

**GEOPHYSICALCORNER**

# Gas Hydrate and LNG Tankers

*(The Geophysical Corner is a regular column in the EXPLORER, edited by Bob A. Hardage, senior research scientist at the Bureau of Economic Geology, the University of Texas at Austin.)*

By **BOB HARDAGE**

Theoretical models have been developed at the Bureau of Economic Geology that relate formation velocity and resistivity to hydrate concentration ( $C_{gh}$ ) in deepwater, near-seafloor sediments. Our studies indicate that in numerous targeted intervals across the Gulf of Mexico,  $C_{gh}$  is 0.5 to 0.6 of the available pore space in unconsolidated deepwater sediments.

The reaction of most explorationists to this finding is "Too bad. That gas concentration is too low to be of interest." This conclusion is logical for anyone whose experience has been only with conventional gas reservoirs, where gas concentrations of 50 to 60 percent are not appealing.

It may not be a correct conclusion for gas hydrate reservoirs.

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Let's consider how the formation of hydrate causes a high concentration of natural gases by comparing the physical sizes of a sediment grain and a unit-volume of hydrate.

A unit-volume of Structure I hydrate is shown as figure 1. Limited page space does not permit the unit-volume geometries of Structure II and Structure H hydrates to be illustrated. This crystalline structure is called a "unit-volume" because Structure I hydrate grows in increments of this fundamental building block. This unit-volume consists of eight cages of structured water that can each trap one gas molecule.

Dendy Sloan at the Colorado School of Mines defines the diameter of each cage of this unit-volume as a length that varies from 8 to 10 angstroms. Because any arbitrary diameter across this unit-volume will span no more than six cages (probably no more than four cages, actually), the diameter of a unit-volume of hydrate is less than 60 angstroms ( $6 \times 10^{-9}$  m).

For a size comparison, sedimentologists define the low end of the very-fine grain scale to be fragments of sediment that have diameters of about 60 microns ( $6 \times 10^{-5}$  m). The diameter of a very-fine sediment grain is thus larger than the diameter of a unit-volume of hydrate by a factor of  $10^4$ .

Because the volume of an object is proportional to (diameter)<sup>3</sup>, if we ratio the volume of a very-fine grain and the volume of a unit-volume of hydrate we find that this  $10^4$  difference in diameters means that  $10^{12}$  unit-volumes of hydrate can fit into the space occupied by one very-fine sediment grain.

Assuming that on average only 80 percent of the eight cages in a unit-volume manage to trap a gas molecule, hydrate formation causes approximately  $6 \times 10^{12}$  gas molecules to be compressed into a volume equal to that of a single very-fine grain.

This simple arithmetic supports the statement by Pellenberg and Max that

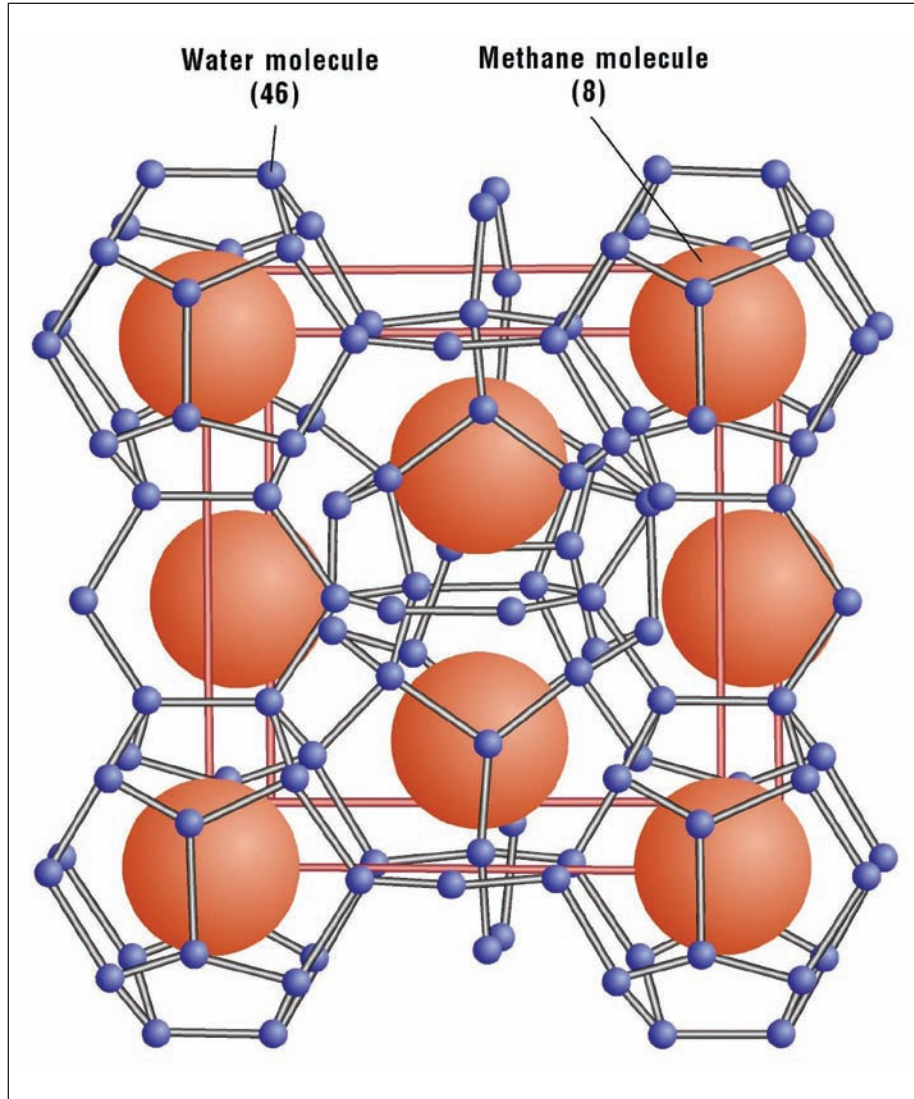


Figure 1 – One unit-volume of Structure I hydrate showing eight methane molecules trapped in the eight cages of 46 structured water molecules that compose this particular hydrate crystalline structure. (Adapted from a drawing by Bjorn Kvamme, University of Bergen, Norway.)

$C_{gh}$	$\phi$			
	0.4	0.5	0.6	0.7
0.4	7%	9%	10%	12%
0.5	8%	10%	13%	14%
0.6	10%	13%	15%	18%
0.7	12%	14%	18%	21%

Table 1 – Hydrate energy density  $E_{gh}$  relative to LNG energy density  $E_{LNG}$  for ranges of porosity  $\phi$  and hydrate concentration  $C_{gh}$  that are common to deep water, near-seafloor sediments across the Gulf of Mexico. The relationship between  $E_{gh}$  and  $E_{LNG}$  is defined by the first equation below.

hydrate has the highest energy density (184,000 BTU/ft<sup>3</sup>) of any form of biogenic or thermogenic gas found naturally. By comparison, liquid natural gas (LNG) represents the highest energy density (430,000 BTU/ft<sup>3</sup>) of natural gas that humans can create using cryogenic technology.

Hydrate thus has an energy density  $E_{gh}$  that is 0.42 that of the energy density  $E_{LNG}$  of LNG.

For any deepwater, near-seafloor sediments where clusters of hydrate unit-volumes can be assumed to be distributed throughout the sediment pore space, the energy density of the

gas trapped in the structured-water prison cells of this dispersed hydrate can be expressed as

$$E_{gh} = (0.42\phi C_{gh})E_{LNG}$$

where  $\phi$  is the porosity of the host sediment containing the hydrate.

\* \* \*

Table 1 shows how  $E_{gh}$  is related to  $E_{LNG}$  for:

- ✓ Common porosity ranges found in deepwater, near-seafloor sediment.
- ✓ That range of  $C_{gh}$  that causes the

reaction "Too bad the concentration is so low."

Now let us consider a specific example: If a hydrate system has a porosity of 0.5 and a hydrate concentration of 0.5, how large does a hydrate accumulation have to be in order to have an amount of stored energy that equals the energy stored in one LNG tanker?

Simply solve the energy-balance equation

$$E_{gh}(\text{hydrate reservoir volume}) = E_{LNG}(\text{tanker volume}).$$

Using the ratio  $E_{gh}/E_{LNG} = 0.1$  from table 1 for  $\phi = 0.5$  and  $C_{gh} = 0.5$ , the result is

$$\text{Hydrate reservoir volume} = 10 \text{ LNG tanker volumes.}$$

If we assign length, width and depth dimensions of 600, 100 and 50 feet to our hypothetical LNG tanker volume, the size of the hydrate reservoir that has the same equivalent stored energy is 826 acre-ft ( $\sim 10^6$  m<sup>3</sup>).

Thus, when the hydrate concentration in deepwater sediments is only 0.5 of the available pore space, we see that there is a tremendous amount of gas in a small volume of sediment.

When Mother Nature causes hydrate to form, the result is an impressive concentration of energy that is independent of burial depth. Because structured-water hydrate has a large bulk modulus and is difficult to compress, hydrate will have the same crystalline structure, and thus the same energy density of entrapped gas, when it is a seafloor outcrop that it has at a deep depth below the seafloor.

This concept about the relationship between gas concentration and confining pressure differs from the logic that has to be used in dealing with compressible gases found in conventional reservoirs.

**Punchline** – There may be a large number of LNG tanker equivalents awaiting the bold who initiate deepwater hydrate production.

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The only intent of this discussion is to illustrate that a tremendous amount of energy is stored in deepwater hydrate. What has been avoided is any discussion of the challenges of trying to produce that hydrate.

As a geophysicist, I have two observations about strategies for producing deep-water hydrate:

- ✓ Hydrate production is the engineer's problem.
- ✓ I am glad I am not the engineer assigned to the problem.

For geophysicists, it is exciting to try to unravel the mysteries of deep-water hydrate systems using 4C OBC seismic data and rock physics theory. Refer to Geophysical Corner articles published in the July 2006 and August 2006 EXPLORERS and available on the AAPG Web site, if you wish to know how some of this multi-component seismic research is being done. □

*(Editor's note: Hardage is senior research scientist at the Bureau of Economic Geology, Austin, Texas.)*