

Evaluation of different in-situ recovery strategies by numerical simulation

**Department of Chemical Engineering
Petroleum Research Center
the University of Utah**

**Chung-Kan Huang
Milind D. Deo**

Outline

- Objectives
- Process definition
- Reaction and kinetic model
- Modeling
- Summary
- Future work
- Acknowledgement

Objectives

- ❑ Simulate oil production from shale - perform in-situ recovery process analyses
 - ❑ Two heating options available
 - ❑ In-situ combustion (if the process can be made operational)
 - ❑ In-situ pyrolysis
- ❑ Preliminary reaction and kinetic models with options for improvements
- ❑ Test the models by observing the impact of selected process parameters on production performance, and base on the observation we improve the recovery process.
- ❑ Use conventional thermal reservoir simulator – STARS from Computer Modeling Group, Calgary, Canada

Process definitions

❑ in-situ combustion:

- Heat required for kerogen pyrolysis is completely supplied by combustion reactions inside the reservoir.
- Air is pumped into the reservoir and reacts with fuels originally existing in the reservoir such as kerogen, coke and oil.

❑ in-situ pyrolysis:

- Heat is provided by external heating source, such as electrical heating, chemical reactions.

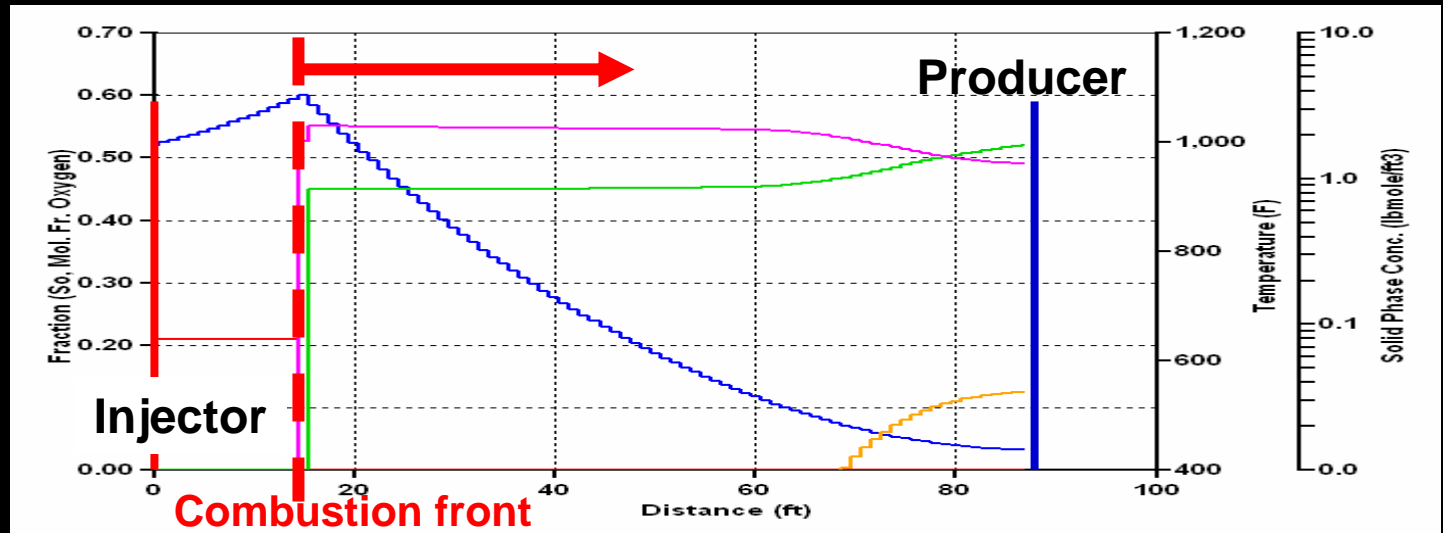
❑ Modified in-situ process:

- The recovery process combines in-situ pyrolysis and in-situ combustion, the purpose is to minimize the energy requirement and minimize the oil consumption as fuel.

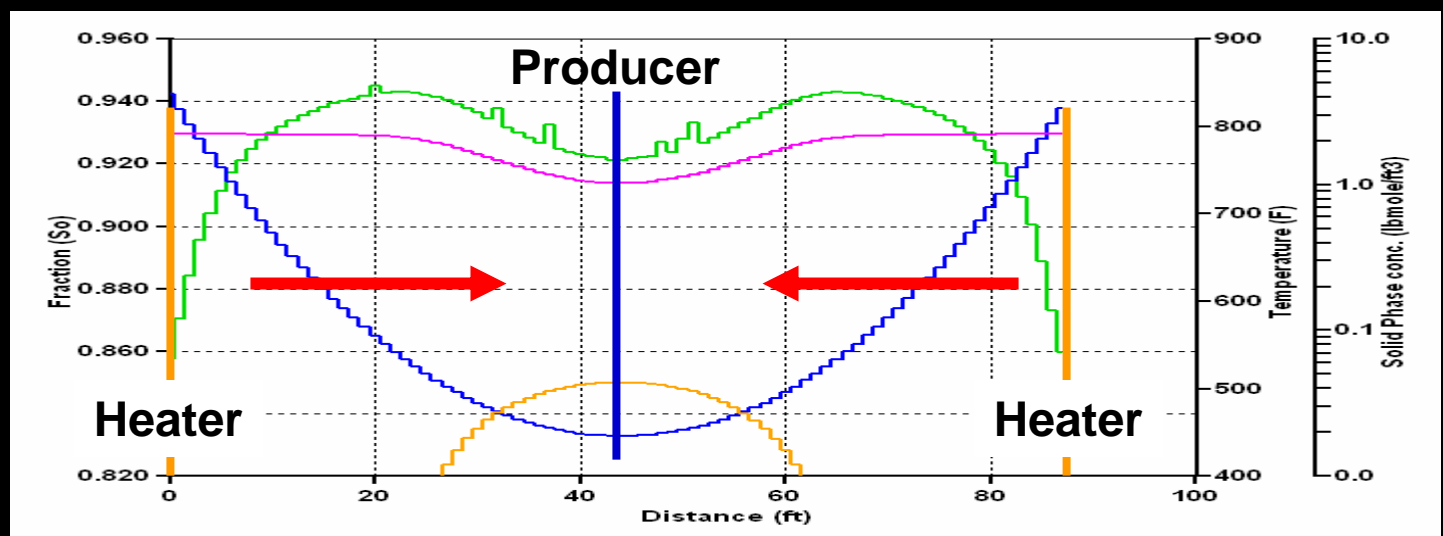
Process snapshot – 1D

O₂ mol. fr Temperature S_o coke conc. kerogen conc.

in-situ
combustion

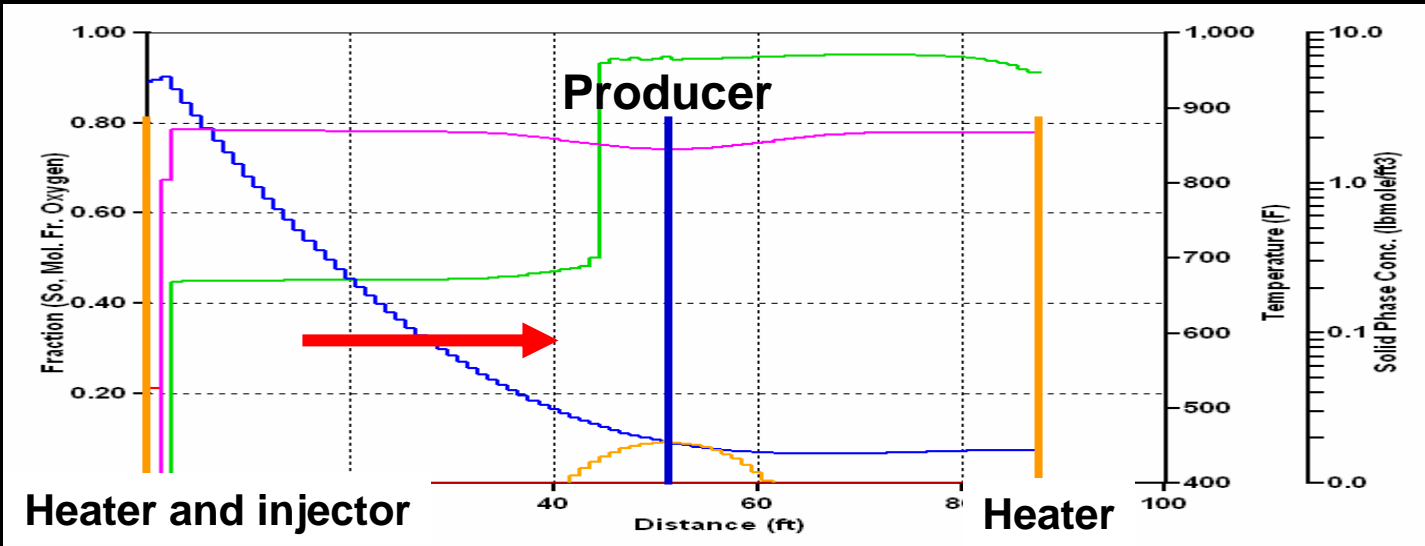


in-situ
pyrolysis



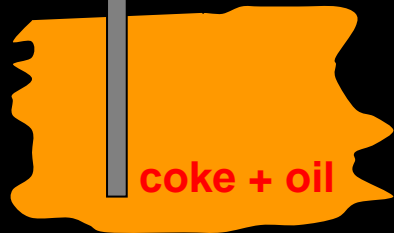
Concept of Modified Process

O₂ mol. fr Temperature S_o coke conc. kerogen conc.



in-situ pyrolysis stage

Heater

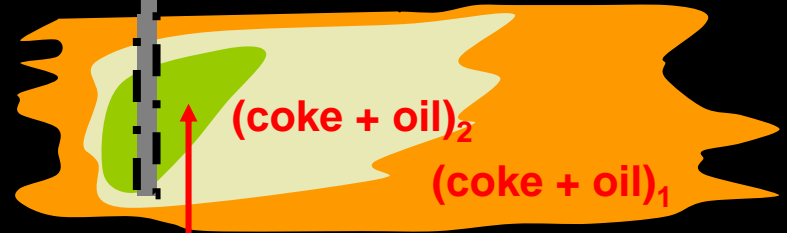


coke + oil



in-situ combustion stage

Injector



(coke + oil)₂

(coke + oil)₁

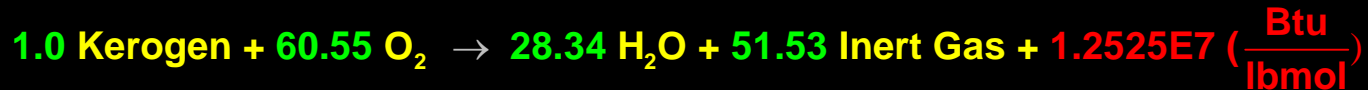


Completed combustion zone

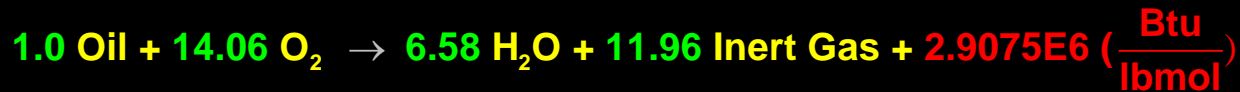
$S_{O_2} < S_{O_1}$

Reaction models - Hypothesis

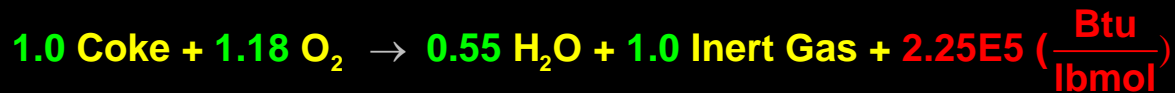
Kerogen burning :



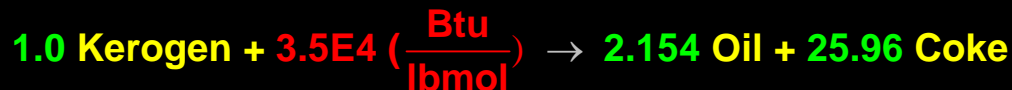
Oil burning :



Coke burning :



Kerogen pyrolysis (50 / 50 mass basis):



Molecular weight $\left(\frac{\text{lb}}{\text{lbmol}} \right)$:

Kerogen = 675; Coke = 13; Oil = 156.7; Inert Gas = 40.8

Kinetic models - Hypothesis

(Assume 1st for each reacting component)

Kerogen burning:

$$A = 4.02E10; E_a = 57000 \left(\frac{\text{Btu}}{\text{lbmol R}} \right)$$

Oil burning:

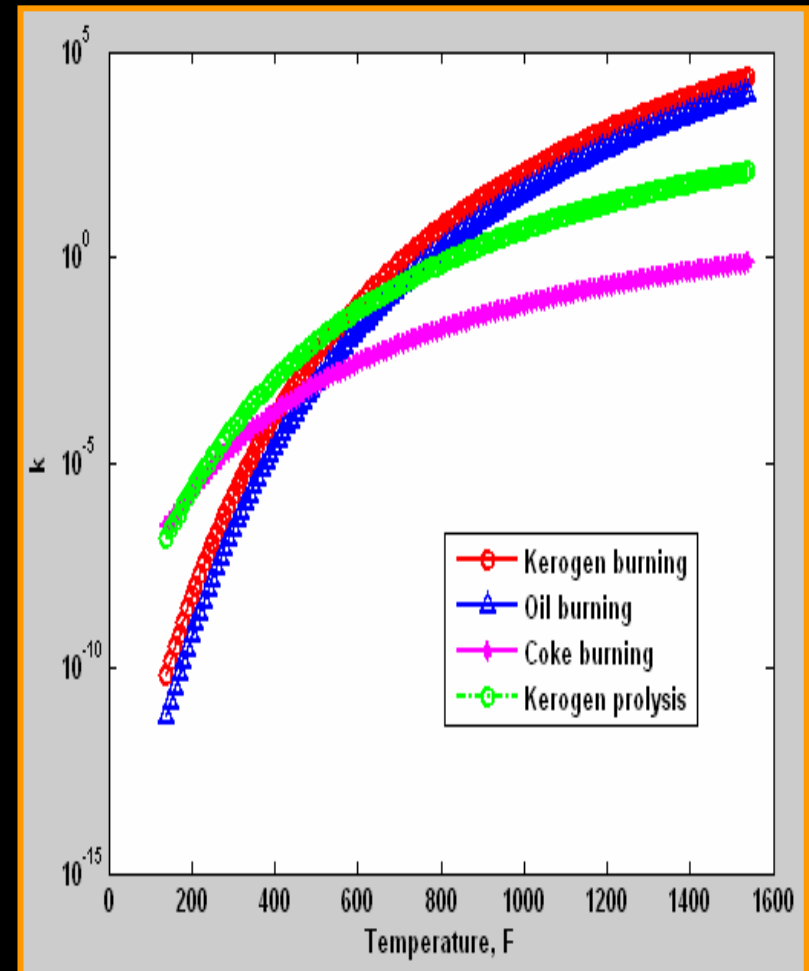
$$A = 3.02E10; E_a = 59450 \left(\frac{\text{Btu}}{\text{lbmol R}} \right)$$

Coke burning:

$$A = 416.7; E_a = 25200 \left(\frac{\text{Btu}}{\text{lbmol R}} \right)$$

Kerogen pyrolysis

$$A = 8.167E5; E_a = 35000 \left(\frac{\text{Btu}}{\text{lbmol R}} \right)$$



Modeling of in-situ combustion

➤ Parameters (base-case):

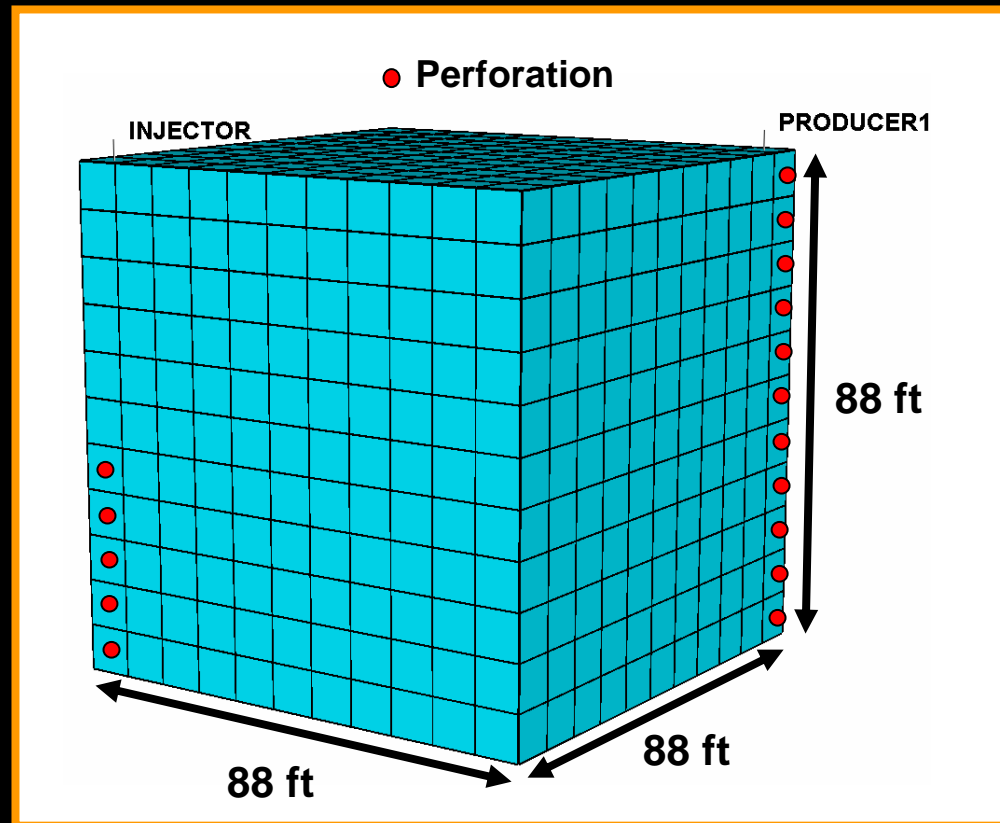
- Initial kerogen concentration.
(0.08 lbmol / cf _[P.V.] ~ 11.1 wt.%)
- Air flow rate.
(100,000 scf / day)
- Horizontal permeability.
(1,000 mD)
- Vertical permeability.
(10 mD)

Porosity : 35 % ($v_f + v_k$) (3 ~ 10 % v_f)

Residual water : 10 %

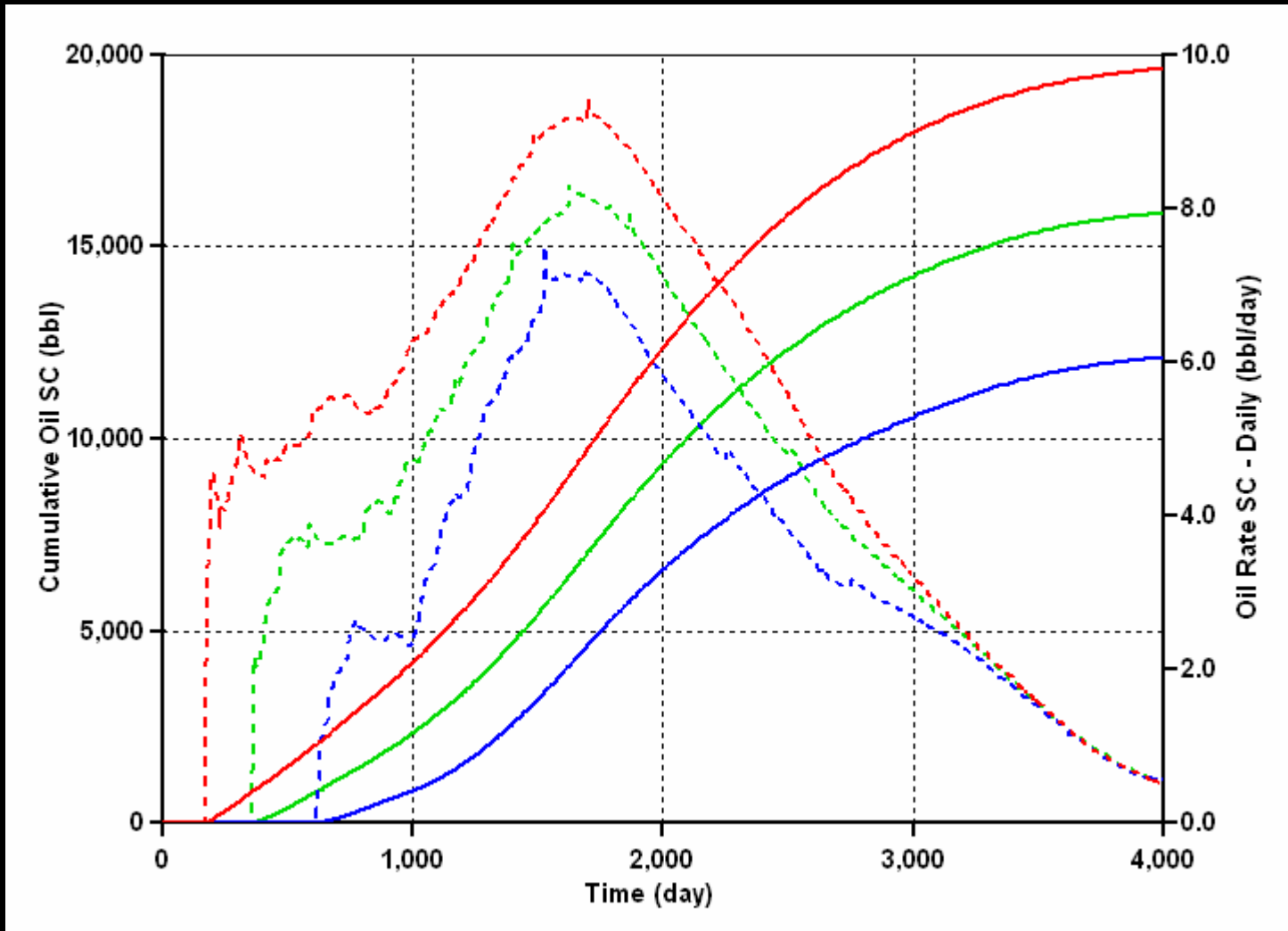
Initial pressure : 200 psi

$P_{\text{production}}$: 100 psi



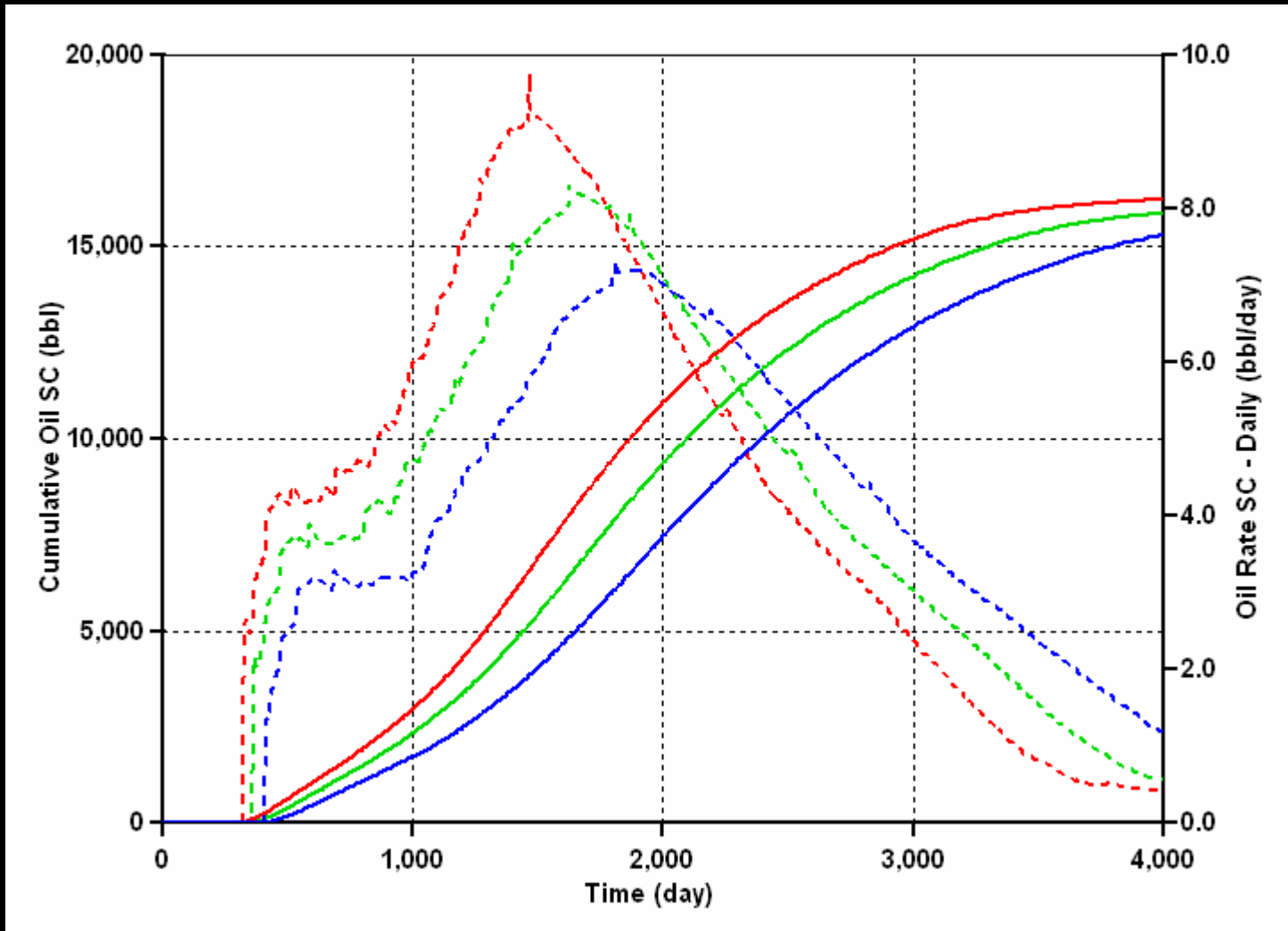
in-situ combustion

Effect of initial kerogen concentration [9.7 11.1 12.5 wt.%]



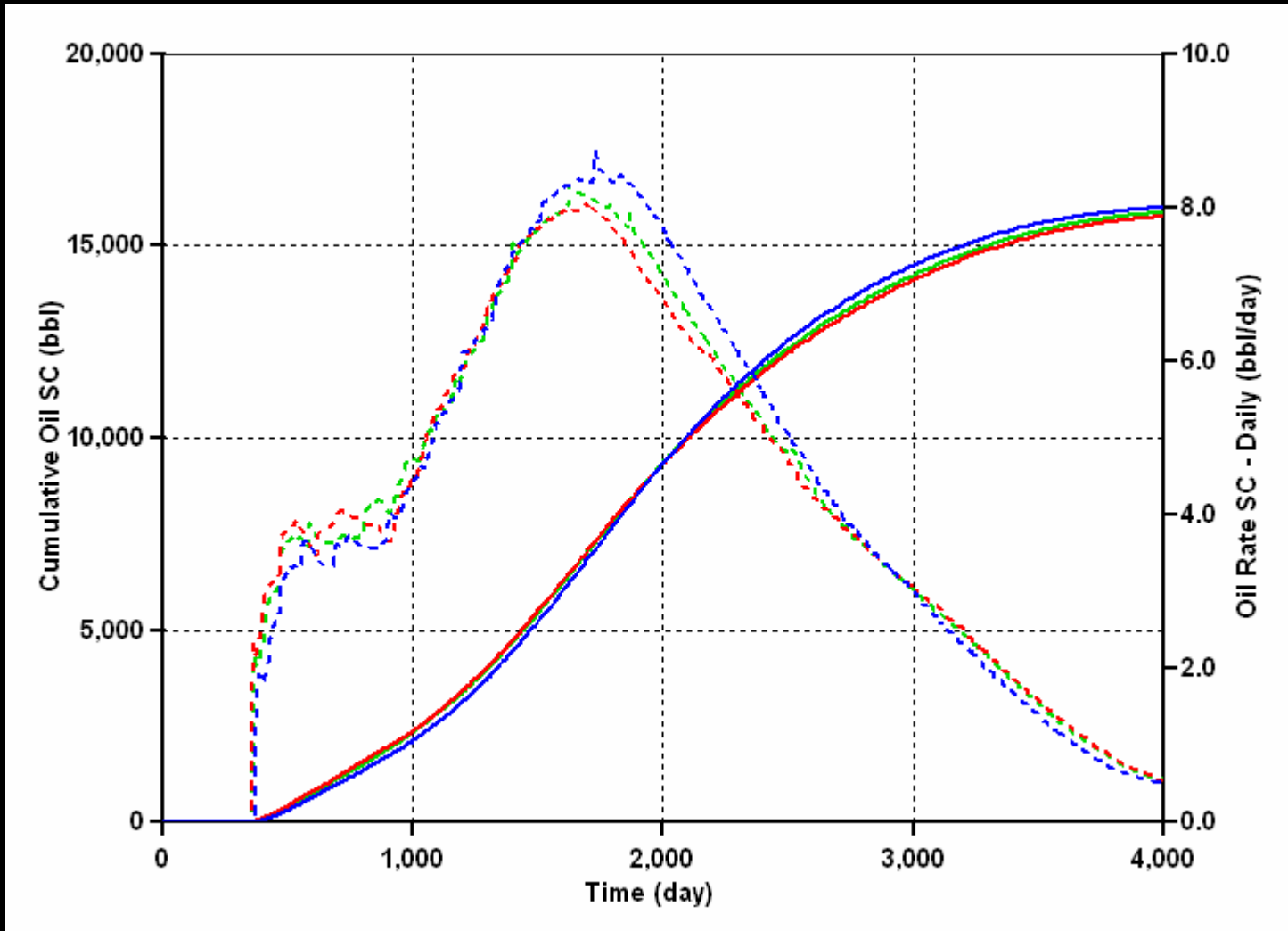
in-situ combustion

Effect of air flow rate [90000 100000 110000 scf / day]



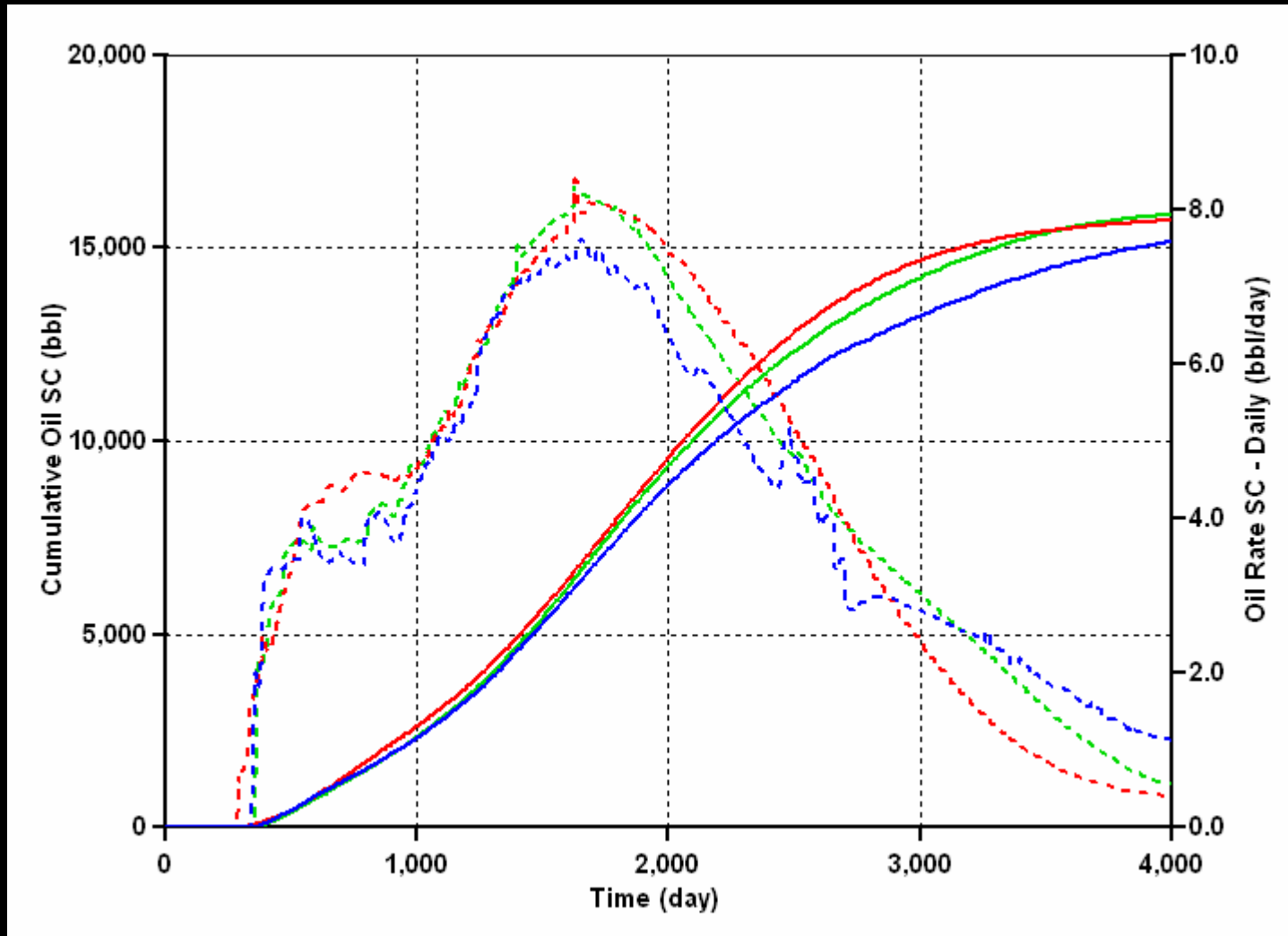
in-situ combustion

Effect of horizontal permeability [500 1000 1500 mD]



in-situ combustion

Effect of vertical permeability [1 10 100 mD]



in-situ combustion

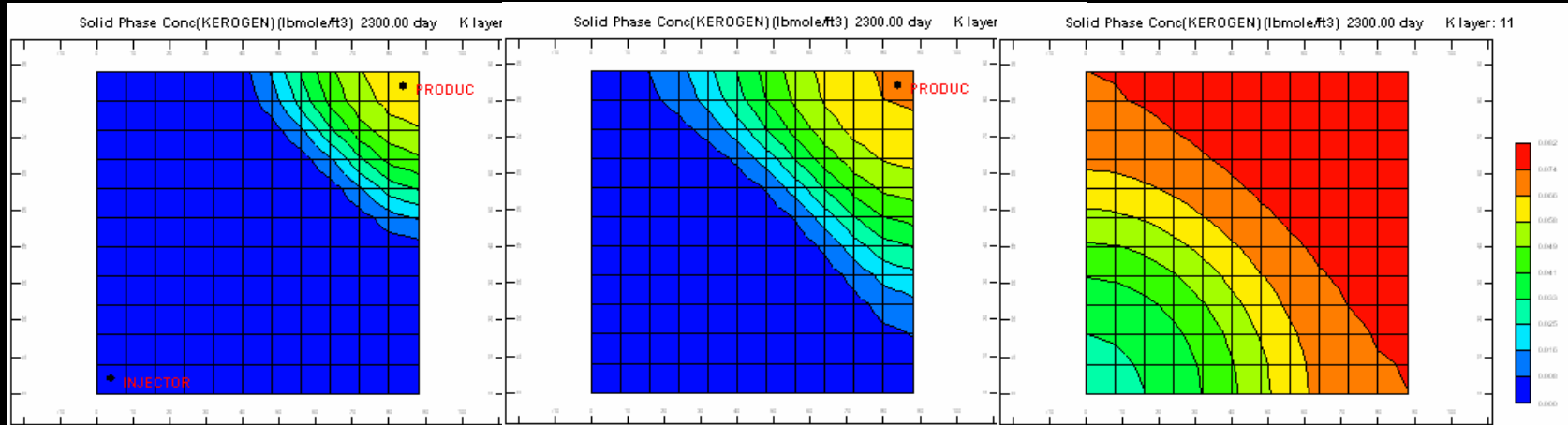
Effect of vertical permeability on kerogen conversion

bottom

middle

top

Low
V. Perm

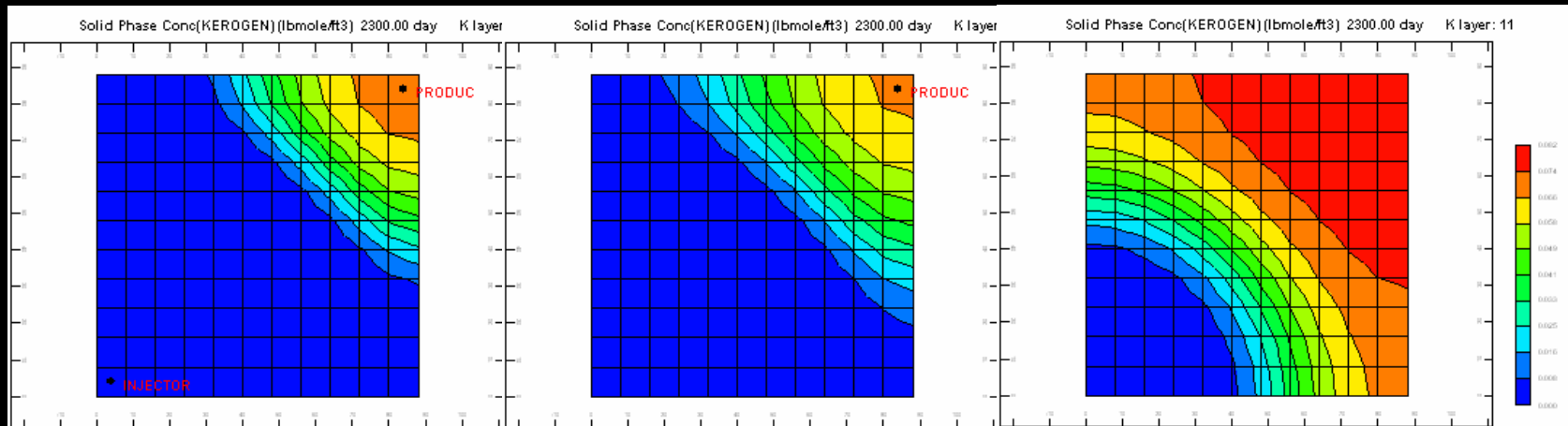


∨

||⇌

∧

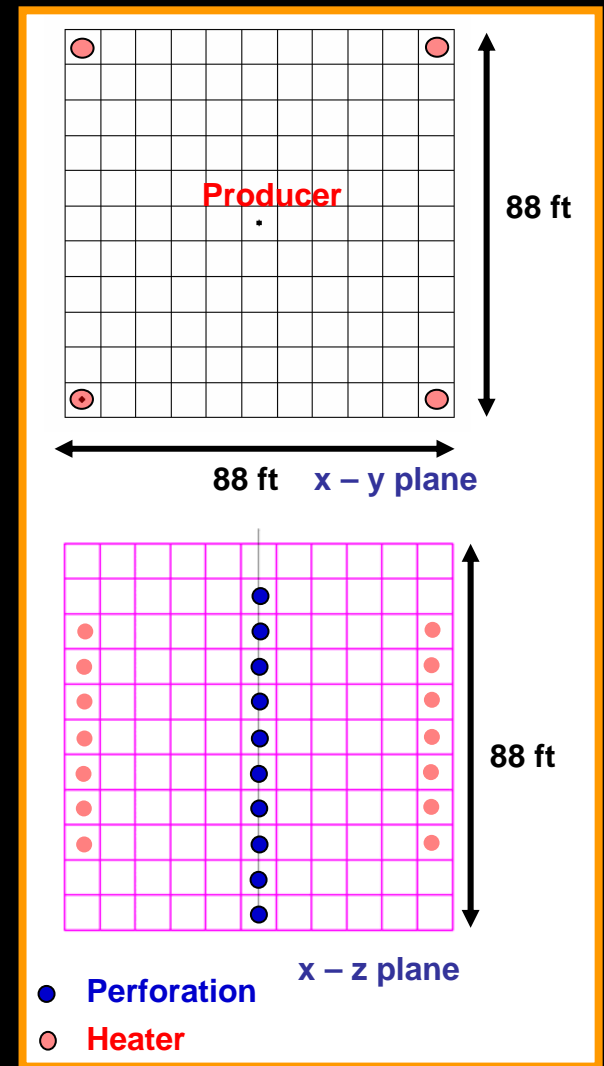
High
V. Perm



Modeling of in-situ pyrolysis

➤ Parameters (base-case):

- Initial kerogen concentration.
(0.08 lbmol / cf _[P.V.] ~ 11.1 wt.%)
- Heating rate per heater
(350000 btu / day)
- Horizontal permeability.
(10 mD)
- Vertical permeability.
(1 mD)



Porosity : 35 % ($v_f + v_k$) (3 ~ 10 % v_f)

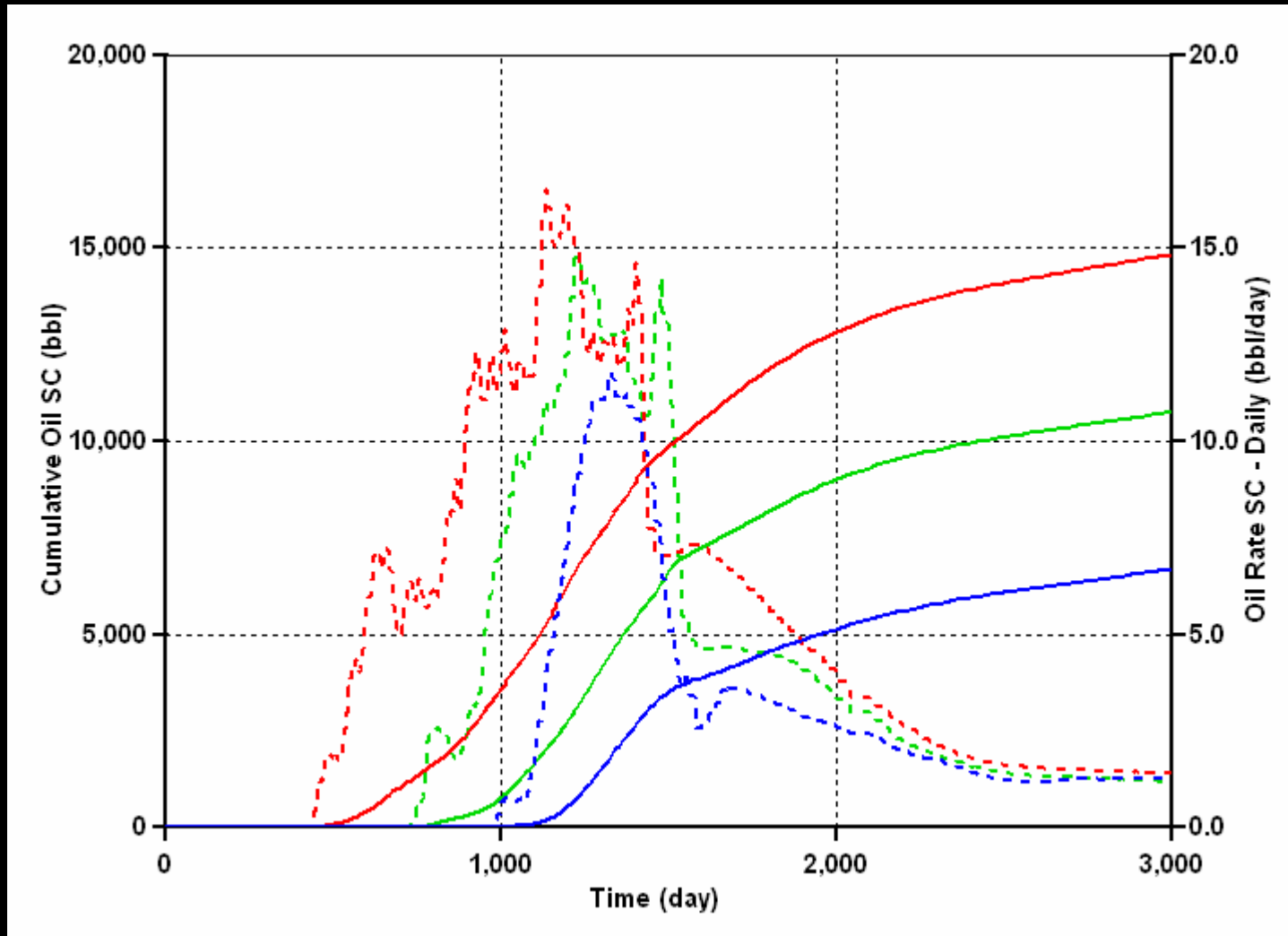
Residual water : 10 %

Initial pressure : 200 psi

$P_{\text{production}}$: 100 psi

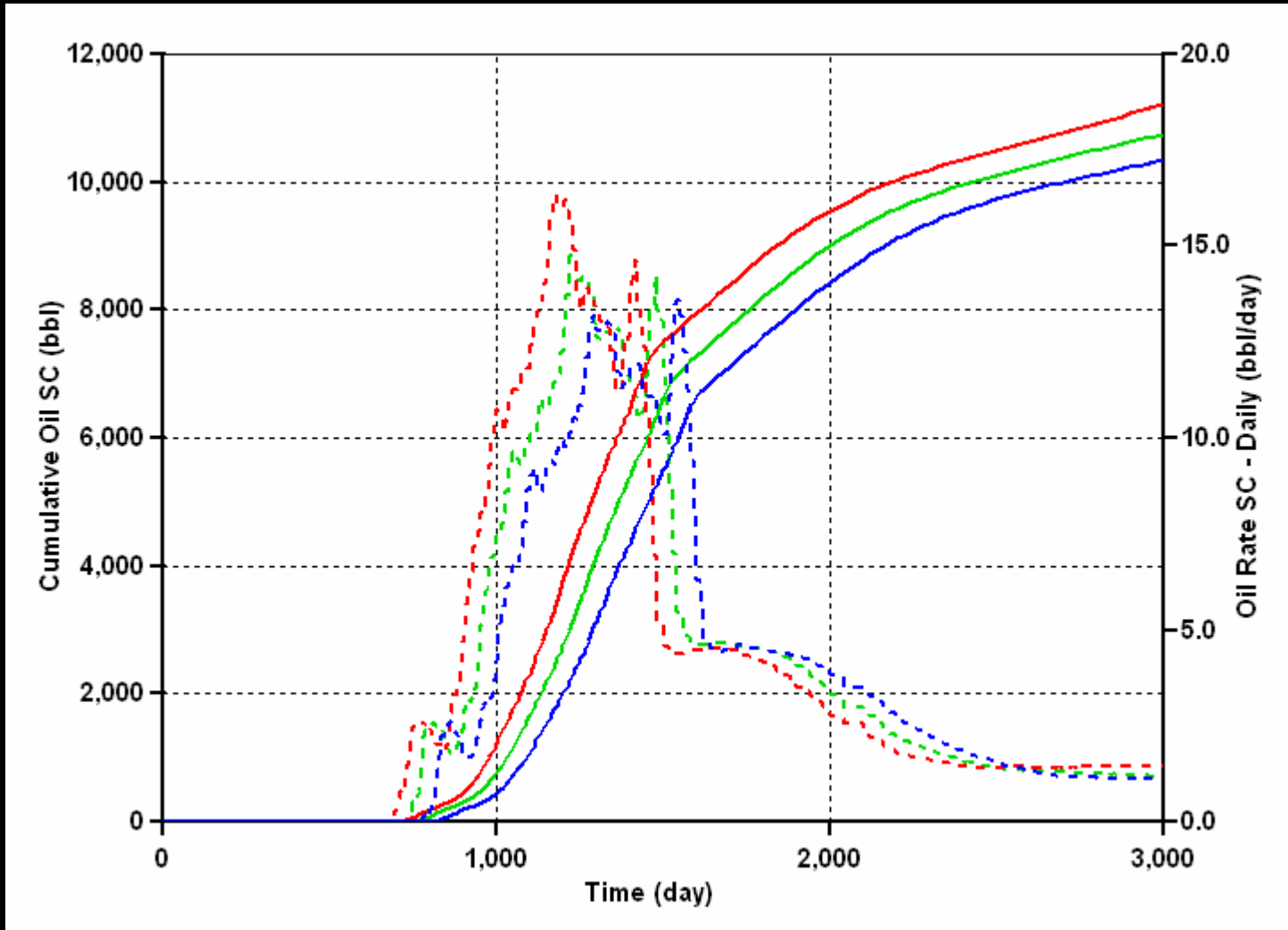
in-situ pyrolysis

Effect of initial kerogen concentration [9.7 11.1 12.5 wt.%]



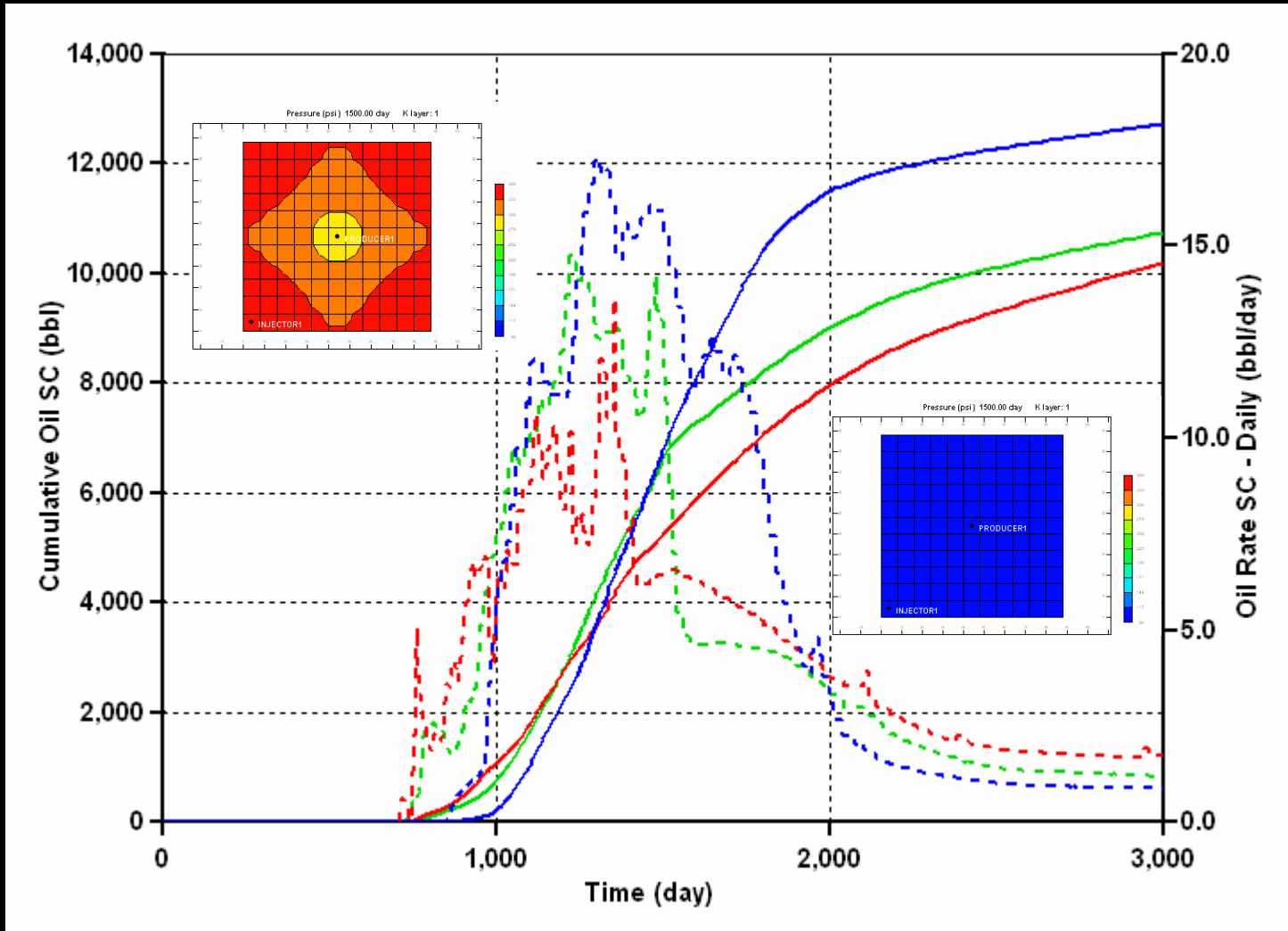
in-situ pyrolysis

Effect of heating source [330000 350000 370000 btu / day]



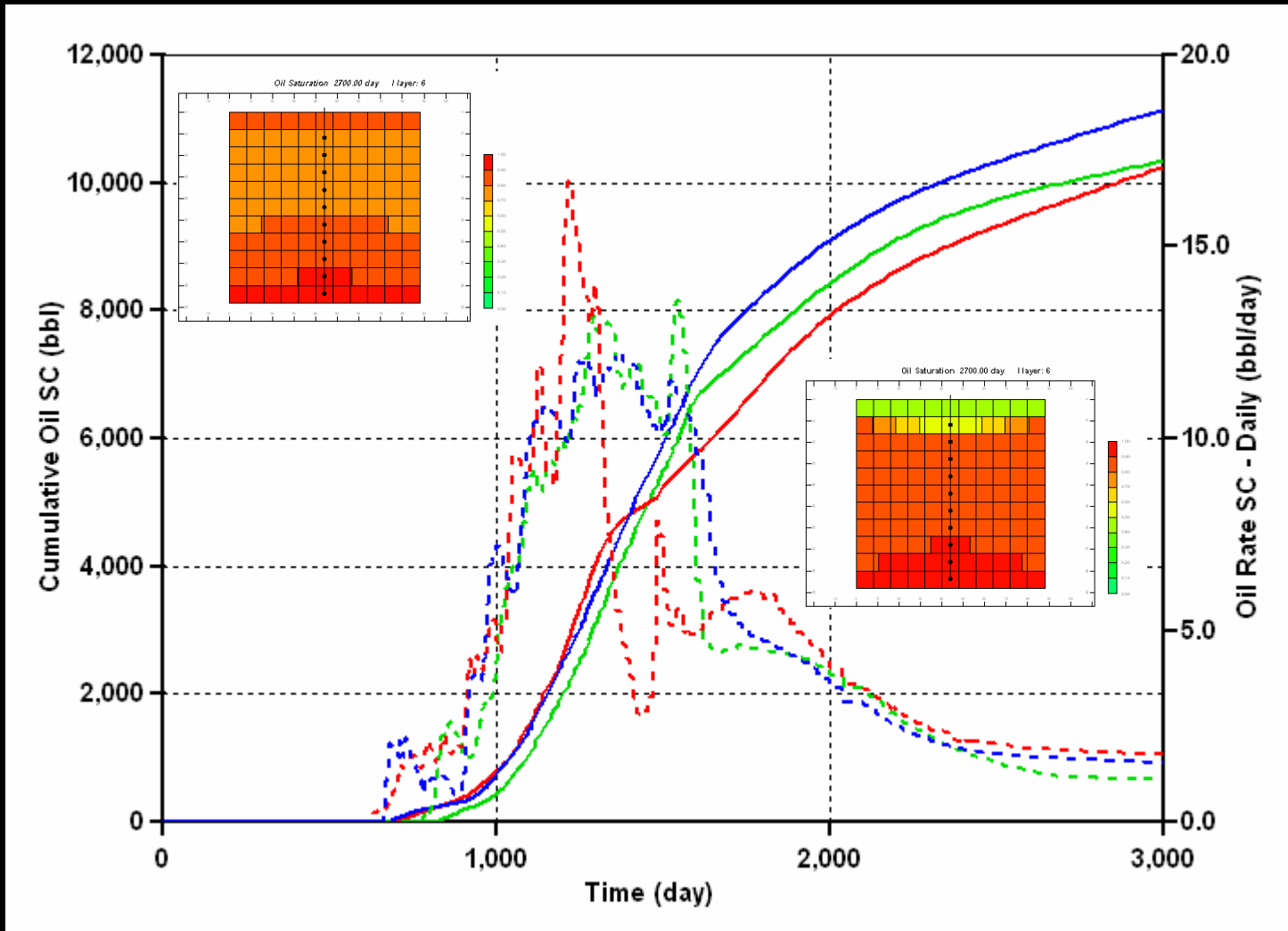
in-situ pyrolysis

Effect of horizontal permeability [1 10 100 mD]



in-situ pyrolysis

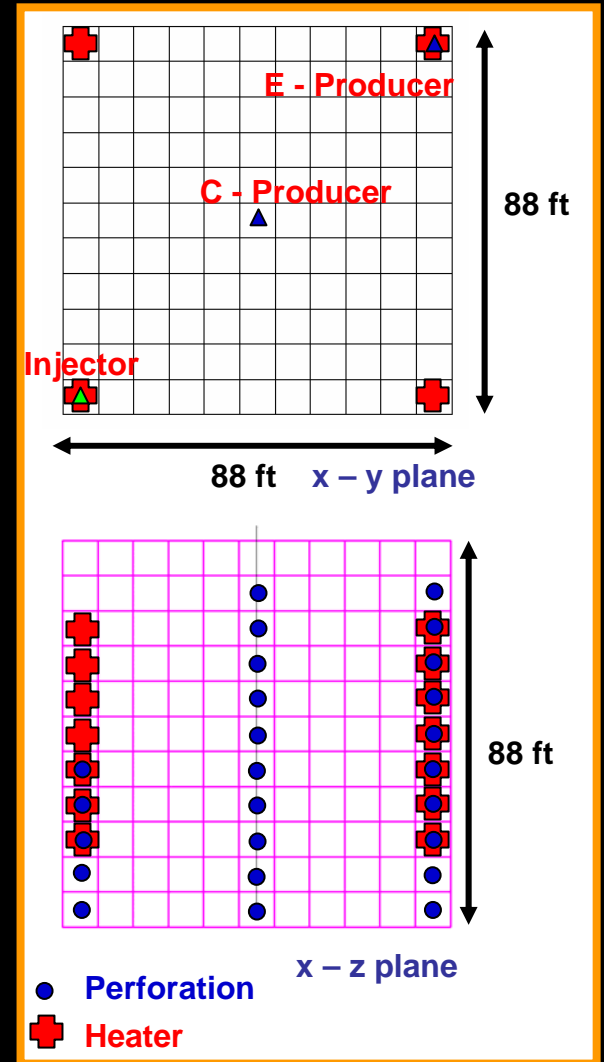
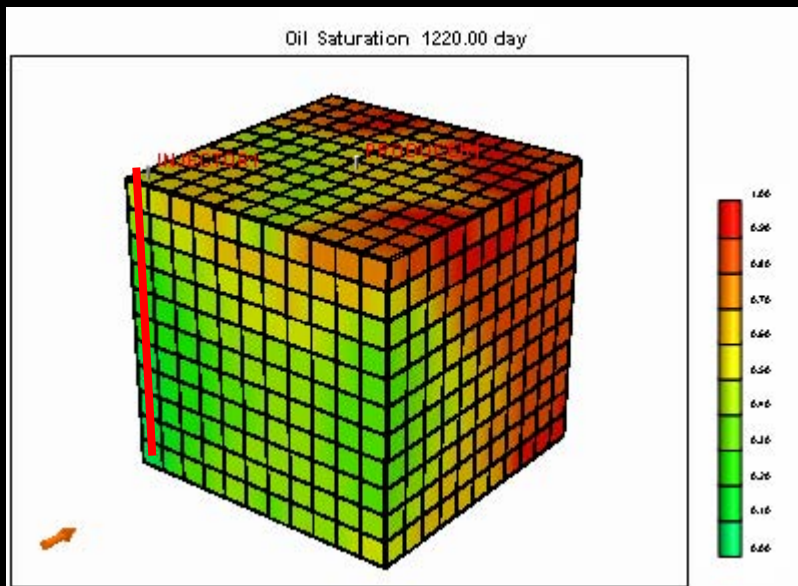
Effect of vertical permeability [0.1 1 10 mD]



Modeling of Modified Process

➤ Parameters (base-case):

- In-situ pyrolysis & combustion
 - Timing for switch
 - Air flow rate
 - Location of producer



Porosity : 35 % ($v_f + v_k$) (3 ~ 10 % v_f)

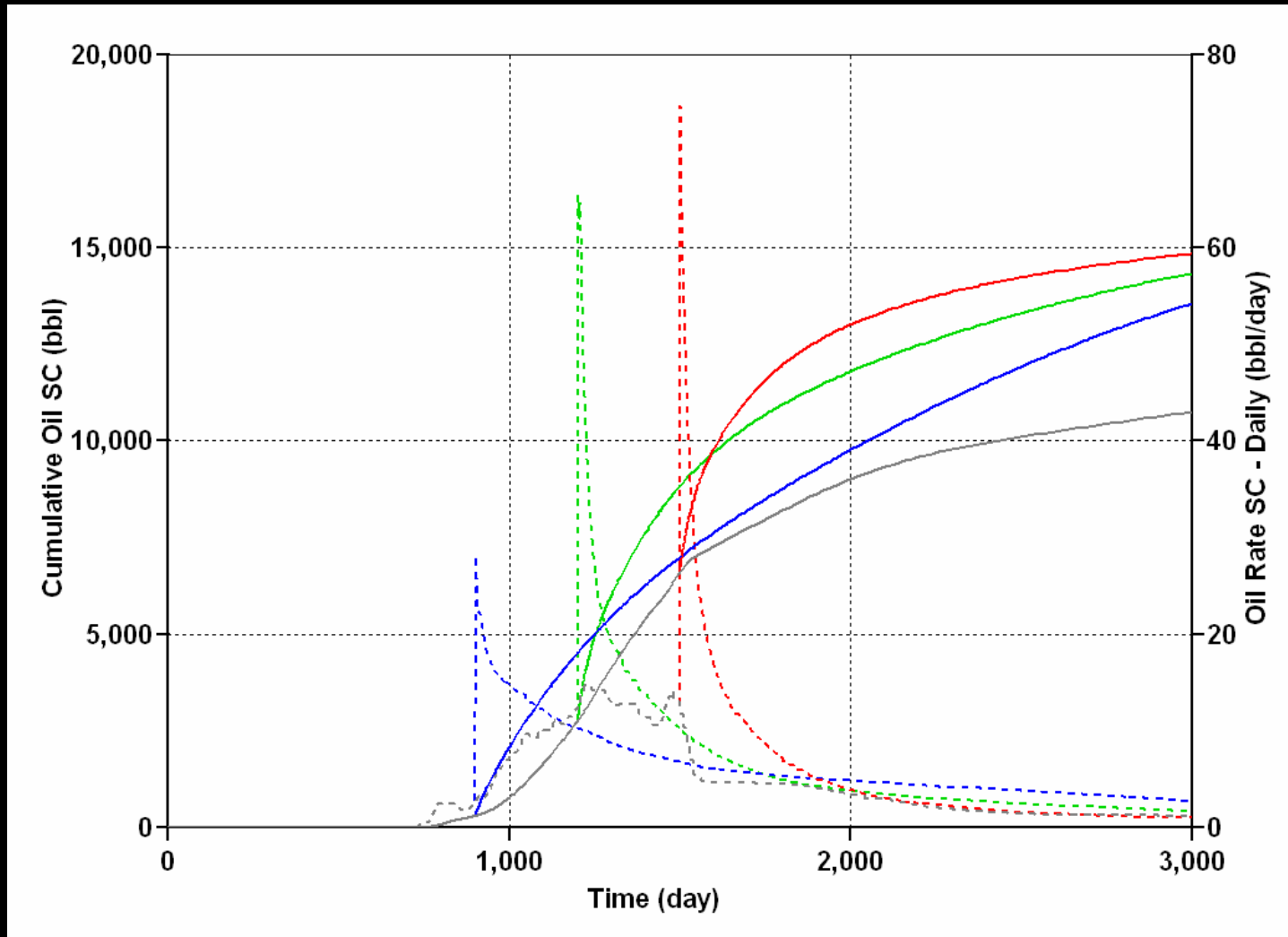
Residual water : 10 %

Initial pressure : 200 psi

$P_{\text{production}}$: 100 psi

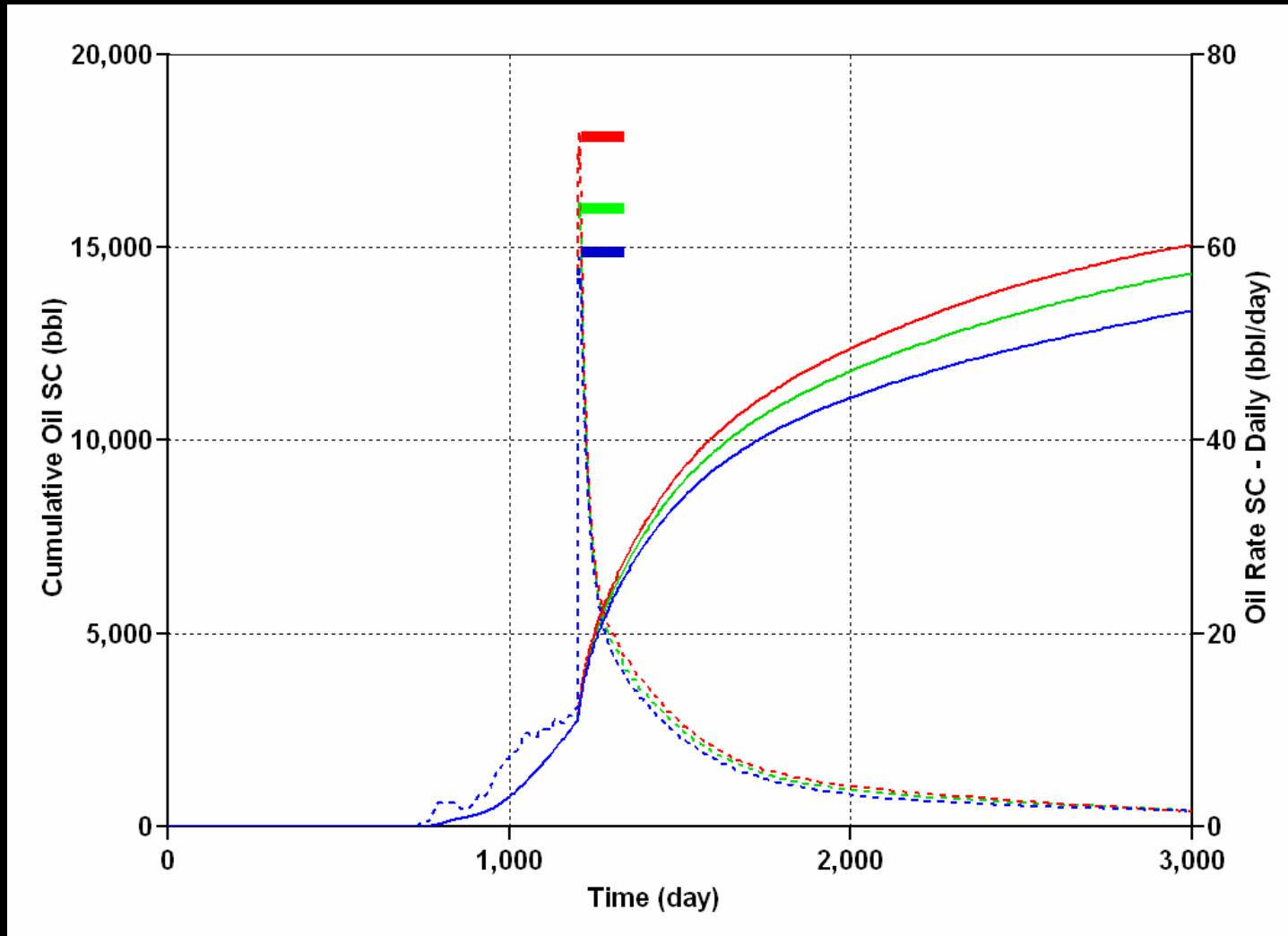
Process modification

Time to switch [N/A 900 1200 1500thday]



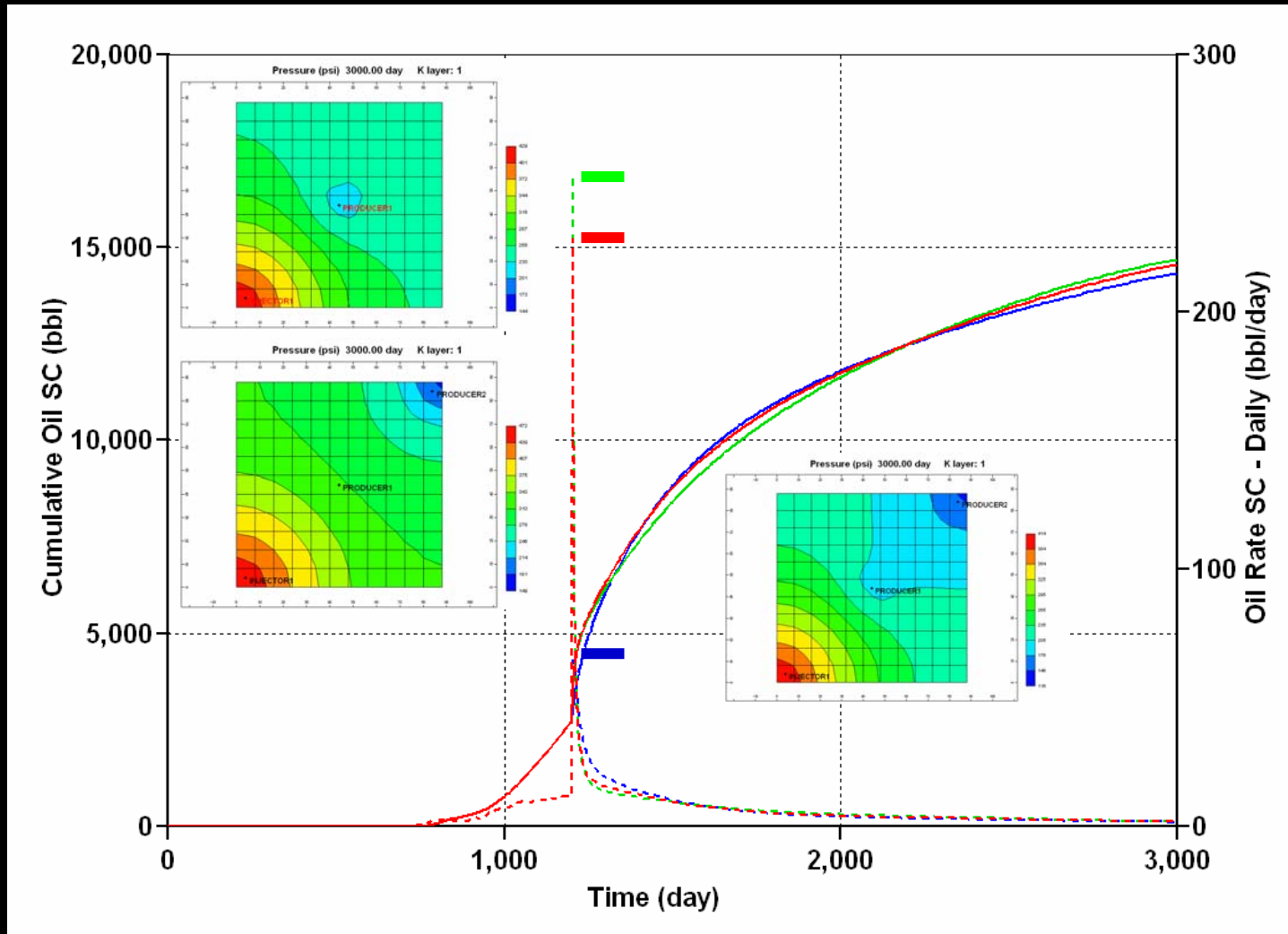
Process modification

Air flow rate [50000 70000 90000 sft / day]



Process modification

Well locations [1 – producer (C) 1 – producer (C→E) 2 – producer (E)]



Summary

- ❑ Preliminary reaction stoichiometric and kinetic models
- ❑ A number of assumptions regarding process parameters
 - Permeability creation for in-situ combustion
- ❑ Higher kerogen content leads to higher recovery as expected
- ❑ In in-situ combustion, higher air flow rate leads to higher recoveries
- ❑ Permeabilities play important role in in-situ pyrolysis
- ❑ In-situ combustion is energy sufficient – if the process is operationally viable
- ❑ Process optimization possible by combining concept of two processes

Future work

❑ Reaction model

- Component characterization, lumping
- Stoichiometry and kinetics

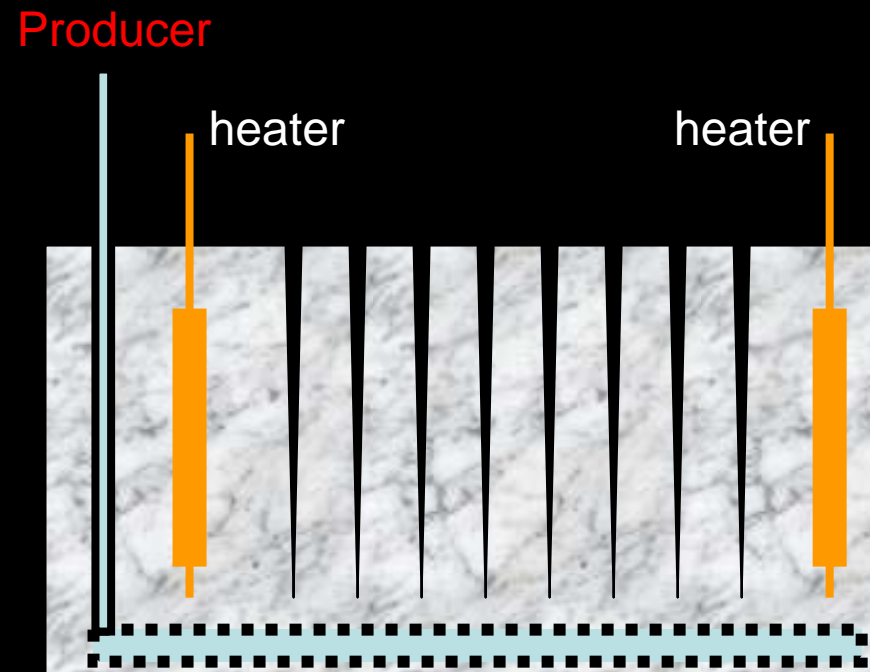
❑ Process parameters

❑ Reservoir characterization

- Fractures, faults
- Reservoir heterogeneity

❑ Geomechanical coupling

❑ Engineering to address specific needs



Acknowledgement

□ Department of Energy

□ Petroleum Research Center at University of Utah

□ Utah Heavy Oil Center at University of Utah

□ Computer Modelling Group LTD.