Evaluation of Heat Induced Methane Release from Methane Hydrates

Introduction

Clathrates, or gas hydrates, are cages of water molecules which are populated by guest gas molecules. Gas hydrates naturally occur on Earth in low temperature and moderate pressure environments including continental shelf, deep ocean, and permafrost sediments. High concentrations of methane are trapped in hydrates, providing significant near-surface reserves of carbon and energy. Thermodynamics predicts that hydrate deposits may be destabilized by reducing the pressure in the system or raising the temperature. However, the rate of methane release due to varying environmental conditions remains relatively unconstrained and complicated by multiple feedback effects on clathrate dissociation.





In this study, synthetic hydrate dissociation in sediment due to localized increases in temperature was monitored and observed at the mesoscale (>20L) in a laboratory environment. Experiments were conducted in the Seafloor Process Simulator (SPS) at Oak Ridge National Laboratory (ORNL) to simulate heat induced dissociation. The SPS, containing a column of Ottowa sand satu-

rated with water with 25mg/L Sno-Max dissolved to aid nucleation, was pressurized and cooled well into the hydrate stability field. A fiber optic distributed sensing system (DSS) was embedded at four depths in the sediment column. This allowed the temperature strain value (a proxy for temperature) of the system to be measured with high spatial resolution to monitor the clathrate formation/dissociation processes. A heat exchanger embedded in the sediment was heated using hot recirculated ethylene glycol and the temperature drop across the exchanger was measured. These experiments indicate a significant and sustained amount of heat is required to release methane gas from hydratebearing sediments. Heat was consumed by hydrate dissociation in a growing sphere around the heat exchanger until steady state was reached. At steady state



all heat energy entering the system was consumed in maintaining the temperature profile in the sediment. Only when the temperature of the heat exchanger was further increased did further hydrate dissociation occur. Cessation of heat resulted in hydrate formation within minutes. Over several hours the vessel overpressure decreased to values lower than those observed prior to heating, indicating enhanced hydrate accumulation.

LUNA Quasi-Distributed Sensing System (DSS)

The LUNA DSS infers a hybrid temperature strain value (TS value) from a wavelength shift in the frequency of light reflected from Bragg gratings embedded in the fiber optic cable every 1cm. Unlike systems that measure continuously along the cable, the discrete nature of this system results it in 'Quasi-Distributed' moniker.



2.5 cm

Fig. 1 - A hand placed on a LUNA DSS fiber produces a distinct signature in the temperature contour plot. This illustrates the resolution of the system. The location of the sensors is computed via an interative Newton-Rhapson method and the data is gridded with a natural neighbor algorithm.

-15 -10 -5 0 5 10 15

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Experimental Setup



Fig. 3- Heat flow and hydrate dissociation. When heat is introduced into the system through the heat exchanger, the bulk vessel pressure rises steadily; a sharp rise is also observed after each increase of heat input. The difference between the output and input fluid temperature (ΔT) also increases each time the input temperature is raised confirming that more energy is being transferred to the system. Expansion due to the bulk sand temperature rising cannot account for the total rise in pressure observered at each fluid temperature increase. Also note how the pressure drops quickly as soon as heat is removed from the heat exchanger, despite the relatively slow decrease in the bulk temperature.

The DSS plot on the left shows the initial conditions of the system before heat was introduced. These measurements indicate a homogeneous temperature distribution indicating the system was at equilibrium. The DSS plot on righ right is after the system was subjected to four heating steps over a period of about 3.5 hours. The sharp gradient observed is the boundary between the sand/hydrate heated by the heat exchanger. Areas where hydrate has dissociated are indicated by cool areas due to the endothermic nature of hydrate dissociation.

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Data Interpretation

The volume of hydrate dissociated was estimated by picking the dissociation volume based on the sharp temperature/strain gradient detected by the LUNA system. The volume dissociated was estimated as a cylinder due to the observed shape.

From the volume of hydrate dissociated the energy required for hydrate dissociation was calculated. The percentage of energy consumed by hydrate disociation is small compared to the energy added to the system through the heat exchanger. This extra energy was likely maintaining the observed temperature gradient against the cooling efforts of the cold room by warming the sand, warming hydrate, and finally warming liquid water. Work is currently underway to model the heat flow in this system in greater detail to allow a better understanding of the internal dynamics

Temperature Steps Fig.3	Volume Hydrate Dissociated [mL]	Moles Hydrate Dissociated [mol]	Energy Required [kJ]	Energy Input * [kJ]
1	130	0.97	55	151,700
2	300	2.3	130	228,000
3	440	3.3	190	344,500

*Cumulative energy input from beginning of experiment at steady state conditions only. (i.e. energy required to maintain the hydrate-free volume.)

Table 1- From results in figure 3 we calculate the energy required to dissociate the volume of hydrate estimated from the LUNA system. These are cumulative amounts of both hydrate and heat required.

Heat input is approximately constant once the system has reached steady state and can be determined in non-steady state conditions by the difference of the areas under the temperature of fluid in/out curves. The dissocation of hydrate is very stochastic in nature. Such rapid fluxuations in hydrate may pose hazards to drilling operations in the form of rapid well pressure increase. The experimental system quickly reached steady state after a temperature increase, indicating that significant quantites of energy would be required to harvest gas from gas hydrate deposits.



Fig. 5- A vertical cross section through the sediment column. The area inbetween DSS planes suffers from some interpolation artifacts due to the large ratio of vertical sensor spacing to horizontal sensor spacing.

Conclusions

These results suggest that significant heating of the sediment must occur before gas hydrates begin releasing methane into the atmosphere as the process is self limiting with regards to the thermodyamics of hydrate dissociation and overpressure generated by hydrate dissociation. Hybrid production methods that simultaneously increase temperature and decrease pressure are likely needed to effectively exploit gas hydrate energy reserves. Results also suggest that heating only influences hydrate close to the heat source and to dissociate hydrate far from the heat exchanger likely requires large amounts of heat energy scaling at best with the square of the distance. Further analysis of distributed sensing data will likely yield insight to hydrate formation/dissociation pathways and better characterize the steady state system. Further work will compare experimental results with numerical reservoir models to examine fluid and heat flow in the system.