What's Wrong With My Waterflood???

SPE Tulsa Section
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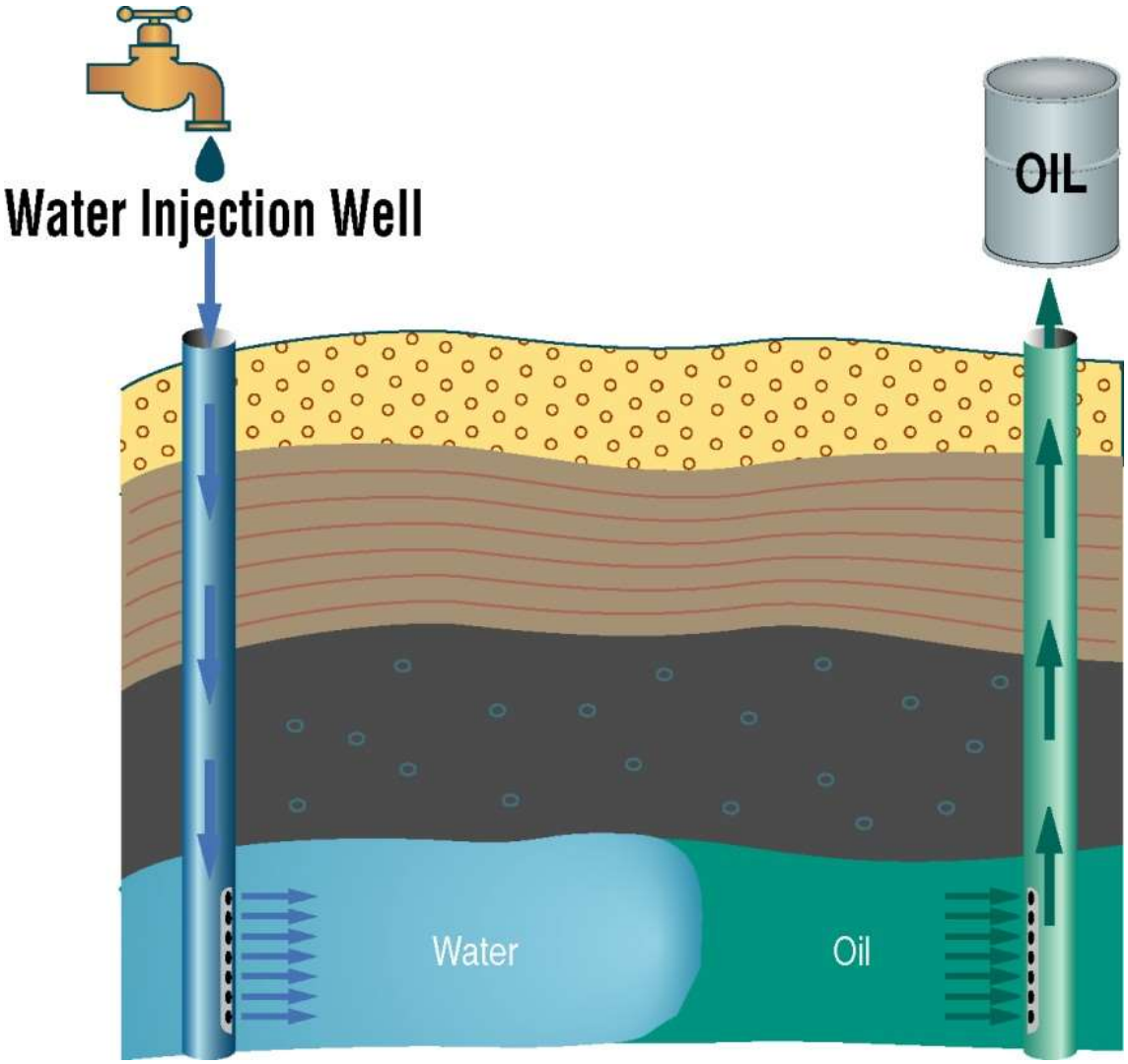
F. J. "Deacon" Marek, P.E.
Senior VP – Technical Advisor

William M. Cobb & Associates, Inc.
Dallas, Texas

TOPICS

- ***Waterflooding is a secondary oil recovery process***
  - *follows "primary", solution gas drive recovery*
  - *therefore a "secondary" recovery process*
- ***Ideal waterflood reservoir conditions***
- ***Waterflood recovery factors***
- ***Common problems with waterflood performance***


Water Injection Well
OIL
Water
Oil

Waterflooding as a Recovery Process

- ***Recognized enhanced oil recovery technique since the early 1900's***
- ***Pennsylvania***
  - ***Accidental waterflood ~ 1890's***
  - ***Illegal waterflooding ~ 1910's***
  - ***Legalized waterflooding ~ 1921***
- ***Oklahoma early 1931***
- ***Texas, Kansas, New York, and California were also early players***

Ideal Waterflood Properties

Rock Properties

- ***Shallow (cheap)***
- ***High perm***
- ***Low perm variation***
- ***High porosity***
- ***High rock continuity at current well spacing***
- ***Low residual oil saturation***

Fluid Properties

- ***Higher API gravity***
  - ***Lower viscosity***
  - ***Lower mobility ratio***
  - ***Improved areal sweep***
- ***Low energy (low GOR)***
  - ***Low bubble point Press.***
  - ***Low primary recovery***
  - ***Lower Sg at depletion***
  - ***Higher S/P ratio***

Waterflood Recovery Factors

- ***Primary oil recovery factors typically range from about 5% to 20% OOIP for solution gas drive reservoirs***
- ***Waterflood recovery factor***
  - ***Primary + Secondary recovery***
  - ***Generally 20% to 40%+ OOIP***
- ***Secondary/Primary (S/P) ratio***
  - ***Generally ranges from 0.5 to 2.0+***
  - ***Generally higher for lower energy oil***

Two Typical Waterflood Problems

1. *Longer than expected response time*
2. *Early water breakthrough*

P R O B L E M 1

L O N G R E S P O N S E T I M E

Long Response Time

1. *High gas saturation*
2. *Low injector/producer ratio*
3. *Low injectivity (low perm)*
4. *Poor injection efficiency*

Long Response Time

1. ***High gas saturation***
   - ***Probably most common reason***
   - ***We'll spend most of our time here***
2. ***Low injector/producer ratio***
3. ***Random pattern (or no pattern)***
4. ***Low injectivity***
5. ***Poor injection efficiency***

1. High Gas Saturation (Sg)

- ***Higher primary depletion (lower BHP) leads to higher gas saturation (Sg), but does depend on Pbp***
- ***High gas saturation leads to:***
  - ***Large "fillup" volume***
  - ***Lengthy fillup time***
  - ***Early water breakthrough***
  - ***Reduced waterflood oil recovery***
- ***Example gas saturation calculation….***

Gas Saturation

Oil and gas saturations at start of injection:

So = (1-Swc)*(1-Erb)*(Bo/Bob)

Sg = 1 - Swc – So

Where:

So = oil saturation, fraction PV

Sg = gas saturation, fraction PV

Swc = connate water saturation, fraction PV

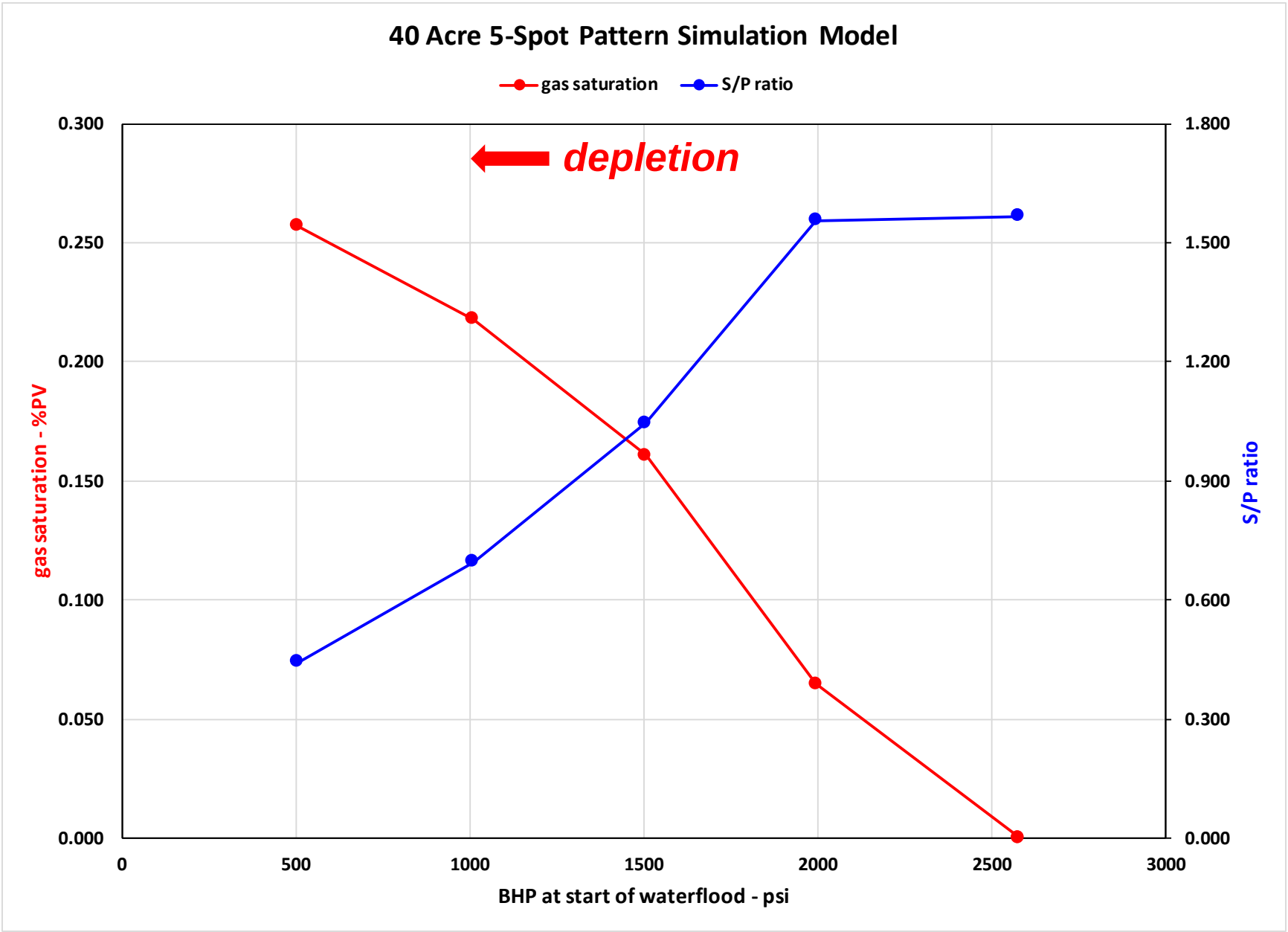
Erb = oil recovery from bubble point, fraction OOIP

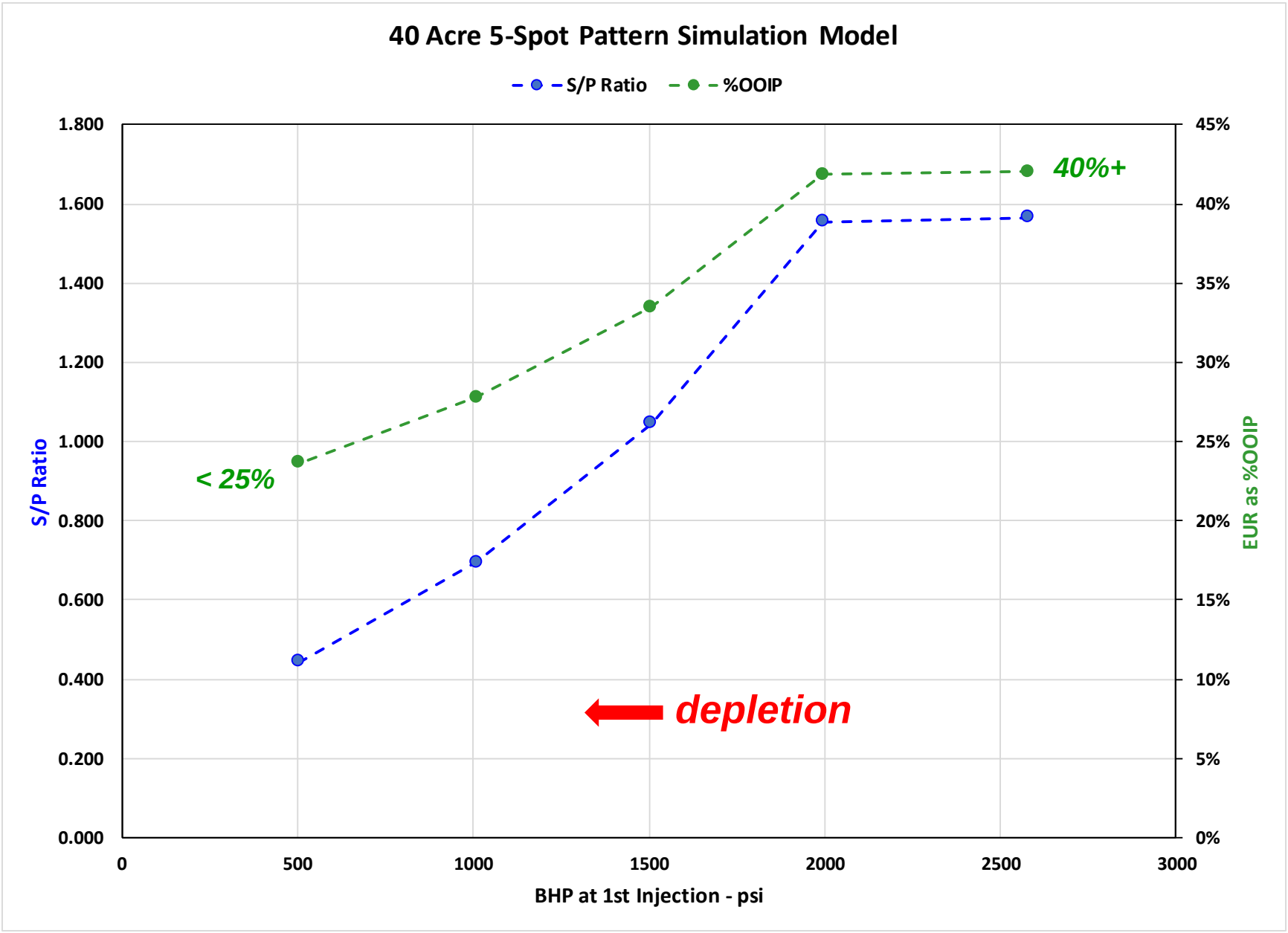
Bo = current oil FVF, RB/STB

Bob = oil FVF at bubble point, RB/STB

Gas Saturation (Sg)

- ***Sg is a function of depletion (BHP) below the system bubble point pressure***
- ***Following graph is for an oil with moderate properties***
  - ***Rsi ~ 750 scf/STB***
  - ***Boi = 1.40***

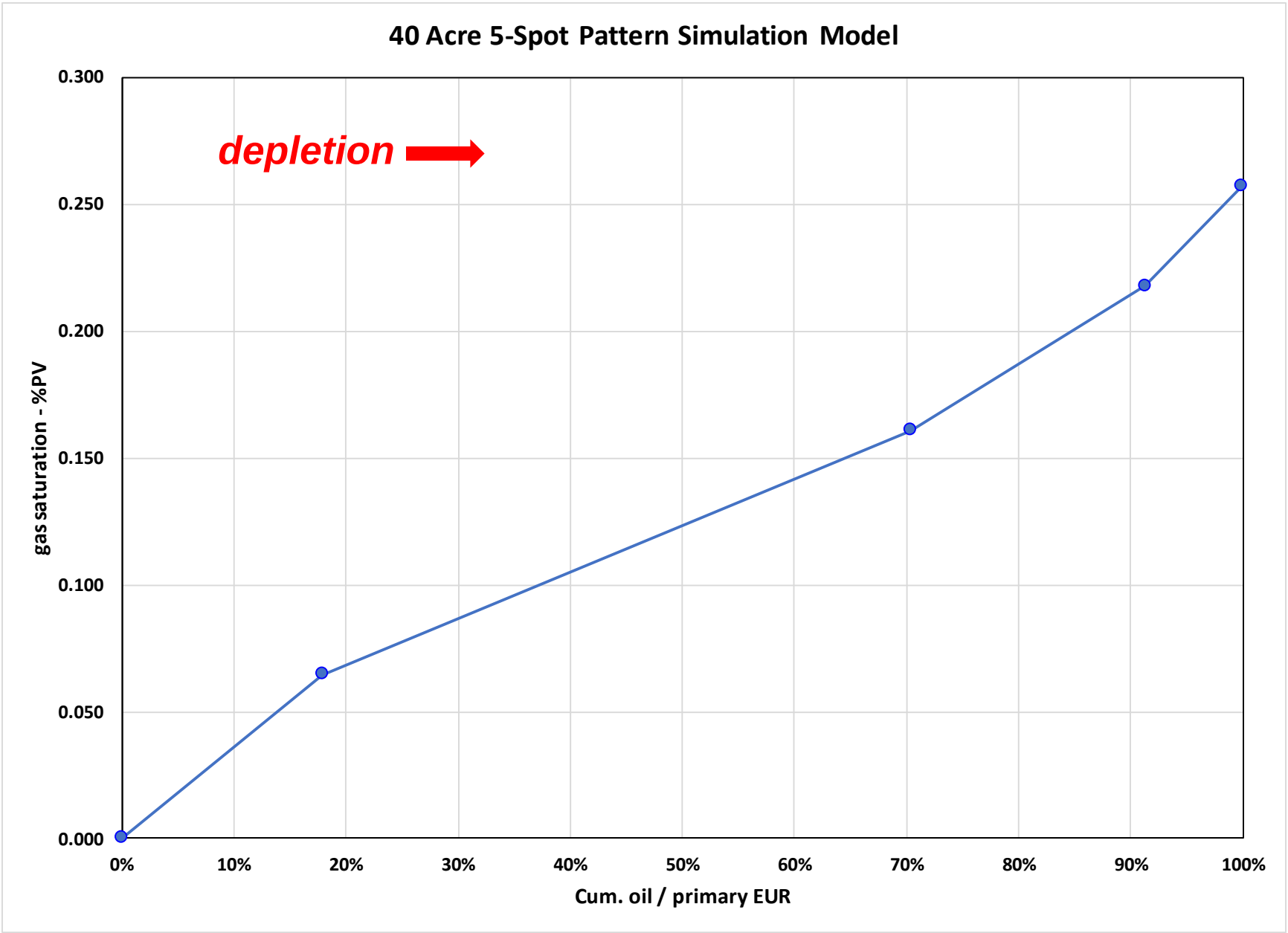

40 Acre 5-Spot Pattern Simulation Model
gas saturation
S/P ratio
depletion
0.300
0.250
0.200
0.150
0.100
0.050
0.000
1.800
1.500
1.200
0.900
0.600
0.300
0.000
gas saturation - %PV
S/P ratio
0
500
1000
1500
2000
2500
3000
BHP at start of waterflood - psi

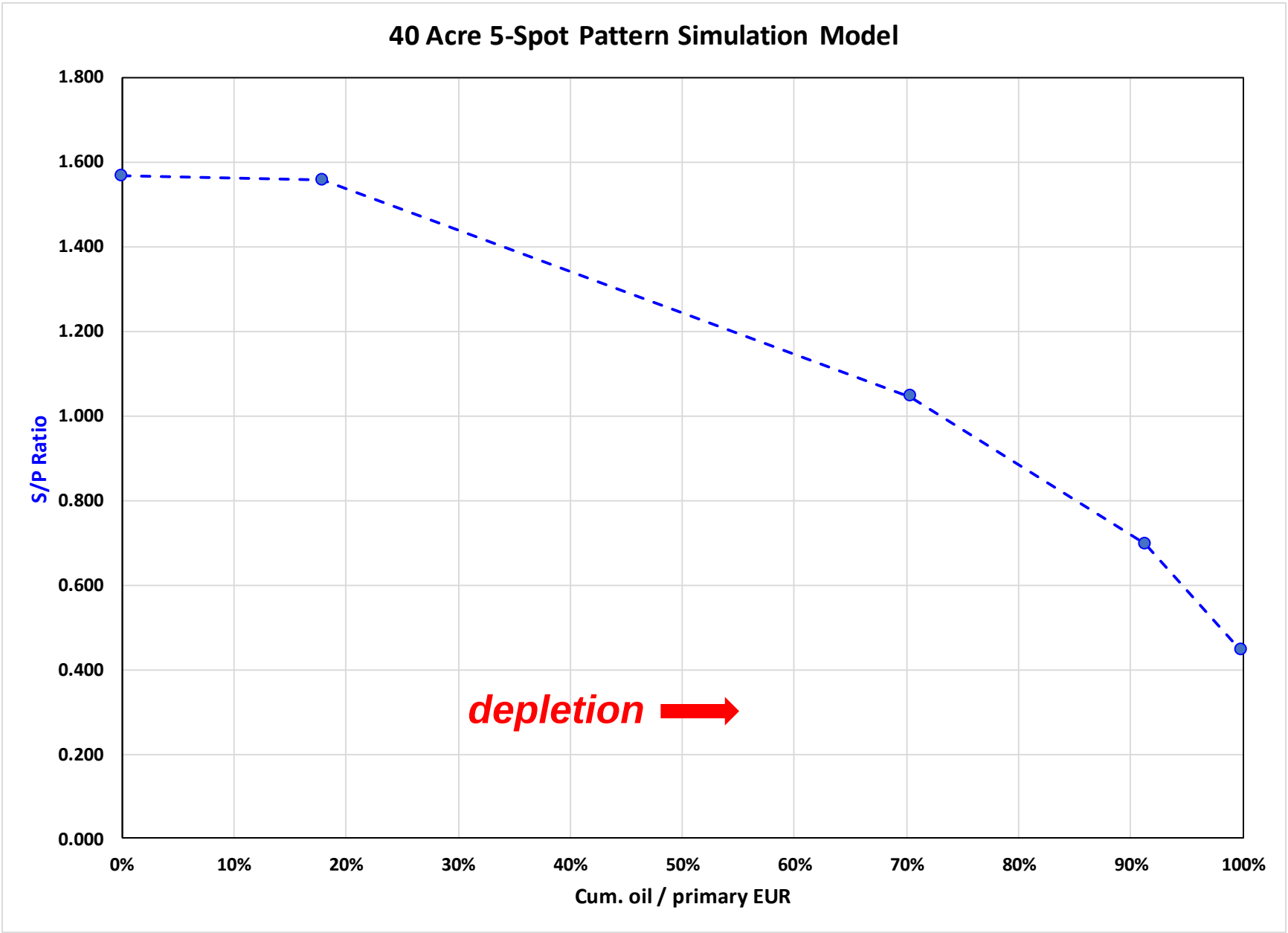

40 Acre 5-Spot Pattern Simulation Model
S/P Ratio
%OOIP
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
S/P Ratio
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
EUR as %OOIP
40%+
< 25%
depletion
0
500
1000
1500
2000
2500
3000
BHP at 1st Injection - psi

Gas Saturation (Sg)

- ***Sg is a function of depletion (BHP)***
- ***But many times, BHP is unknown***
- ***Cumulative oil production can be used as a "proxy" for BHP depletion:***

Depletion = Cum. oil / primary EUR


40 Acre 5-Spot Pattern Simulation Model
depletion
0.300
0.250
0.200
0.150
0.100
0.050
0.000
gas saturation - %PV
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Cum. oil / primary EUR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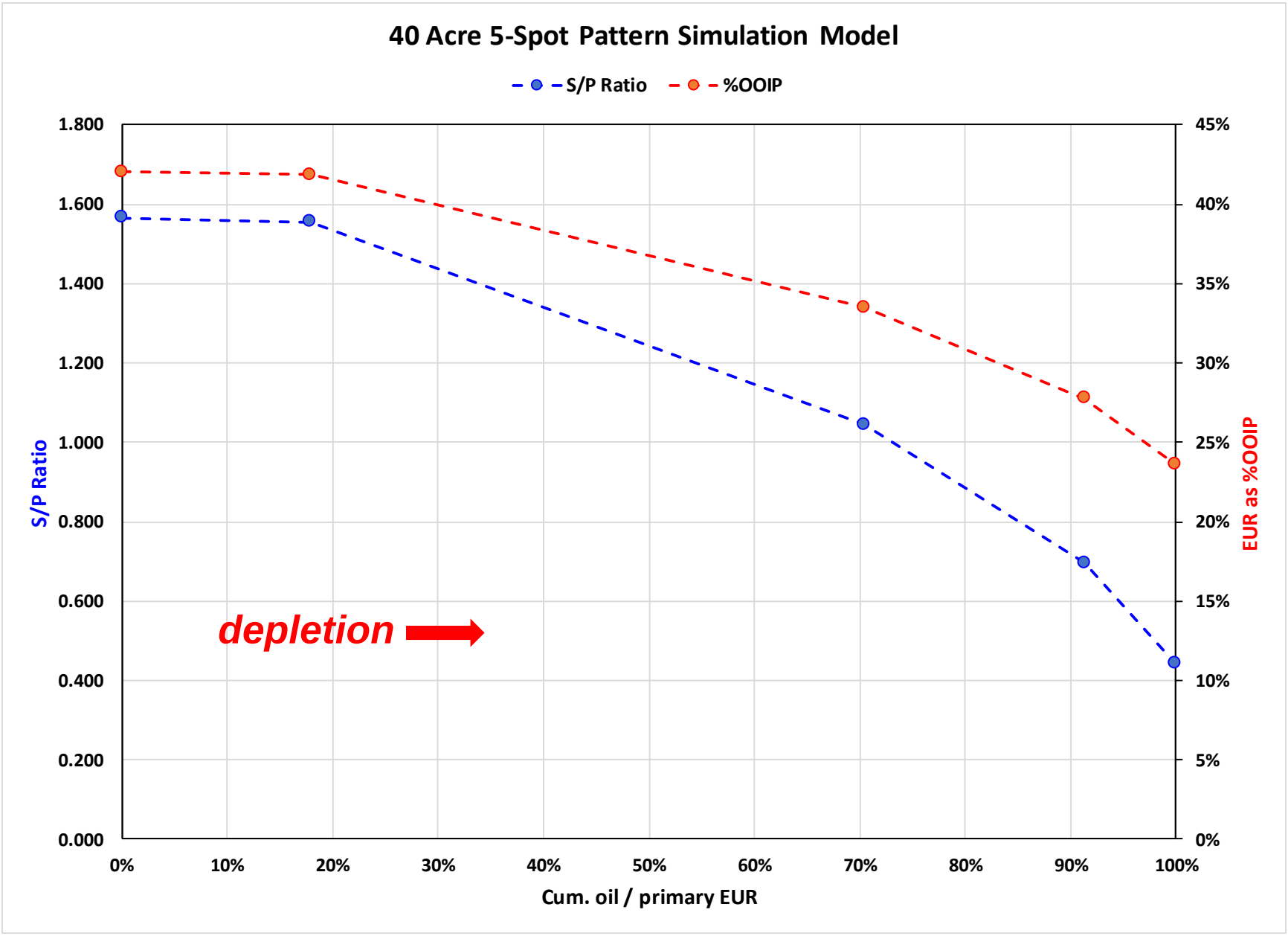
S/P Ratio
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Cum. oil / primary EUR
depletion


40 Acre 5-Spot Pattern Simulation Model
S/P Ratio
%OOIP
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
S/P Ratio
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
EUR as %OOIP
depletion
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Cum. oil / primary EUR

Long Response Time

1. ***High gas saturation***
2. ***Low injector/producer ratio***
3. ***Low injectivity (low perm)***
4. ***Poor injection efficiency***

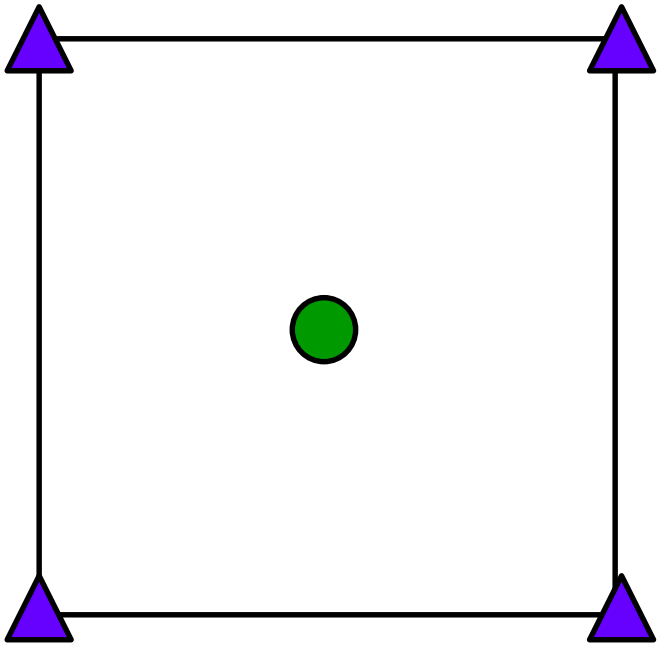
2. Low Injector/Producer Ratio

- ***Extends gas fillup time***
- ***May need to convert more wells to injection***
- ***Re-configure or fully develop the waterflood pattern***
- ***Example***
  - ***use a 9-spot versus a 5-spot pattern***
  - ***Next slide…***

Five Spot Pattern

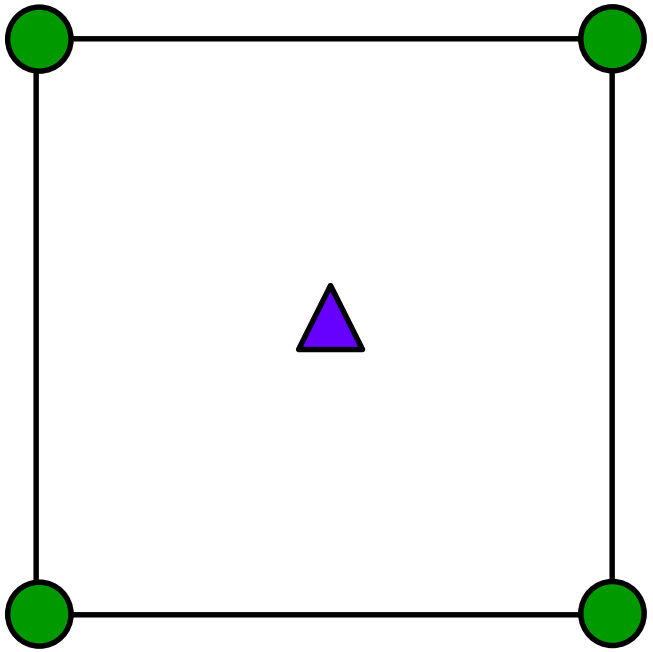
1:1 injector to producer ratio

normal



1:1 injector to producer ratio

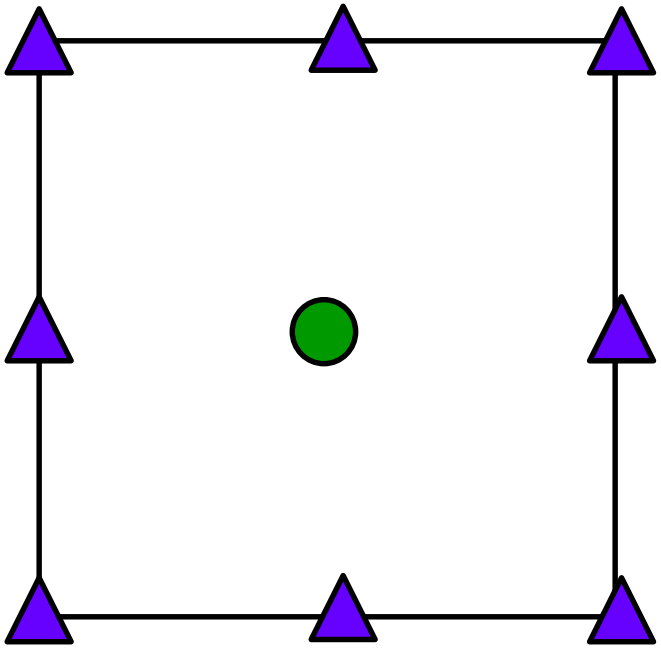
inverted



Nine Spot Pattern

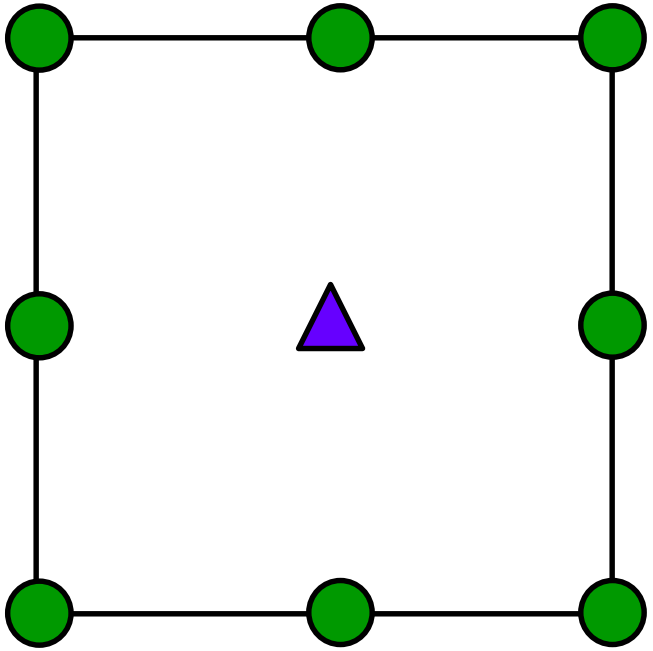
3:1 injector to producer ratio

normal



1:3 injector to producer ratio

inverted



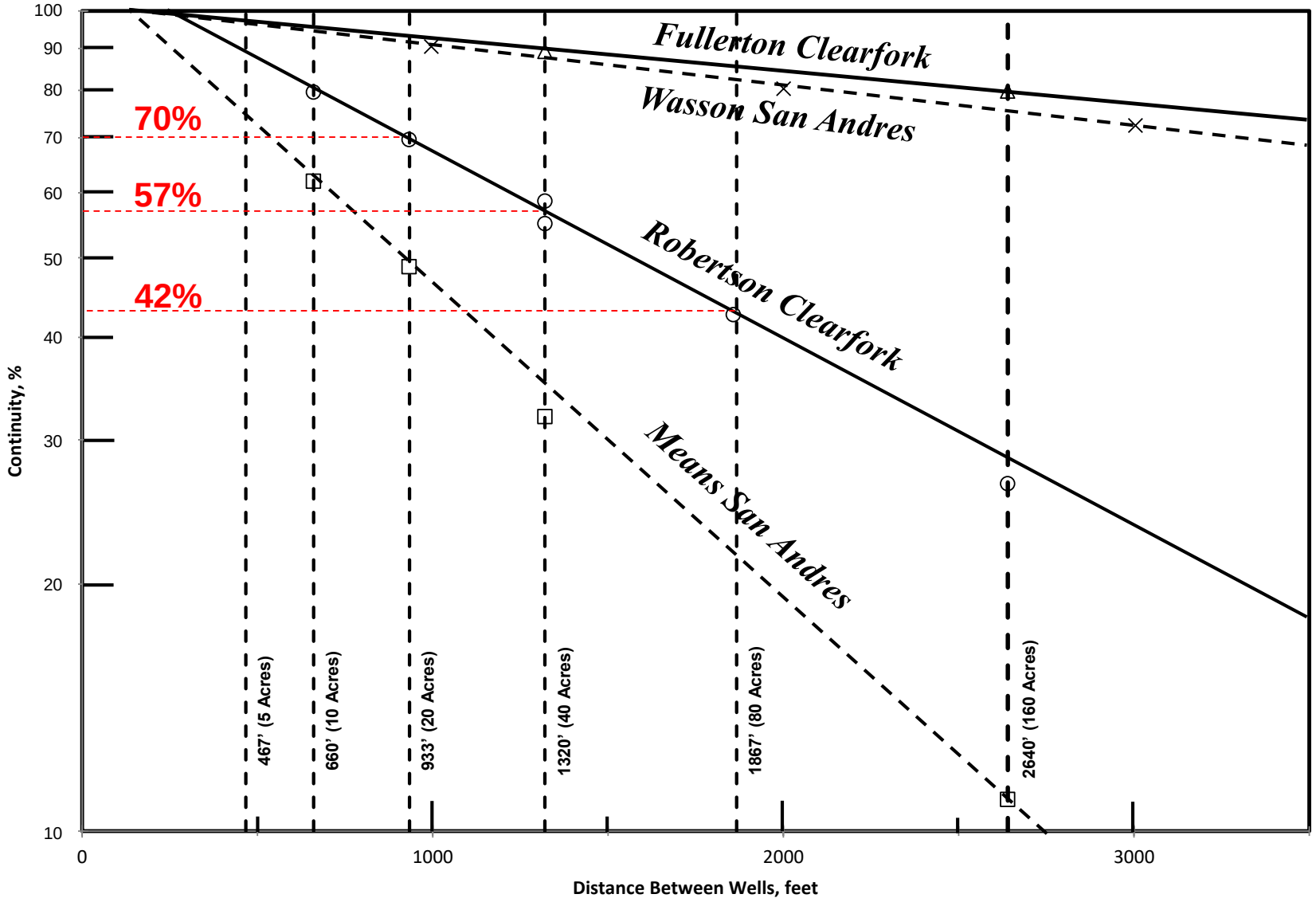
Long Response Time

1. ***High gas saturation***
2. ***Low injector/producer ratio***
3. ***Low injectivity (low perm)***
4. ***Poor injection efficiency***

3. Low Injectivity

- ***May be due to low permeability***
  - ***May be addressed with well stimulation***
    - ***Acid or small frac***
  - ***Only solution may be infill drilling***
- ***Could be due to poor rock continuity***
  - ***Again, only solution is infill drilling***

From SPE #18941, Gould & Sarem, Fig. 5



Long Response Time

1. *High gas saturation*
2. *Low injector/producer ratio*
3. *Low injectivity (low perm)*
4. ***Poor injection efficiency***

4. Poor Injection Efficiency

- ***Loss of some of the injection water out of zone***
  - ***Very common, happens in most floods***
- ***Potential causes***
  - ***Poor cement jobs***
  - ***Excessive injection pressure***
    - ***Surface pressure***
    - ***Bottom hole injection gradient***
- ***Should run periodic injection profile surveys to monitor injection operations***

P R O B L E M 2

P R E M A T U R E W A T E R B R E A K T H R O U G H

Early Water Breakthrough

- ***Possible directional permeability***
- ***Poor mobility ratio ('M')***
- ***High permeability variation***
- ***High gas saturation (discussed earlier)***
- ***Large hydraulic fractures oriented from injector to producer***

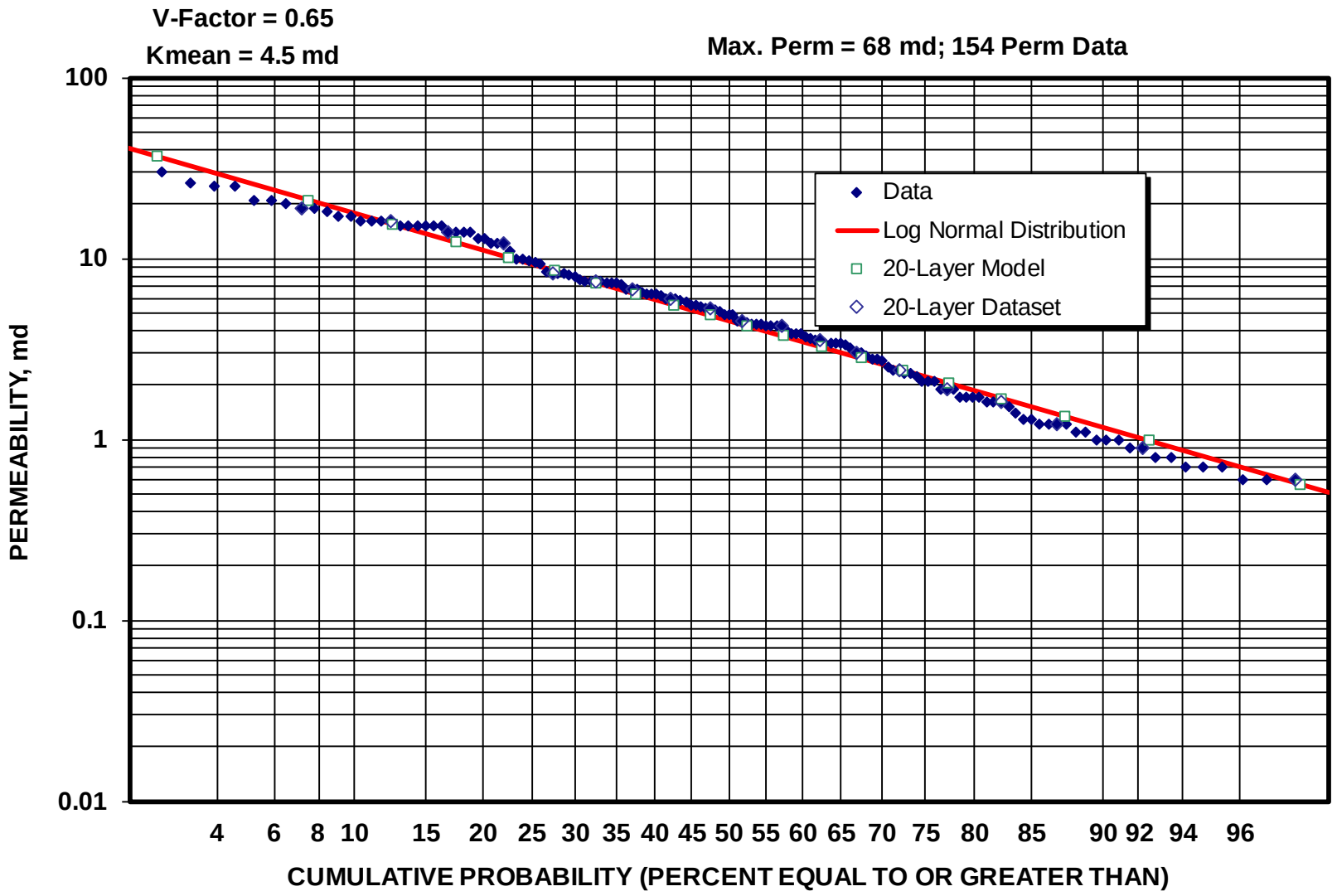
Early Water Breakthrough

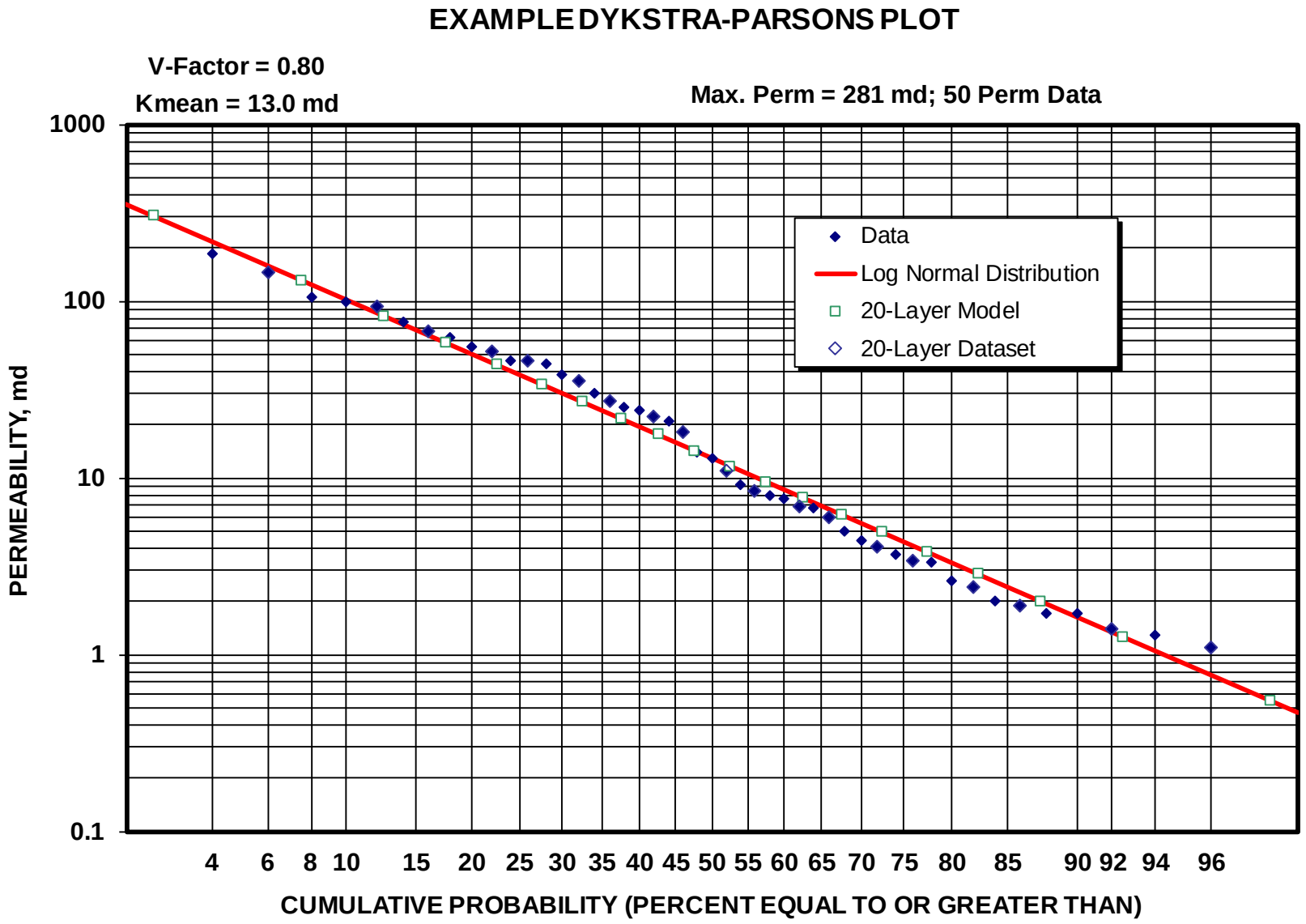
- ***Possible directional permeability***
- ***Poor mobility ratio ('M')***
- ***High permeability variation***
  - ***Dykstra-Parsons 'V' factor***
- ***High gas saturation***
- ***Large hydraulic fractures oriented from injector to producer***

Dykstra-Parsons 'V' Factor

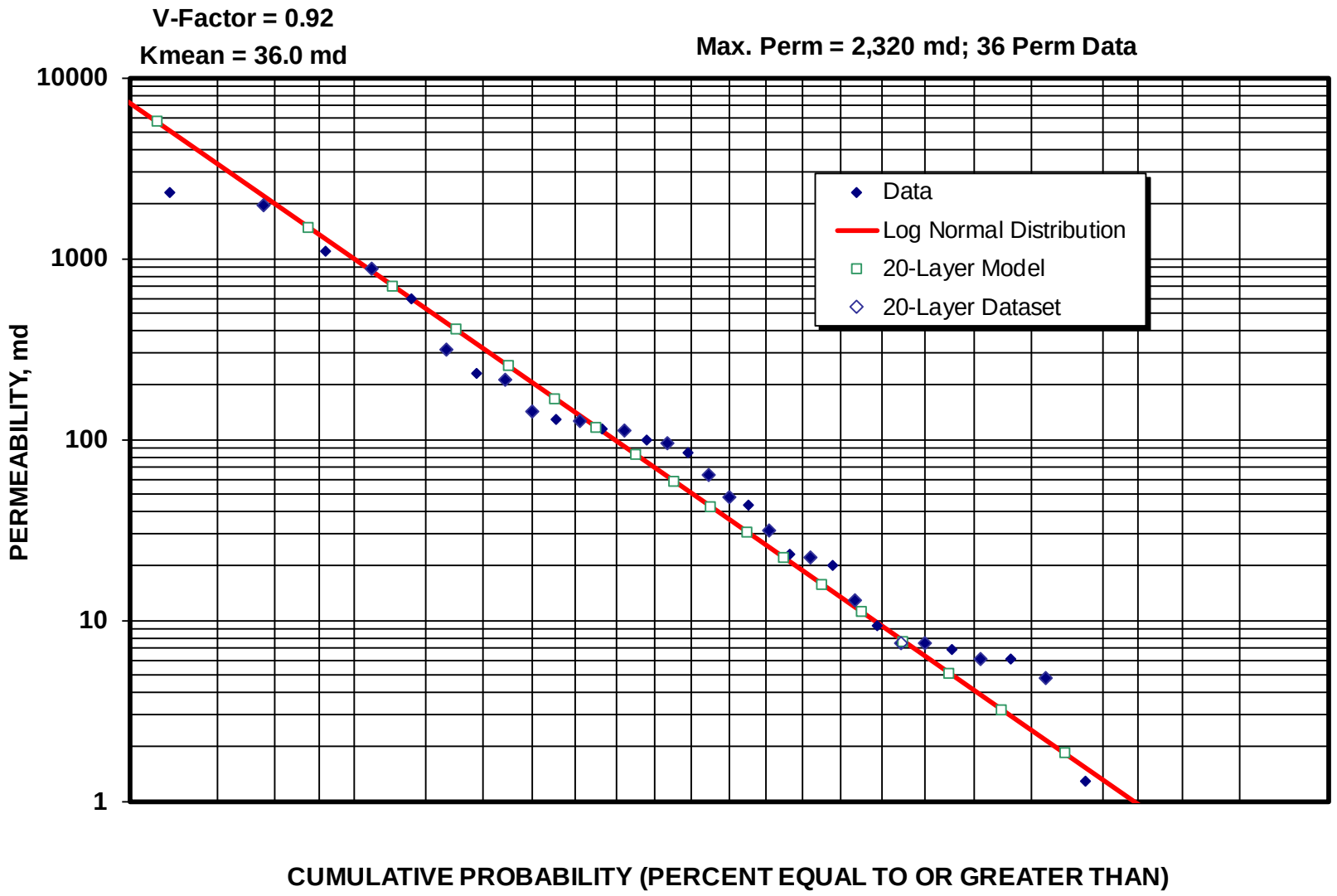
- *Calculated from core data*
- *'V' factor is a measure of perm variation*
  - *Lower slope ('V') > less perm variation*
  - *Higher slope ('V') > more perm variation*
- *Theoretical range for 'V'*
  - *Zero for equal value perm's – no variation*
  - *Approaches 1.0 for extreme variation*
- *Practical, "real world" range for 'V'*
  - *Close to 0.5 for very homogeneous sand (E TX Woodbine)*
  - *'V' = 0.90+ for some West Texas carbonates*

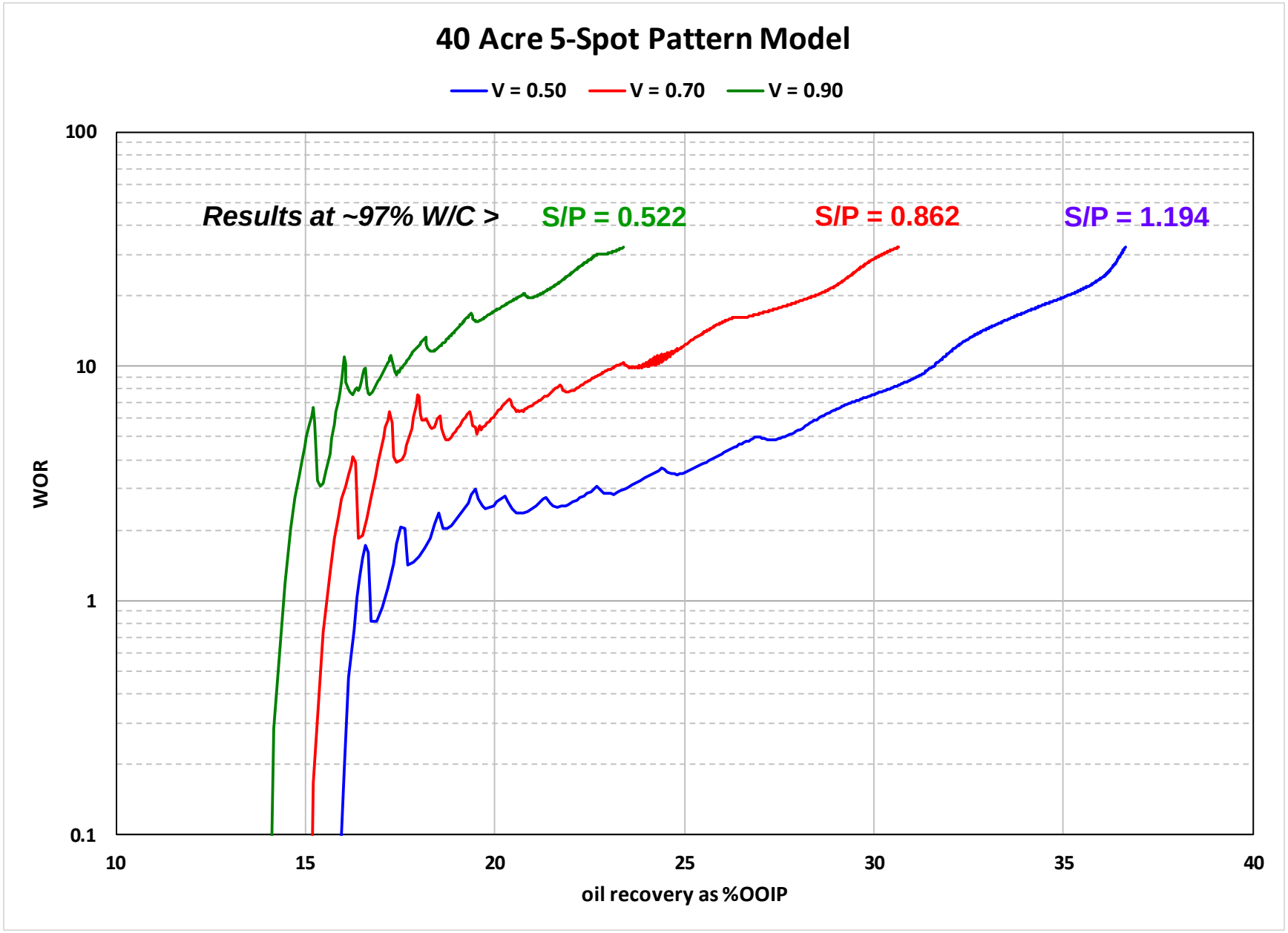
EXAMPLE DYKSTRA-PARSONS PLOT




EXAMPLE DYKSTRA-PARSONS PLOT
V-Factor = 0.80
Kmean = 13.0 md
Max. Perm = 281 md; 50 Perm Data
PERMEABILITY, md
1000
100
10
1
0.1
Data
Log Normal Distribution
20-Layer Model
20-Layer Dataset
4 6 8 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 92 94 96
CUMULATIVE PROBABILITY (PERCENT EQUAL TO OR GREATER THAN)

EXAMPLE DYKSTRA-PARSONS PLOT




40 Acre 5-Spot Pattern Model
V = 0.50
V = 0.70
V = 0.90
Results at ~97% W/C >
S/P = 0.522
S/P = 0.862
S/P = 1.194
100
10
1
0.1
WOR
10
15
20
25
30
35
40
oil recovery as %OOIP

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