

# Overview of SAGD Operations: Gas, Solvents And Water



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- ▶ **Aquathermolysis**
- ▶ A term coined by Hyne et. al. at the University of Calgary.
- ▶ Denotes a **Solvolysis** (a reaction of bitumen substrate with the solvent).
- ▶ The solvent is **Aqueous** (steam condensate).
- ▶ High Temperature.
- ▶ Understood in terms of normal organic chemistry.

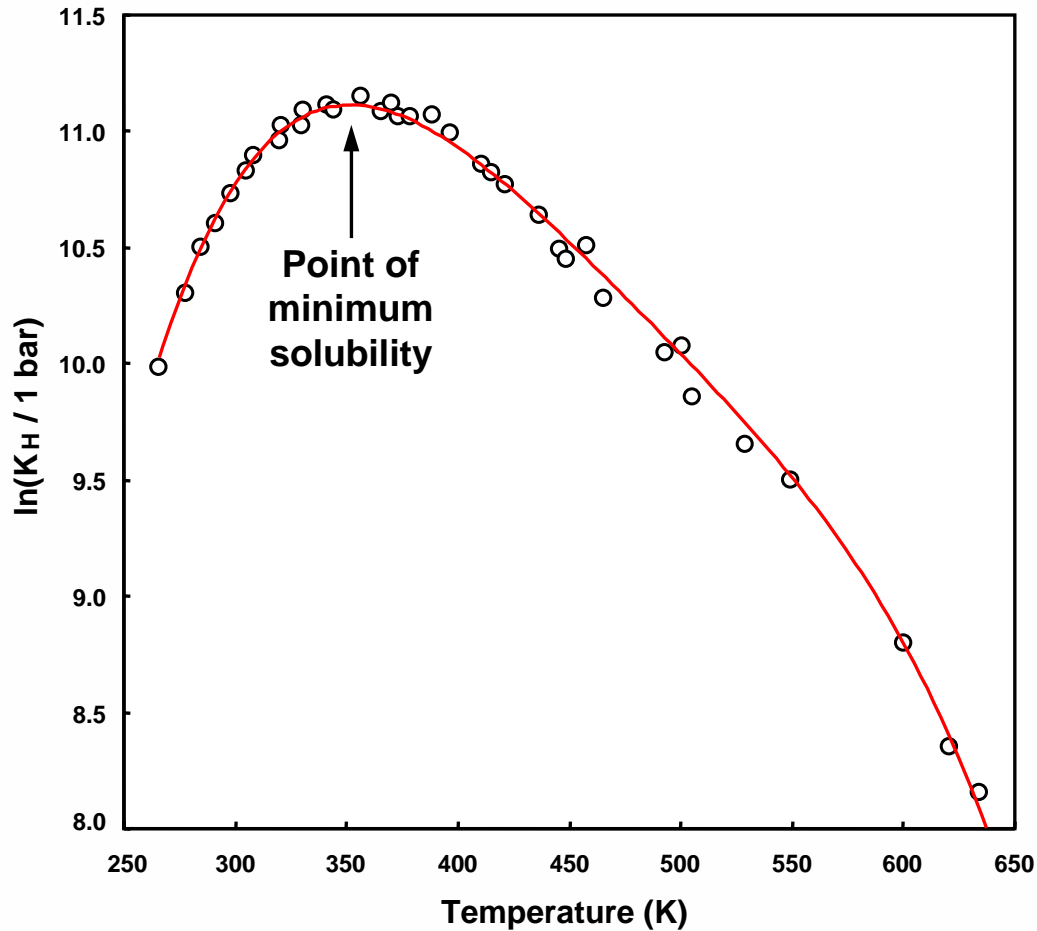
## Background: Source of Gases in SAGD

- ▶ **Aquathermolysis** is the source of a number of gases found in SAGD production, among them:
  - ▶ Hydrogen Sulphide
  - ▶ Carbon Dioxide
  - ▶ Minor amounts of methane (can often be ignored).
- ▶ **Most methane production is due to solution gas.**

- ▶ Partitioning of **aquathermolysis** and solution gas methane in the steam zone.
- ▶ There are three phases:
  - ▶ Bitumen
  - ▶ Water
  - ▶ Gas Phase (or steam phase).
- ▶ Complicated by unusual solubility of gases in water at high temperature and pressure.

# Henry's Law Constant for Methane in Water

Henry's Law Constant for CH<sub>4</sub> in H<sub>2</sub>O



At high temperature, solubility increases dramatically.

- ▶ **Asymptotic behavior of gas solubility near the critical point of water (374°C).**

$$K_D = y/x$$

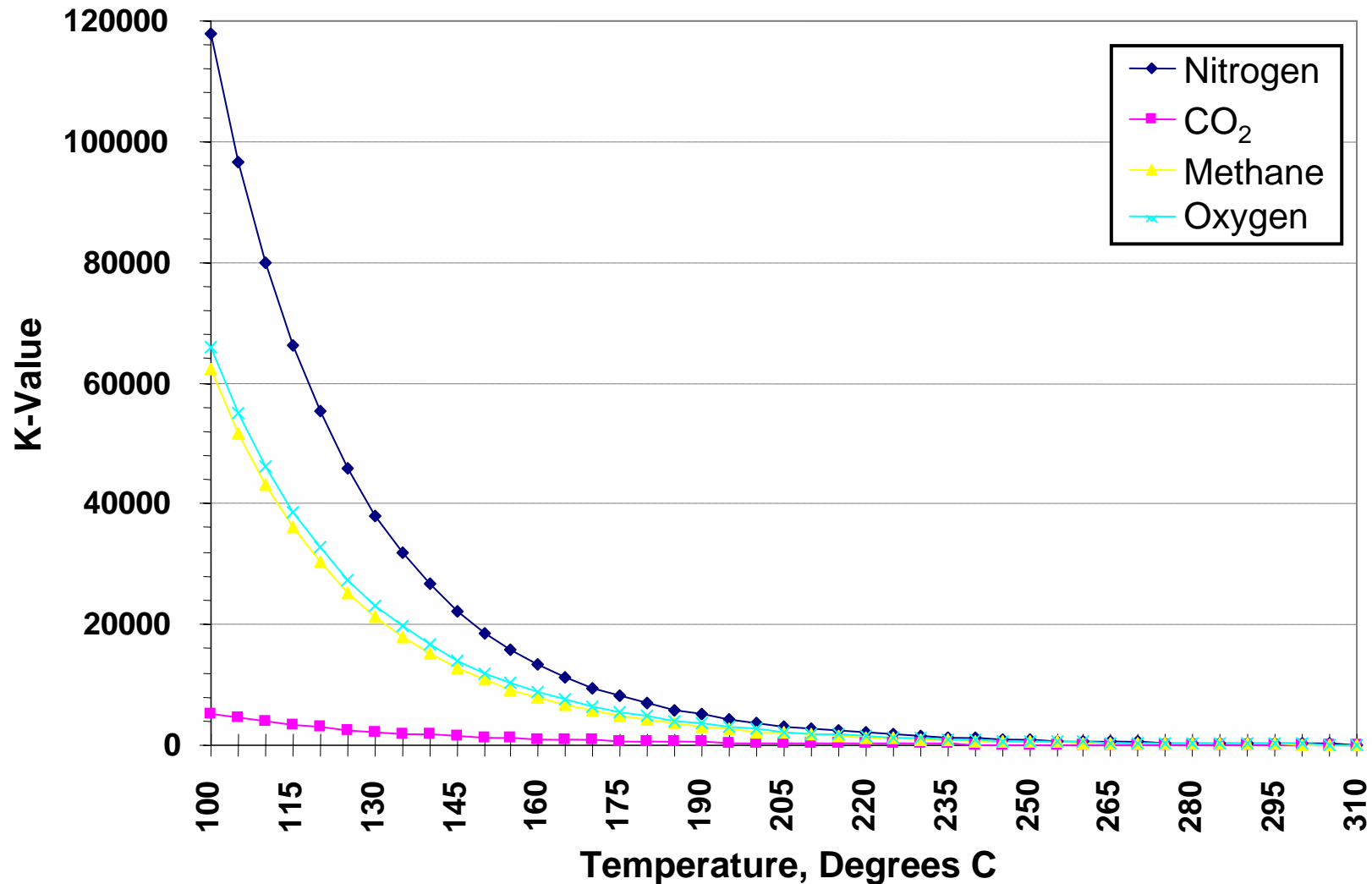
- ▶ **Harvey, Levelt Sengers , Japas , (1990's).**

*$RT \ln ( K_D )$  linear with  $(\rho_L - \rho_C)$*

*and approaches zero at  $T_C$*

**All gases increase in solubility in water at SAGD temperatures, as KD approaches unity.**

# K-Values for Selected Gases in Water at Saturated Steam Temperatures



# Typical Results: Field vs. Predicted

**Initial Pressure 400 kPag**

**Temperature = 208° C**

**Predicted H<sub>2</sub>S = 21.8 L/Tonne  
Bitumen**

**Actual H<sub>2</sub>S = 22.1 L/Tonne**

**Initial Pressure 3000 kPag**

**Temperature = 240° C**

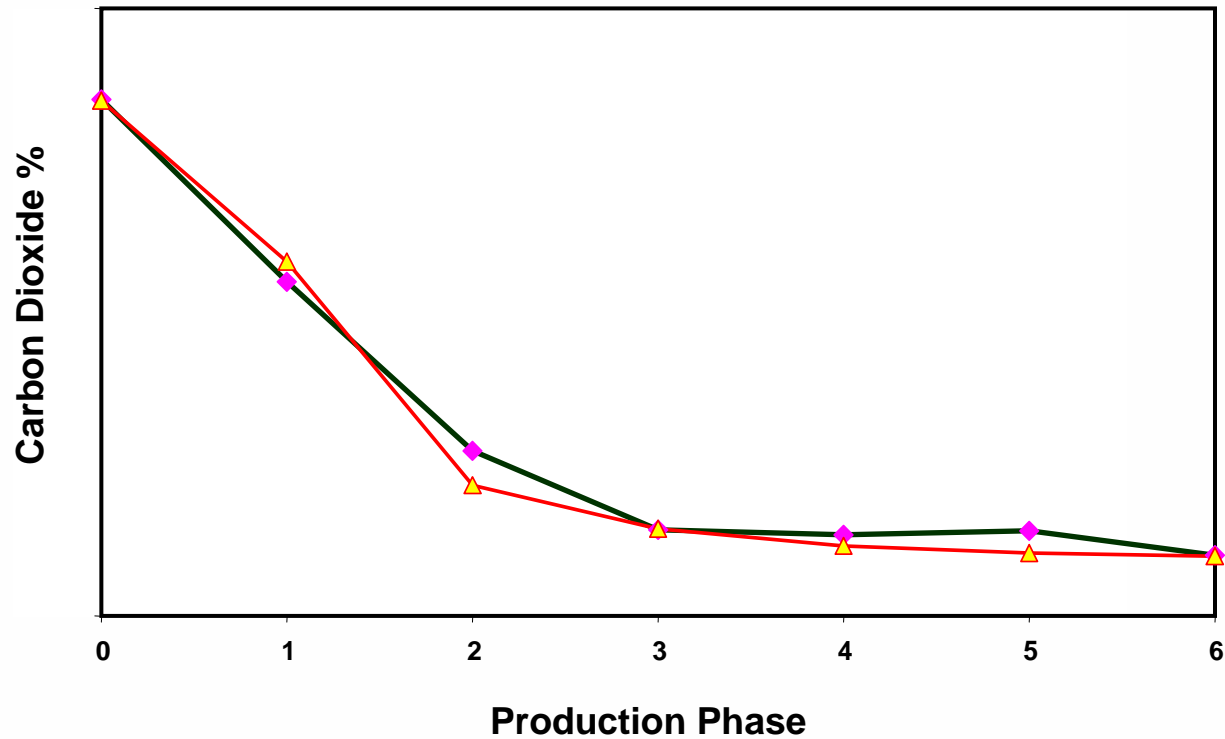
**Predicted H<sub>2</sub>S = 50 L/Tonne  
Bitumen**

**Actual H<sub>2</sub>S = 55 L/Tonne**

- ▶ **Normally GOR = 1 – 16.**
- ▶ **H<sub>2</sub>S varies from 1,000 to 30,000 ppm.**
- ▶ **Predictions (Thimm, 2001) match field results.**

# Field vs. Theoretical Results

## Produced Gas Carbon Dioxide Content



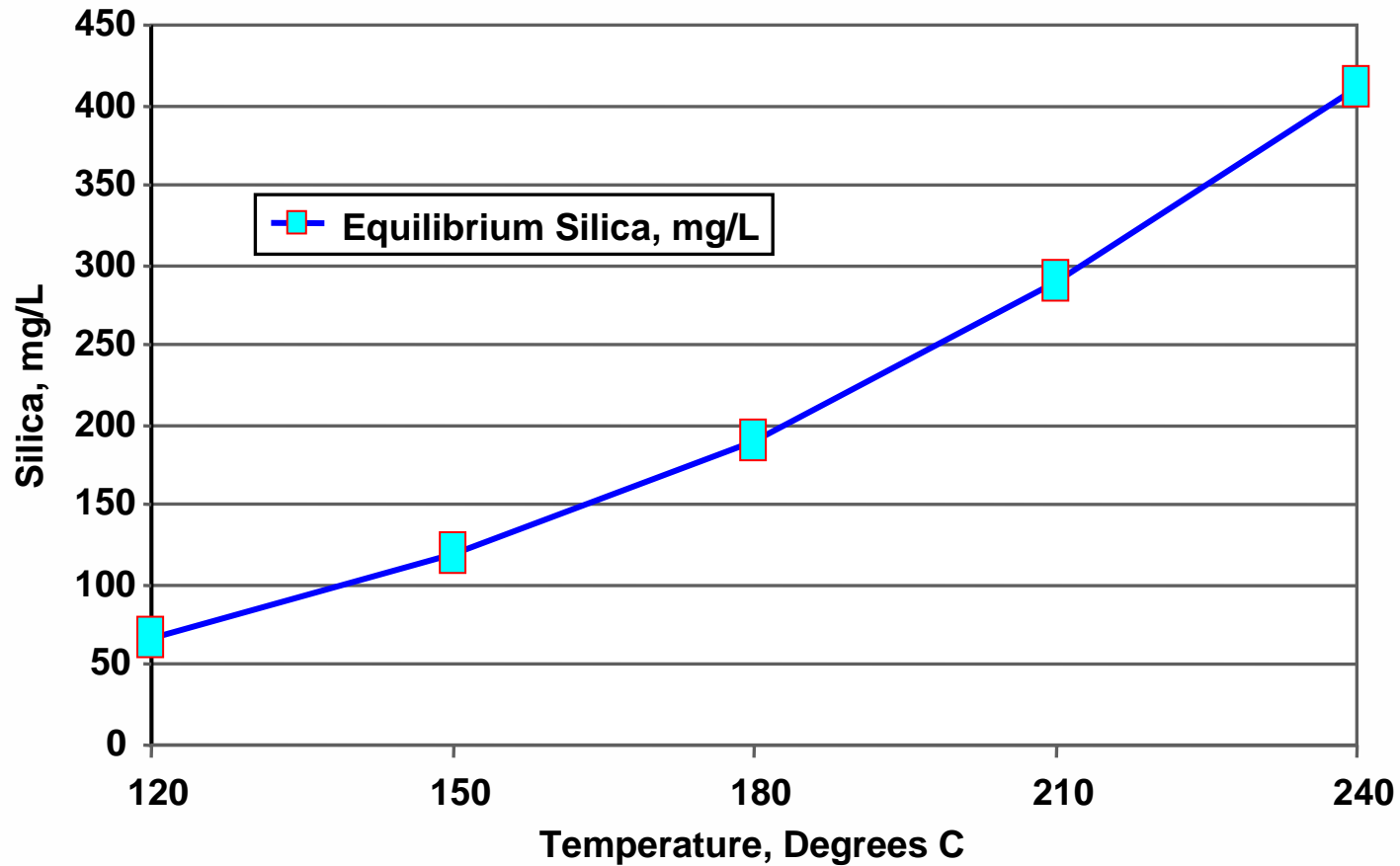
—◆— **Field Measurements**

—▲— **Calculated by this theory**

- ▶ **We have the means of calculating the concentration of carbon dioxide in the steam condensate of the SAGD steam zone.**
- ▶ **Carbon dioxide suppresses the solubility of quartz in the SAGD steam zone.**
- ▶ **In principle, we can estimate the silica production rate from theory of solution thermodynamics.**

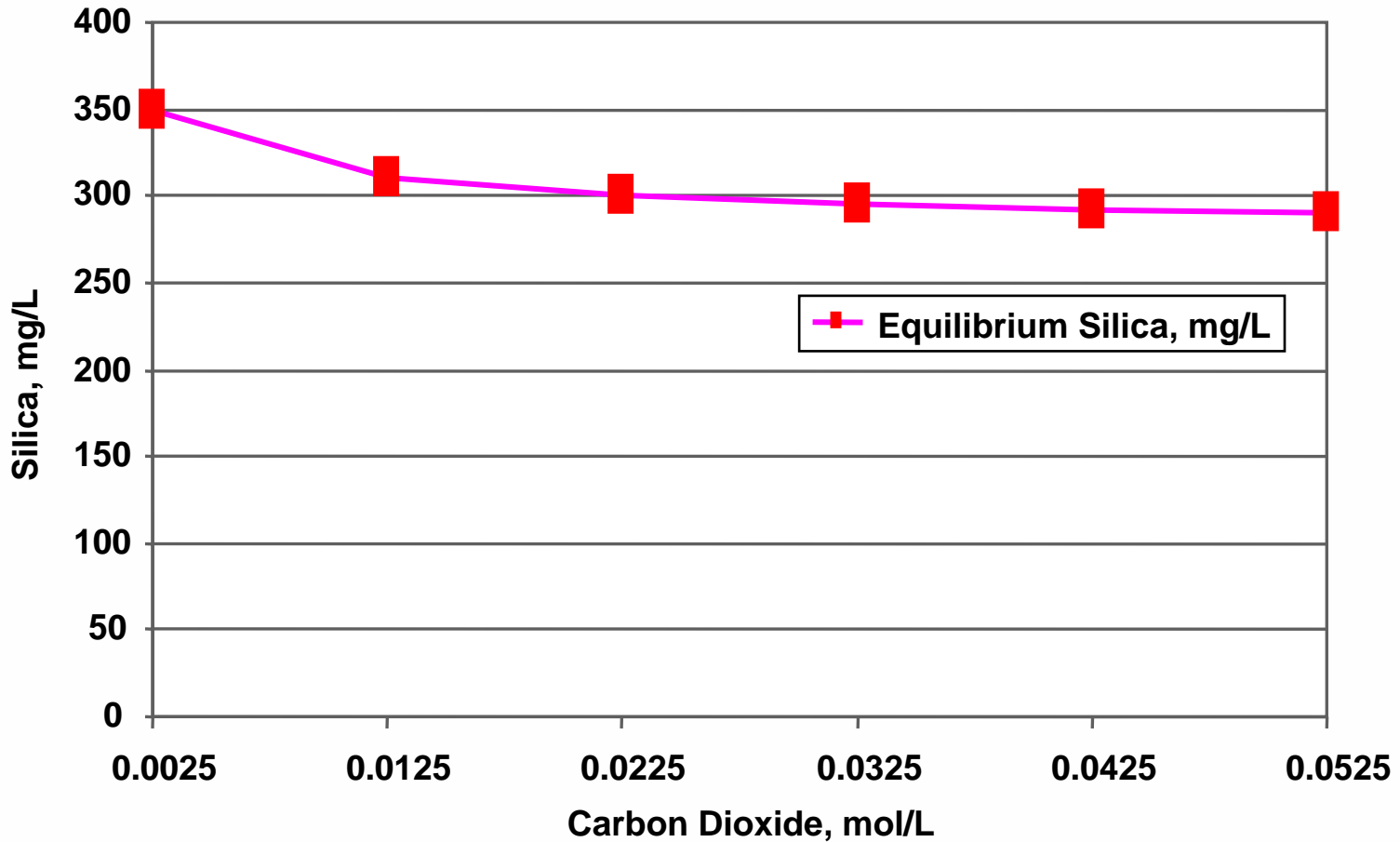
# Quartz By Solmineq Simulation

Equilibrium Silica, mg/L, as Function of Steam Zone Temperature



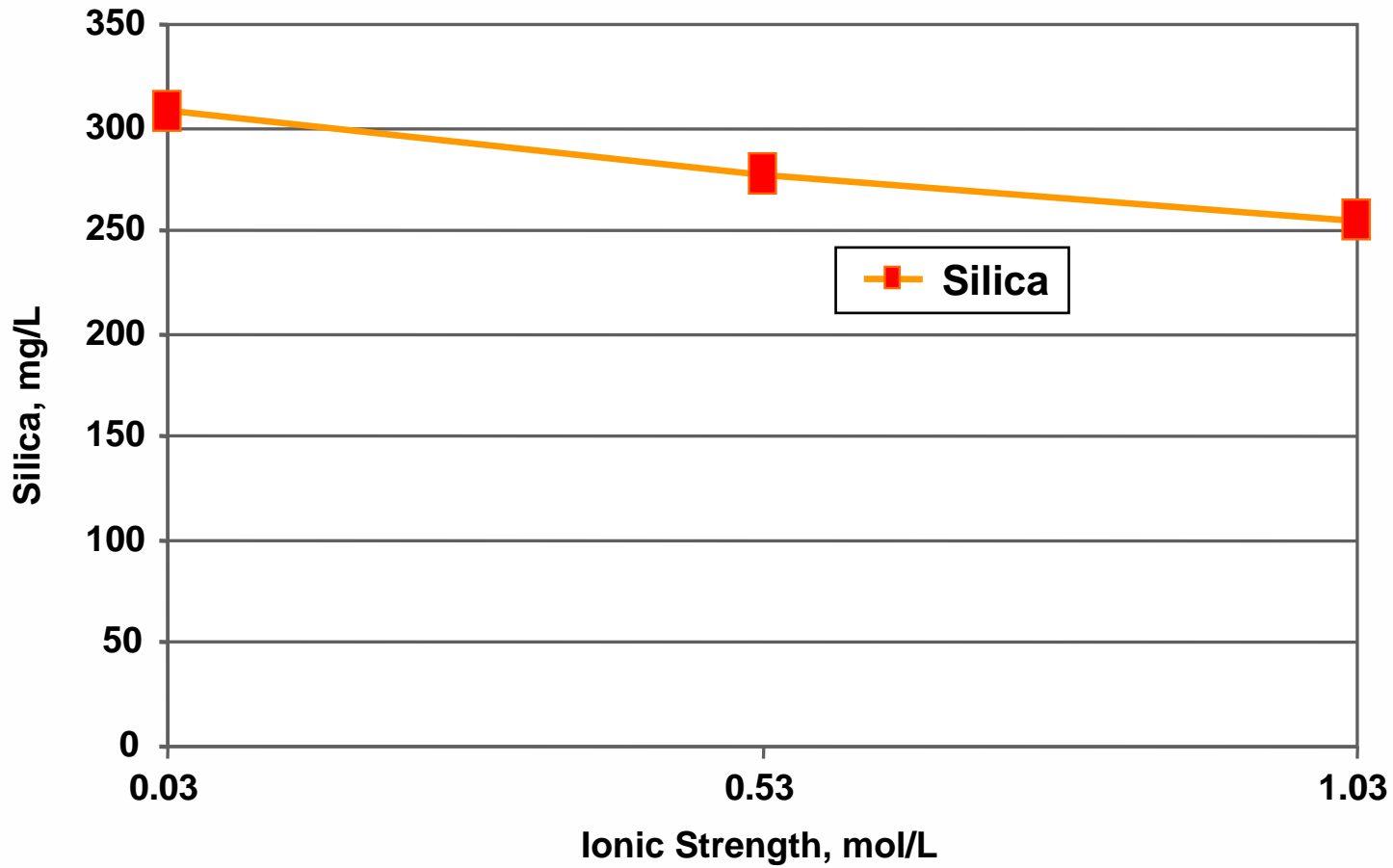
# Carbon Dioxide Effect

Equilibrium Silica, mg/L, with Carbon Dioxide in Steam Condensate

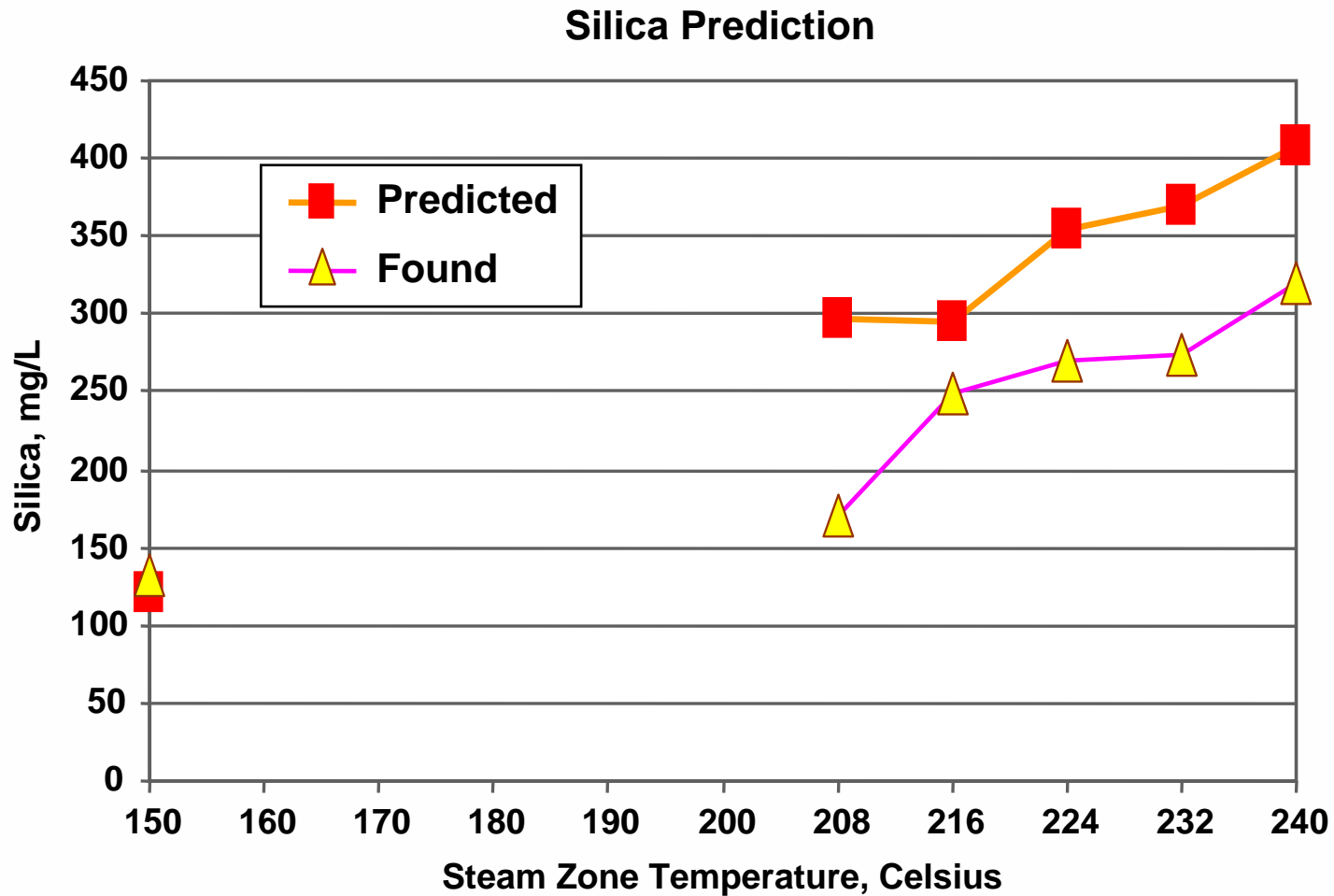


# Ionic Strength Effect

## Silica Solubility as Function of Ionic Strength

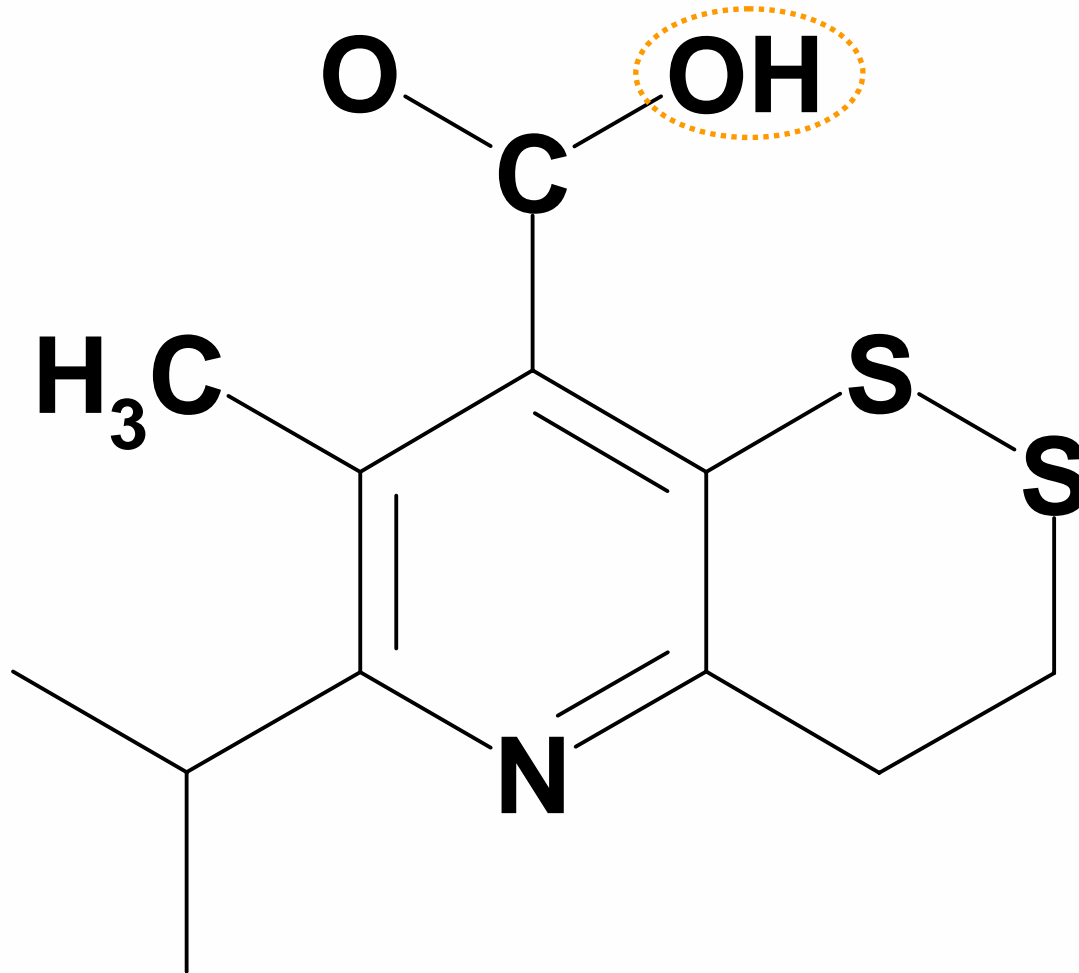


# Combination of Effects: Field Vs. Theory

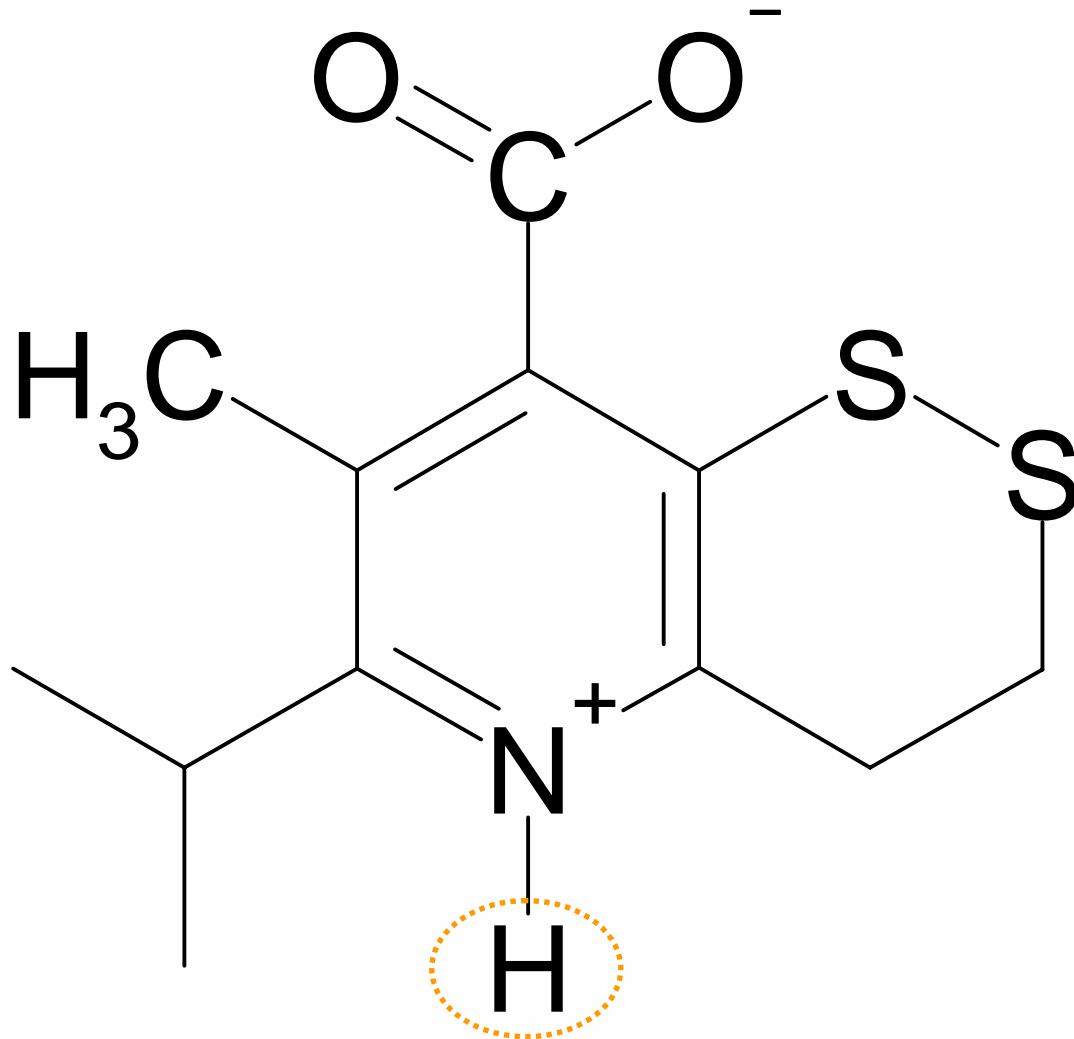


- ▶ **Method of silica analysis appears to be important to account for 25% deviation.**
- ▶ **Poorest agreement in 2 cases where reactive silica analysis by **colourimetric methods** is involved. So-called “reactive silica” analysis.**
- ▶ **Other methods involve **ICP analysis**, but the time delay and crystallization during transport and analysis are an issue.**

# Organic Derived from Bitumen



# Found as Precipitate with $\text{Ca}^{2+}$ and $\text{SiO}_3^{2-}$



- **The solution thermodynamics also apply to various hydrocarbon solvents.**
- **This allows predictions of:**
  - **Optimal solvent composition choice for solvent co-injection.**
  - **Prediction of retention of solvent components in the reservoir.**
- **Theory predicts reduction of hydrogen sulphide production per bbl of bitumen.**

► **Extension of theory to higher hydrocarbons.**

$$RT \ln K = 2A_{Kr}(\rho_L - \rho_C) / \rho_C^2$$

$A_{Kr}$  = Krichevskii Parameter (MPa).

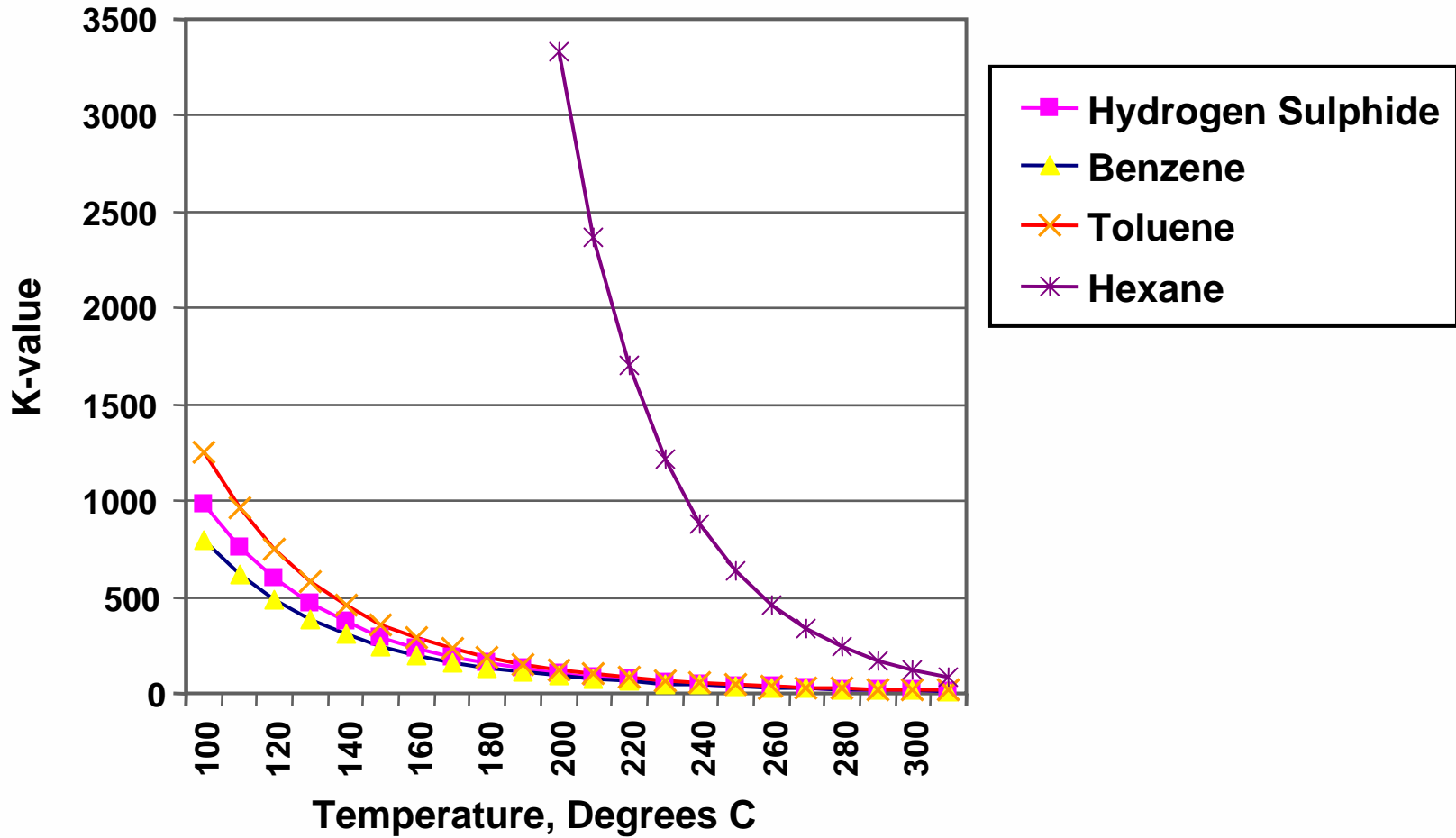
$\rho_L$  = Density of water.

$\rho_C$  = Density of water at critical point.

## Some Krichevskii Parameters

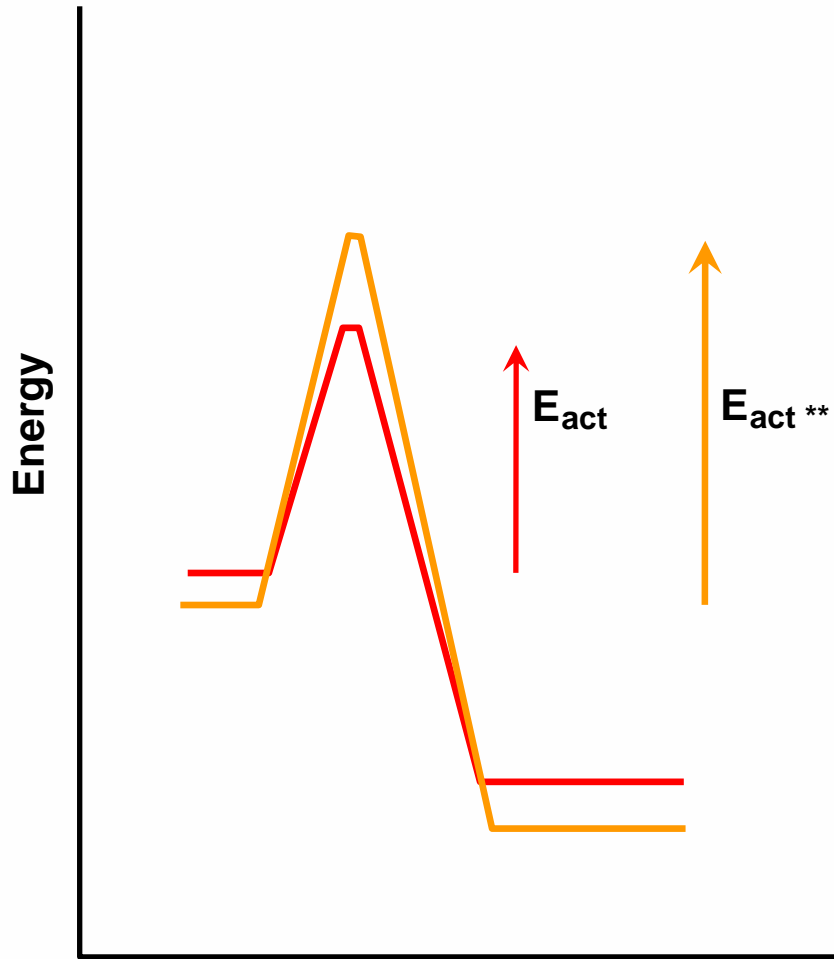
▶ <b>Carbon dioxide</b>	<b>121.7 MPa</b>
▶ <b>Hydrogen sulphide</b>	<b>96.6 MPa</b>
▶ <b>Methane</b>	<b>162.6 MPa</b>
▶ <b>Ethane</b>	<b>162.9 MPa</b>
▶ <b>Hexane</b>	<b>169.0 MPa</b>
▶ <b>Octane</b>	<b>178.4 MPa</b>
▶ <b>Benzene</b>	<b>93.6 MPa</b>
▶ <b>Toluene</b>	<b>100.0 MPa</b>

## K-Values in Steam Condensate



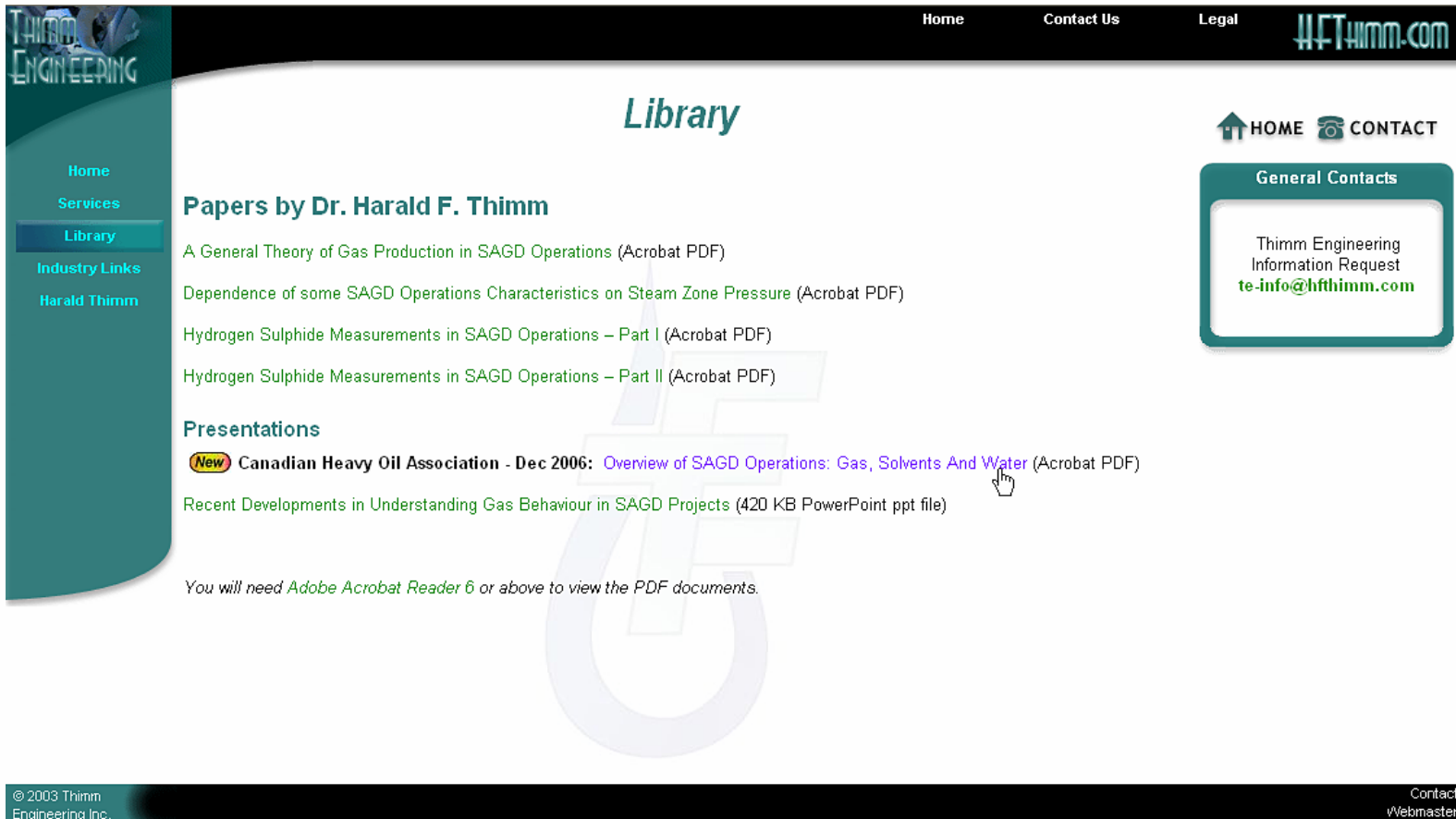
- **The solution thermodynamics also apply to various hydrocarbon solvents.**
- **This allows predictions of:**
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# Activation Energy for Solvolysis



- ▶ **Production of hydrogen sulphide should decline if the Hyne mechanism for aquathermolysis is correct.**
- ▶ **Initial results show this is so, but replication is needed.**
- ▶ **This theory is not yet on a quantitative basis.**
- ▶ **Expect a reduction of about 1 order of magnitude on the basis of initial results, enough to eliminate need for a sulphur recovery plant in some operations.**

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## Library

### Papers by Dr. Harald F. Thimm

- [A General Theory of Gas Production in SAGD Operations \(Acrobat PDF\)](#)
- [Dependence of some SAGD Operations Characteristics on Steam Zone Pressure \(Acrobat PDF\)](#)
- [Hydrogen Sulphide Measurements in SAGD Operations – Part I \(Acrobat PDF\)](#)
- [Hydrogen Sulphide Measurements in SAGD Operations – Part II \(Acrobat PDF\)](#)

### Presentations

- New** [Canadian Heavy Oil Association - Dec 2006: Overview of SAGD Operations: Gas, Solvents And Water \(Acrobat PDF\)](#)
- [Recent Developments in Understanding Gas Behaviour in SAGD Projects \(420 KB PowerPoint ppt file\)](#)

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- ▶ **Dr. Ken Kisman, Rangewest Resources Ltd. (discussions)**
- ▶ **Dr. A.H. Harvey, NIST (formerly NBS), Boulder, Colorado (data)**
- ▶ **Dr. A. Plyasunov, Chemistry, University of Arizona (data)**
- ▶ **Doug Komery, AERI (permission to use information from UTF pilot)**
- ▶ **Dr. C. Palmgren (NAOSC, formerly PetroCanada), Calgary (support)**