Strategies for Gas Production From Hydrate Accumulations Under Various Geological and Reservoir Conditions

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CONTRIBUTIONS FROM THE PARTICIPANTS OF: The Mallik Project, The Maurer/Anadarko Hydrate Project, The BP Hydrate Project

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OUTLINE

NUMERICAL STUDIES

- **Classification of natural hydrate accumulations**
- **Production from hydrate Classes 1 through 3**
  - **Geological implications for production strategies**
  - **Reservoir conditions**
  - **Sensitivity analysis**
- **Identification of knowledge gaps**

The EOSHYDR2 Module of TOUGH2

- **TOUGH2 [*Pruess, 1991; Pruess et al., 1999*]: General-purpose multiphase, multicomponent model for simulation of fluid and heat flow and transport in porous and fractured media**
- **EOSHYDR2: Module for non-isothermal hydrate dissociation/formation, CH_4 flow, and phase behavior [*Moridis et al., 1998; 2002*]**

Methane hydrates

$CH_4.N_mH_20 = CH_4 + N_mH_20(l,i)$, $5.75 \leq N_m \leq 7.4$

Second-gas hydrates

$G.N_GH_20 = G + N_G H_20(l,i)$, $G = C_\nu H_{2\nu+2}, H_2S, CO_2, N_2$

Binary hydrates

$\chi_m[CH_4.N_mH_20]\ \chi_G\ [G.N_GH_20]$, $\chi_m+\chi_G = 1$

The EOSHYDR2 Module of TOUGH2

BERKELEY LAB

1. Components

- (1) H_2O
- (2) CH_4(native gas)
- (3) CH_4(dissociated gas)
- (4) G (native gas)
- (5) G (dissociated gas)
- (6) Hydrate
- (7) Salt
- (8) Inhibitor
- (9) Heat

- Components in red: Minimum necessary

2. Phases

(1) Aqueous
H_2O, CH_4(n), CH_4(d), G (n), G (d), S, I

(2) Gas
CH_4(n), CH_4(d), G (n), G (d), H_2O, I

(3) Solid-Hydrate
$\chi_m[CH_4.N_mH_20]$ χ_G $[G.N_\nu H_20]$

(4) Solid-Ice
H_2O

TOUGH2/EOSHYDR2 capable of handling (a) equilibrium or kinetic dissociation, and (b) all possible dissociation mechanisms (depressurization, thermal stimulation, inhibitor effects, combinations)

Classification of natural hydrate accumulations

CRITERIA: reservoir geology and initial conditions

- **CLASS 1: Formation includes two zones**
  - The hydrate interval (bottom at hydrate stability)
  - An underlying two-phase zone with mobile gas

- **CLASS 2: Formation includes two zones**
  - The hydrate interval (bottom at hydrate stability)
  - An underlying single-phase zone of mobile water

- **CLASS 3: Formation composed of a single zone**
  - Formation coincides with the hydrate interval
  - Absence of a hydrate-free interval

Production From Class 1 Hydrates

OBVIOUS INITIAL TARGETS FOR INITIAL PRODUCTION

- Hydrate at equilibrium - minimum need for stimulation
- Easiest to produce

PRODUCTION STRATEGY

- Depressurization is the main strategy
- When combined with thermal stimulation, the effect is multiplicative
- Inhibitor use: warm brine potential
- Thermal recuperation (?)
- Multiple well systems: superior to single wells
- Horizontal wells: superior to vertical wells

PRODUCTION POTENTIAL INCREASES WITH

- ◆ FORMATION TEMPERATURE
- Intrinsic and relative permeability
- Thickness of free gas zone
- Thickness and saturation of the hydrate zone

Production From Class 1 Hydrates

North Slope BP Accumulation - Depressurization

HYDRATE

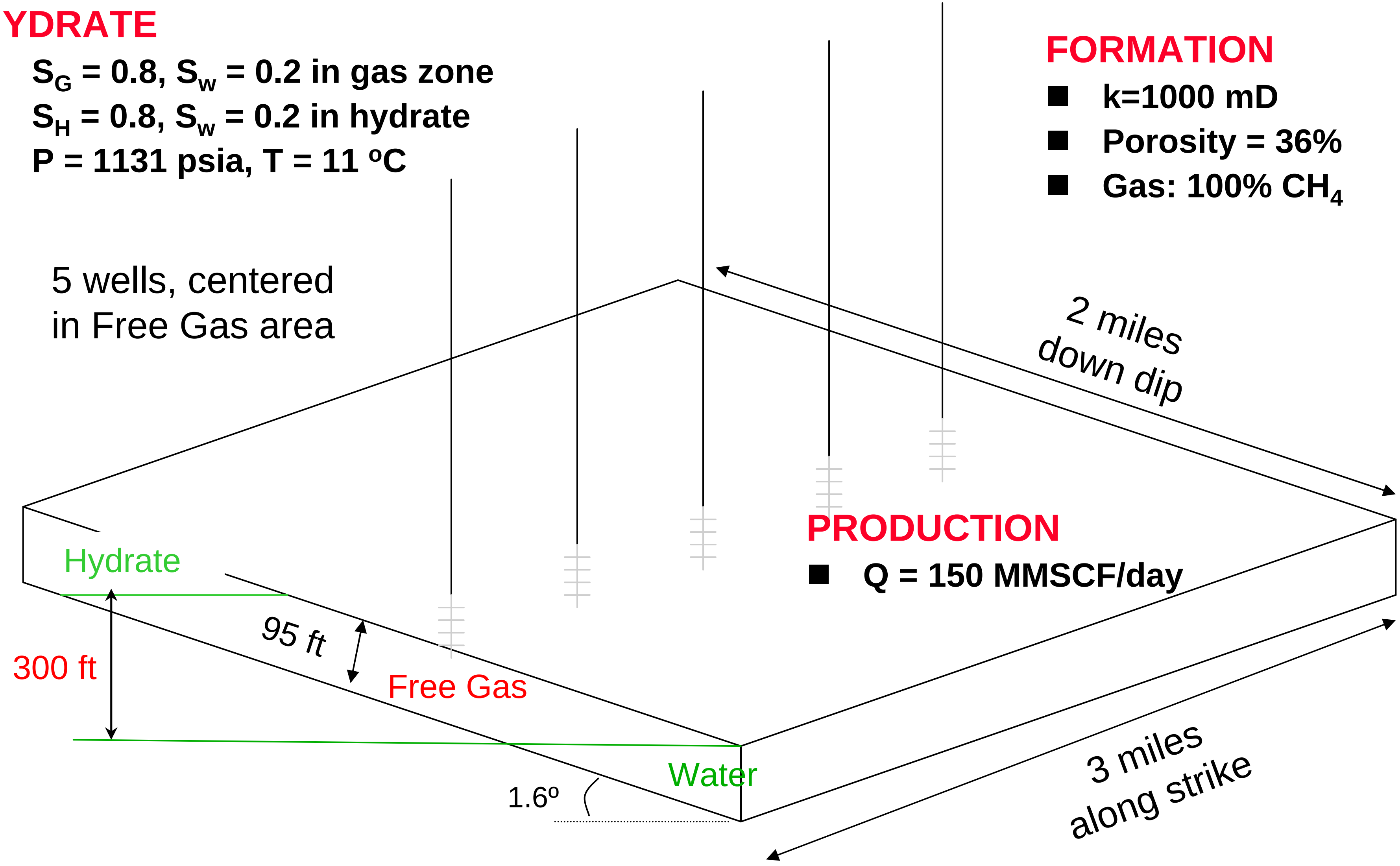
- $S_G = 0.8$, $S_w = 0.2$ in gas zone
- $S_H = 0.8$, $S_w = 0.2$ in hydrate
- P = 1131 psia, T = 11 ºC

FORMATION

- k=1000 mD
- Porosity = 36%
- Gas: 100% CH_4

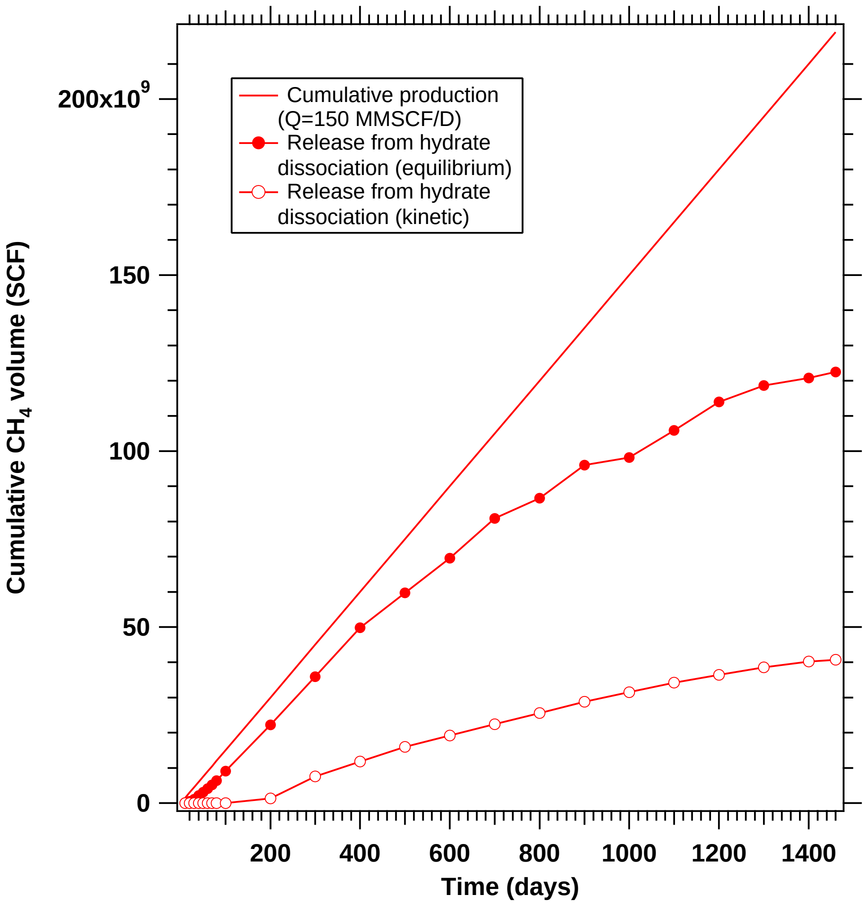
PRODUCTION

- Q = 150 MMSCF/day



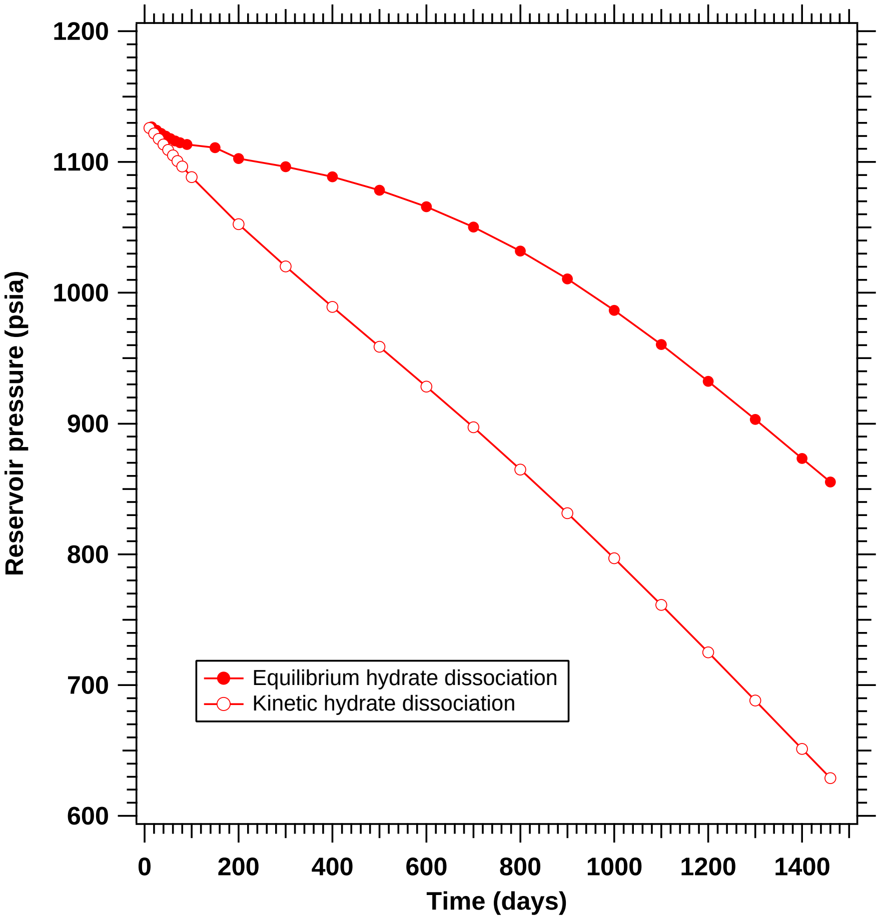
Production From Class 1 Hydrates

North Slope BP Accumulation - Depressurization



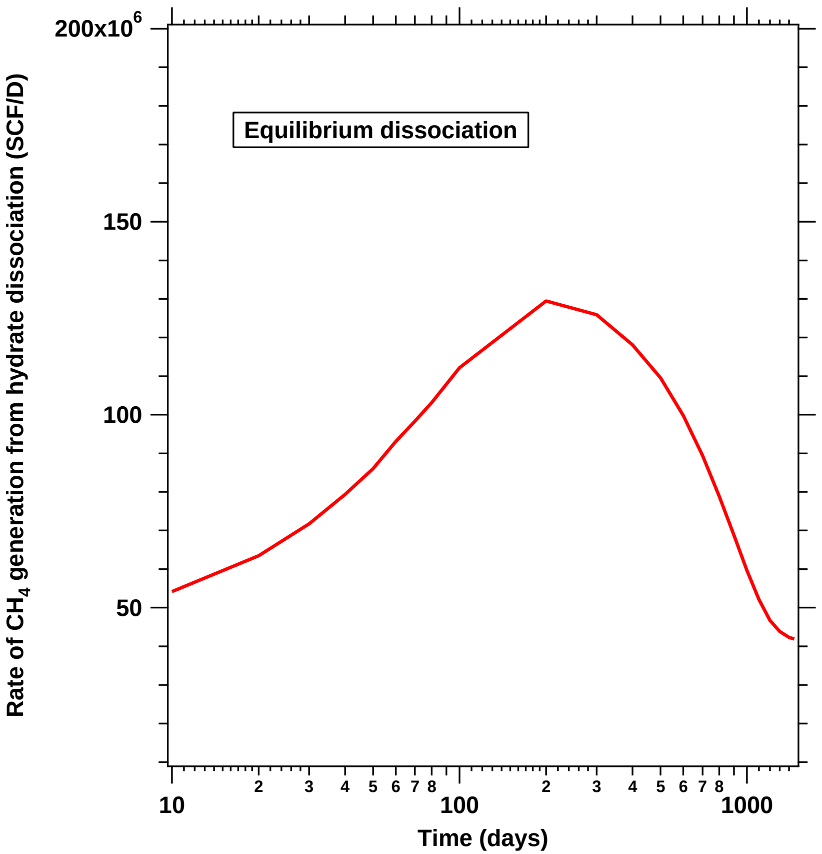
Cumulative CH_4 release

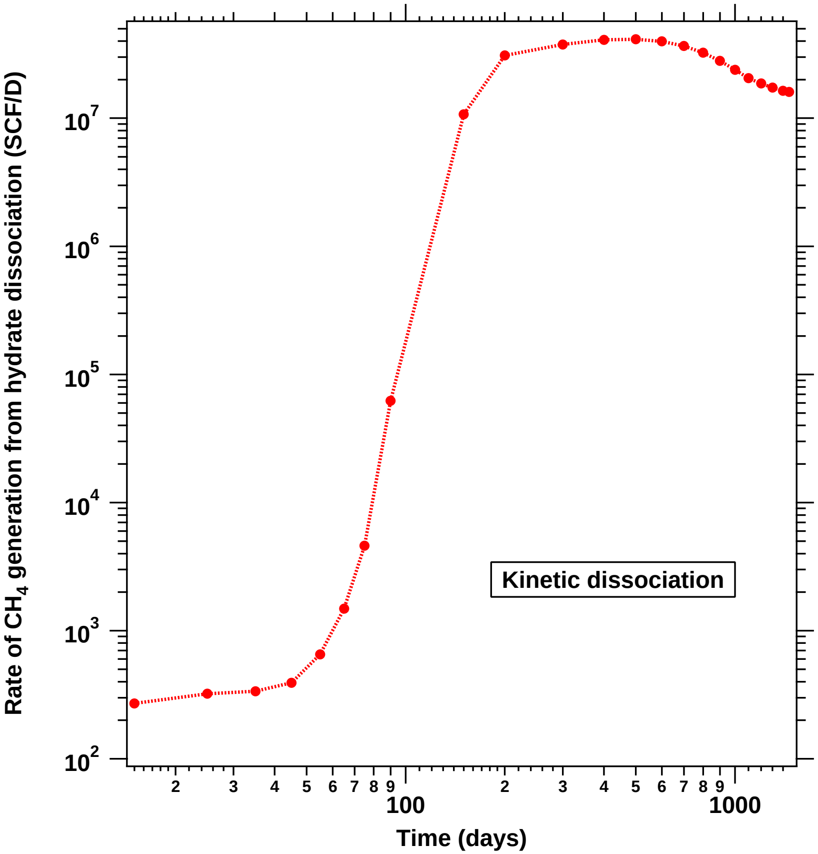
Pressure evolution



Production From Class 1 Hydrates

North Slope BP Accumulation

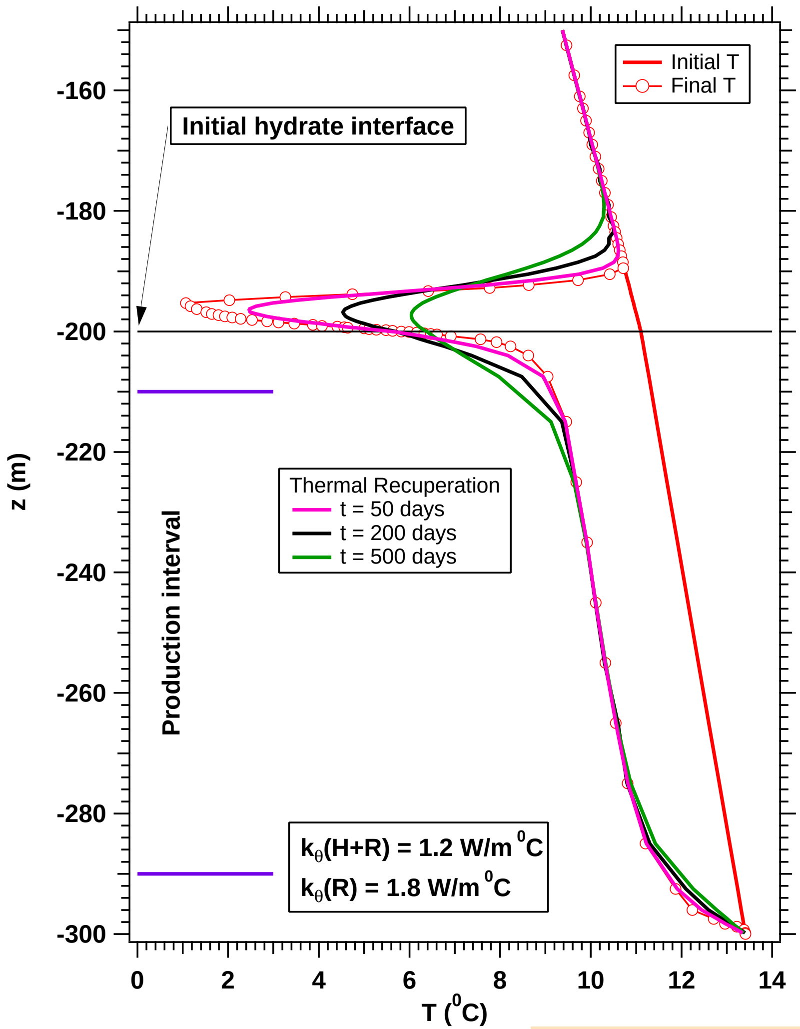


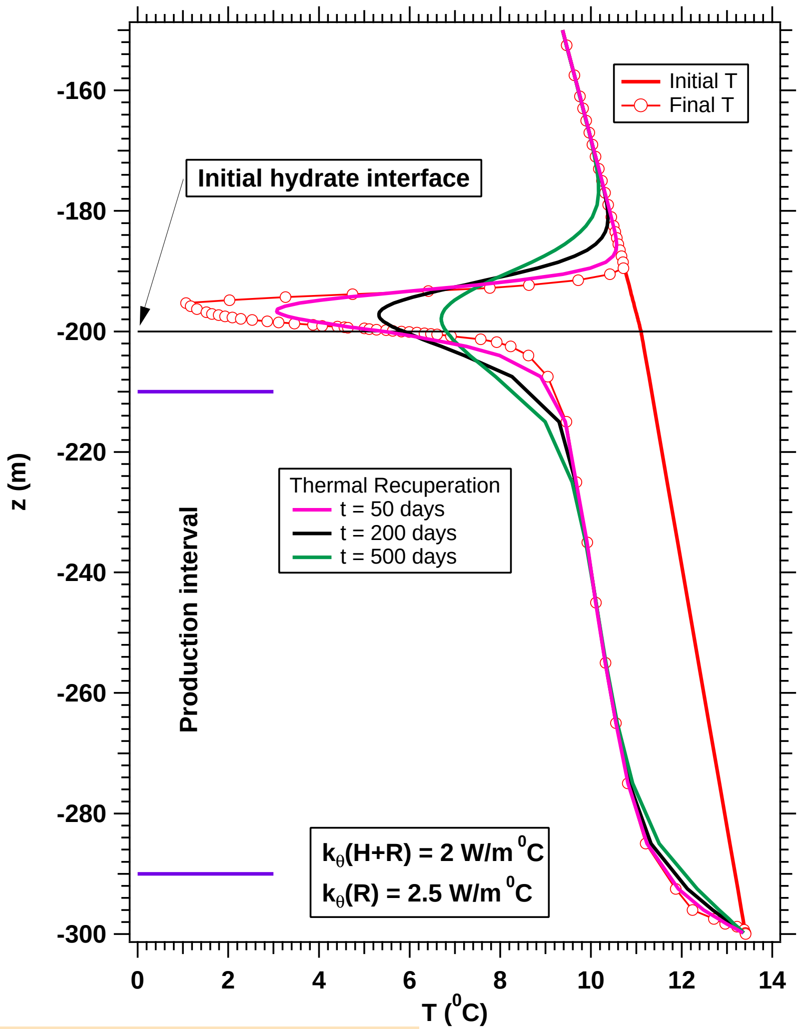


Rate of CH_4 release in the reservoir

Production From Class 1 Hydrates

North Slope BP Accumulation





Thermal recuperation potential?

Production From Class 1 Hydrates
Eileen Area Accumulation

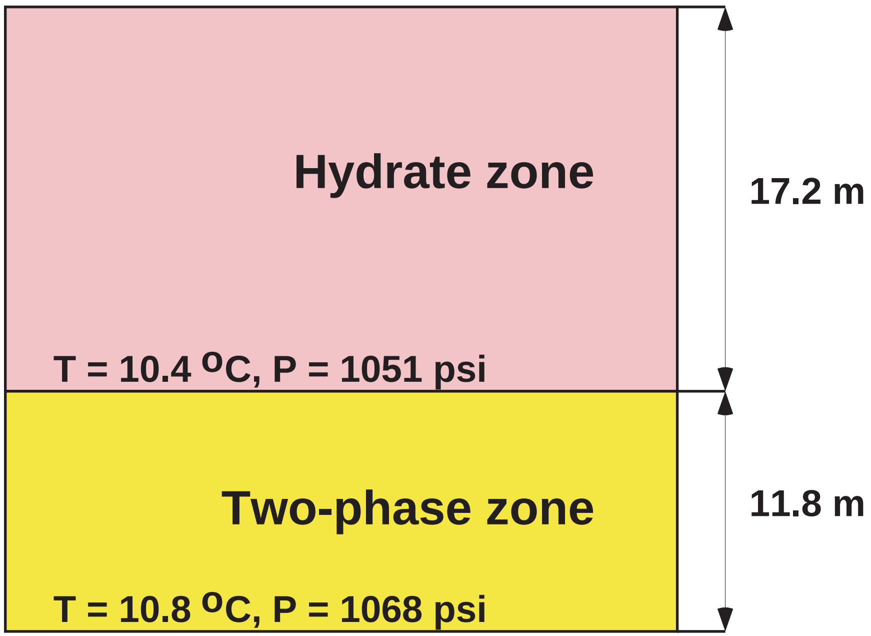
Unit C

- **DEPRESSURIZATION**
  - Single vertical well
  - Maximum pressure differential: well kept at atmospheric pressure
  - Well completed in the top 1.85 m (6 ft) of C2

- **DEPRESSURIZATION + THERMAL STIMULATION**
  - Multi-well systems (e.g., five-spot pattern)

GAS HYDRATE ACCUMULATION

UNIT C, EILEEN AREA, ALASKA

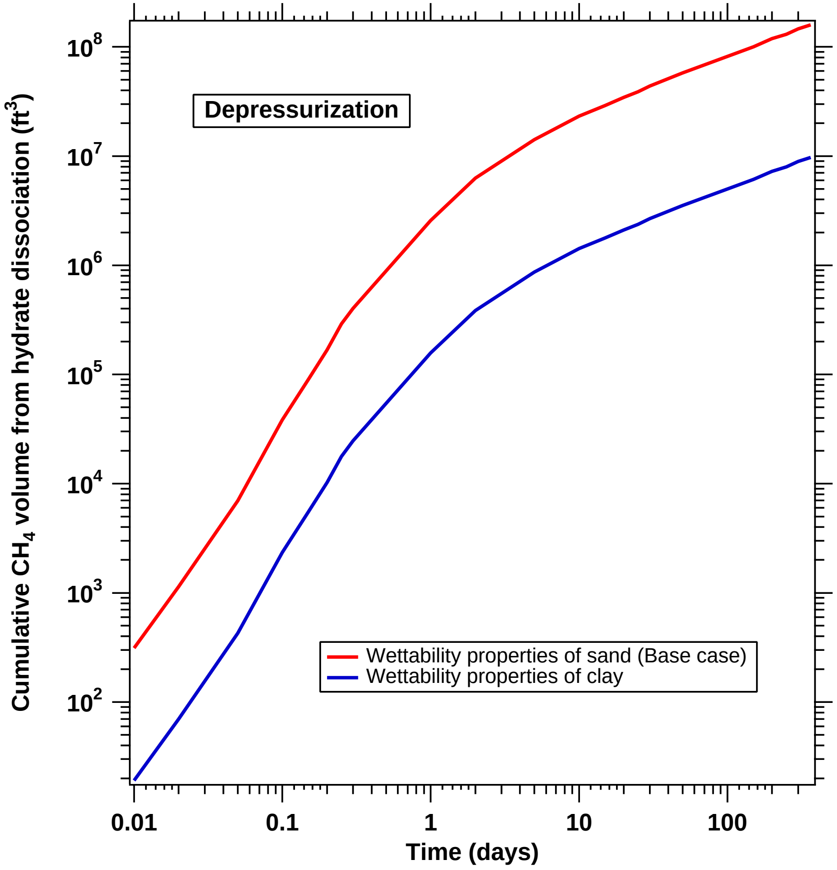


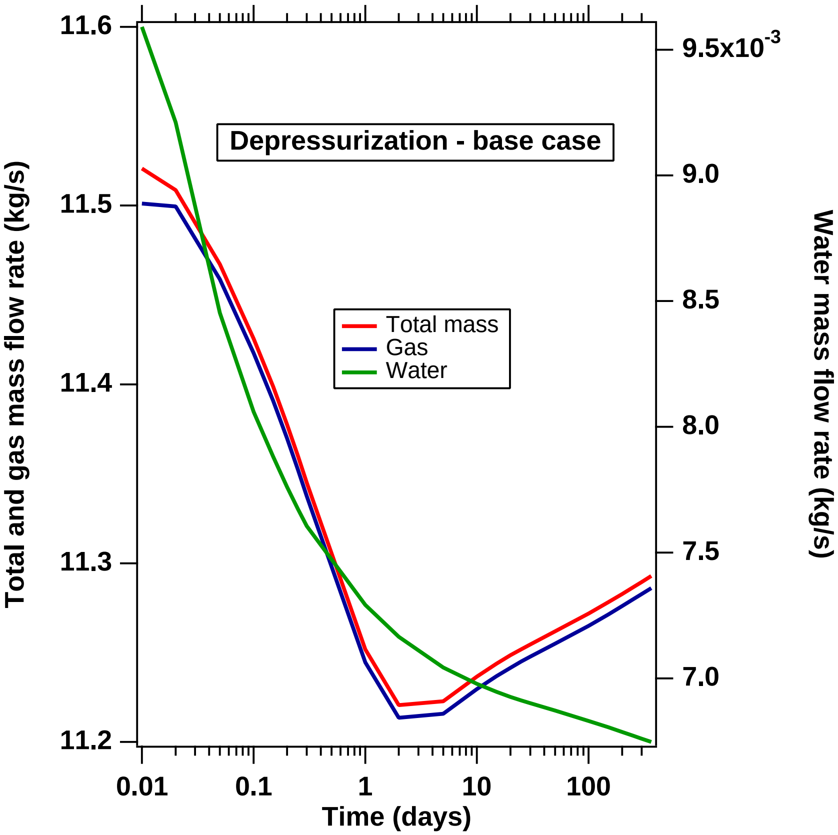
Not to scale

Production From Class 1 Hydrates

Eileen Area Accumulation

Depressurization





- Significant volume releases
- Dramatic effect of wettability

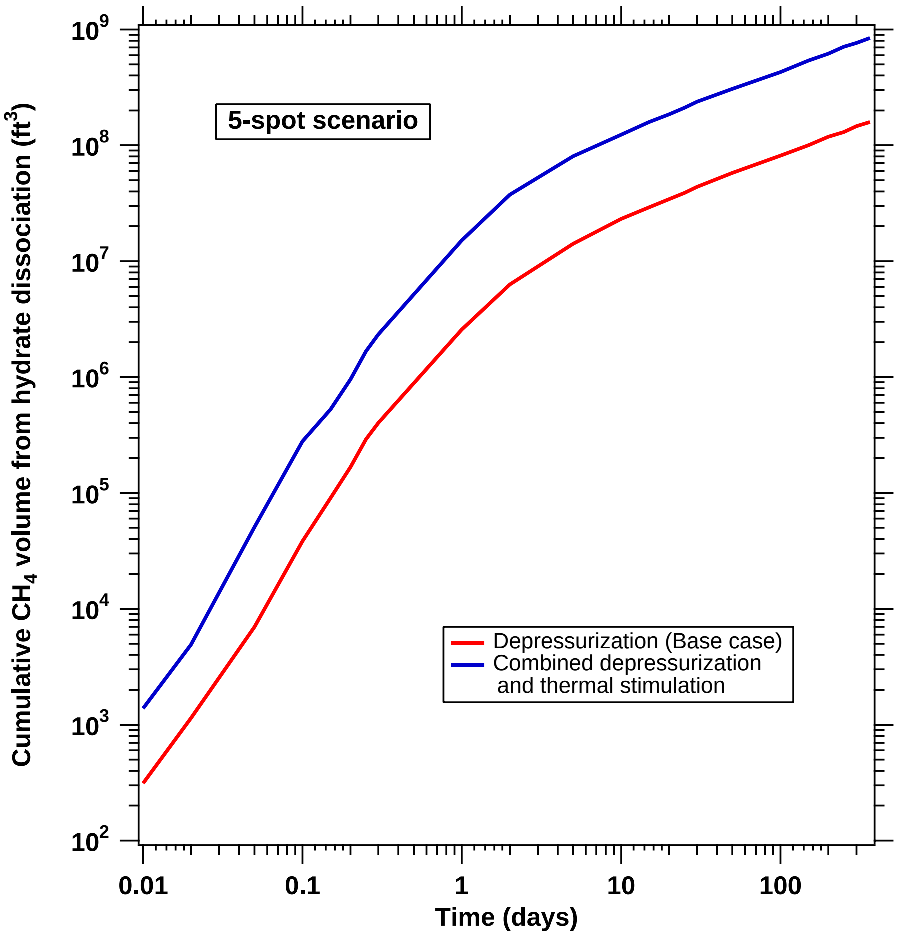
- The water mass fraction in production stream is very small

Production From Class 1 Hydrates

Eileen Area Accumulation

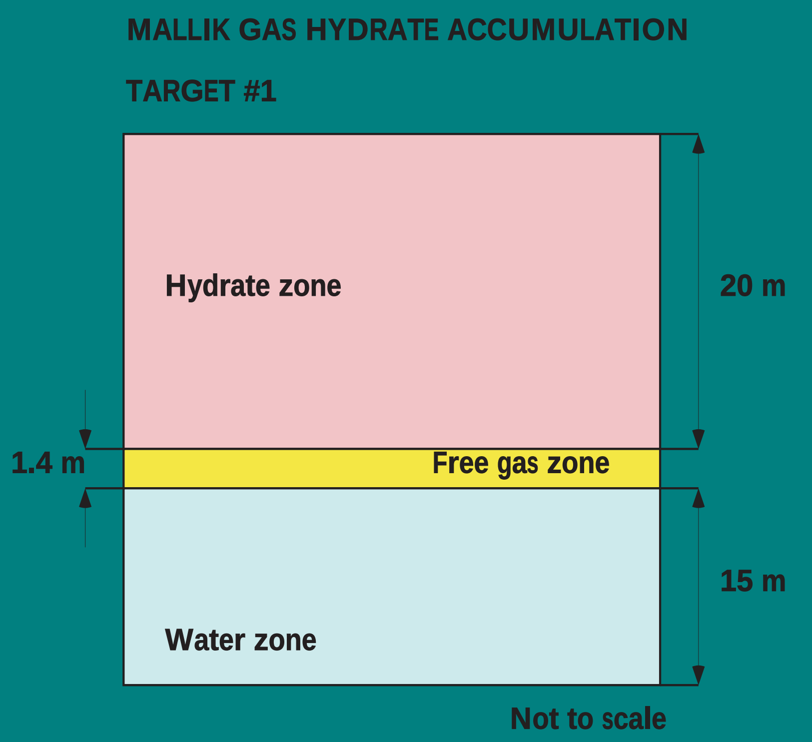
- **DEPRESSURIZATION + THERMAL STIMULATION**
- **Multi-well system (five-spot pattern)**
- **Wells completed in the top 1.85 m of C2**
- **Steam injection (3000 KJ/kg) at a rate of 1.85 kg/s**
- **Production well kept at atmospheric pressure**

◆ **The released CH_4 volume is about an order of magnitude larger than that from simple depressurization**



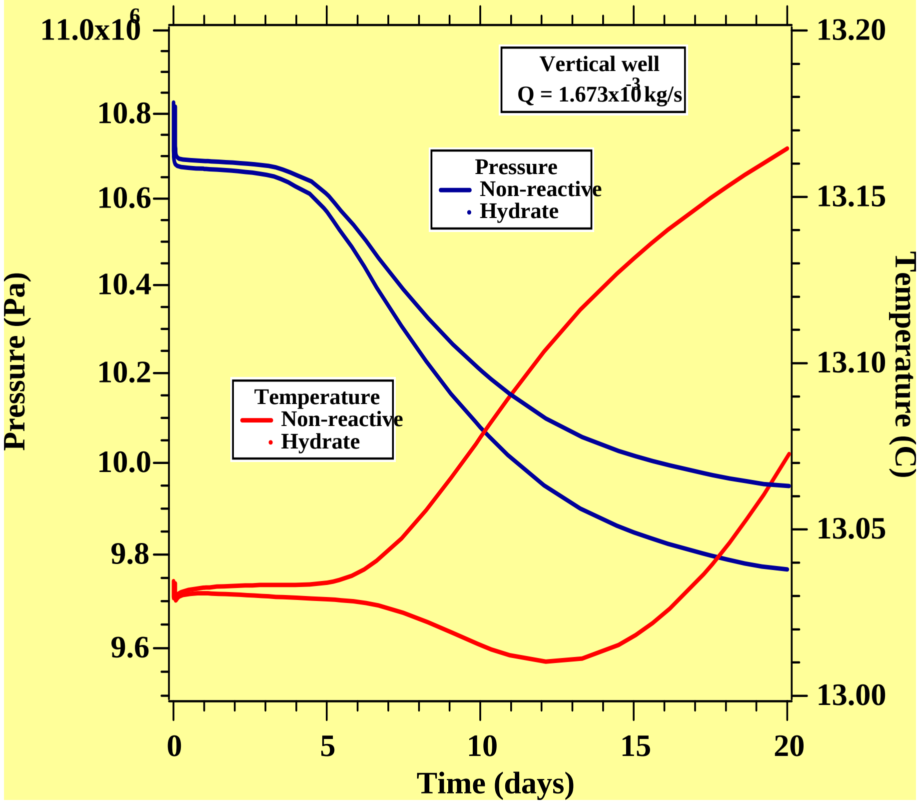
Production From Class 1 Hydrates

Mallik Area Accumulation



P = 10.824 MPa, T = 13.03 ºC

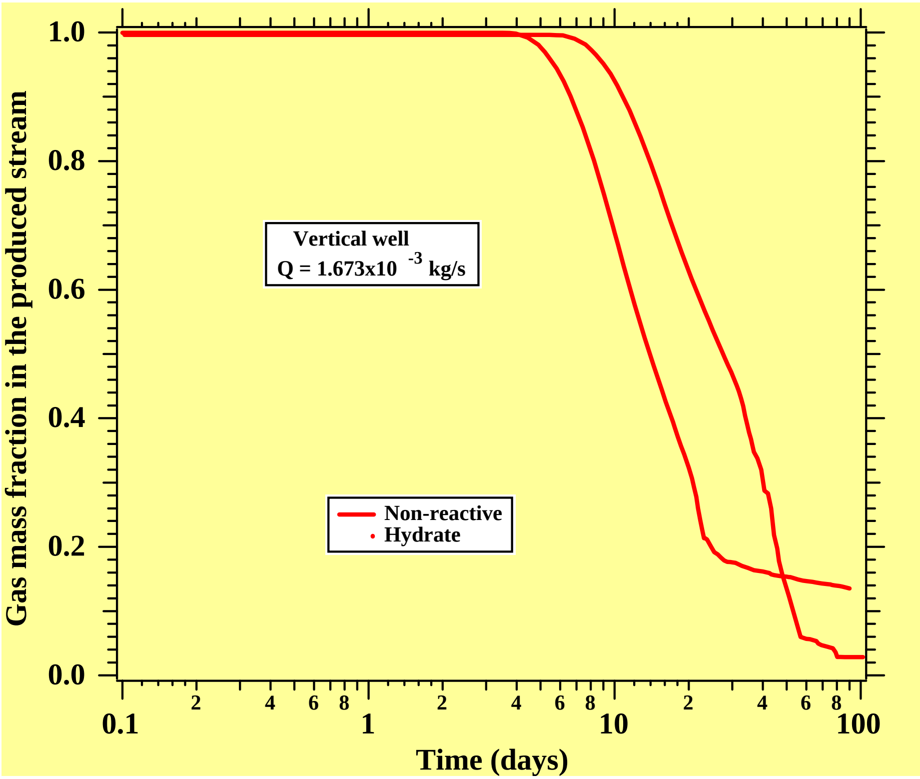
k = 20 mD, ϕ = 0.28, S_h = 0.8

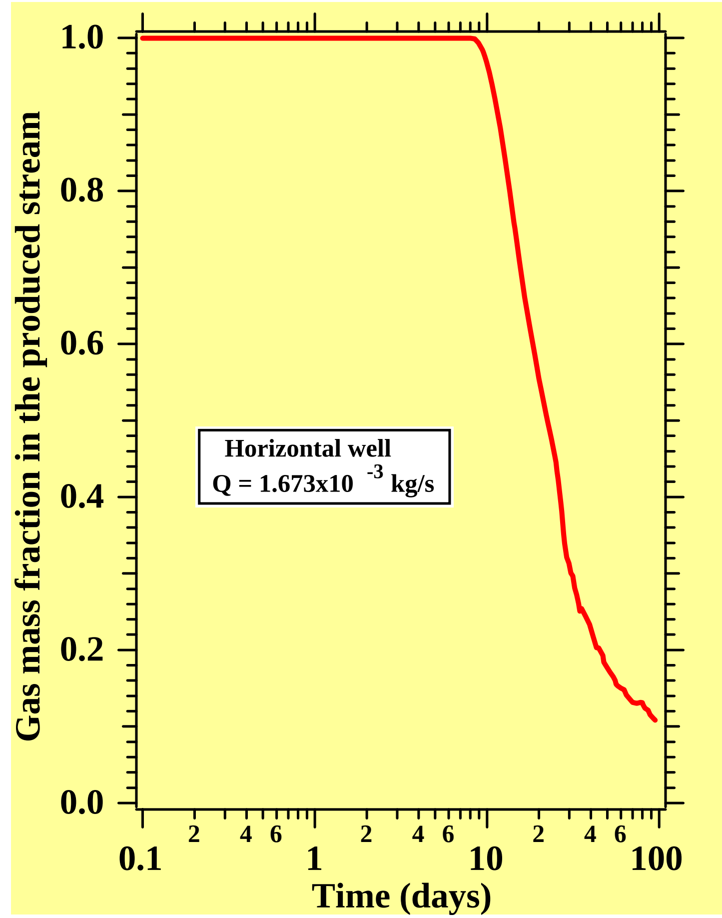


Discernible differences in pressure and temperature performance between dissociating and non-dissociating scenarios

Production From Class 1 Hydrates

Mallik Area Accumulation



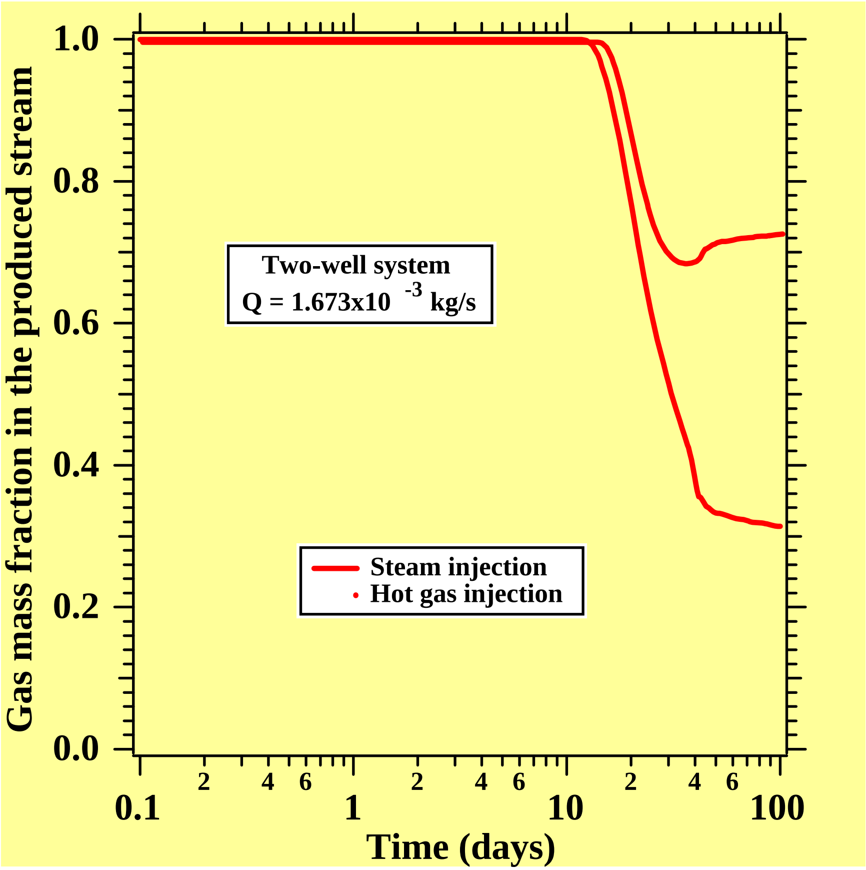


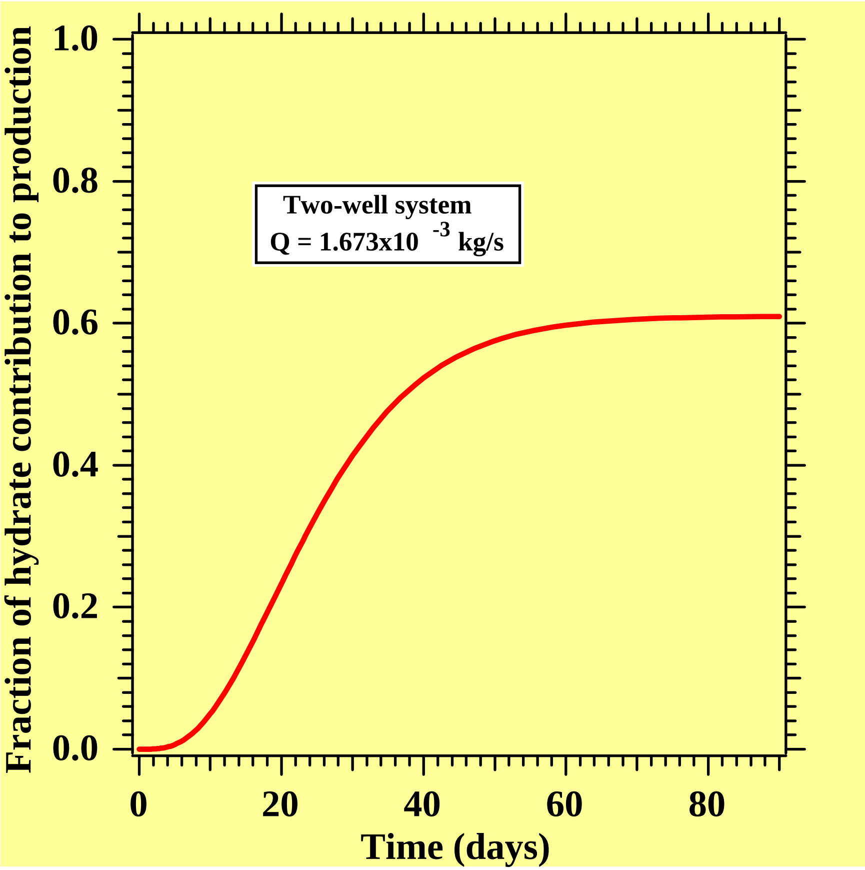
Discernible differences in gas mass fraction performance between dissociating and non-dissociating scenarios

Horizontal wells appear to have an advantage over vertical wells

Production From Class 1 Hydrates

Mallik Area Accumulation





Two-well systems: advantage over a single vertical or horizontal well
Hot gas injections: superior to steam injection

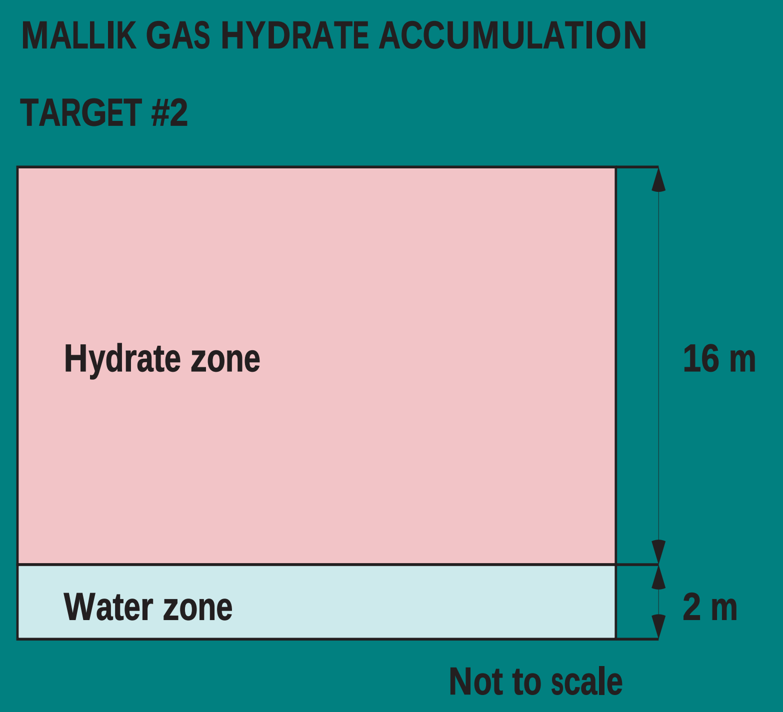
Production From Class 2 Hydrates

Mallik Area Accumulation

AT FIRST GLANCE:

- **Advantages**
- The source of the gas is known to be the hydrate deposit
- Depressurization more efficient because of the incompressibility of water
- Cooling effects less significant

- **But**
- Possible gas permeability issues
- Environmental concerns

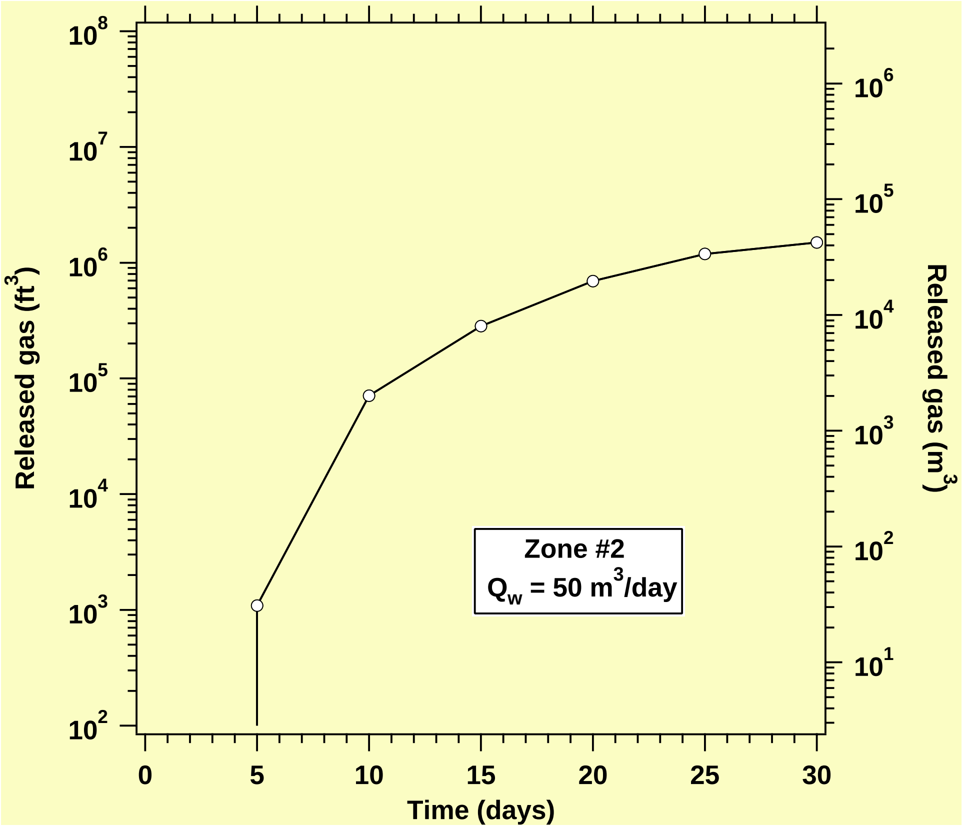


P = 9 MPa, T = 7.5 °C

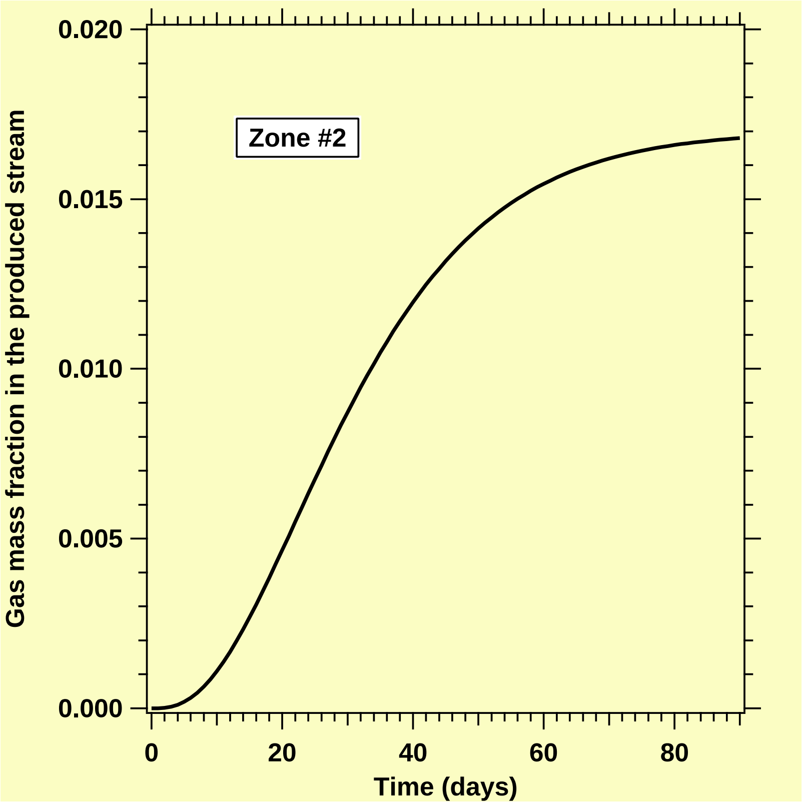
k = 20 mD, ϕ = 0.28, S_h = 0.8

Production From Class 2 Hydrates

Mallik Area Accumulation



Depressurization - single well



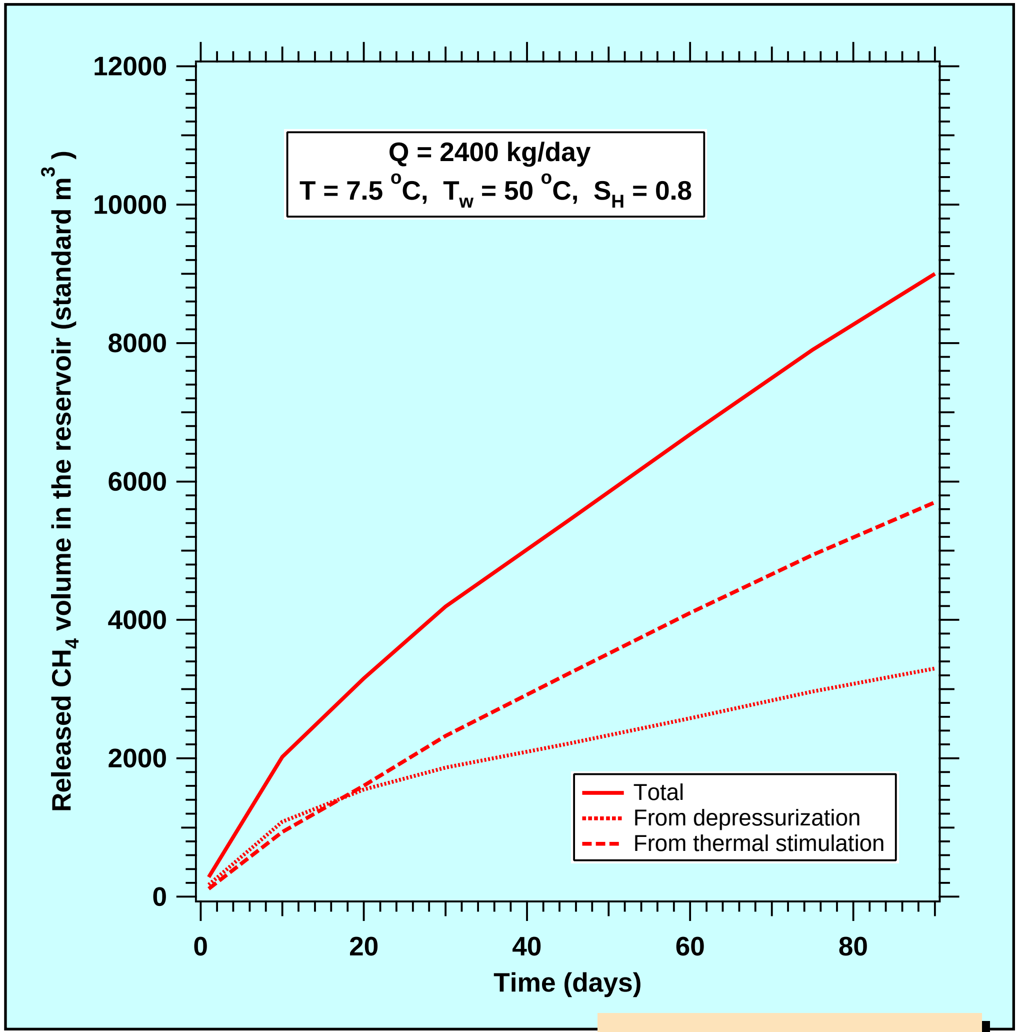
- **Feasible, but**
- **Large volumes of undesirable water**

Production From Class 2 Hydrates

Mallik Area Accumulation

Approach

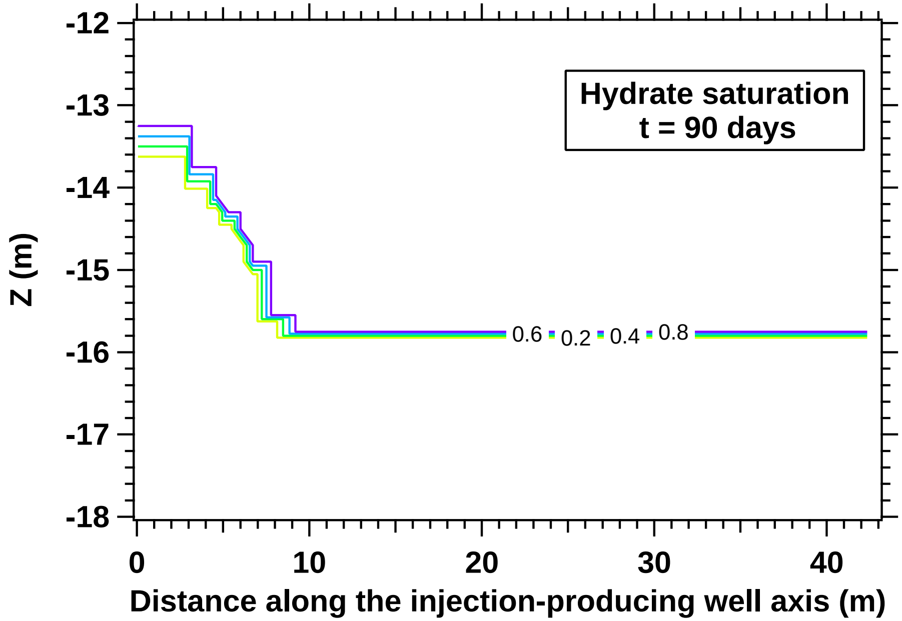
- Five-spot pattern (60m side)
- Hot water injection, fluid production
- Water recirculation (zero net water withdrawal)
- Combination of thermal stimulation and depressurization
- Well completions: top 1 m of the water zone, hydrate layer (production)
- Salinity: important, continuously diluted
- 70K gridblocks, 350K equations

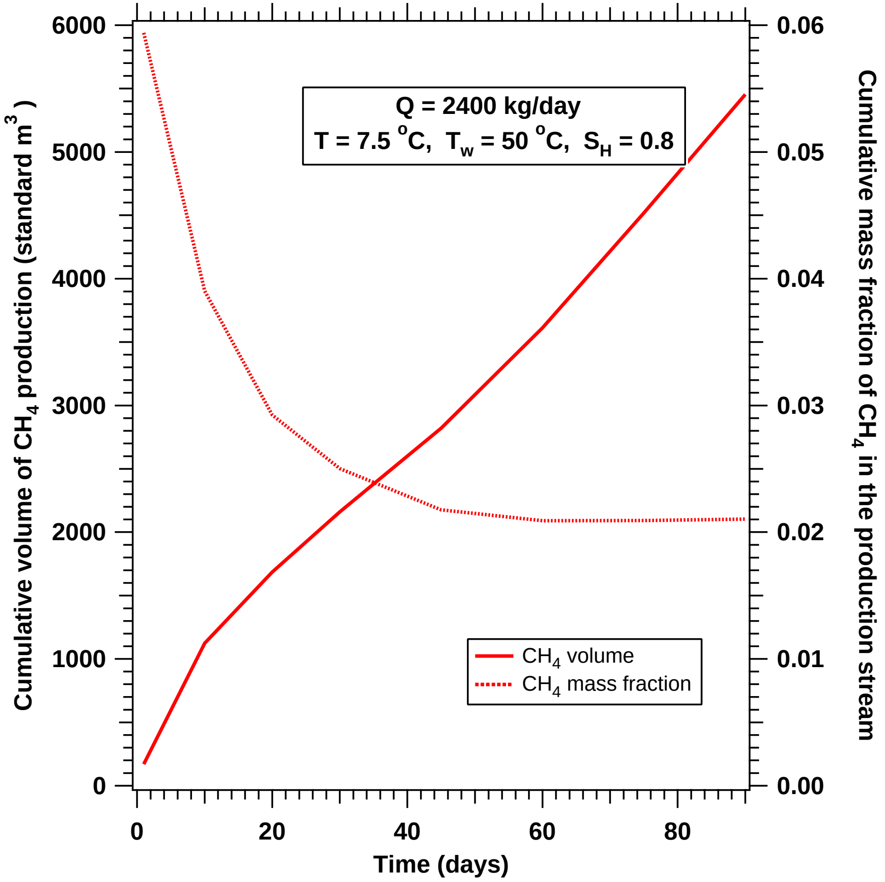


Base case

Production From Class 2 Hydrates

Mallik Area Accumulation



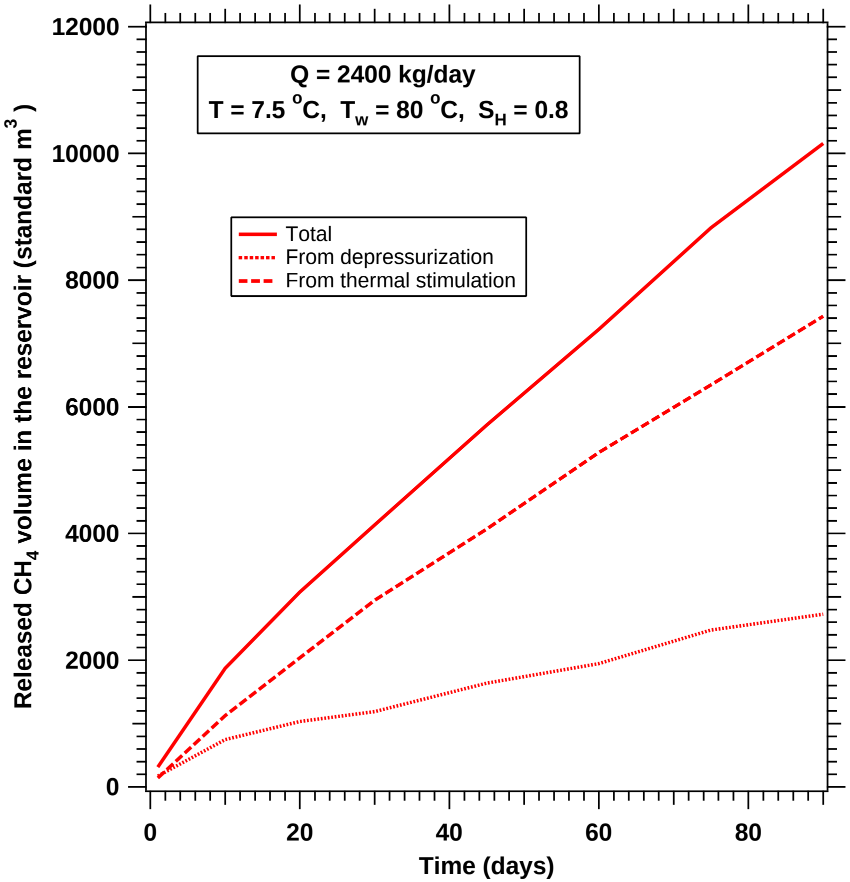


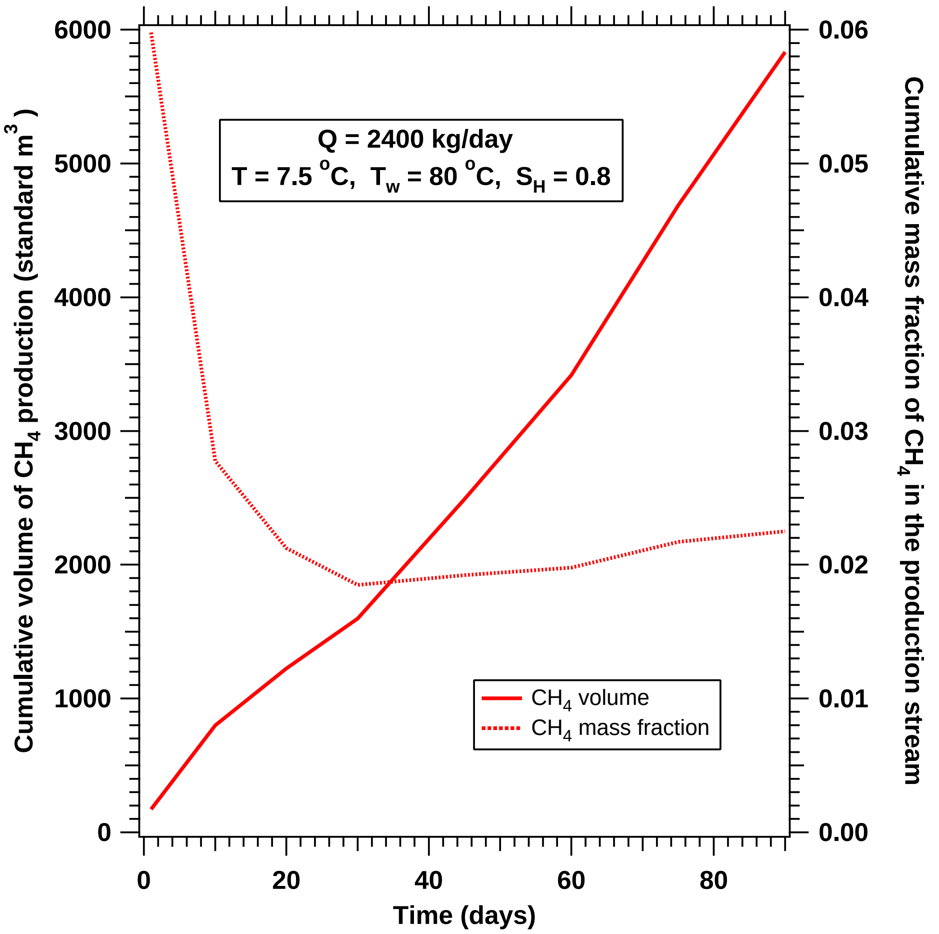
Base Case

Production From Class 2 Hydrates

Mallik Area Accumulation

Effect of T_w

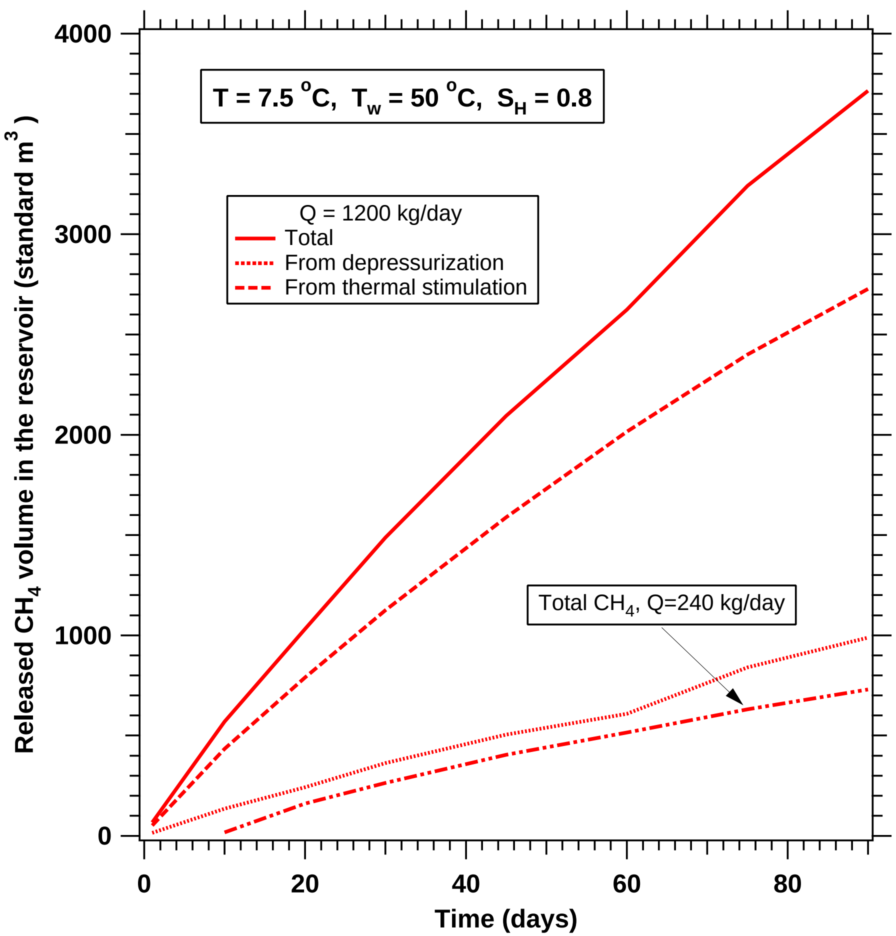


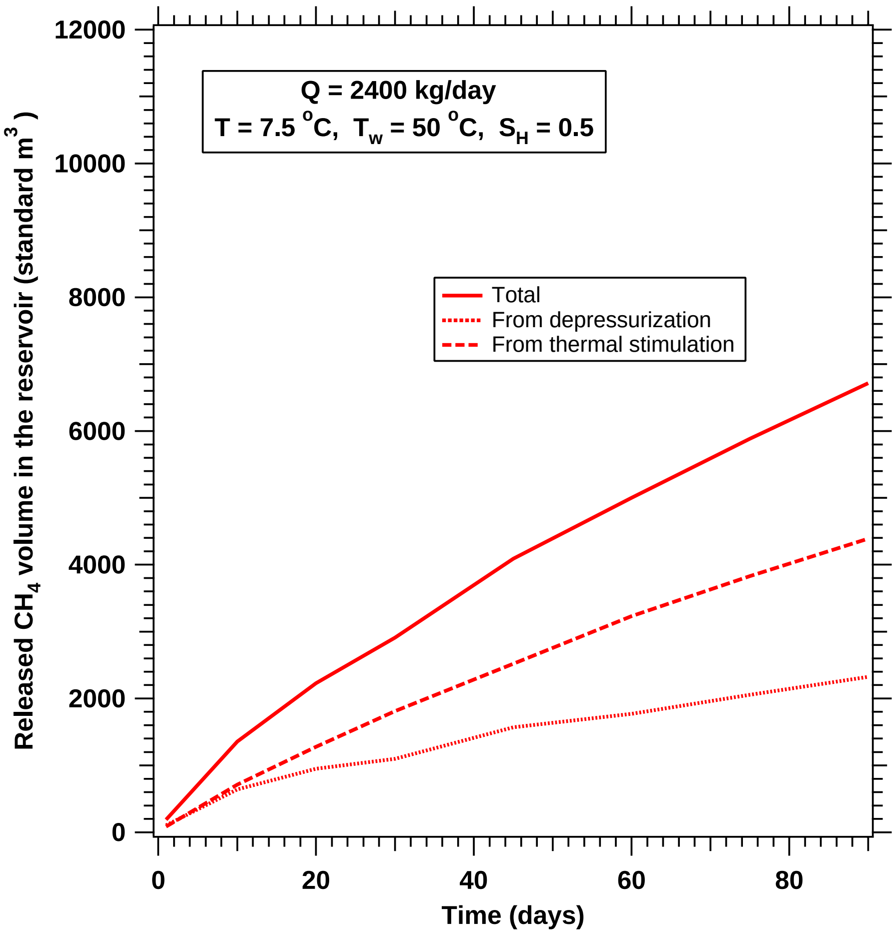


Production From Class 2 Hydrates

Mallik Area Accumulation

Effect of Q

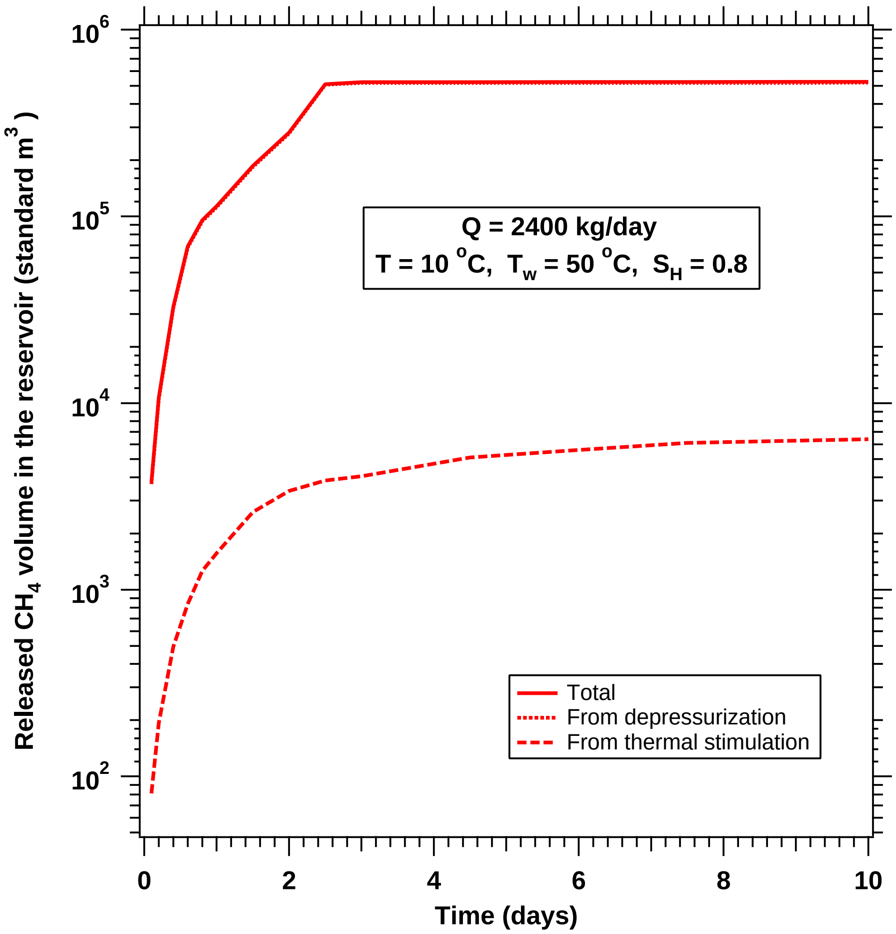




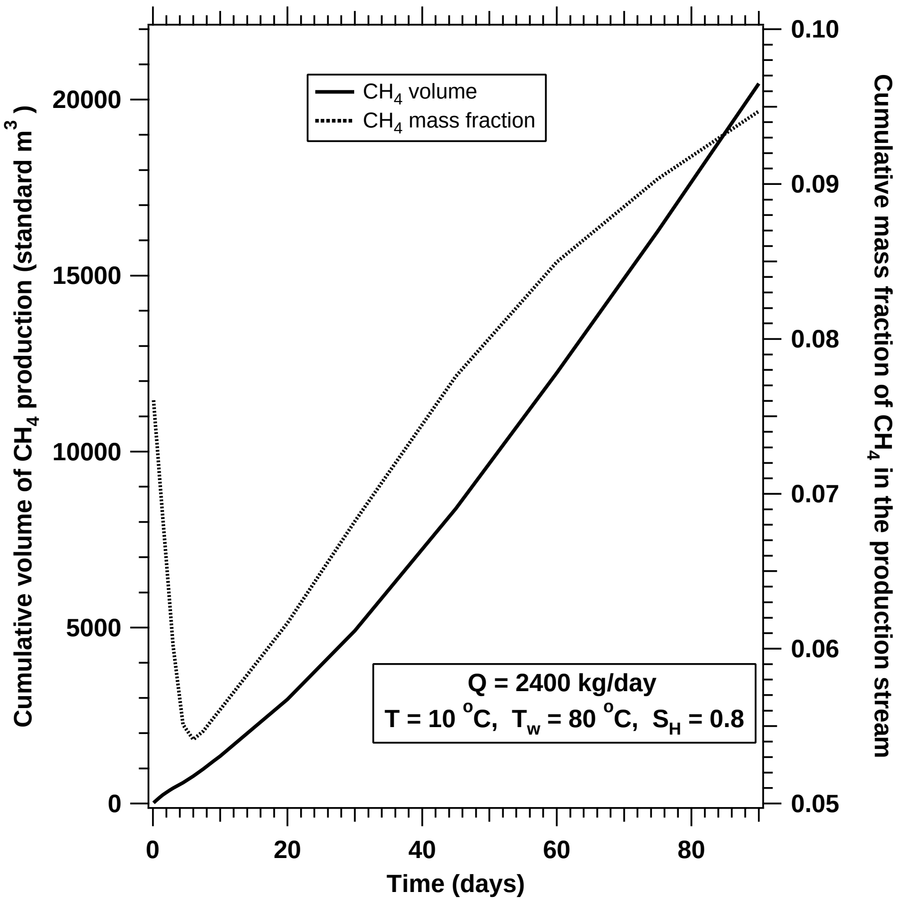
Effect of S_H

Production From Class 2 Hydrates

Mallik Area Accumulation

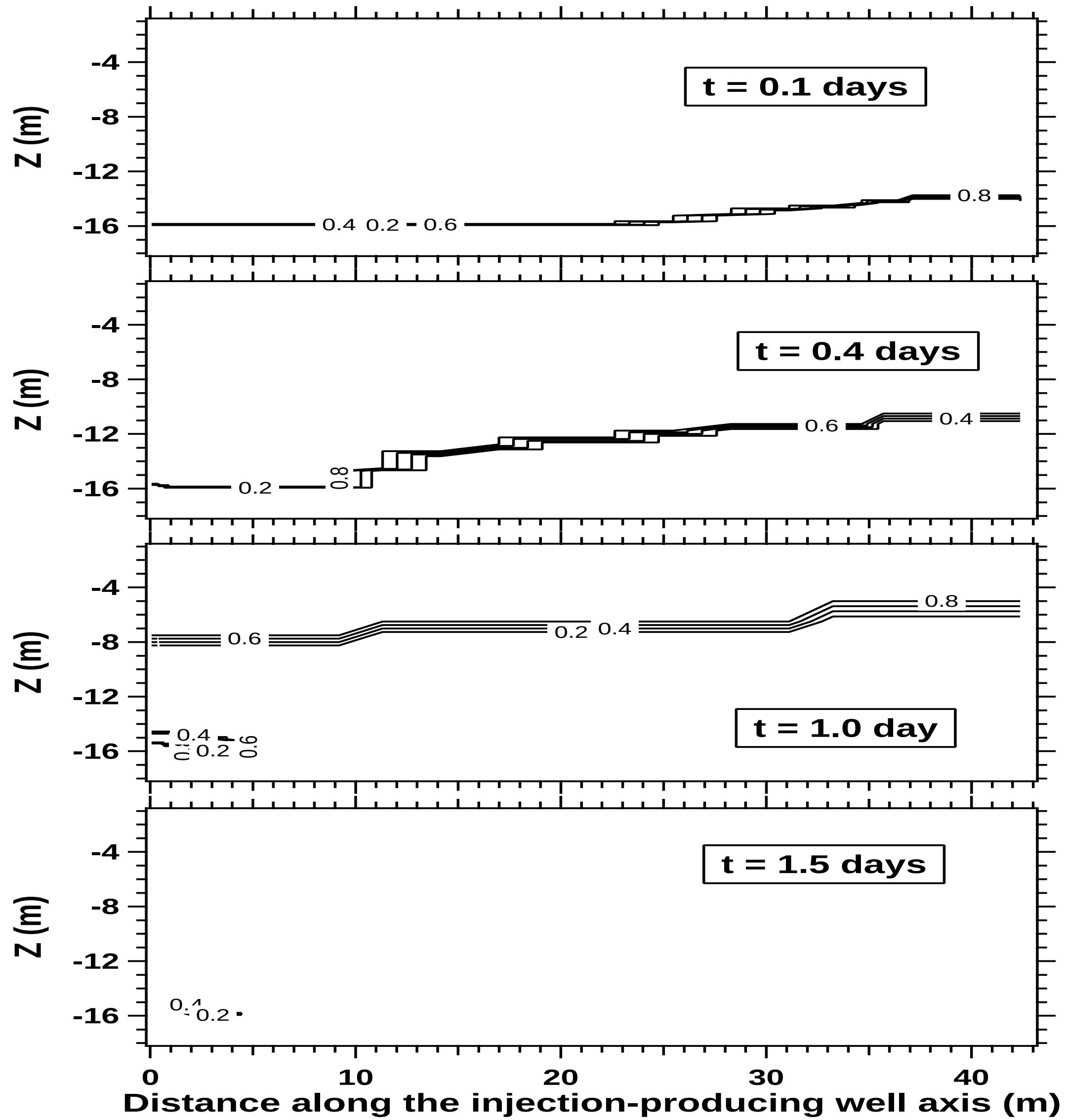


Effect of T: Dramatic!!!



Production From Class 2 Hydrates

Mallik Area Accumulation



Dramatic!!!

Production From Class 3 Hydrates

Mallik Area Accumulation

P = 10.74 MPa, T = 7.5 ^oC

No free gas or water zones

- For flow, fracturing necessary (especially if hydrate saturation is high)
- Huff and Puff: Very little gas released because of small injected volumes, large thermal inertia, abysmally small permeability, continuous dilution of brine front

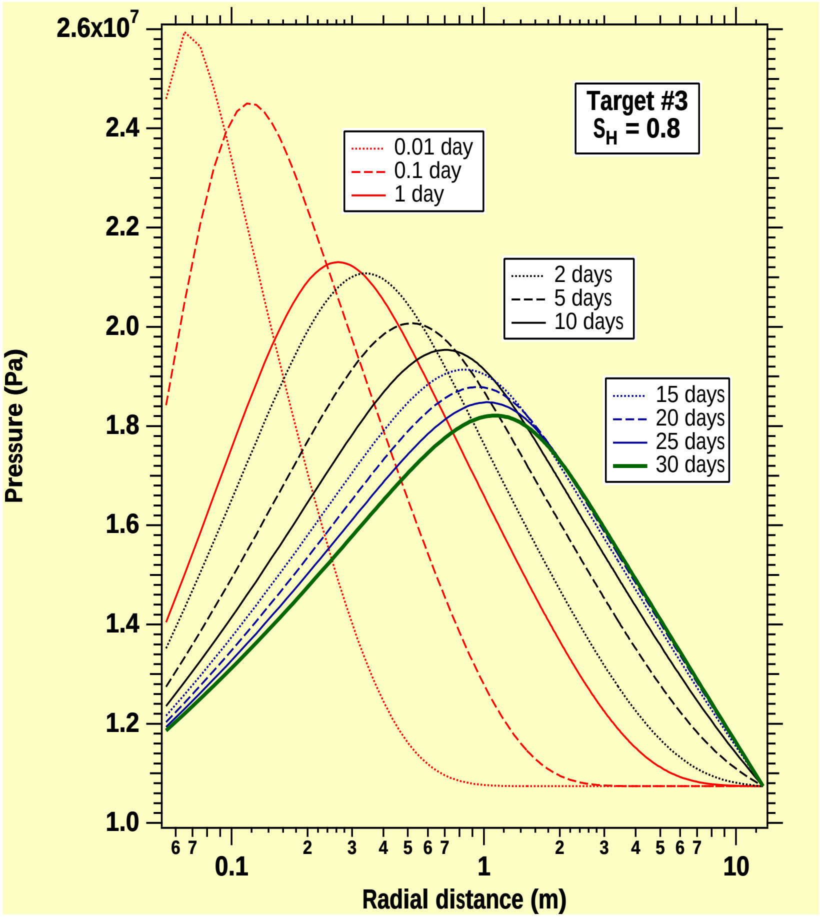
Approach: Circulation of hot water in well

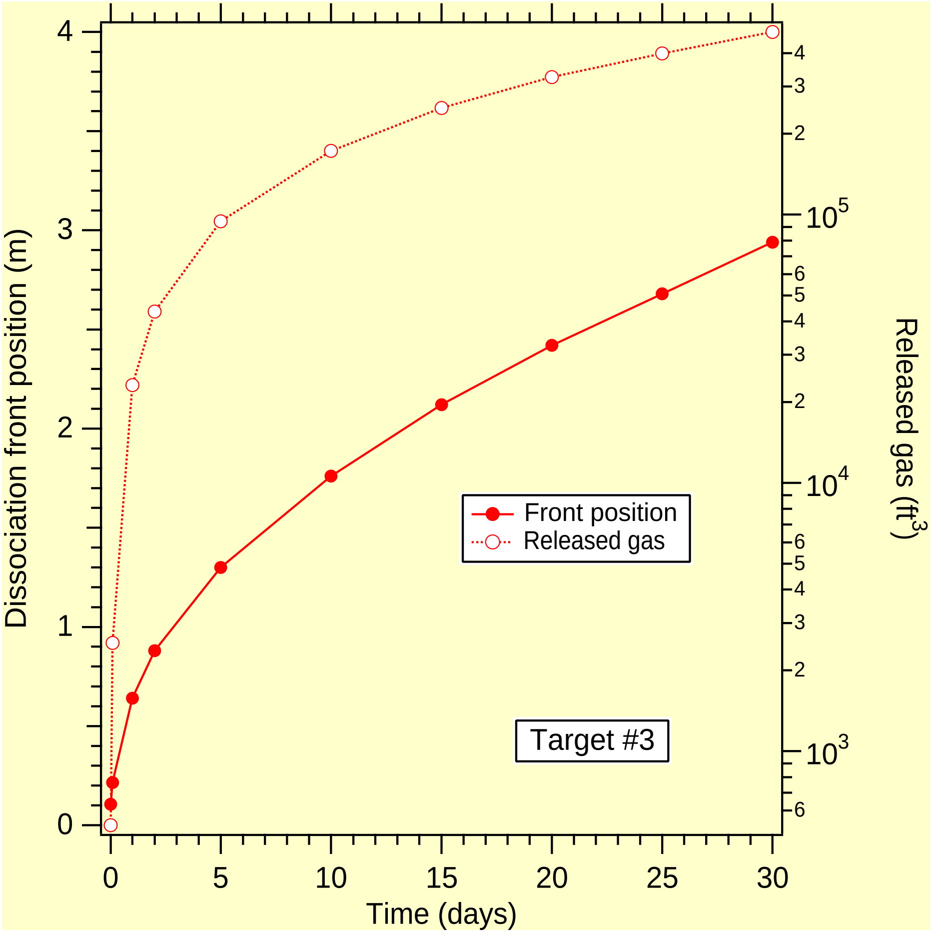
- ❑ Constant well temperature
- Thermal dissociation
- Simple and easy to conduct in the field
- Limited number of interacting processes
- Pressure effects unavoidable

Production From Class 3 Hydrates

Mallik Area Accumulation - Thermal dissociation

Pressure

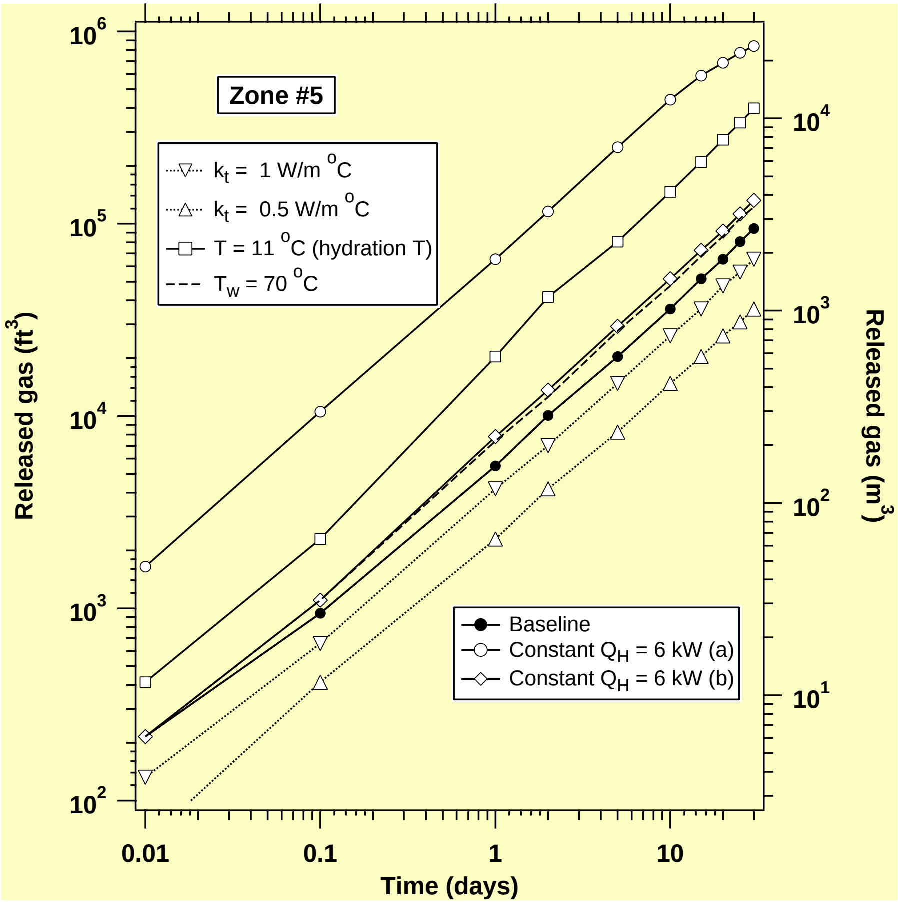




Limited radius of dissociation

Production From Class 3 Hydrates

Mallik Area Accumulation - Thermal dissociation



Sensitivity analysis

Gas production is sensitive to:

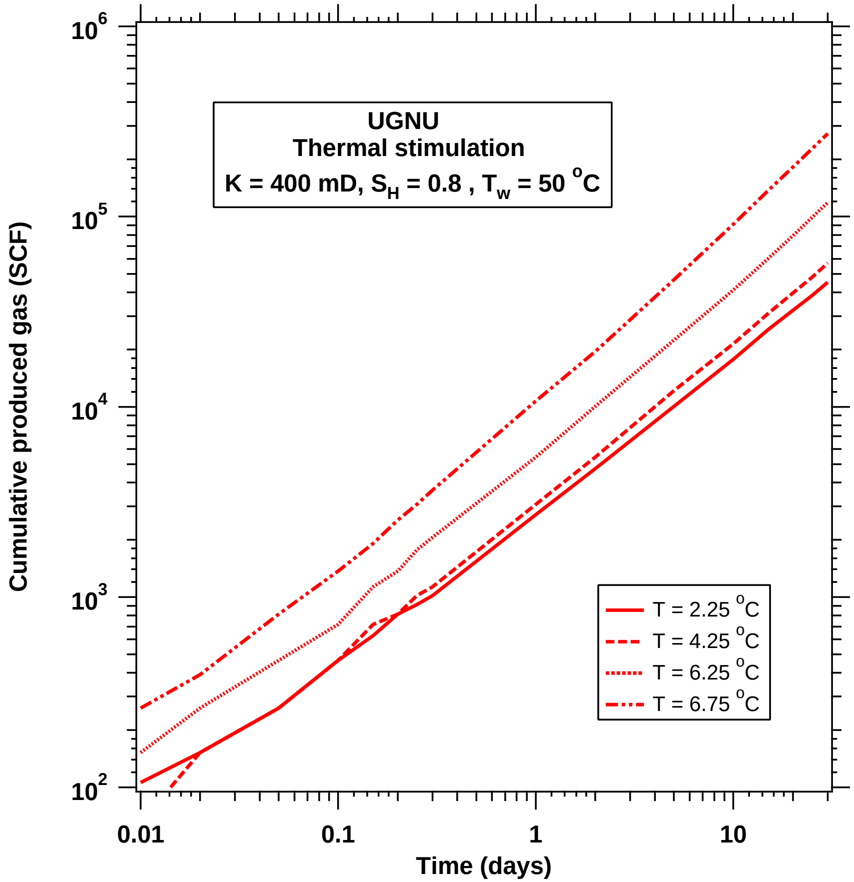
- **Hydrate temperature**
- **Thermal conductivity**
- **Well pressure and temperature (combined depressurization and thermal stimulation)**
- **Heat addition method**
- **Hydrate saturation**

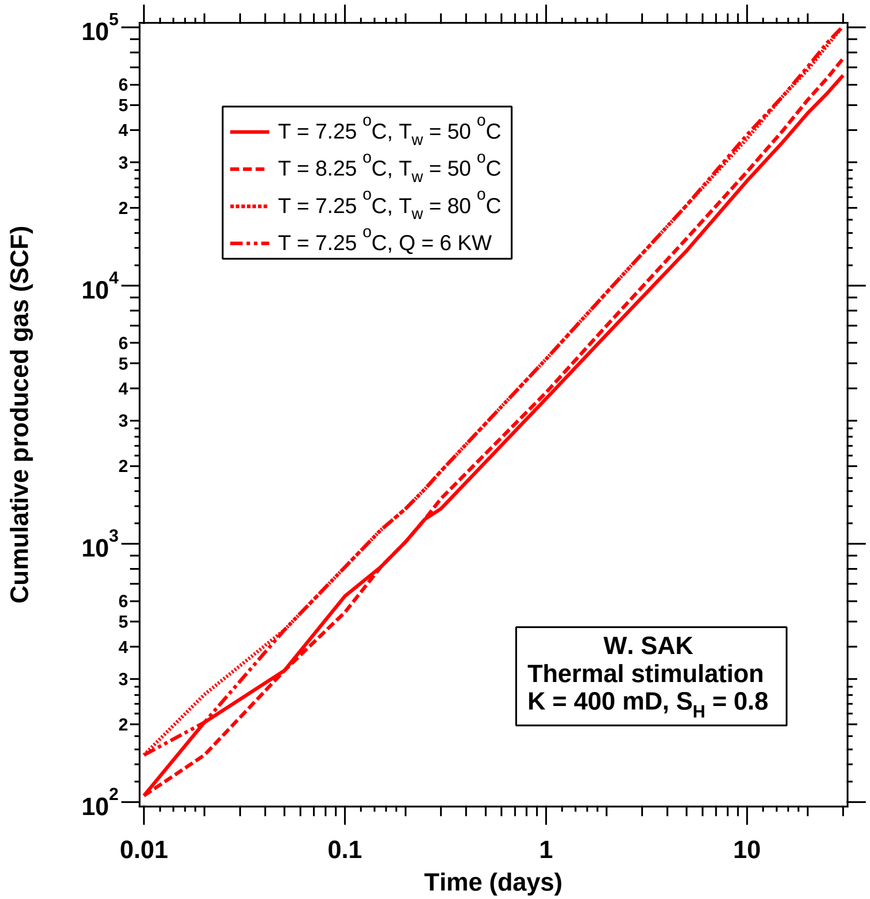
Gas production is not sensitive to:

- **Hydrate specific heat**
- **Formation permeability**

Production From Class 3 Hydrates

North Slope Accumulations

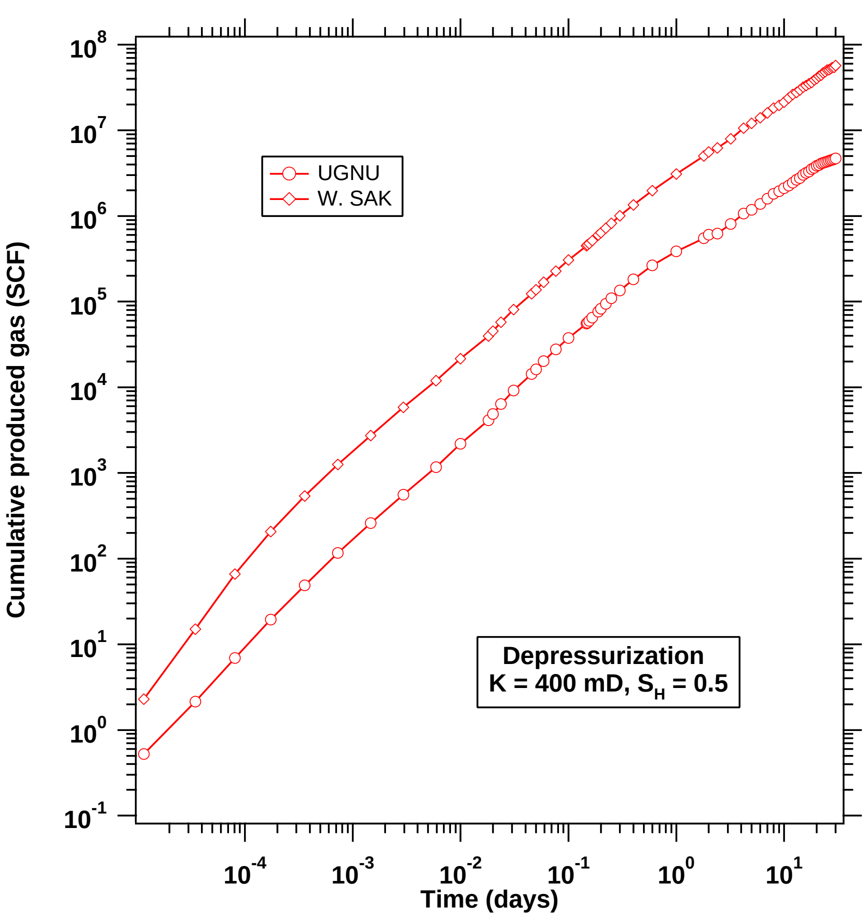


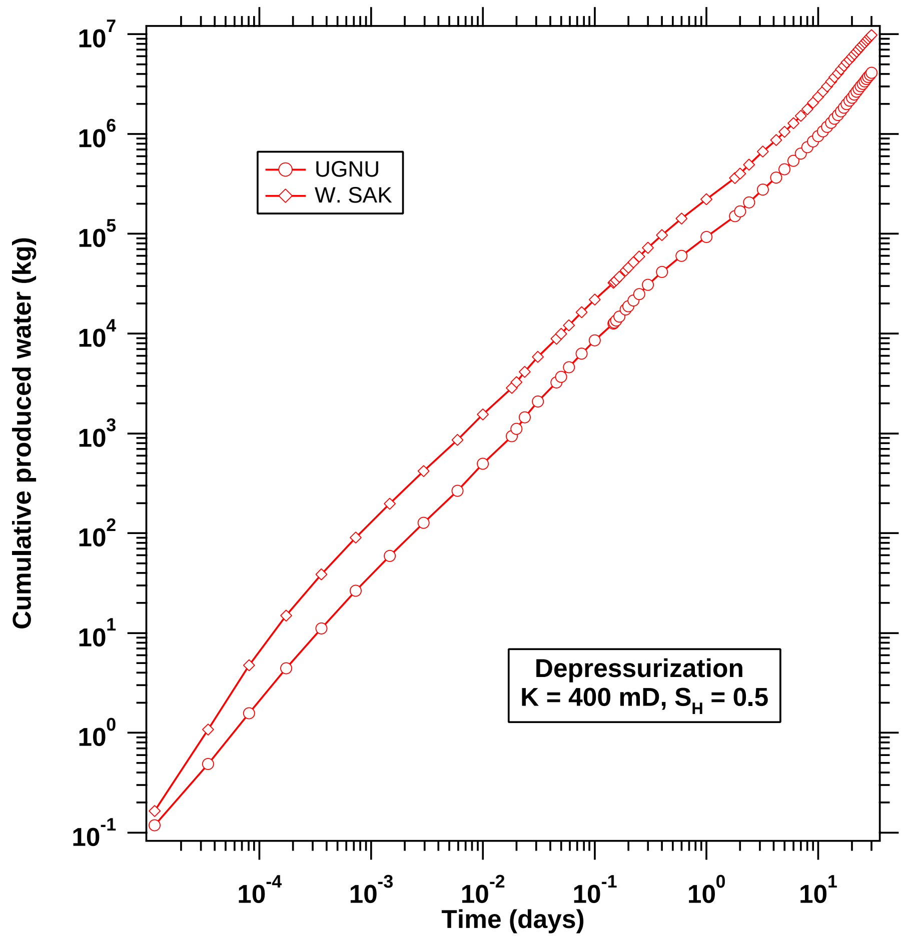


Thermal stimulation: Q increases with T, T_w

Production From Class 3 Hydrates

North Slope Accumulations





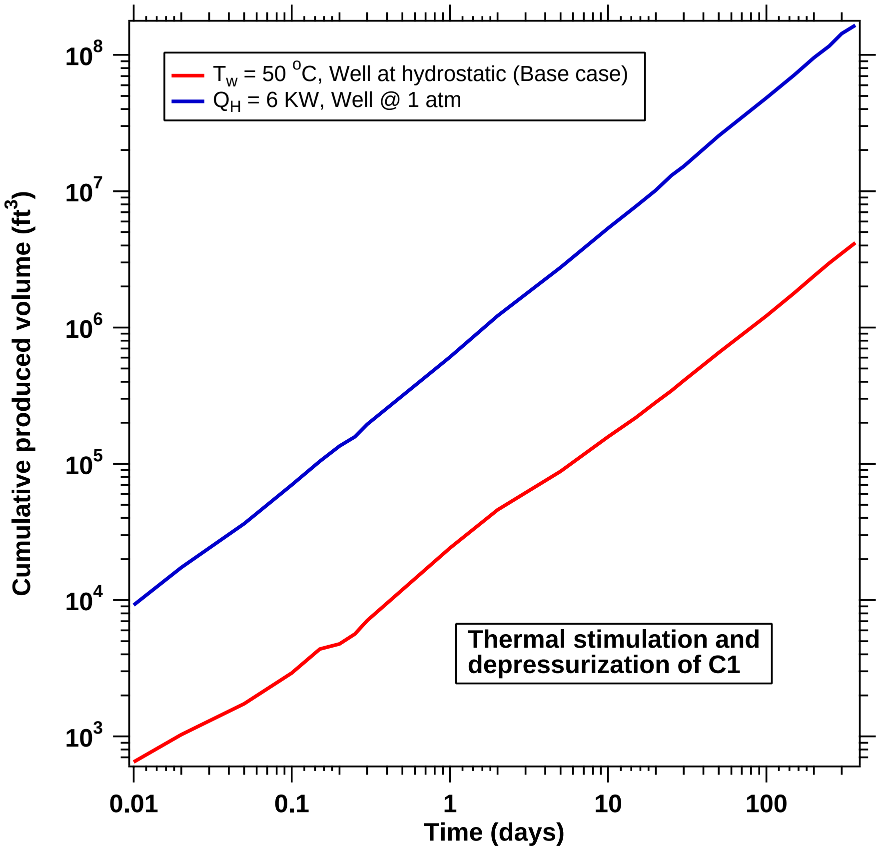
Single well depressurization - Importance of T

Production From Class 3 Hydrates

Eileen Area Accumulation

Unit C

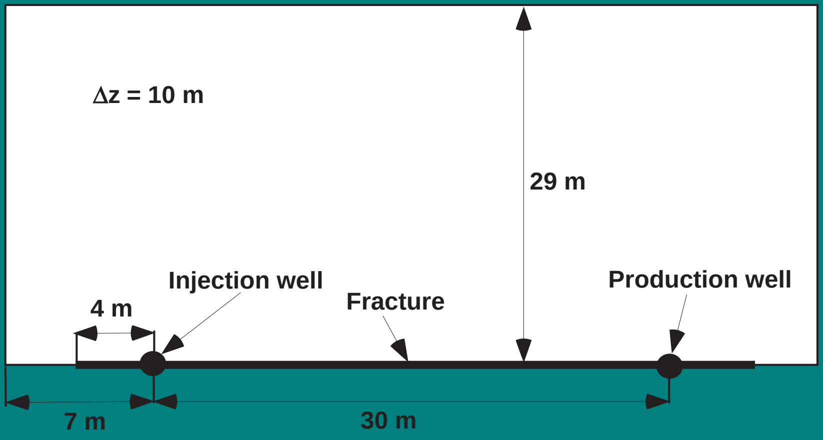
- ❑ **DEPRESSURIZATION + THERMAL STIMULATION**
- ➢ **Single vertical well**
- ➢ **Well kept at hydrostatic pressure and T_w = 50 ºC or at atmospheric pressure**
- ➢ **Well completed in the 17.2 m of C1**

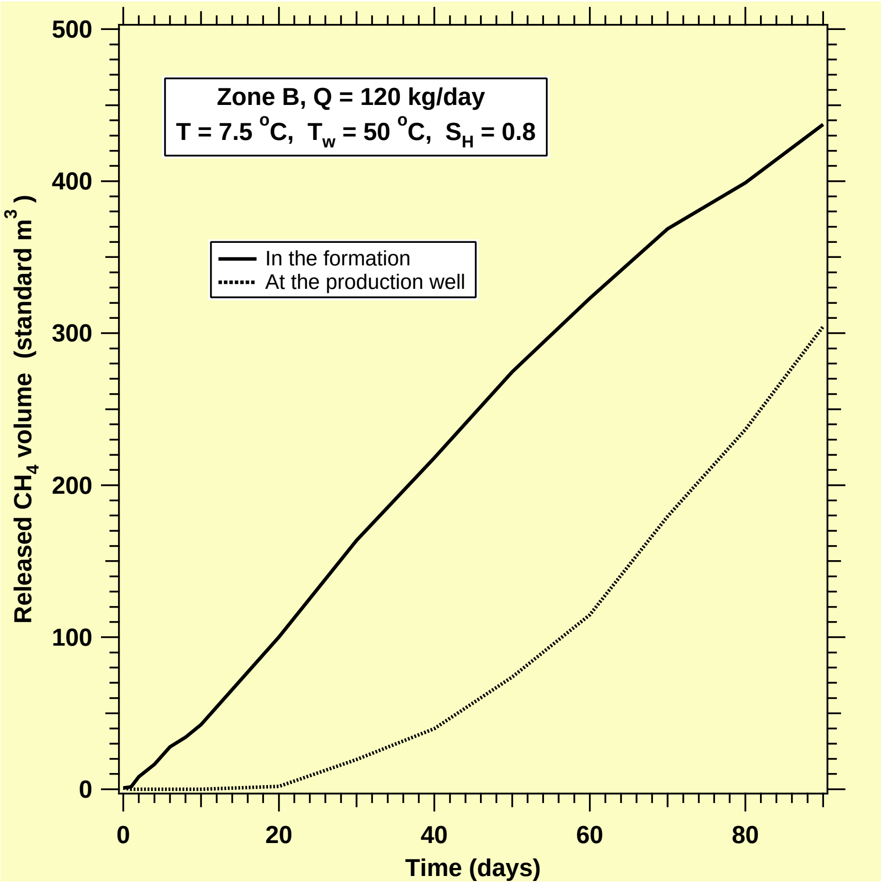


Production From Class 3 Hydrates

Mallik Area Accumulation

- ♦Depressurization + thermal dissociation
- ♦ Same approach as in Zone A
- ♦Two wells (injection, production) connected by fracture
- ♦ Low injection rates



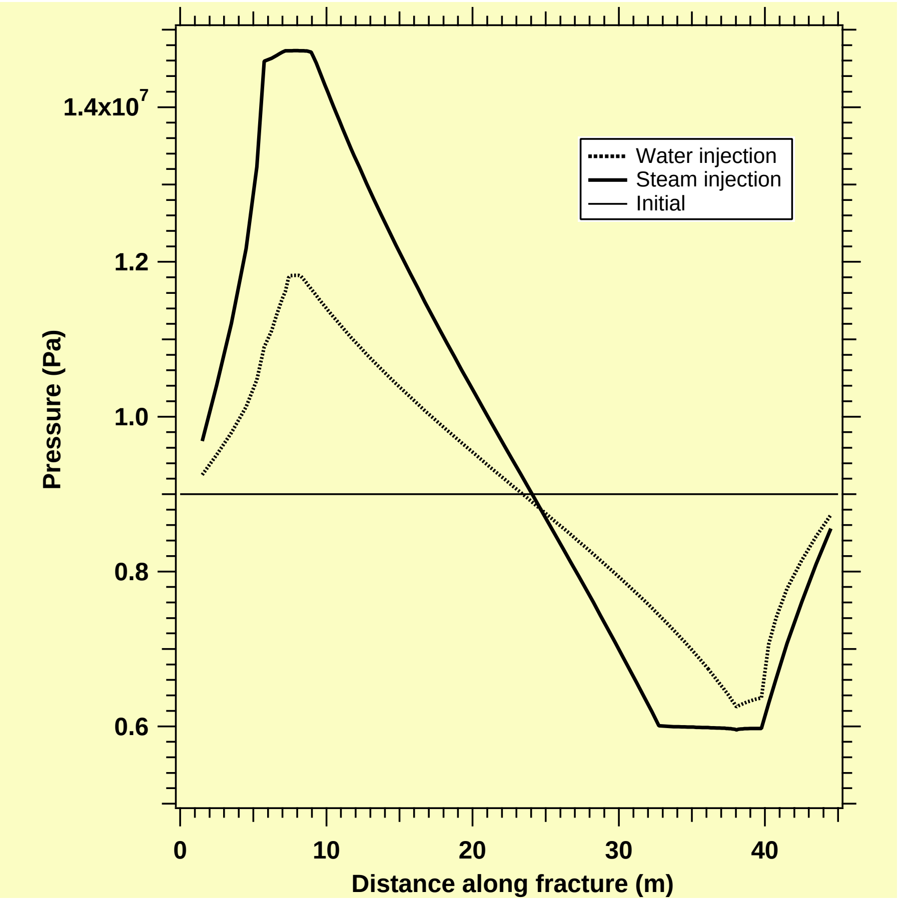


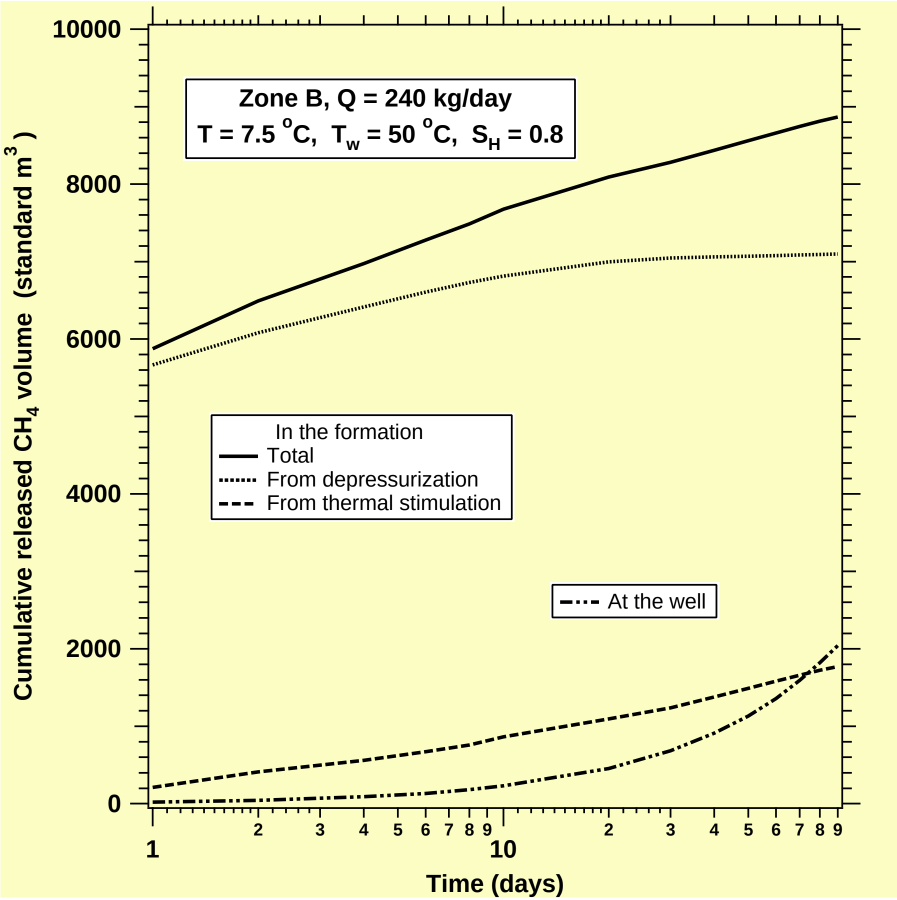
Water Injection: Slow gas release - no depressurization-generated gas

Production From Class 3 Hydrates

Mallik Area Accumulation

Steam Injection: Far more promising





Strategy: Highest possible specific enthalpy, highest possible Q, avoid fracturing bounding formations

CONCLUSIONS & DISCUSSION

Strategies for gas production from hydrate accumulations

- Depressurization appears to be the primary production method across hydrate classes.
- Thermal stimulation is a very promising production strategy only when used in conjunction with depressurization, and its potential increases from Class 1 to Class 3.
- Initial formation temperature is probably the most important factor affecting production in all classes. Thus, deeper deposits are more desirable targets in all classes.
- For commercial gas production, Class 1 hydrate accumulations appear to be the primary initial targets.
- In Class 1 accumulations, depressurization appears to be an effective gas production method from hydrates.
- In Class 2 accumulations, the most promising strategy involves combination of depressurization and thermal stimulation, and is enhanced by multi-well systems.
- In Class 3 deposits, combinations of depressurization and thermal stimulation and combinations thereof appear promising.
- These observations should be viewed as general principles because extreme variability, case-specificity and a limited knowledge base.

CONCLUSIONS & DISCUSSION (cont.)

CAUTION IS RECOMMENDED

- Results should not be viewed as definitive predictive answers
- The focus is the determination of relative importance of processes involved in dissociation (sensitivity analysis), not the absolute system response

EOSHYDR2 STATUS

- EOSHYDR2 incorporates state-of-the-art relationships describing processes and phenomena in hydrate environments.
- It is not known whether these relationships and the corresponding parameter values are accurate under realistic field conditions.
- There are important knowledge gaps.
- The importance of code validation using field and laboratory data cannot be overemphasized

➢Validation: focus of the current LBNL effort

RELEVANCE OF AVAILABLE INFORMATION: The 800-lb gorilla

- ◆ Practically all currently available information has been derived from laboratory studies
- It is not known if the synthetic hydrates used in the laboratory studies are representative of hydrates in natural accumulations
- NO representative sample of a natural (undisturbed) gas hydrate has been obtained to-date

Challenges & Knowledge Gaps in the Simulation of Gas Production from Methane Hydrates

- **Process type**
  - Equilibrium vs. kinetic dissociation
- **Kinetic parameters**
  - Parameter values and T-dependence
- **Hysteretic behavior**
  - Differences between heating (dissociation) and cooling (formation) P-T curves - dramatic effect on production under depressurization
  - Possible H-T hysteresis (?)
- **Methane dissolution near the hydration point**
- **Water, methane and hydrate properties in the vicinity of the hydration point**
- **Relative permeability**
  - Adequacy of the 3-phase Lenhard and Parker [1988] model
  - Dependence of k_r on conditions
- **Hydrate thermal properties**
  - Hydrate thermal conductivity and T-dependence
  - Adequacy of the Bejan [1982] parallel model
  - Anomalous thermal behavior of hydrates [USGS, 2001]
- **Hydrate property and behavior dependence on the hydration number**
  - Possibly responsible for the unpredictability in hydrate behavior