CONCEPTUAL DESIGN OF AN EXPERIMENTAL FACILITY FOR EXTRACTING NATURAL GAS FROM NATURAL GAS HYDRATE

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ABSTRACT

This paper presents a conceptual design of an integrated experimental facility to test various possible techniques to produce natural gas from subsea natural gas hydrate. This facility is intended to study different aspects during the implementation of these techniques for the production of natural gas. These include dissociation behavior of the gas hydrate and its interaction with the surrounding sediment bed. This is necessary in view of the fact that any deformation of the sediment bed has a direct impact on the gas release as well as on the stability of the production rig. The facility will also be utilized to study other aspects related to the formation and stability of the hydrate under the seabed conditions, collection of the gas after NGH dissociation etc. under different operating conditions.

Keywords: gas hydrates, thermal stimulation, depressurization, natural gas

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INTRODUCTION

Natural gas hydrate (NGH) is a highly concentrated form of natural gas. One cubic meter of methane hydrate can hold up to 164 m$^3$ of gas at standard temperature and pressure (STP) [1]. Moreover, vast amounts of gas hydrate, conservatively estimated as containing more than double the amount of carbon contained in the fossil fuels at present taken together, exist in the permafrost regions and under the sea bed. India too possesses a good amount of NGH in some of its offshore regions. The large concentration of natural gas in the form of hydrates can be a very attractive energy source if it can be dissociated in an environmentally safe way to produce the gas and get it to a market. Hence it is imperative to devise ways of exploiting this source of energy to secure the future energy requirements the world over. Several techniques like depressurization, thermal stimulation, addition of chemicals, and sequestering carbon dioxide have been proposed to dissociate the hydrates. However in case of seabed NGH, daunting challenges pertaining to the implementation of these methods as well as environmental impact on release of the gas from the NGH have till date eluded the development of a commercially viable technology to exploit this vast source of energy. Efforts are underway towards meeting this objective. In this paper, we present a conceptual design of an experimental facility which could be useful to study different types of production techniques of natural gas from NGH existing in the oceanic sediment bed.

BRIEF REVIEW OF SOME PROPOSED TECHNIQUES

Several studies on the production of natural from NGH have been reported in the literature. These include both laboratory experiments and computer simulations. The distribution of the hydrates under the oceanic condition shows different level of their aggregation. This along with the nature of the sediment (which determines the porosity) makes it imperative to adopt different strategies for gas production. Moreover, implementation of one or combination of many strategy/strategies would require specialized devices. Collection of the gas after hydrate dissociation posed another engineering challenge. Whichever strategy is followed, the ultimate acceptance would depend on the sustainability of the method in terms both energy economy and stability of the production rig in the ocean in face of any possible seabed instability. Supply of external energy is needed not only for hydrate dissociation by either depressurization or thermal stimulation, but also to compensate for the cooling effect due to endothermic nature of the hydrate dissociation. In addition, propagation of the heat inside the sediment bed plays a crucial role in effective and controlled dissociation of the hydrate. In case of depressurization, gas production is adversely affected by the generation and accumulation of the sediment at the gas outlet. This calls for devising a means of “cleaning up” of the pathway thorough which the gas flow occurs. The proposed techniques are based on causing thermodynamic instability of the hydrate right inside the sediment. However, in view of the observed facts of declining gas
production, it has become necessary to make some different strategy whereby the dissociation could be done in batches of the bed. This may be possible by adopting seabed mining. In this method, chunks of the hydrate bed may be taken out in batches and lifted in the sea where decreased pressure and increased temperature will provide a natural way for hydrate dissociation. To test these ideas, it is necessary to carry out experimentations on a larger scale than have been attempted till date. The present paper focuses on these aspects. However, the basis of gas production still remains pressure reduction and temperature increase to a region where hydrate is unstable. Hence some of the reported works on depressurization and thermal stimulation are reviewed briefly. Use of chemicals for large scale production seems uneconomical and so is excluded from the following discussion.

**Depressurization**

Kono et al. (2002) synthesized methane gas hydrate in laboratory to carry our dissociation experiments by depressurization. The reactor volume was 188 cm³ and glass beads of different sizes were used as the representative sediment bed. From the experimental data, they derived overall rate expressions for hydrate dissociation and found the values to different for the different types of the glass beads.

Guang et al. (2007) carried out depressurization experiments in a laboratory-scale pressure vessel (38 mm id and 500 mm height). It was found that the hydrate dissociation was kinetically controlled for such a scale of volume. They also carried out simulation of the dissociation process on a field scale reservoir. This indicated that at larger scale, flow-ability of the gas which is dictated by the bed permeability, rather the dissociation kinetics controls the production behavior.

Alp et al. (2007) studied gas production by depressurization for hypothetical Class 1G and Class 1W hydrate reservoirs. A second dissociation front was observed in Class 1G. Well bore heating was needed in case of Class 1W bed. During production, hydrate lenses (bands of alternating high-low hydrate saturation) developed in both the types of reservoir.

Zhou et al. (2009) employed a larger pressure vessel (72 litre) to study the formation and dissociation characteristics of the methane hydrate in a packed bed of sand. Ice formation was observed during the dissociation of hydrate. They obtained a gas production rate varying from 9.5 to 13.0 LPM.

Su at al. (2010) used a three dimensional middle size reactor of diameter 300 mm and height 100 mm to study the three-dimensional behavior of hydrate dissociation in a packed bed of natural sand. Both formation and dissociation experiments were carried out. They determined the dissociation pressure suitable for their case as 1.5 MPa.
Haligva et al. (2010) formed methane hydrate in silica sand bed. They found that the recovery of methane depended on the size of the silica sand particles initially, and later became independent. In some experiments, the temperature dropped below the freezing point of water which led to increase in the gas recovery.

**Thermal Stimulation**

Castaldi et al. (2007) discussed the feasibility of a down-hole combustion method as a means of in situ heat generation. Thus a local heat source is provided which can reduce the heat loss during the conventional way of supplying heat to the reservoir. Carbon dioxide produced during the combustion could be sequestered as hydrate thereby eliminating any problem due to CO₂ release.

Tsimpanogiannis and Lichtner (2007) made a parametric study numerically on the hydrate dissociation in oceanic sediment. The parameters chosen were porosity, permeability and transport and thermodynamic properties of the system. They showed that rate of hydrate dissociation depended on the permeability of the sediment. Very high dissociation pressure was found to develop at low permeabilities. This could result in fracturing of the sediment bed.

Pang et al. (2009) studied gas hydrate dissociation in a reactor of 10 litre volume. Effects of water temperature, heating rate, hydrate saturation, and the dissociation pressure on the dissociation rate, and the extent of the buffering effect were investigated experimentally to determine the gas production. The observed a decrease in the dissociation rate due to ice melting. They suggested a combination of thermal stimulation and depressurization is a better way of producing gas from hydrate.

Yang et al. (2010) used a middle size reactor in which they carried out cyclic hot water injection to produce from a hydrate bearing sediment. The cyclic injection method was suggested to work better than continuous injection method for a reservoir with a high hydrate saturation and low permeability, in which the released gas and water are difficult to penetrate the tight sediment zone.

**PRESENT WORK**

As can be seen, most of the work related to gas hydrate dissociation to produce natural gas has been carried out in laboratory scale set ups. While these work give significant insight into the mechanism of gas production and the effects of various parameters on hydrate dissociation, the issue of sea bed instability due to hydrate dissociation needs to be investigate and understood more as this has a direct bearing on the operability of the overall production system. Besides, under the deep sea condition, the issues of controlled dissociation of the hydrate followed by collecting the gas produced have also to be resolved. For example, several factors hinder heat transfer through the sediment bed. Also to
innovate a viable gas production technology, it is necessary to look into the energy requirement and the tradeoff to be made. To address all these aspects, it necessitates the use of a pilot scale set up which could approximate the undersea conditions so as to give a more realistic understanding of the whole process of hydrate production. Such a plant can be used to test various possibilities of gas production. Since hydrate dissociation is an endothermic process; so heat transfer is an important consideration during natural gas production from NGH. It needs to be seen how heat supply can be maintained to compensate for the heat of absorption. This experimental setup can predict the heat required for continuous natural gas production. Also we can predict minimum heat requirement for natural gas production.

In this paper we present a conceptual design for a multifaceted facility to study the gas production in a simulated undersea bed. As shown in Figure 1, the setup broadly consists of the following units:

1. Hydrate formation unit
2. Hydrate storage unit
3. Hydrate dissociation unit

HYDRATE FORMATION UNIT

This unit consists of subunits. It is suggested that new concepts of hydrate dissociation and gas production may be tested by using gases which can form hydrate more readily than methane. The unit includes provisions to pretreat the system by way of cooling, addition of some hydrate promoter etc. The operating parameters will be chosen so as to form large enough quantity of hydrate to do further experimentations. A chiller is included to meet the cooling requirement.

HYDRATE STORAGE UNIT

Suitable provision to store the hydrate formed is necessary to satisfy “supply-on-demand” requirement for the set of experimentations. The storage would be done in a well-insulated vessel. The apparatus would be such that required quantity of hydrate could be taken without causing significant dissociation of the remaining hydrate. The pressure and temperature for storage would need special provision. It is preferable to store at ambient pressure. This would make the handling of the hydrate easier than having high pressure-high temperature storage.

HYDRATE DISSOCIATION UNIT

This is the heart of the whole set up as the gas production studies would be carried out. The unit consists of subunits

(a) to make hydrate-sediment bed,
(b) to maintain high pressure above the sediment bed,
(c) to dissociate hydrate,
(d) to monitor the instability of the sediment bed on hydrate dissociation,
(e) To collect the gas produced.

Making of the sediment bed with hydrate would need special apparatus for compaction of the
combined mass of the hydrate and sediment. The compacted mass then need to be placed inside a high-pressure chamber of dimension that would enable one to study the hydrate dissociation process in three-dimension. To dissociate the hydrate, the hydrate bed may be heated by various heat source means like hot water. The same setup may be used to study the depressurization process and a hybrid of thermal stimulation and depressurization. The experimental setup can predict which thermal source is effective for gas production. Provision has been made for visual observation of the deformation of the sediment bed during the hydrate dissociation.

Figure 2 depicts more details of the proposed setup. In this is shown, a suitable gas from a gas cylinder is pressurized, precooled or liquefied and stored before being taken for hydrate formation. Liquefaction of gas may be necessary for some cases as the kinetics of hydrate formation increases with liquefied gas as has been shown for CO$_2$. From the hydrate reactor, the hydrate is taken to a hydrate storage device after filtering out the water. Suitable cooling device is provided to this hydrate storage chamber to eliminate the possibility of regasification of the hydrate. The hydrate and the sediment will be mixed and compacted separately before being taken to the dissociation chamber.

An elaborate data acquisition system is integrated with the whole setup to monitor the state in each of the units and collect the data for further analyses.

**CONCLUSIONS**

A pilot scale experimental setup has been proposed to carry out hydrate dissociation experiments under the subsea conditions. The proposed setup will enable three-dimensional observation of the hydrate dissociation in the sediment bed and its effect on the deformation of the sediment bed. Different techniques for hydrate dissociation may be tried in this setup to arrive at a suitable strategy for gas production. This strategy could be developed further for developing commercial technology of gas production.
Inside dissociation vessel
Making of sediment bed with hydrate

Fig1: Overall operational steps for dissociation studies of hydrate

Fig2: Schematic diagram of hydrate formation and dissociation process
REFERENCES


