Evaluation and Optimization of Double Displacement Process

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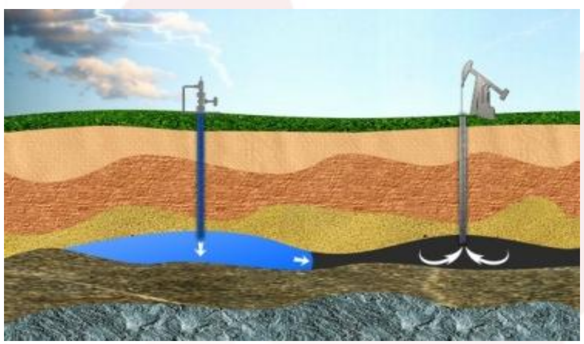
Outline

- Introduction
- Oil Recovery Mechanism from DDP
- Methodology
- Result and Discussion
- Conclusion

Introduction

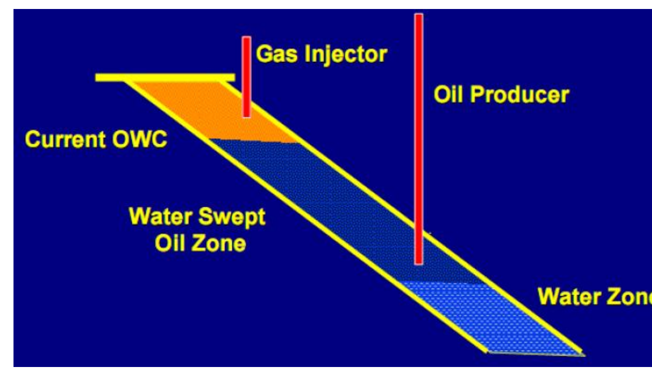
Water injection + **Gas injection** = **DDP**

Water injection



A lot of oil remaining

Gas injection

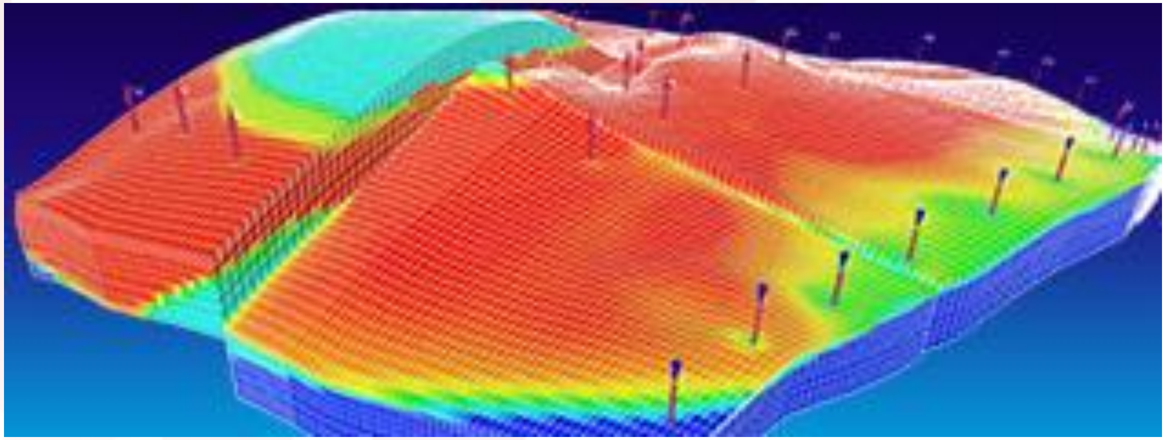


Objectives

- To study the effect of different design parameters on double displacement process.
  - Stopping time for water injection
  - Water and gas injection rate
  - Well pattern
- To study the effect of different system parameters on double displacement process.
  - Relative permeability
  - Vertical to horizontal permeability ratio
  - Wettability

Introduction

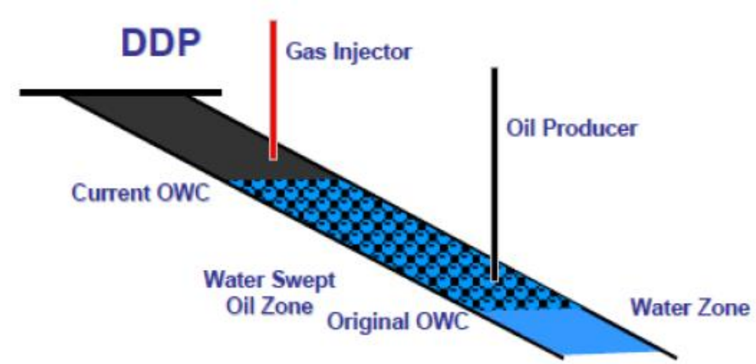
- Use ECLIPSE reservoir simulator to evaluate the performance of DDP.



Oil Recovery Mechanism from DDP

<u>Oil recovery by gravity drainage</u>

- The important feature in gravity-drainage reservoirs is the **density difference** between reservoir oil and gas.
- The fluids in petroleum reservoirs have all been subjected to the forces of gravity fluids, i.e., gas on top, oil underlying the gas, and water underlying oil.



Methodology

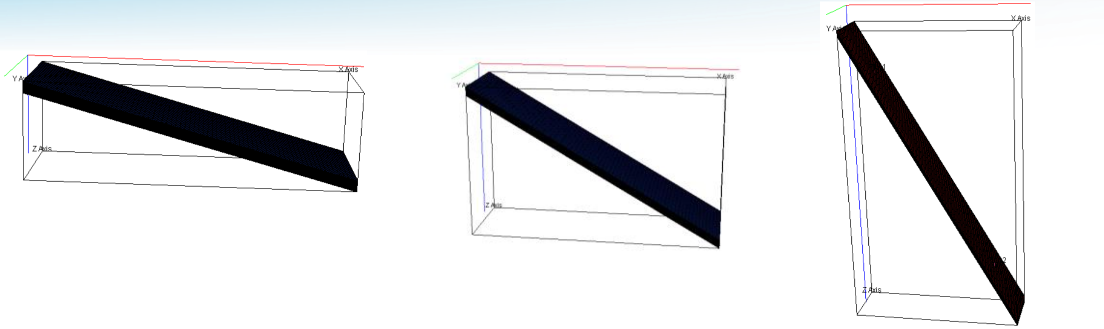
Construct the reservoir model with different dip angle

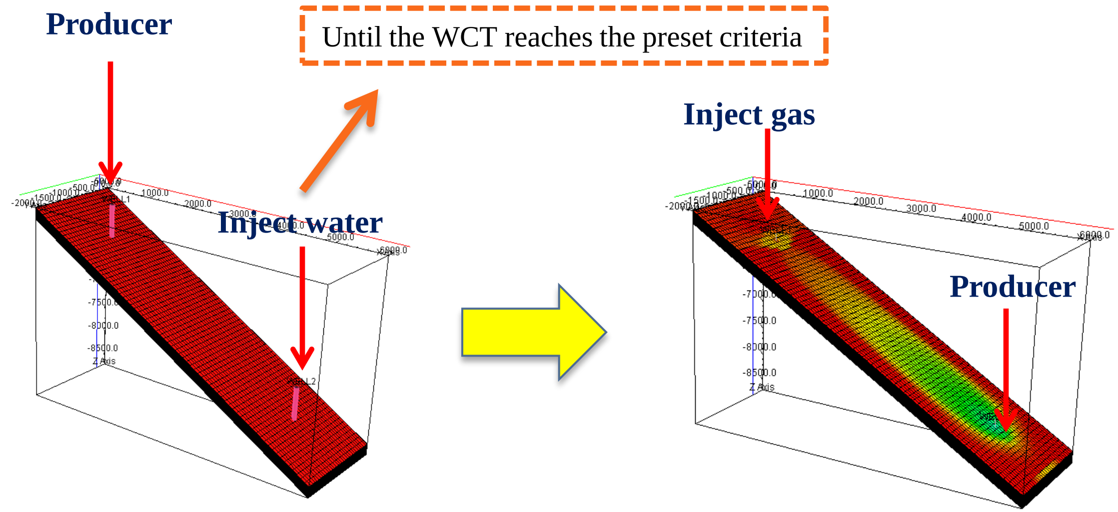
Inject water on bottom of the reservoir until the WCT reaches the preset criteria

Shut-in all well to stabilize the reservoir pressure

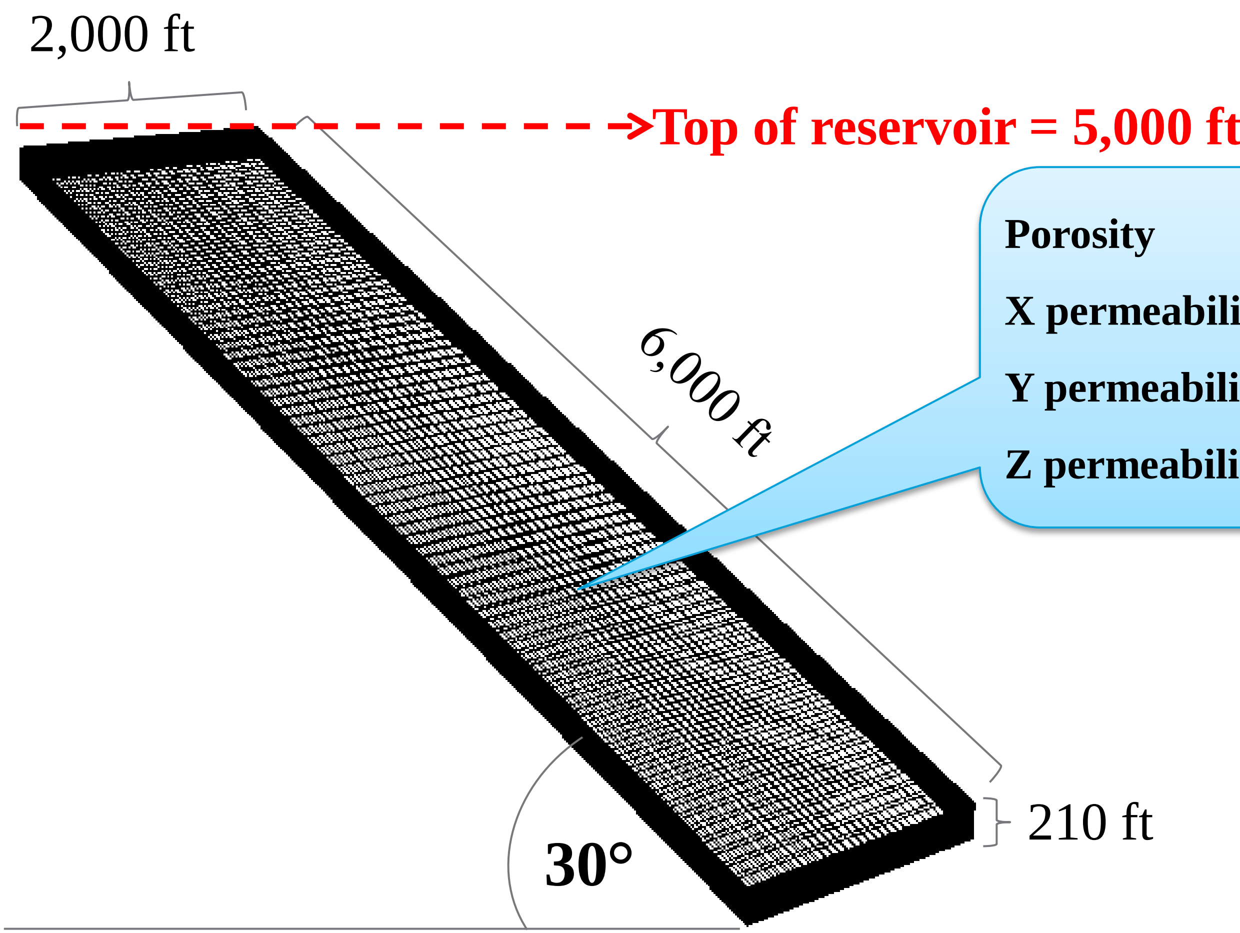
Inject gas on top of the reservoir

Discuss the results



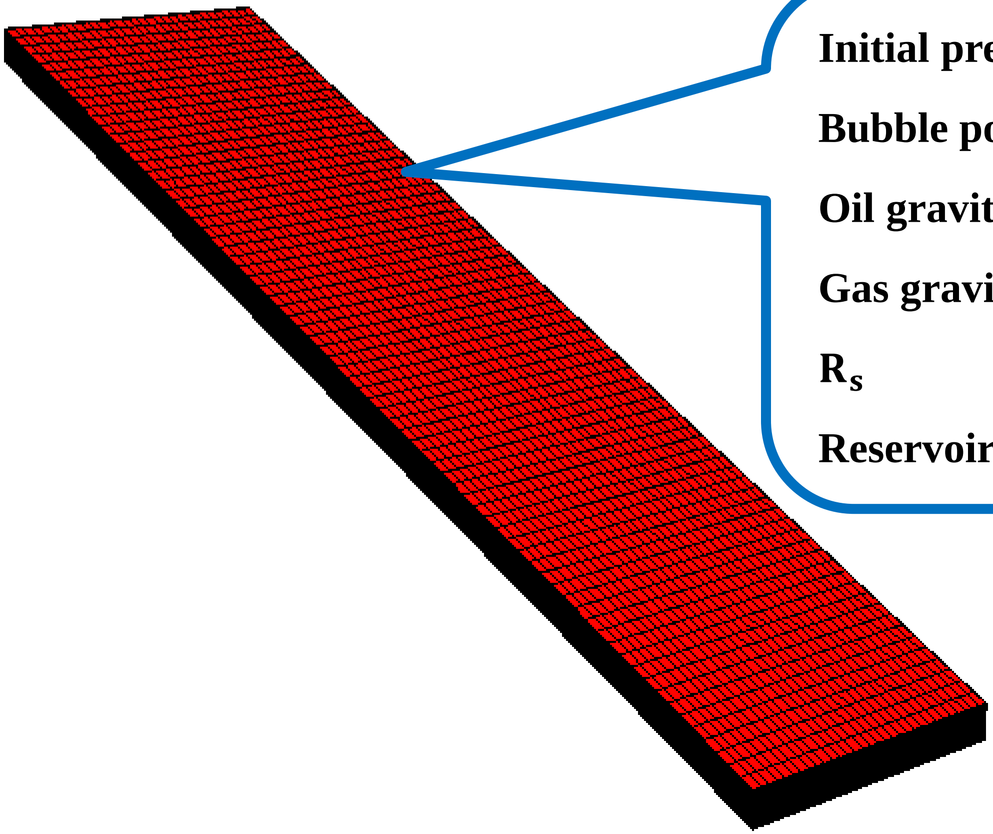


Reservoir Model Construction



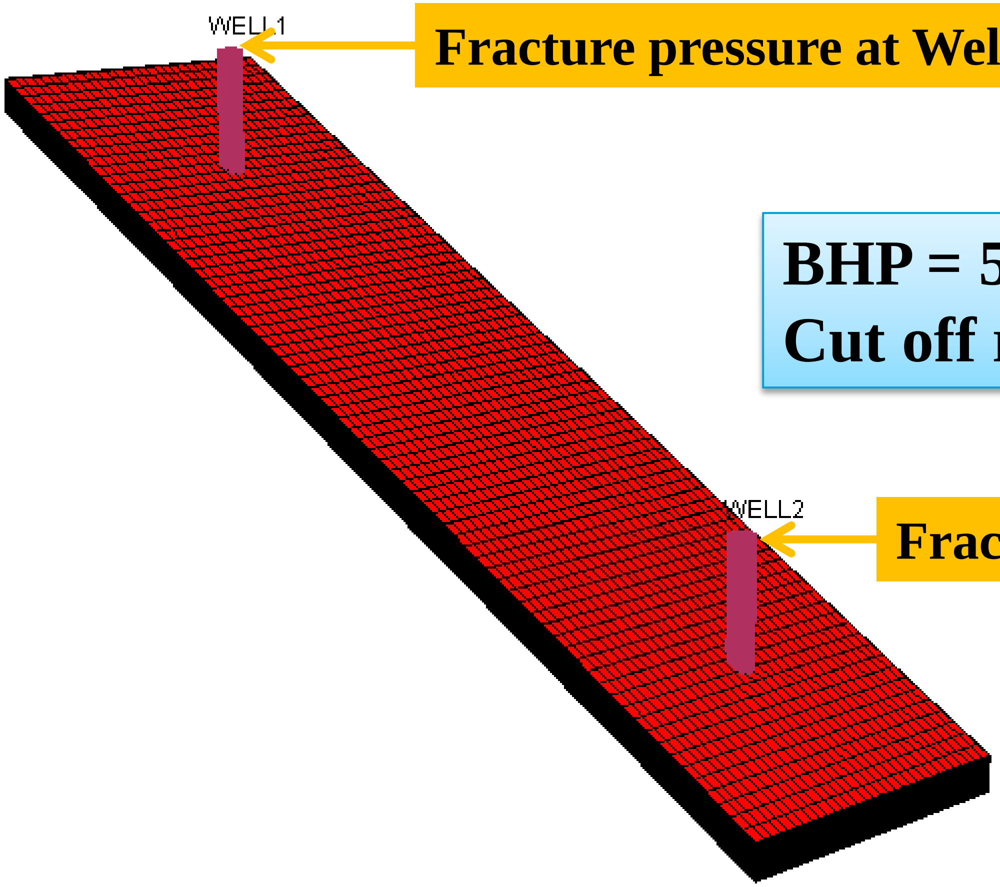
Porosity	**=**	**15.09**	**%**
X permeability	**=**	**32.529**	**mD**
Y permeability	**=**	**32.529**	**mD**
Z permeability	**=**	**3.2529**	**mD**

Pressure – Volume – Temperature (PVT)



Initial pressure	**=**	**2,377**	**psia**
Bubble point pressure	**=**	**2,242**	**psia**
Oil gravity	**=**	**39**	**API**
Gas gravity	**=**	**0.7**	
R_s	**=**	**650**	**SCF/STB**
Reservoir temperature	**=**	**200**	**°F**

Well schedule



Fracture pressure at Well 1 = 3,500 psia

BHP = 500 psia
Cut off rate = 100 STB/D

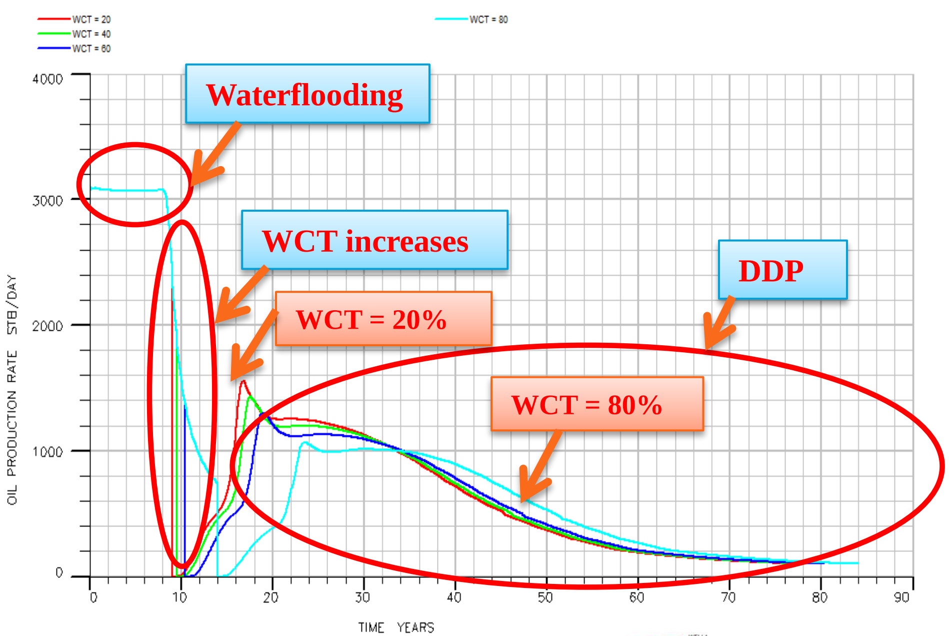
Fracture pressure at Well 2 = 4,305 psia

Result and Discussion

1. Stopping time for water injection

4 WCT criteria →

- 20%
- 40%
- 60%
- 80%

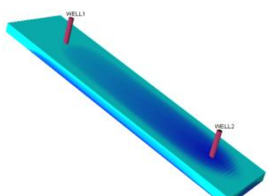


Stopping criteria for waterflood	Production life (years)	RF (%)
20 % WCT	78.14	64.09
40 % WCT	79.05	66.22
60 % WCT	80.21	68.56
80 % WCT	84.05	68.57

INCREASE

RF slightly increases but consumes much more times

A lot of surrounding water →



WCT = 60% is selected

2. Water and gas injection rate

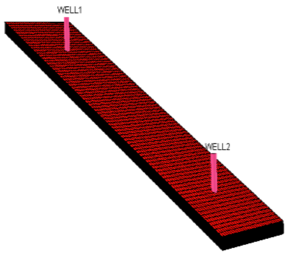
Case	Water injection rate (RB/D)	Gas injection rate (RB/D)
1	4,000	4,000
2	4,000	6,000
3	4,000	8,000
4	6,000	4,000
5	6,000	6,000
6	6,000	8,000
7	8,000	4,000
8	8,000	6,000
9	8,000	8,000

Case number	Water injection rate (RB/D)	Gas injection rate (RB/D)	At 30 years		
			RF (%)	Wp (STB)	Gp (MSCF)
1	4,000	4,000	46.92	12,190,250	16,708,315
2	4,000	6,000	49.77	12,525,110	27,419,270
3	4,000	8,000	51.96	12,735,336	39,981,800
4	6,000	4,000	50.48	11,903,933	22,279,128
5	6,000	6,000	53.52	12,230,032	36,609,824
6	6,000	8,000	54.31	12,426,672	51,113,044
7	8,000	4,000	52.32	12,061,601	18,900,386
8	8,000	6,000	55.10	12,217,786	38,123,748
9	8,000	8,000	56.94	12,405,736	53,679,112

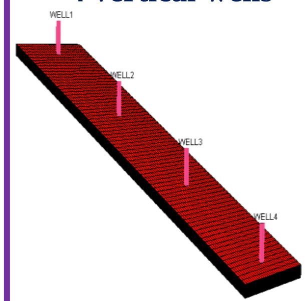
3. Well pattern

6 different well patterns

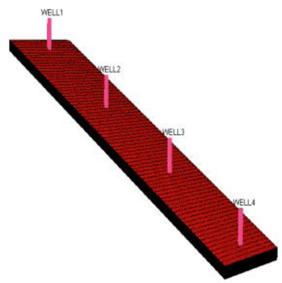
2 vertical wells



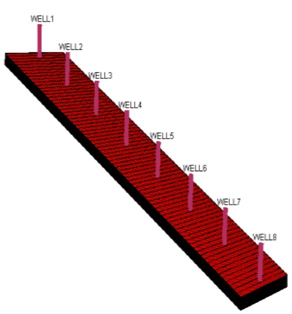
4 vertical wells



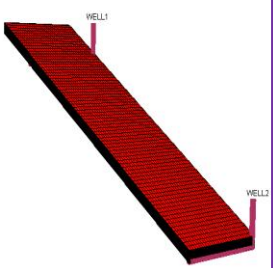
4 vertical wells with 2 injectors



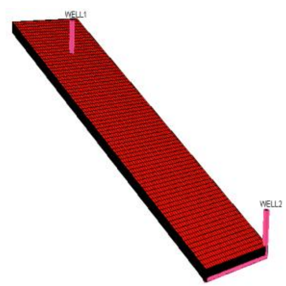
8 vertical wells



2 horizontal wells

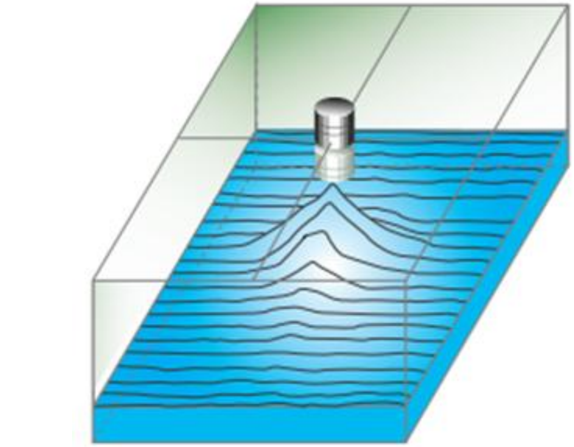


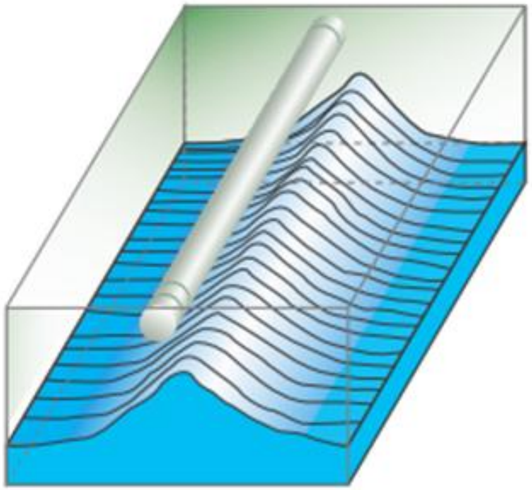
Vertical with horizontal wells

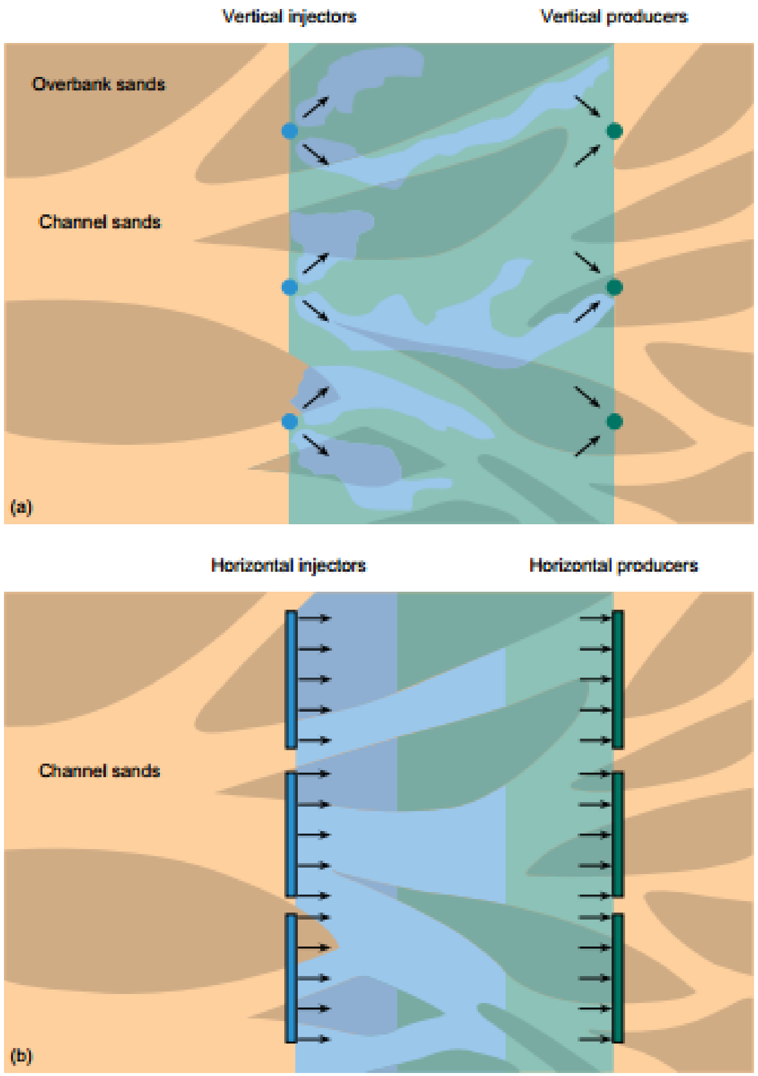


Case	At 30 years RF (%)
2 vertical wells	55.94
4 vertical wells	56.48
4 vertical wells with 2 injectors	57.16
8 vertical wells	59.6
2 horizontal wells	59.49
Horizontal with vertical well	57.11

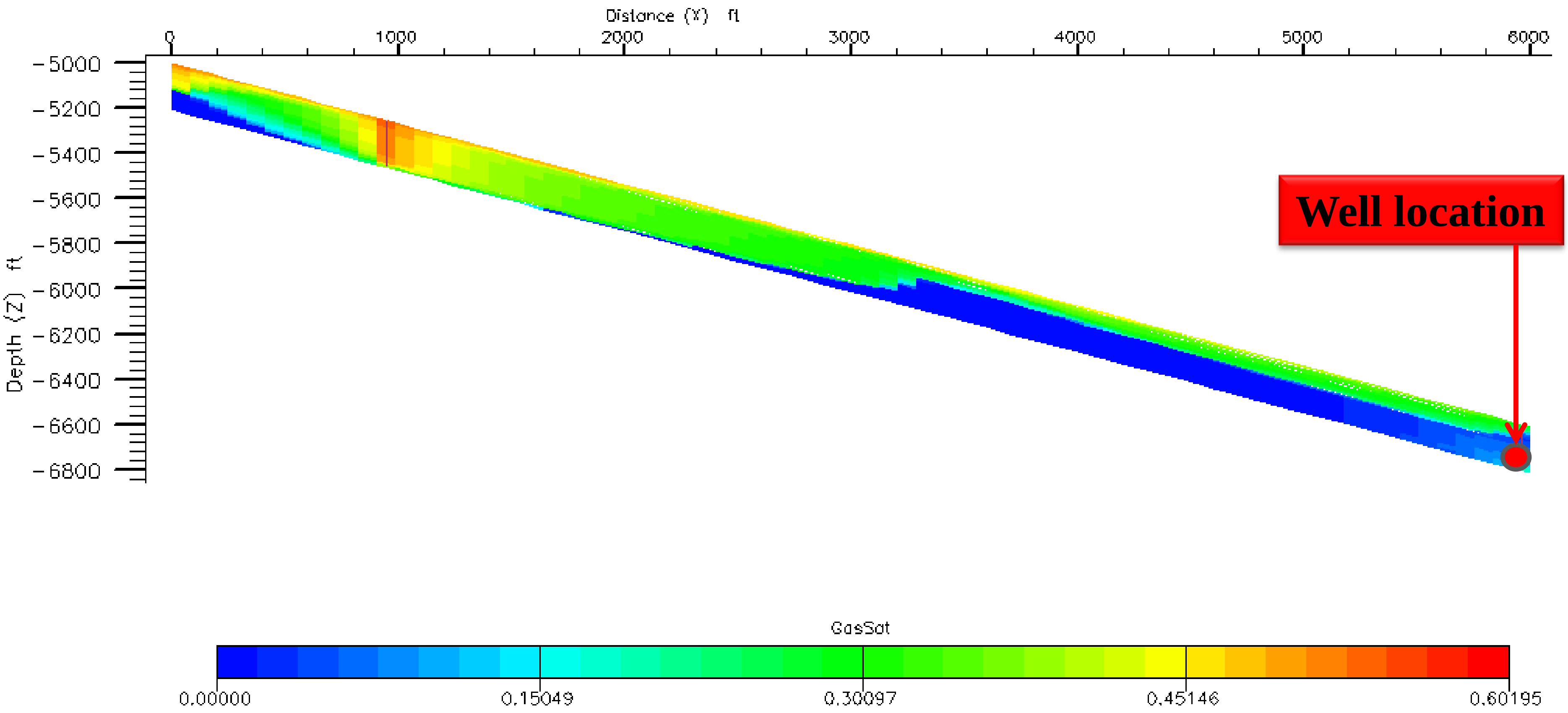
Horizontal well yields better sweep efficiency





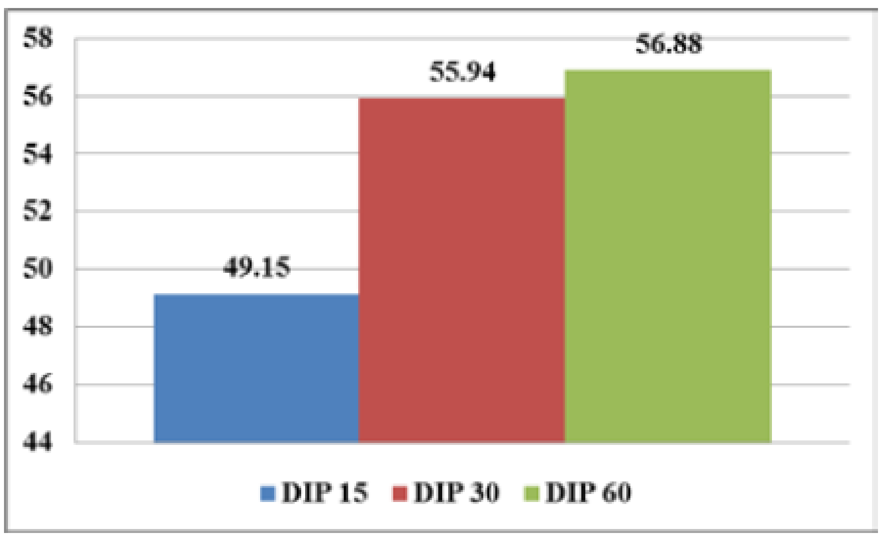


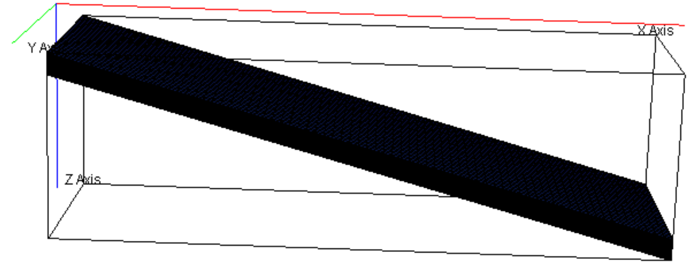
Gas breaks through time is longer

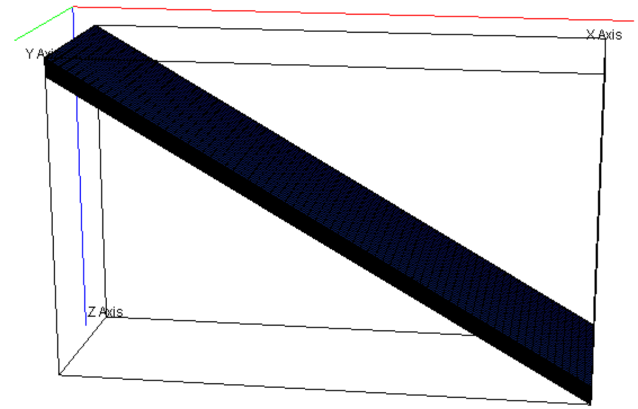


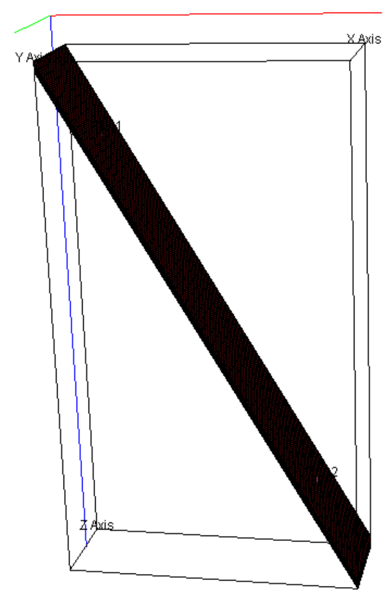
4. Dip angle

- Dip 15
- Dip 30
- Dip 60









Sensitivity analysis

1. Effect of relative permeability correlation

- ECLIPSE default
- Stone 1
- Stone 2

Model	Time (year)	Cumulative water production (STB)	Cumulative gas production (MSCF)	Oil recovery factor (%)
Eclipse default	81.97	18,452,862	203,587,140	**75.98**
Stone 1	**80.89**	**18,494,488**	**201,033,650**	75.96
Stone 2	**82.24**	**18,295,390**	**204,570,850**	**75.95**

2. Effect of vertical to horizontal permeabiltiy ratio

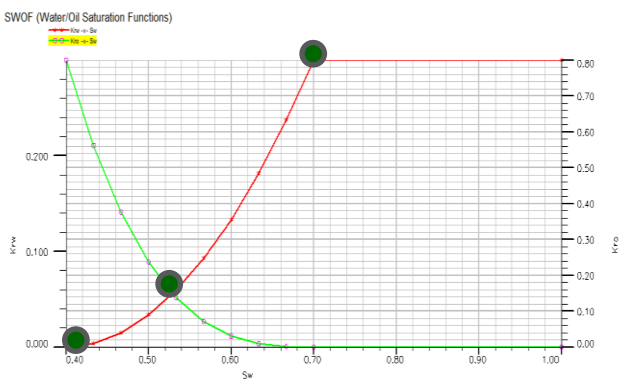
Case	Vertical to horizontal permeability ratio	Vertical permeability (md)	Horizontal permeability (md)
1	0.01	0.32529	32.529
2	0.1	3.2529	32.529
3	1	32.529	32.529

Case	Time (year)	Cumulative water production (STB)	Cumulative gas production (MSCF)	Oil recovery factor (%)
kv/kh = 0.01	71.88	17,823,640	173,751,200	69.48
kv/kh = 0.1	81.97	18,452,862	203,587,140	75.98
kv/kh = 1	85.58	21,431,932	218,704,830	83.44

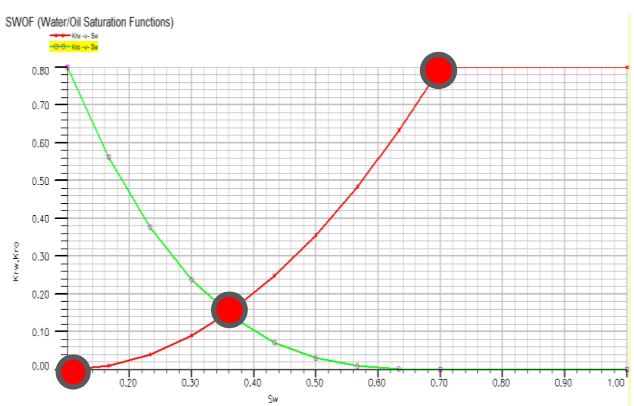
3. Effect of wettability

Property	Water-wet	Oil-wet
Irreducible water saturation	Usually greater than 20%	Generally less than 15%
Cross over saturation	Greater than 50% water saturation	Less than 50% water saturation
Relative permeability to water at ROS	Generally less than 30%	Greater than 50% and can approach 100%

Water-wet



Oil-wet



Case	Time (year)	Cumulative water production (MMSTB)	Cumulative gas production (BSCF)	Oil recovery factor (%)
Water-wet	78	13.57	191.4	79
Oil-wet	111	23.72	230.89	78.82

Conclusion

1. The case in which water injection is stopped when the **water cut is 80%** yields the highest amount of oil recovery

2. **Injects with rate of 8000 RB/D** yields the maximum oil recovery and shortest in production period

3. **Using the pattern of 2 horizontal wells** yields a good oil recovery factor in a reservoir with 15, 30, and 60 degree dip angle

4. **A reservoir with 60 degree dip angle** yields the best DDP performance.

Conclusion(effect of sensitivity)

1. There are slightly different results for each relative permeability correlation.

2. k_v/k_h is 1 , shows the significantly higher in oil recovery factor and less production period.

3. Water-wet is the more favorable condition for DDP.

Thank you for your attention

Back up

Critical water injection rate

$$i_{crit} = \frac{7.853x10^{-6} k k_{rw} A(\rho_w - \rho_o)\sin\alpha}{\mu_w (M^* - 1)}$$

= 3,800 STB/D

Critical gas injection rate

$$i_{crit} = \frac{0.044 k A(\rho_g - \rho_o)\sin\alpha}{\frac{\mu_o}{k_{ro}} - \frac{\mu_g}{k_{rg}}}$$

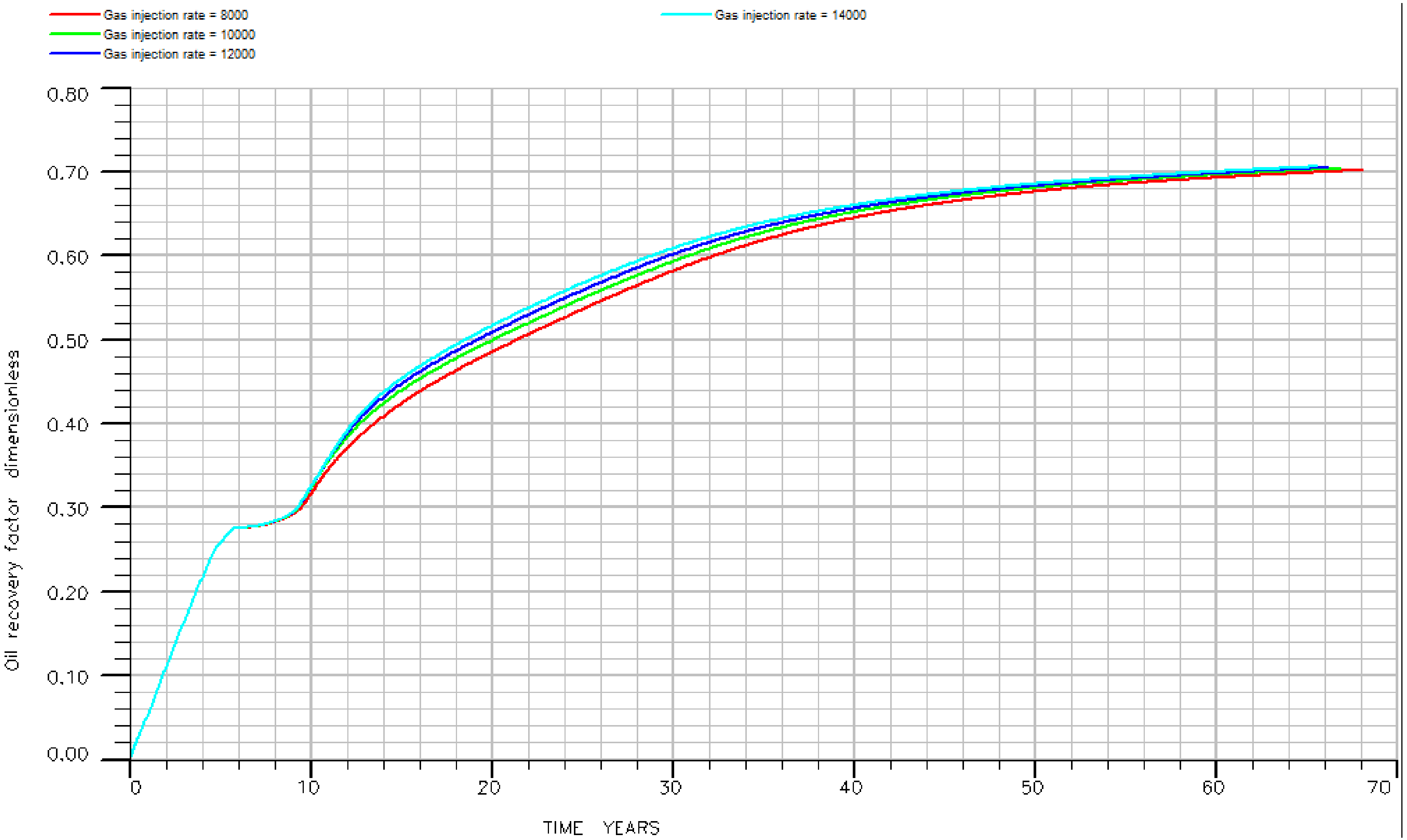
= 3,500 MSCF/D

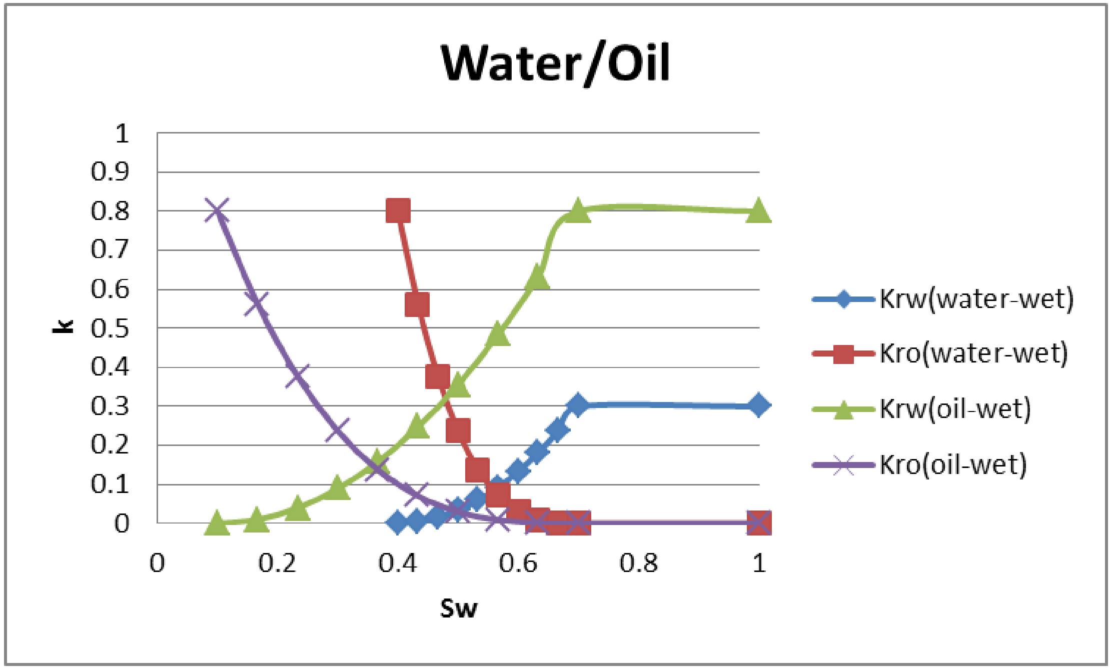
Increase water injection rate

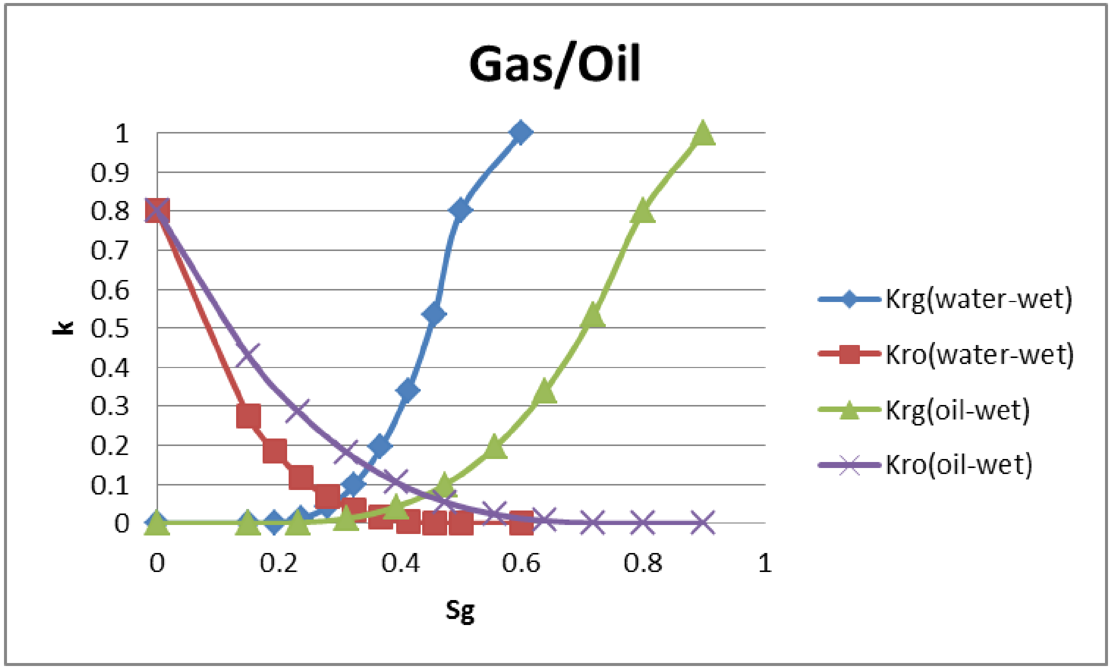
Case	Water injection rate (RB/D)	Gas injection rate (RB/D)	At 30 years			
			Np (STB)	RF (%)	Wp (STB)	Gp (MSCF)
1	**4,000**	**4,000**	**14,701,093**	**40.94**	**12,229,271**	**17,251,296**
4	**6,000**	**4,000**	15,483,581	43.12	12,453,345	21,592,824
7	**8,000**	**4,000**	15,528,904	43.25	13,121,383	22,020,652

Slightly increases

Increase gas injection rate




Water/Oil
k
Sw
Krw(water-wet)
Kro(water-wet)
Krw(oil-wet)
Kro(oil-wet)


Gas/Oil
k
Sg
Krg(water-wet)
Kro(water-wet)
Krg(oil-wet)
Kro(oil-wet)

Summary for each type of wettability (waterflood period)

Case	Time (year)	Cumulative water production (STB)	Cumulative gas production (MSCF)	Oil recovery factor (%)
Water-wet	**9.84**	**471,203**	**5,345,329**	35.9
Oil-wet	10.66	1,247,751	9,270,772	**39.26**

Summary for each type of wettability (DDP)

Case	Time (year)	Cumulative water production (STB)	Cumulative gas production (MSCF)	Oil recovery factor (%)
Water-wet	**85.8**	**13,414,620**	**198,840,690**	74.45
Oil-wet	120	23,842,592	246,912,060	**77.83**

Summary for each type of wettability (waterflood period)

Case	Time (year)	Cumulative water production (STB)	Cumulative gas production (MSCF)	Oil recovery factor (%)
Water-wet	**9.66**	**457,831**	**5,429,140**	35.42
Oil-wet	10.41	1,104,607	9,331,281	**38.71**

Summary for each type of wettability (DDP)

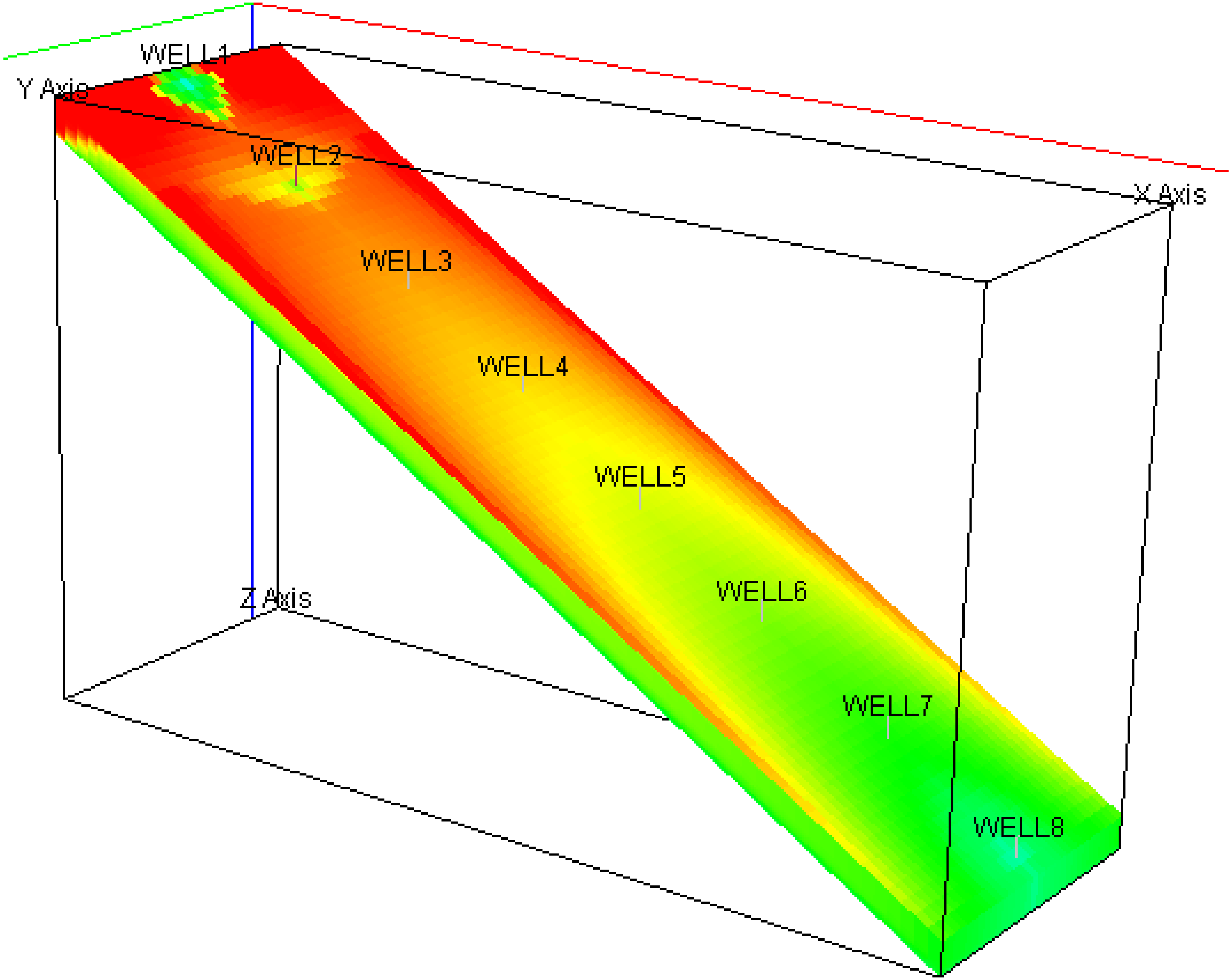
Case	Time (year)	Cumulative water production (STB)	Cumulative gas production (MSCF)	Oil recovery factor (%)
Water-wet	**78.41**	**13,566,025**	**191,396,450**	76
Oil-wet	111	23,724,488	230,894,740	**78.82**

Summary for each type of wettability (waterflood period)

Case	Time (year)	Cumulative water production (STB)	Cumulative gas production (MSCF)	Oil recovery factor (%)
Water-wet	**9.62**	**285,396**	**5,151,701**	31.83
Oil-wet	10.35	590,031	8,366,834	**34.15**

Summary for each type of wettability (DDP)

Case	Time (year)	Cumulative water production (STB)	Cumulative gas production (MSCF)	Oil recovery factor (%)
Water-wet	**79.74**	**13,276,718**	**202,330,350**	77.61
Oil-wet	101	20,976,292	271,044,190	**81.53**



WELL1
Y Axis
WELL2
X Axis
WELL3
WELL4
WELL5
Z Axis
WELL6
WELL7
WELL8

52,476 STB = $ 4,198,080

Be worthwhile

For oil-water

$$k_{ro} = \left(\frac{1-S_w-S_{or}}{1-S_{wi}-S_{or}}\right)^{N_o}$$

$$k_{rw} = k_{rwend}\left(\frac{S_w-S_{wi}}{1-S_{wi}-S_{or}}\right)^{N_w}$$

For oil-gas

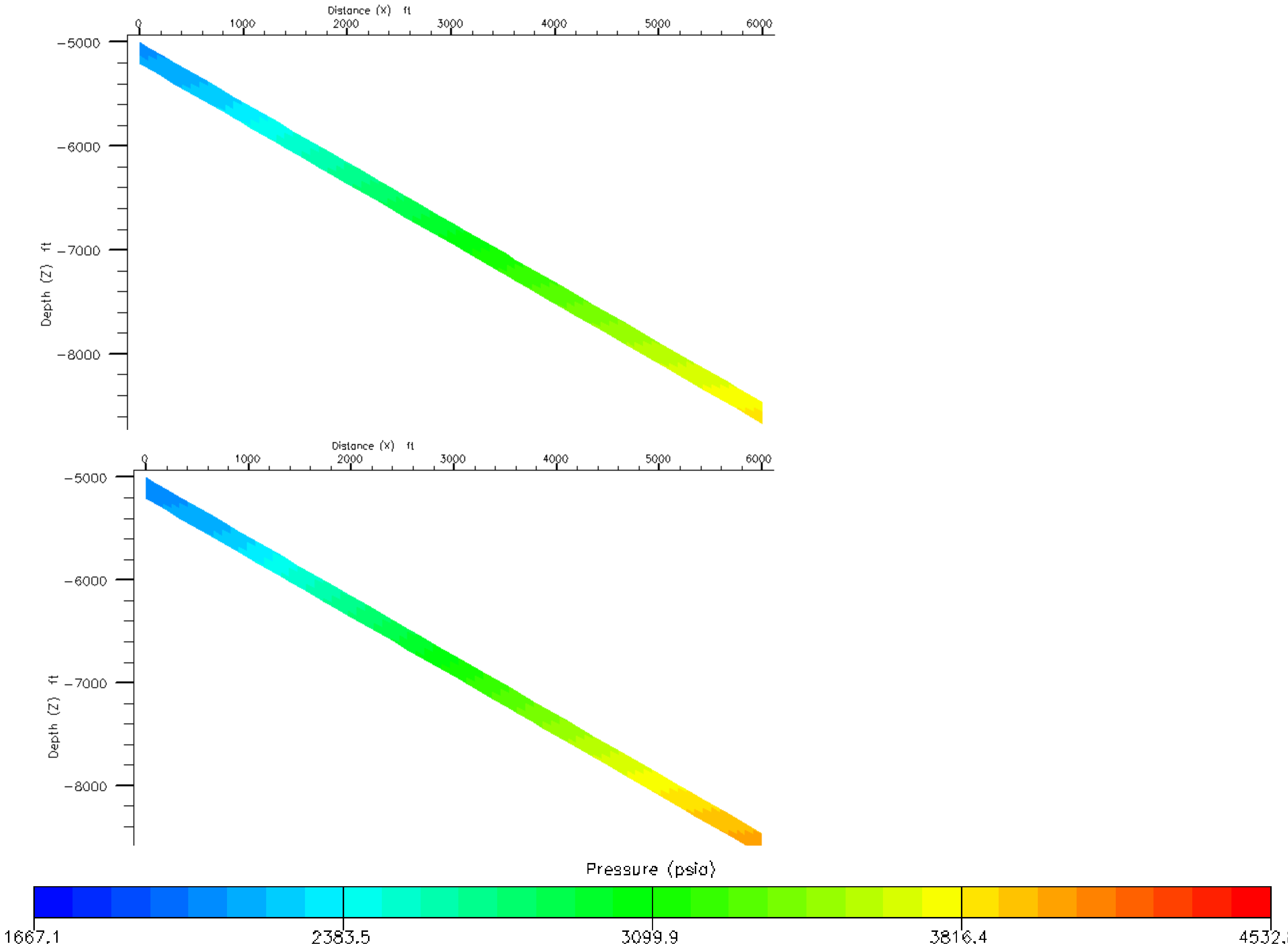
$$k_{ro} = \left(\frac{1-S_g-S_{wi}-S_{or}}{1-S_{wi}-S_{or}}\right)^{N_o}$$

$$k_{rg} = \left(\frac{S_g-S_{gc}}{1-S_{wi}-S_{or}-S_{gc}}\right)^{N_g}$$

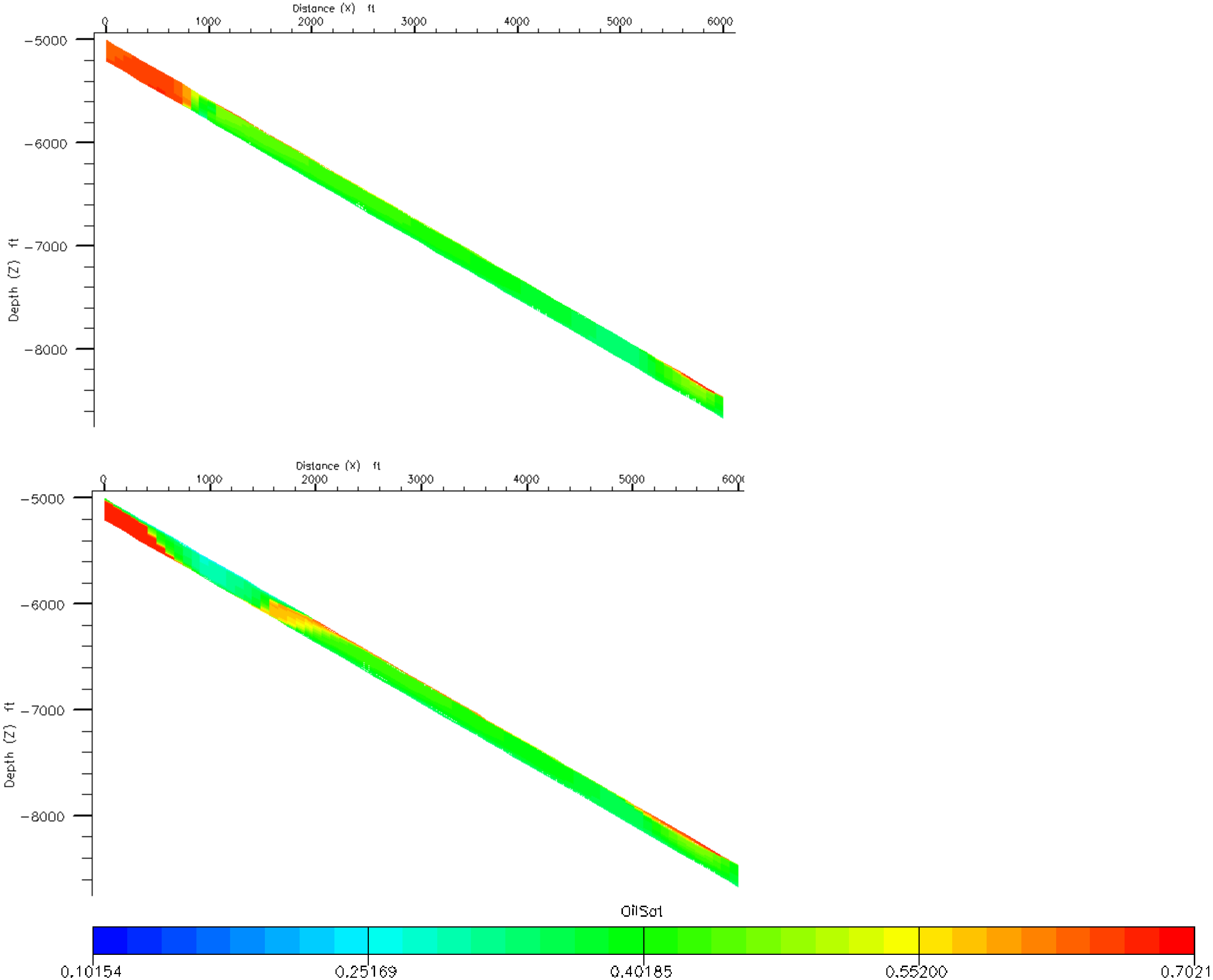
Table 4.3 : Parameters for Corey's correlation

Corey water	2	**Corey Gas/Oil**	3	**Corey Oil/Water**	3
S_{wmin}	0.3	S_{gmin}	0	**Corey Oil/Gas**	3
S_{wcr}	0.3	S_{gcr}	0.15	S_{org}	0.1
S_{wi}	0.3	S_{gi}	0.15	S_{orw}	0.3
S_{wmax}	1	$k_{rg}(S_{org})$	0.8	$k_{ro}(S_{wmin})$	0.8
$k_{rw}(S_{orw})$	0.8	$k_{rg}(S_{gmax})$	0.8	$k_{ro}(S_{gmin})$	0.8
$k_{rw}(S_{wmax})$	0.8				

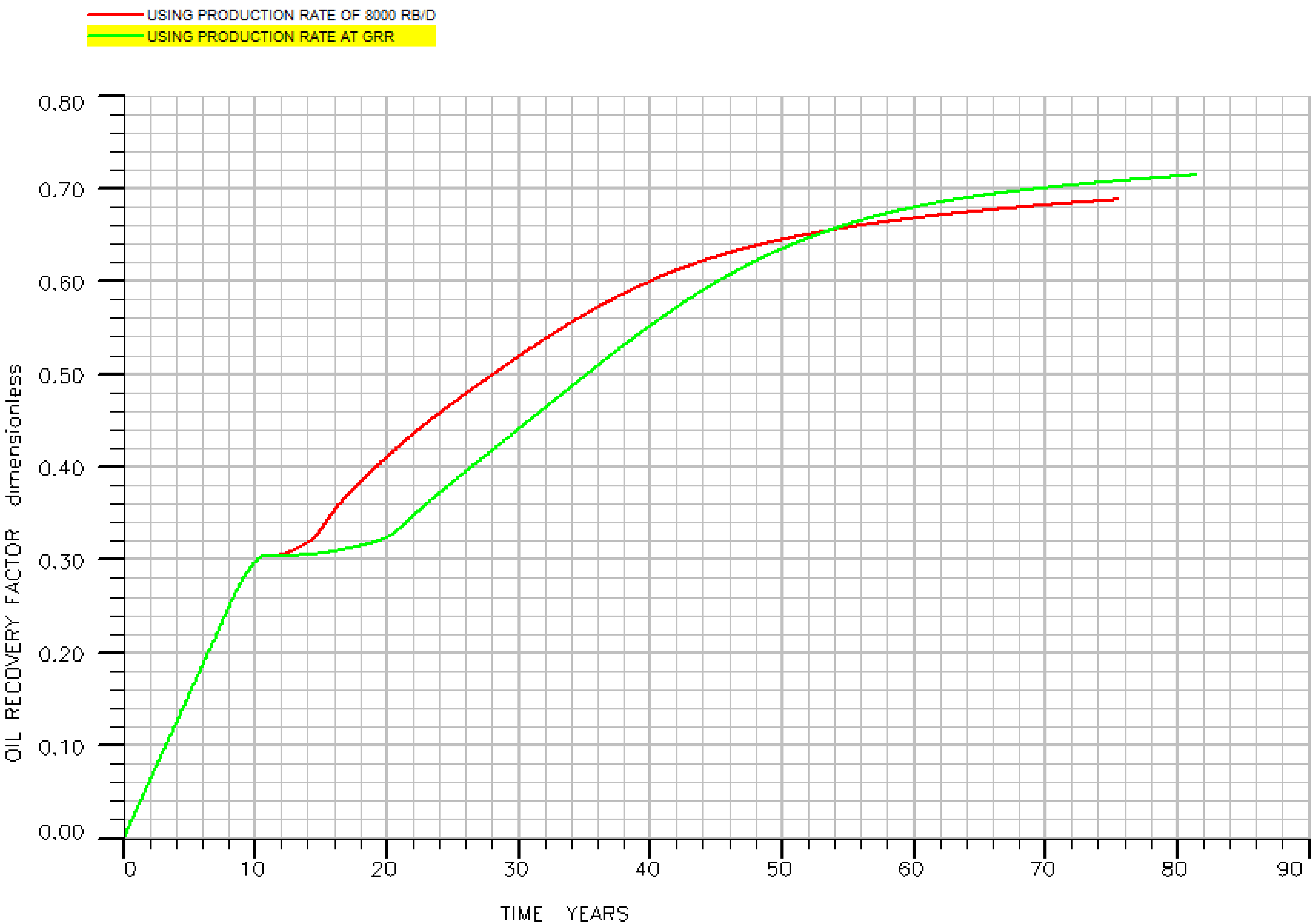
Stabilize the reservoir pressure



Allow the oil flow to down structure



Voidage VS G.R.R.



Convention case VS Located at the edge