SAGD高级井筒模拟和优化

Modelling & Optimization of Advanced SAGD Wellbore Completions

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Agenda

- Introduction to FlexWell
- Demo – Setting up a FlexWell Model
- Demo – Optimizing Circulation using CMOST
- Case Studies

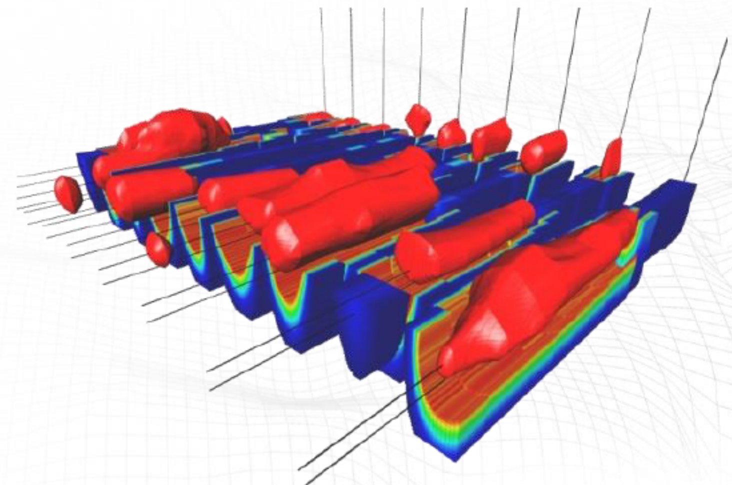
Well Models

Source-Sink Model

- Simplistic; quick run times
- Focus – reservoir deliverability
- Full field applications – History Matching, Forecasting

Capabilities

- Gravity, friction, and heat loss
- Complex well trajectories
- Multi-lateral Wells



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Wellbore Modelling – Why does it matter?

Understand Wellbore Interaction

- Undulating Wells
- Reservoir affects on Production-Injection Integration
- Completion affects – model tubing strings & annulus

Optimize Well Performance

- Circulation Start-up
- Operating Parameters (Steam-Split)
- Completion Optimization
- History Match – Temperature & Pressure Fall-off tests

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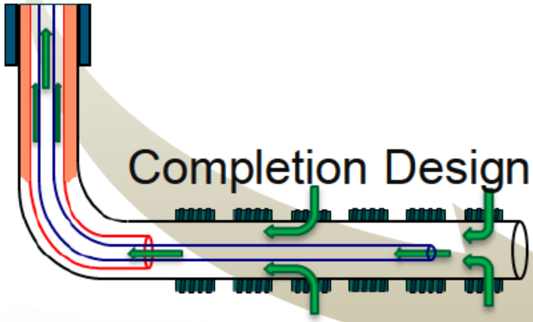
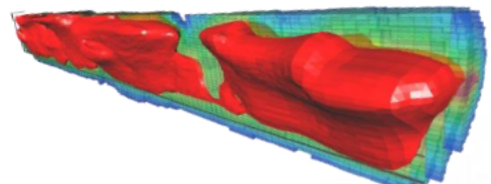
Integrated Subsurface Modelling



Completion Design



Well Completions
customized
for your Reservoir

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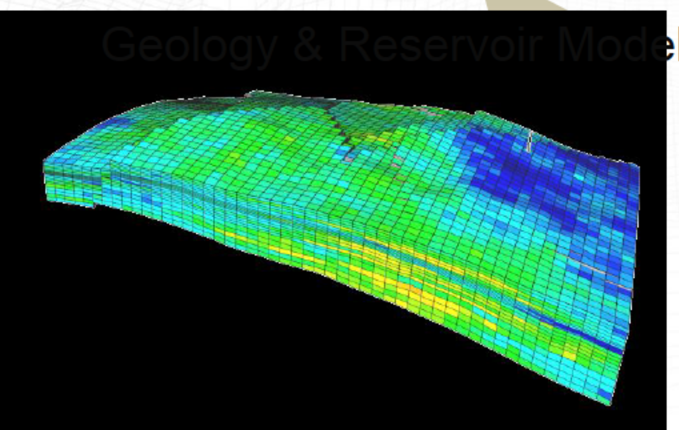

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FlexWell Features

- Discretized mechanistic wellbore model
- Models fluid and heat flow in the wellbore and between the wellbore and the reservoir
- Capable of modelling difficult flow dynamics

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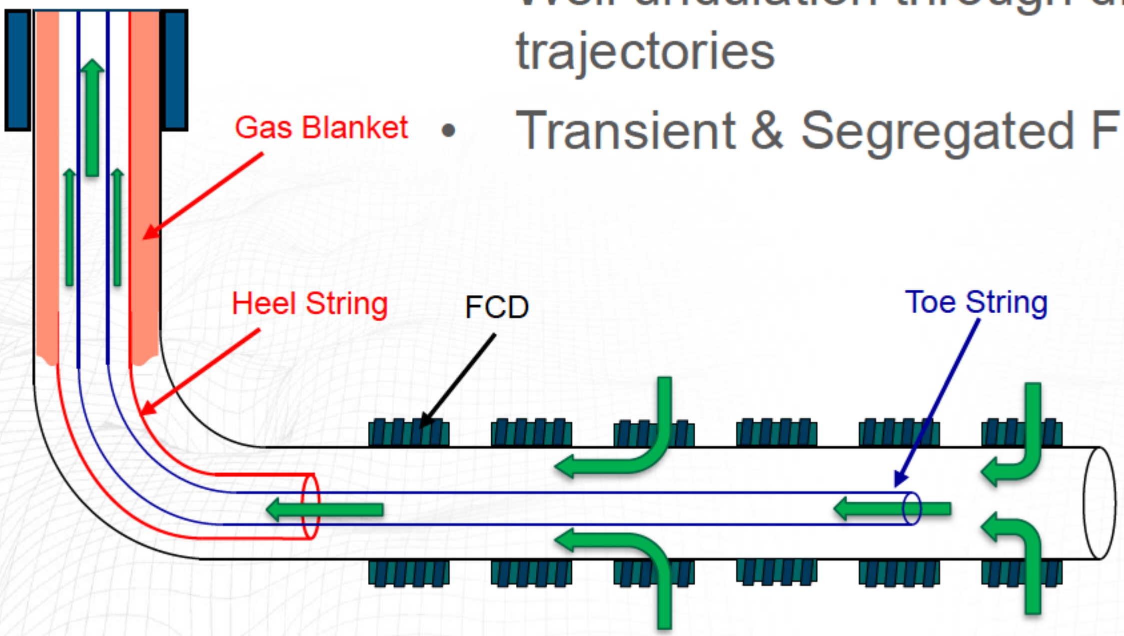
FlexWell Features

Complex Well Completions

- Multiple flow strings (communicate via annulus)
- Well undulation through different layers to follow trajectories
- Transient & Segregated Flow



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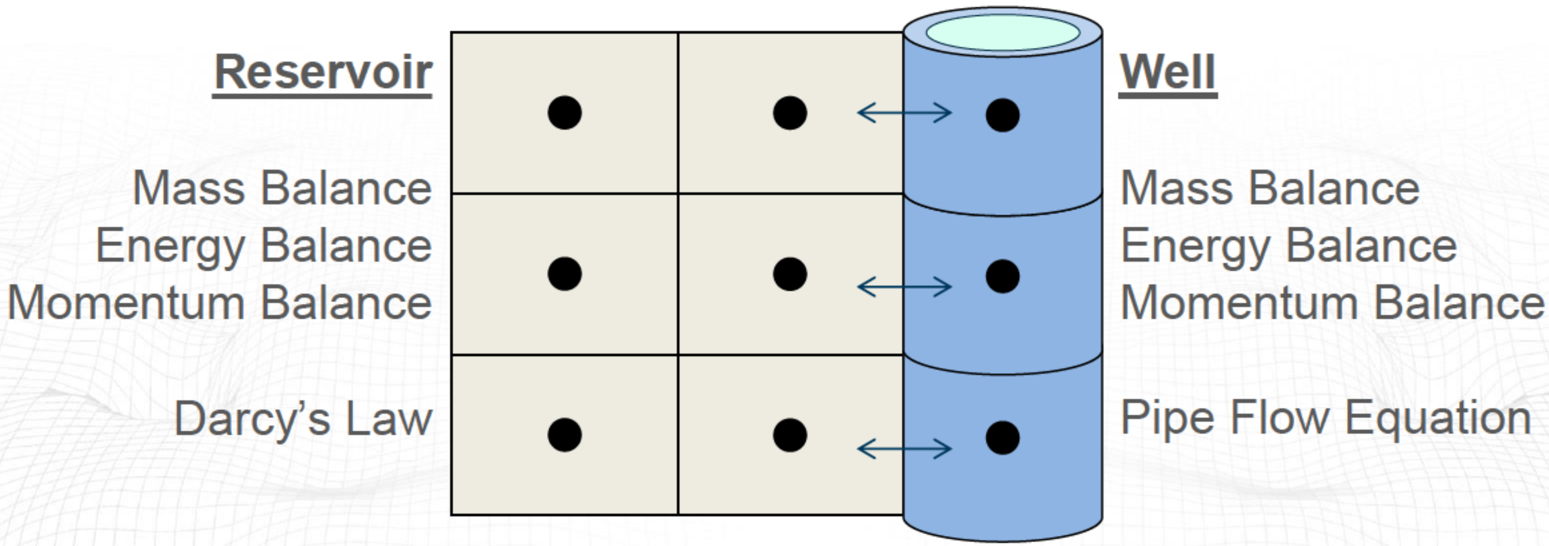
FlexWell Features

Each specified FlexWell is solved independently and is coupled with the reservoir

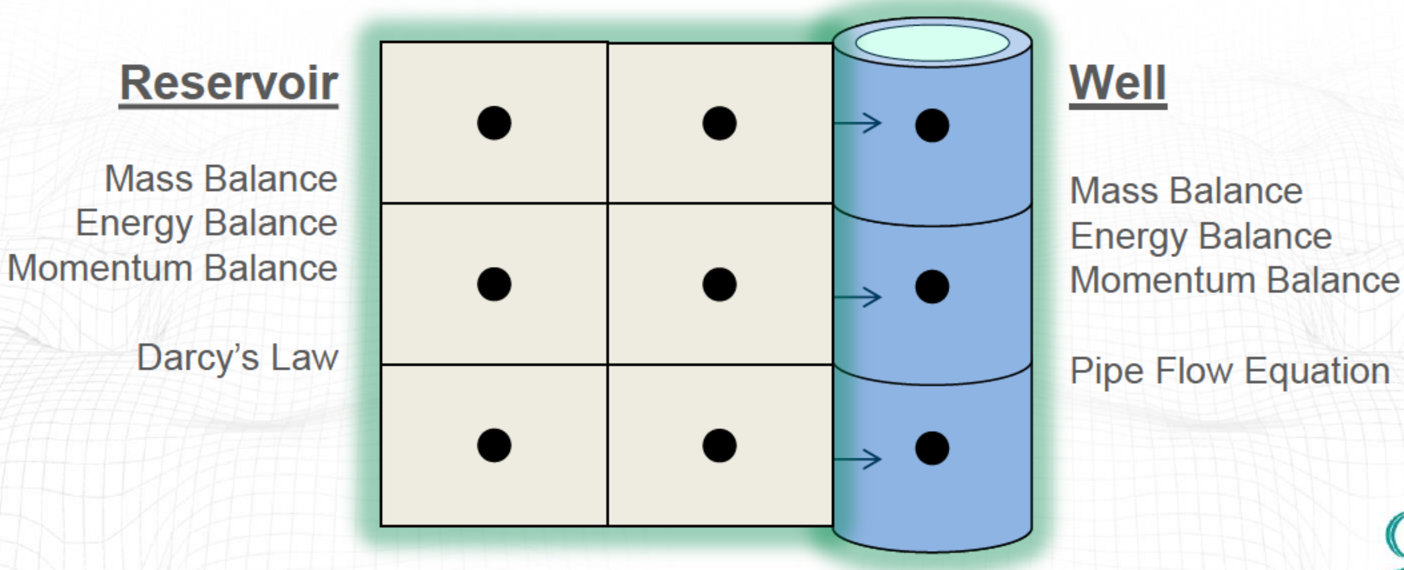


FlexWell Features

At every time-step:

1. Wellbore is solved first, keeping reservoir constant
2. Reservoir is solved second, keeping wellbore constant

   Thus Reservoir lags behind the wellbore by 1 iteration



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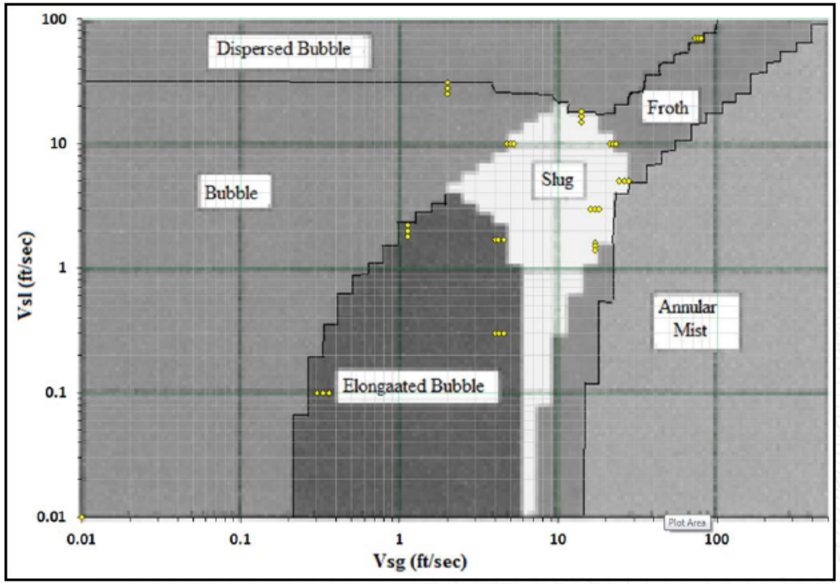
FlexWell Features

- Flow regime is evaluated from gas and liquid velocities
- STARS supports following flow regimes
  - Dispersed Bubble
  - Stratified
  - Annular Mist
  - Froth I, II
  - Liquid
  - Gas
  - Intermittent



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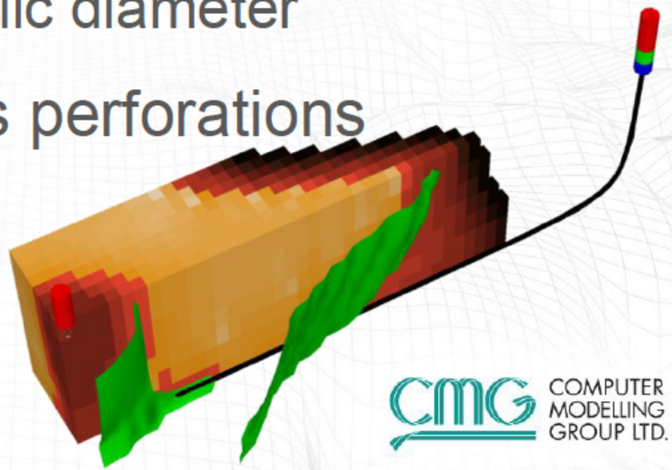
FlexWell Features

- Tubing/Annulus String Diameter may be constant or variable (E.g. tapered tubing)
- Flow Control Devices (FCDs)
- Solid deposition via reaction (E.g. THAI process)
    - Solid deposition reduces hydraulic diameter
- Packers - Stop axial fluid flow across perforations



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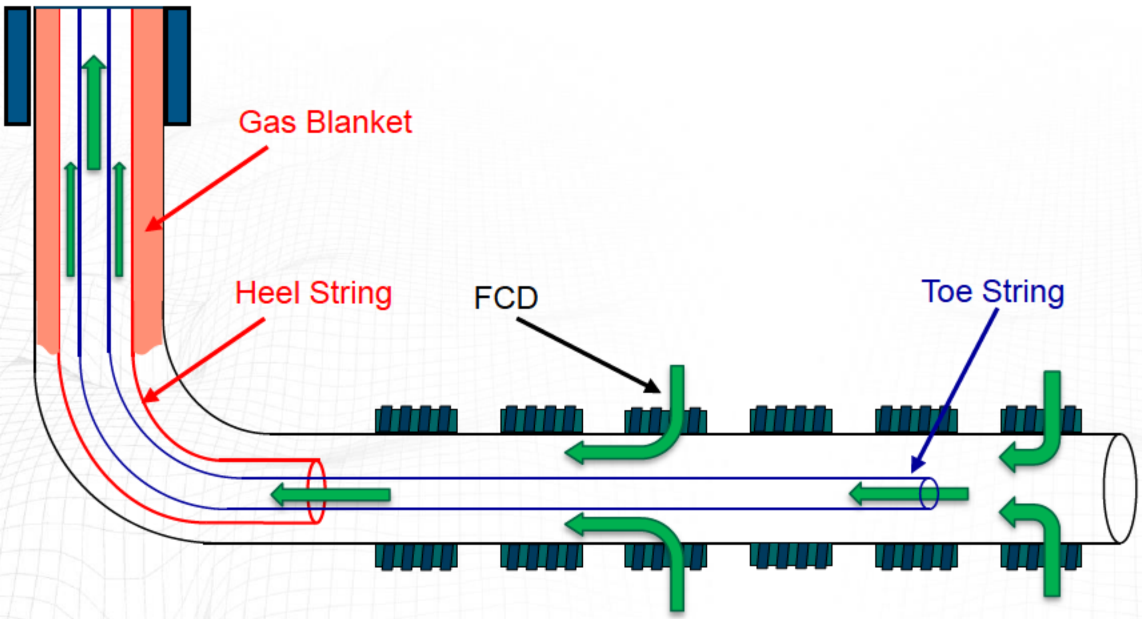
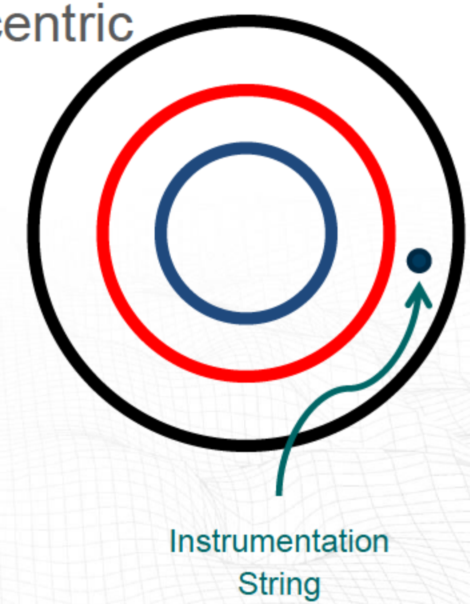
FlexWell Configurations

FlexWell may consist of:

- An annulus
- Up to 3 tubing strings, one of which may be concentric
- One instrumentation tubing





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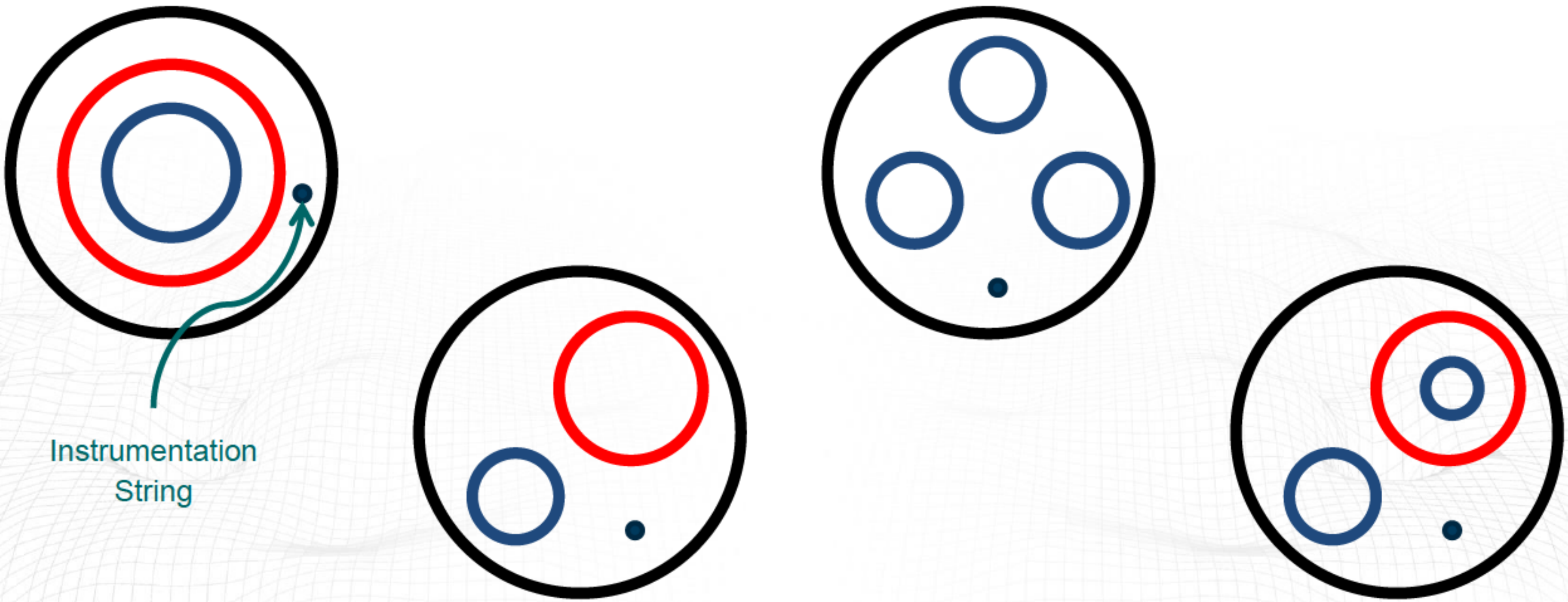
FlexWell Configurations

Lot of Flexibility built-in



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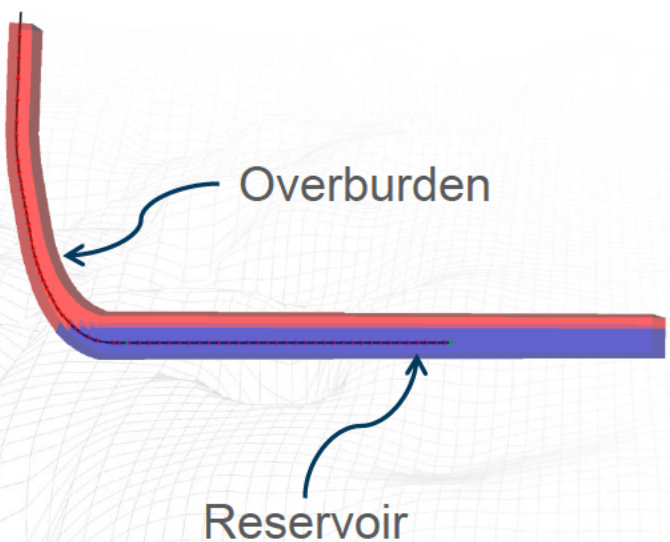
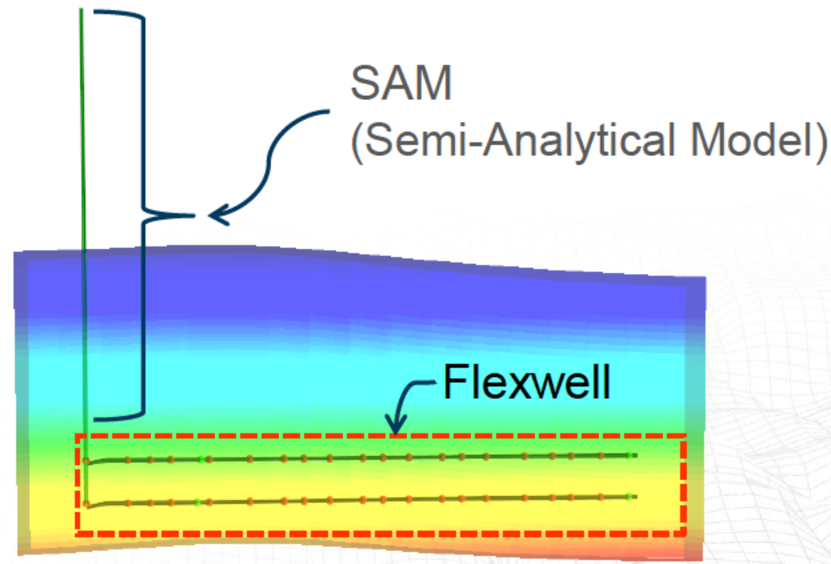
Modelling Wellbore to Surface

OPTION # 1
FlexWell to Surface
Overburden gridded to surface





OPTION # 2
FlexWell in Reservoir Section
SAM in Riser Section

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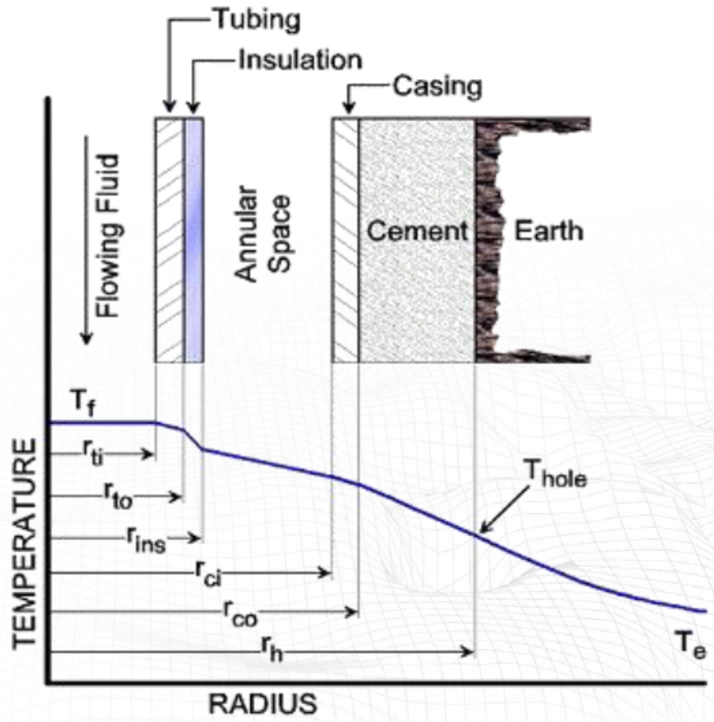
Semi-Analytical Model (SAM)

- SAM calculates pressure drop and heat loss from the wellhead to the first perforation
- Steady-State Assumption
- Momentum & Energy Balance Equations are solved for each segment



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Modelling Lift Mechanism

Modeling Pumps

- SAM can be used

OR

- Use FlexWell to surface: withdrawal Point and Reference Layer can be specified to simulate a downhole pump
    - Allows fluid withdrawal from any defined point along a tubing

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Modelling Lift Mechanism

Modelling Gas Lift

- SAM model can be used in combination with FlexWell
- Definition of gas-lift port locations (SAM)

OR

- Extend the FlexWell to surface and model the gas injection string as one of the tubulars in FlexWell

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Workflow Demo

Demo Example – SAGD Model

- Convert Source-Sink Model to FlexWell Model
- Modelling Circulation Period & SAGD
- Dual Parallel Tubing Configuration

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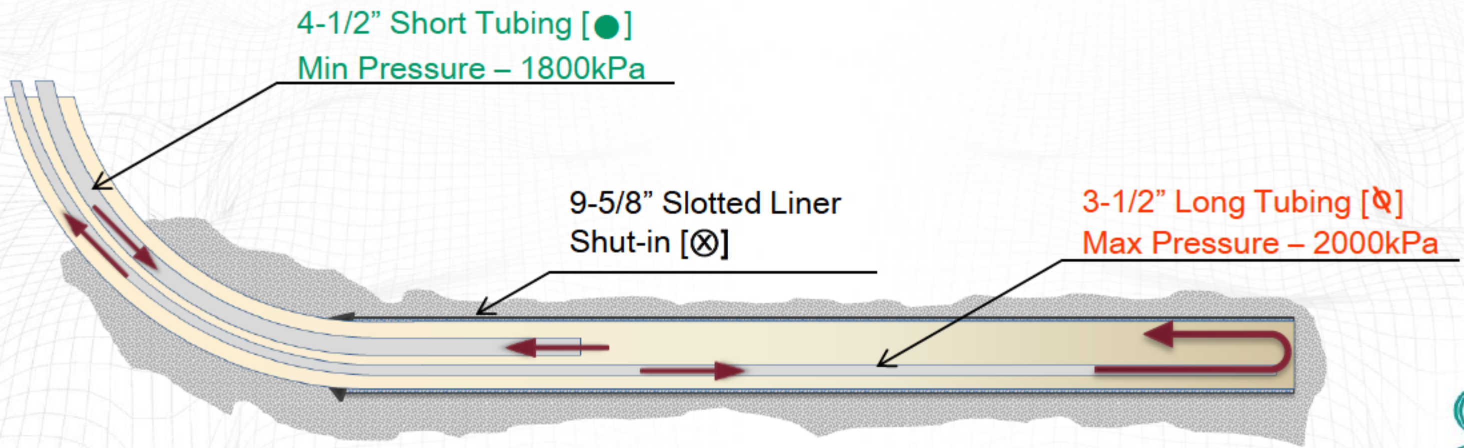
Demo Example

Circulation Period Setup

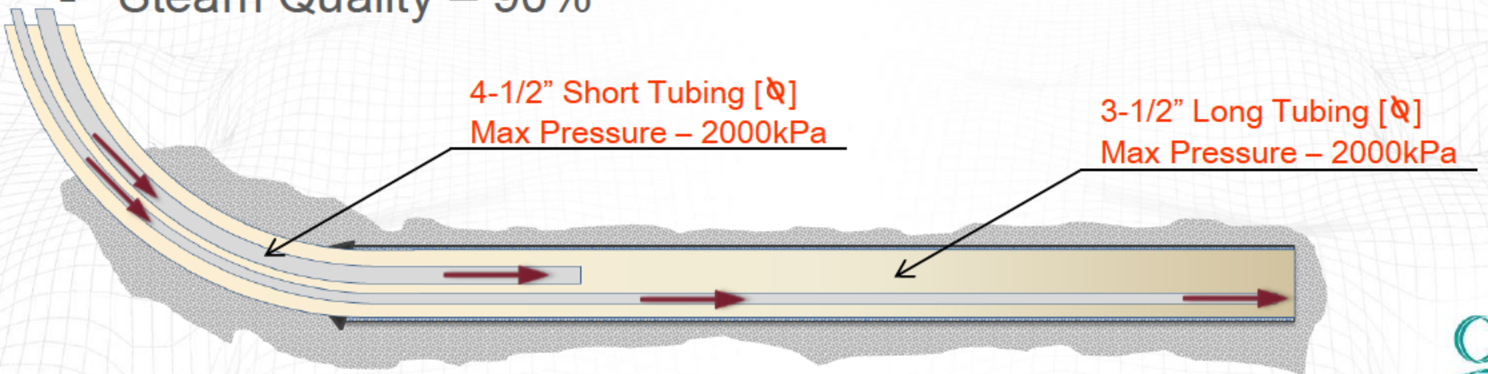
- Annulus – Shut-in
- Inject in Long Tubing
- Produce returns from Short Tubing
- Circulation Period – 90 days



Demo Example

SAGD Period – Injector Constraints

- Annulus – Shut-in
- Inject in Injector Long Tubing & Short Tubing
  - Maximum BHP – 2000kPa
  - Maximum Injection Rate – 250m^3/day
  - Steam Temperature – 212℃
  - Steam Quality – 90%



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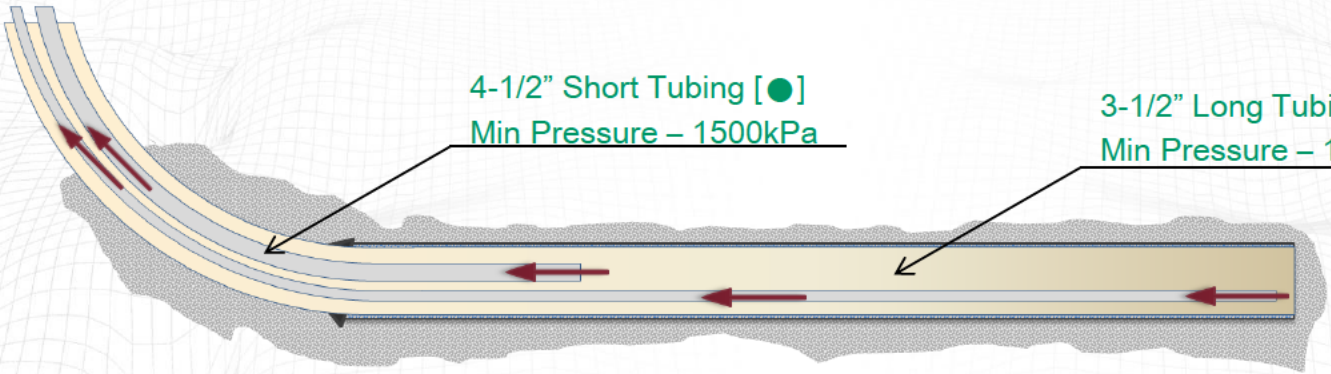
Demo Example

SAGD Period – Producer Constraints

- Annulus – Shut-in
- Producer from Long Tubing & Short Tubing
  - Minimum BHP – 1500kPa
  - Maximum Liquid Rate – 800m^3/day
  - Maximum Steam Rate – 5m^3/day



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Demo Example: Well Set-up

		Injector FlexWell	Producer FlexWell
Circulation	Annulus	Injector_Annulus (SHUTIN)	Producer_Annulus (SHUTIN)
	Long Tubing	Injector_LgTb_SAGD ( )	Producer_LgTb_CIRC ( )
	Short Tubing	Injector_ShTb_CIRC (●)	Producer_ShTb_SAGD (●)
SAGD	Annulus	Injector_Annulus (SHUTIN)	Producer_Annulus (SHUTIN)
	Long Tubing	Injector_LgTb_SAGD ( )	Producer_LgTb_SAGD (●)
	Short Tubing	Injector_ShTb_SAGD ( )	Producer_ShTb_SAGD (●)

Demo

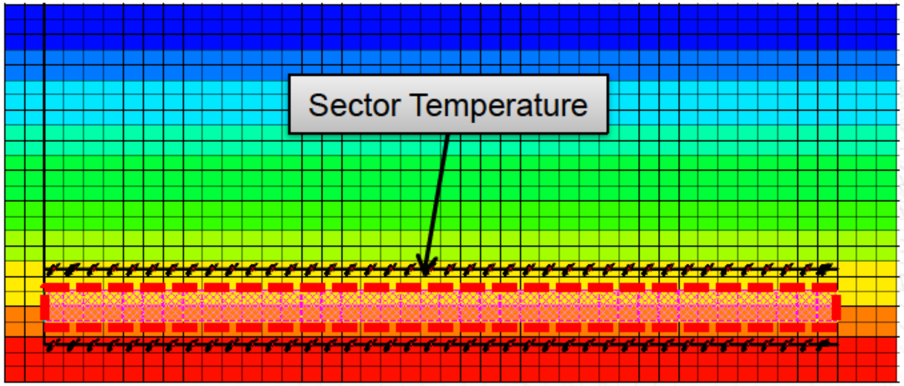
Circulation Optimization

Optimization Parameters

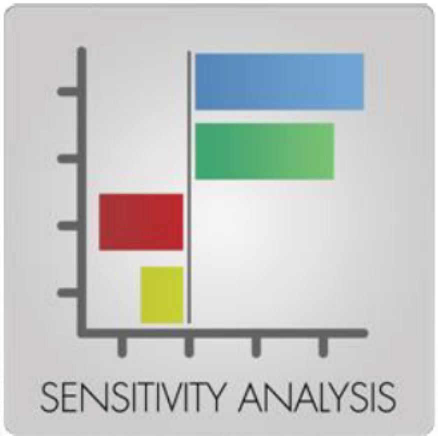
- Duration
- Back Pressure
- Injection Pressure

Performance Criteria

- Average Sector Temperature (between wells)
- Cumulative Oil at 1 year of SAGD production



What is CMOST?



- Better understanding
- Identify important parameters

- Calibrate simulation model with field data
- Obtain multiple history-matched models

- Improve NPV, recovery, etc.
- Reduce cost

- Quantify uncertainty
- Understand and reduce risk

How is it Done?

CMOST uses Master Datasets to specify parameters to be altered

- Datasets with CMOST keyword strings

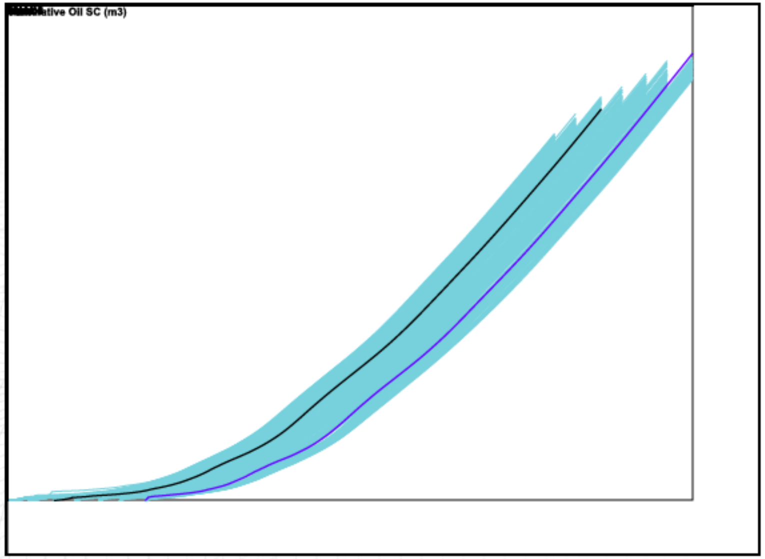
Files can be created:

- Manually (Text Editor)
- Through CMOST (CMOST CMM Editor)
- Through Builder

Demo

Circulation Optimization

- Optimize Circulation to ensure good start-up
- Reduce Circulation period by 2 weeks resulting in similar start-up temperature and Cumulative Oil produced



	Base Case	Optimized Case
Injection Pressure	2000	2500
Delta Pressure	200	75
Duration	90 days	75 days

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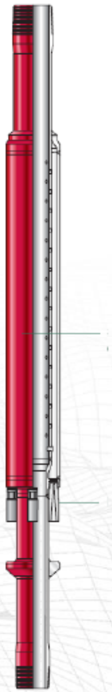
Modelling Flow Control Devices

Flow Control Devices

- Multiple steam injection points along the well - can result in a more uniform or controlled steam chamber growth
- Capability to optimize steam injection relative to geology
- CMG has utilized strong cooperation with industry to implement FCD's into FlexWell
- Weatherford GDA, Baker Equalizer tools are among some FCD's that can be simulated in STARS using FlexWell



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Modelling Flow Control Devices

Generalized models for various types:

- Orifice
- Friction
- Venturi

Modelling Flow Control Devices

FCDTABLE Format

- Simple format that works with all FCD types
- Delta Pressure versus Flow-rate Table
- Pressure or volumetric flow-rate (mass rate* & molar rate*) can be defined as dependent variable
- Optional dependencies include
    - Gas-phase mass fraction (Steam)
    - Inlet temperature
    - Inlet pressure
    - Water-cut *

**upcoming STARS Release*

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Case Studies

SPE 170076 – SAGD Wellbore Completion Optimization Using Scab Liner & Steam Splitter

SPE 171131 – Investigation of Orifice Type Flow-Control Device Properties on the SAGD Process Using Coupled Wellbore Reservoir Modeling

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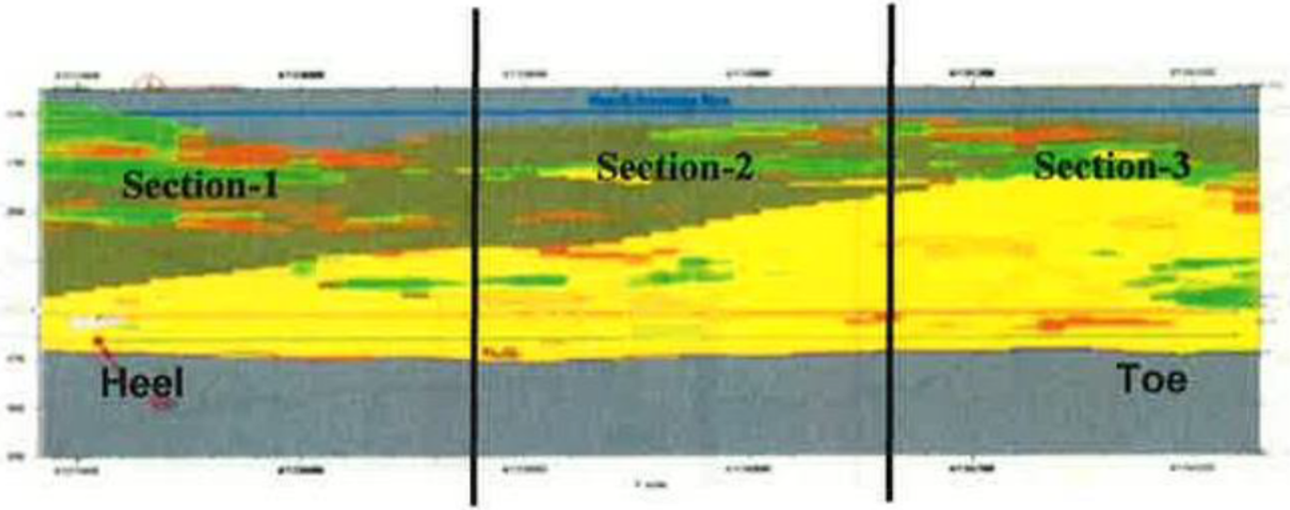
SPE 170076 – L. Zhao & K. Ghesmat, CNRL

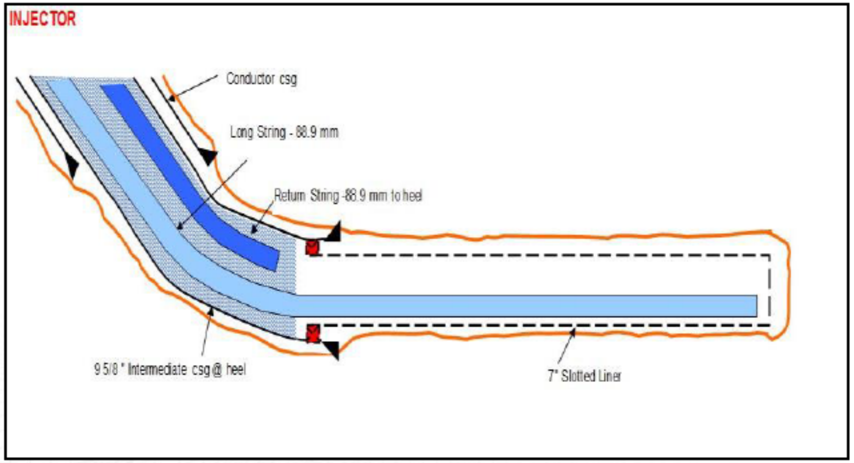
SAGD Wellbore Completion Optimization Using Scab Liner & Steam Splitter

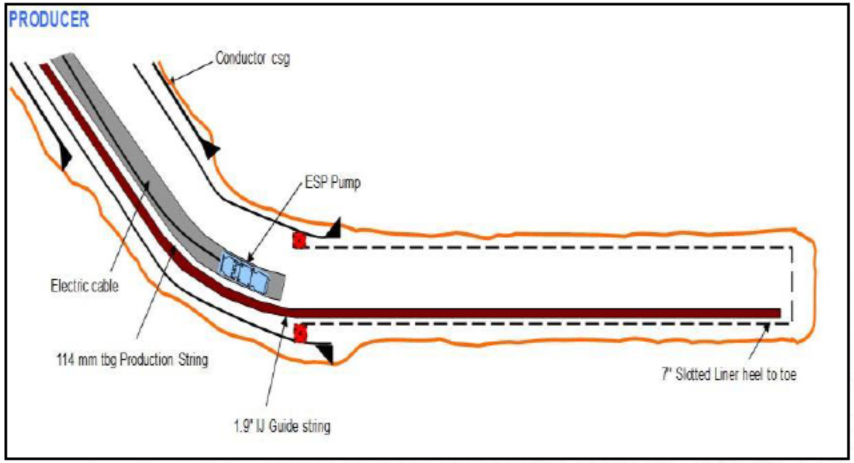
Geological Background

- Low ceiling around the heel - Section 1
- Good quality sand in the middle - Section 2
- Relative good but thick pay near the toe - Section 3



Conventional Completions





- Conventional completion design would inject more steam into the heel
- Steam breakthrough was a major concern because of the low-ceiling near the heel

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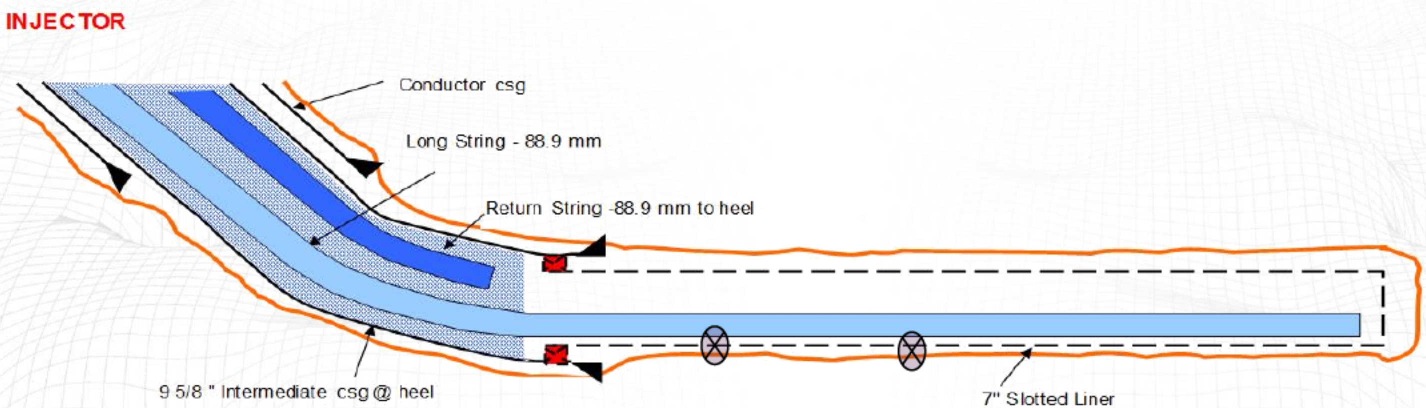
Completion Optimization

- A 4.5” long string is run instead of conventional dual string design
- Different numbers of steam splitter could be inserted in 4.5” long string
- Depending on the size and numbers of ports, various percentages of steam may exit from each splitter
- Steam splitter may change the pressure profile inside the injector



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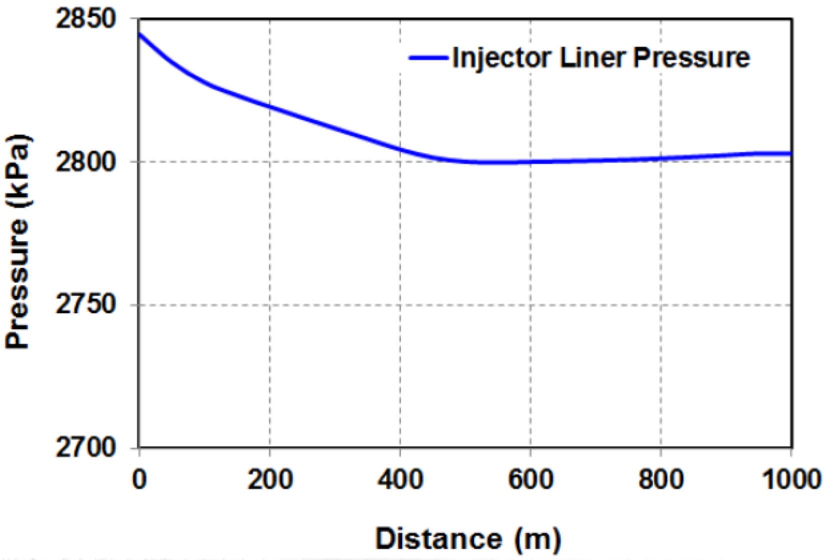
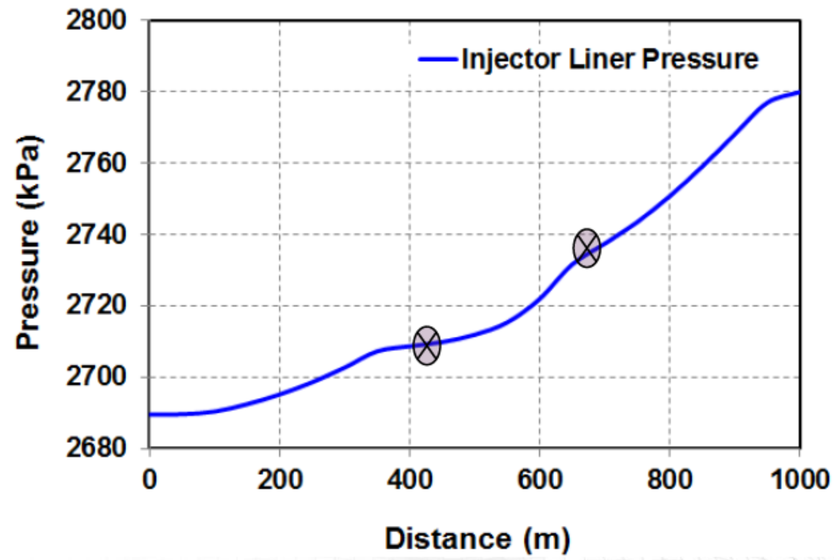
Steam Splitter Optimization

Standard Configuration



Steam Splitters



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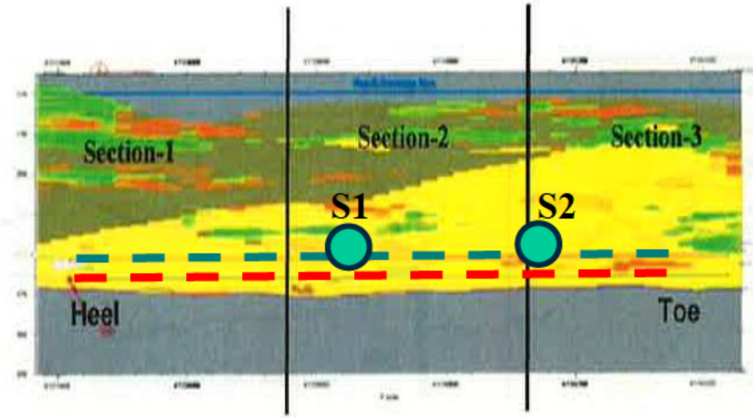
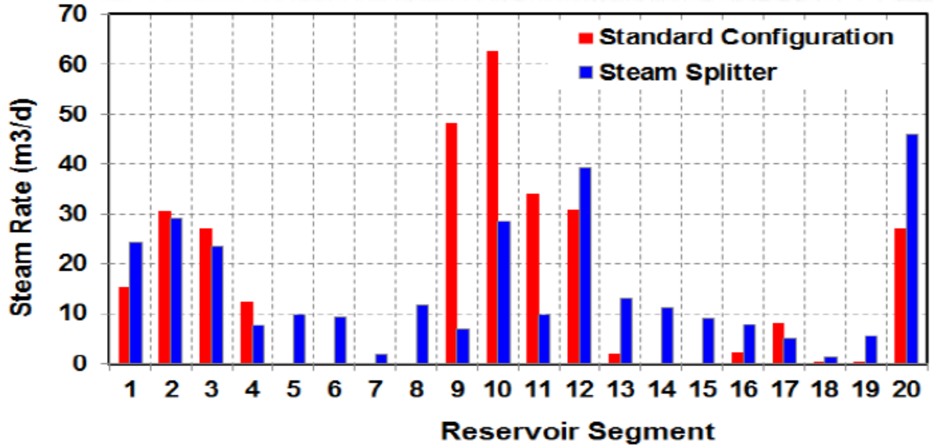
Steam Splitter Optimization

Two steam splitters are installed at 500m and 750m with open toe

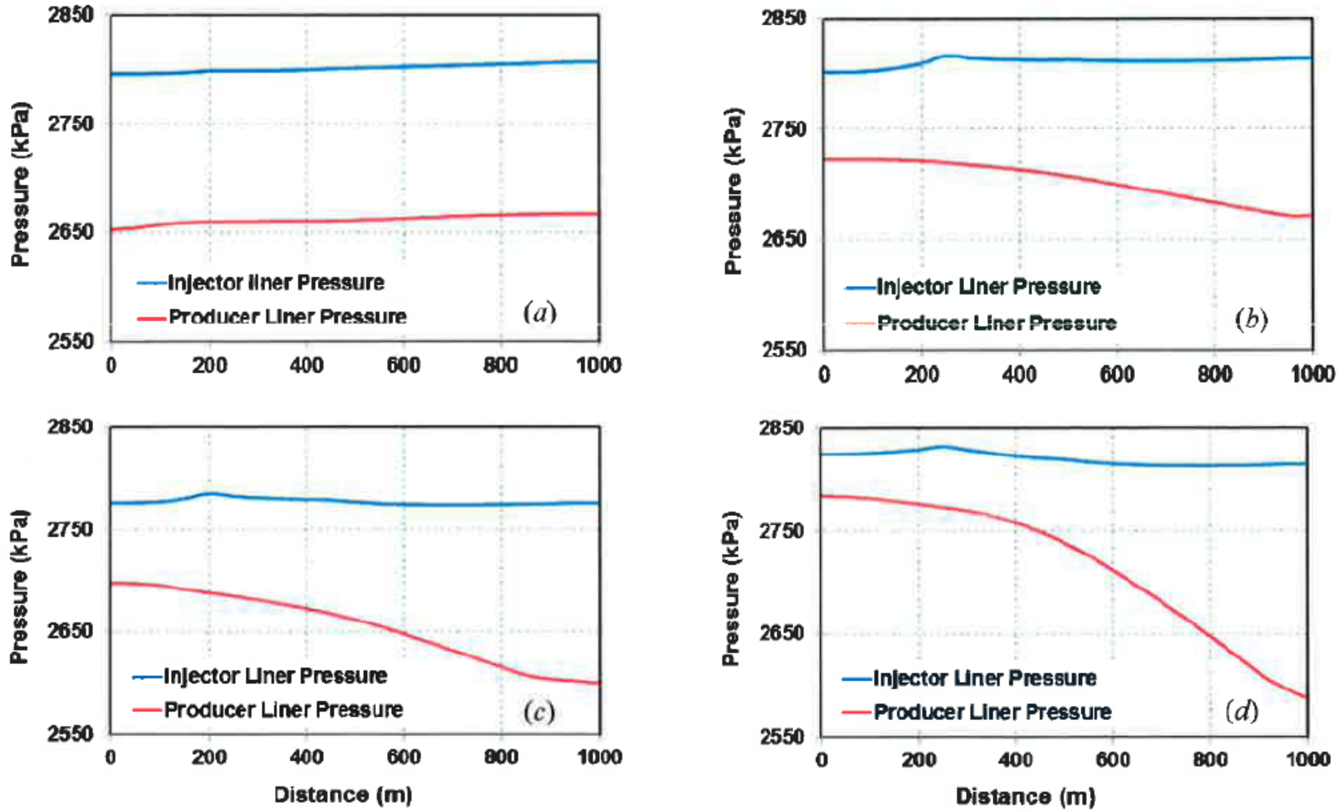


Steam Percentages:

- Toe: 50%
- Splitter 1: 25%
- Splitter 2: 25%



Scab Liner Completion



Case (a) – No Scab Liner Case (b) – 3.5" Scab Liner
Case (c) – 4.5" Scab Liner Case (d) – 5.5" Scab Liner

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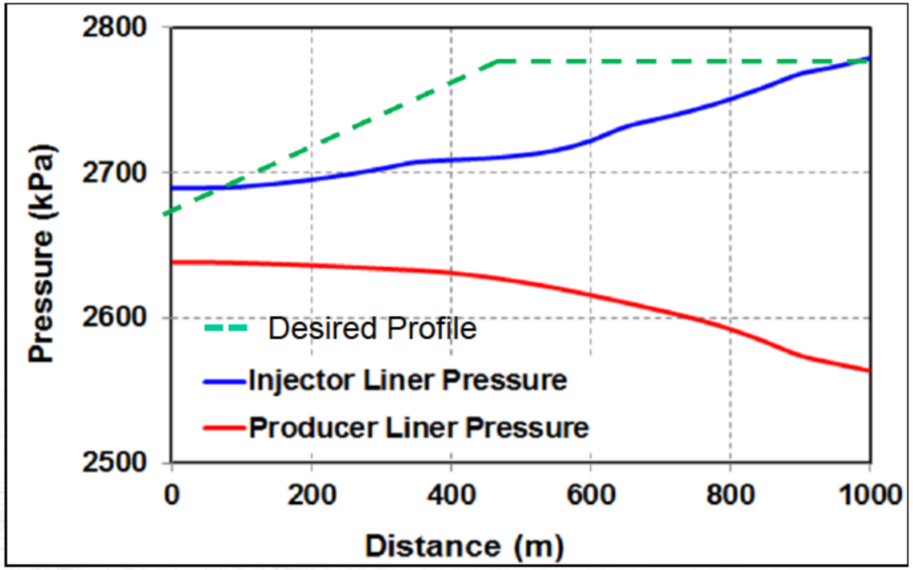
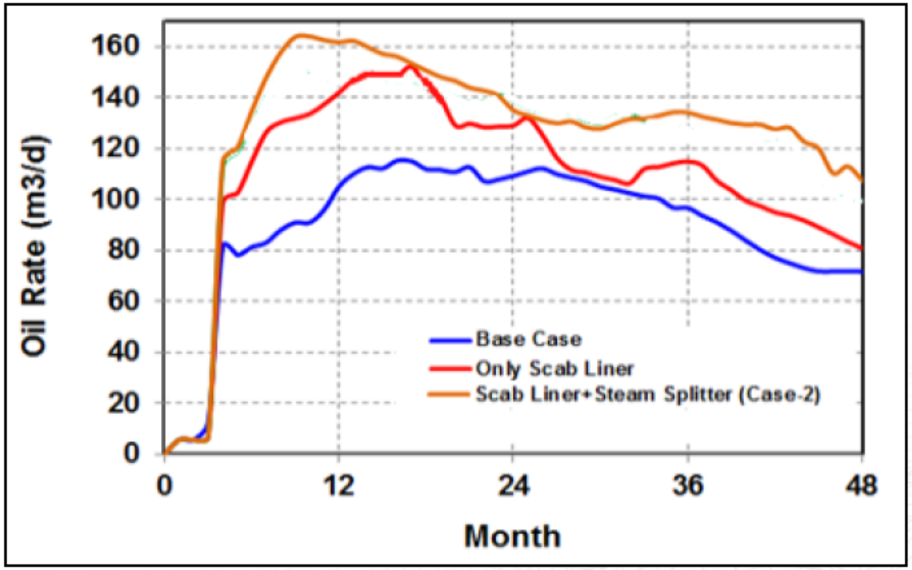
Completion Optimization





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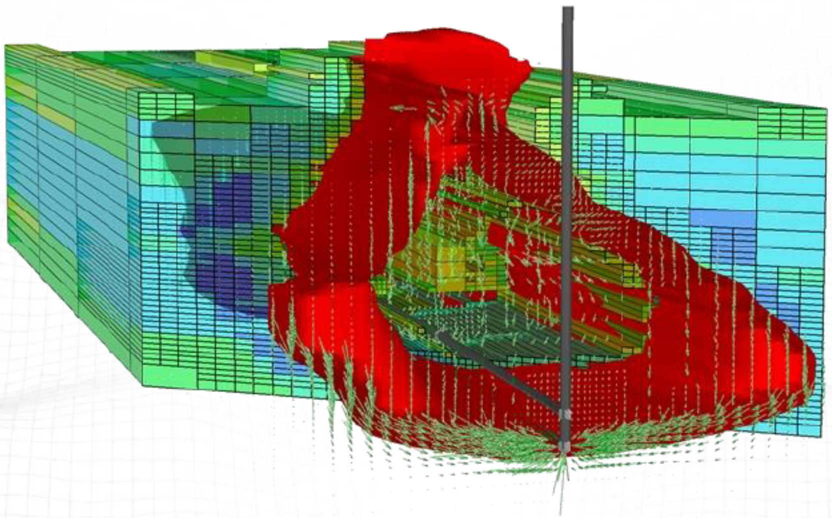
Optimization Conclusion

- Integrated Reservoir – Wellbore Modelling
- Completion design customized to address geological heterogeneity



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SPE 171131 – M. Noroozi, M. Melo, R.P. Singbeil & B. Neil, Weatherford

Investigation of Orifice Type Flow-Control Device Properties on the SAGD Process using Coupled Wellbore Reservoir Modelling

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FCD Optimization

Phase I – Sensitivity Analysis

- Number of FCDs
- Location of FCDs
- Properties of FCDs

Phase II - Optimization

- Injector Well
- Producer Well

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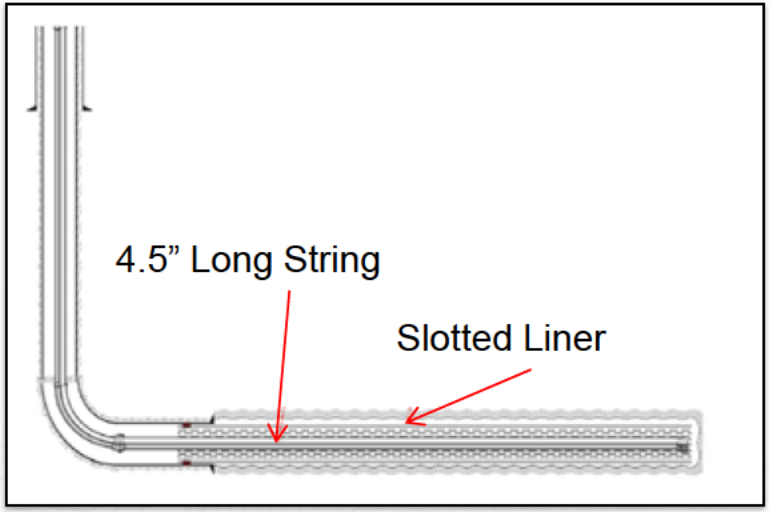
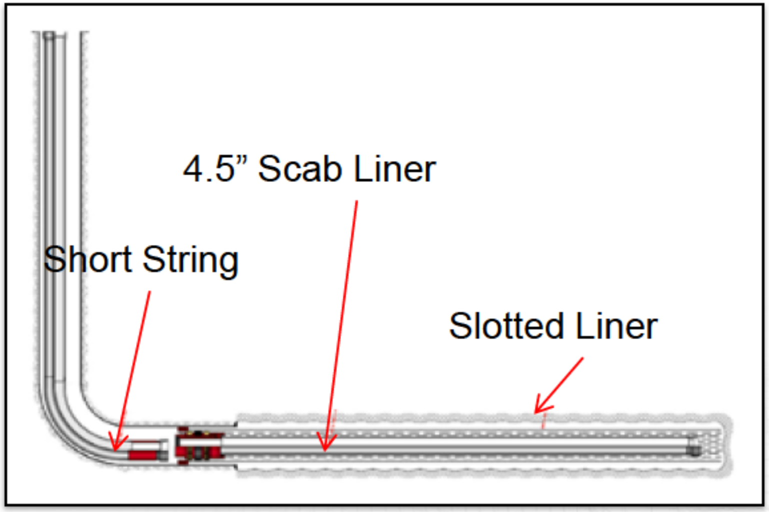
Conventional Completions



Injector Well – Single Long Tubing



Producer Well – Scab Liner

Promoted steam chamber growth near the toe of the well-pair

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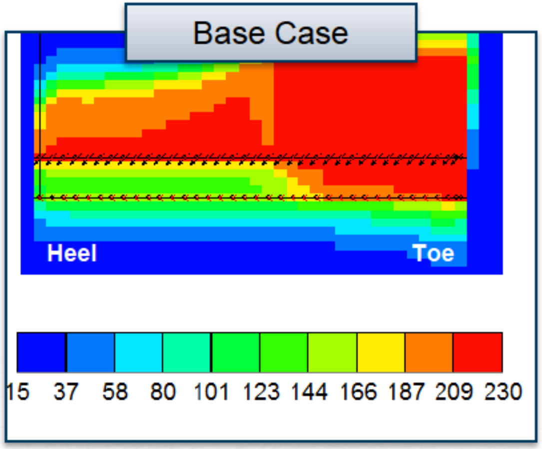
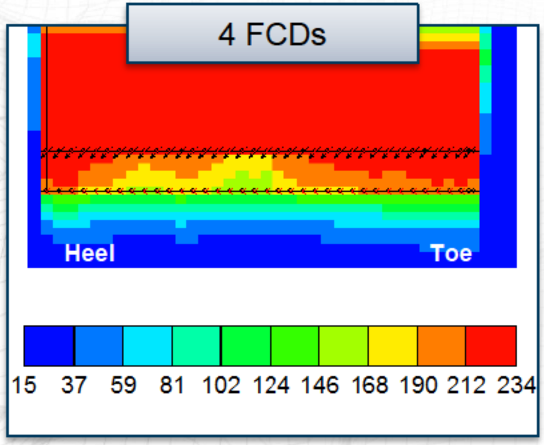
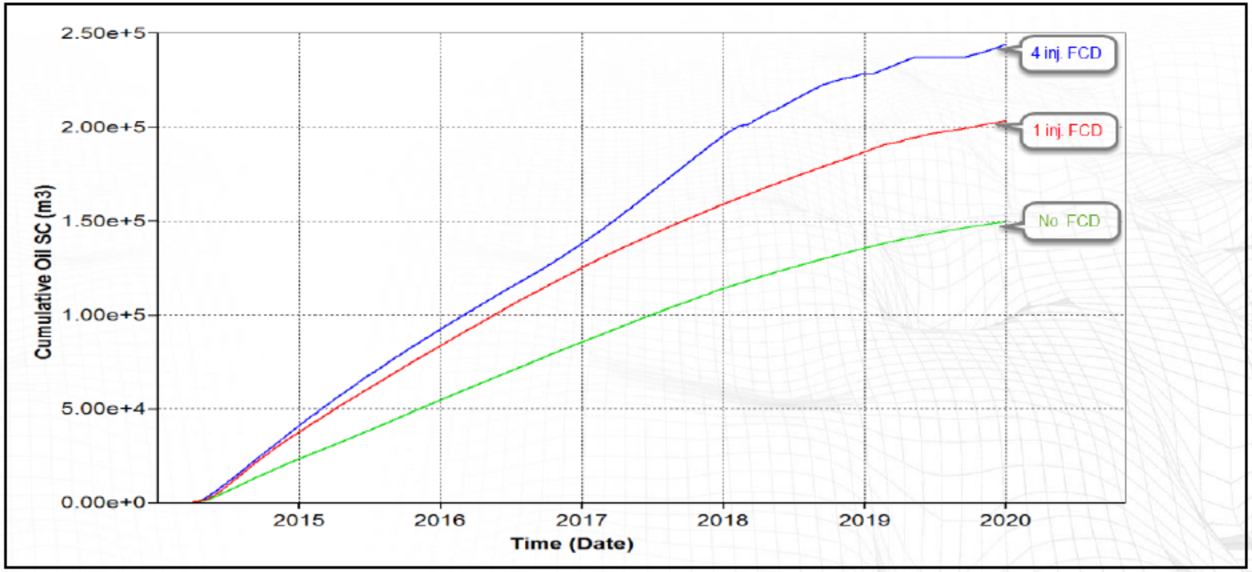
Phase I – Sensitivity Analysis





Injector – Total Number of FCDs

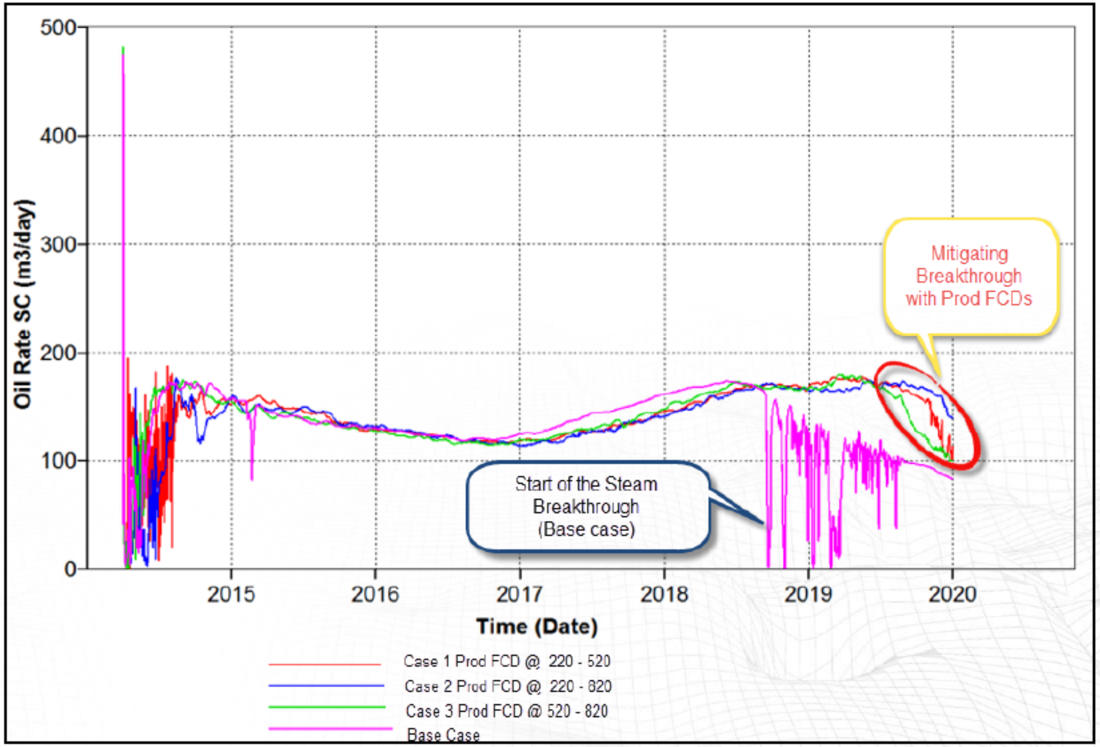
- Insufficient heating of Reservoir near heel in Base Case
- FCDs installed on Injector – long string
- 4 FCDs case showed significant improved steam conformance



Phase I – Sensitivity Analysis

Producer FCDs

- Mitigation of steam break through with Production FCDs
- Location had minimal impact on Steam-Oil-Ratio and Oil Rate



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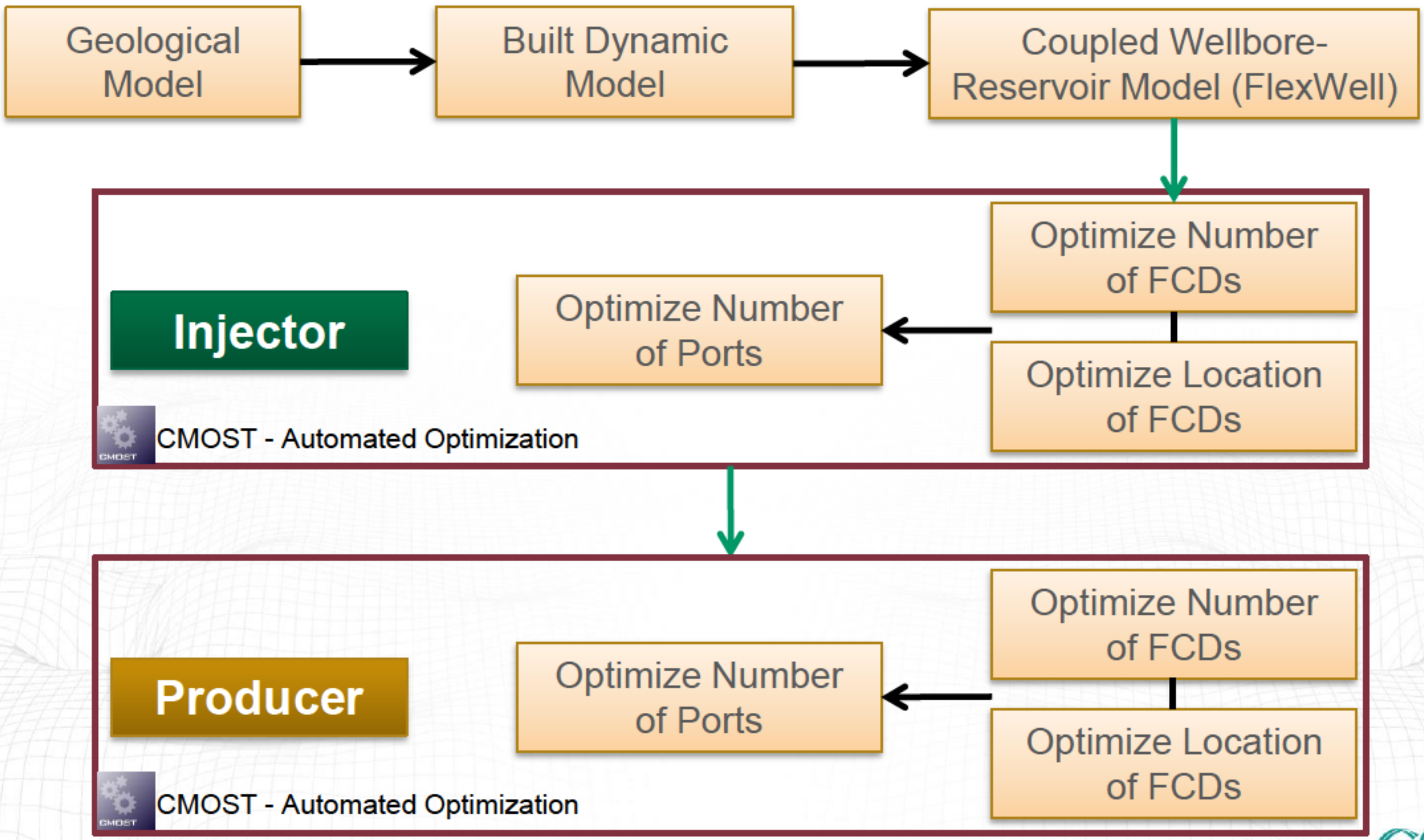
Phase II – Optimization



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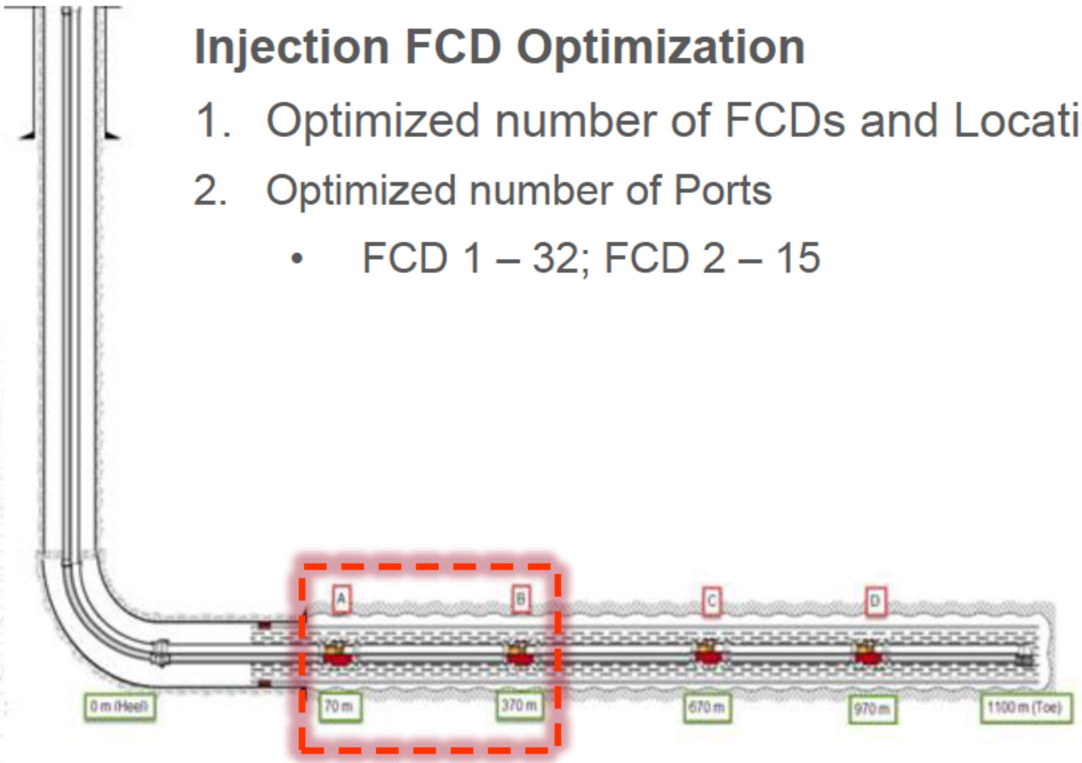
Phase II – Optimization



Injection FCD Optimization

1. Optimized number of FCDs and Location
2. Optimized number of Ports
   - FCD 1 – 32; FCD 2 – 15

Case	Location of Injector FCDs
1	a
2	c
3	a + c
4	a + b
5	b + d
6	a + d + c
7	a + b + d
8	a + b + c
9	a + b + c + d

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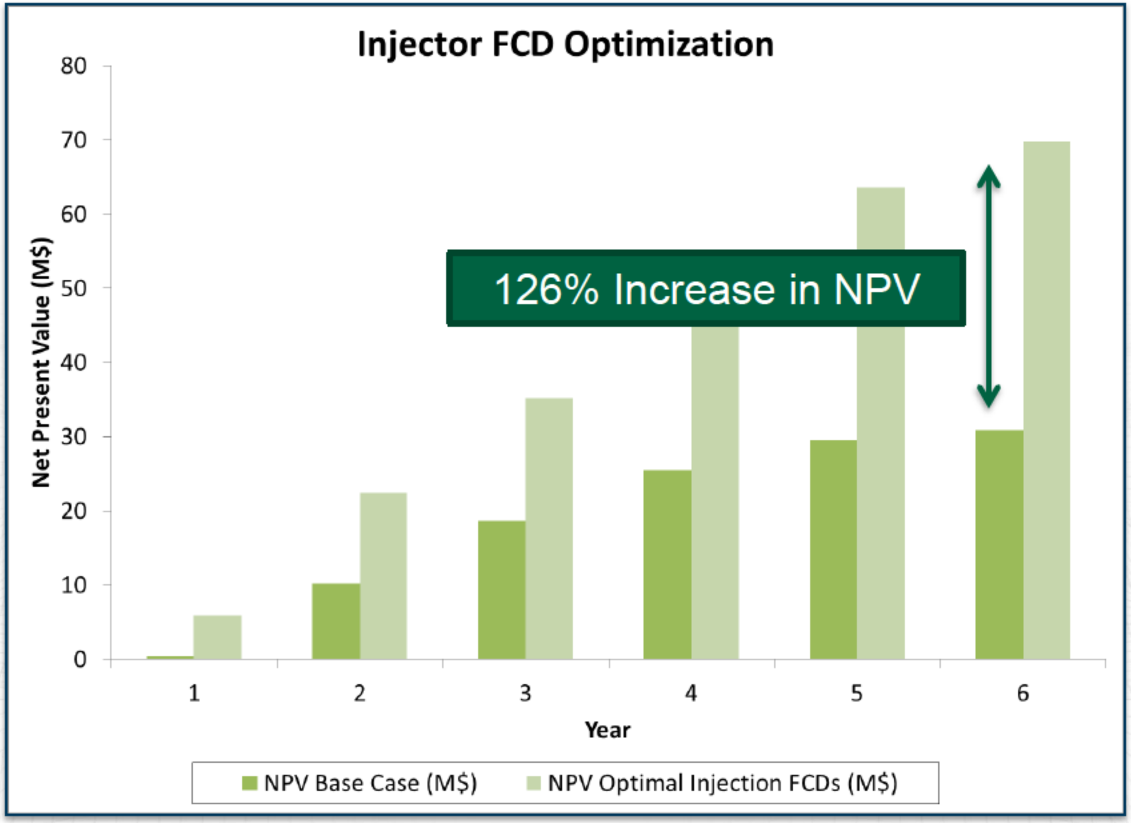
Phase II – Optimization

Injection FCD Optimization



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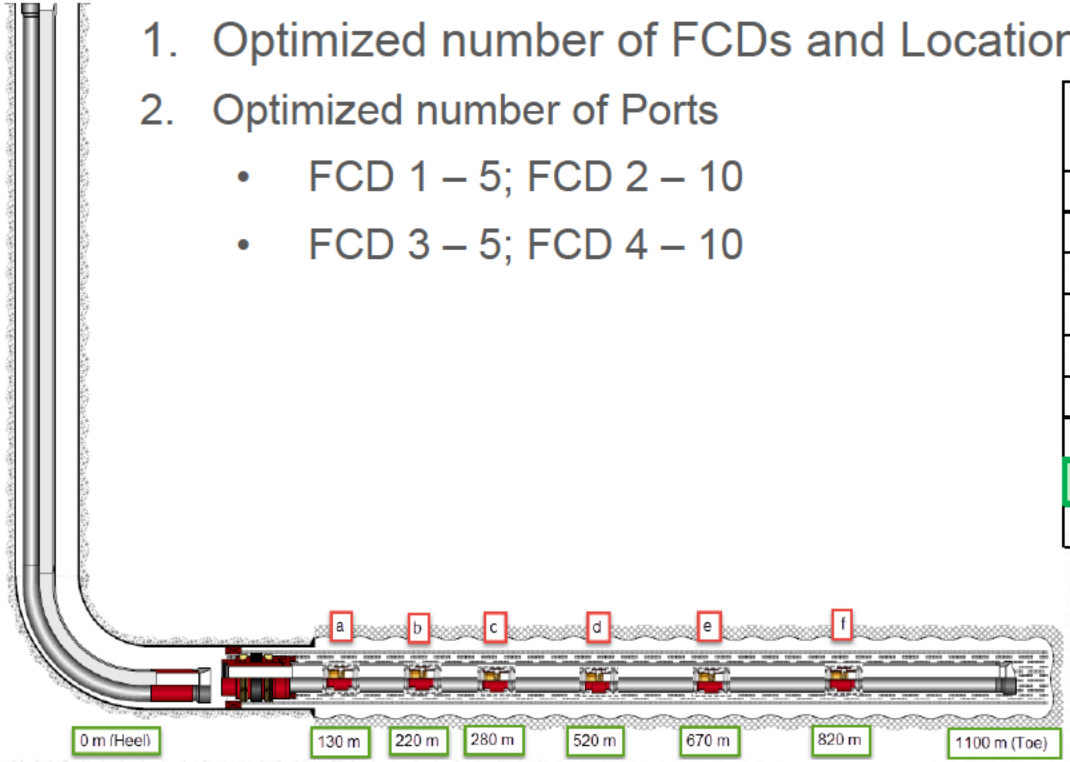
Phase II – Optimization

Production FCD Optimization

1. Optimized number of FCDs and Location
2. Optimized number of Ports
   - FCD 1 – 5; FCD 2 – 10
   - FCD 3 – 5; FCD 4 – 10

Case	Number of Producer FCDs	Location of Production FCDs
1	1	b
2	1	d
3	1	f
4	2	b + d
5	2	b + f
6	2	d + f
7	3	b + d + f
8	4	a + c + d + f
9	5	a + c + d + e + f



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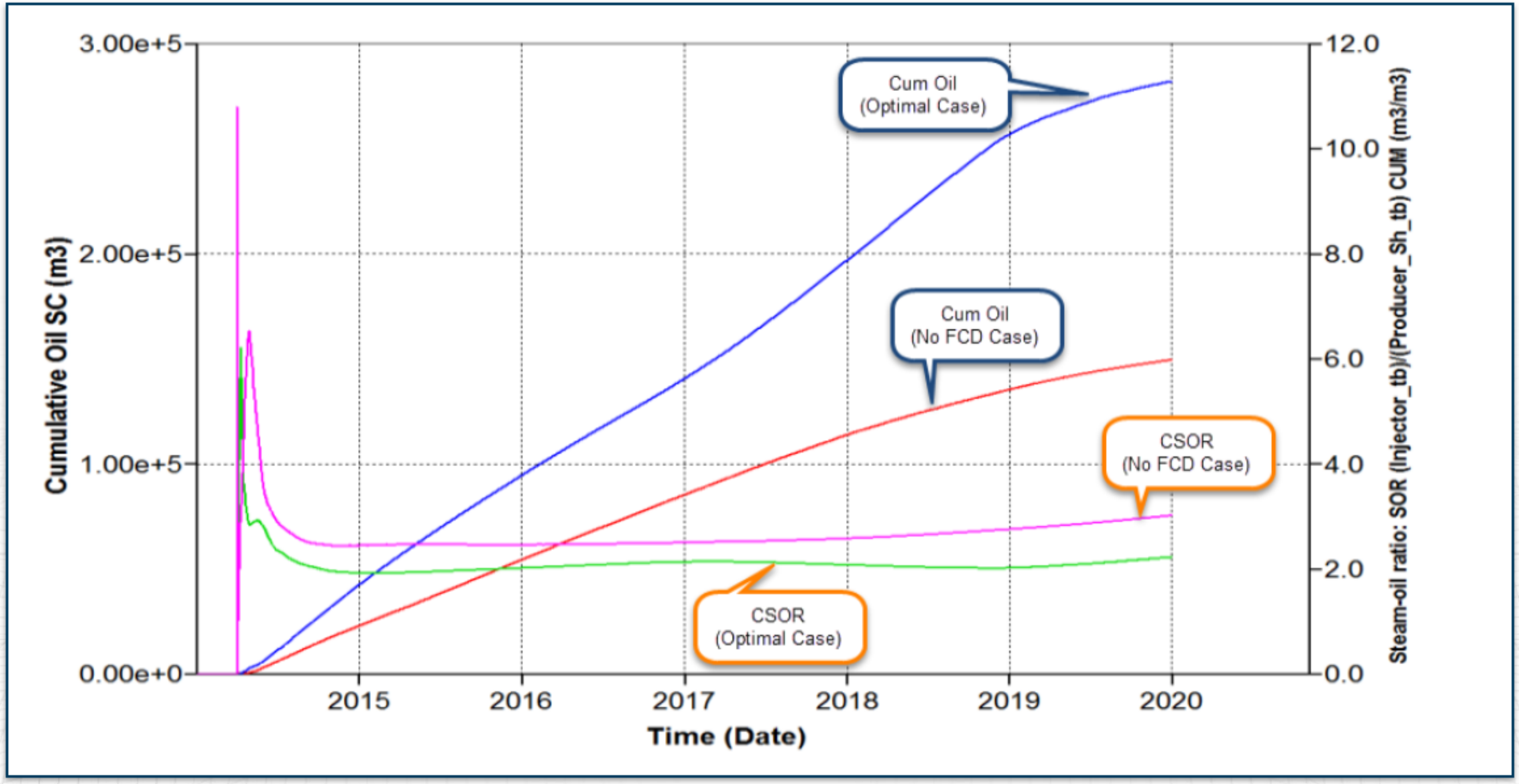
Final Result



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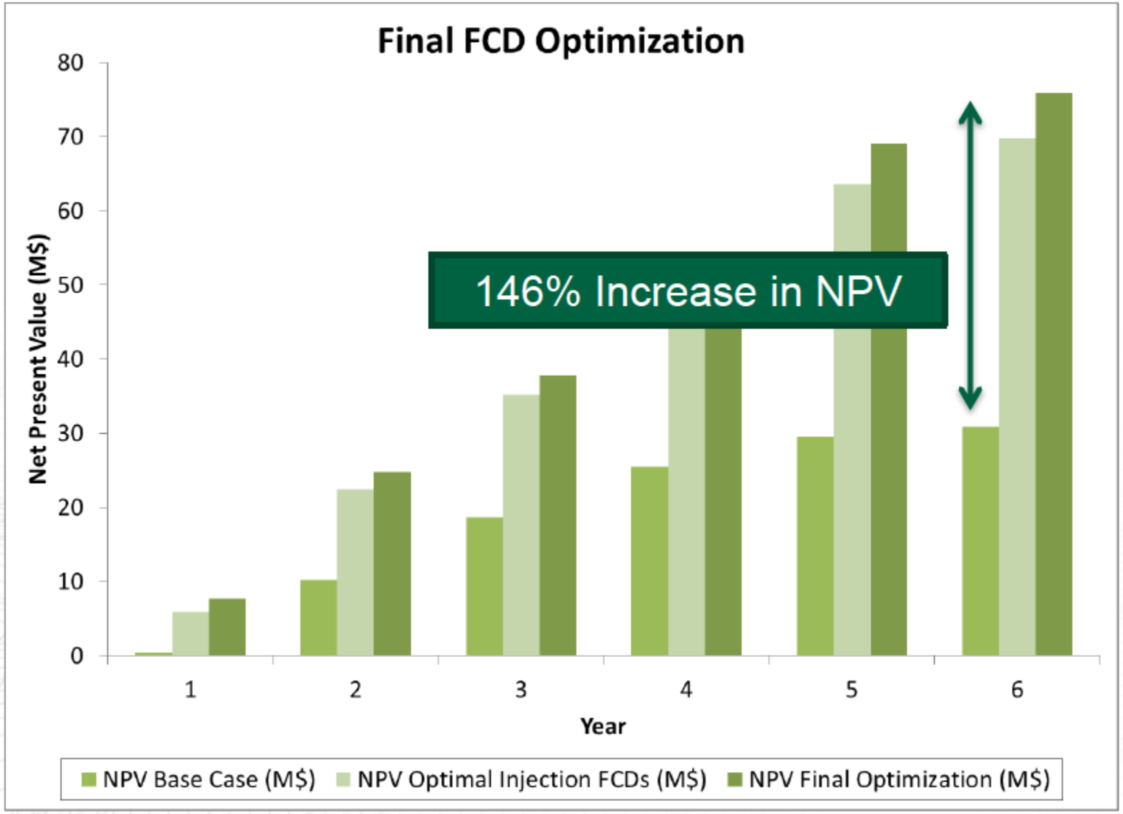
Final Result



Optimization results

Injection FCDs : NPV 126 % ▲
Production FCDs: NPV 146 % ▲

NPV based workflow
Coupled wellbore reservoir model (FlexWell)
Automatic optimization

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Additional Resources

- Steam Splitter and ICD Optimization at McKay
  (Southern Pacific: SPE 165487, SPE 171109)
- SAGD Startup: Circulation vs Bullheading at Firebag
  (Suncor: SPE 157918)
- SAGD Startup with undulating wells at Carmon Creek
  (Shell: SPE 148819)
- Model Prediction Control to Automate SAGD wells at Leismer
  (Statoil: SPE 165535)

Conclusions

- FlexWell provides the capability to model complex wellbore completions coupled with the reservoir simulation model
- Better understand how the wellbore hydraulics affect the recovery
- Optimize well completions and improve the value of the asset

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