

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

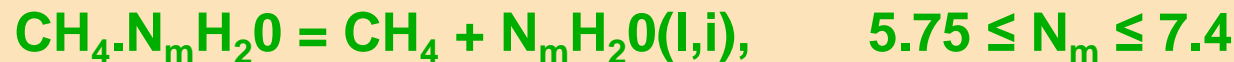
- **Classification of natural hydrate accumulations**
- **Production from hydrate Classes 1 through 3**
 - **Geological implications for production strategies**
 - **Reservoir conditions**
 - **Sensitivity analysis**
- **Identification of knowledge gaps**

The EOSHYDR2 Module of TOUGH2

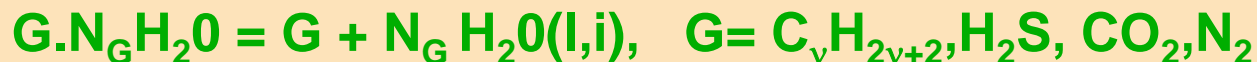


- TOUGH2 [*Pruess, 1991; Pruess et al., 1999*]:
General-purpose multiphase, multicomponent model for simulation of fluid and heat flow and transport in porous and fractured media
- EOSHYDR2: Module for non-isothermal hydrate dissociation/formation, CH₄ flow, and phase behavior [*Moridis et al., 1998; 2002*]

Methane hydrates



Second-gas hydrates



Binary hydrates



1. Components

- (1) H₂O
 - (2) CH₄(native gas)
 - (3) CH₄(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
H₂O, CH₄(n), CH₄(d), G (n), G (d), S, I

(2) Gas
CH₄(n), CH₄(d), G (n), G (d), H₂O, I

(3) Solid-Hydrate
 $\chi_m[\text{CH}_4 \cdot N_m \text{H}_2\text{O}] \chi_G [\text{G} \cdot N_v \text{H}_2\text{O}]$

(4) Solid-Ice
H₂O

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

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



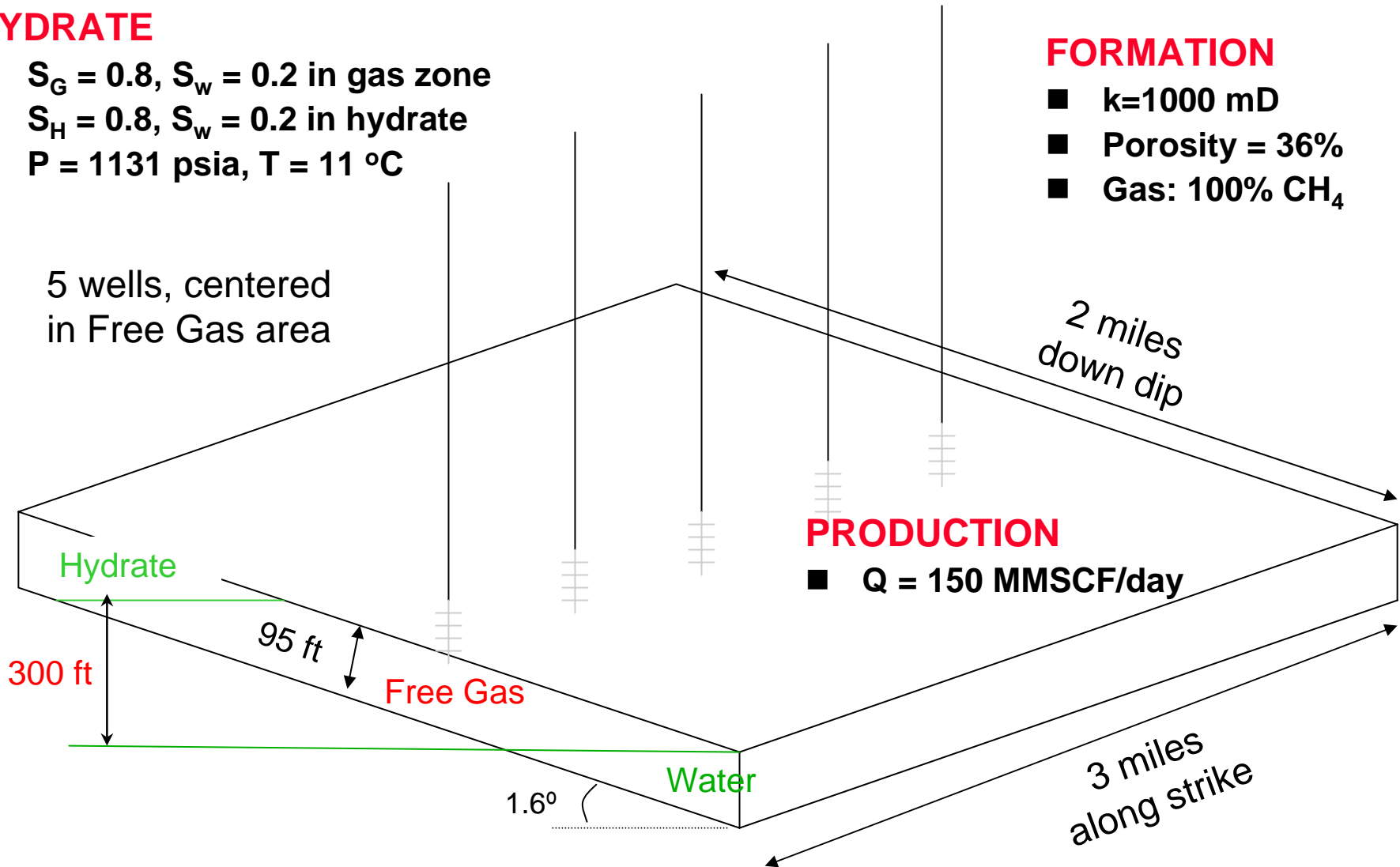
North Slope BP Accumulation - Depressurization

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, $T = 11$ °C

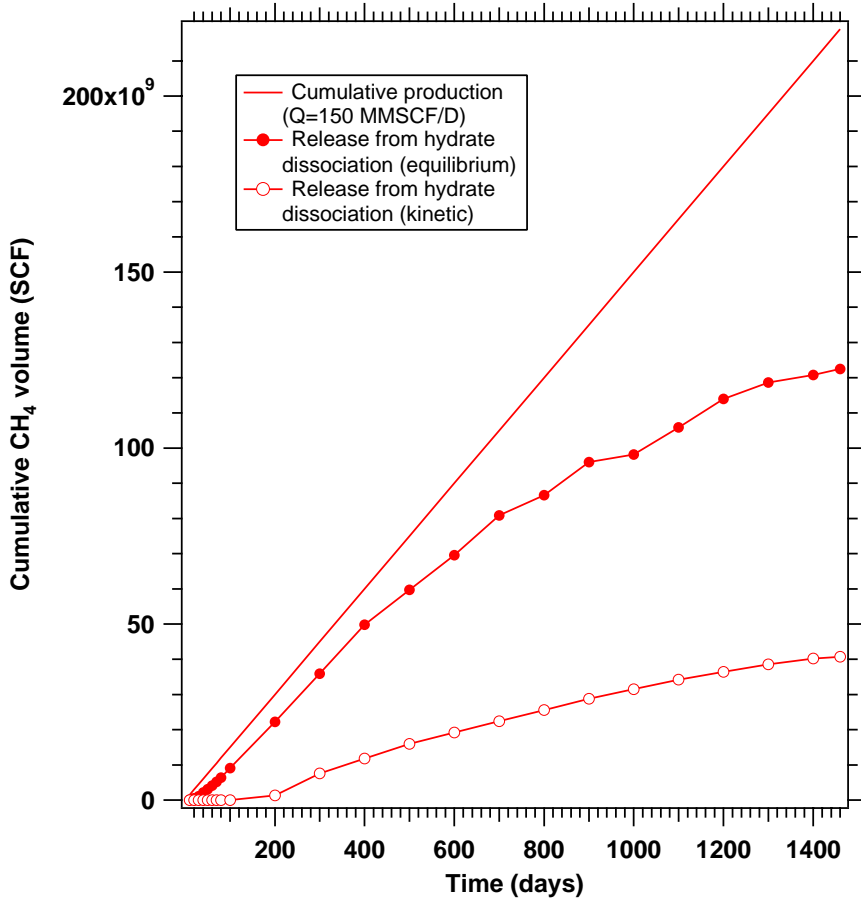
FORMATION

- $k=1000$ mD
- Porosity = 36%
- Gas: 100% CH₄

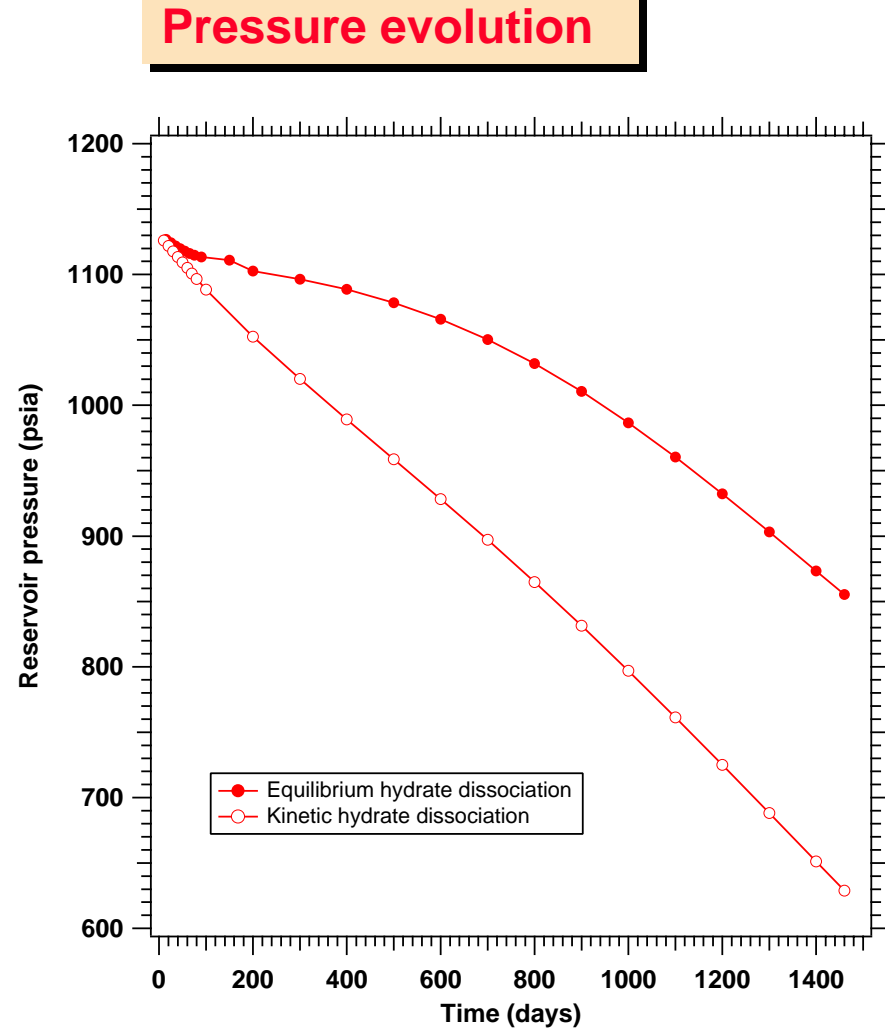


Production From Class 1 Hydrates

North Slope BP Accumulation - Depressurization

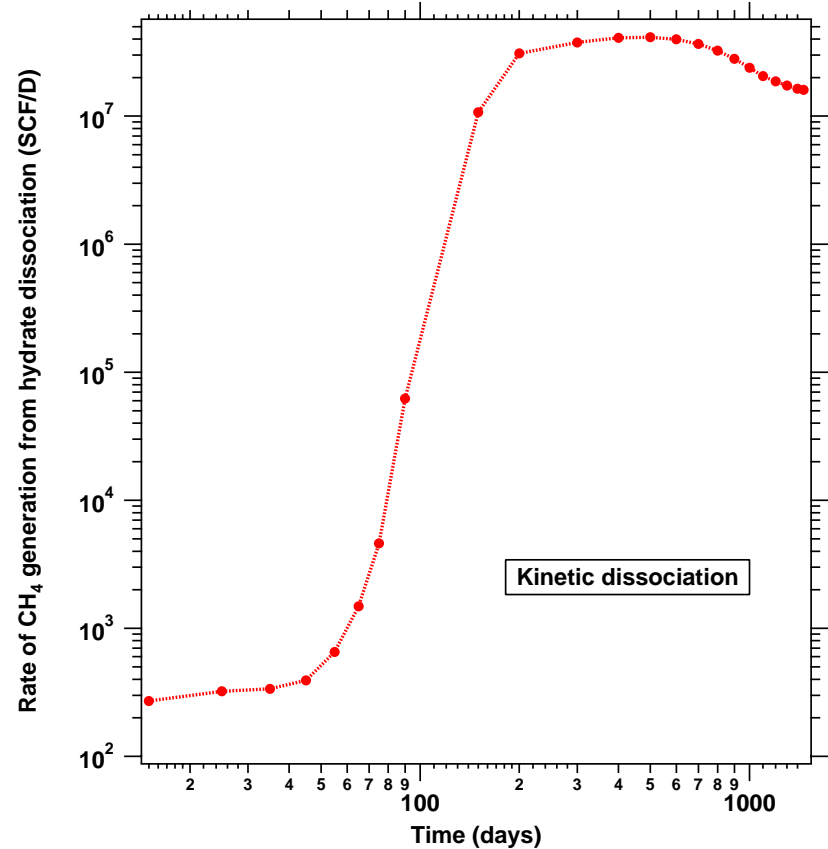
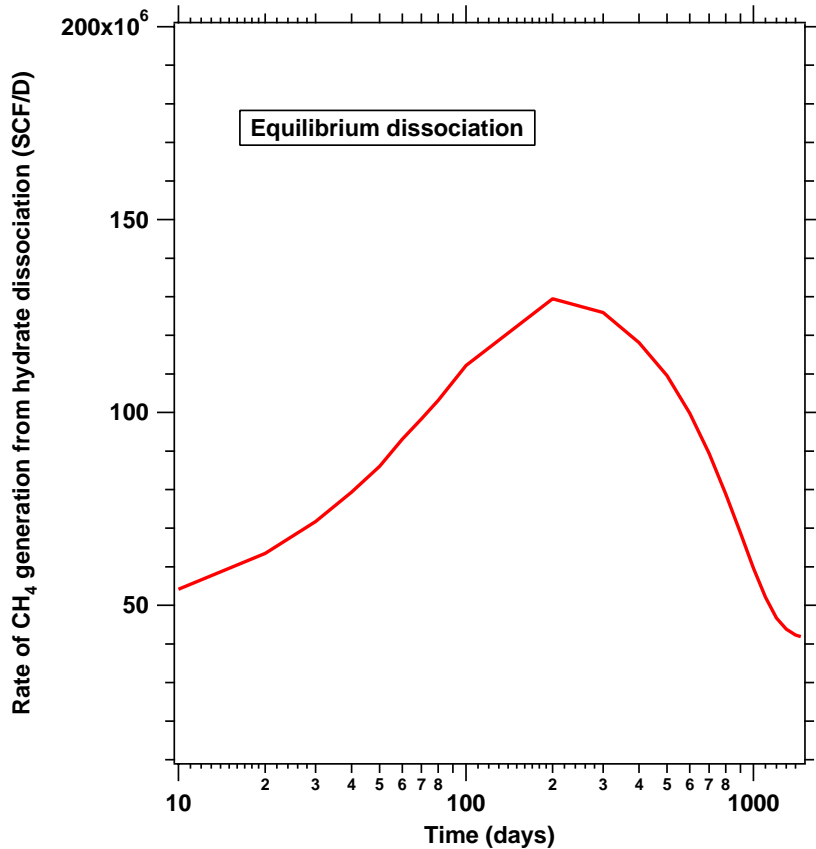


Cumulative CH₄ release



Production From Class 1 Hydrates

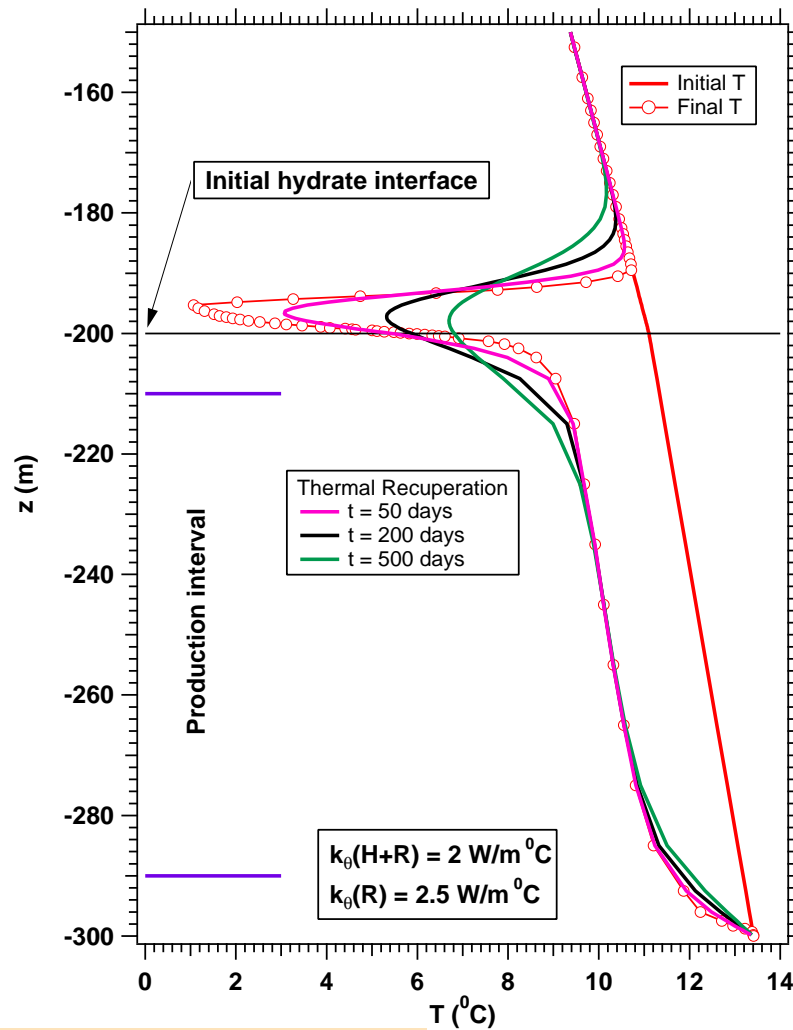
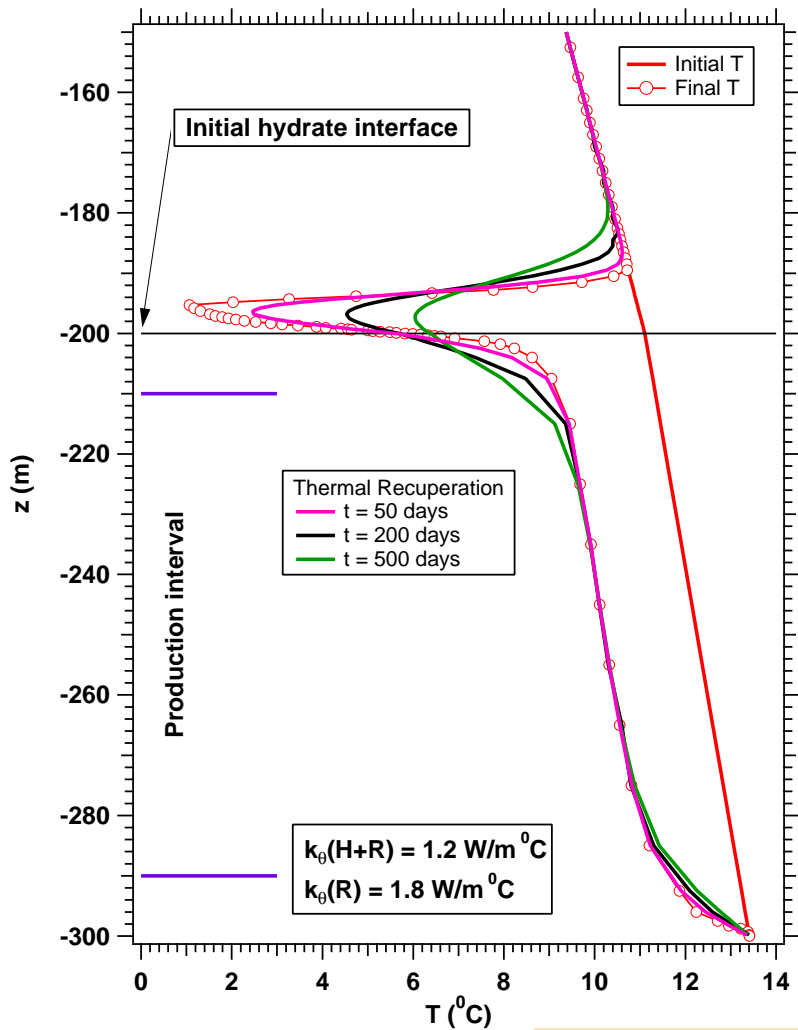
North Slope BP Accumulation



Rate of CH₄ 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

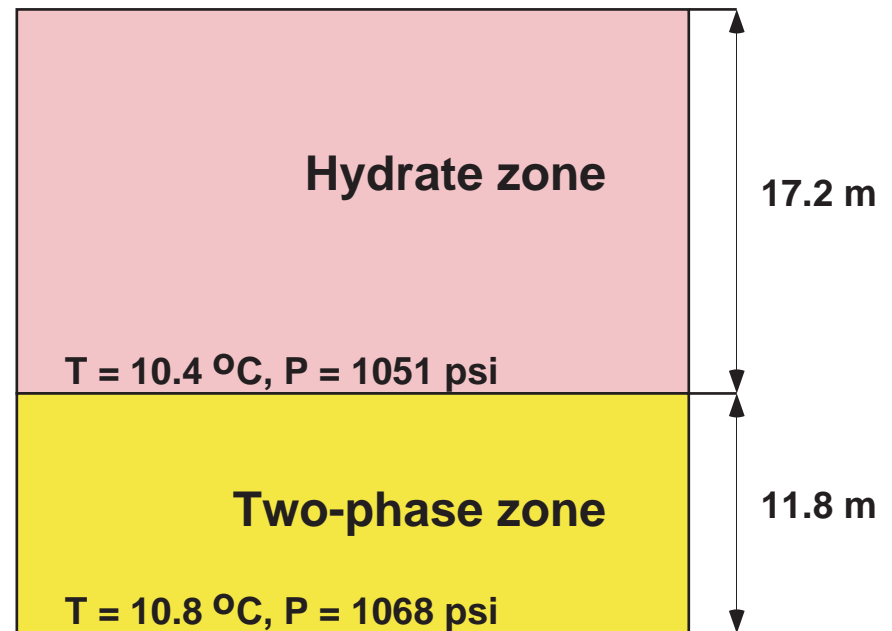
- Single vertical well
- Maximum pressure differential: well kept at atmospheric pressure
- Well completed in the top 1.85 m (6 ft) of C2

□ DEPRESSURIZATION + THERMAL STIMULATION

- Multi-well systems (e.g., five-spot pattern)

GAS HYDRATE ACCUMULATION

UNIT C, EILEEN AREA, ALASKA



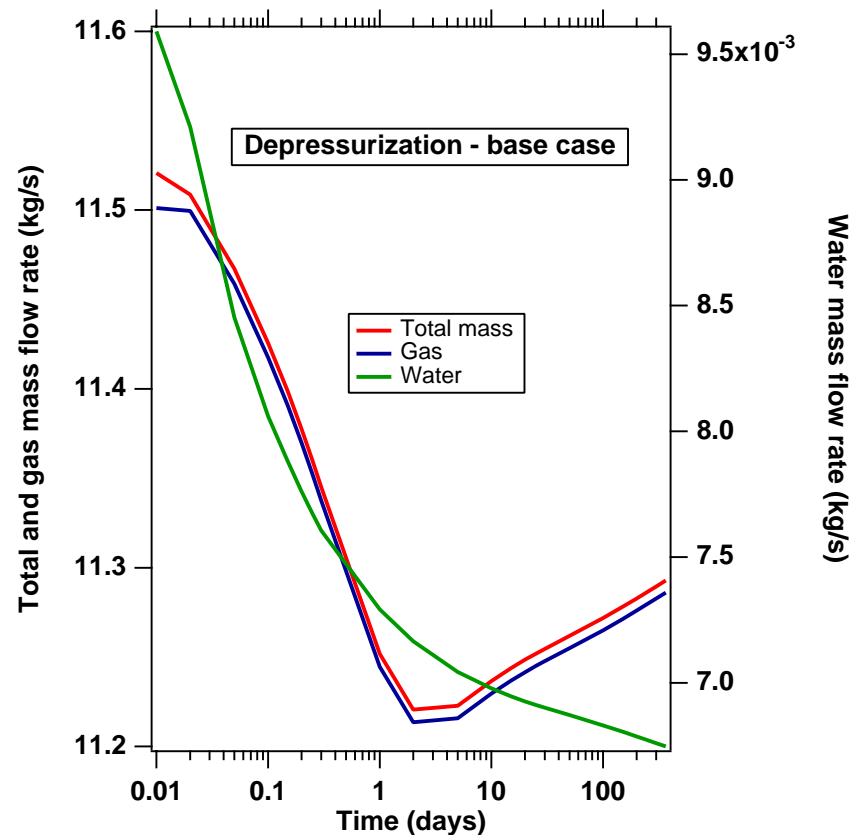
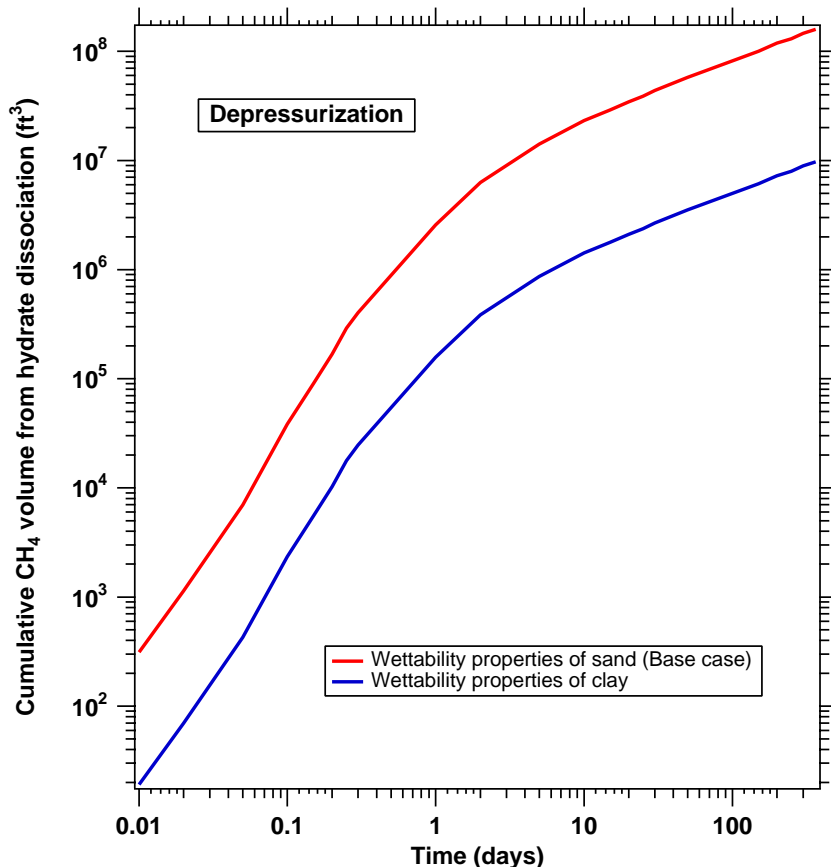
Not to scale

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

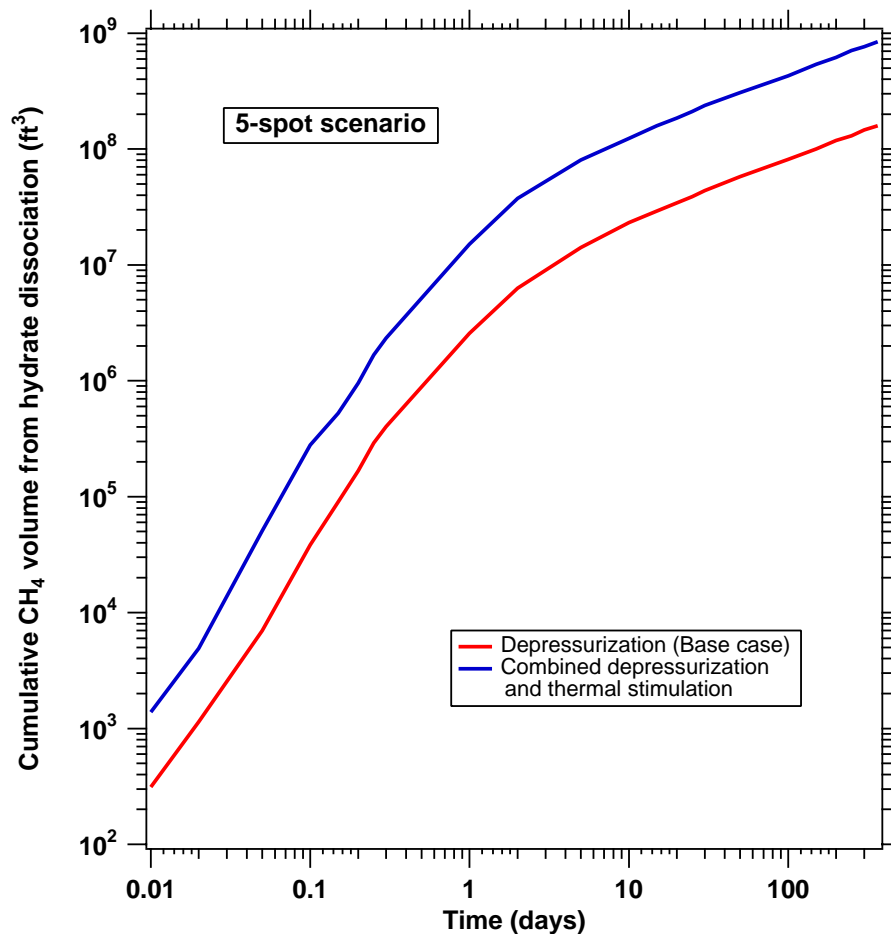
Eileen Area Accumulation



□ DEPRESSURIZATION + THERMAL STIMULATION

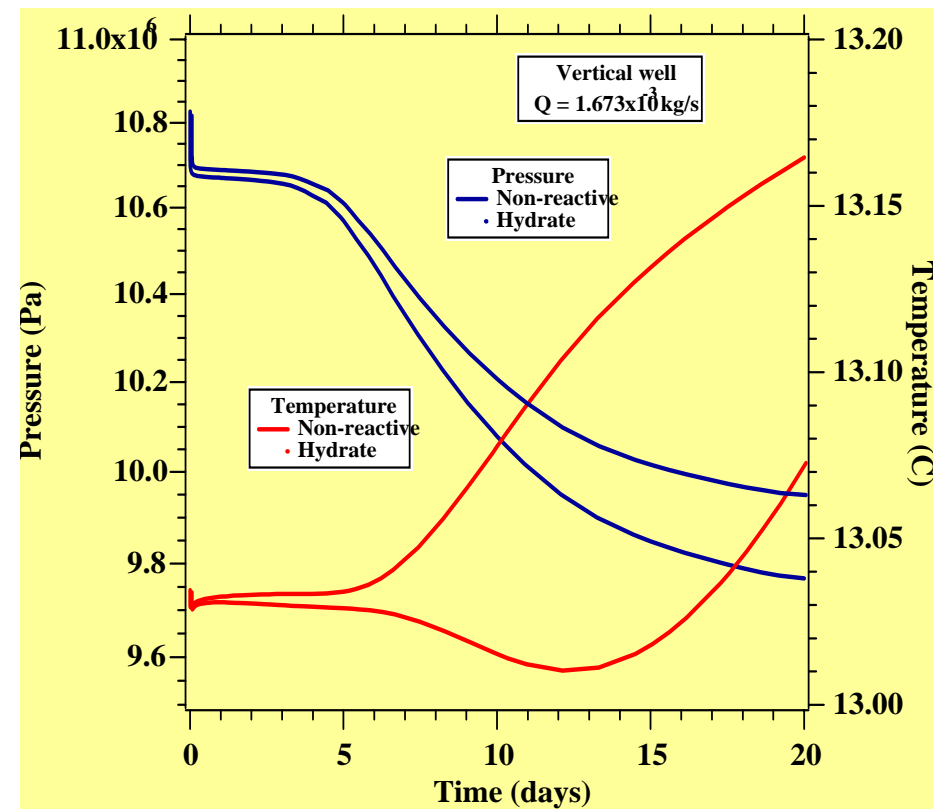
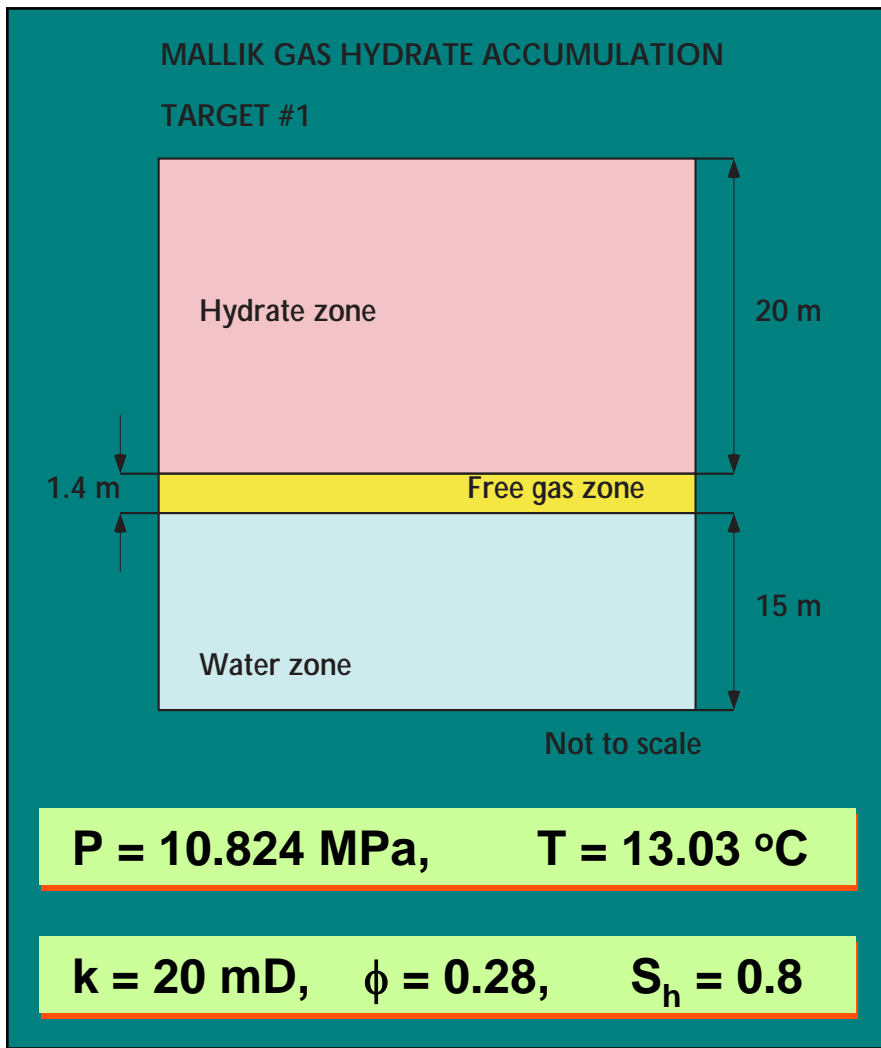
- Multi-well system (five-spot pattern)
- Wells completed in the top 1.85 m of C2
- Steam injection (3000 KJ/kg) at a rate of 1.85 kg/s
- Production well kept at atmospheric pressure

◆ The released CH₄ volume is about an order of magnitude larger than that from simple depressurization



Production From Class 1 Hydrates

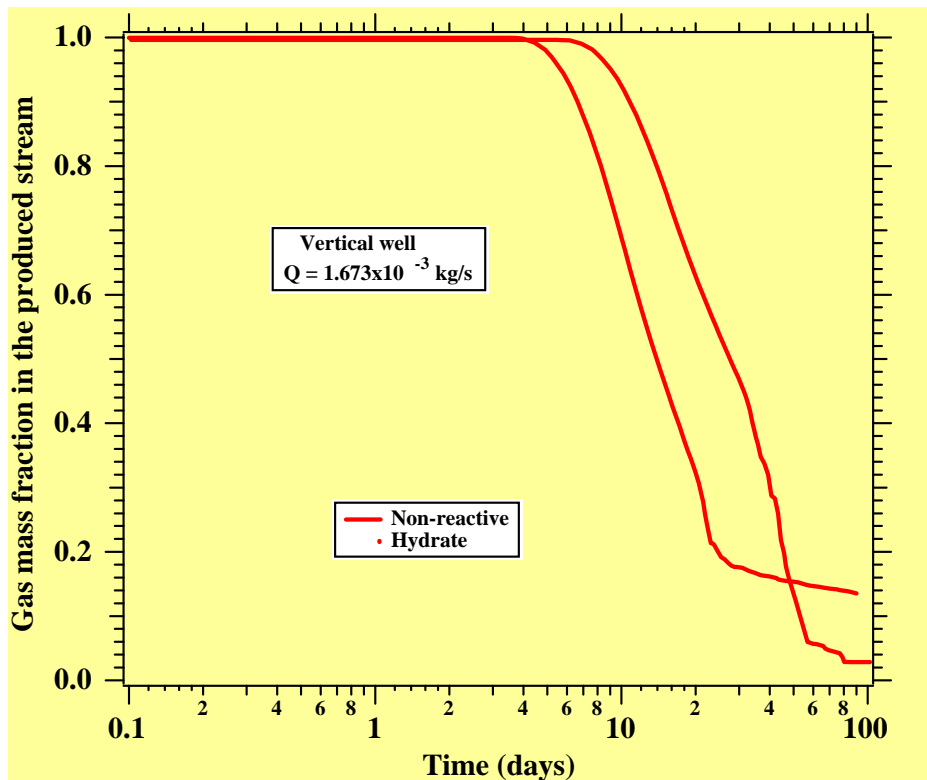
Mallik Area Accumulation



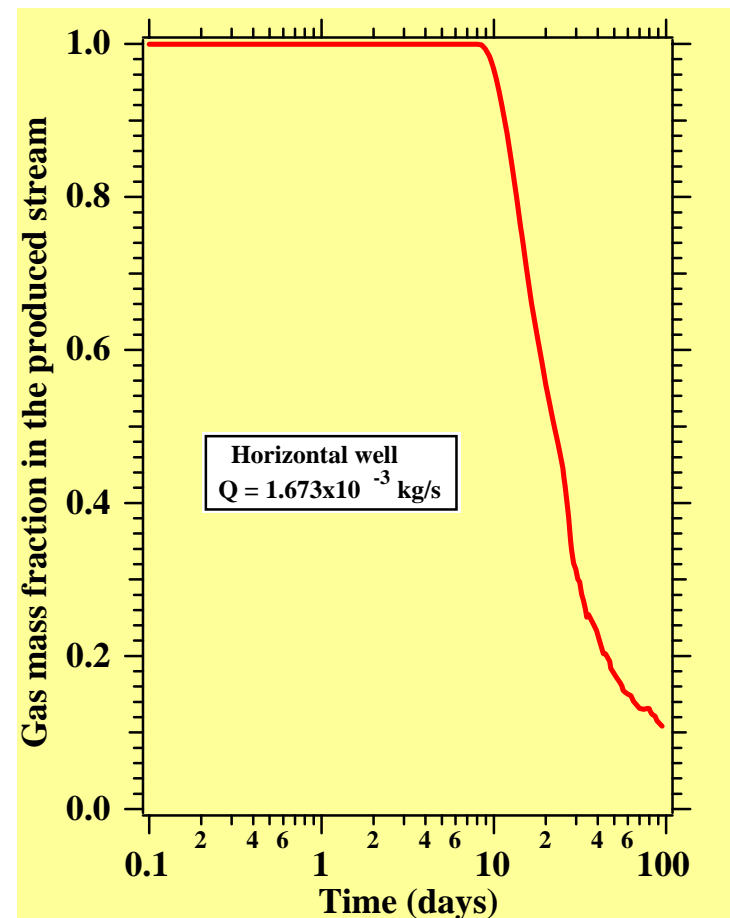
Discernible differences in pressure and temperature performance between dissociating and non-dissociating scenarios

Production From Class 1 Hydrates

Mallik Area Accumulation



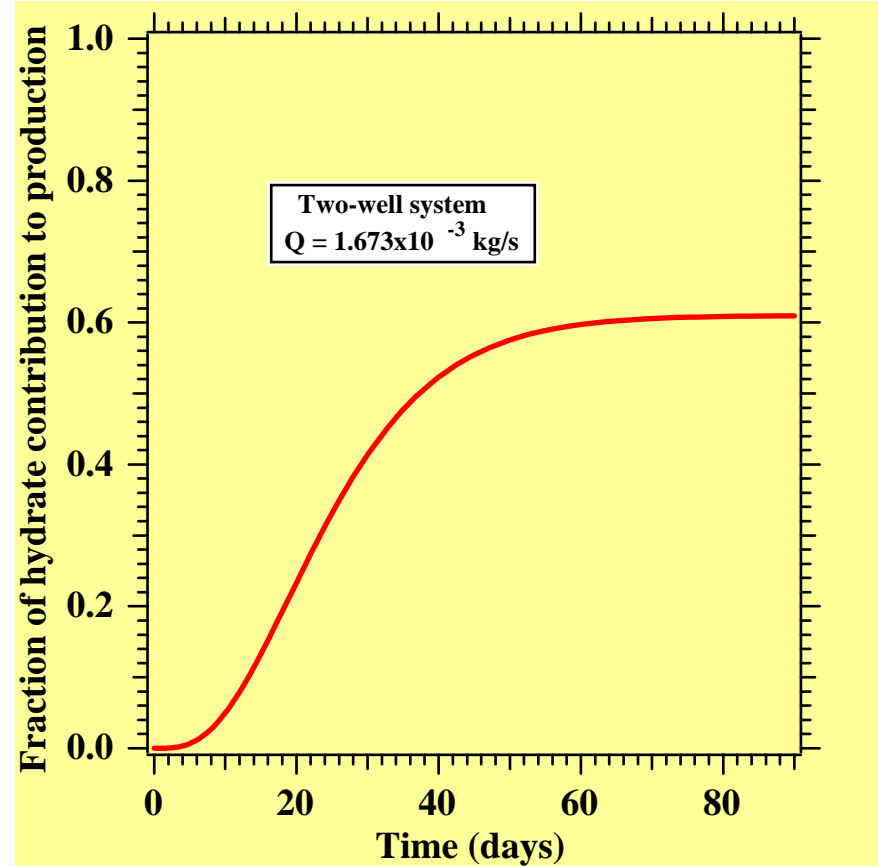
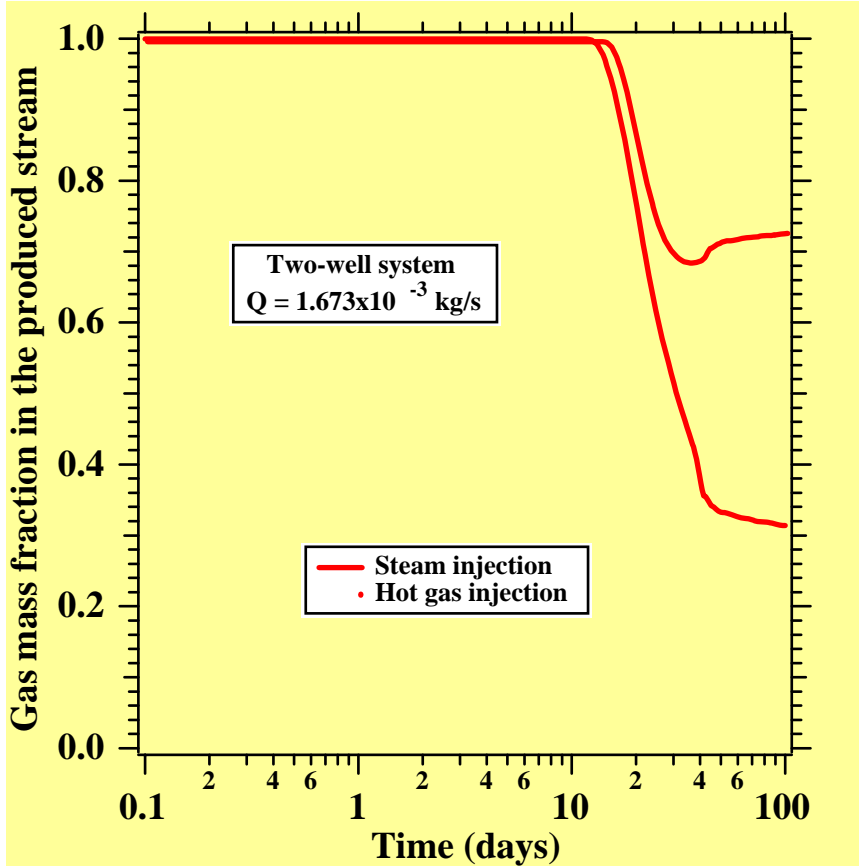
Discernible differences in gas mass fraction performance between dissociating and non-dissociating scenarios



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

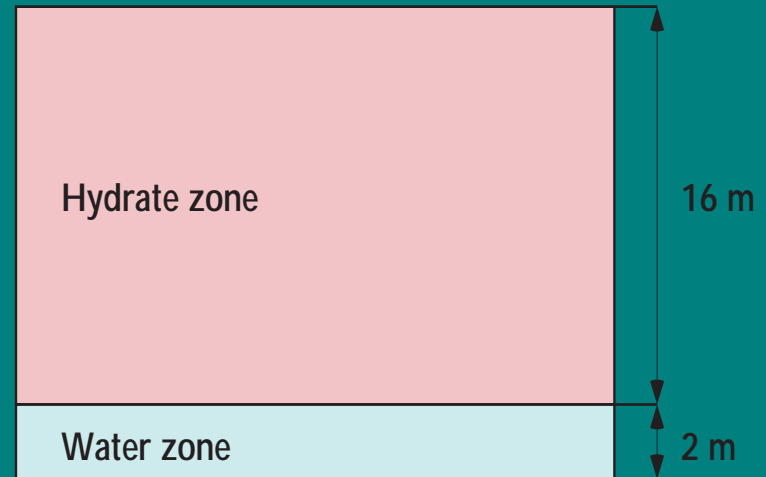
- The source of the gas is known to be the hydrate deposit
- Depressurization more efficient because of the incompressibility of water
- Cooling effects less significant

■ But

- Possible gas permeability issues
- Environmental concerns

MALLIK GAS HYDRATE ACCUMULATION

TARGET #2



Not to scale

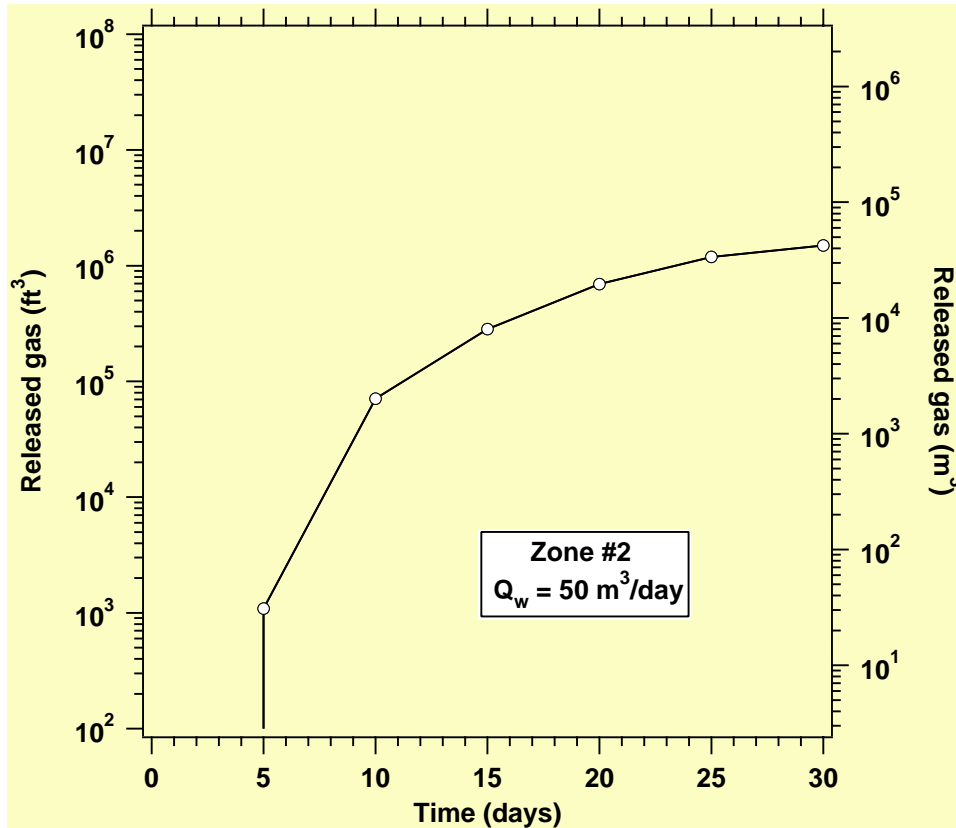
$P = 9 \text{ MPa,}$

$T = 7.5 \text{ }^\circ\text{C}$

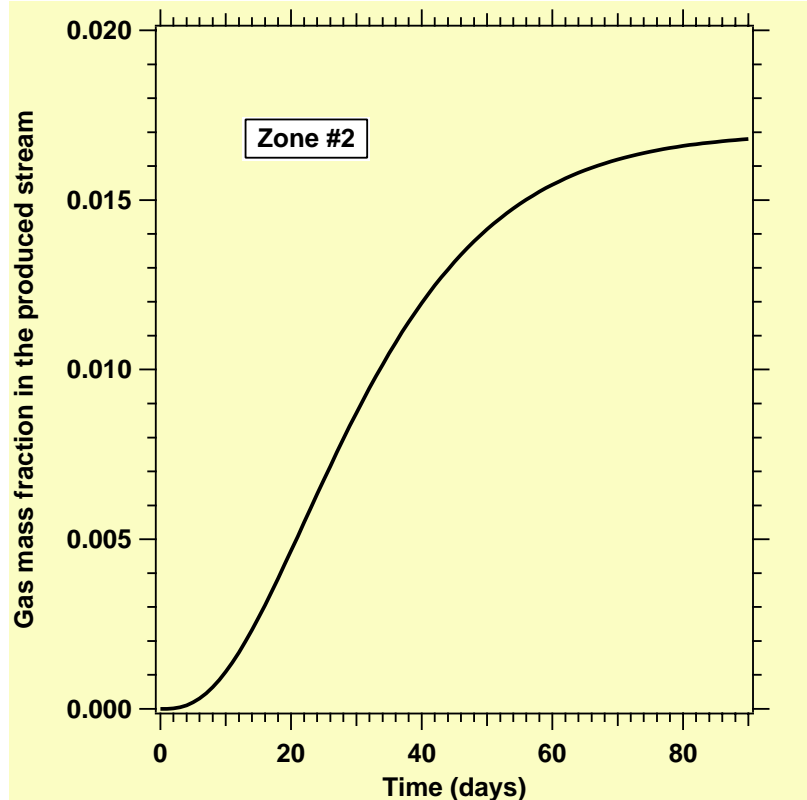
$k = 20 \text{ mD, } \phi = 0.28, S_h = 0.8$

Production From Class 2 Hydrates

Mallik Area Accumulation



Depressurization - single well



- Feasible, but
- Large volumes of undesirable water

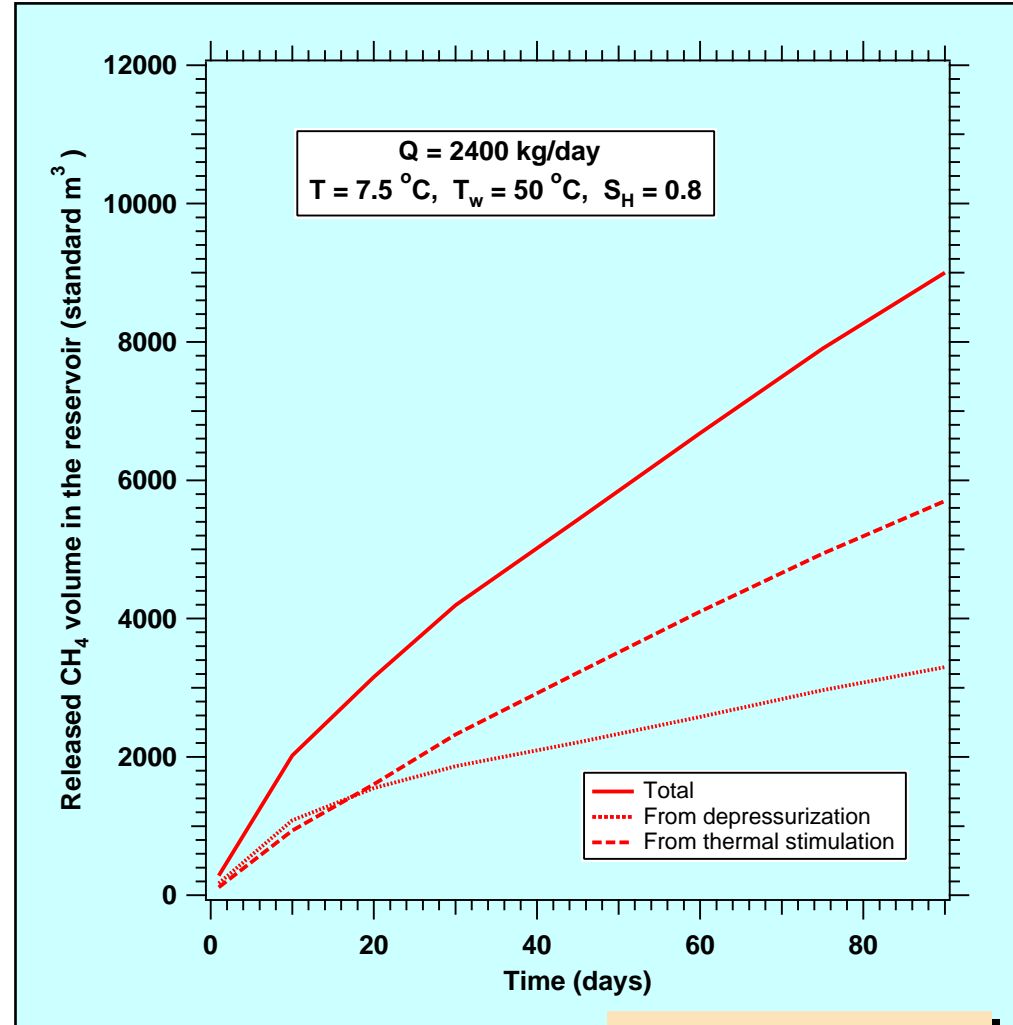
Production From Class 2 Hydrates

Mallik Area Accumulation



Approach

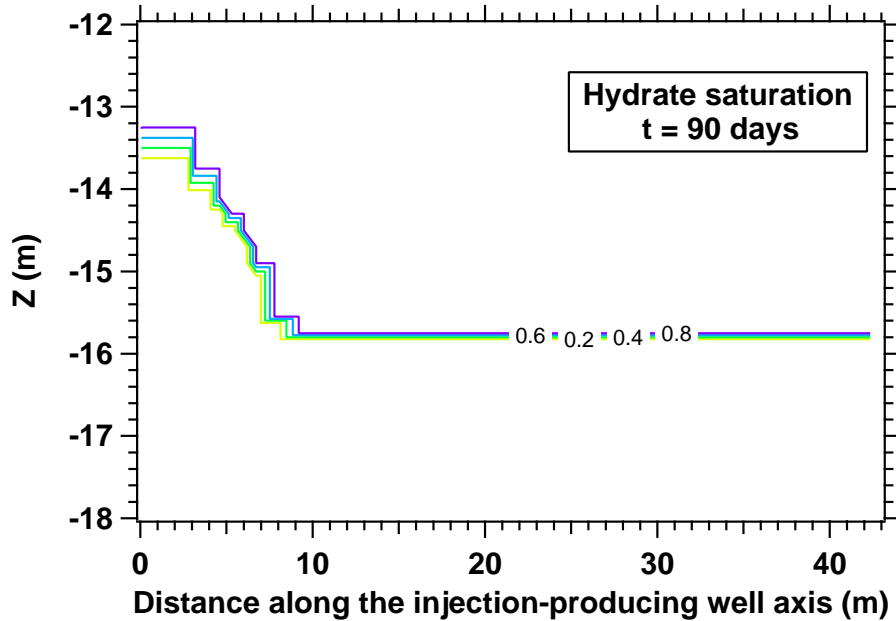
- Five-spot pattern (60m side)
- Hot water injection, fluid production
- Water recirculation (zero net water withdrawal)
- Combination of thermal stimulation and depressurization
- Well completions: top 1 m of the water zone, hydrate layer (production)
- Salinity: important, continuously diluted
- 70K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



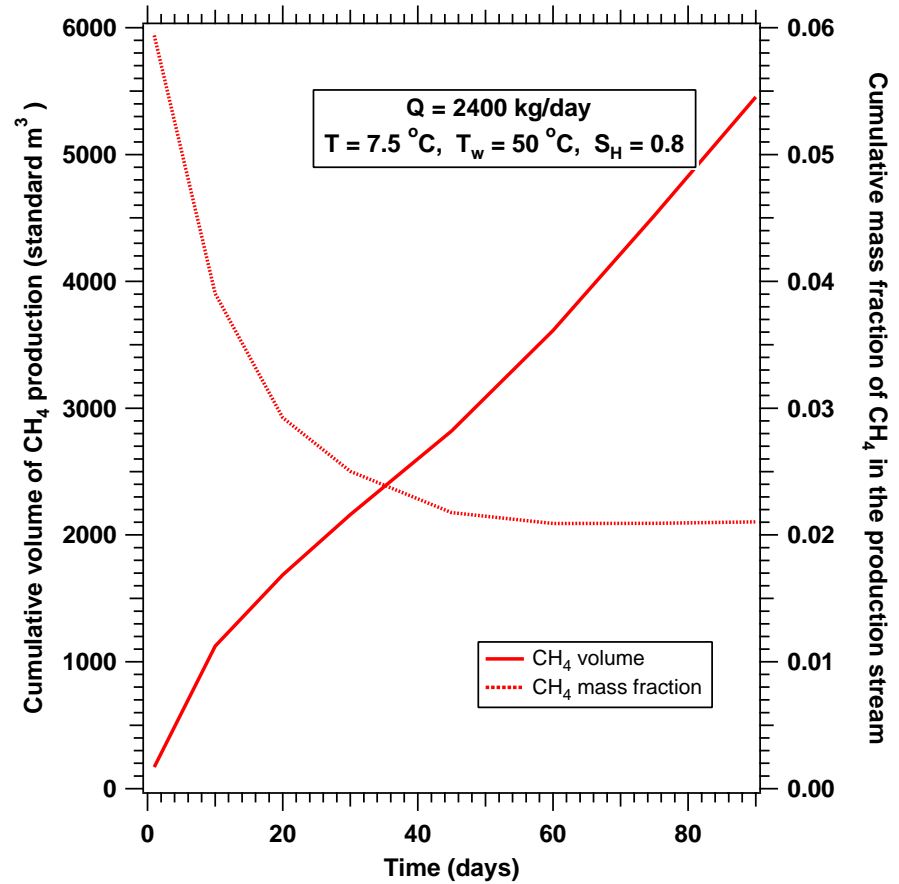
Base case

Production From Class 2 Hydrates

Mallik Area Accumulation



Base Case

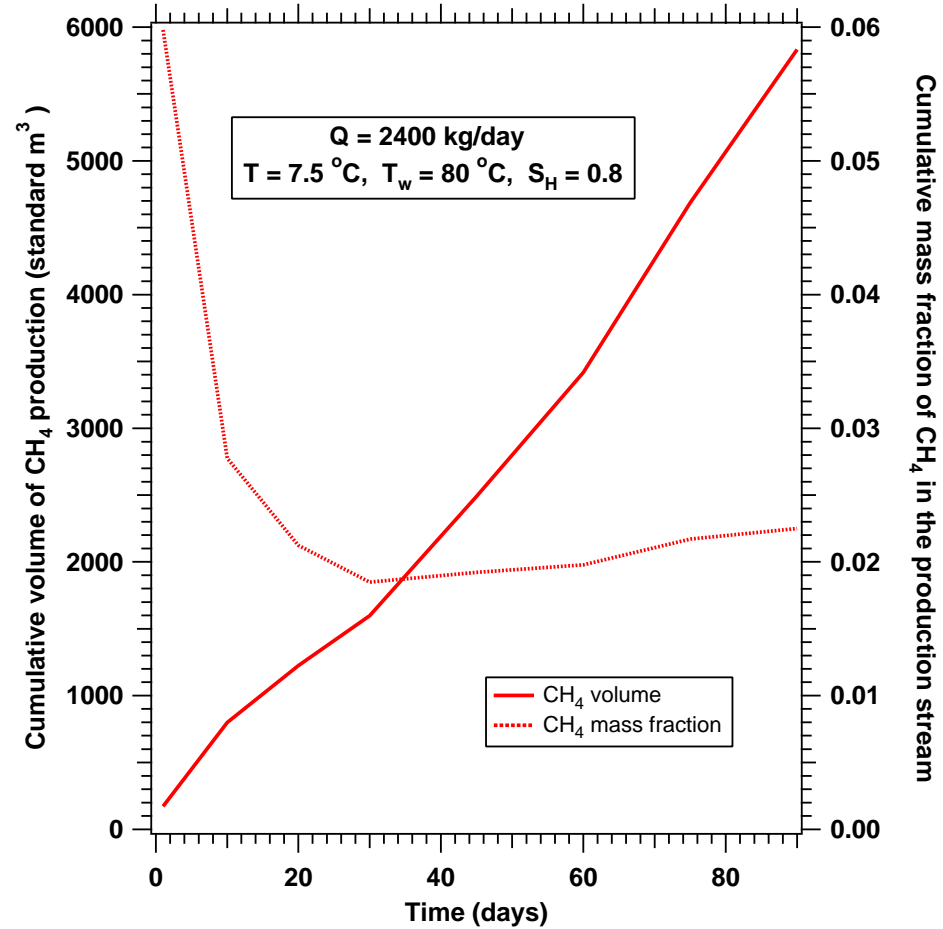
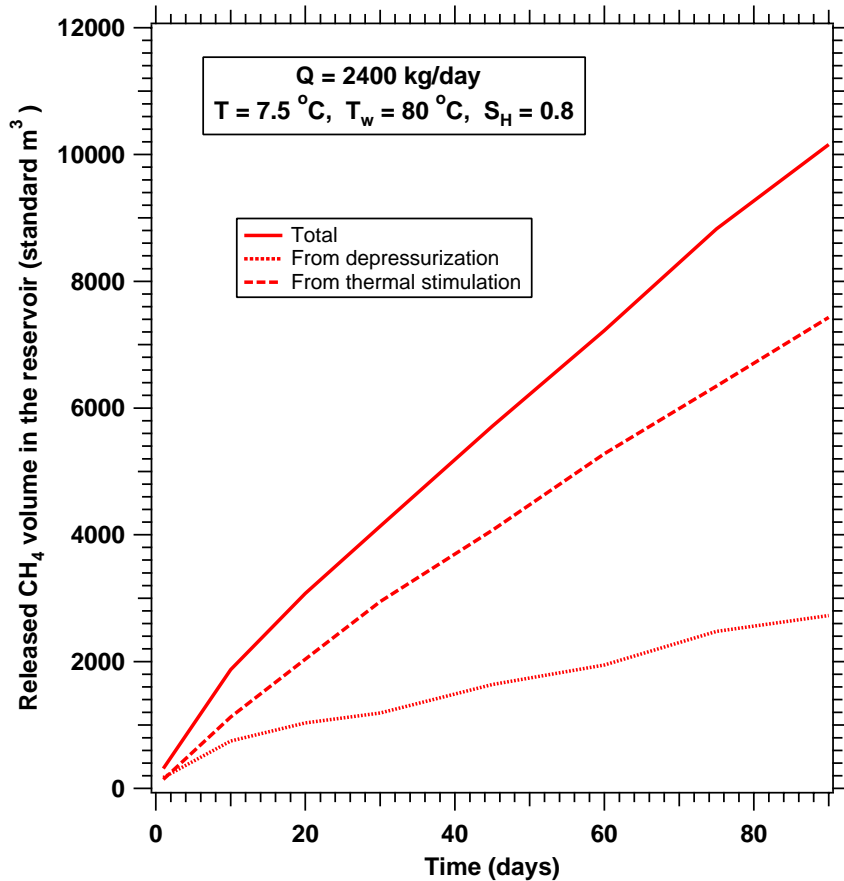


Production From Class 2 Hydrates

Mallik Area Accumulation



Effect of T_w

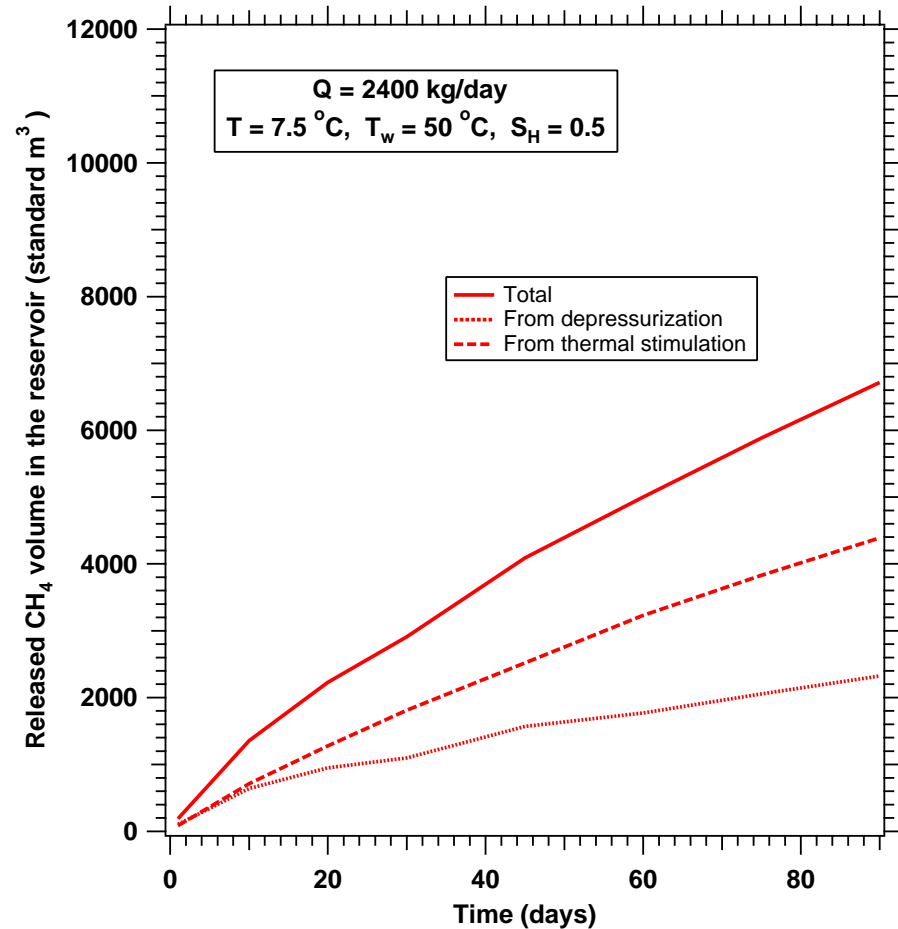
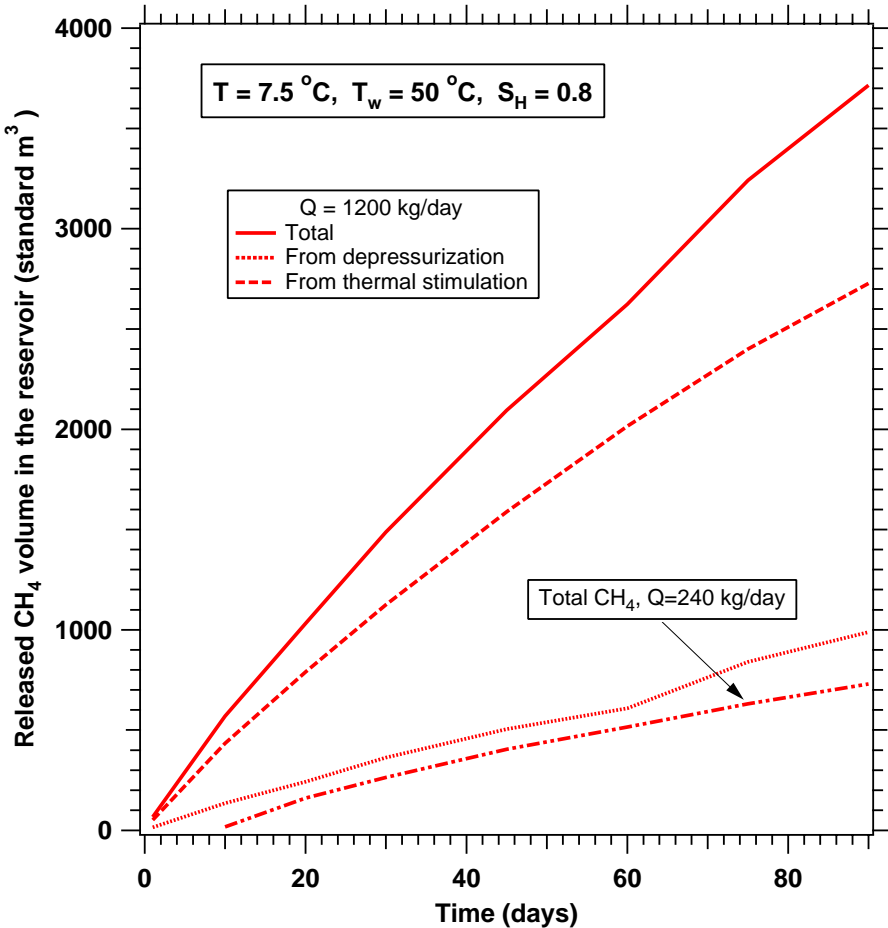


Production From Class 2 Hydrates

Mallik Area Accumulation



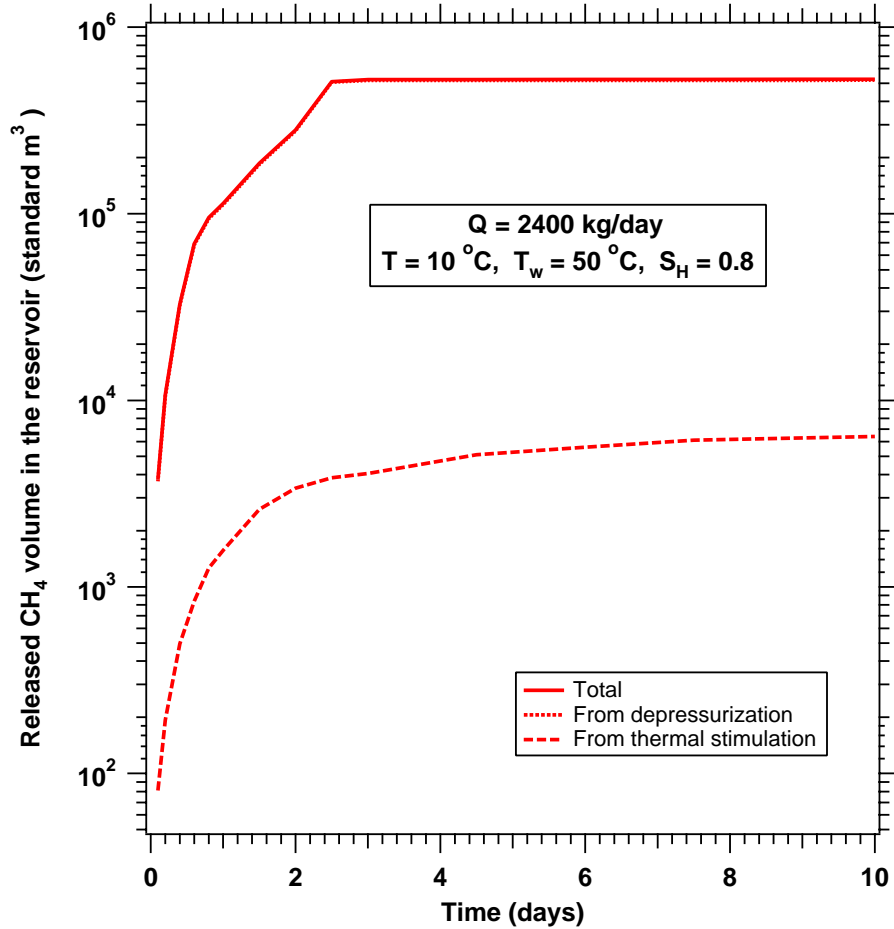
Effect of Q



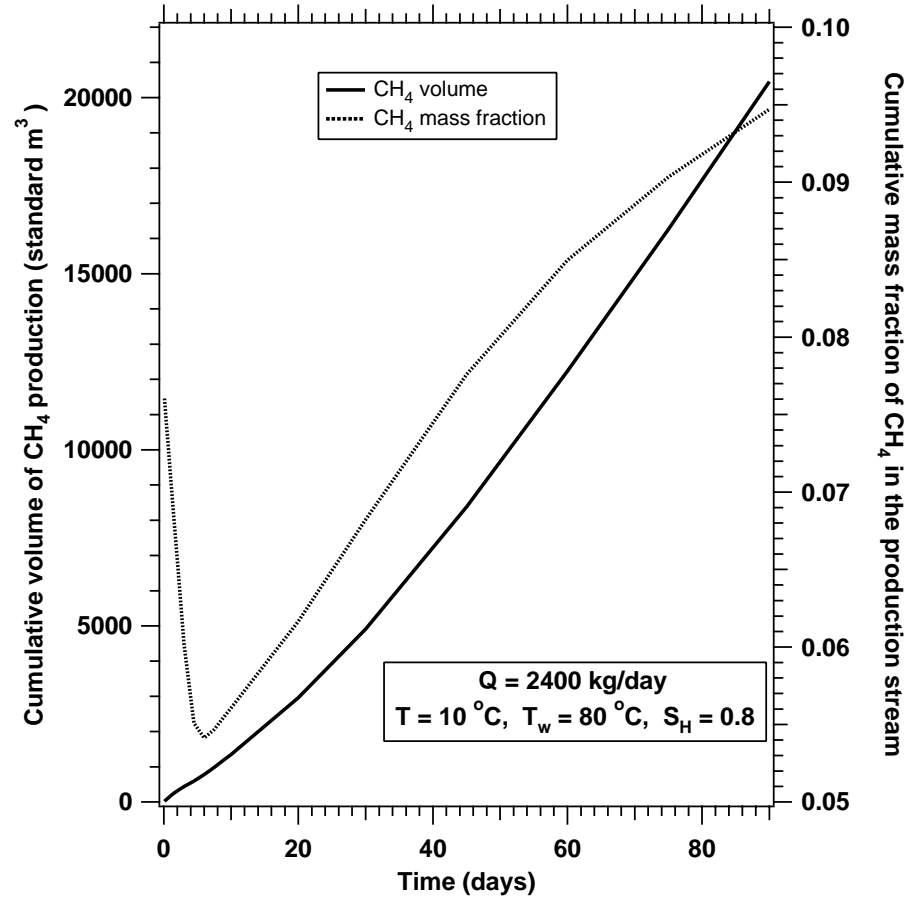
Effect of S_H

Production From Class 2 Hydrates

Mallik Area Accumulation

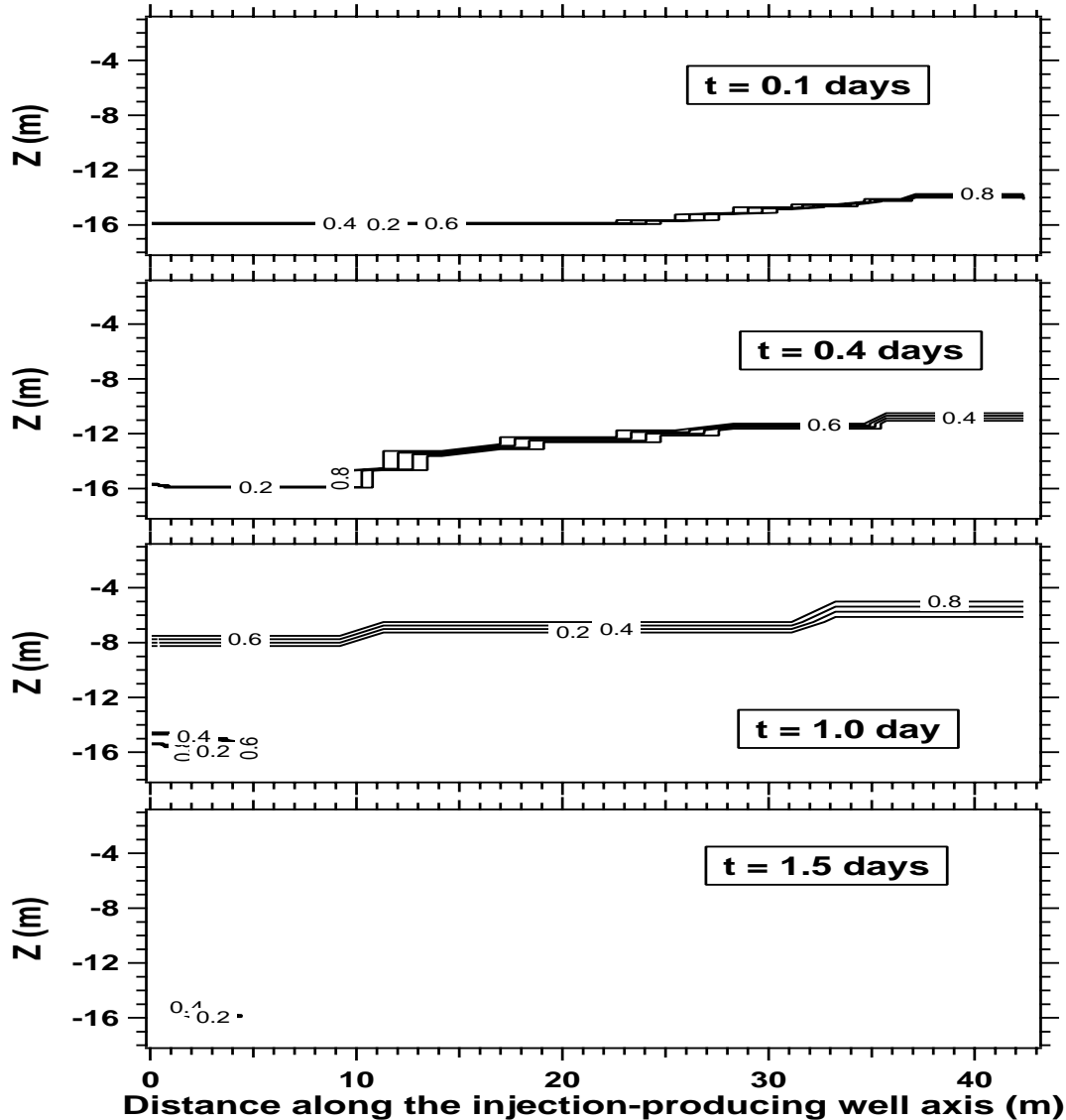


Effect of T: Dramatic!!!



Production From Class 2 Hydrates

Mallik Area Accumulation



Dramatic!!!

Production From Class 3 Hydrates

Mallik Area Accumulation



P = 10.74 MPa, T = 7.5 °C

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

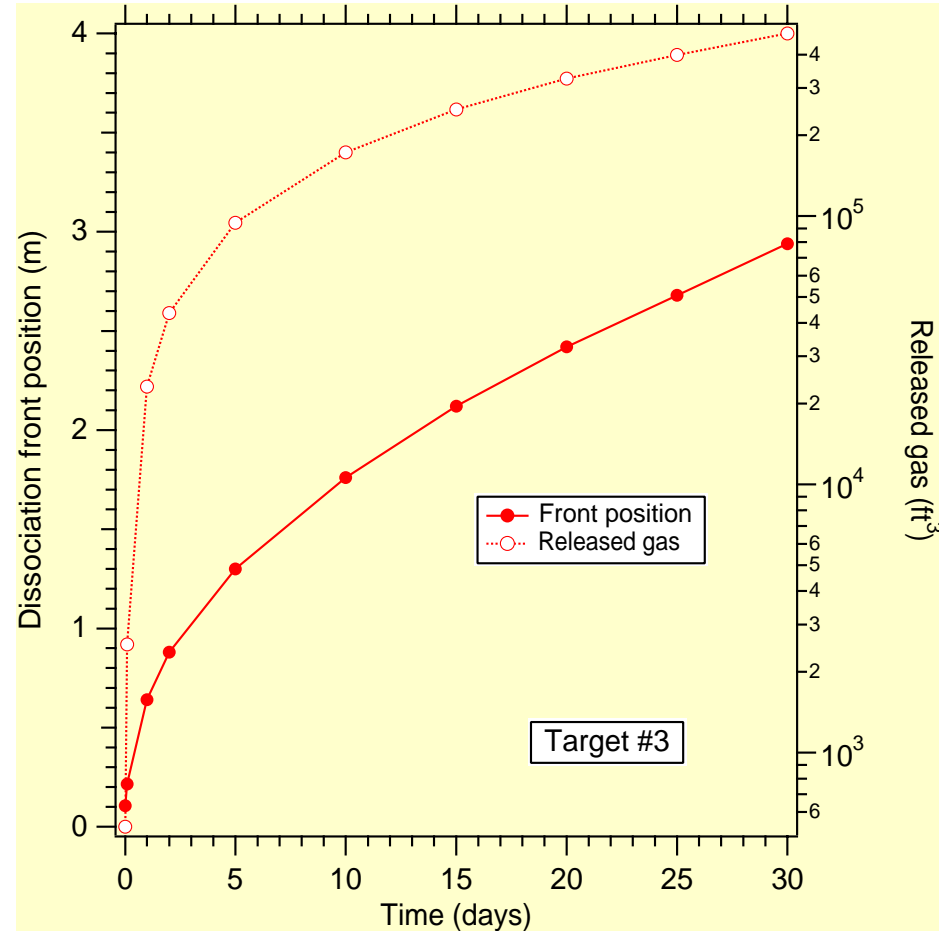
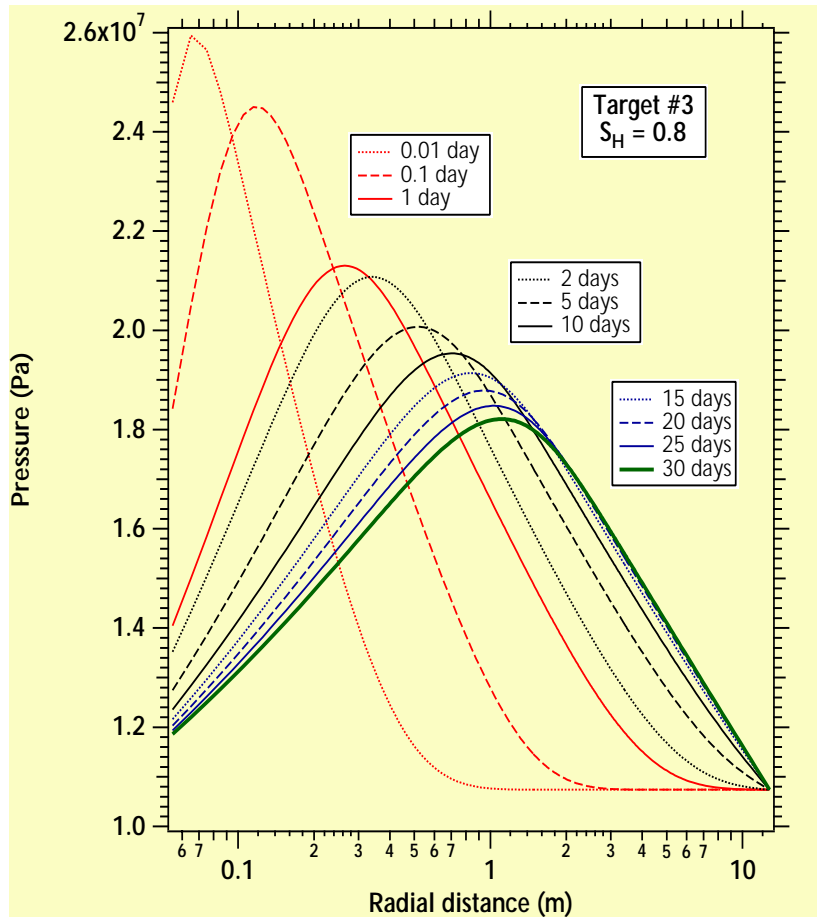
- Constant well temperature**
- **Thermal dissociation**
- **Simple and easy to conduct in the field**
- **Limited number of interacting processes**
- **Pressure effects unavoidable**

Production From Class 3 Hydrates

Mallik Area Accumulation - Thermal dissociation



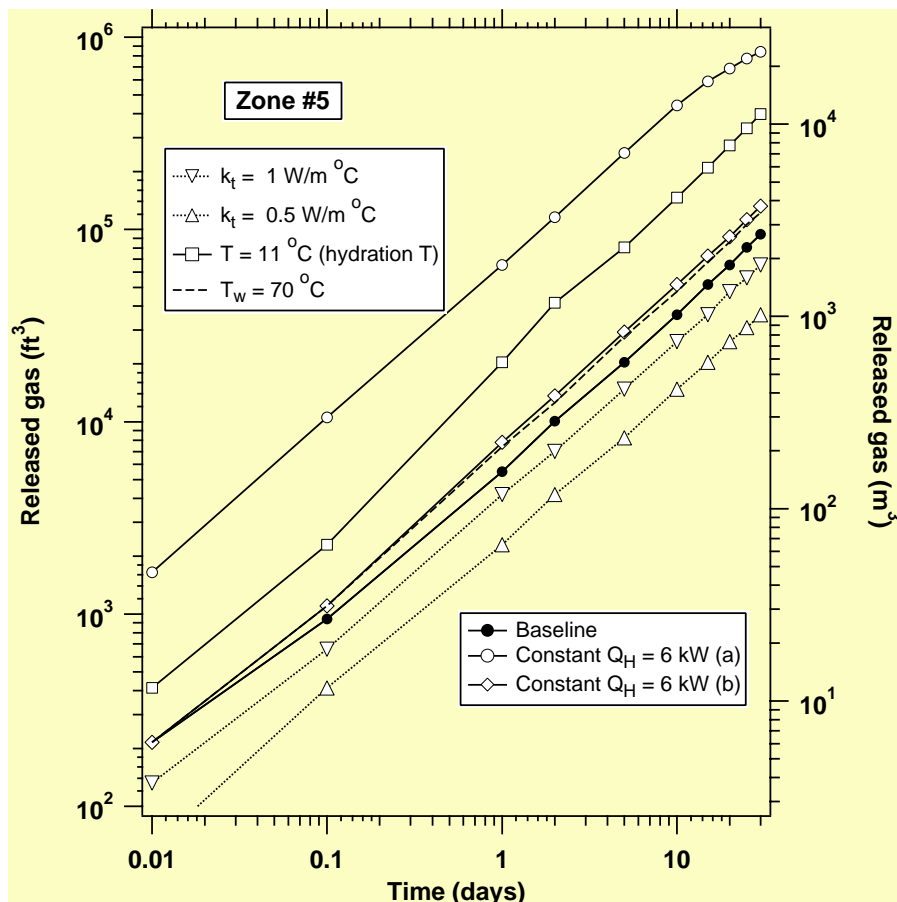
Pressure



Limited radius of dissociation

Production From Class 3 Hydrates

Mallik Area Accumulation - Thermal dissociation



Sensitivity analysis

Gas production is sensitive to:

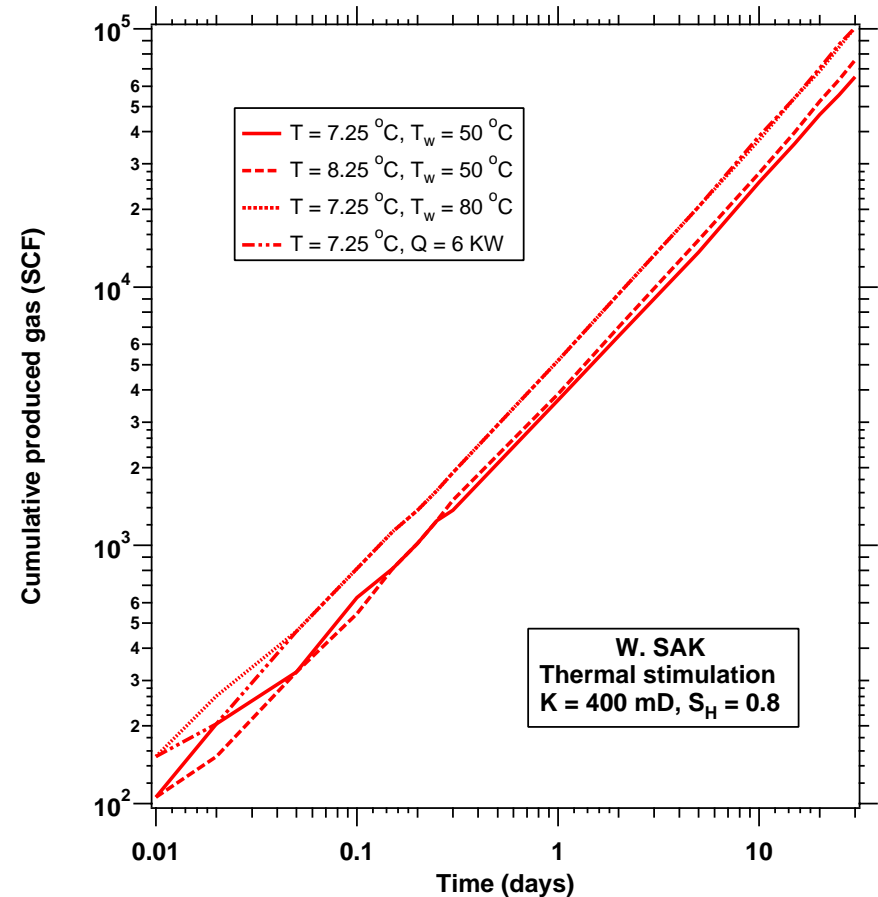
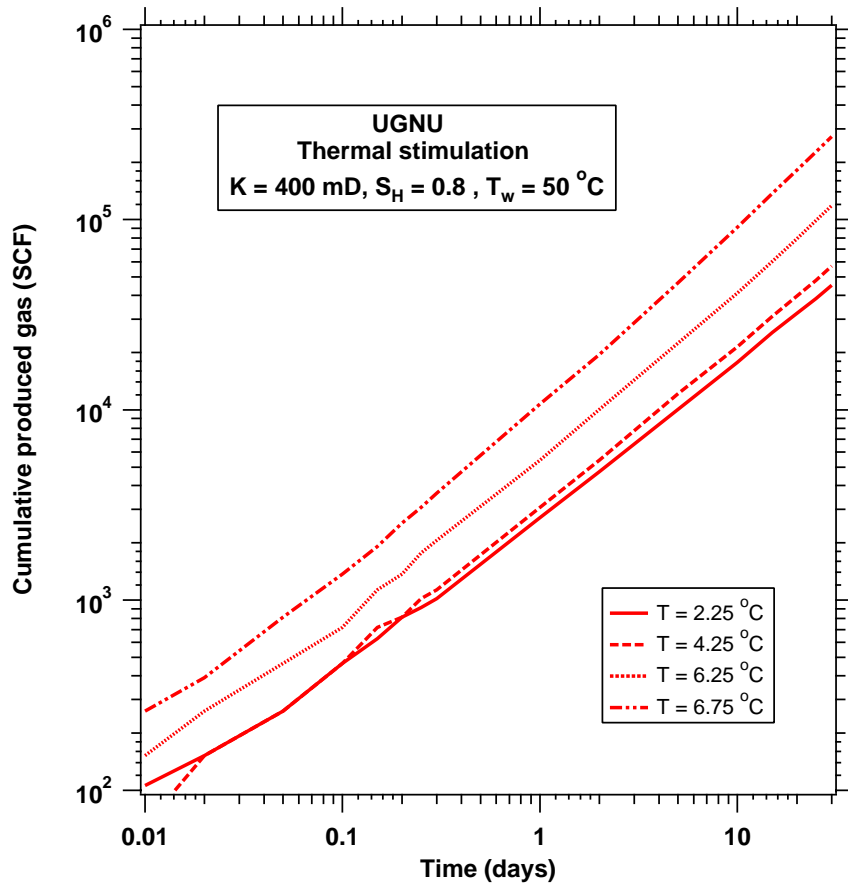
- Hydrate temperature
- Thermal conductivity
- Well pressure and temperature (combined depressurization and thermal stimulation)
- Heat addition method
- Hydrate saturation

Gas production is not sensitive to:

- Hydrate specific heat
- Formation permeability

Production From Class 3 Hydrates

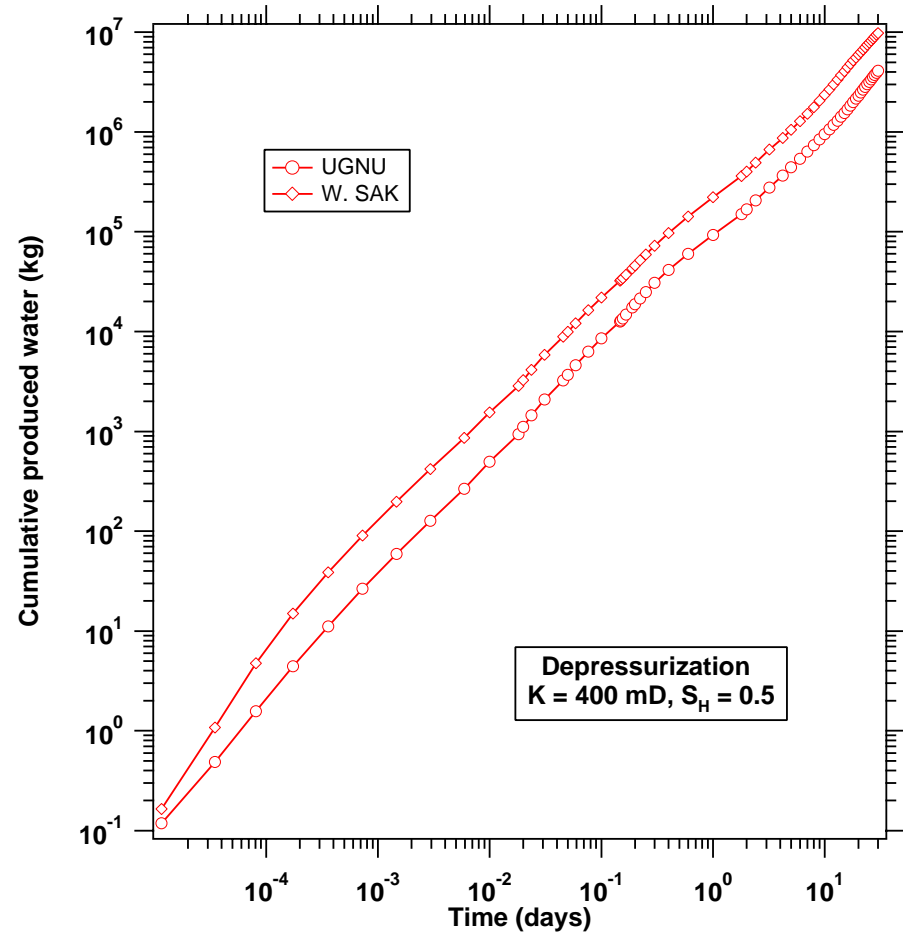
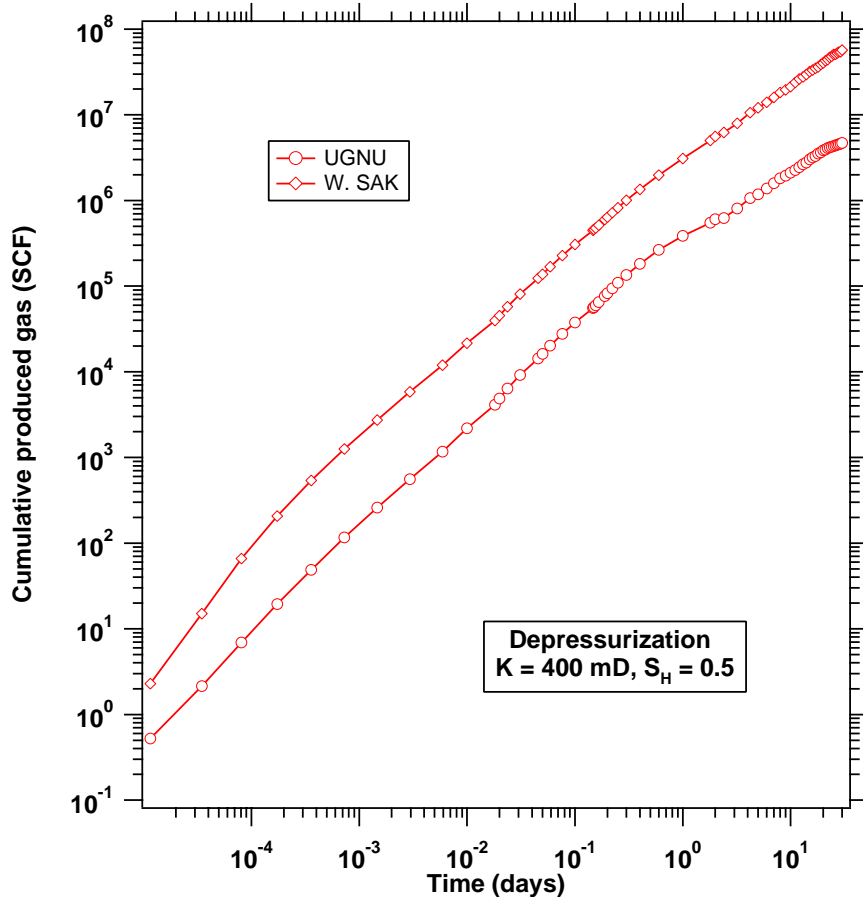
North Slope Accumulations



Thermal stimulation: Q increases with T , T_w

Production From Class 3 Hydrates

North Slope Accumulations



Single well depressurization - Importance of T

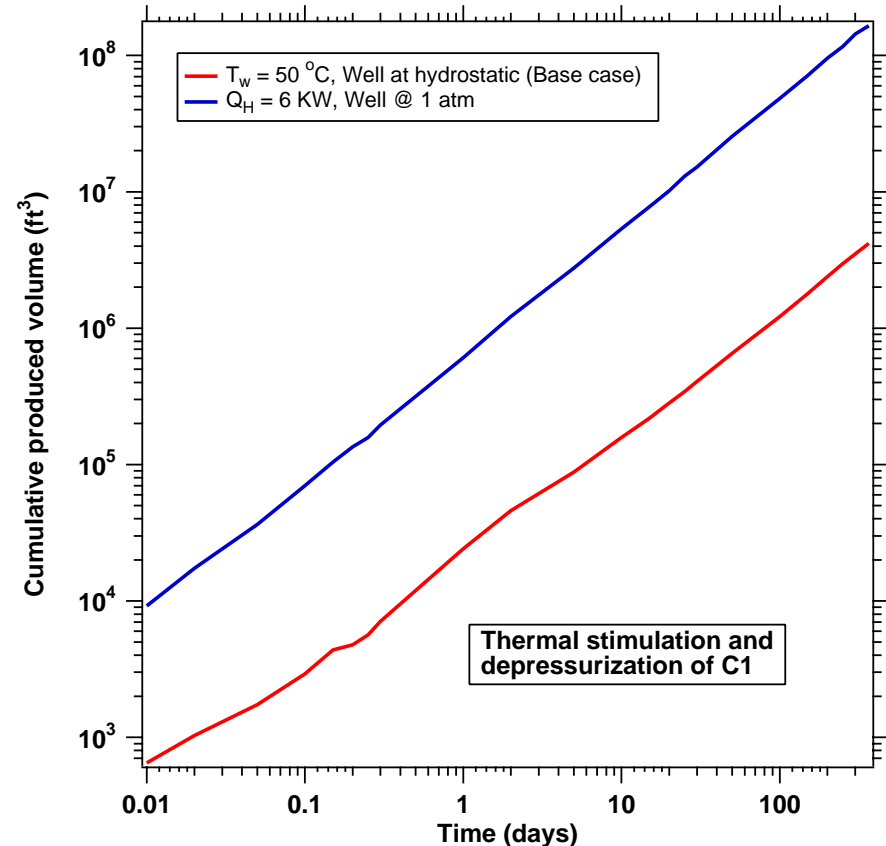
Production From Class 3 Hydrates

Eileen Area Accumulation



Unit C

- **DEPRESSURIZATION + THERMAL STIMULATION**
- **Single vertical well**
- **Well kept at hydrostatic pressure and $T_w = 50\text{ }^\circ\text{C}$ or at atmospheric pressure**
- **Well completed in the 17.2 m of C1**

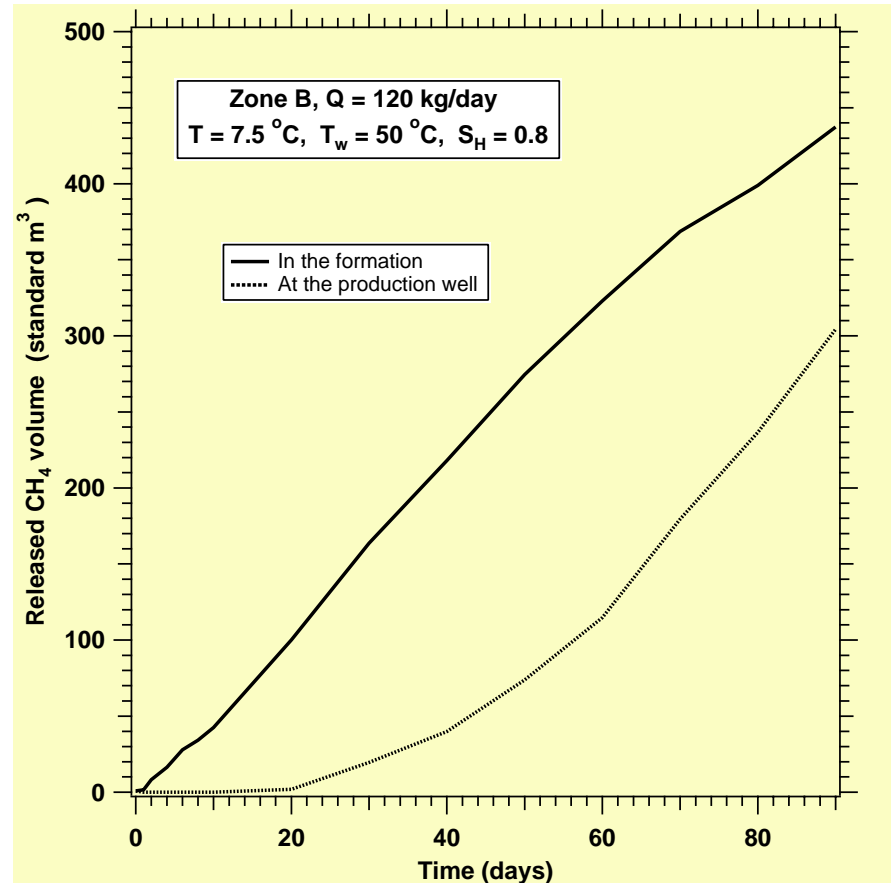
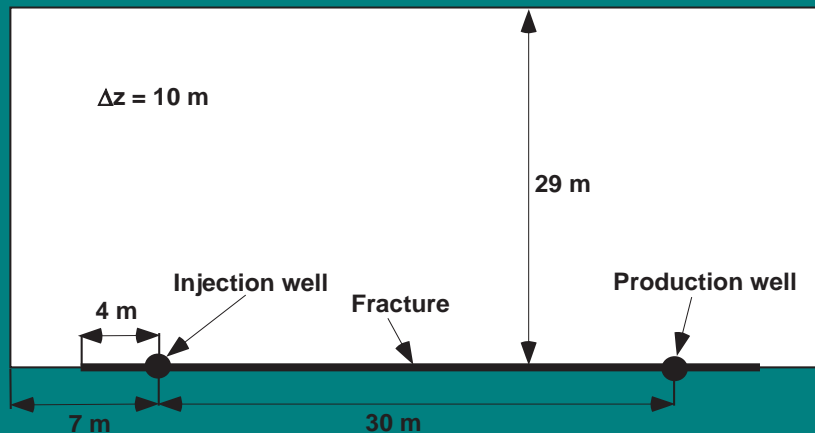


Production From Class 3 Hydrates

Mallik Area Accumulation



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



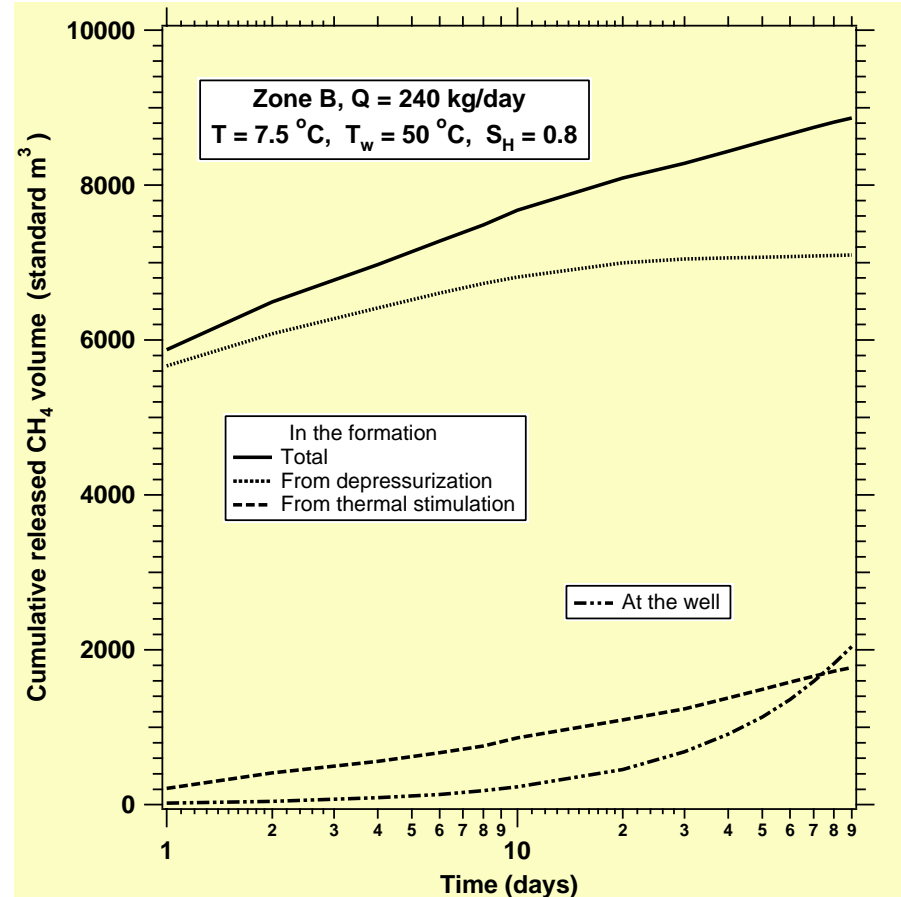
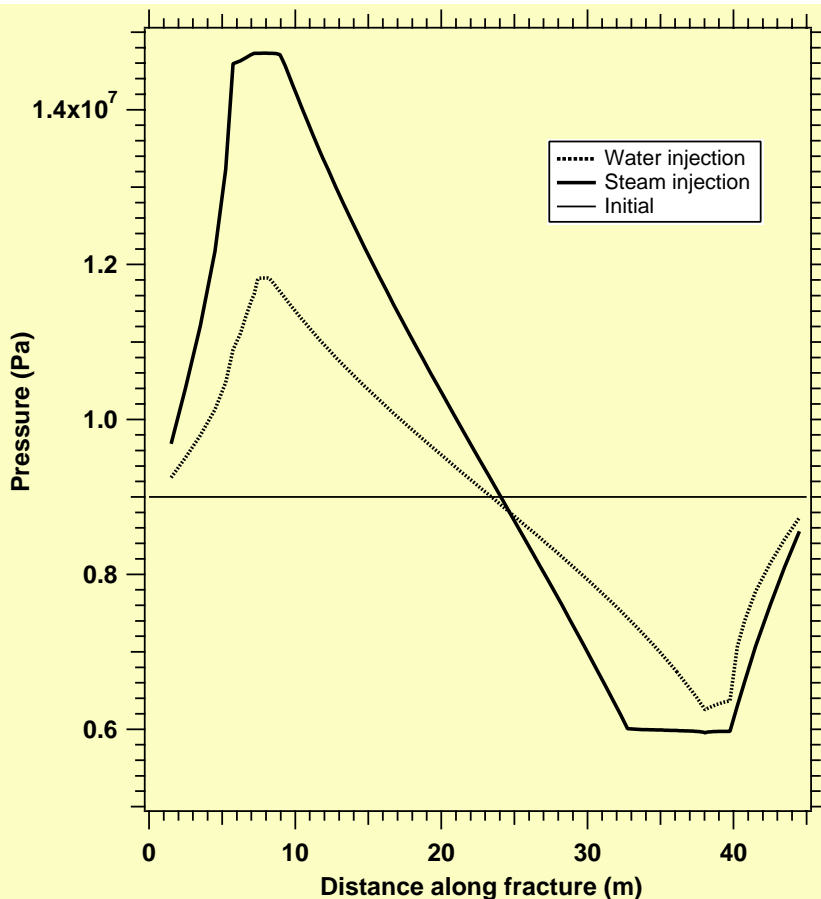
**Water Injection: Slow gas release -
no depressurization-generated gas**

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.**

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