R224-P026 **Room: Poster Session Hall** **Time: May 28**

Toward the methane hydrate production; What we have realized? What we do not know yet?

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The practicality of gas hydrate as an alternative energy resource of the conventional natural gas requires technologies to surface solid gas hydrate in marine sediments. The most realistic method for this purpose is to dissociate the gas hydrate to the vapor phase in underground formation with heat stimulation or depressurization using techniques for oil and gas industry, and produce the gas through a wellbore.

The processes to dissociate the gas hydrate and bring gas to the surface need the following knowledge and techniques:

1) Construction technology of infrastructures such as well and production facility constructions,

2) Surface and bottom hole devices for heat stimulation and/or depressurization

3) Flow assurance in the well with knowledge of multiphase flow with the thermodynamics of gas hydrate-water-vapor system,

4) Localized multiphase fluid and heat flow near the wellbore with thermodynamics of gas hydrate, and effects of gas hydrate dissociation on the formation properties and structures,

5) Reservoir scale multiphase fluid and heat flow with thermodynamics of gas hydrate, and effects of gas hydrate dissociation on the formation properties and structures,

6) Environmental impacts of large scale gas hydrate such as sea bottom stability.

Those are quite complex processes including many components such as multiphase fluid flow and coupling with structural mechanics of the formation in various scales. The real formations contain anisotropy, heterogeneity, and discontinuity such as faults and fractures. In the Eastern Nankai Trough region, the gas hydrate deposit exists in pore spaces of sand layer in turbidite sediments. In such formation, the effects of the heterogeneity and anisotropy are important.

To know the feasibility of the gas hydrate production technologies, understanding of 1) to 6) processes are necessary along with the techniques to assure the economically feasible gas production in each process. During the METI Tokai-oki to Kumano-nada programs, physical and mechanical properties of the formation were taken to collect necessary data to understand the behavior of the formations in the Eastern Nankai Trough region to the production methods. Two onshore production tests carried out in Mackenzie Delta, NWT, Canada were field scale simulations of the gas production to understand what is really happen in the dissociation process.

Table 1 summarizes the knowledge we obtained in the two offshore drilling campaigns and two production tests, as well as the remained questions. When all of the processes are clearly understood, we will realize whether the gas hydrate is really the resource or not. However, pressure and temperature conditions and physical characters are varied in each field, and long-term behaviors of the field cannot be made clear by a short-term production tests and numerical modellings. On the other hand, some problems might be solved by improvements of technology.

In the future development plan should be designed to solve the remained problems, and to clarify the technical and economical feasibility of the field development. Marine production test in the target field is the most valuable operation to know the real response of the specific field, but cost and risk of the failure are high. Onshore production tests were believed to give higher chance of monitoring, but even onshore, the complete control of the condition and phenomena is impossible. Laboratory experiments are strong tool to know the response of a component of the hydrate field, but the real situation may be different from the simplified laboratory condition. The numerical modelling should be verified by field and laboratory data. The fact is that we need to combine each way.

(The authors acknowledge MH21 Methane Hydrate research consortium funded by the Ministry of Economy, Trade and Industry)

表1 過去の基礎試錐・陸上産出試験でわかったこと、わからないこと

プロセス	わかったこと	まだわからないこと
坑井掘削をはじめとする生産のためのインフラストラクチャー建設	水平坑井（100m）を含め、海底面下のハイドレート層に坑井掘削・仕上げが可能。 セメントの健全性、ハイドレート層以外の地層の安定性なども問題が見出された。	仕上げられた坑井が生産のための長期にわたる加熱・減圧に耐えられるか。
地層に熱を供給する、あるいは減圧するための坑内及び地表機器の開発	陸上（極地）における温水循環による加熱システム、減圧システムの実証ができた。ただし、双方のシステムの限界（実際に投入できる熱、及び達成できる減圧幅）も明らかになった。	海洋・大水深の環境で安全・安定に機能するシステムの設計できるか。
凍結・再ハイドレートを考慮した、坑井内のガスと水多相流の流動と、熱の輸送（フロー・アシュアランス）	熱刺激において低流量（最大350m^3/day gas）程度の流体輸送に成功、減圧1回目 坑内条件への圧入やや高い流量（2000m^3/day gas）と短期（一日以内）の流動を実現。ただし、出砂他の影響で中断。	海洋・大水深の温度・圧力環境で大流量（10000m^3/day gas 以上）長期・安定した流動を維持できるか。
坑井近傍での地層孔隙中の局所的な熱及び多相流体の移動とハイドレート分解、及びハイドレート分解が地層の形態と物性値に与える影響	陸上産出試験の条件下で、熱刺激で達成できる分解範囲がほぼ明らかになった。 減圧法で一定範囲のハイドレートをより効率よく分解できることがわかった。 減圧と水の生産によって生じる問題点（出砂など）が見出された。	温水循環にかわる効率よく地層に熱を送れる熱刺激法がありうるか。 減圧法が長期、広範囲、かつ安定的に適用可能か。 双方の欠点を補うほかの手法、組み合わせの手法があるか。
貯留層スケールでの地層孔隙中の熱及び多相流体の移動とハイドレート分解、及びハイドレート分解が地層の形態と物性値に与える影響	限られた情報のみ	二度の陸上産出試験はいずれも分解領域が坑井近傍に留まり、非均質性の影響などに関して十分なデータが取得されていない。 貯留層スケールの現象はロカリティが大きく、試験から一般的な情報を得ることはもとより難しい。
広範囲にハイドレートが分解することによる地層の安定性など環境への影響	ハイドレートが存在する状態、分解後の状態での力学特性など基礎的な物性値が得られつつある。	実際に生じる現象は、数値シミュレーション及び思考実験によって想定されている状態であり、実証的なデータはない。

Table 1 Knowledge obtained in the past programs and remained questions

Process	Knowledge obtained	Remained questions
Construction of the infrastructures to dissociate the gas hydrate such as well construction and production facility construction	Safe drilling in the gas hydrate deposit (including 100m horizontal drilling) and completion is possible. Several problems such as cement integrity, instability in shallower and deeper zones were found as well.	Long term stability of the drill hole under the heat stimulation and depressurization. Design of the production facilities including riser pipe for long term safe production.
Surface and bottom hole devices to for heat stimulation and/or depressurization	Heat stimulation by hot water circulation and depressurization systems work in the arctic onshore environment. Also the limit and problems were made clear.	System design for the offshore and deep-water condition.
Flow assurance in the well with knowledge of multiphase flow with the thermodynamics of gas hydrate-water-vapor gas system	Max 350m^3/day gas flow under the hot water circulation condition and 2000m^3/day gas flow under the depressurization with deep injection condition were achieved that terminated the flow within one day.	System design for the offshore and deep-water condition and high flow rate more than 10000m^3/day gas.
Localised multiphase fluid and heat flow near the wellbore with thermodynamics of gas hydrate, and effects of gas hydrate dissociation on the formation properties and structures	Effect and extent of dissociation domain of hot water circulation. Efficient dissociation may be possible by the depressurization in limited domain. Problems caused by water flow such as sand production were found.	Alternative heat stimulation method of hot water circulation that inject heat and extract gas. Stability and sustainability of the depressurization method. Other possible production procedure to solve the problems
Reservoir scale multiphase fluid and heat flow near the wellbore with thermodynamics of gas hydrate, and effects of gas hydrate dissociation on the formation properties and structures	Limited information.	Dissociation domains of the last two onshore production tests were too small to collect information about the effect of heterogeneity etc. Higher locality limit the knowledge of general behavior from the tests in specific conditions.
Environmental impacts of large scale gas hydrate such as sea bottom stability. Infrastructure construction such as drilling and completion and construction of production facilities	Basic character and properties of the hydrate bearing sediments such as the situation of gas hydrate in the pore spaces, strength of the formation with and without hydrate etc have been obtained.	Real phenomena are not known. Current consideration on this issue is based only on the thought-experiment and numerical simulation.