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A METHOD OF HARVESTING GAS HYDRATES FROM MARINE SEDIMENTS

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ABSTRACT

Gas hydrates bind immense amounts of methane in marine sediments. If produced cost effectively, they can serve as a stable energy supply. No viable technologies for extracting gas hydrates from deep ocean deposits have been developed to date. Due to the shallow depths, low hydrate concentration, low permeability of the gas hydrate stability zone, lack of driving pressure and the slow melting process, low productivity is anticipated for gas production from gas hydrates in marine sediments. Therefore, only a large number of low cost wells can support an offshore production facility and pipeline transport to shore. The method of harvesting natural gas from sea floor gas hydrates presented in this paper is a combination of several new concepts including electrically adding heat inside hydrate rich sediments to release gas, using an overhead receiver to capture the gas, allowing gas to form hydrates again in the overhead receiver, and lifting produced hydrates to warm water to release and collect gas. This approach makes the best use of the nature of hydrates and the subsea pressure and temperature profiles. Consequently, it leads to a simple and open production system which is safe, economical, energy efficient, environmentally friendly, and without significant technical difficulties. Basic analyses and calculations on the feasibility and heat efficiency of the proposed method are presented and discussed.

Keywords: gas hydrates, marine sediments, overhead receiver, electrical heating, open production system

INTRODUCTION

Gas hydrates are ice-like crystalline solids formed from a mixture of water and natural gas, usually methane. They can occur in marine sediments as disseminated cements, nodules, veins and massive layers [1]. As shown in Fig. 1, seawater temperature decreases from the surface to the sea floor. The hydrate formation temperature (HFT) corresponding to the hydrate phase boundary, on the other hand, increases due to the increase in hydrostatic pressure. The prevailing temperature is the lowest at the sea floor. Below the sea floor, temperature rises again with the local geothermal gradient. When the water depths exceed 300 to 500 meters, gas hydrates are stable in the zone from the sea floor to the hydrate baseline where the temperature is equal to the HFT. This zone is called the Gas Hydrate Stability Zone (GHSZ). The thickness of the GHSZ can be as large as 1100 m from the sea floor in deep ocean [2].

It is common knowledge that the amount of methane bound in gas hydrates in marine sediments is enormous, although the estimates are speculative [3]. If produced cost effectively, they can serve as a stable energy supply. There are three major challenges faced by future hydrate production from marine sediments. They include hydrate dissociation, flow assurance and cost efficiency. In order to produce gas from hydrates

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in marine sediments, gas must first be released and made flowable. Significant thermal energy is required for the dissociation of hydrates. Three methods have been proposed in the past for hydrate dissociation, including thermal injection, depressurization and hydrate inhibitor injection. However, their applications are extremely difficult in the deep water environment. No viable technologies for extracting gas from deep ocean hydrates have been developed to date.

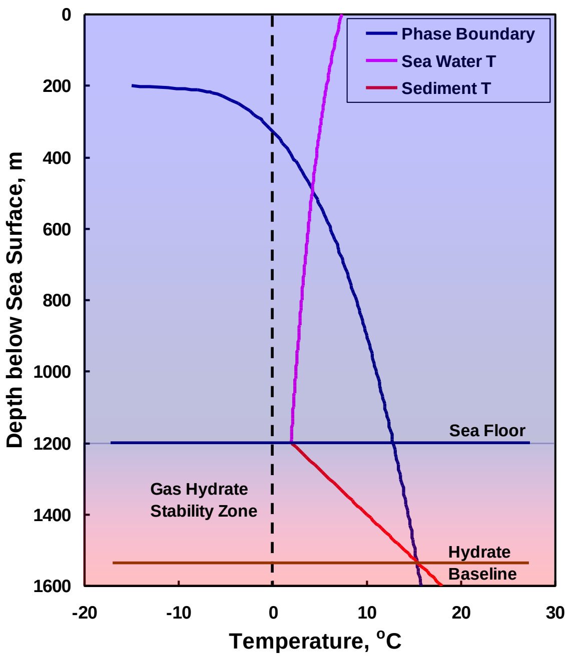

Figure 1: Subsea temperature profile and hydrate phase boundary

The second challenge is the flow assurance of gas produced from hydrates. The high pressure, low ambient temperature and existence of water on the sea floor are ideal conditions for possible hydrate reformation and blockage of gas flow. Proper insulation, heating and/or inhibitor injection will be needed to avoid hydrate reformation. These measures are either technically challenging or cost prohibitive.

The third and perhaps most important chalenge is the cost efficiency of the overall production process. Due to the shallow depths of the GHSZ, low concentration of hydrates (normally several volumetric percentages), requirement of melting of the solid hydrates, and lack of driving pressure, low productivity is anticipated for gas production from gas hydrates in marine sediments. Current offshore oil and gas production technologies and facilities have been developed for high production rates from large oil or gas reservoirs. These methods will not be cost effective for gas production from hydrates in marine sediments.

The way of harvesting natural gas from sea floor gas hydrates proposed in this paper is a combination of several new concepts aimed at overcoming the technical barriers, maintaining cost and energy efficiencies, and minimizing safety and environmental concerns.

METHOD DESCRIPTION

Overhead Receiver

Hydrates are about 10% lighter than seawater. Once released from sea floor sediments, hydrate particles or gas move upward in still seawater due to buoyancy. The released hydrates or free gas can be captured with an overhead receiver as shown in Fig. 2. The receiver can be any shape and size, and can be made of any material. It can be like a canopy with a wide opening at the bottom, or like a hot-air balloon with a small opening at the bottom. Gas forms hydrates again when moving through the cold seawater or inside the overhead receiver if the temperature is kept below the HFT. This will naturally happen on the sea floor where the temperature is the lowest. The overhead receiver can be used to capture (1) produced hydrate particles or gas, (2) hydrate particles or gas released from drilling and any other operations, and (3) seeped gas from sea floor vents.

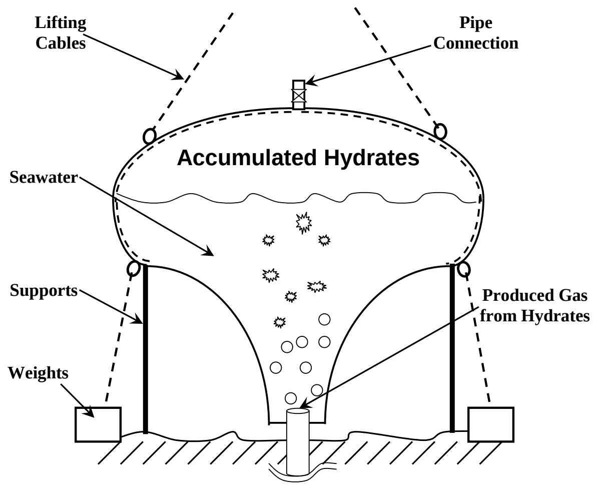

Figure 2: Overhead receiver to capture hydrate particles or gas

Open-Well Production

First, a relatively large diameter well is drilled from the sea floor to the hydrate baseline. Then, smaller radial holes are drilled, as shown in Fig. 3. Electrical heaters can be inserted into the small holes to warm up the hydrate rich sediments to release gas. Small diameter radial holes can be drilled with an appropriate angle to allow the released gas to flow into the well. The released gas flows upward due to buoyancy in the large diameter well and is captured by the overhead receiver above the outlet. Hydrates will form again when the gas moves through the cold seawater or inside the receiver. The production rate can be controlled by the heating rate. The wall of the large diameter well may need to be insulated or warmed to prevent hydrate deposition or to release hydrate deposits periodically.

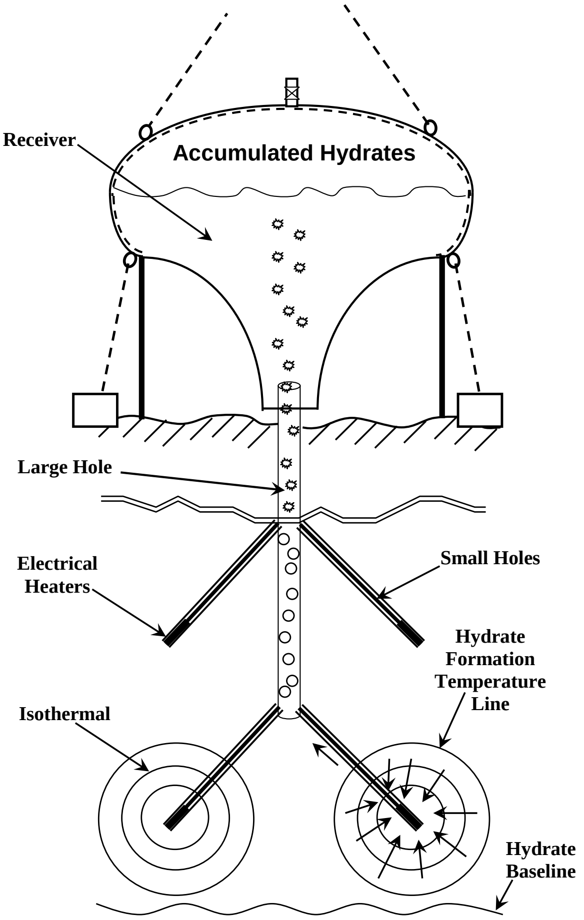

Figure 3: Open-well production from deep formation

Free gas and even oil can exist below the hydrate baseline. These hydrocarbon fluids must be depleted first using conventional production technology before producing gas from the hydrates. After the reservoir below the hydrate baseline is depleted, the tubing and casing can be removed and the wellbore can be cemented at the hydrate baseline to prevent possible gas blowout. Then, the borehole can be reamed to a larger diameter to produce gas from the hydrates as described above. A check valve at the well head may be needed to restrict the heat exchange between inside the well and the environment.

Small diameter holes can also be drilled directly from the sea floor to the hydrate rich sediments. Then, electrical heaters are inserted to warm sediments to above the HFT. The released gas flows out through the small holes and is captured by the overhead receiver as shown in Fig. 4. The gas will form hydrates again when moving through the cold seawater and inside the receiver.

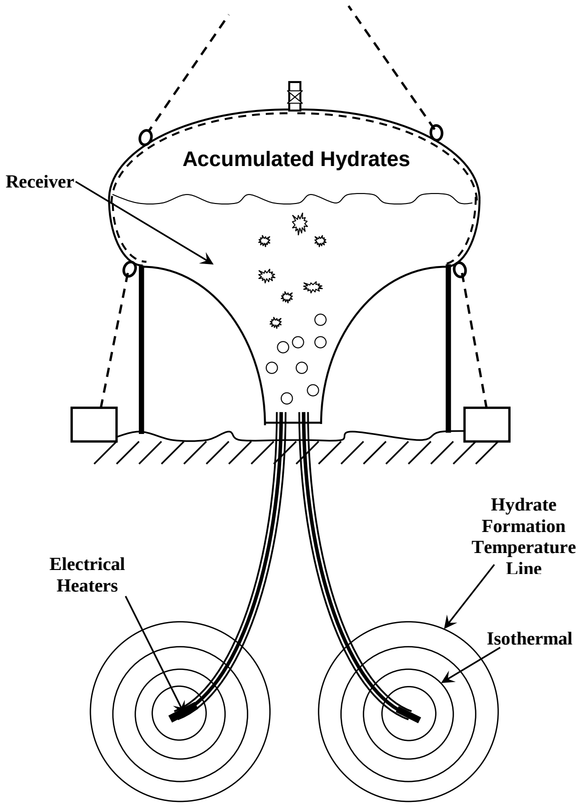

Figure 4: Open-well production from shallow formation

In order to release the gas from hydrates, heat is needed to warm the sediments to the HFT and to meet the hydrate melting latent heat. Because of the poor permeability and low thermal conductivity of the sediments, electrical heating from inside the sediments seems to be the most efficient and convenient method. Corresponding to the heat transfer from the electrical heater to the surrounding marine sediments, a temperature profile will be developed such that the temperature at the center (where the heater is) is the highest and decreases to the environmental temperature with an increase in distance from the center. Naturally, isothermal contour surfaces, which correspond to the same temperatures, are formed as closed boundaries.

As shown in Fig. 5, there is an isothermal contour surface corresponding to the HFT. The hydrates within the HFT contour surface are melted and the hydrates outside the HFT contour surface remain as solid. The released gas flows out through the holes connecting to the production well. The released gas will not flow outside the HFT line for two reasons: (1) The hydrate sediments are non-permeable; (2) Gas and water beyond the HFT line will form hydrates again and seal the path.

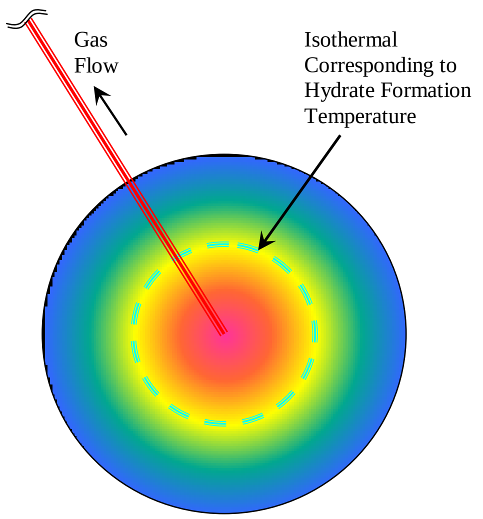

Figure 5: Dissociated gas confined within HFT contour surface

Hydrates Dissociation

When a certain amount of hydrates are accumulated in the receiver, it can be lifted to warmer seawater as shown in Fig. 6. Hydrates will dissociate when the pressure is reduced and the temperature is above the HFT. Gas can flow from the top of the receiver through a pipe to the floating vessel. Then, the gas can be compressed and transported to shore. The hydrate dissociation rate can be controlled by lifting to different water depths. One floating vessel can be used for production from many harvesting sites. The produced hydrates can also be conveniently stored and transported in deepwater. The inside structures of the receiver can be designed to ensure heat exchange with the seawater.

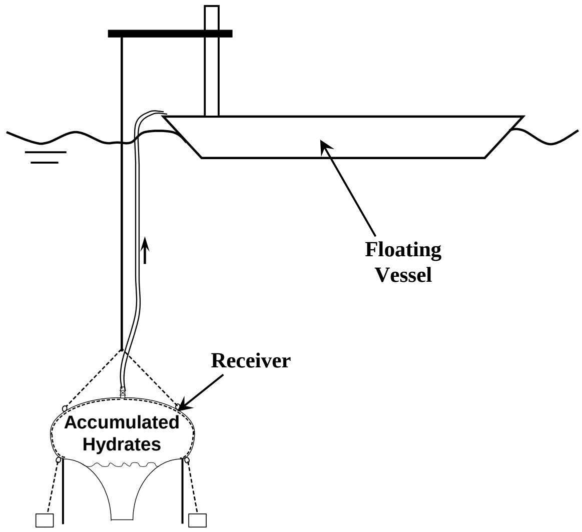

Figure 6: Hydrate dissociation in shallow warm water

Production Scenario

Since hydrates are dispersed in marine sediments as low concentration solid, their extraction will be a slow process. Therefore, only a large number of low cost production wells can achieve the desired production rate and cost efficiency. The simple and open production system proposed in this paper will ensure low CAPEX and OPEX. Since the production system is open and the flow is buoyancy driven, there is no pressure difference between the inside and outside of the receiver. No high strength materials are needed for manufacturing of the well casing and the overhead receiver. Produced gas is accumulated in the overhead receiver and transported to the surface in the form of hydrates. There are no pump, tubing, subsea pipeline and riser needed. There are no flow assurance challenges. The production rate can be easily controlled by changing the electrical heating rate.

As shown in Fig. 7, many wells can be drilled using low cost drilling technology (normally the hydrate rich marine sediments are unconsolidated). Electrical heat introduction and hydrate accumulation in the overhead receivers can be precisely controlled and closely monitored. Once a receiver is full of hydrates, it can be lifted to shallow water for gas production, and a new empty receiver can be placed at the same production well for continuing accumulation.

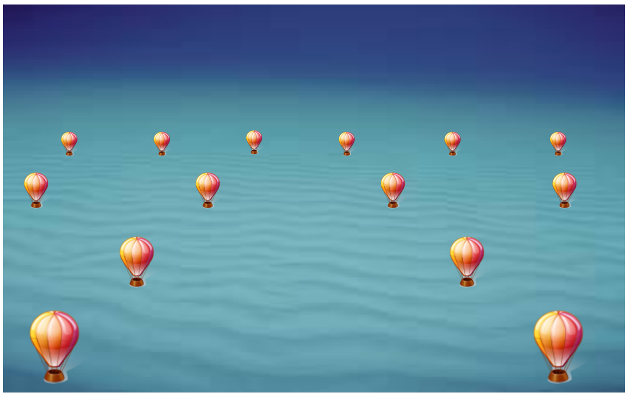

Figure 7: Imaginary hydrate farm on sea floor

HEAT ECONOMY

The largest difference between the sediment temperature and the hydrate dissociation temperature is about 12 ^{o}C. This temperature difference becomes smaller with an increase in depth below the sea floor and finally reaches zero at the hydrate baseline. The majority of the heat needed to melt hydrates in the region close to the hydrate baseline is the latent heat of hydrate dissociation. The heat required to produce the hydrates and the heat contained in the produced hydrates can be estimated based on an assumption of the hydrate volumetric concentration in the sediments. Heat loss to the surroundings due to thermal conduction is dependent on the thermal conductivity of the sediments and the temperature gradient (or how fast the heat is introduced). The majority of this heat loss will contribute to the increase in the surrounding temperature and the hydrate dissociation during the continuous production. This heat loss is not considered in the following calculations.

10% Hydrate Concentration

First, the hydrate volumetric concentration in marine sediments is assumed to be 10%. The volumetric specific heat capacity of ice/hydrates and sediments is assumed to be 2,000 KJ/m^3-^{o}C. The hydrate melting latent heat is about 390,000 KJ/m^3-^{o}C [4]. The heat required to warm 1 m^3 sediments (with 10% hydrates) by 10 ^{o}C (18 ^{o}F) is

$$Q_{Warm-up} = 2{,}000 \times 10 = 20{,}000 \quad KJ \ .$$

The heat required to melt the 10% hydrates in 1 m^3 sediments is

$$Q_{Melting} = 390{,}000 \times 0.1 = 39{,}000 \quad KJ \ .$$

The total heat required to produce the 10% hydrates in 1 m^3 sediments is

$$Q_{TR} = Q_{Warm-up} + Q_{Melting}$$
$$= 20{,}000 + 39{,}000 = 59{,}000 \quad KJ \ .$$

0.1 m^3 (10% of 1 m^3) of hydrates can produce 16.7 standard cubic meters or 590 scf gas. The heat value in 1 scf of methane is 1012 btu (1 btu equals 1.054 KJ). Therefore, the total heat in the 590 scf of gas production from 1 m^3 sediment is

$$Q_{TP} = 1012 \times 1.054 \times 590 \approx 630{,}000 \quad KJ \ .$$

The ratio of the required heat to the produced heat based on 10% hydrate concentration is

$$R_{10\%} = \frac{Q_{TR}}{Q_{TP}} = \frac{59{,}000}{630{,}000} = 9.4\% \ .$$

2% Hydrate Concentration

Similarly, if the hydrate volumetric concentration is assumed to be 2%, the required heat to warm 1 m^3 sediments by 10 ^{o}C (18 ^{o}F) is

$$Q_{Warm-up} = 2{,}000 \times 10 = 20{,}000 \quad KJ \ .$$

The heat required to melt the 2% hydrates in 1 m^3 sediments is

$$Q_{Melting} = 390{,}000 \times 0.02 = 7{,}800 \quad KJ \ .$$

The total heat required to produce the 2% hydrates in 1 m^3 sediments is

$$Q_{TR} = Q_{Warm-up} + Q_{Melting}$$
$$= 20{,}000 + 7{,}800 = 27{,}800 \quad KJ .$$

0.02 m^3 of hydrates can produce 3.34 standard cubic meters or 118 scf of gas, and the total heat contained in the produced gas is

$$Q_{TP} = 1012 \times 1.054 \times 118 \approx 126{,}000 \quad KJ .$$

The ratio of the required heat to the produced heat based on 2% hydrate concentration is

$$R_{2\%} = \frac{Q_{TR}}{Q_{TP}} = \frac{27{,}800}{126{,}000} = 22\% .$$

CONCLUDING REMARKS

A novel method is proposed in this paper for harvesting gas hydrates from marine sediments. It is based on a new concept of using an overhead receiver to capture the gas released from dissociation of hydrates in the sediments. The gas is allowed to reform hydrates inside the receiver and be accumulated during production. Once the receiver is full of hydrates, it can be lifted to shallow warm water for hydrate dissociation and gas collection. This leads to a simple and open production system. There are no high pressure and flow assurance issues. There are no high strength tubing, subsea pipeline or riser needed. Consequently, technical difficulties, safety issues and environmental concerns are minimized. Low CAPEX and OPEX are ensured. The simple and open production system also makes it possible to develop a massive hydrate production field on the sea floor (envisioned as a hydrate farm) in order to achieve high production rates and economic viability.

Electrical heating is proposed for the dissociation of the hydrates in marine sediments. The heat ratio between the required heat and the produced heat is about 9.4% assuming 10% hydrate volumetric concentration in sediments. The heat ratio is about 22% if the hydrate concentration is assumed to be 2%.

REFERENCES

[1] Collett TS, Lewis R, Uchida T. *Growing interest in gas hydrates*. Oilfield Review, Summer 2000:42-57.

[2] Kvenvolden KA, Lorenson TD. *A global inventory of natural gas hydrate occurrence*. USGS, http://walrus.wr.usgs.gov/globalhydrate/

[3] Collett TS. *Energy resource potential of natural gas hydrates*. AAPG Bulletin, 2002; 86:1972-1996.

[4] Rueff RM, Sloan ED, Yesavage VF. *Heat capacity and heat of dissociation of methane hydrates*. AIChE Journal, 1988; 34(9):1468-1476.