Experimental Results of Hydrate Reservoir Destabilization Through Heating

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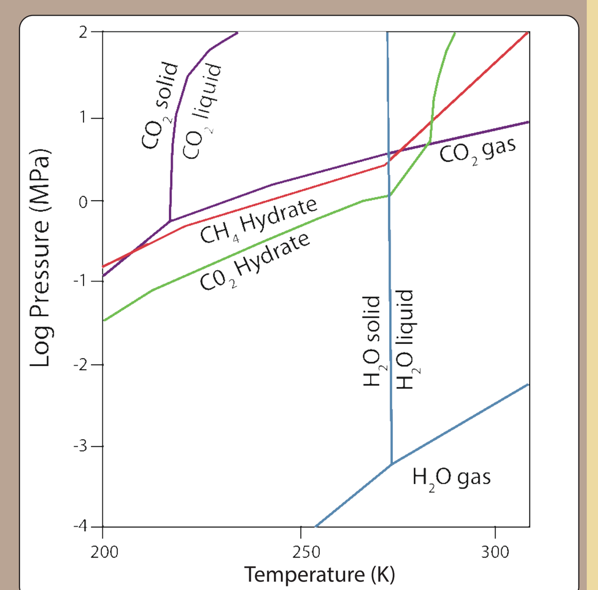
Introduction

Clathrate destabilization may occur through depressurization of the reservoir, addition of chemical inhibitors, or heating the reservoir. Experiments were conducted at the Oak Ridge National Laboratory Seafloor Process Simulator to examine the impact of heating on gas hydrate reservoirs like those found in sediments at the ocean bottom.



Reservoir Destabilization Impacts:
- Hazards to deep water drilling operations

- Energy resource extraction from gas production

- Possible explanation of methane plumes on Mars and other planteary bodies.

- Clathrate Gun Climate Hypothesis

Seafloor Process Simulator

Location: Oak Ridge National Laboratory

Size: 0.32m x 0.91m (~72L)

Maximum Working Pressure: 20.68 MPa

Number of Ports: 41

Material: Hastelloy

Temperature Control: Refrigerated Room

For more details see Phelps et al. (2001)

Distributed Sensing (DSS)

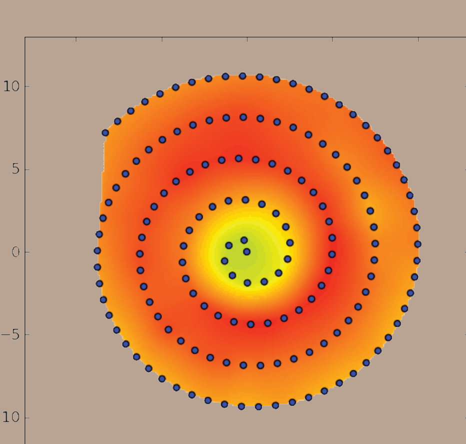
- Collects hybrid temperature strain data based on Bragg grating reflections.

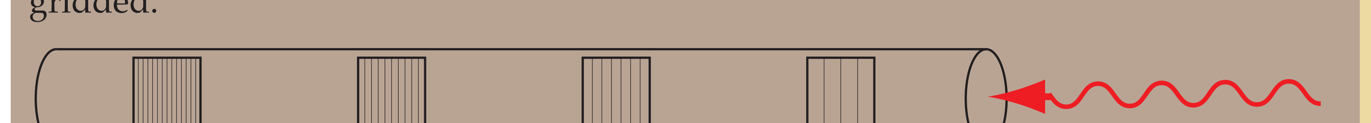
-LUNA Optical Backscatter Reflectometer and Multiplexer used to interrogate 8 cables once every 60 seconds.

- Fiber optic cables with about 200-300 sensors tied into Archimedian Spiral.

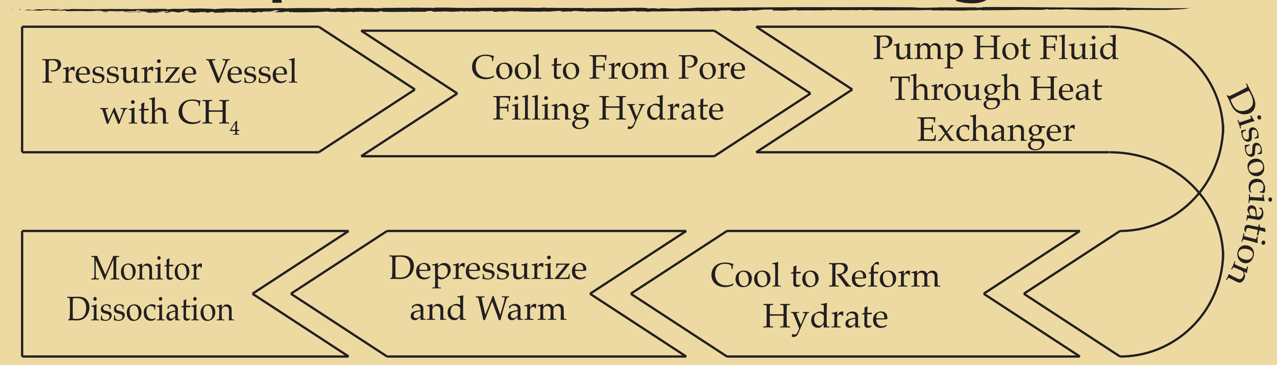
- Bragg grating every 1cm along cable.

- Positions determined numerically and data are gridded.





Experimental Design



Sediment Column:
- Ottowa Sand

- Saturated with Water

- SnoMax Nucleation Agent Added

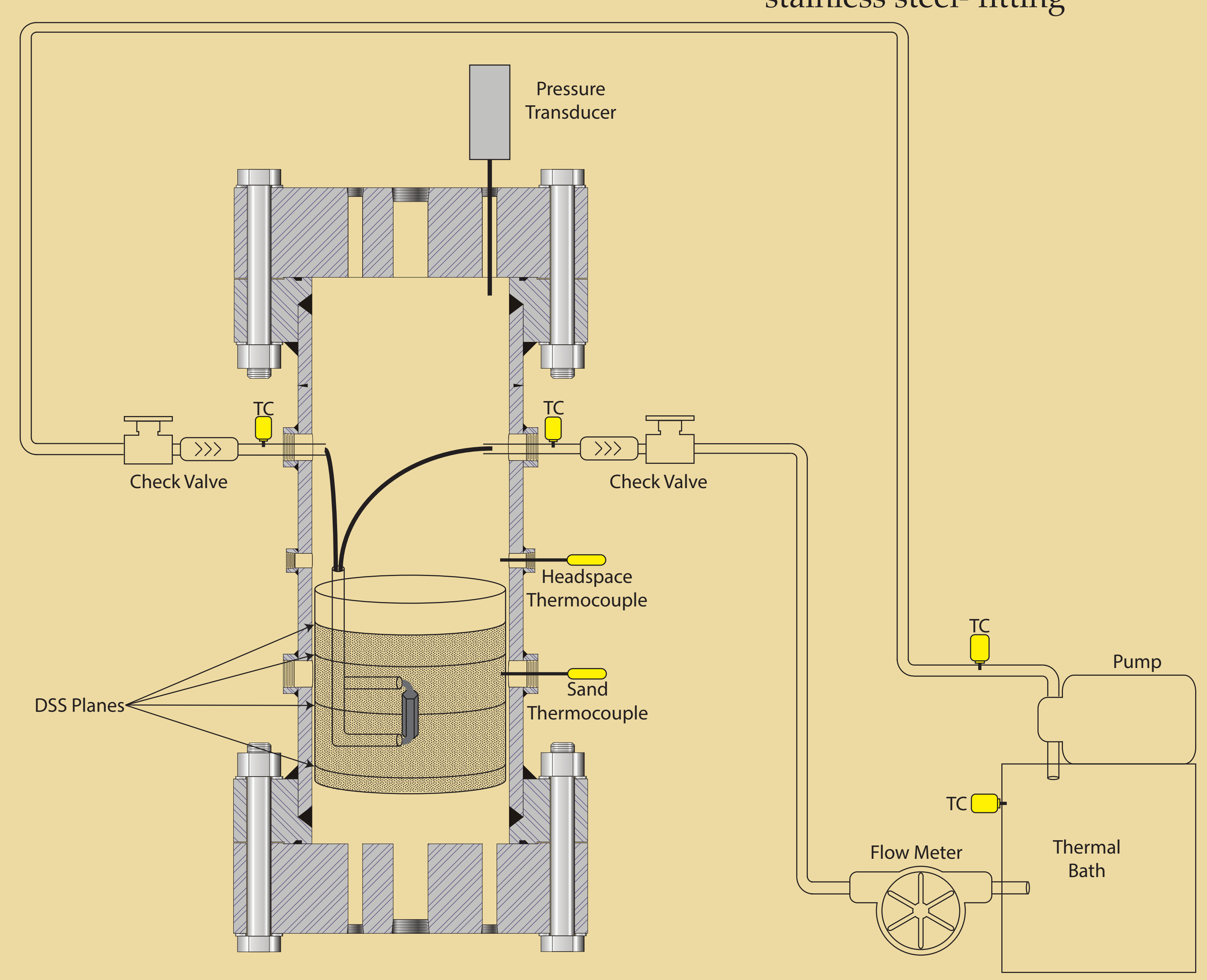
- 25 cm Tall x 30 cm Diameter

Heat Transfer Fluid:
- 32 % Ethylene Glycol

- Heat Capacity of 3698-3796 J kg^{-1} K^{-1}

- Average Pumping Rate order of 100 mL/min

- Transfered through stainless steel- fitting



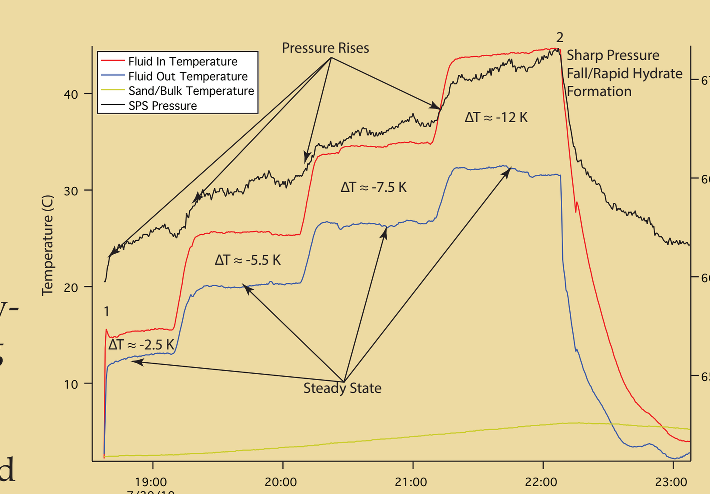
Vessel P/T Results

- Sharp pressure rises with each increase in heat input to the system, indicating clathrate dissociation.

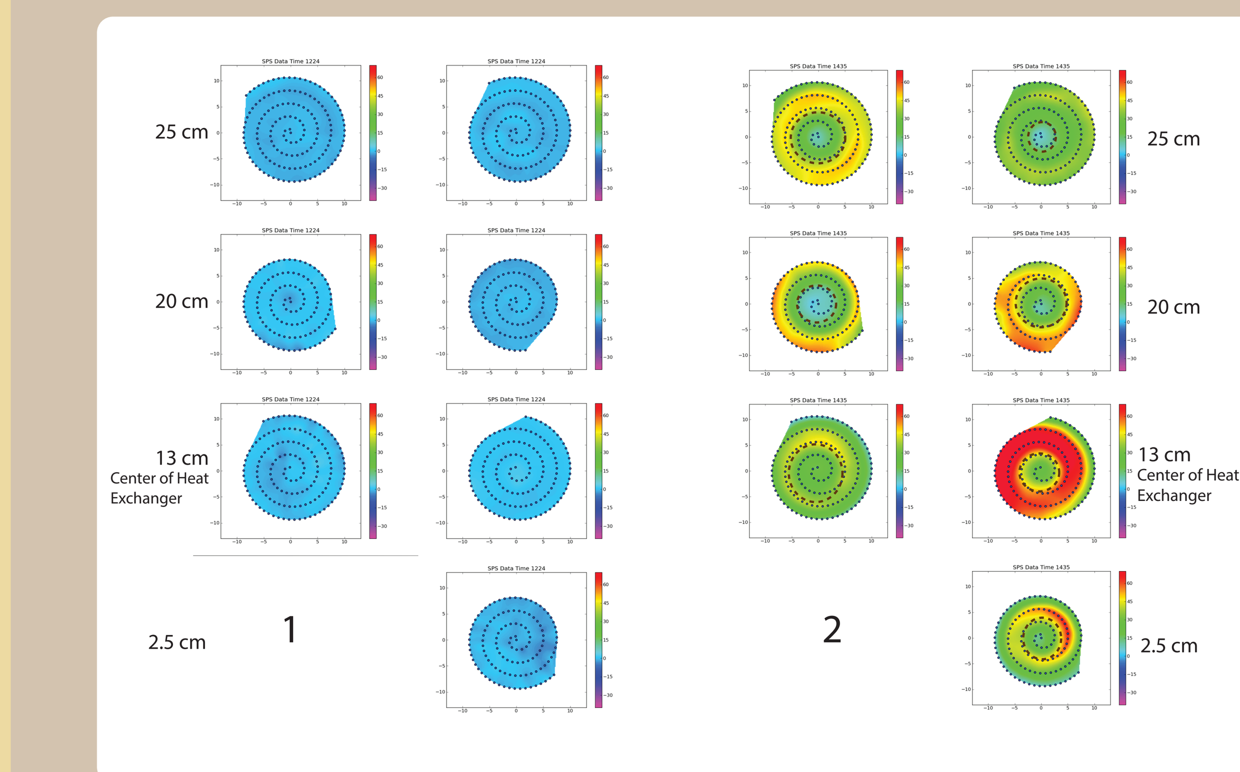
- Gradual, long term rise in vessel temperature cannot account for pressure increases.

- Rapid formation of hydrate following shutdown of the fluid pumping system as sediments cool.

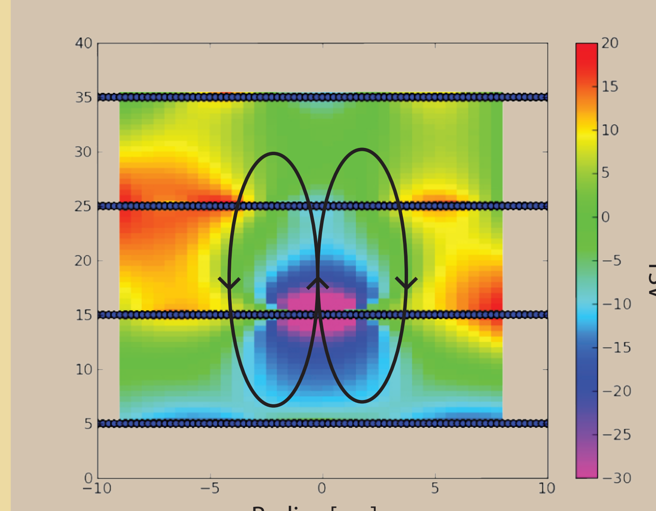
- Higher fluid temperatures resulted in higher ΔT, larger volume of hydrate is dissociated.



DSS Results



Cross sections at time 1 (equilibrium before pumping) and time 2 (at the end of pumping). Two columns represent the two fibers present on each plane. There is good agreement between the sensors. Dashed outlines represent the interpreted hydrate dissociation boundary.



A vertical cross section through the sediment column during maximum heating. Some interpolation artifacts appear between DSS planes due to the ratio of vertical sensor spacing to horizontal sensor spacing. The area around the heat exchanger exhibits low TS values indicating hydrate dissociation and/or strain change. Convective fluid movement likely plays an important role in heat distribution in addition to conductive heat transfer based on the axis-symmetric profile observed.

Model Design

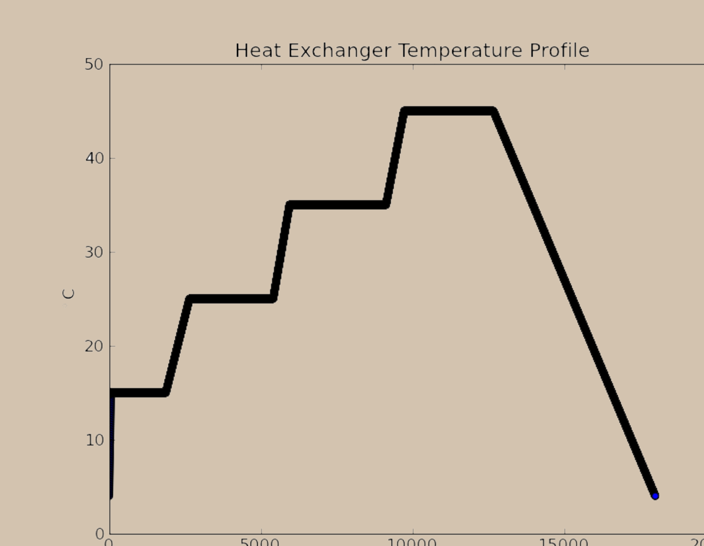
Assumptions:
- Linear change in heat exchanger temperature.

- Simple latent heat addition

- Conduction only

- Uniform 30% pore filling hydrate distribution

- Boundary temperature remains constant 273 K



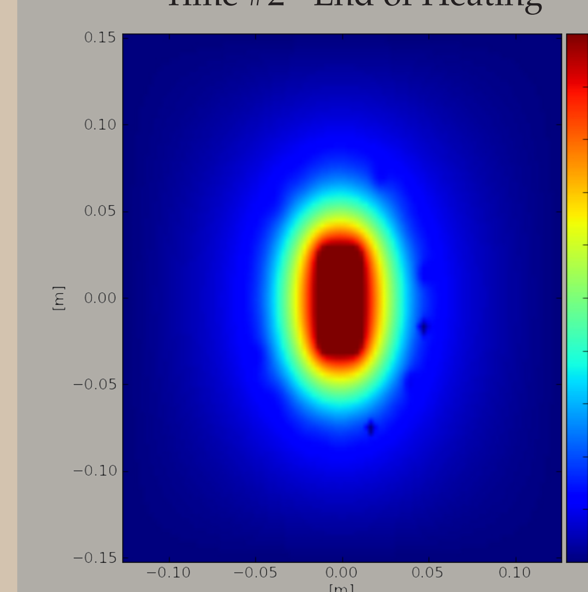
- Model written using matplotlib and Numpy python modules.

- Leapfrog numerical method for time series prediction

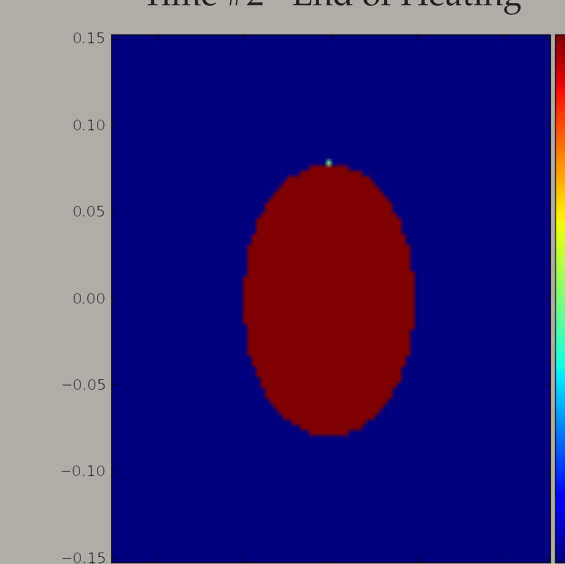
- 100x100 cell model

Model Comparison

Model Temperature Profile
Time #2 - End of Heating



Model State
Time #2 - End of Heating



State 0 = Pore Filling Hydrate
State 1 = Just Dissociated
State 2 = Dissociated

Model temperature profiles agree fairly well with experimental data, but experimental data show low TS values in the vacinity of the heat exchanger. This is possibly a strain influence. More advanced model parameterizations will allow further detailed study of strain responses. Turning off model latent heating changed the volume of dissociation, but not dramatically. Convection is likely the second order term for approximating the physical system.

Conclusions

- Events such as dike swarms, hot fluid flow, and small imact events could induce short-duration heating of a hydrate reservoir.

- Rapid heating events evolve gas rapidly, but are not likely to entirely dissociate the reservoir.

- To efficiently dissociate a mass of hydrate both depressurization (to reduce overpressure) and heating (to combat endothermic cooling) must be used.

- Simple numerical models provide a good first indication of expected experimental results, but require further sophistication to capture the complexity of the system.

- A more dense spacing of DSS grids in the vertical dimension is desired, but current data can possibly can be interpolated more effectively or such an artifical sensor network could be placed into the model to observe the behavior.

- Strain interactions are likley important in the system, but are currently poorly understood.

Future Work

- Parameterize Convection in Heat Flow Model

- Estimate Heat Loss in System Plumbing

- Improve Gridding Scheme

- Use Actual vs. Ideal Fluid Input Temperature as Input Deck

- Produce and Compare Estimated Fluid Output Temperatures

- Model Vessel Pressure Profiles

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