Fire from Ice: Methane Hydrate Petroleum Systems and Resources

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Introduction and Overview

Methane hydrates occur in polar permafrost regions and marine outer continental margins and represent a potentially enormous energy resource.

Hydrates are naturally occurring crystalline compounds of natural Bas enclosed within a cage-like lattice of water ice. Chemists call such structures clathrates. In methane hydrates, water crystallizes in the cubic system, rather than in the hexagonal structure of normal ice. The resulting compound packs a lot of methane in its dense organization. One cubic foot of hydrate contains about 164 cubic feet of methane Bas.

With adequate Bas concentrations, methane hydrates form and are stable under moderate- to high pressure, low temperature conditions. This Methane Hydrate Stability Zone (MHSZ) typically occurs: 1) on continental margins at water depths greater than about 300 m and bottom water temperatures close to 0° C, where Bas hydrate is found from the sediment surface to depths of about 1100 m below the seafloor, and 2) in polar continental regions, where Bas hydrate can be present in sediment and permafrost at depths between about 150 and 2000 m.

Early estimates of the total resource were as speculative as they were impressive. Current work using geology-based Total Petroleum System (TPS) assessments still yields very large numbers.

The USGS recently estimated that there are about 85.4 trillion cubic feet (Tcf) of undiscovered, technically recoverable Bas resources within methane hydrates in northern Alaska alone (Collett, 2009). The Minerals Management service conducted an evaluation of the petroleum system for the Gulf of Mexico and estimated a mean value of21,444 Tcf with 6,717 Tcf in place in sandstone reservoirs (Frye, 2008). Mean estimated resource of domestic methane hydrate in place is about 200,000 Tcf (NETL, site accessed 4/28/11).

Compare this to proved conventional U.S. reserves of about 2 73 Tcf shale Bas reserves of 687 Tcf and a total natural Bas resource (including CBM but excluding hydrates) of about 2,170 Tcf (Potential Gas Committee, 2011; EIA, 2010).

Hydrate Petroleum Systems

Source

Two primary source mechanisms have been recognized based on carbon and hydrogen isotopic analysis (Uchida, et al, 2009): microbial decay of organic matter within the Bas-hydrate stability zone, and thermogenic methane. Thermogenic methane may migrate from thermally mature,

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deep-seated organic shales, or by leakage from deeper, conventional free gas reservoirs (Lorenson, 2011).

Reservoir

An important difference between methane hydrate accumulations and more conventional gas fields is the nature of the reservoir beds containing the gas: methane hydrate deposits occur in young, relatively unconsolidated sediments where the ice-like hydrate structure holds the gas in place. Methane hydrates occur within a range of reservoir facies, from mudstones to gravels. Sandy siliciclastic reservoirs are considered (Fire from Ice Abstract continued) to be the most favorable for commercial exploitation.

Seal

The seal is provided by the clathrate structure itself. In fact, it is increasingly recognized that the hydrate accumulations may provide a top and lateral seal for deeper free-gas reservoirs outside the methane hydrate stability zone (MHSZ).

Trap

The trapping mechanism, too, is attributed to the arrangement of methane within the clathrate structure. As free gas migrates into the MHSZ, it is chemically trapped within the crystalline configuration of the naturally formed clathrate.

Exploration technologies

Recent efforts have shifted from resource assessment to evaluating exploration methods for recognizing and mapping commercial hydrate-bearing zones, and production technologies for safe, commercial extraction.

Early exploration methods used seismic signatures known as "bottom-simulating reflectors" (BSR) to identify potential hydrate occurrence. The BSR is the result of an impedance contrast between gas hydrate-filled sediments in the MHSZ and water-filled and/or potentially free gas zones beneath the interface. BSRs are not always evident, and are not universally considered an accurate predictor of commercial-scale accumulations.

Ongoing research has identified other geological models and geophysical characteristics which support the existence of potential high gas hydrate saturations in reservoir-quality sands. For example, successful drilling projects in the Gulf of Mexico have demonstrated that the seismic character of sands are phase reversed across the base of the MHSZ with the phase reversal caused by high velocity gas hydrate pore fill (USGS, 2009).

Production methods

Research into producing methane from hydrates has focused on two primary methodologies:
1) reducing the pressure, and/or 2) increasing the temperature within the deposit. As the temperature/pressure curve shifts outside the MHSZ, the gas naturally disassociates from the clathrate structure. Recent short-term production tests have demonstrated the viability of commercial hydrate production through depressurization, the first time this had been accomplished on the North Slope (MH21 Research Consortium, 2011). A relatively new idea involves the injection of carbon dioxide (CO_2) into the deposit, which has the potential to displace methane from the hydrate structure in-situ. This would help to stabilize the reservoir as the methane disassociates, while at the same time providing the added benefit of carbon sequestration.

Additional research

Other areas of hydrate research include slope stability studies and drilling hazards associated with methane disassociation and seabed collapse.

Finally, methane hydrates must play a significant role in the global carbon cycle, and researchers are studying their port in global climate processes and climate change.