by drilling mud and subsequent enlargement of the hole in unconsolidated formations. The gamma ray, neutron and density logs respond normally and can be interpreted for lithology and porosity. The resistivity log sees both water ice and gas hydrate as non-conductive, and estimates of the amount of pore space filled by solid ice or gas hydrate can be attempted. The major source of error in this approach is knowledge of the formation water salinity, assuming some water remains unfrozen to provide the conductivity seen by the logging tool. In the proposed project area, salinities are known to be low at shallow depths (2000 to 6000 ppm). In calculating the corresponding resistivity (Rw) at 2000 ft. for these salinities at the formation temperatures, the possible error in calculated water saturations due to uncertainties in salinity and temperature could easily be a factor of two. There is a lack of core laboratory studies to quantify the range of gas hydrate saturations or the parameters suitable for use in log saturation calculations (ibid).

Gas hydrate and ice permafrost on the ANS show high acoustic velocities and low transit time compared with unfrozen formations. Base permafrost is usually picked where the resistivity reduces to a consistent value less than about 50 ohm-m and the sonic transit time at that point increases in the sands from around 100 μs/ft to 140-150 μs/ft (Collett and others, 1989). Gas hydrate within the permafrost is very difficult to distinguish from water ice.

Geochemical detection involves analysis of formation water and gas composition and isotopic fractionation to determine the presence of hydrate gas, the source of the gas, and the processes leading to the formation and dissociation of the hydrate (Paull and Dillon, 2001). Pore water freshening, coupled with presence of large amounts of methane has been documented as an indicator of hydrate occurrence (Hesse and Harrison, 1981). Gas composition and isotopic analysis is available for the Barrow Gas Fields, as well as formation water analysis, and this information will be integrated in the study, in the context of the significant findings of global hydrate studies.

The pressure and temperature conditions under which gas hydrate exist have been reported for both methane hydrate and gas with heavier components. Produced gas from the Walakpa Gas Field is approximately 97% methane, 2% ethane, and around .3 % propane, and an earlier study of methane hydrate resource potential indicated that the base of the hydrate stability zone in the Walakpa Gas Field could exceed 2,000 ft. (Glenn and Allen, 1991). The salinity of the water in which gas hydrate forms may also affect the range of gas hydrate stability, with increasing salinity reducing the range (Wright and Dallimore, 2004). Because formation water salinities at shallow depths in the Barrow Gas Field region are low, this effect is expected to be small.

Modeling of the gas hydrate stability zone to incorporate detailed gas and formation water composition, and gas hydrate structure can be accomplished using tools such as HWHYD developed at Heriot-Watt University, or CSMHYD, developed at Colorado School of Mines. Modeling gas hydrate stability based on known compositional characteristics and geothermal and pressure gradients provides a valuable means of indicating the probable presence or absence of gas hydrate in the subsurface. (Heriot-Watt University, 2006).

One critical requirement for the formation of in-situ hydrates in the subsurface is that the formation temperature must be below the hydrate stability temperature at the depth of the formation, based on the known phase behavior of hydrates. Permafrost is characteristic of suppressed mean surface temperature, and decreased geothermal gradient, and therefore, thicker permafrost can be linked to thicker hydrate stability zone (Holder and others, 1987). The permafrost zone thins from east to west along the North Alaskan coast (Lachenbruch and others, 1988 and Collett and others, 1989), leading to a thinner hydrate stability zone. One key objective of this study is to determine whether or not the hydrate stability zone in the Barrow Gas Fields is thick enough to intersect with gas-bearing reservoir formation, and all available temperature log and wireline log information will be analyzed in order to accurately determine the geothermal gradient, and depth to base permafrost and base hydrate stability zone.

Gas samples have been collected and analyzed on several occasions for gas produced from the Barrow Gas Fields, and compositional and isotopic analysis of samples from 9 wells (three from each field) is currently underway as part of this study. The results of this analysis will be incorporated in hydrate stability zone modeling for the three fields, as well as utilized for geochemical investigation which may help to infer the presence of methane hydrates.

Highly Relevant Recent/Ongoing Projects

The current state of information on gas hydrates in permafrost has been greatly advanced by recent projects conducted in Alaska and Canada. As summarized below, these multi-phase projects represent the first efforts to verify theoretical and laboratory-based results using geologic, geophysical and production data collected in areas known to contain gas hydrate accumulations. The results and techniques incorporated in these studies will significantly influence the direction and goals of this study.

The Mallik 2002 Consortium: Drilling and Testing a Gas Hydrate Well project began in 1998, with the first research wells to core hydrate bearing sediment and production testing of the hydrate-bearing reservoir. In 2001 - 2002, a production research well and two observation wells were drilled in the Canadian Mackenzie Delta. Full-scale field experiments monitored the physical behavior of the hydrate deposits in response to depressurization and thermal stimulation. A depressurization test was achieved by a series of MDT tests, and a thermal method was successfully tested using circulation of a heated fluid and measuring the recovery of gas dissociated due to the addition of heat. The results of the Mallik testing were used to develop and calibrate a gas hydrate production simulator, and the simulator was used to make long term production predictions (Collette 2005). Simulation results show that cumulative production from hot water injection will be possibly two times higher than simple depressurization, but that depressurization could still recover significant amounts of gas potentially without the capital cost of thermal injection facilities. Validated with data from Mallik, the ToughFX/Hydrate model allows simulation of hydrate dissociation and resultant fluid flows under currently contemplated production scenarios (Boswell, 2005). (GSC et al. 2004; Osadetz, 2003; DOE Project No. DE-AT26-97FT34342 and DE-AC26-01NT41007 technical and status reports).

The ongoing *Alaska North Slope Gas Hydrate Reservoir Characterization* project was initiated in 2002 to determine reservoir extent, stratigraphy, structure, continuity, quality, variability, and geophysical and petrophysical property distribution in a known gas hydrate area of the ANS. Relevant findings include:

- Regional structural mapping of reservoir units, the mapping of shallow fault offsets, and determination of syndepositional faulting and fault-seal potential.

- Adaptation of the commercial modeling package CMG STARS to provide reservoir modeling capabilities for hydrate prospects; use of the model to determine production potential of various gas hydrate settings.
- Geophysical modeling that enabled the correlation of seismic attributes with critical hydrate reservoir parameters (e.g., zone thickness and hydrate saturation).
- Seismic modeling of shallow velocity fields (<950 ms) that suggested that both amplitude and waveform variations may help locate has hydrate-bearing reservoirs
- Use of Landmark software suite to integrate and analyze detailed log correlations, specially processed log data, gas hydrate composition information, and specialized 3-D seismic volumes.

(DOE Project Nos. DE-AT26-97FT34342 and DE-FC-01NT41332 topical and status reports. Reports/abstracts from AAPG Hedberg Research Conference, *Natural Gas Hydrates: Energy Resource Potential and Associated Geologic Hazards,* September 12-16, 2004.)

As part of the *Methane Hydrate Production from Alaskan Permafrost* project, the HOT ICE well was drilled in 2003-2004 for the purpose of developing and testing new methods of drilling and recovering methane hydrates. The well was completed at a depth of 2,300 feet, which is approximately 300 feet below the gas hydrate stability zone. Gas-bearing sands were encountered in highly porous sandstones that were situated within the hydrate stability zone. The research team also acquired a 3-D Vertical Seismic Profile at the well, which resulted in very high resolution images of the subsurface, and possible indications of hydrate updip and east of the well site. Analyses of the core, log, and seismic data from the well indicate that the hydrate in this region occurs in patchy deposits and may require a high methane flux from the subsurface in order to form more continuous drilling prospects. (DOE Project No. DE-FC26-01NT41331, topical and status reports. Reports/abstracts from AAPG Hedberg Research Conference, *Natural Gas Hydrates: Energy Resource Potential and Associated Geologic Hazards,* September 12-16, 2004).

This collection of recently-funded DOE studies has contributed to the understanding that hydrates most often occur as discrete grains that form within pores and act as part of the framework of the sediment rather than as grain coatings or cements. This finding is critical to improving the interpretation of well log, reflection seismic data, and a variety of other reservoir parameters (Boswell, 2005).

Another project worth noting is the West Siberian Messoyakha Gas Field, which has been suggested to be an example of a hydrate accumulation currently in commercial production using conventional production methods. The production history of this field has been proposed as evidence that the hydrate resource is being depleted by depressuring the free gas accumulation beneath a hydrate-bearing zone, thus dissociating the gas hydrates. This is of significance to the Barrow Gas Field Study, in that the proposed production model involves drilling a horizontal development well in the free gas interval in close proximity to the hydrate-free gas interface. However, recent studies indicate that the contribution to production from hydrates in Messoyakha may have been overestimated (Ginsburg, 1993; and Collett and Ginsburg, 1998).

Other sources of information relevant to the subject project include: 1) *Comparative Assessment of Advanced Gas Hydrate Production Methods* – a current project that will provide a better understanding of the methane hydrate dissociation process and methane migration towards the wellbore. (DOE Project No. DE-FC26-06NT42666 documentation); and 2) *Stability Zone of Natural Gas Hydrates in a Permafrost Bearing Region of the Beaufort-Mackenzie Basin: Study of a Feasibility Energy Source* -- An analysis of geological and geophysical data from 150 wells in the Beaufort-Mackenzie region leading to reinterpretation of the depth of methane hydrate stability and construction of the first contour maps displaying thickness of hydrate stability zones below permafrost. (GSC, October 2004).

Development Strategies

While gas hydrate represents a very significant potential resource on the ANS, adequate production testing has not proven the feasibility of commercial production and the recovery factory has not been quantified. Problems being addressed by ongoing and proposed research on the ANS are: 1) can gas hydrate accumulations be identified and delineated; 2) can natural gas be produced from gas hydrate; and if so, 3) in what quantities and at what rate?

Three approaches proposed for the production of gas from gas hydrate are: thermal injection; chemical injection, and depressurization; (Collette, 2004). The Mallik project included a depressurization test, and a thermal method was also successfully tested. Simulation results show that cumulative production from hot water injection will be possibly two times higher than simple depressurization, but that depressurization could still recover significant amounts of gas potentially without the capital cost of thermal injection facilities (Collett, 2005). The results of prior DOE studies (DOE Project No. DE-FG21-91MC28131) suggest the presence of gas hydrates in the Barrow area gas fields. This project includes a two-phase study to better understand the nature and occurrence of gas hydrates in the Barrow gas fields, and to evaluate the potential influence of gas hydrates as a recharge mechanism for gas supply and production.

Phase 1 will incorporate previous research results (Glenn and Allen 1991) with the current knowledge base to quantify the probability that methane hydrates exist in association with the Barrow gas fields. A hydrate stability zone model, incorporating detailed gas composition, formation water salinity, and formation pore pressure and temperature gradient information will be utilized to define the depth ranges of the hydrate stability zone in the area of the Barrow Gas Fields. If the results of this work provide compelling evidence for a hydrate accumulation, the available seismic, well and production history information will be used to characterize the reservoir and its fluids. A static reservoir model will be constructed to establish reservoir boundaries, pore fluid properties, and pressure and temperature conditions. This detailed reservoir characterization will be used to choose an optimum location and configuration for a dedicated gas hydrate test well, and as input to dynamic production simulation modeling.

Phase II of the project will include drilling a test well, producing gas hydrate indirectly through production of free gas from beneath the free gas/gas hydrate interface. The free gas/gas hydrate interface will be monitored during production to help establish the contribution to the free gas zone from gas hydrates. The proposed production method involves extracting gas from the hydrates through depressurization. Data collected from the test well will be used as input to the reservoir model to confirm whether gas hydrates are contributing to gas produced from the free gas zone.

Future Implications

Verifying the presence of a significant gas hydrate accumulation in the gas fields of Barrow will provide an opportunity to test the potential of producing gas hydrates through depressurization. Modeling results will contribute to the current understanding of the gas hydrate stability zone and whether that zone is associated with or perhaps contributing to production from the Barrow Gas Fields. Ultimately, this study will provide unique insight into the role played by gas hydrate in recharging a producing gas field and will provide a platform for continued development of the tools and technologies developed by previous gas hydrate research. It has been suggested that if hydrates are a factor in the resource potential of the Barrow Gas Fields, the remaining reserves base of the Walakpa Gas Field could be several orders of magnitude greater than current estimates (Collett, 1998).

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