PETE 4241 Project Report 2019

Coupled geomechanical reservoir simulation in Volve Field

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Abstract

MEM provides the geomechanical information required by engineering software used for casing point selection, optimizing the number of casing strings, drilling stable wellbores, designing completions, performing fracture stimulation, and simulating reservoir production. In this project,

Introduction

An MEM is a numerical representation of the geomechanical state of the reservoir, field, or basin. In addition to property distribution (e.g., density, porosity) and fracture system the model incorporates pore pressures, state of stress, and rock mechanical properties. The stresses on the reservoir are caused by the overburden weight, any superimposed tectonic forces, and by production and injection (**Fig. 1**).

MEM is fundamental to the success of geomechanics applications. It provides the geomechanical information required by engineering software used for casing point selection, optimizing the number of casing strings, drilling stable wellbores, designing completions, performing fracture stimulation, and simulating reservoir production (SLB, 2018).

One of import application of MEM is the coupled flow and rock mechanics reservoir simulation. The problem of coupled fluid flow and rock mechanics is encountered in many areas of geoscience. Changes in the pore pressure of a geological formation due to injection or removal of fluid can lead to rock deformation. Similar mechanisms are encountered in oil and gas recovery processes. (Garipov et al, 2016).

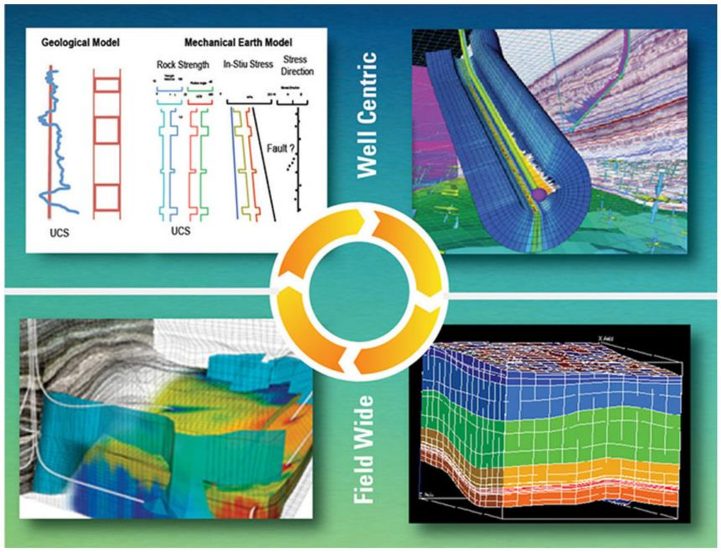


Figure 1 – Using MEMs throughout the life of a field (SLB, 2019)

In this paper, we present a generic …

Description of Volve Field

The Volve field (**Fig. 2**) is a shallow water field located 200 kilometers to the West of Stavanger. It was discovered in the year 1993 and commenced production in the year 2008. At peak production, the Volve field produced 56,000 barrels per day and production a total of 63 million barrels in its 8 year lifetime from 2008 to 2016. The recovery percent of this field was 54%. Equinor (formerly Statoil) in 2018 together with its license partners released data to the general public for research and training purposes. Data released included high-resolution geophysical logs, subsurface measurements, various drilling and geological reports, and the reservoir model.

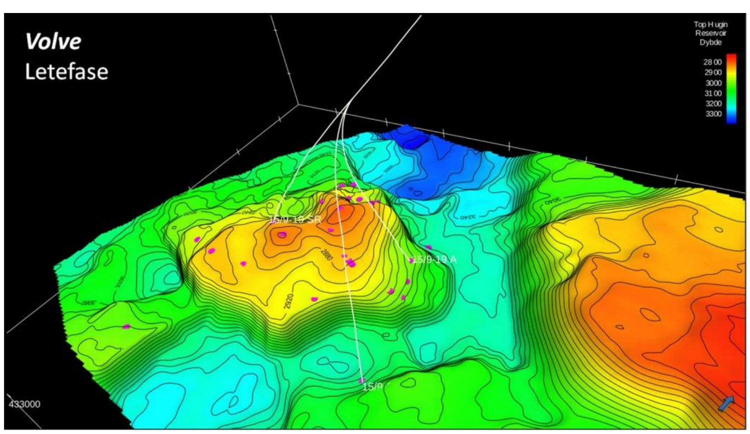
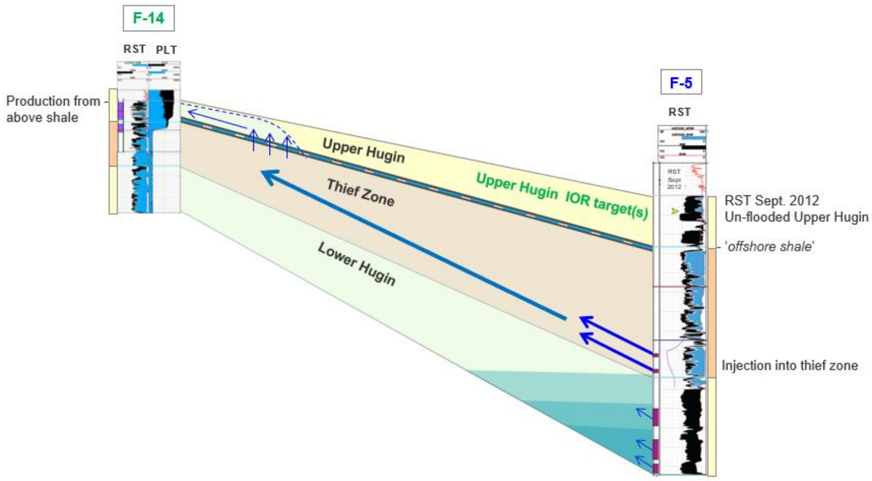


Figure 2 – 3D model of Volve field (Equinor, 2019)

Volve is a field in the central part of the North Sea, 5 km north of the Sleipner Øst field.

Volve produced oil from sandstone of Jurassic age in the Hugin Formation (Byberg, 2016)

[TODO] More geology and stratigraphy description



Constructing MEM for Volve field

The general MEM workflow (Fig. 3) can be summarized as follows:

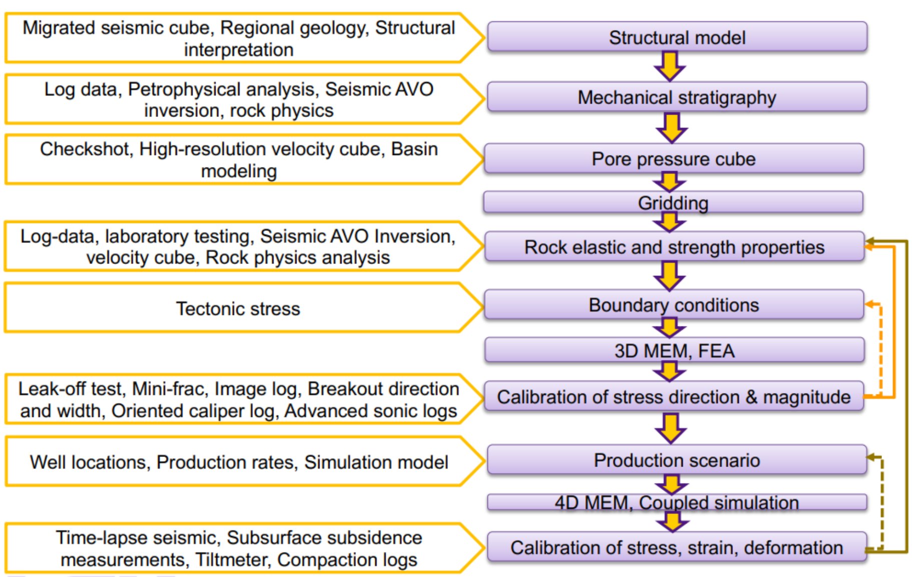


Figure 3 – MEM modeling workflow (Olorode, 2019)

One of key step in MEM is to extract the pore pressures, state of stress, and rock mechanical properties from the log data. In the Volve field, the log data of 9 wells (**Table 1**) with bulk density (RHOB), transmission wave velocity (DT, DTS), well trajectory (MD/TVD) are available to evaluate those quantities.

Table 1 – Log data of 9 wells in Volve Field (Equinor, 2019)

WellName	LAS	RHOB	DTC/DT	DTS	TVD
15_9-F4	✔	✔	✔	✔	✔
15_9-F1B	✔	✔	✔	✔	✔
15_9-F5	✔	✔	✔	✖	✔
15_9-F1C	✔	✔	✖	✖	✔
15_9-F11B	✔	✔	✖	✖	✔
15_9-F12	✔	✔	✔	✖	✔
15_9-F14	✔	✔	✔	✔	✔
15_9-F15C	✔	✔	✔	✖	✔
15_9-F15D	✔	✔	✖	✖	✔

The sample plot of log data of Well 15_9-F-1 B are shown as follows (**Fig. 4**):

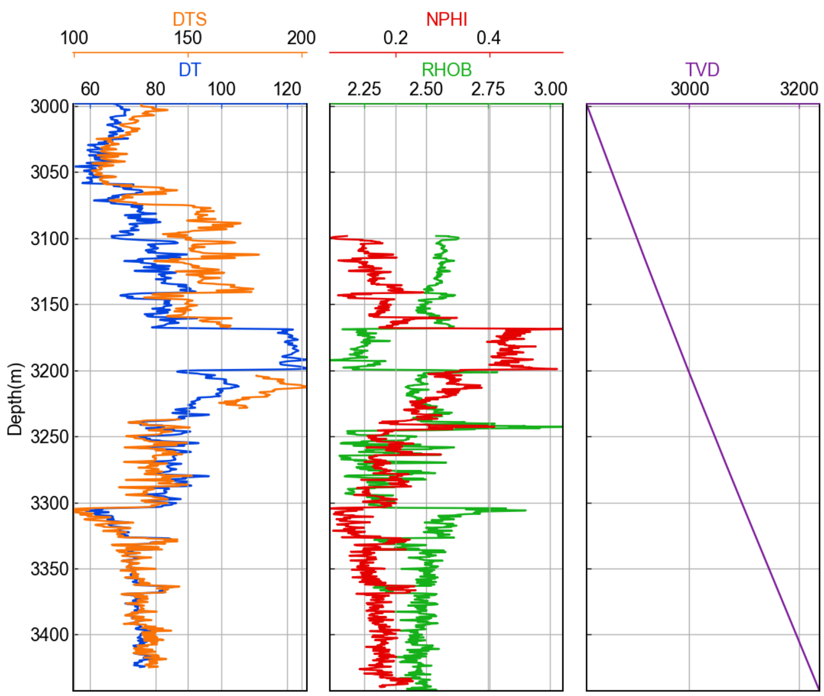


Figure 4 – Well log of Well 15_9-F-1 B

All other log figures can be found on our project repository, https://github.com /BinWang0213/PETE4241_19SP_ProjectCode

Principal stresses: We have the well log data that can be used to calculate Sv using the relationship:

$$S_v(z) = \rho_w g z_w + \int \rho_b(z) g dz \quad (1)$$

Lang et al. (2011) provides a relationship relating maximum horizontal stress (SHmax) and minimum horizontal stress (Shmin) with vertical stress (Sv):

$$S_{Hmax} = S_{hmin} + k(S_v - S_{hmin}) \tag{2}$$

where k is a constant defining the ratio of SHmax to Shmin. It ranges from 0 to 2 where k=0 represents isotropic horizontal stress system. Among limited stress regime studies available for Volve field, Sen and Ganguli (2019) use fracture gradient as the Shmin gradient and use the above relationship to calculate the SHmax gradient for four wells in the volve field. Their findings suggests that Sv>SHmax>Shmin, which means that the stress regime is normal faulting regime. Upon examination of their findings, we reach to the conclusion that the stress gradient for horizontal stresses can be roughly estimated by the relationships:

$$\begin{aligned} S_{Hmax} &= 0.89 S_v \\ S_{hmin} &= 0.84 S_v \end{aligned} \tag{3}$$

The three principle stresses are named S1, S2 and S3 for simplicity.

Pore pressure: Pore pressure at different true vertical depths is calculated using the hydrostatic pressure gradient. Density of formation fluid is assumed to be 1g/cc.

$$P_p(z) = \rho_w g z \tag{4}$$

Rock porosity: The rock porosity (φ) is calculated from density log using the following relationship:

$$\phi = \frac{\rho_{matrix} - \rho_{bulk}}{\rho_{matrix} - \rho_{fluid}} \tag{5}$$

Young's modulus and Possion ration: Elastic properties of the rock can be calculated from Shear wave velocity (Vs) and Compressive wave velocity (Vp) logs.

$$\begin{aligned} G &= \rho_b V_s^2 \\ \nu &= \frac{(V_p^2 - 2V_s^2)}{2(V_p^2 - V_s^2)} \\ E &= 2G(1+\nu) \end{aligned} \tag{6}$$

Unconfined Compressive Strength (UCS): The unconfined compressive strength (UCS) is calculated using the relationship for North Sea:

$$UCS = e^{(-6.36 + 2.45 log(0.86 V_p - 1172))} \tag{7}$$

Based on **Eqs. 1-7**, the pore pressures, state of stress, and rock mechanical properties for each well can be calculated. A sample plot of MEM properties is shown in **Fig. 5**.

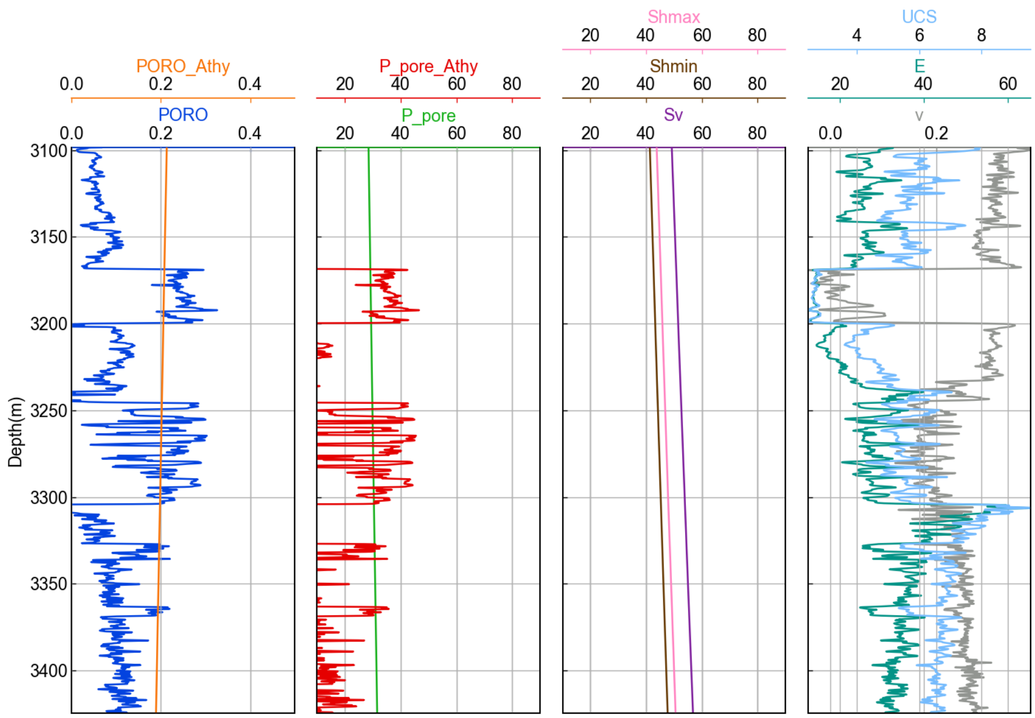
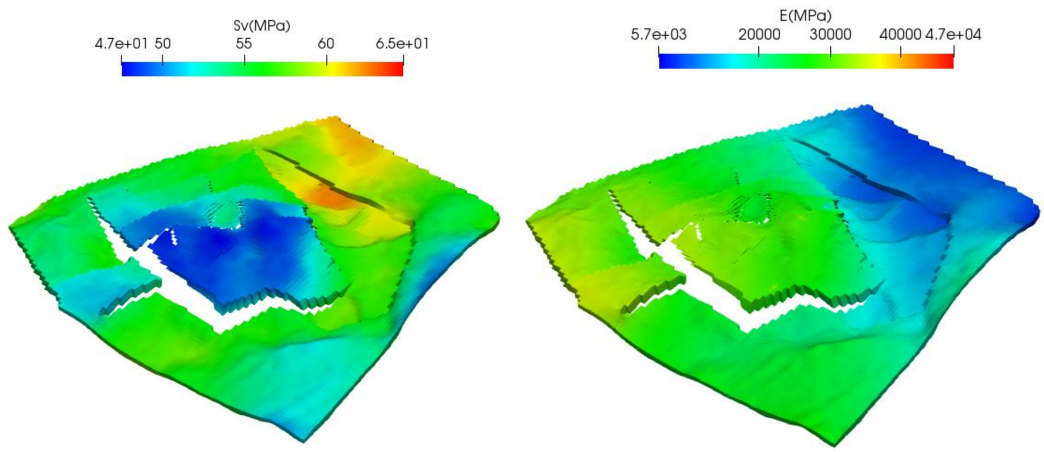


Figure 5 – Estimated MEM properties of Well 15_9-F-1 B

Once the MEM properties for each well is calculated. The MEM properties for each gridblock of 3D reservoir simulation model can be interpolated using Kriging spatial interpolation method. The sample results of vertical stress (Sv), Young's modulus (E) and Poisson ratio for 3D model are shown as follows (**Fig. 6**):



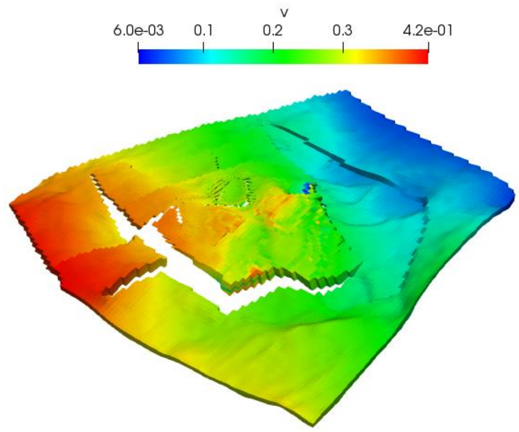


Figure 6 – Estimated MEM properties of 3D reservoir simulation model

Reservoir Simulation Model

The general MEM

[TODO] Basic coupling algorithm description and CMG model introduction

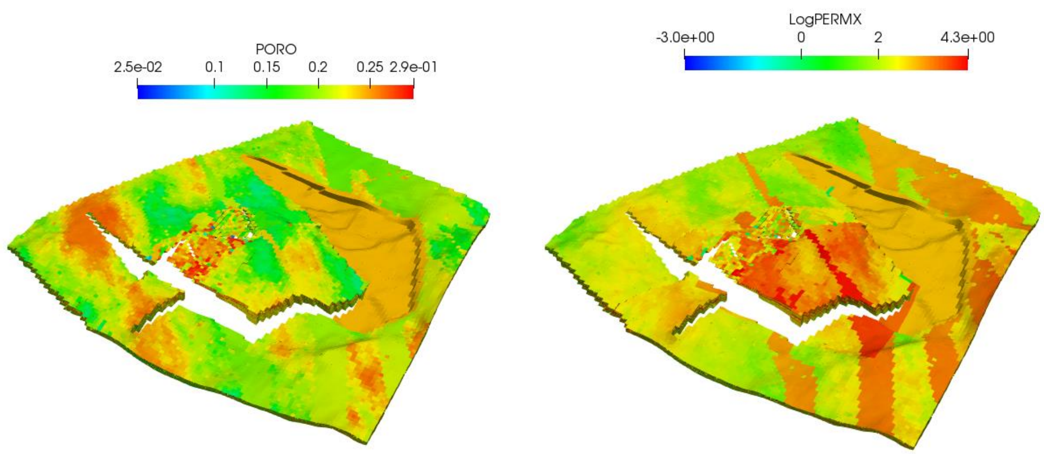


Figure 7 – Porosity and Permeability field of reservoir model for Volve field

Flow simulation: As shown in **Fig. 2**, there are three kinds of non-neighbor connection 1) fracture-matrix connectivity,

$$\begin{aligned} \psi_{f-m}^{NNC} &= \lambda_{f-m} T_{f-m}^{NNC} (p_f^{n+1} - p_m^{n+1}) \\ \psi_{f-m}^{NNC} &= -\psi_{m-f}^{NNC} \end{aligned} \tag{1}$$

One-way geomechanics coupling: As shown in **Fig. 2**, there are three kinds of non-neighbor connection 1) fracture-matrix connectivity,

Two-way geomechanics coupling: As shown in **Fig. 2**, there are three kinds of non-neighbor connection 1) fracture-matrix connectivity,

Simulation results and discussions

We build a two-dimensional base model which comprises one horizontal well with five stages of hydraulic fractures to demonstrate the application of the developed EDFM model. The base model parameters are summarized in **Table 2** and all other fluid properties are the same with Table 1.

Property	**Unit**	**Value**
Domain dimensions (x,y)	m	200,140
Formation thickness,	m	10
Matrix permeability	nD	100
Fracture permeability	D	1
Fracture width	m	1.0e-3
Well BHP	MPa	4
Production time	days	2500

We run simulation studies to demonstrate the applicability of our EDFM. We examine the effects of the irregular fracture pattern with complex geometries on the transient gas rate of multiple-fractured horizontal wells.

History Matching: High-resolution is needed near fracture to capture the large pressure gradient and the corresponding changes of the gas compressibility and viscosity in the ultra-tight matrix.

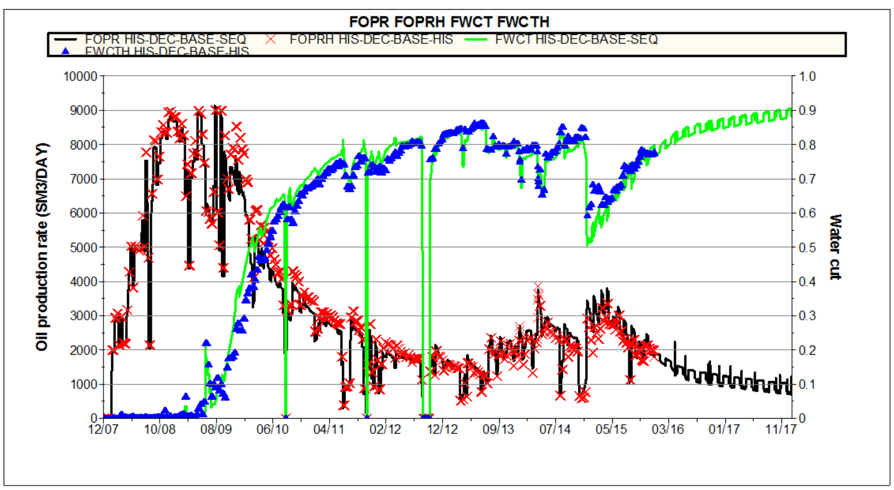


Figure 7 – xxx

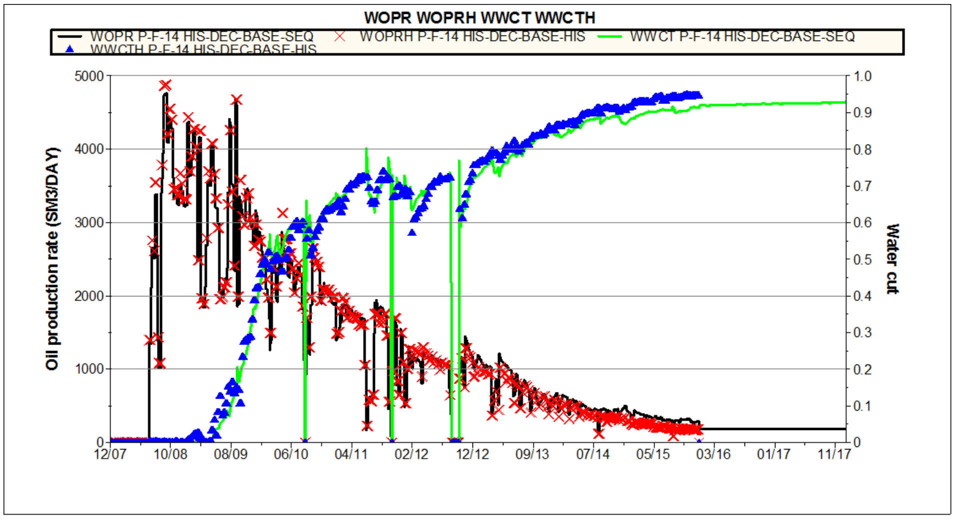


Figure 8 – Well F-14

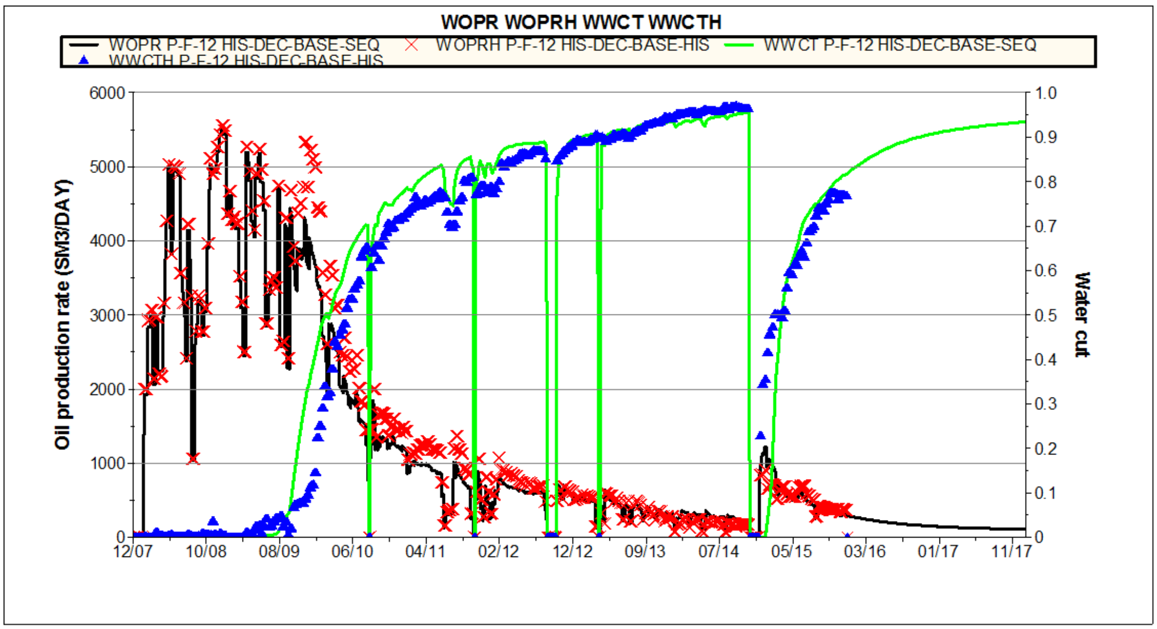


Figure 8 – Well F-12

[TODO] general stress and oil saturation analysis

Effect of geomechanics: High-resolution is needed near fracture to capture the large pressure gradient and the corresponding

Comparison of one-way and two-way couplings: High-resolution is needed near fracture to capture the large pressure gradient and the corresponding

Conclusion

Based on the field data and analytical modeling, the production and economic performance for polymer flooding and CO_2 flooding for Delhi field has been evaluated. Several conclusions can be drawn accordingly:

- Case studies on the Delihi field indicates the difference of recovery factor between the model and field data are less than 1%. The proposed method reasonable for initial EOR project evaluation.

References

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