

# EVALUATION OF INTELLIGENT DUAL-LATERAL WELL IN MULTI-LAYERED RESERVOIRS

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# Outline

- Introduction
- Objectives
- Methodology
- Result and Discussion
- Conclusion and Recommendation

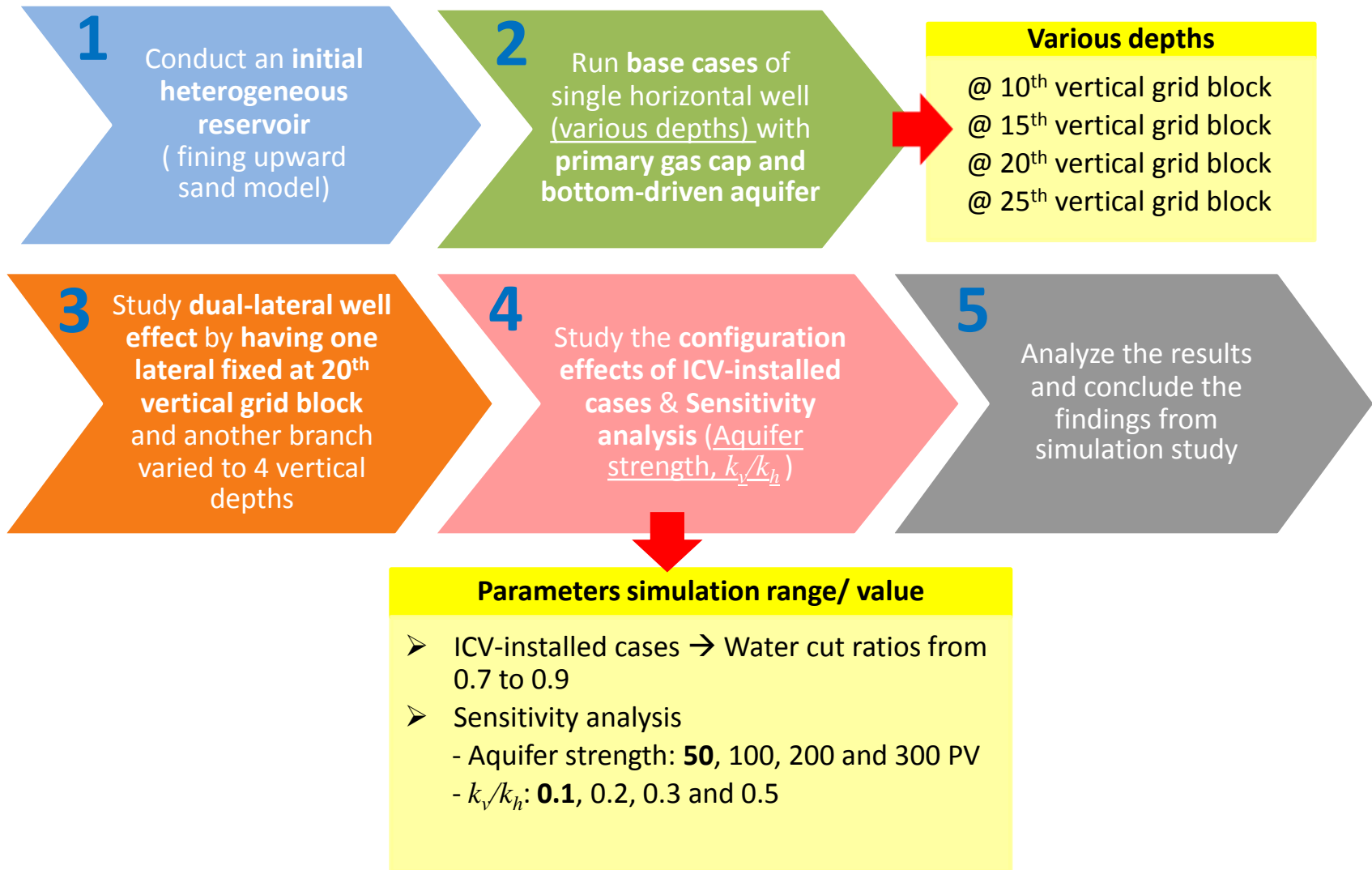
# Introduction

- Multilateral horizontal wells → **increase exposure contact area** to reservoir  
→ **enhance oil and gas** recovery
- Challenging constraints is **how to select a compatible configuration, completion system** and **other related parameters** to ensure the effectiveness of well geometry
- **Water crestring** → one of the **major common production problems** happening in the aquifer-based reservoir
- To suitably operate the intelligent completion for multilateral horizontal wells with water crestring production problem → Expected related parameters are **well configuration** as well as **petrophysical properties**

# Objectives

- To evaluate the **effects of vertical location** of varied lateral well and **preset water cut ratio** on **intelligent completion system equipped in dual-opposing multilateral wells** in multi-layered reservoirs
- To study the **sensitivity analysis** of petrophysical properties which are **aquifer strength** and **ratio of vertical permeability to horizontal permeability** on intelligent completion system equipped in dual-opposing multilateral wells in multi-layered reservoirs

# Methodology



# Results and Discussions

- All reservoir simulations are performed based on **30-years** of production time
- Liquid production rate is varied within the range of 2,000-5,000 STB/D at first
- Then the optimized production rate is chosen to represent the production rate for the rest of the simulation cases under other constraints
- Simulation outline can be categorized into 2 parts
  - Part 1) **Well configuration** and **effect of intelligent completion**
  - Part 2) **Sensitivity analysis** on selected cases of intelligent completion equipped in dual-lateral wells

➤ *Simulation Part 1: Well configuration and effect of intelligent completion*

**Horizontal well**

Horizontal well base cases →  
Optimization of location &  
liquid production rate

**Dual-lateral well**

Effect of second lateral (L1)'s  
depth of 10<sup>th</sup>, 15<sup>th</sup>, 20<sup>th</sup> and 25<sup>th</sup>  
vertical grid block by having first  
lateral's depth fixed at 20<sup>th</sup> grid  
block

**Dual-lateral well with ICV equipped**

Effect of ICV equipped dual-lateral  
wells which L1's depth of 10<sup>th</sup>, 15<sup>th</sup>,  
20<sup>th</sup> and 25<sup>th</sup> vertical grid block  
by having first lateral's depth fixed  
at 20<sup>th</sup> grid block

➤ *Simulation Part 2: Sensitivity analysis on selected cases of intelligent completion equipped in dual-lateral wells*

**Effect of aquifer strength on ICV quipped  
in dual-lateral wells**

Aquifer strength's effect of **50**, 100, 200 and  
300 PV on selected cases

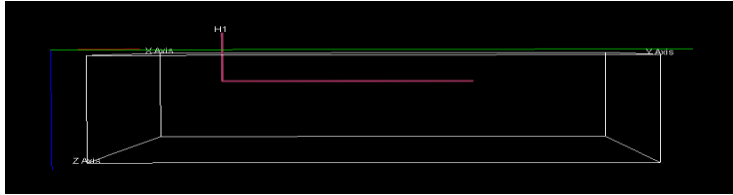
**Effect of  $k_v/k_h$  ratio on ICV equipped in  
dual-lateral wells**

$k_v/k_h$  ratio of **0.1**, 0.2, 0.3 and 0.5 on  
selected cases

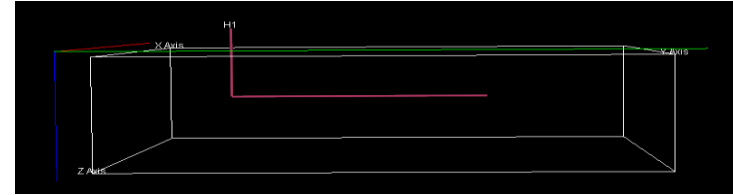
# ➤ Simulation Part 1: Well configuration and Effect of intelligent completion

## Horizontal well location

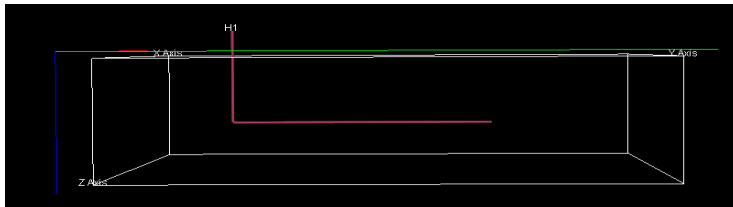
@ 10<sup>th</sup> vertical grid block



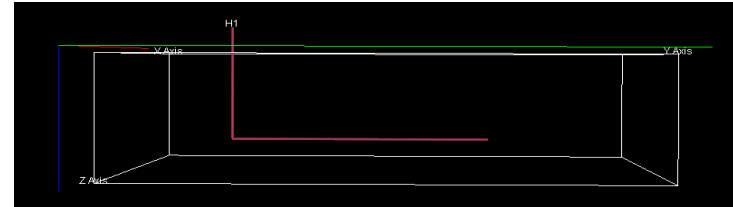
@ 15<sup>h</sup> vertical grid block



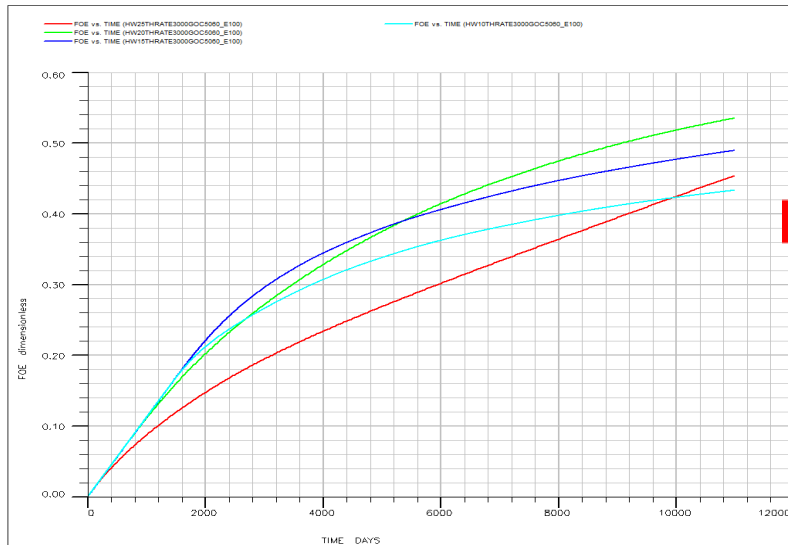
@ 20<sup>th</sup> vertical grid block



@ 25<sup>th</sup> vertical grid block



Comparison of simulated FOE from horizontal wells located at various depths



FOE and FOPT obtained from horizontal well simulation located at different depths

Location of horizontal well	FOE (fraction)	FOPT (MMSTB)
20 <sup>th</sup> grid block (5,200 feet)	0.535	14.274
15 <sup>th</sup> grid block (5,150 feet)	0.489	13.054
25 <sup>th</sup> grid block (5,250 feet)	0.454	12.102
10 <sup>th</sup> grid block (5,100 feet)	0.433	11.551

## Optimization of liquid production rate

- **Liquid production rate of 3,000 STB/D is initially selected**
- **When oil is being more produced, more amount of water could be produced in the same time especially for reservoir that is supported by strong water aquifer**

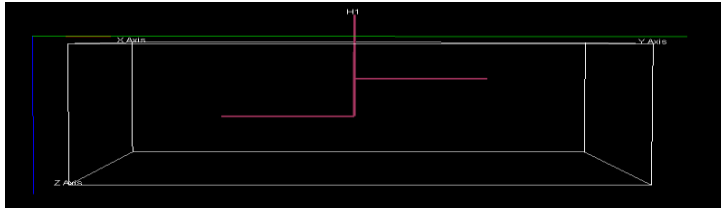
*FOE and FWPT obtained from horizontal well at different liquid production rates*

Liquid production rate (STB/ D)	FOE (fraction)	FWPT (MMSTB)
3,000	0.535	18.689
4,000	0.550	29.285
5,000	0.554	40.161

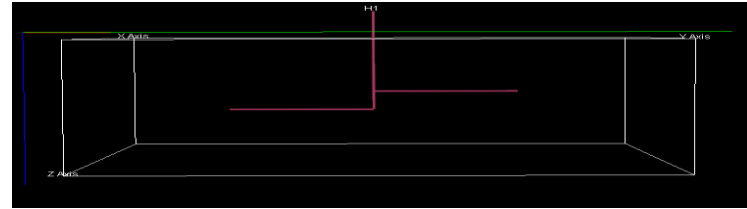
- FWPT obtained from cases of liquid production rate of 4,000 and 5,000 STB/D are significantly higher than keeping the liquid production rate at 3,000 STB/D (56.7% and 114.9%)
- Thus, **3,000 STB/D is remained as an optimum liquid production rate** for other following simulation cases

## Effect of second lateral's depth in dual-lateral well

L1 at 10<sup>th</sup> grid block, L2 at 20<sup>th</sup> grid block



L1 at 15<sup>th</sup> grid block, L2 at 20<sup>th</sup> grid block



L1 at 20<sup>th</sup> grid block, L2 at 20<sup>th</sup> grid block



L1 at 25<sup>th</sup> grid block, L2 at 20<sup>th</sup> grid block



FOE and FWC obtained from dual lateral wells with second laterals located at different vertical grid blocks

Dual-lateral well with varied depth on L1	FOE (fraction)	FWC (fraction)
10 <sup>th</sup> grid block	0.418	0.908
15 <sup>th</sup> grid block	0.515	0.882
20 <sup>th</sup> grid block	0.555	0.856
25 <sup>th</sup> grid block	0.504	0.828

Comparison between single horizontal well and dual-lateral well

Horizontal well's depth at	FOE (fraction)	Dual-lateral well with varied depth on L1 at	FOE (fraction)
10 <sup>th</sup> grid block	0.433	10 <sup>th</sup> grid block	0.418
15 <sup>th</sup> grid block	0.489	15 <sup>th</sup> grid block	0.515
20 <sup>th</sup> grid block	0.535	20 <sup>th</sup> grid block	0.555
25 <sup>th</sup> grid block	0.454	25 <sup>th</sup> grid block	0.504

- **Dual-lateral well is proven to be more effective than single horizontal well** due to the fact that branches in the dual-lateral well drain the fluid **more distributional**, not emphasizing only just on one side as in the case of single-layered horizontal well

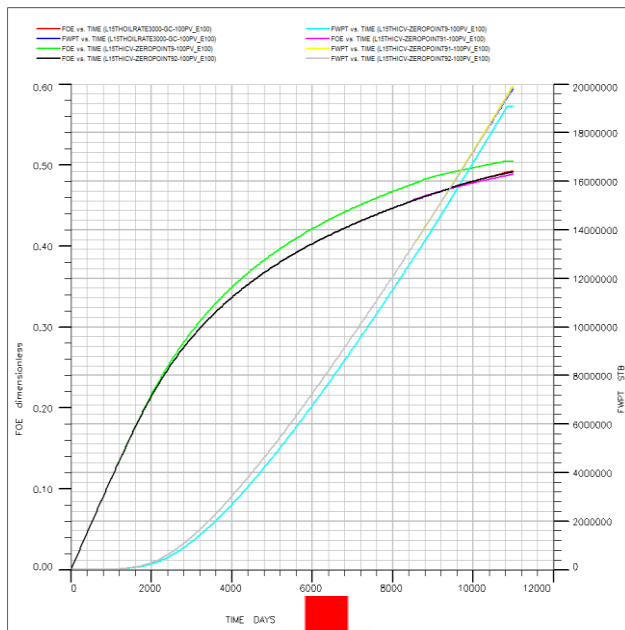
## ➤ Simulation Part 2: Sensitivity analysis on selected cases of intelligent completion equipped in dual-lateral wells

### Aquifer strength's impact in dual-lateral wells with intelligent completion, with L1 at the depth of 15<sup>th</sup> grid block

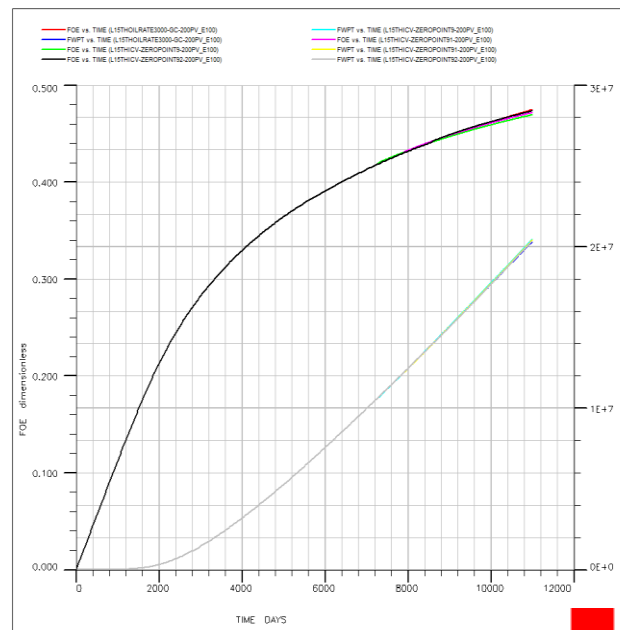
Comparison of FOE and FWPT between the case of having no ICV installed and ICV installed at water cut ratio of 0.90, 0.91 and 0.92, bottom aquifer strength is 100PV

Comparison of FOE and FWPT between the case of having no ICV installed and ICV installed at water cut ratio of 0.90, 0.91 and 0.92, bottom aquifer strength is 200PV

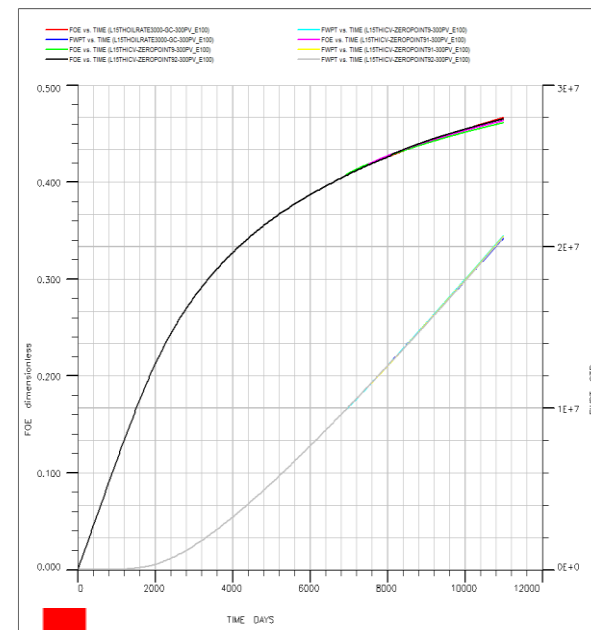
Comparison of FOE and FWPT between the case of having no ICV installed and ICV installed at water cut ratio of 0.90, 0.91 and 0.92, bottom aquifer strength is 300PV



➔ @ water cut of 0.9 → more FOE gained 0.491 to 0.504 and better manage to get **less water production** from 19.819 to 19.075 MMSTB

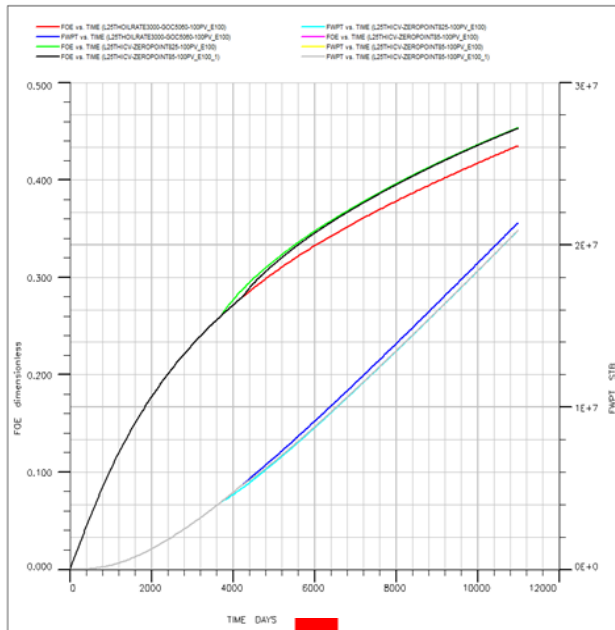


➔ Insignificant difference between case of installing ICV and no ICV at every water cut ratio



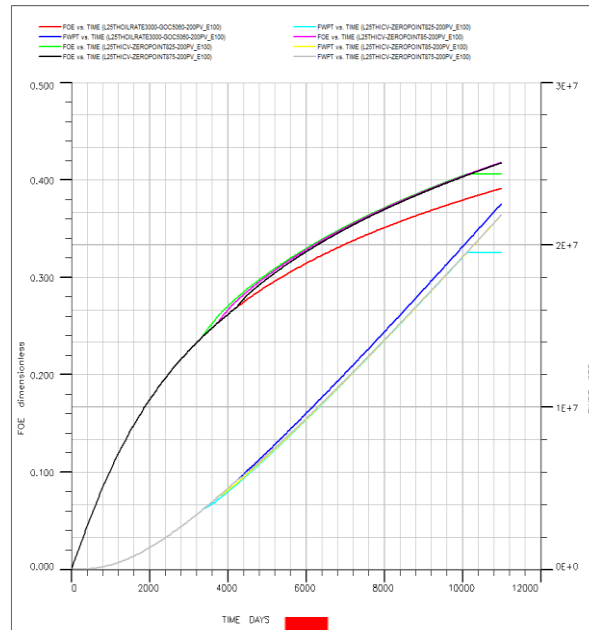
# Aquifer strength's impact in dual-lateral wells with intelligent completion, with L1 at the depth of 25<sup>th</sup> grid block

Comparison of FOE and FWPT between the case of **having no ICV installed and ICV installed** at water cut ratio of **0.825, 0.85 and 0.875**, bottom aquifer strength is **100PV**



@ water cut of 0.825 → **more FOE** gained from 0.435 to 0.453 and better manage to get **less water production** from 21.363 to 20.877 MMSTB

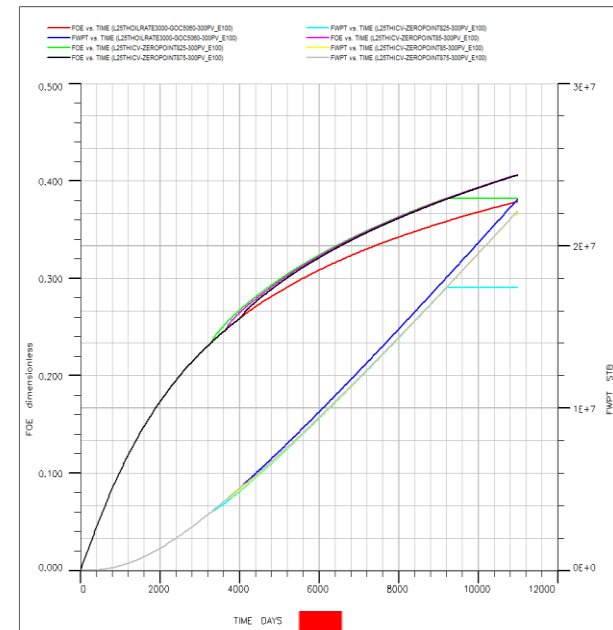
Comparison of FOE and FWPT between the case of **having no ICV installed and ICV installed** at water cut ratio of **0.825, 0.85 and 0.875**, bottom aquifer strength is **200PV**



@ either water cut of 0.85 or 0.875 → **more FOE** gained from 0.391 to 0.417 and better manage to get **less water production** from 22.534 to 21.838 MMSTB

**\*\* albeit the well is shut in before production lifetime**

Comparison of FOE and FWPT between the case of **having no ICV installed and ICV installed** at water cut ratio of **0.825, 0.85 and 0.875**, bottom aquifer strength is **300PV**

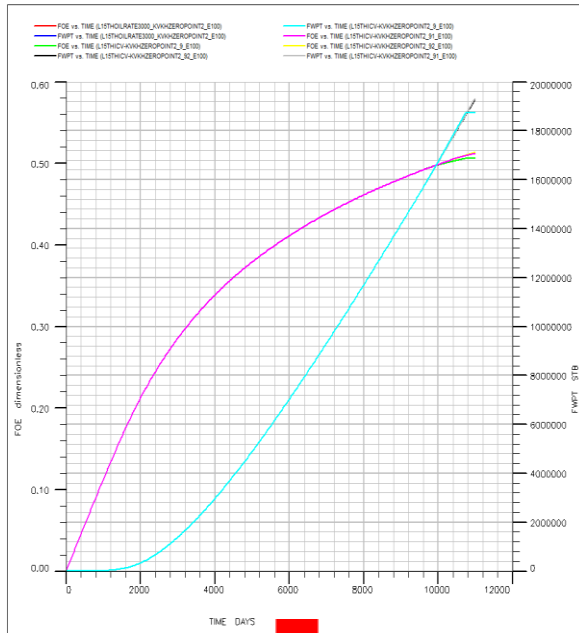


@ either water cut of 0.85 or 0.875 → **more FOE** gained from 0.378 to 0.405 and better manage to get **less water production** from 22.872 to 22.144 MMSTB

**\*\* albeit the well is shut in before production lifetime**

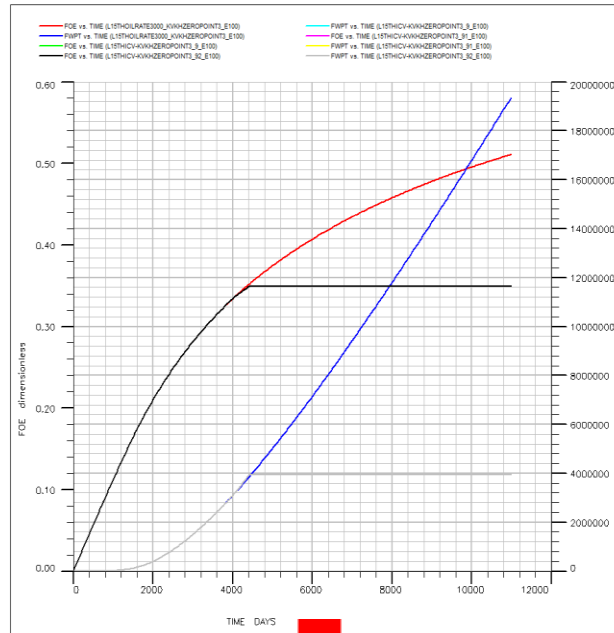
# [kv/ kh ratio's impact in dual-lateral wells with intelligent completion, with L1 at the depth of 15th grid block](#)

Comparison of FOE and FWPT between the case of **having no ICV installed and ICV installed** at water cut ratio of 0.90, 0.91 and 0.92, where kv/ kh is 0.2



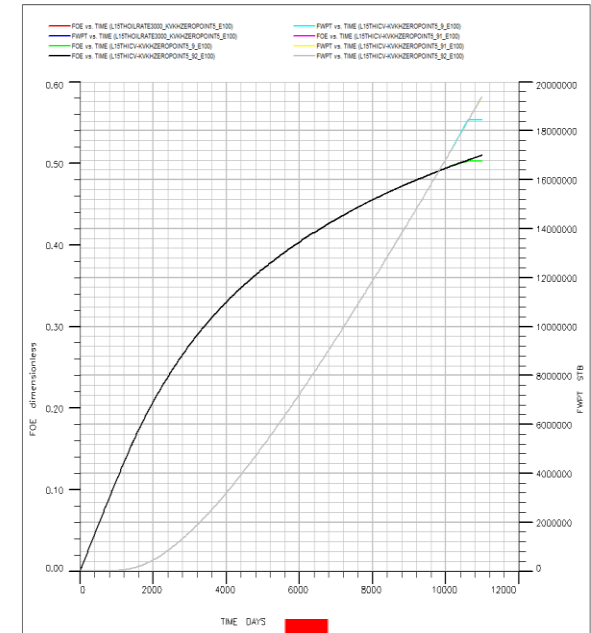
**Insignificant difference** between case of installing ICV and no ICV at every water cut ratio

Comparison of FOE and FWPT between the case of **having no ICV installed and ICV installed** at water cut ratio of 0.90, 0.91 and 0.92, where kv/ kh is 0.3



@ either water cut ratio of 0.90 and 0.91, the cases without ICV installed yields the **similar result** as ones having ICV equipped// @ water cut ratio 0.92, the well is **shut in** at less than half way of the simulation

Comparison of FOE and FWPT between the case of **having no ICV installed and ICV installed** at water cut ratio of 0.90, 0.91 and 0.92, where kv/ kh is 0.5



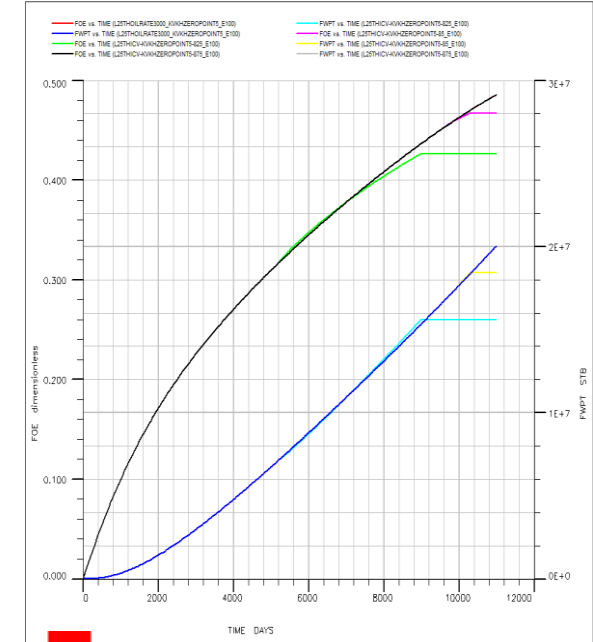
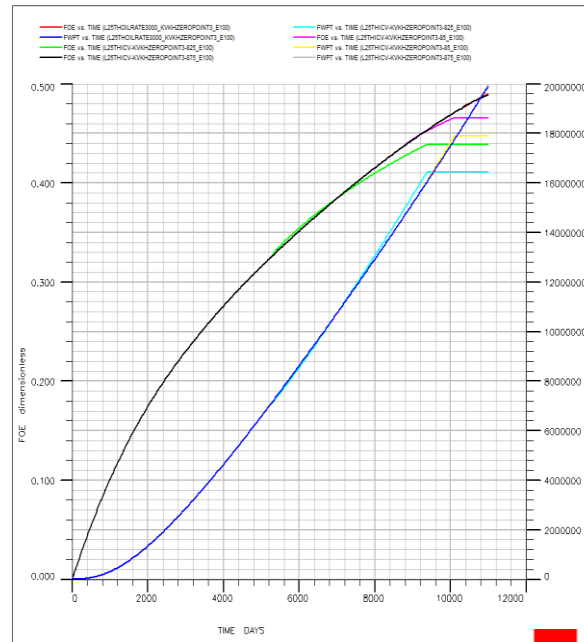
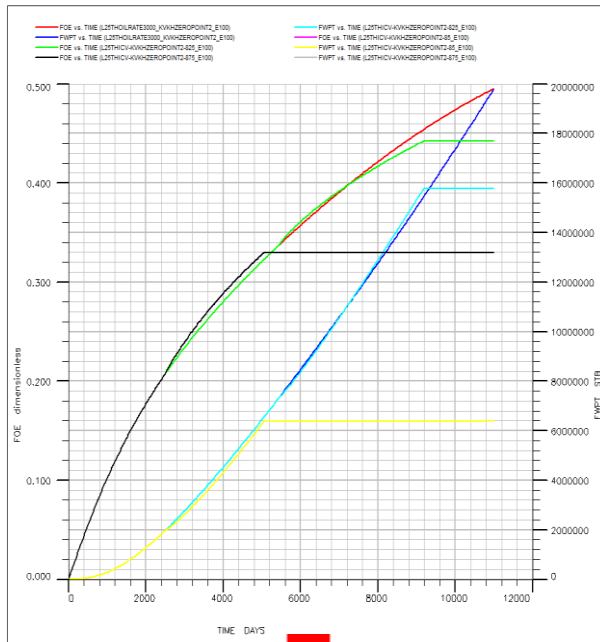
**Insignificant difference** between case of installing ICV and no ICV at every water cut ratio

# kv/ kh ratio's impact in dual-lateral wells with intelligent completion, with L1 at the depth of 25th grid block

Comparison of FOE and FWPT between the case of **having no ICV installed and ICV installed** at water cut ratio of 0.825, 0.85 and 0.875, where kv/ kh is **0.2**

Comparison of FOE and FWPT between the case of **having no ICV installed and ICV installed** at water cut ratio of 0.825, 0.85 and 0.875, where kv/ kh is **0.3**

Comparison of FOE and FWPT between the case of **having no ICV installed and ICV installed** at water cut ratio of 0.825, 0.85 and 0.875, where kv/ kh is **0.5**



All cases having intelligent completion equipped allow all of the wells to shut in before the end of the simulation  
 → **poor result** of FOE and FWPT

@ water cut ratio of 0.825 and 0.85, wells are **shut in early**// @ water cut ratio of 0.875 → **similar result** as the case without ICV equipped.

# Conclusion

## ➤ **Effect of physical aspects multi-lateral well**

- Dual-lateral well shows advantage over single horizontal well by improving oil production approximately 2% when both have equal effective length
- Improvement of dual-lateral well over horizontal well can be accomplished by installation of intelligent completion to the right location of dual-lateral well as well as presetting appropriate water cut ratio
- Preset water cut ratio has to be carefully chosen for each specific depth of branch of dual-lateral well. Inappropriate water cut ratio has to be avoided. Too less water cut ratio affects the ineffectiveness of intelligent completion as well is shut in too quickly before production lifetime terminates

## ➤ **Sensitivity analysis of petrophysical properties**

- Aquifer strength represented by aquifer size, bigger than 50PV is recommended for installation of intelligent completion. However, when aquifer size exceeds certain value, well can be shut in too early than expected production life time for some values of water cut ratio
- Ratio of vertical permeability to horizontal permeability also plays a major role in effectiveness of intelligent completion installed in dual-lateral well. When this ratio is higher than most common value of 0.1, water cresting phenomena can early reach lateral wells especially if they are located close to bottom aquifer

# Recommendation

- More precise ICV locations in each lateral can be studied. As in more realistic working environment, ICVs are installed in various sections in each branch of horizontal or multilateral wells. Each of the laterals with more sub-segments can be simulated to see effects of ICV installed location. In this study, simplification is performed to adopt one lateral as one segment and have just one ICV installed
- ICV for gas triggering can be installed for further study. More accurate result of ultimate best possible oil recovery is expected to be yielded if gas coning effect can be observed as much as water in this study.
- Preset water cut ratio is slightly varied in this study. A more practical study should be performed with broader range.
- More petrophysical properties can be explored in similar study to see if there is any significance emphasizing on importance of having intelligent completion installed such as aquifer strength of 100PV in this study.

Thank you ;)

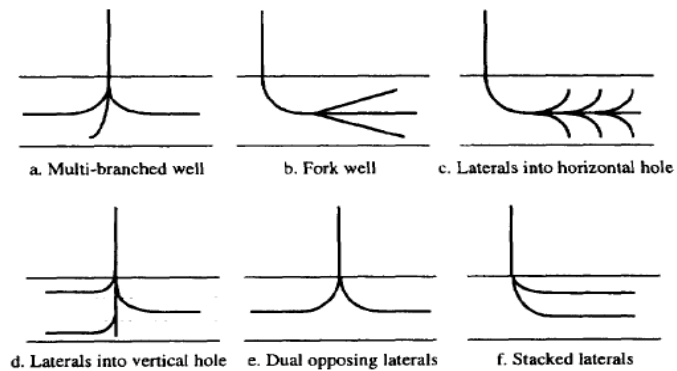
**BACK UP....**

# Relevant theory

## ➤ *Multilateral wells*

- **Multilateral well or multiple lateral wells** are wells with more than one lateral leg branching into the formation(s)

### *Multilateral well geometry*

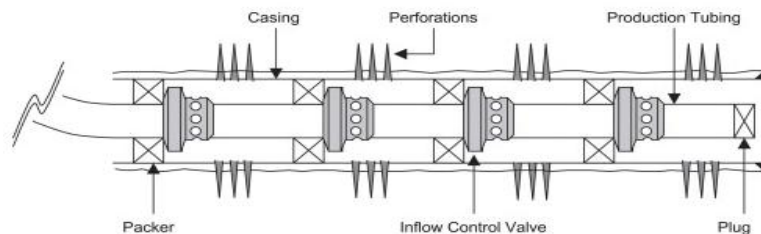


- **Main advantages** of drilling horizontal and multilateral wells over the conventional vertical wells are **Cost-saving// More reserves per area //Adaptability** in complex oil reservoir

## ➤ *Intelligent Completion System*

- A so called smart or intelligent well is typically defined as the well, either single or multilateral, in which every lateral (in case multilateral) is controlled by ICV or Inflow Control Valves
- It can obtain the downhole pressure and temperature data in real time to identify problem in reservoir or wellbore
- Ultimately gain the optimization of the production scenario without performing any costly well intervention
- This ability will lead operator to minimize fluid loss, effectively manage the reservoir by maintaining well integrity and maximizing the production

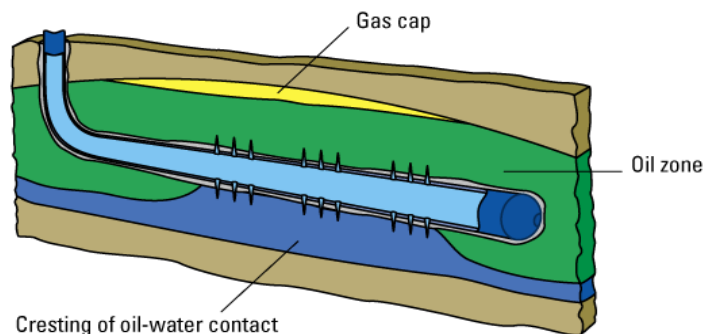
*Illustration of intelligent completion composing ICV and zonal isolation packers*



## ➤ *Water Encroachment*

- Naturally-drive water influx has been described as the incursion of water into oil or gas bearing formations
- This is one of the mechanisms of oil production in which the water displaces and moves the reservoir fluids towards the well borehole
- Similar to other natural phenomena that if the water influx affects too much, this can ultimately lead to the overwhelmed invasion of water in the targeted oil production or as known as water coning
- Highly is recognized as one of the main petroleum production problems that have been happening so far

*Water encroachment phenomena or water cresting*



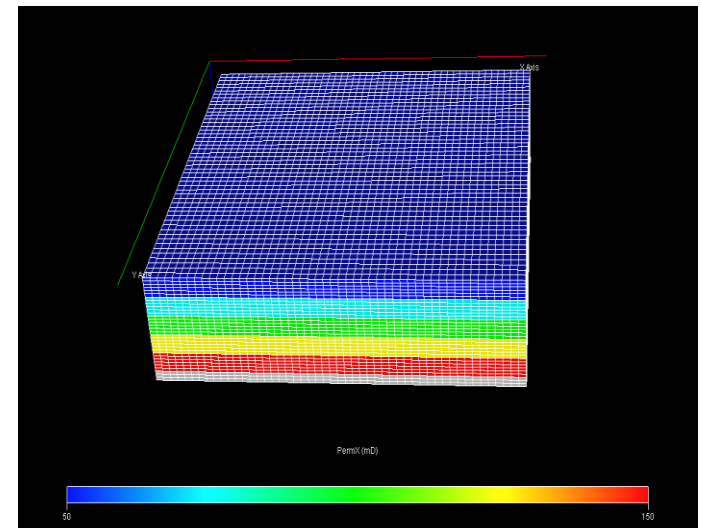
# Reservoir model using ECLIPSE®100

## ➤ *Grid section*

- The **reservoir size** is set to be 2500 × 2500 × 300 feet
- Total grid blocks of 50 × 50 × 50 feet in X, Y and Z direction, respectively
- Permeability is **sequenced from the highest permeability** at top layer **to the lowest permeability** at the bottom of the reservoir

Layer	Vertical grid block	Horizontal permeability (md)	Vertical permeability (md)
1	1-6	50	5
2	7-12	75	7.5
3	13-18	100	10
4	19-25	125	12.5
5	26-30	150	15

*3D view of Horizontal permeability varied by reservoir layers*



## ➤ PVT properties section

### PVT properties of formation water

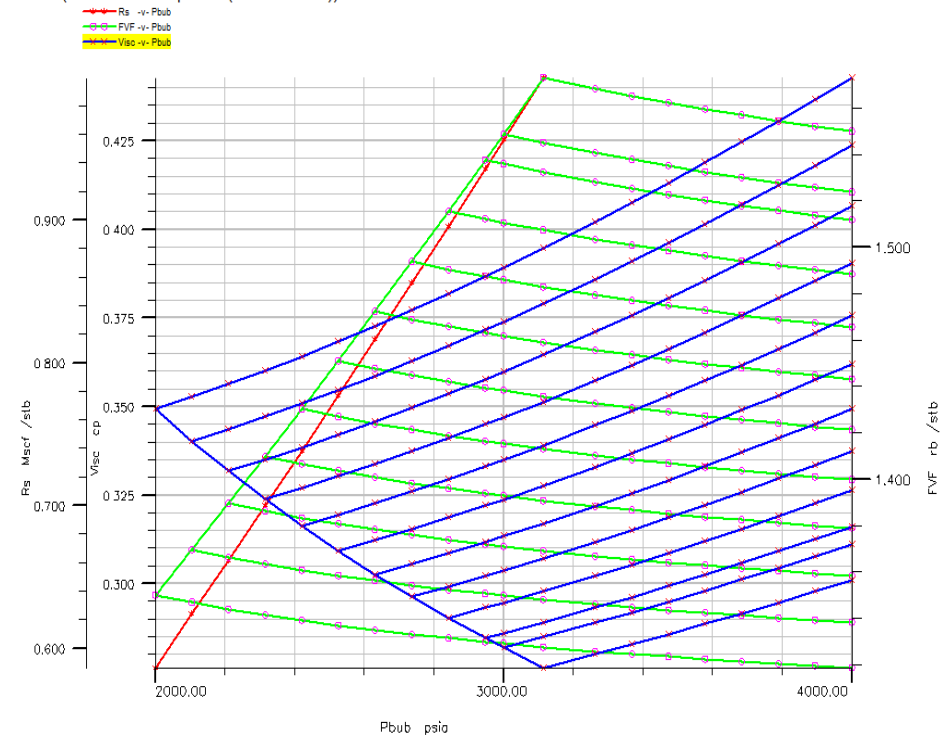
Property	Value	Unit
Reference pressure ( $P_{ref}$ )	3,000	psia
Water FVF at $P_{ref}$ ( $B_w$ )	1.021734	rb/ STB
Water compressibility ( $C_w$ )	$3.09988 \times 10^{-6}$	psi <sup>-1</sup>
Water viscosity at $P_{ref}$ ( $\mu_w$ )	0.3013289	cp
Water viscosibility	$3.360806 \times 10^{-6}$	psi <sup>-1</sup>

### Fluid densities at surface condition

Property	Value (lb/ft <sup>3</sup> )
Oil density ( $\rho_o$ )	49.99914
Water density ( $\rho_w$ )	62.42797
Gas density ( $\rho_g$ )	0.04369958

### Live oil PVT properties

PVTO (Live Oil PVT Properties (Dissolved Gas))



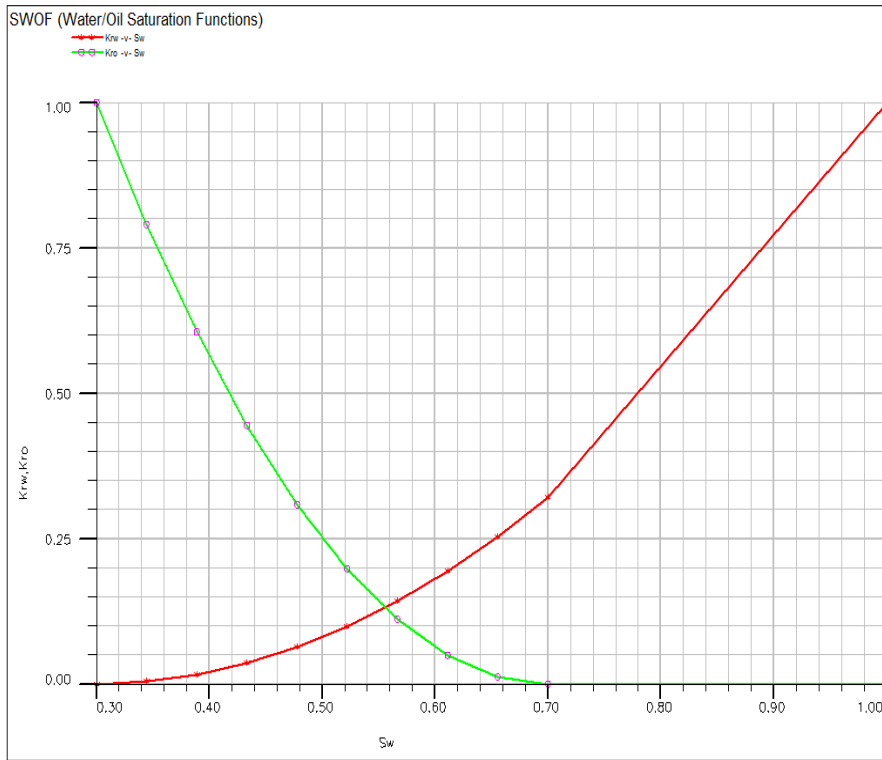
➤ **SCAL (Special Core Analysis) Section**

- Sedimentary sandstone lithology of rock with a **fining upward facies**
- The **moderately water-wet** is assumed in the study → relative permeability curves for both oil and water can be generated by the rule of thumb (Corey's)

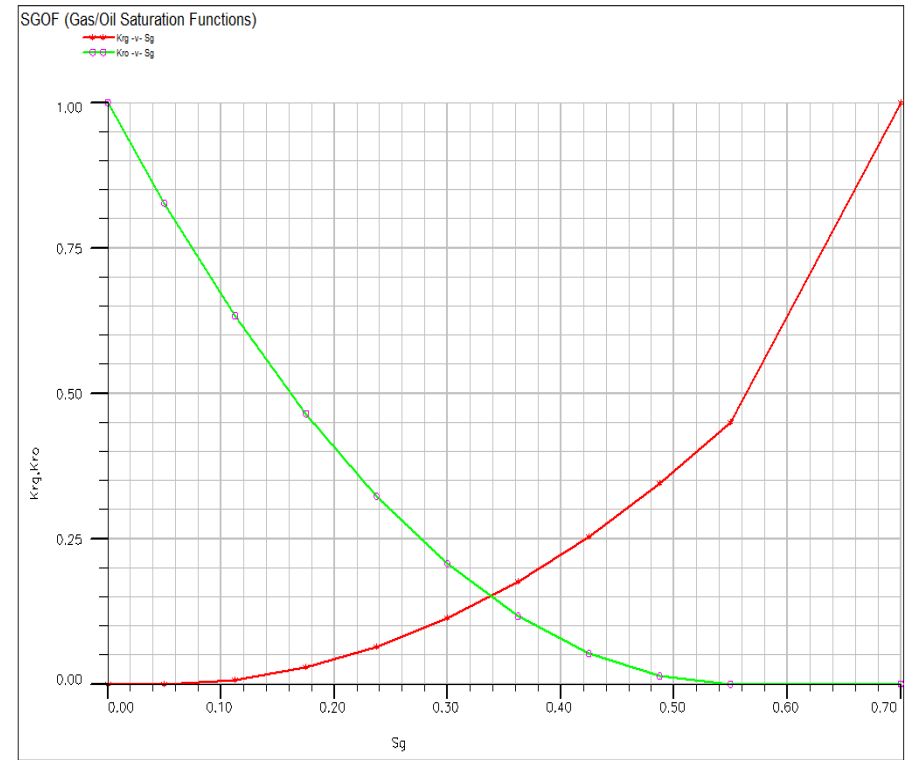
*Summary of required data to generate relative permeability by Corey correlation*

Water		Gas		Oil	
Property	Value	Property	Value	Property	Value
Corey Water	2	Corey Gas	2	Corey Oil/ Water	2
$S_{wmin}$	0.3	$S_{gmin}$	0	Corey Oil/ Gas	2
$S_{wcr}$	0.3	$S_{gcr}$	0.05	$S_{org}$	0.15
$S_{wi}$	0.3	$S_{gi}$	0	$S_{orw}$	0.3
$S_{wmax}$	1	$k_{rg}$ at $S_{org}$	0.45	$k_{ro}$ at $S_{wmin}$	1
$k_{rw}$ at $S_{orw}$	0.32	$k_{rg}$ at $S_{gmax}$	1	$k_{ro}$ at $S_{gmin}$	1
$k_{rw}$ at $S_{wmax}$	1				

## ➤ SCAL (Special Core Analysis) Section – cont'd



Water/oil saturation functions representing relative permeability to water and oil



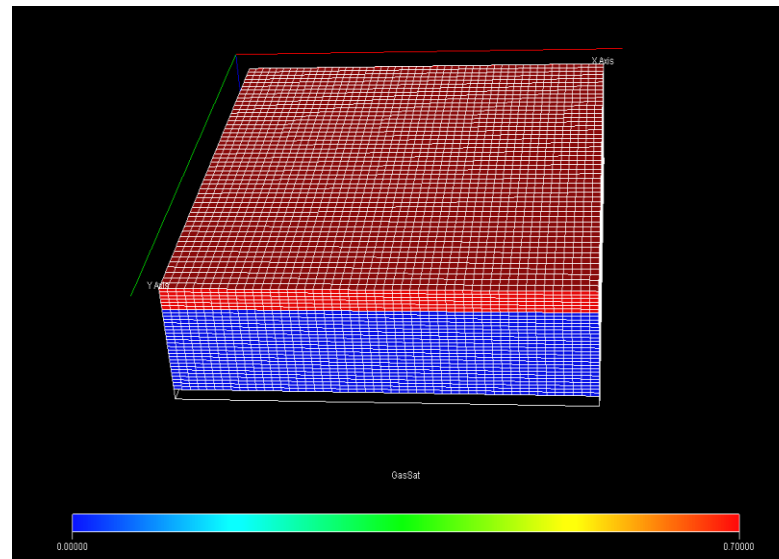
Gas /oil saturation functions representing relative permeability to gas and oil

## ➤ **INITIALIZATION Section**

### *Initialization data*

Data	Value	Unit
Datum depth	5,060	ft
Pressure at datum depth	2,242	psia
WOC depth	12,000	ft
GOC depth	5,060	ft

*Primary gas cap fully filled the top of permeable zone (top face to sixth grid block)*

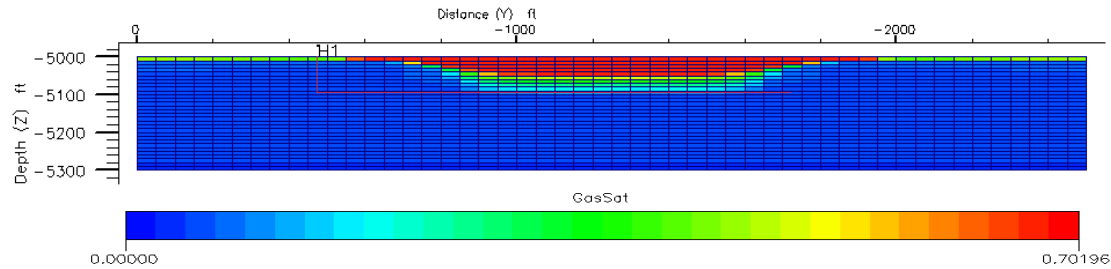


## ➤ **SCHEDULE Section**

- All wells in this study are fixed to have diameter of 0.358 feet with the assumption of **no presence of skin nearby**
- Main well patterns are
  - **Horizontal well**: I, J coordinate of 25, 10 to 35 with **effective length** of the horizontal section is 1,000 feet (20 grid blocks)// **Effective drilling radius** of 300 feet (6 grid blocks) considered as dummy drilling path (J coordinate of 10 to 15) - drilled as part of horizontal well but with no perforation
  - **Dual-lateral well**: Same effective length as of simple horizontal one's// effective radius of 3 grid blocks for each side of the lateral// I, J coordinate of 25, 12 to 38
  - **Dual-lateral well with ICV-equipped**: ICV performs the shut in of the well when observing that **water cut > maximum water cut** set in Well connection economic limit// **Well is tested again at the beginning of the next timestep** and will be reopened if water cut is lower than the set water cut or operating vice versa
- Z location is varied from 10<sup>th</sup>, 15<sup>th</sup>, 20<sup>th</sup> and 25<sup>th</sup> vertical grid block depends on the case

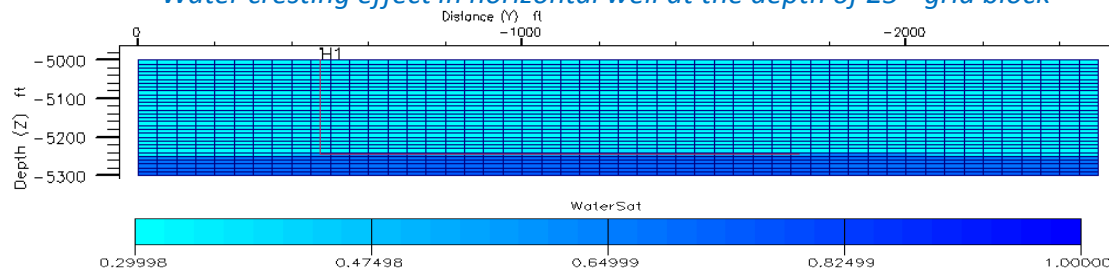
- Worst FOE when horizontal well has its depth at 10<sup>th</sup> vertical grid block due to the **gas-coning effect**

*Gas coning effect in horizontal well at the depth of 10<sup>th</sup> grid block*



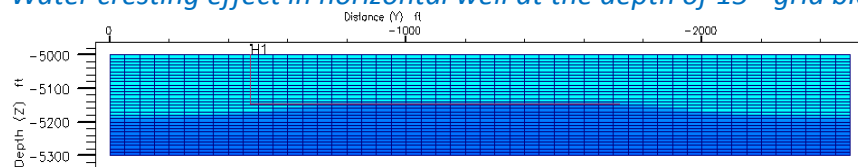
- Still poor FOE when horizontal well has its depth at 25<sup>th</sup> vertical grid block due to the **water cresting effect**

*Water cresting effect in horizontal well at the depth of 25<sup>th</sup> grid block*

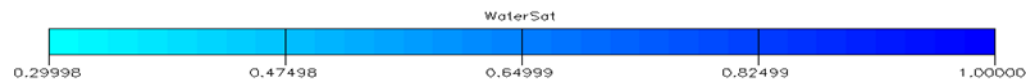
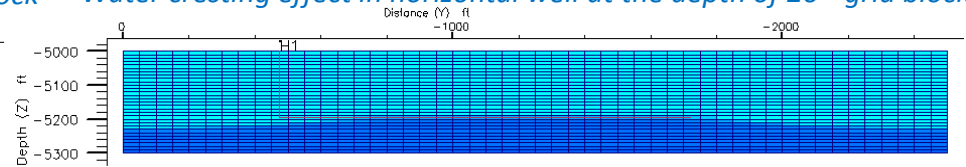


- **Better results** of FOE for horizontal wells' depth of 15<sup>th</sup> and 20<sup>th</sup> vertical grid block

*Water cresting effect in horizontal well at the depth of 15<sup>th</sup> grid block*



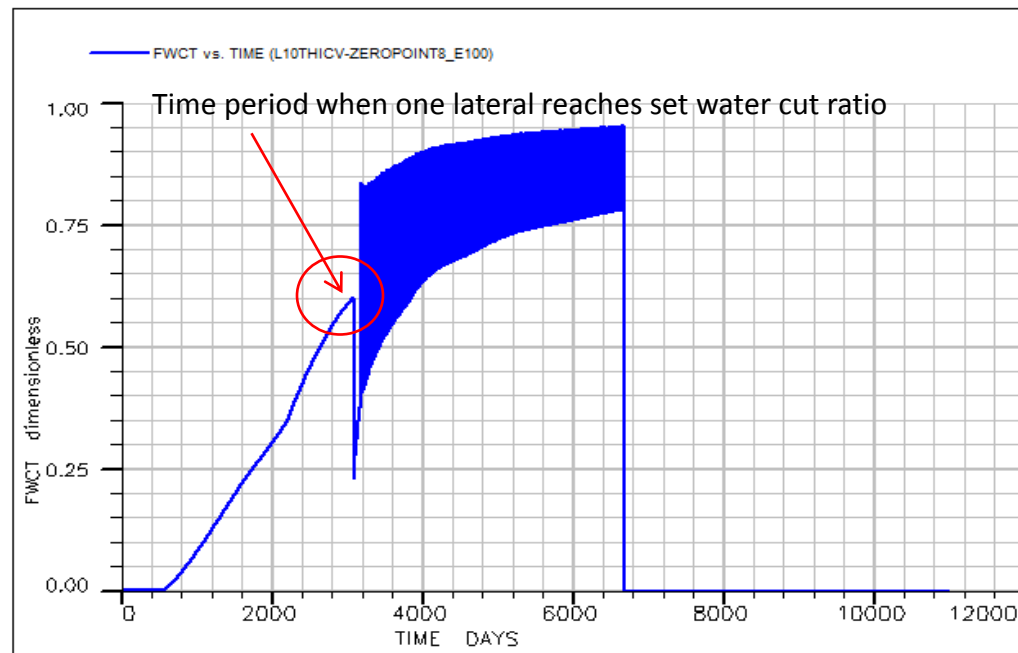
*Water cresting effect in horizontal well at the depth of 20<sup>th</sup> grid block*



*Result of intelligent completion equipped in dual-lateral well,  
with L1's depth of 10<sup>th</sup> vertical grid block*

- **No matter how the preset water cut ratios have been varied, the well still is closed** before the simulation period of 30 years
- This is understood to be majorly affected from the gas coning at the top of reservoir which does not only reduces the oil production but somehow also impacts the continuous water crestring and eventually leaves the well closed as the water crestring fully appears over both of the laterals

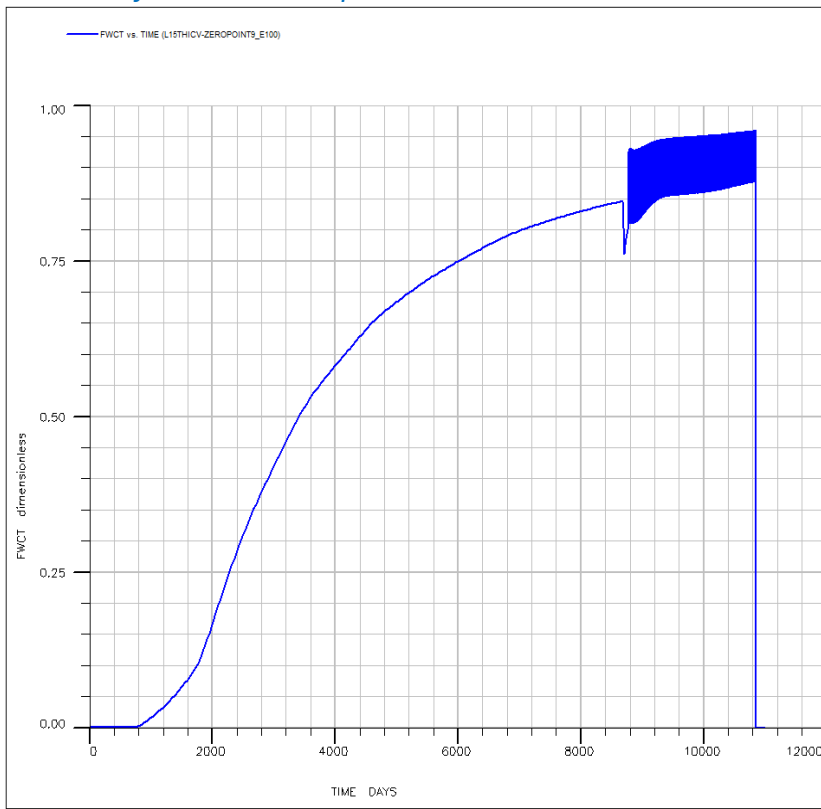
*FWCT of the well when preset water cut ratio is set at 0.8*



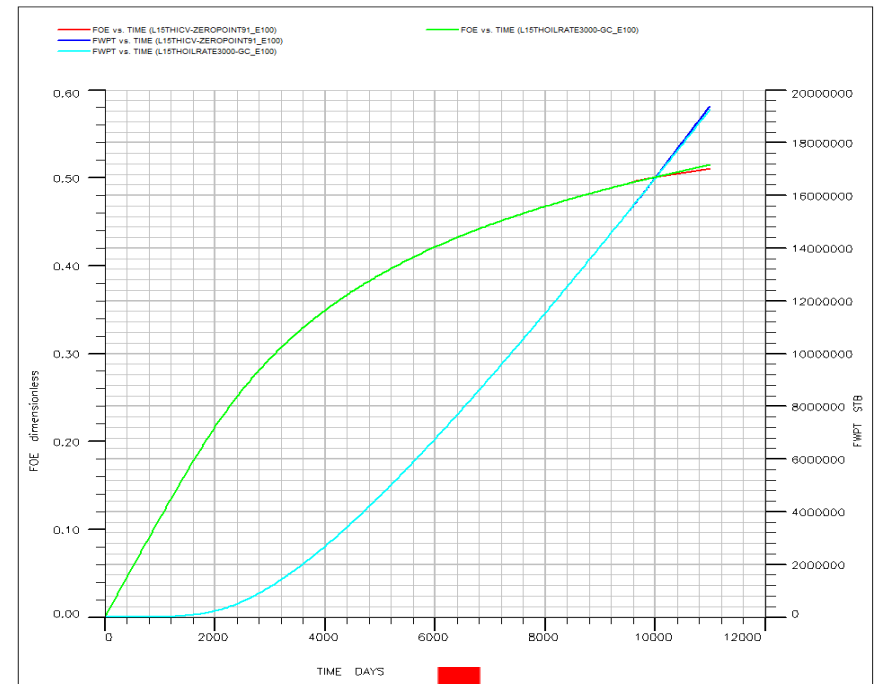
## Result of intelligent completion equipped in dual-lateral well, with L1's depth of 15<sup>th</sup> vertical grid block

- Simulation results shows that the well can maintain producing without lateral close when water cut ratio is more than or equal to 0.91 in this case

FWCT of the well when preset water cut ratio is set at 0.90



Comparison of FOE and FWPT between the case of **having no ICV installed** and **ICV installed** at water cut ratio of 0.91, at dual-opposed well where L1 is fixed at 15<sup>th</sup> grid block

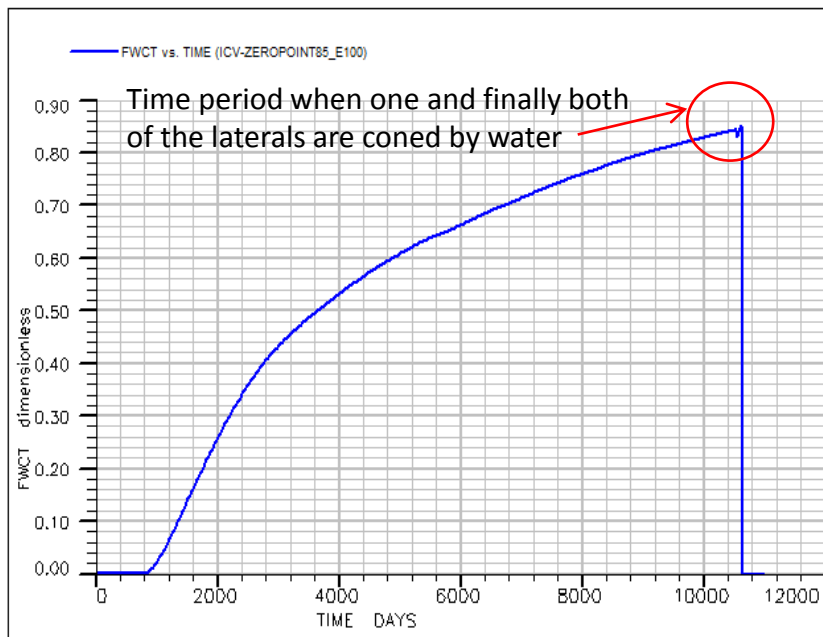


*Insignificant result; carry over to sensitivity analysis part*

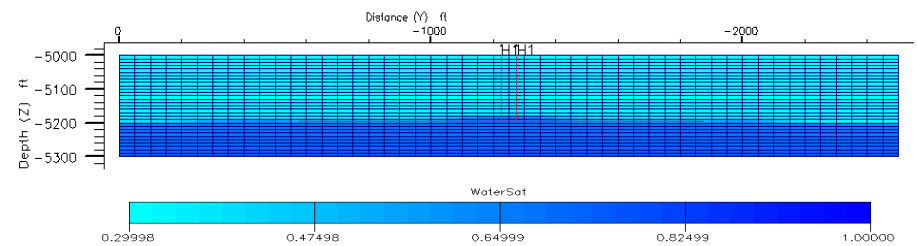
## Result of intelligent completion equipped in dual-lateral well, with L1's depth of 20<sup>th</sup> vertical grid block

- Both of the laterals are **majorly affected from water cresting phenomenon at the same time**
- Ultimately **leaves the well no chance to have just even one lateral open** and leads to the scenario where the whole system cannot be further produced → **No benefit of installing ICV !!**

*FWCT of the well when water cut ratio is set to be 0.85*



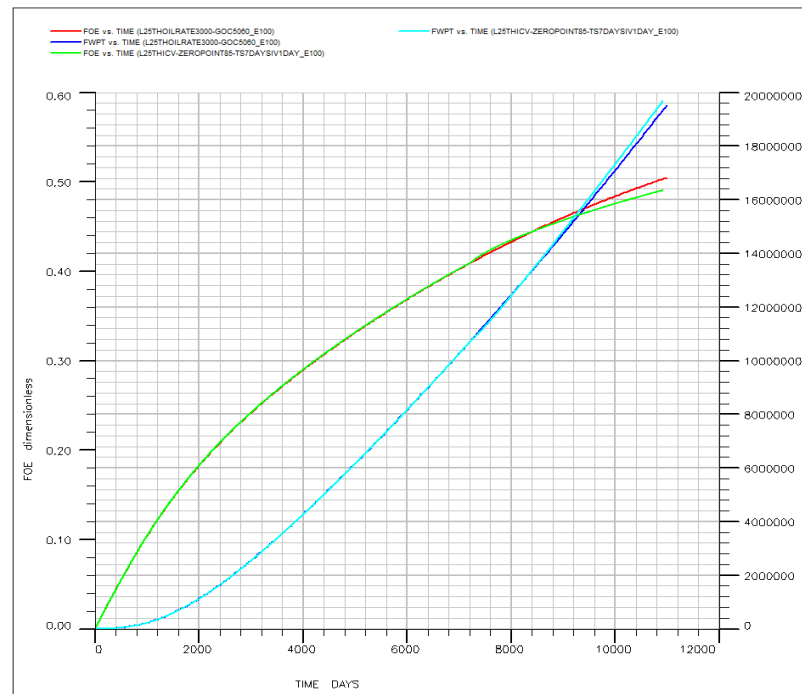
*Two-dimensional side view of the water saturation at 10<sup>th</sup> year of the simulation*



## Result of intelligent completion equipped in dual-lateral well, with L1's depth of 25<sup>th</sup> vertical grid block

- Simulation results of those wells having the ICV equipped show that the **ICV can be effectively operated once the water cut ratio is more than or equal to 0.85**
- Comparison is made, similar to the case of having L1 at 15<sup>th</sup> vertical grid block which is the case that **intelligent completion is proved to be worth of installation**

*Comparison of FOE and FWPT between the case of **having no ICV installed** and **ICV installed** at water cut ratio of 0.85, at dual-opposed well where L1 is fixed at 25<sup>th</sup> grid block*



*Insignificant result;  
carry over to  
sensitivity analysis  
part*