Presentation of MSc's Thesis

'A Framework for Building Transient Well Testing Numerical Models Using Unstructured Grids'

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Title of Thesis:

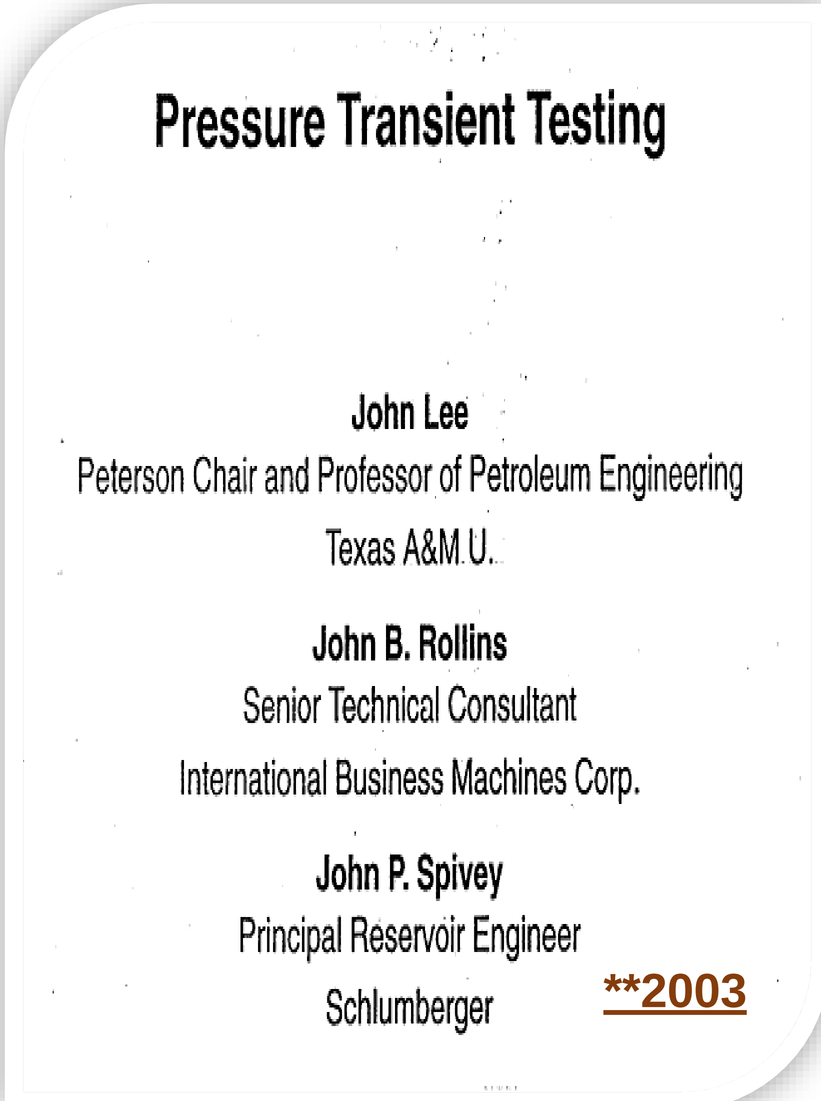
A Framework for Rapid Numerical Well Test Analysis Using an Open Source Simulator

Key Words:
Well Testing; Simulation; Unstructured Grids; MRST; Eclipse

Summary:
In conjunction with the Open Porous Media (OPM), SINTEF Company in Oslo have released the Matlab Reservoir Simulation Toolbox (MRST) aiming to function as an efficient platform for implementing new ideas and discretization methods in reservoir simulations applications. MRST has been developed as an open source program under the General Public License (GPL[1]), and in this thesis, the author intends to modify the existing source code of MRST (Release: 2016b) to implement an unstructured gridding algorithm has the ability to conform the basic geological features of the reservoir as an extension to the black oil framework. The governing equations are evaluated using the finite-volume method and the system of equations is solved fully-implicitly using the Newton-Raphson method. The created model in this thesis is used to build a numerical well testing models to tune the analytical solution results, validated versus the recorded pressure signals from the test, the analytical type curves, and Schlumberger reservoir simulator; Eclipse, to give a better representation for the geological features and the petro-physical properties of the reservoir using an easy procedure to construct the grid and to assign these properties.

[1] http://www.gnu.org/licenses/gpl.html

Application Cases: Numerical Well Testing


Pressure Transient Testing

John Lee
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Schlumberger

****2003**

To validate versus the pressure signals and Eclipse, we used:
Normalized Root Mean Square Error (NRMSE)

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (X_{obs,i} - X_{model,i})^2}{n}}$$

$$\mathrm{NRMSE} = \frac{\mathrm{RMSE}}{X_{obs,max} - X_{obs,min}}$$

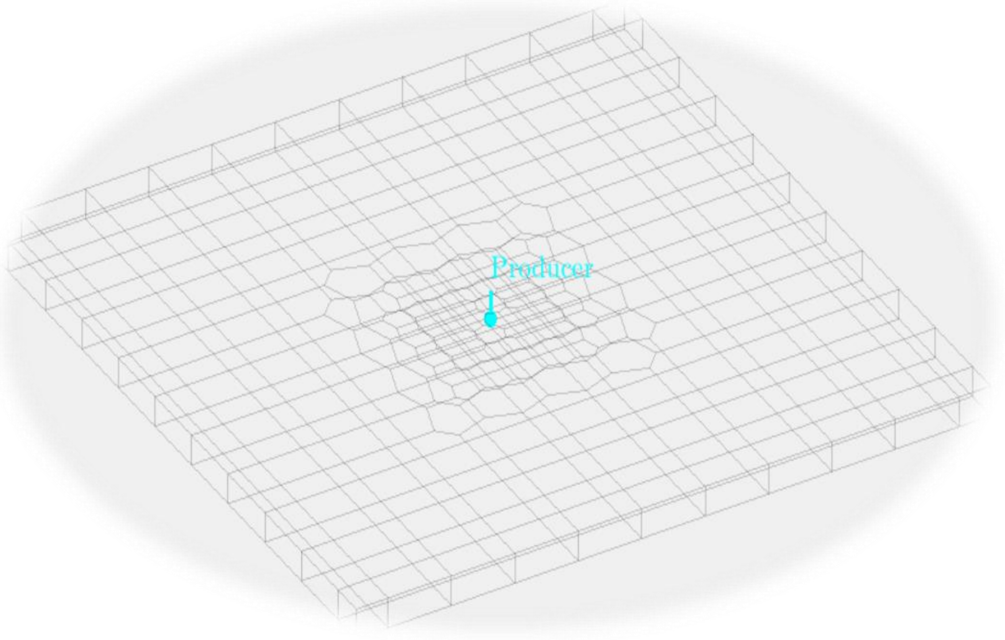
To do sensitivities over the analytical solution parameters, we used:
Mean Absolute Relative Error (MARE)

$$\mathrm{MARE} = \frac{100}{n} \sum_{i=1}^{n} |O_i - P_i| / |O_i|$$

Hybrid Grid, Single Well, 7 Cases Compared to Eclipse Cartesian Grid

\# of Grids 193, 1 to 3 Newton Iter./T.S., CPU Time=4 Secs

Case	Test Type	Phase
1	Draw Down	Oil
2	Variable Rate Draw Down	Oil
3	Build Up	Oil
4	Build Up After Variable Rate Draw Down	Oil
5	Build Up	Gas
6	Injectivity	Water
7	Fall Off	Water



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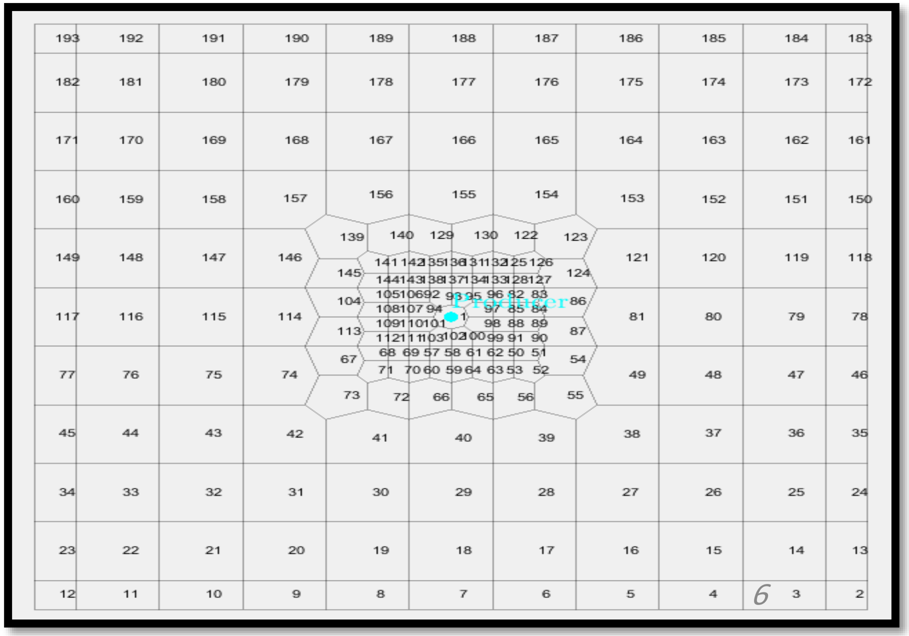
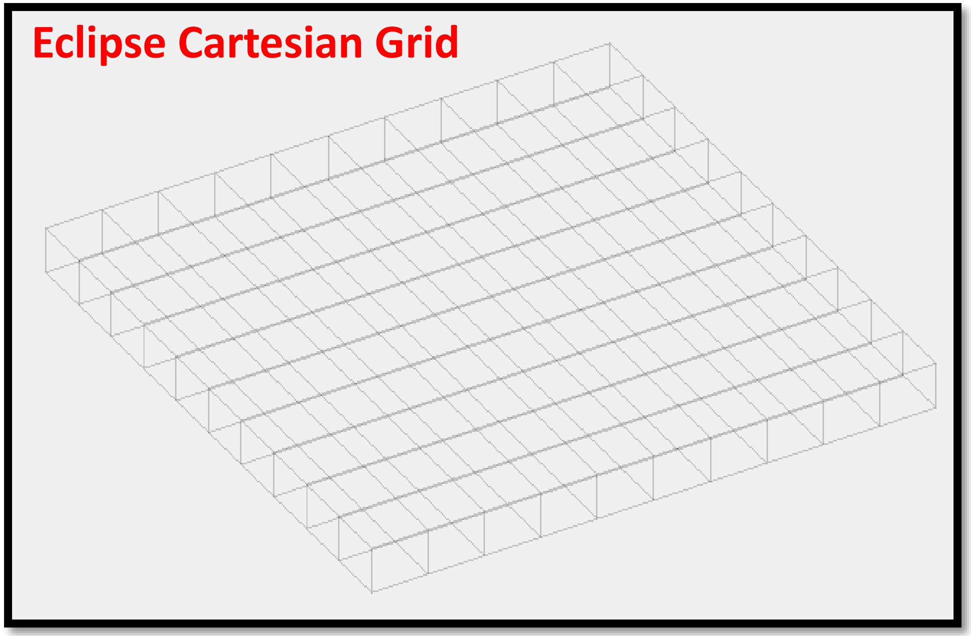
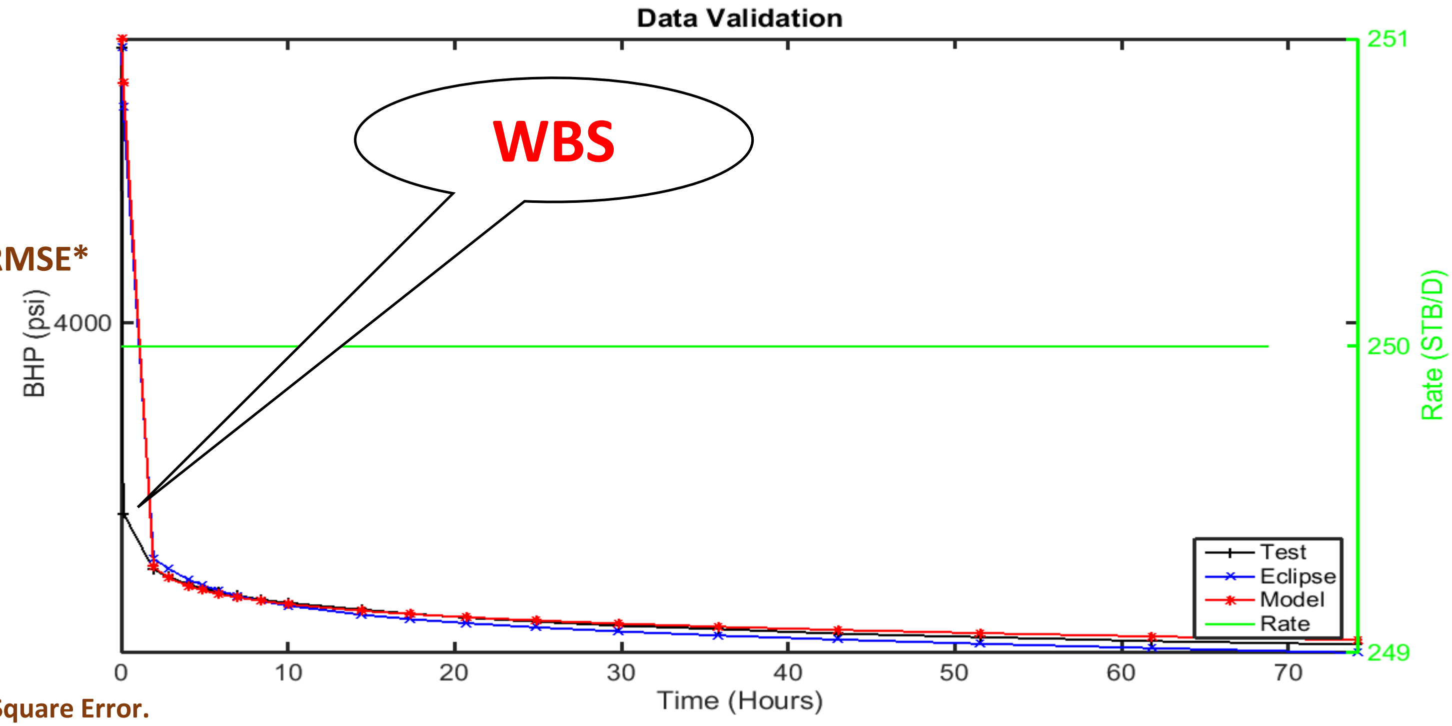


Eclipse Cartesian Grid



Case_ Source	Test Type	Phase	Givens (Model Parameters)
1_ Ex:2.1	Draw Down	Oil	Qo = 250 STB/D, h = 69 ft, φ = 0.039, Bo = 1.136 RB/STB, Pi = 4,412 psia, C_t = 17 x 10^{-6} psi^{-1}, r_w = 0.198 ft, and μ = 0.8 cp
2_ Ex:2.3	A 3-hour Variable Rate Draw Down	Oil	1st hour averaged 478.5 STB/D; 2nd hour, 319 STB/D; and 3rd hour, 159.5 STB/D, h = 10 ft , φ = 0.12, Bo = 1.2 RB/STB, Pi = 3,000 psia, C_t = 48 x 10^{-6} psi^{-1}, r_w = 0.25 ft, and μ = 0. 6 cp
3_ Ex:2.4	Build Up	Oil	after constant rate of 500 STB/D for 3 days h = 22 ft , φ = 0.2, Bo = 1.3 RB/STB, Pwf = 1,150 psia, C_t = 20 x 10-6 psi^{-1}, r_w = 0.3 ft, and μ = 1 cp
4_ Ex:2.6	Build Up After Variable Rate Draw Down	Oil	Time Interval (hours) — Production Rate (STB/D) 0 to 3 — 398.8 3 to 6 — 265.8 6 to 9 — 132.9 h = 22 ft, φ = 0.12, Bo = 1.2 RB/STB, Ct = 4.8 x 10-5 psi-1, rw = 0.25 ft, and μ = 0.6 cp
5_ Ex:3.3	Build Up	Gas	γg = 0.7, Qg = 5,256 Mscf/D, tp = 2000 hrs, z = 0.8678, T= 640°R (180°F), h = 28 ft, φ = 0.18, Bg = 0.962 RB/ Mscf, Pi = 2,906 psia, C_t = 2.238 x 10-4 psi^{-1}, r_w = 0.3 ft, and μ = 0.01885 cp
6_ Ex:9.1	Injectivity	Water	Qw = -100 STB/D, h = 16 ft, φ = 0.15, Bw = 1 RB/STB, Pi = 449 psia, C_t = 7.7 x 10-6 psi^{-1}, r_w = 0. 25 ft, and μ = 1 cp
7_ Ex:9.2	Fall Off	Water	Qw = -807 STB/D, h = 28 ft , φ = 0.25, Bw = 1 RB/STB, Pi = 2,788 psia ,C_t = 1.18 x 10-5 psi-1,r_w = 0. 4 ft, and μ = 1 cp

Case_1: DD-Oil

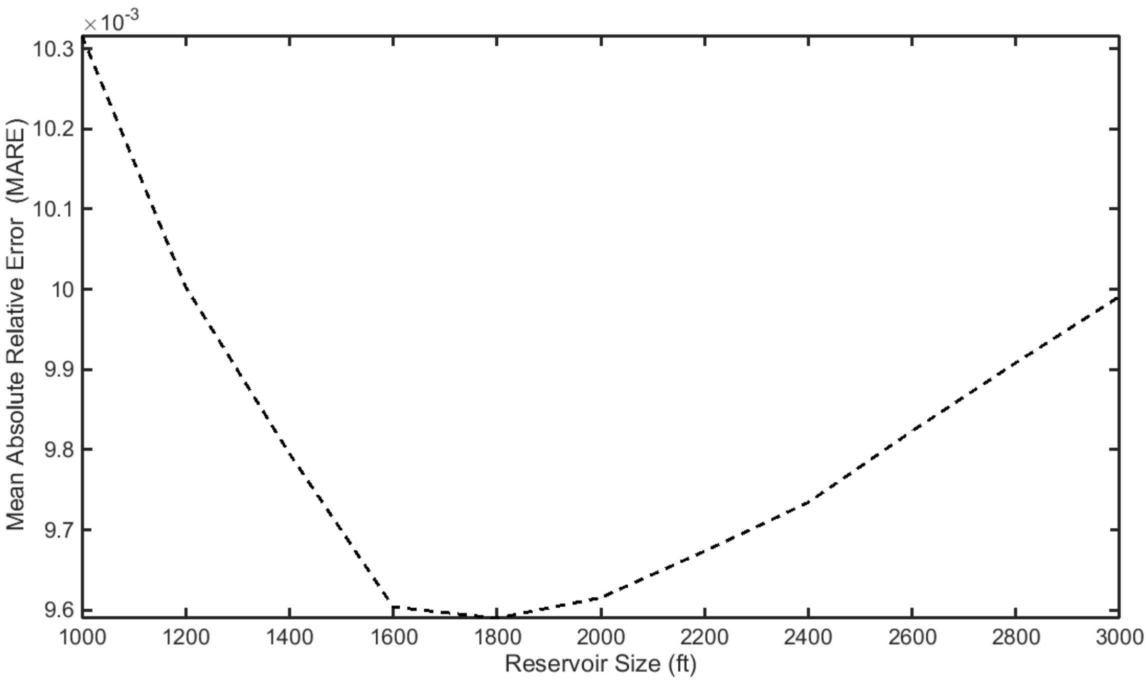


Goodness of Fit Based on NRMSE* Relative to Test Points:

1- Eclipse= 0.0101

2- Model= 0.0096

NRMSE*: Normalized Root Mean Square Error.

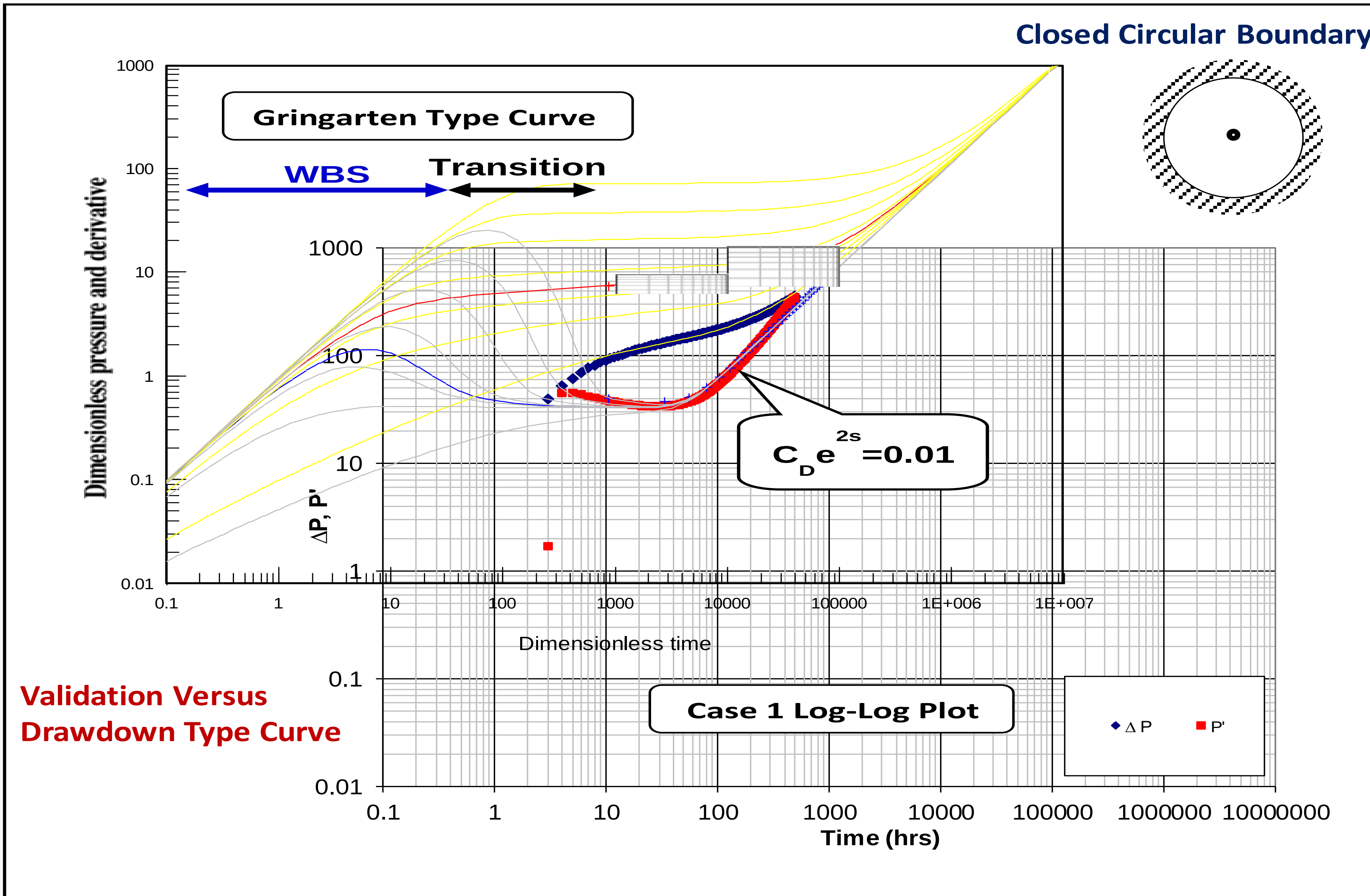


Sensitivity over Reservoir Size to Give Minimum Error:

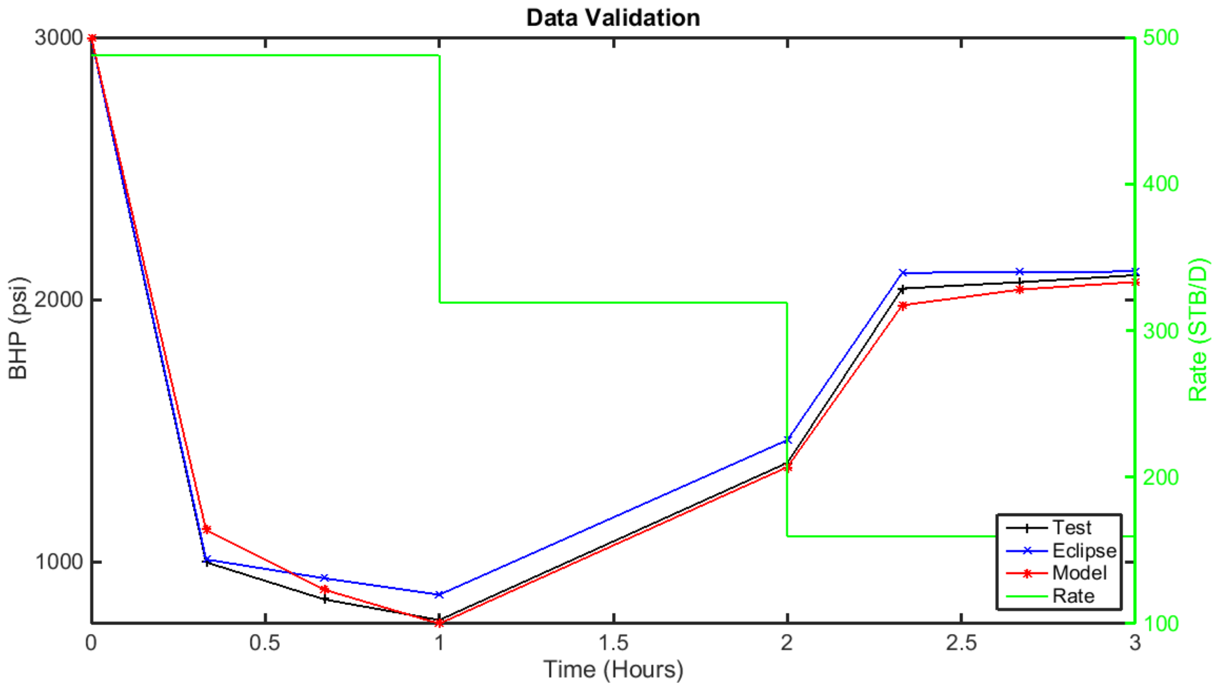
1- Analytical Solution, Infinite Reservoir (N/A)

2- Model , Re = 1800 ft

Case_1: Validation Versus The Analytical Solution

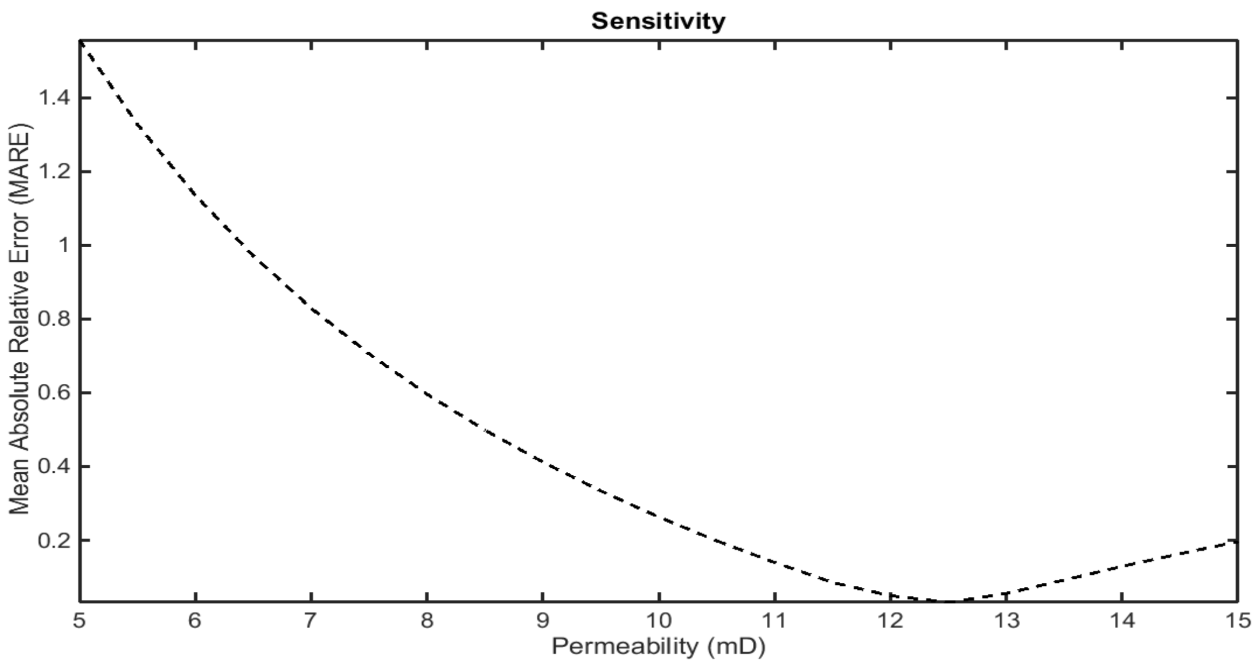


Case_2: Variable Rate
DD-Oil



Goodness of Fit Based on NRMSE*
Relative to Test Points:
1- Eclipse= 0.044
2- Model= 0.031

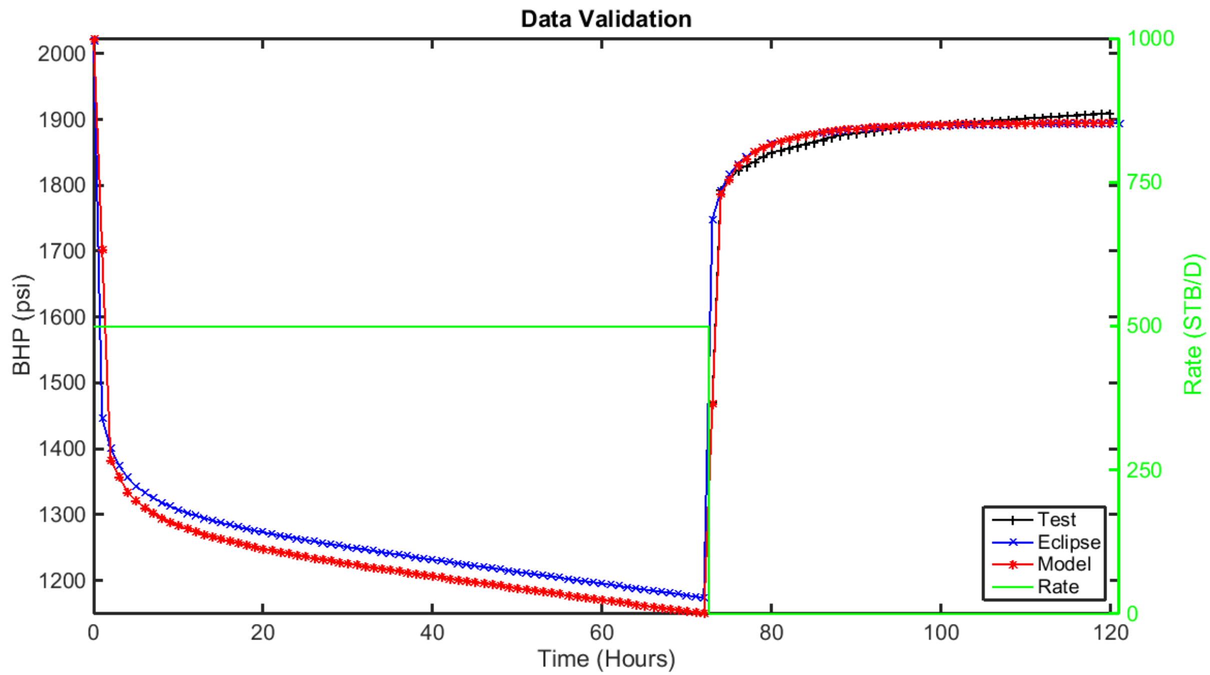
NRMSE*: Normalized Root Mean Square Error.



Sensitivity over Reservoir Permeability to Give Minimum Error:

1- Analytical Solution, K= 12.5 mD
2- Model , K = 12.5 mD

Case_3: BU-Oil

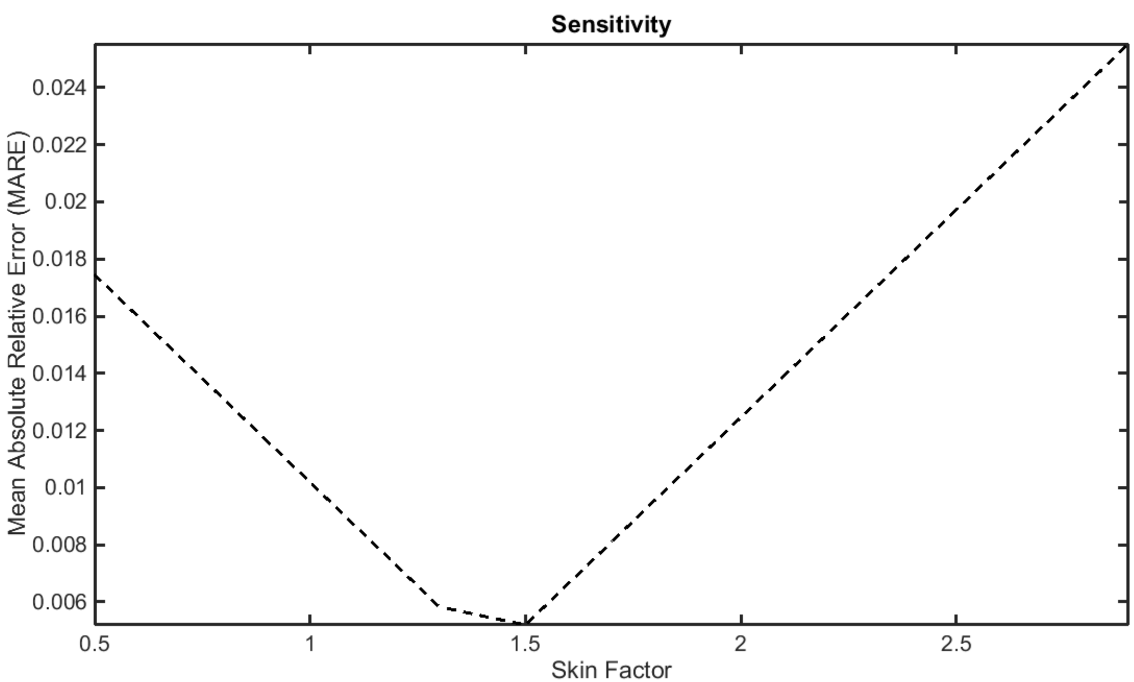


Goodness of Fit Based on NRMSE* Relative to Test Points:

1- Eclipse= 0.0067

2- Model= 0.0042

NRMSE*: Normalized Root Mean Square Error.

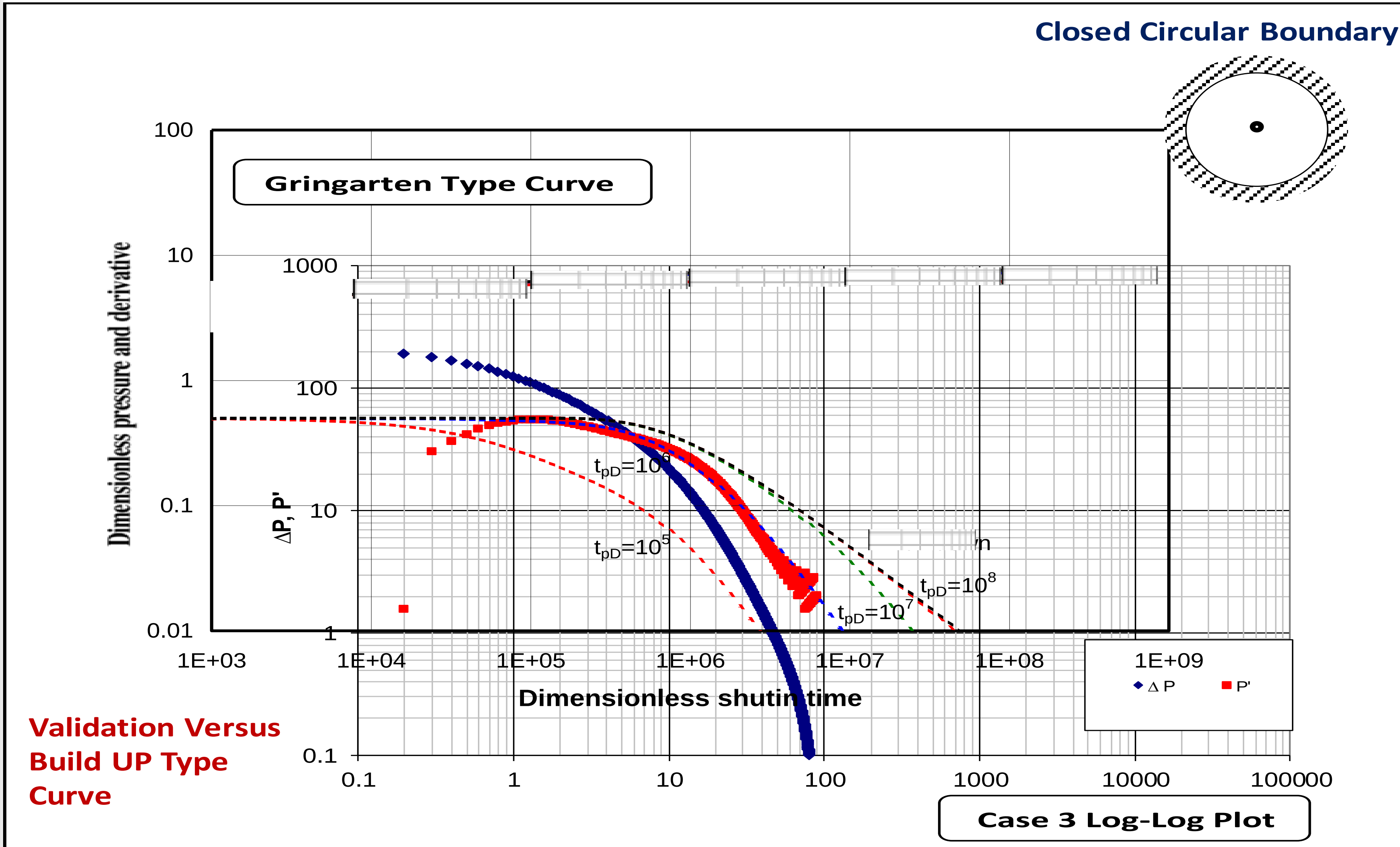


Sensitivity over Skin Factor to Give Minimum Error:

1- Analytical Solution, S= 1.43

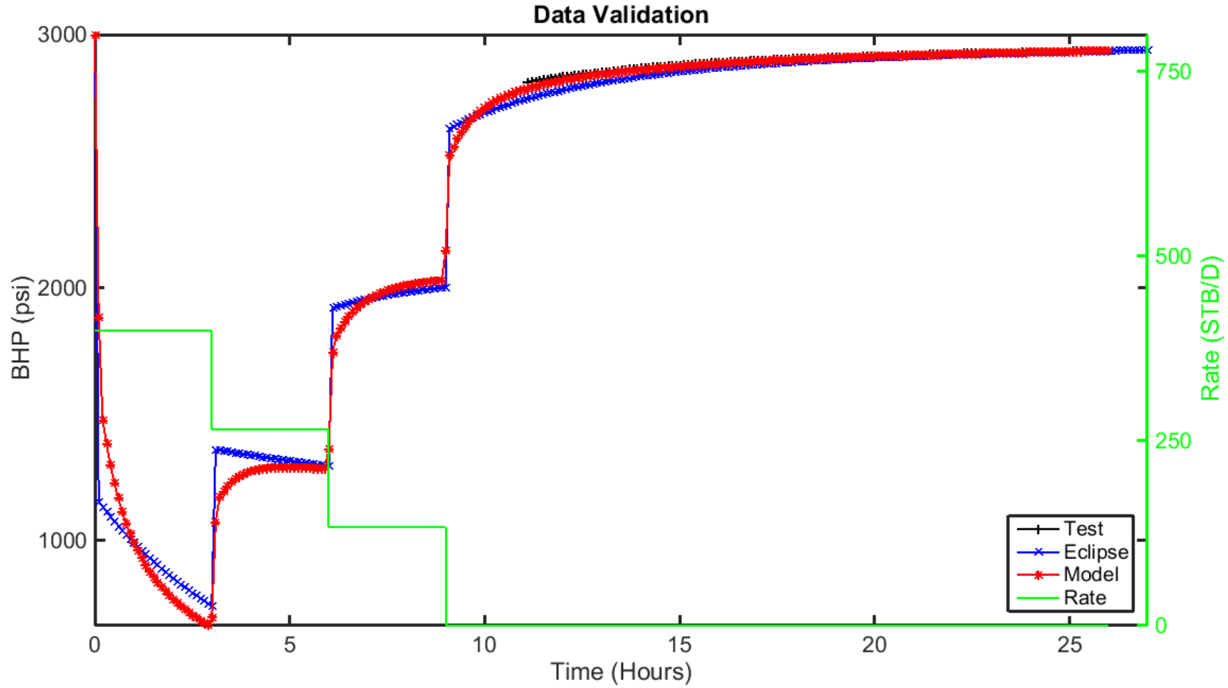
2- Model , S = 1.5

Case_3: Validation Versus The Analytical Solution



Validation Versus Build UP Type Curve

Case_4: Variable Rate BU-Oil

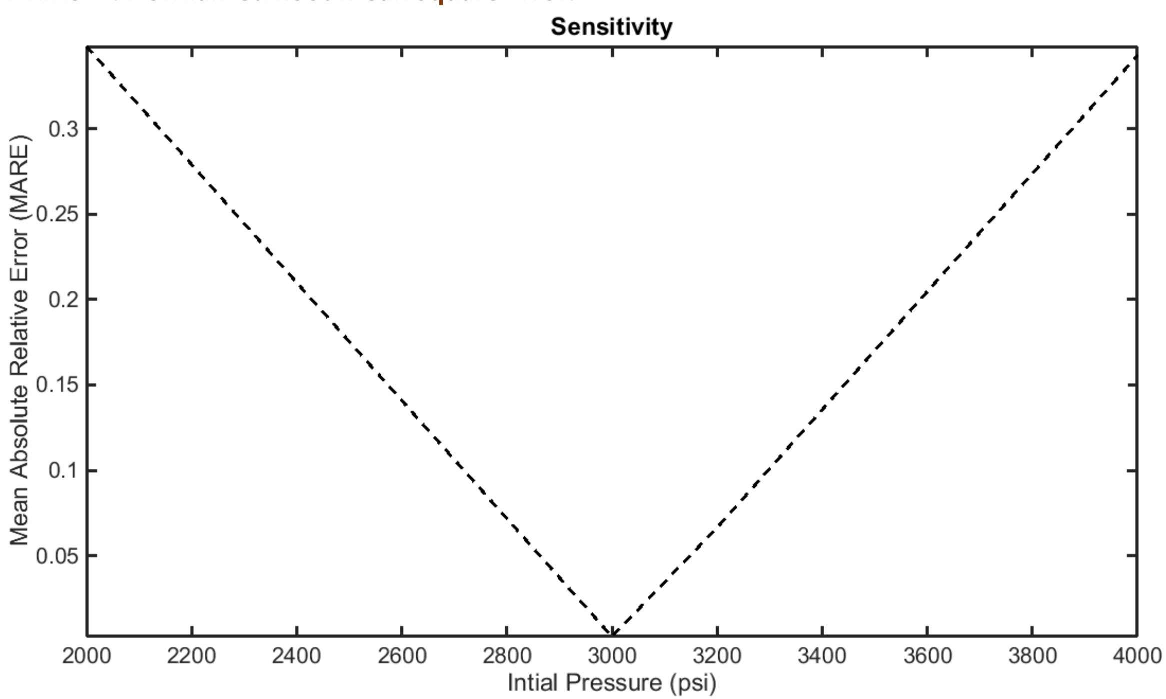


Goodness of Fit Based on NRMSE* Relative to Test Points:

1- Eclipse= 0.009

2- Model= 0.002

NRMSE*: Normalized Root Mean Square Error.

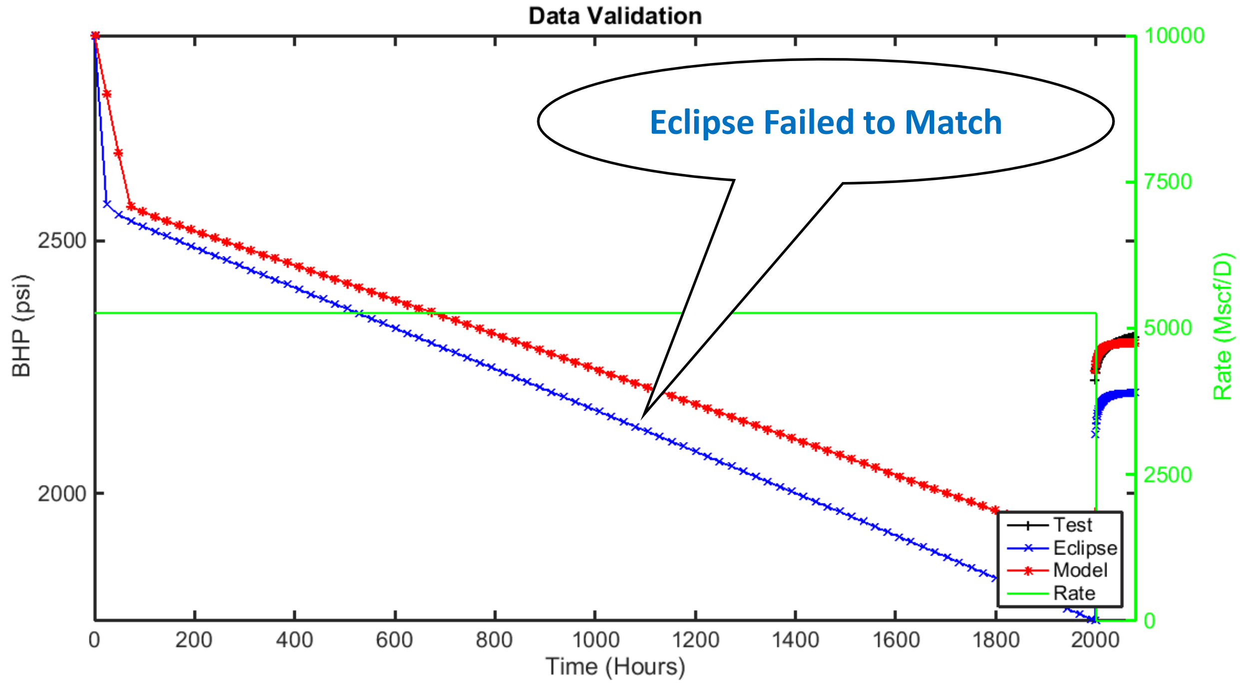


Sensitivity over Initial Pressure to Give Minimum Error:

1- Analytical Solution, Pi= 3000 psi

2- Model , Pi = 3000 psi

Case_5: BU-Gas

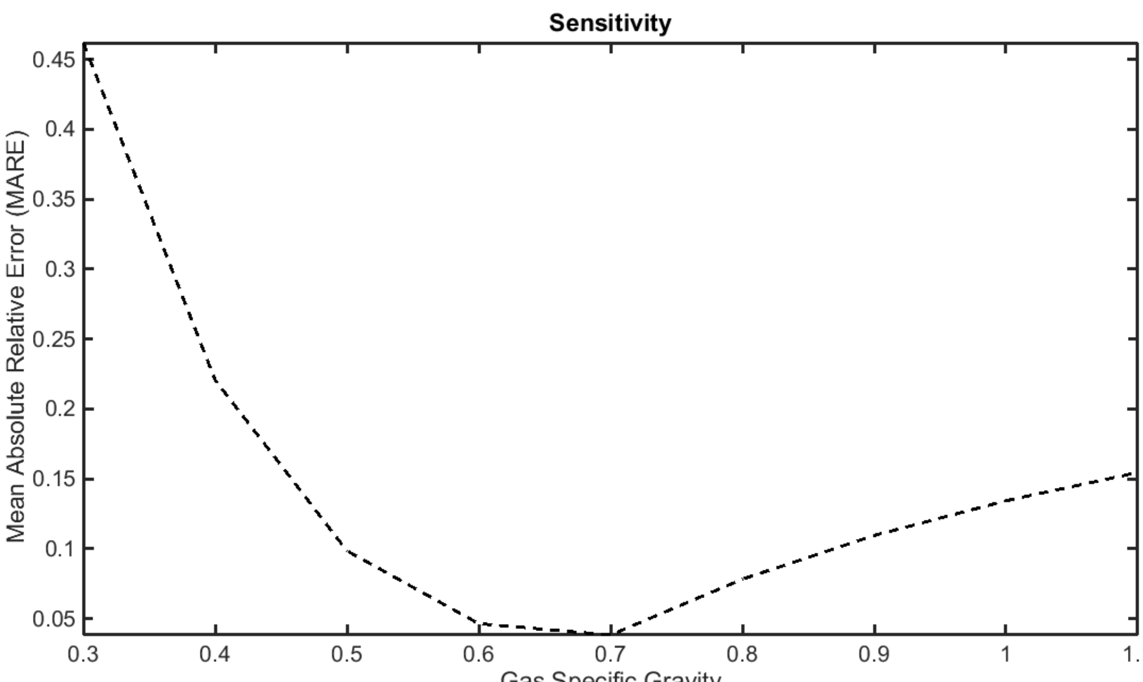


Goodness of Fit Based on NRMSE* Relative to Test Points:

1- Eclipse= 0.098

2- Model= 0.0038

NRMSE*: Normalized Root Mean Square Error.

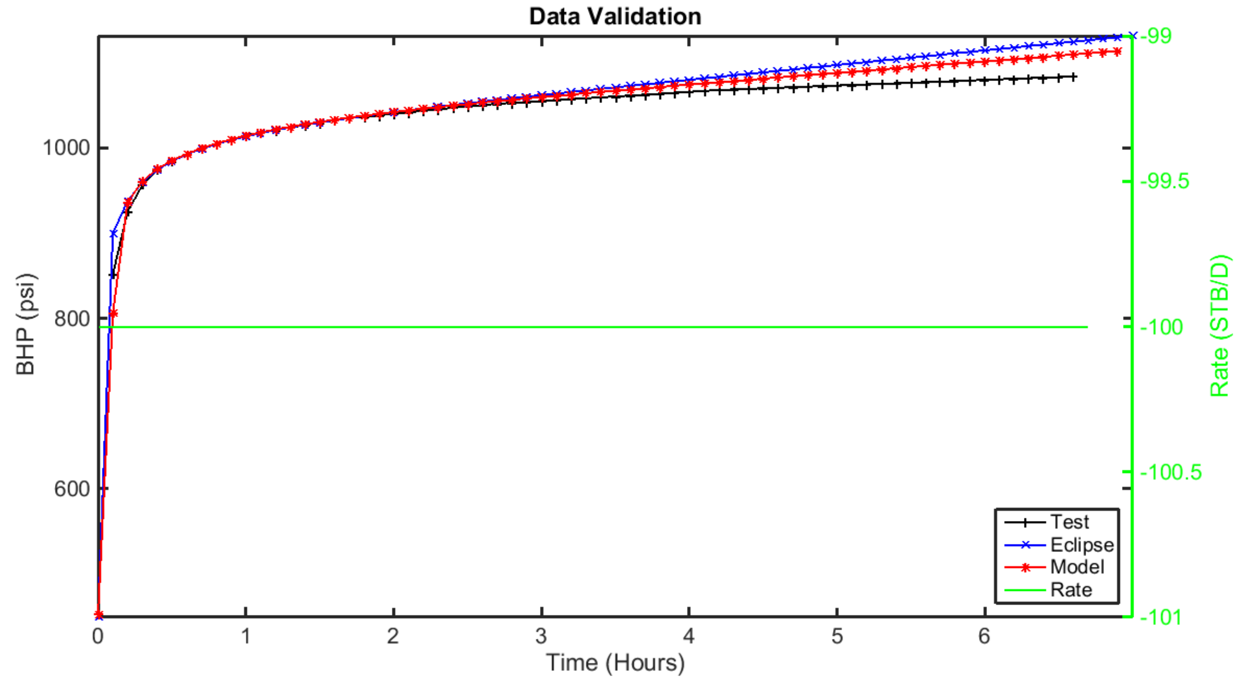


Sensitivity over Gas Specific Gravity to Give Minimum Error:

1- Analytical Solution, γg= 0.7

2- Model , γg = 0.7

Case_6: Inj. Test-Water

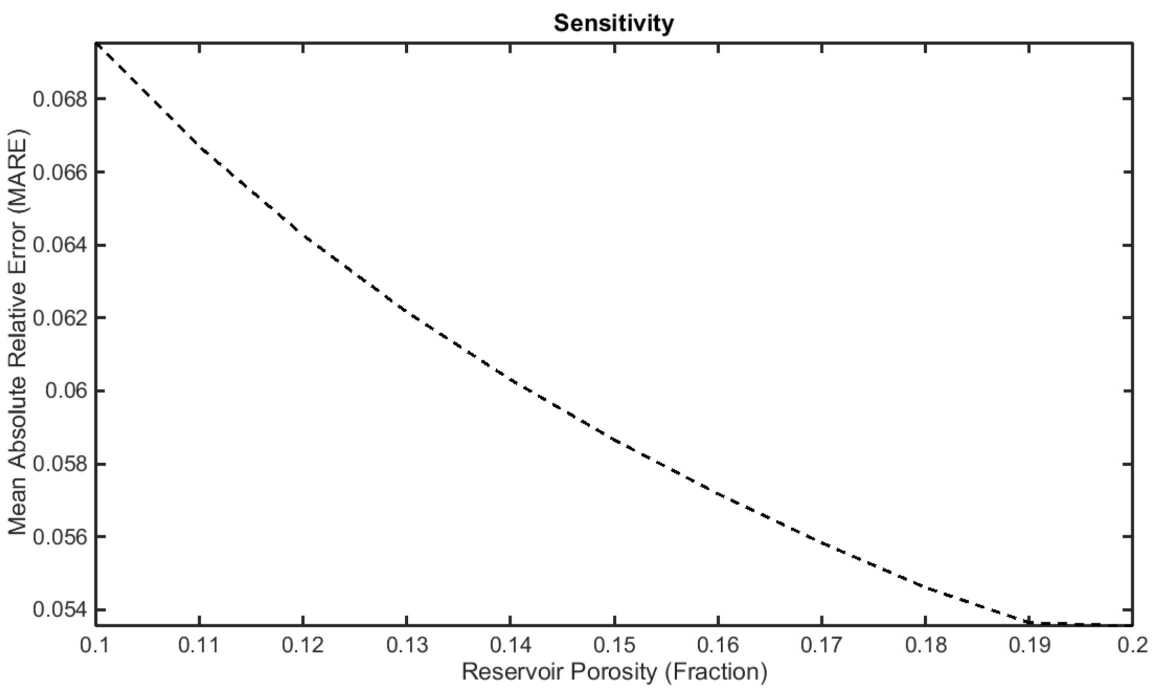


Goodness of Fit Based on NRMSE* Relative to Test Points:

1- Eclipse= 0.012

2- Model= 0.010

NRMSE*: Normalized Root Mean Square Error.

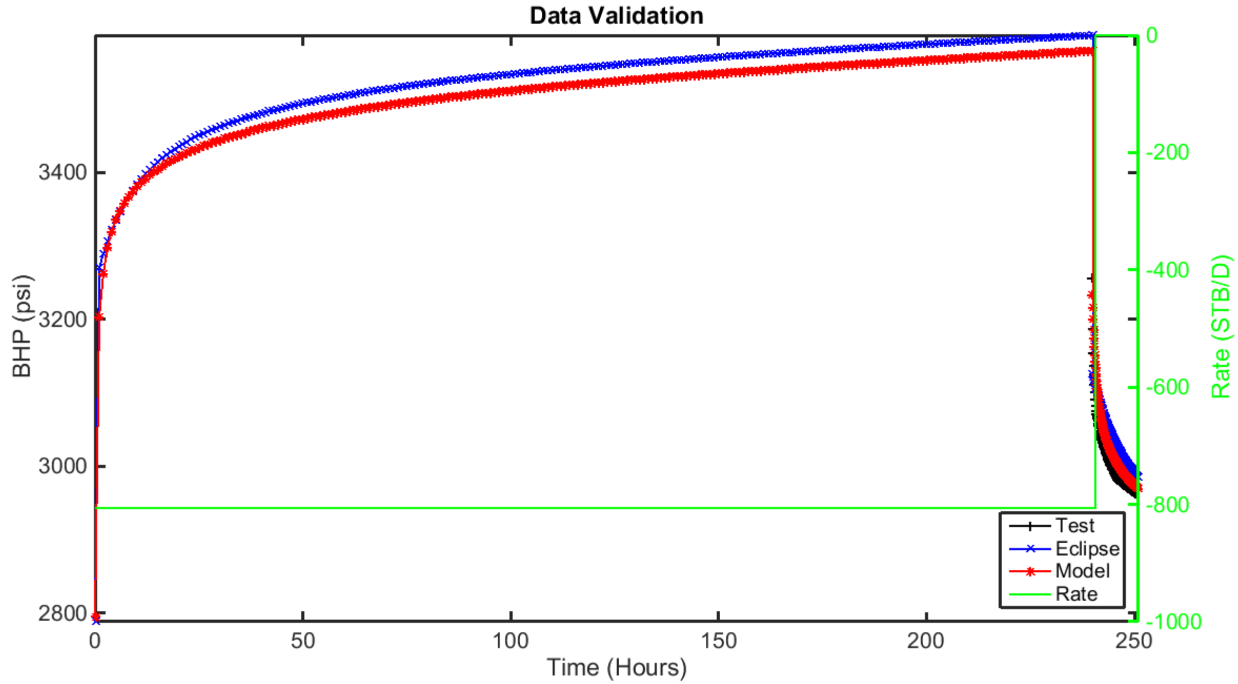


Sensitivity over Reservoir Porosity to Give Minimum Error:

1- Analytical Solution, ϕ= 0.15

2- Model , ϕ = 0.19

Case_7: Fall Off Test-Water

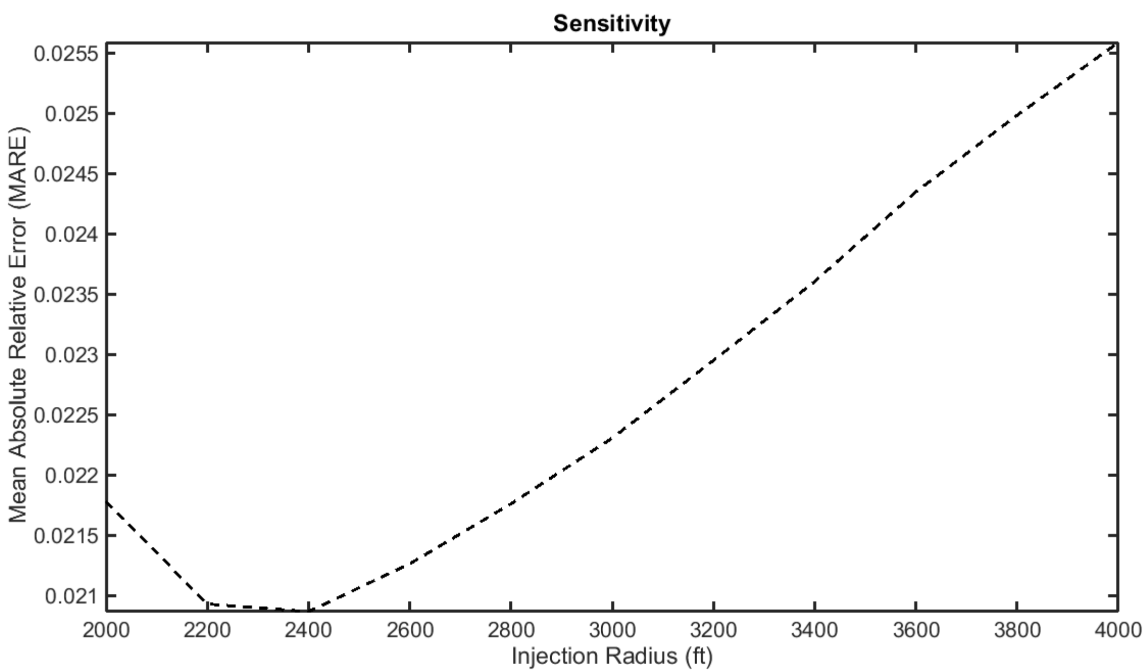


Goodness of Fit Based on NRMSE* Relative to Test Points:

1- Eclipse= 0.02

2- Model= 0.014

NRMSE*: Normalized Root Mean Square Error.



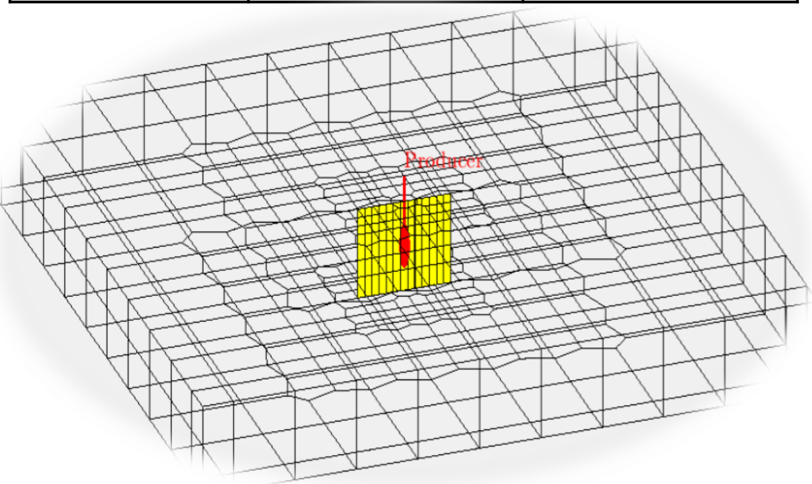
Sensitivity over Injection Radius to Give Minimum Error:

1- Analytical Solution, rinj= 1799 ft

2- Model , rinj = 2400 ft

Hybrid Grid, Single Well + Hyd. Frac., 1 Case Compared to Eclipse Cartesian Grid

Case	Test Type	Phase
8	Draw Down	Gas



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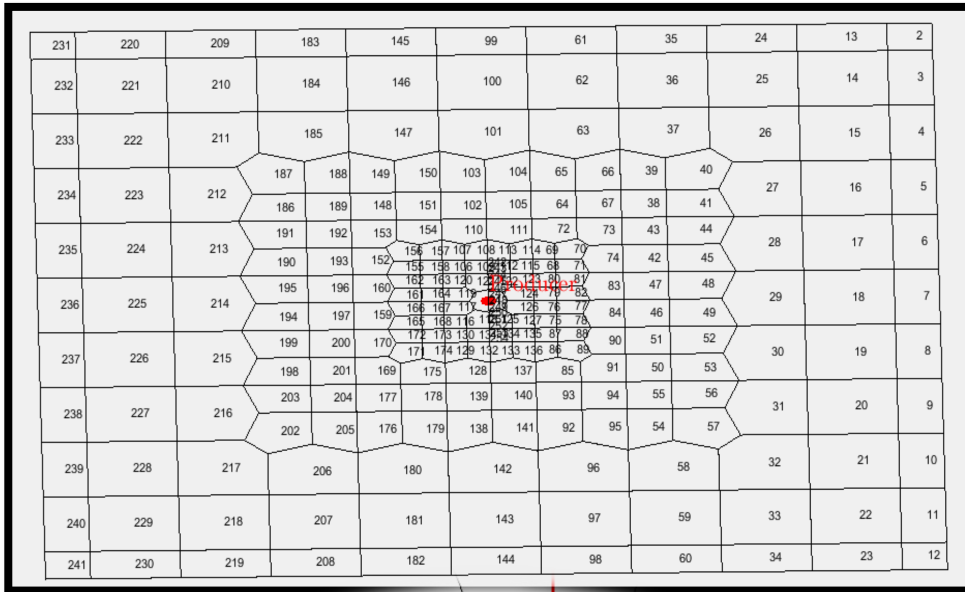
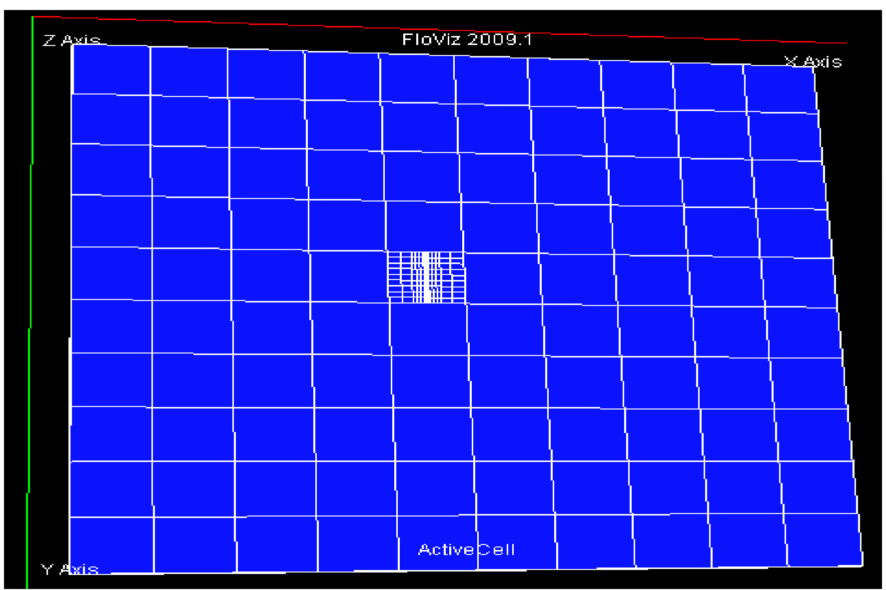
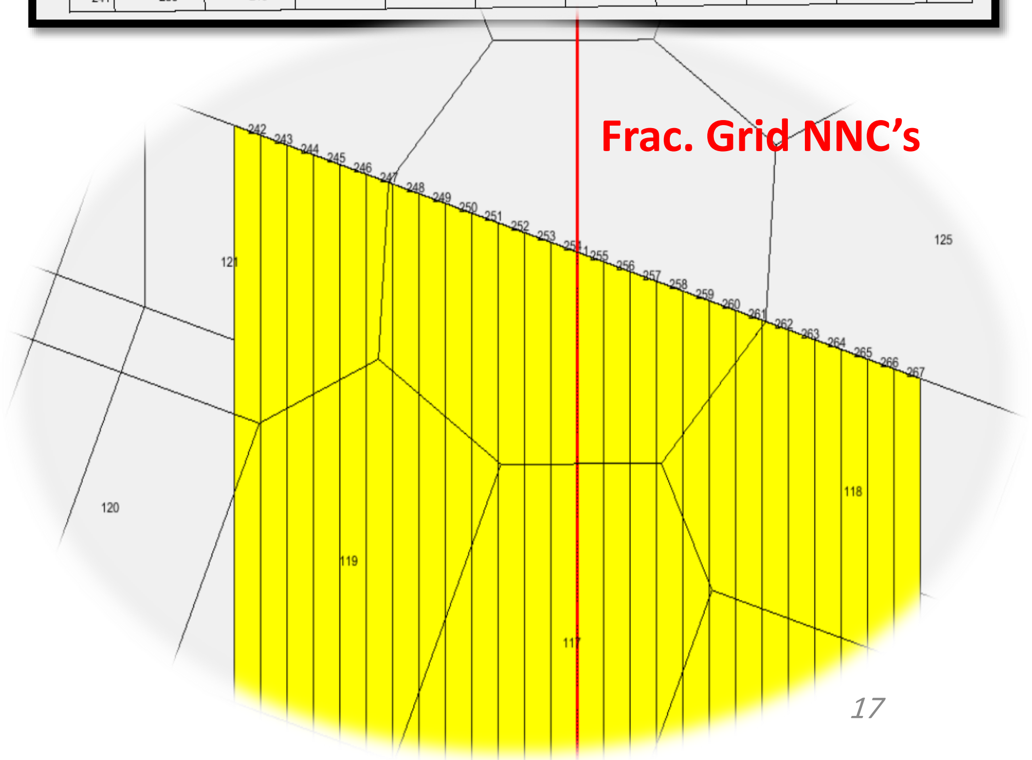


Eclipse Cartesian LGR Grid



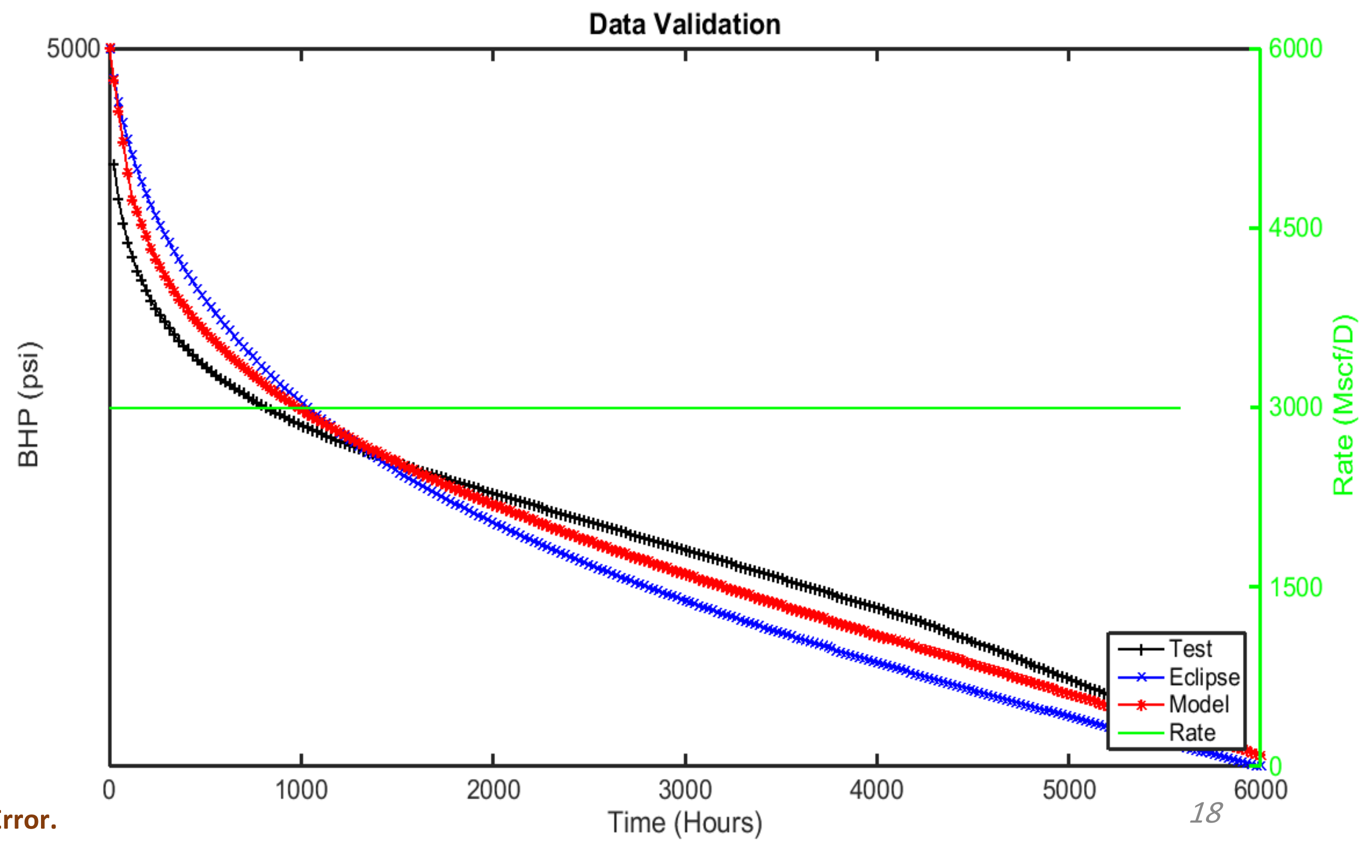
Frac. Grid NNC's



Case_8: DD-Gas, 'Fractured Well'

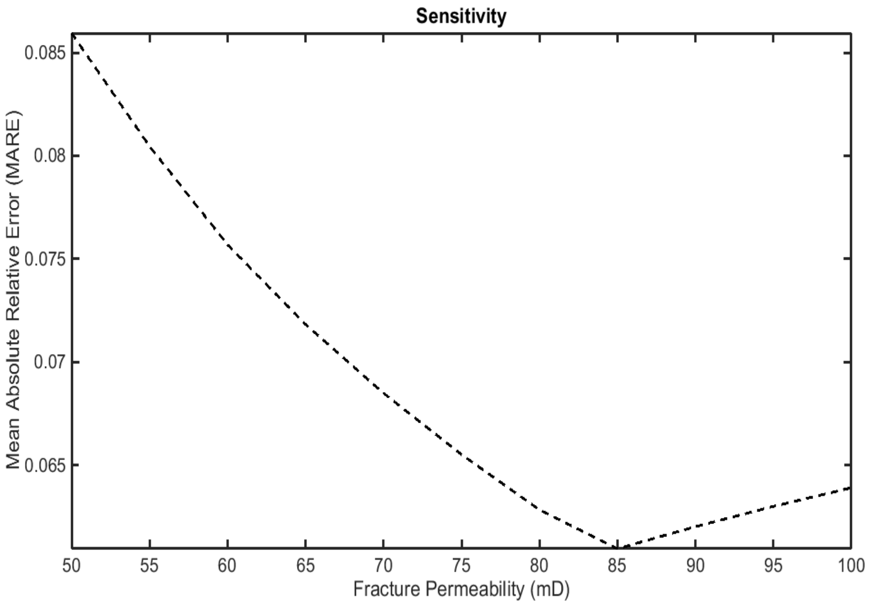
Case_ Source	Test Type	Phase	Givens (Model Parameters)
8_ Ex:6.2	Draw Down	Gas	γg = 0.65, Qg = 3,000 Mscf/D, h = 60 ft , φ = 0.1, Bg = 0.7085 RB/ Mscf, Pi = 5,000 psia, C_t = 2.084 x 10-4 psi-1, r_w = 0.25 ft, z = 0.991, T= 570°R (110°F) ,and μ = 0.01961 cp

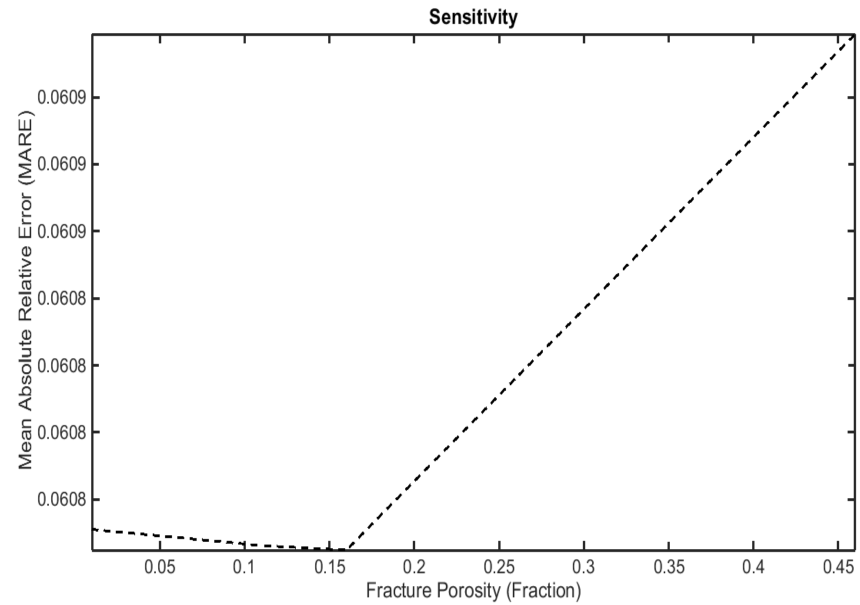
Goodness of Fit Based on NRMSE*
Relative to Test Points:
1- Eclipse= 0.07
2- Model= 0.06

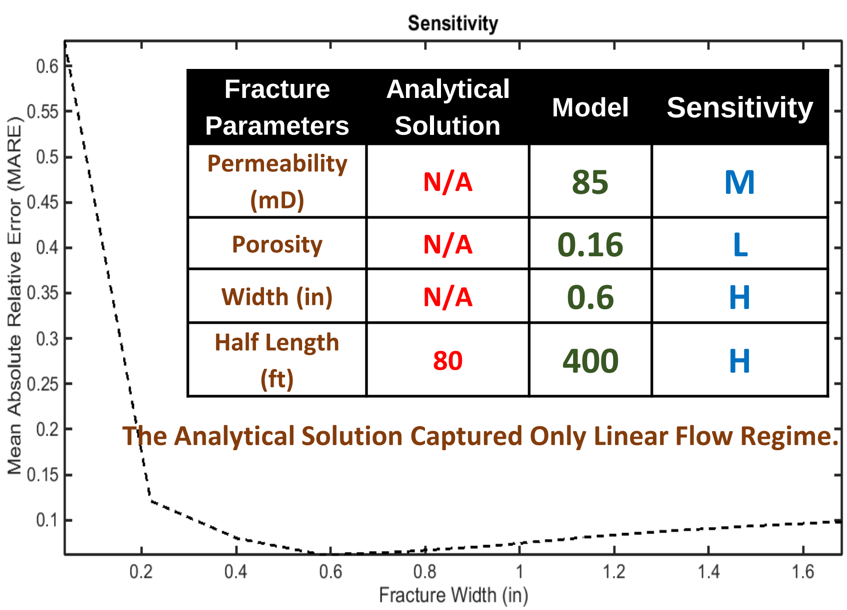


NRMSE*: Normalized Root Mean Square Error.

Case_8: Sensitivities

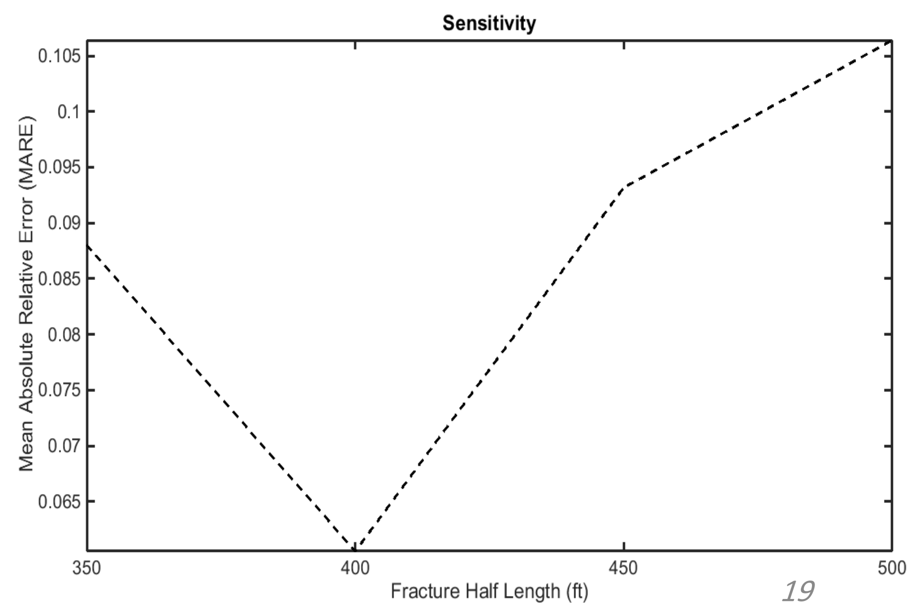




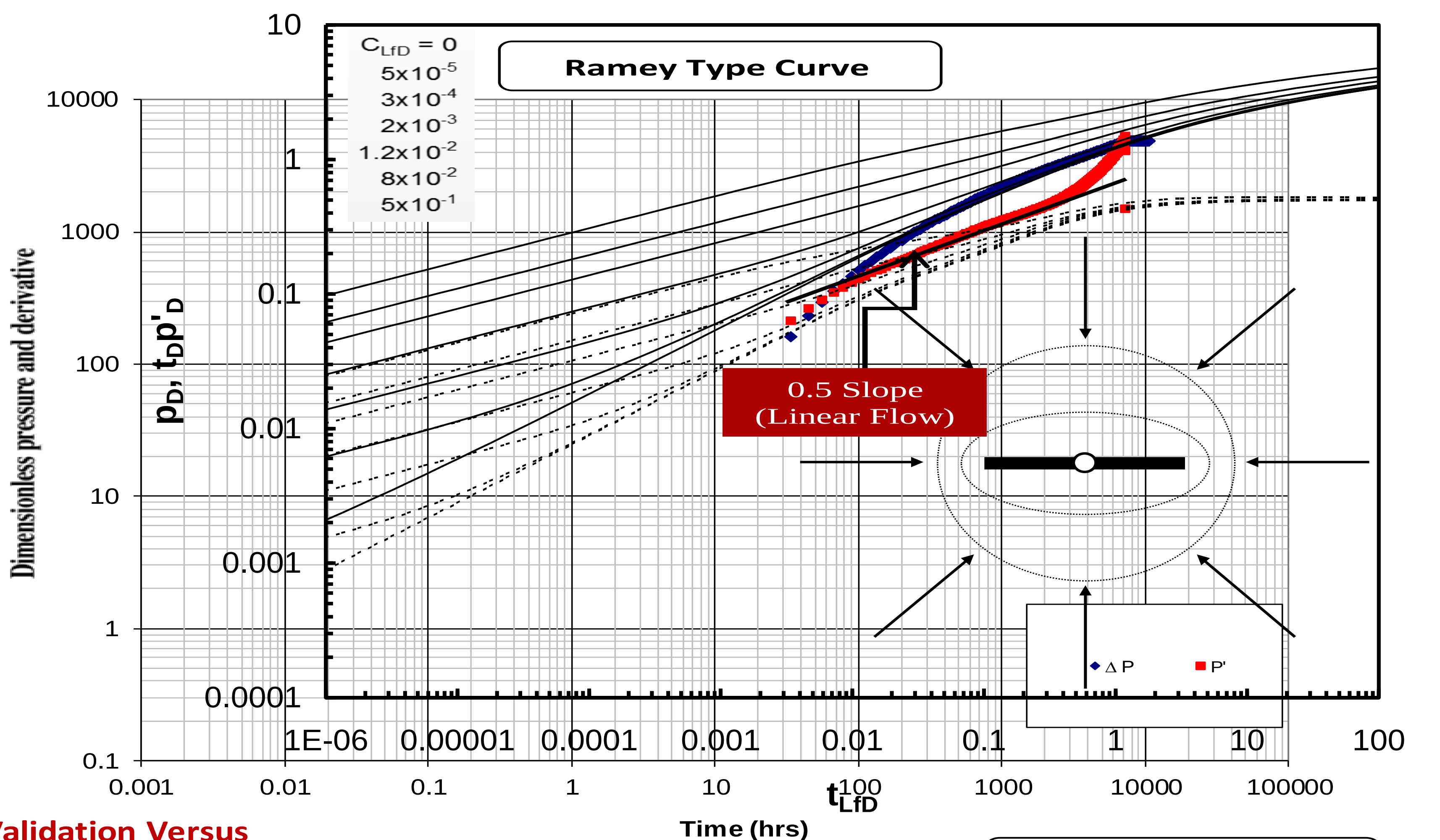


Fracture Parameters	Analytical Solution	Model	Sensitivity
Permeability (mD)	N/A	85	M
Porosity	N/A	0.16	L
Width (in)	N/A	0.6	H
Half Length (ft)	80	400	H

The Analytical Solution Captured Only Linear Flow Regime.



Case_8: Validation Versus The Analytical Solution

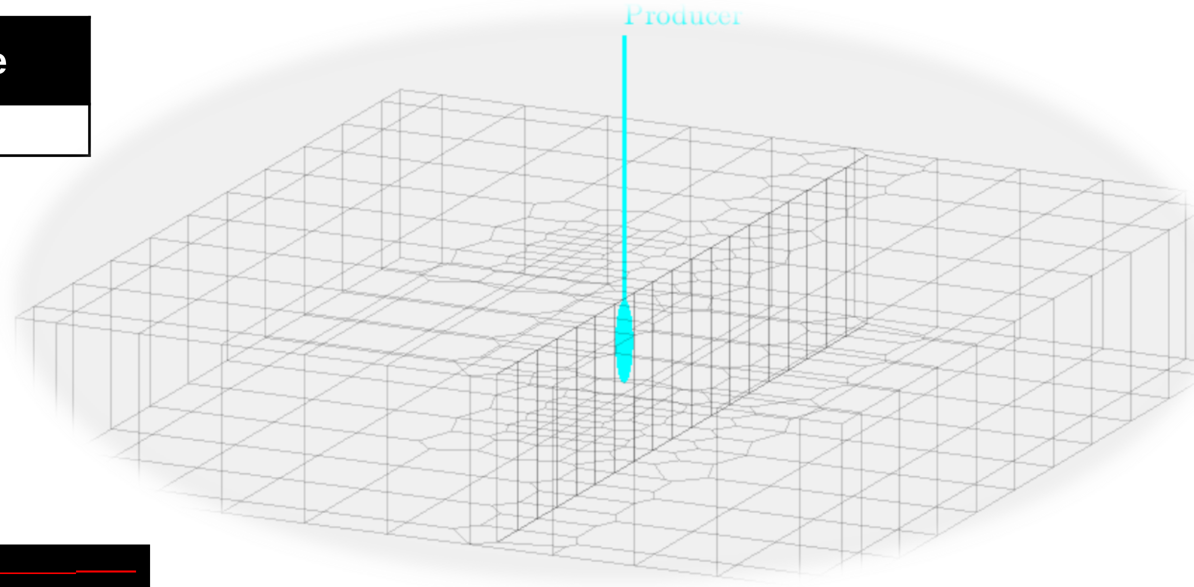


Validation Versus Hydraulically Fractured Well Type Curve

Case 8 Log-Log Plot

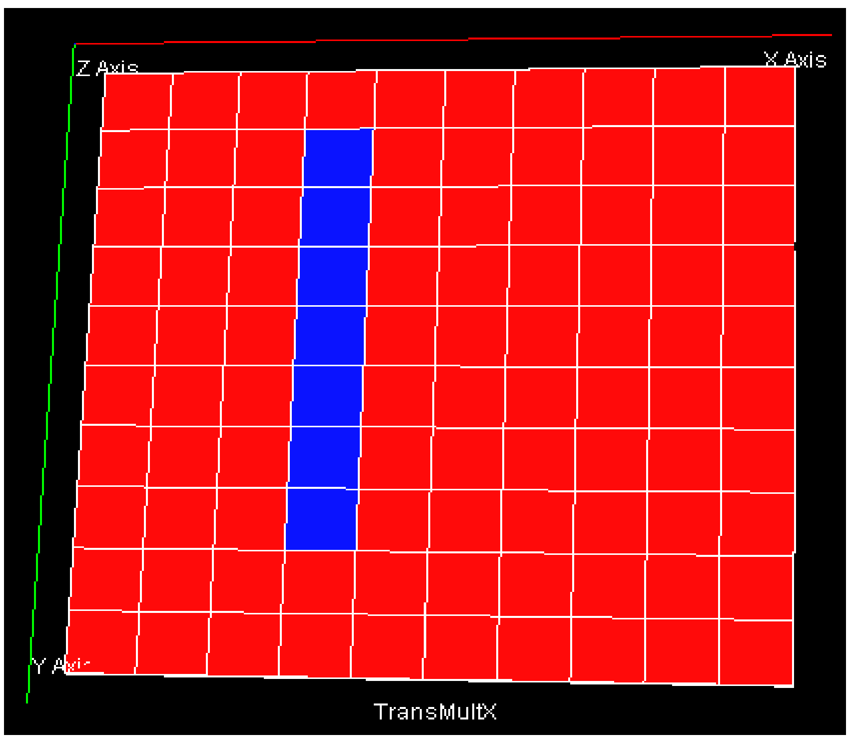
Hybrid Grid, Single Well , 'Distance to Fault', 1 Case Compared to Eclipse Cartesian Grid

Case	Test Type	Phase
9_Ex:2.11	Build Up	Oil



Eclipse Cartesian Grid,

Representing Fault by Setting Transmissibility Multiplier by Zero



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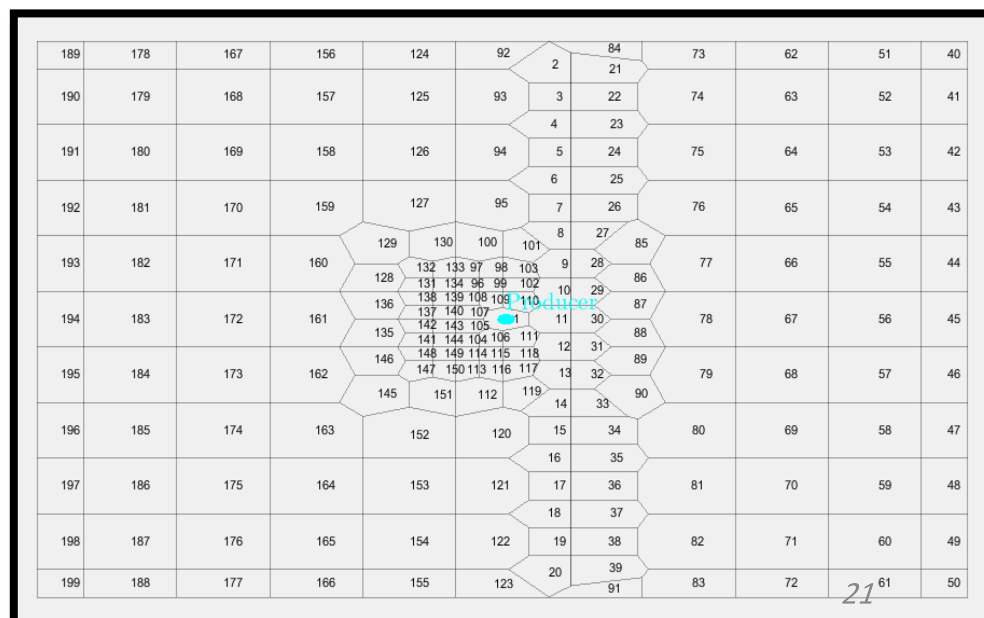
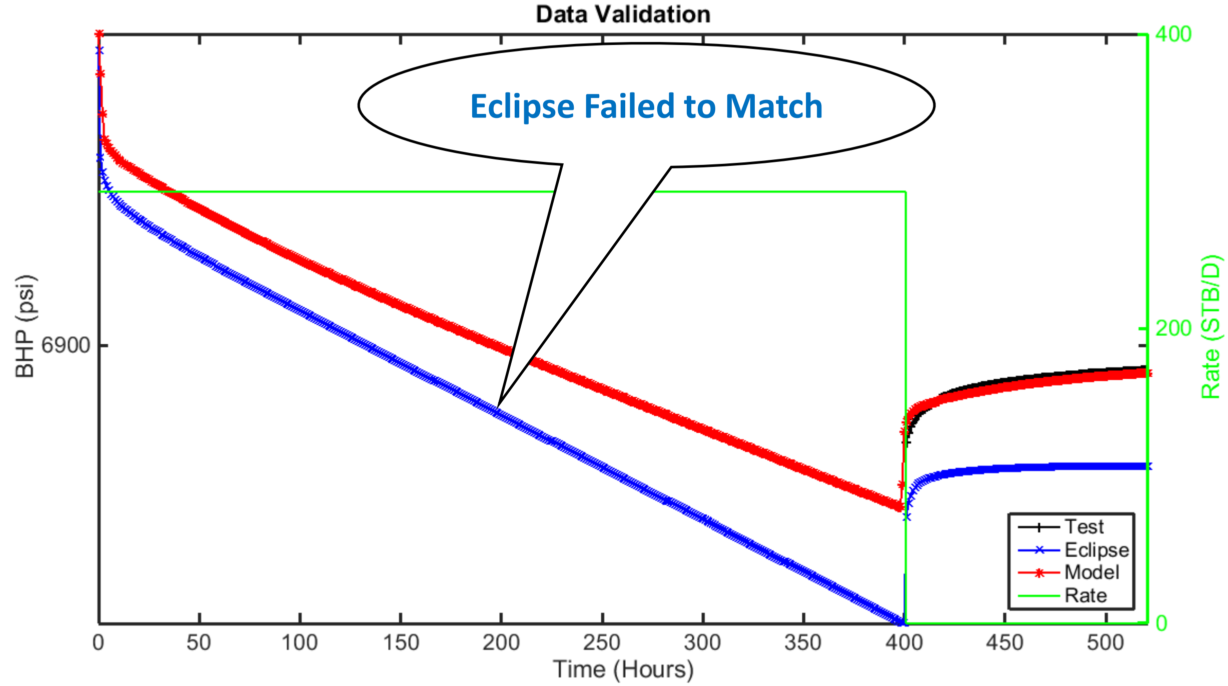


Case_9: BU-Oil, 'Distance to Fault'

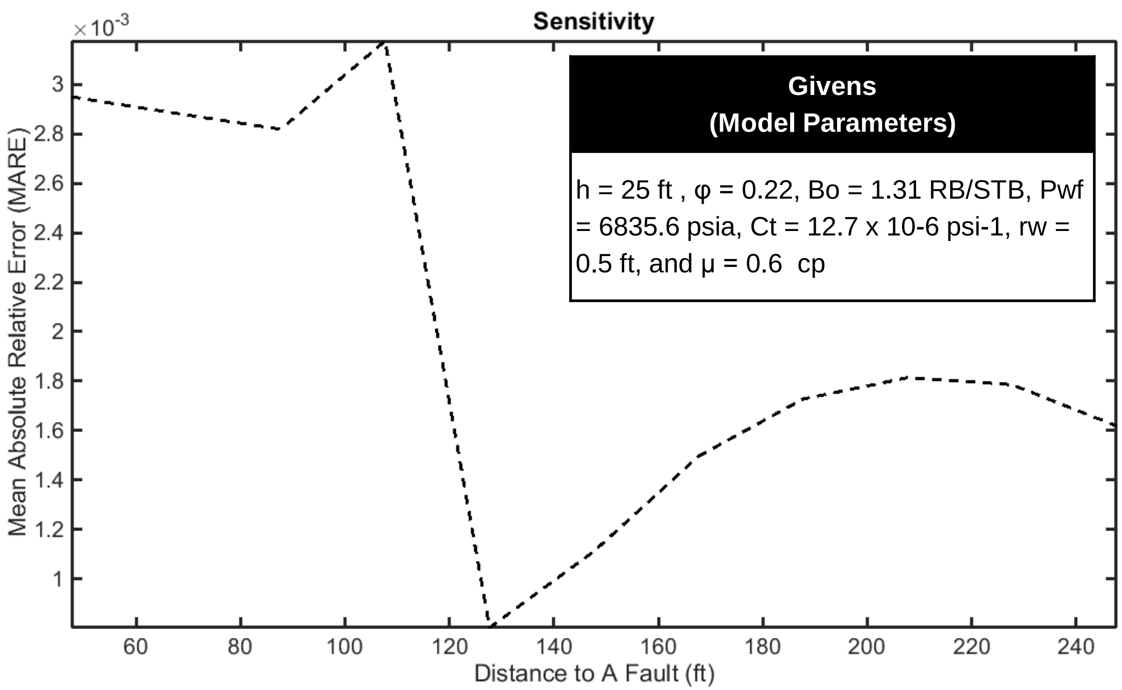


Goodness of Fit Based on NRMSE* Relative to Test Points:

1- Eclipse= 0.2

2- Model= 0.008

NRMSE*: Normalized Root Mean Square Error.



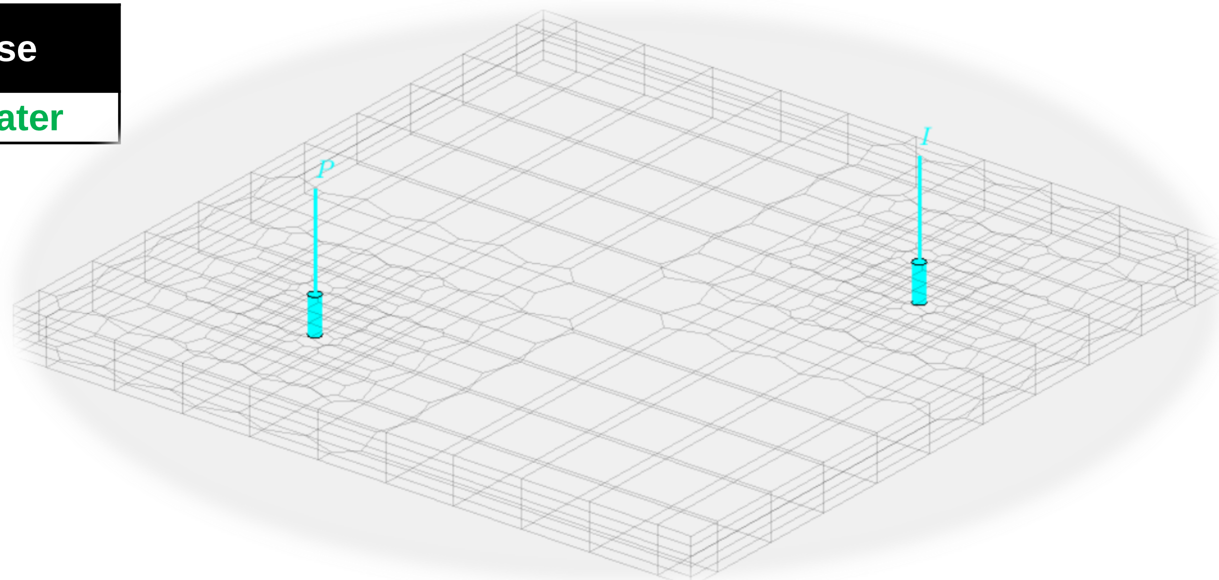
Sensitivity over Distance to Fault to Give Minimum Error:

1- Analytical Solution, x= 147 ft

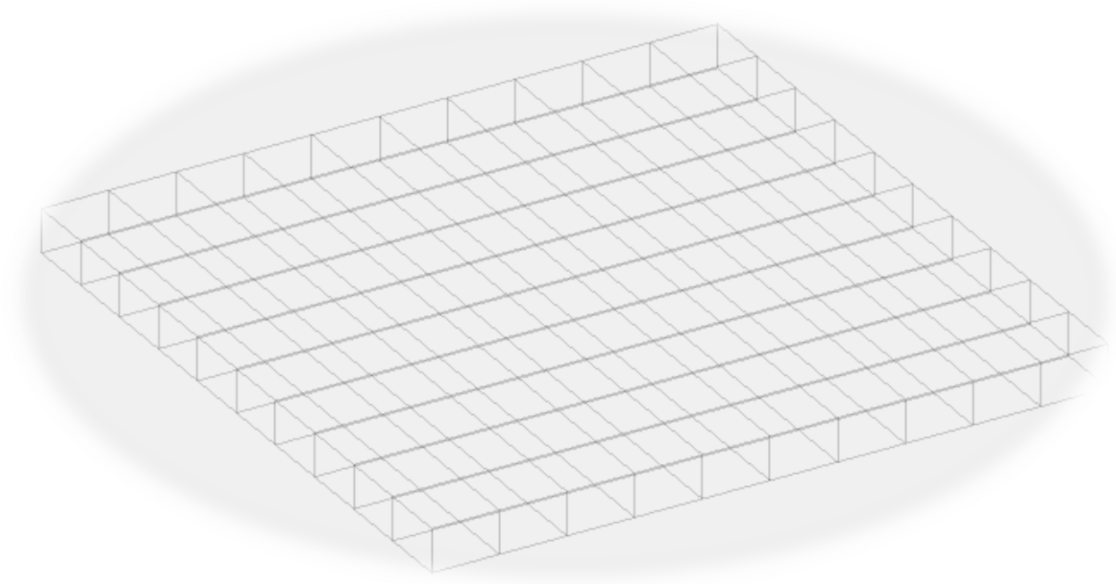
2- Model , x = 128 ft

Hybrid Grid, Two Wells , 'Interference Test', 1 Case
Compared to Eclipse Cartesian Grid

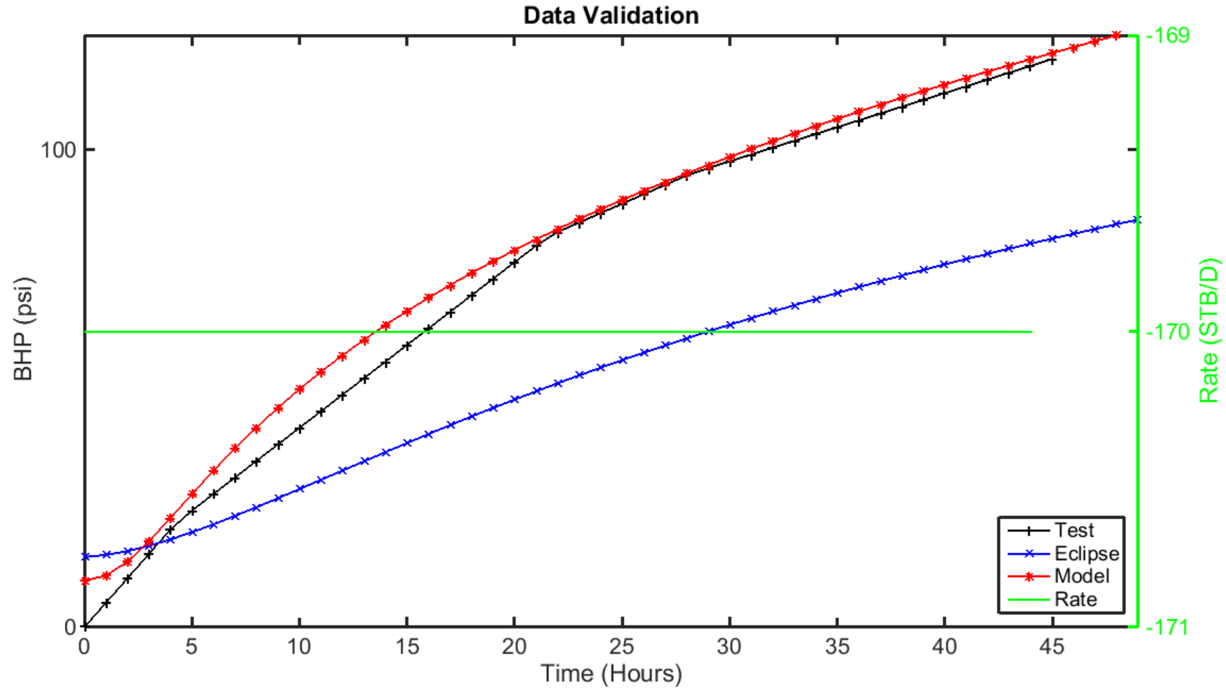
Case	Test Type	Phase
10_Ex:10.1	Interference	Oil/Water



Eclipse Cartesian Grid,



Case_10: BU-Oil, 'Distance to Fault'

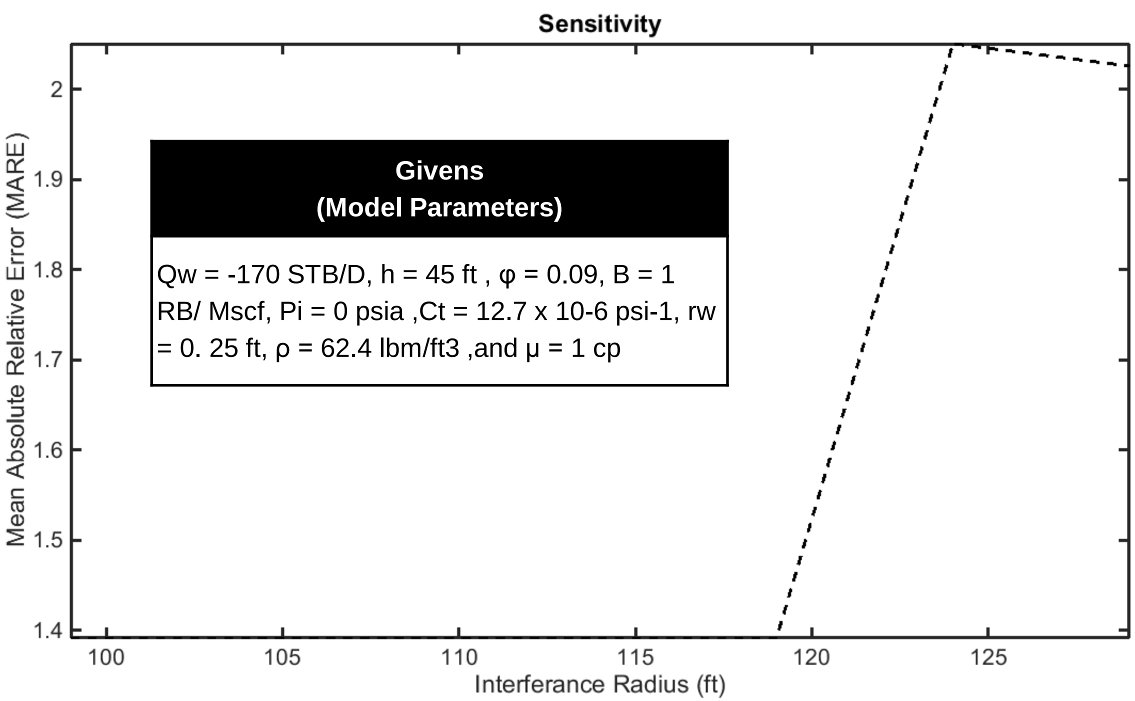


Goodness of Fit Based on NRMSE* Relative to Test Points:

1- Eclipse= 0.8

2- Model= 0.2

NRMSE*: Normalized Root Mean Square Error.



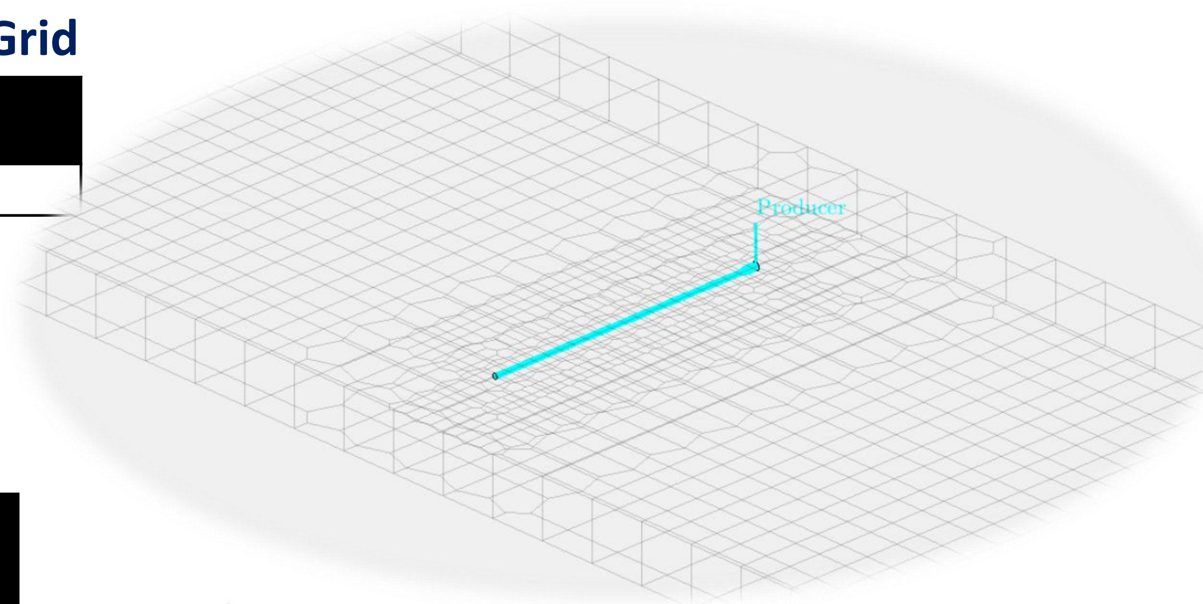
Sensitivity over Interference Radius to Give Minimum Error:

1- Analytical Solution, x= 119 ft

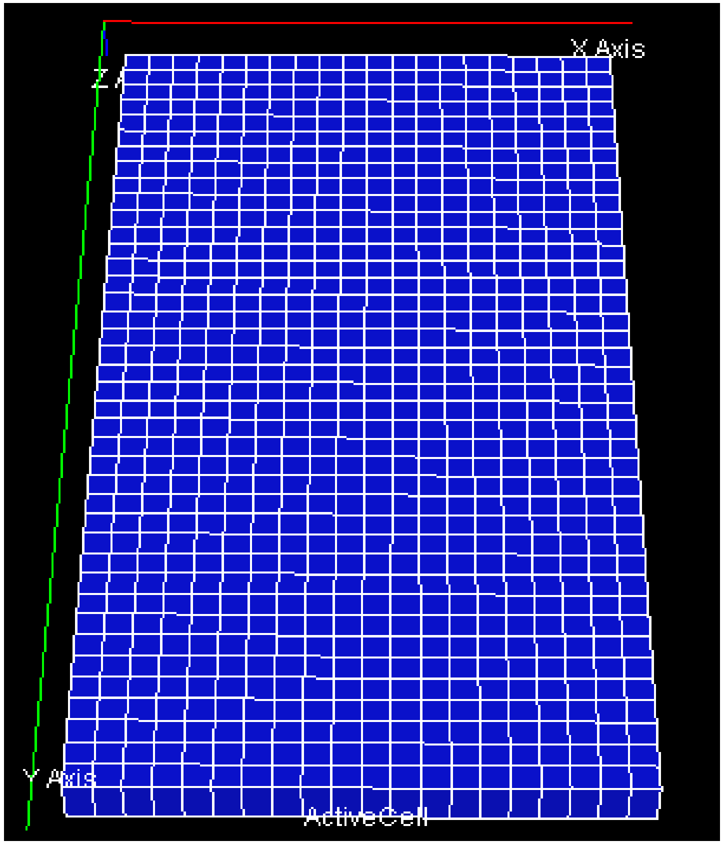
2- Model , x = 119 ft

Hybrid Grid, Single Well , 'Hz. Well', 1 Case Compared to Eclipse Cartesian Grid

Case	Test Type	Phase
11_Ex:12.1	Draw Down	Oil



Eclipse Cartesian Grid,



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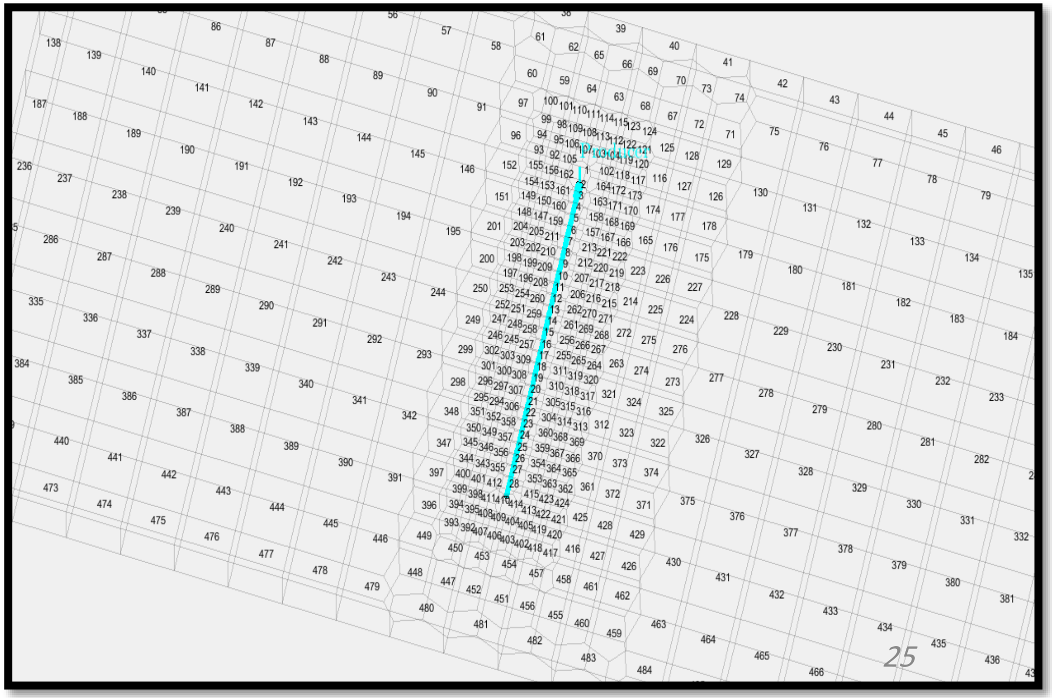
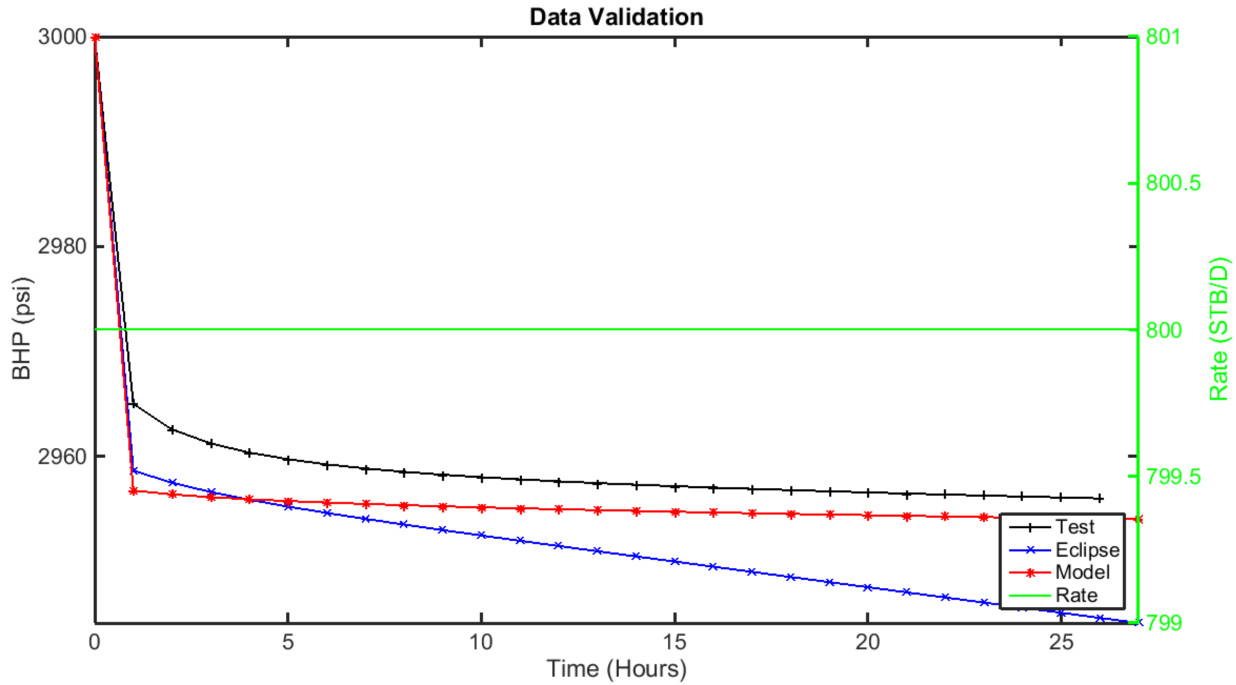


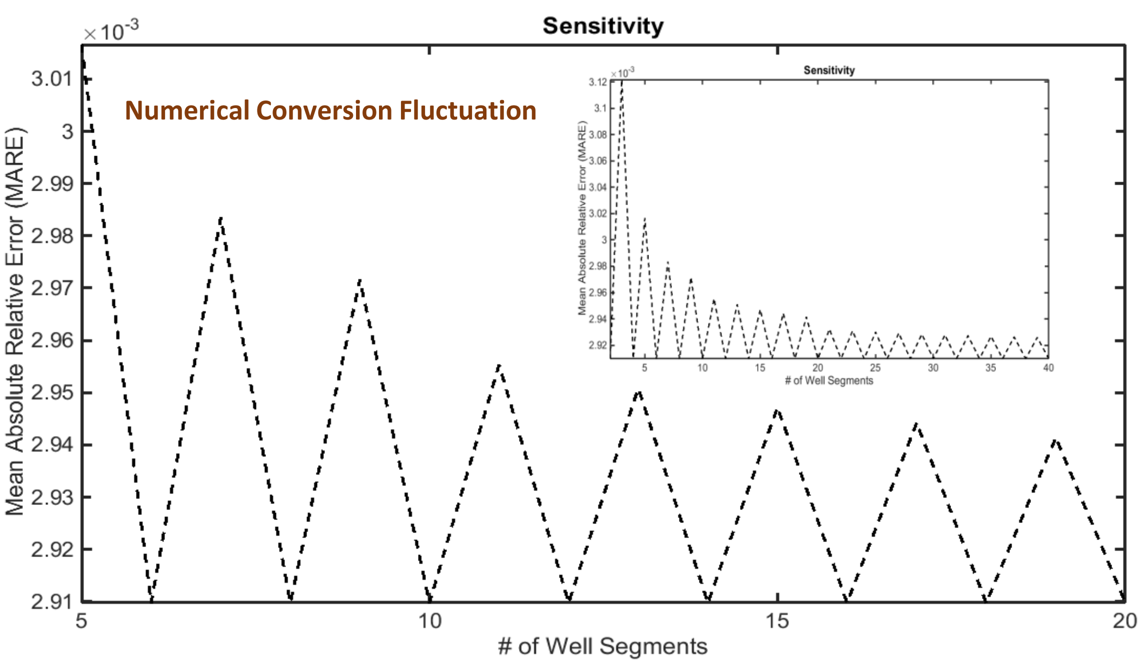
Case_11: DD-Oil, 'Hz. Well'

Goodness of Fit Based on NRMSE*
Relative to Test Points:
1- Eclipse= 0.0037
2- Model= 0.0029

Givens (Model Parameters)
Qo = 800 STB/D , h = 200 ft, φ = 0.2, Bo = 1.25 RB/STB, Pi = 3000 psia, Ct = 15 x 10-6 psi-1, rw = 0.25 ft, and μ = 1 cp Centered in box-shaped drainage area. h = 200 ft, a = 4,000 ft, and b = 2,000 ft. Lw= 1,000 ft kx = 200 md

NRMSE*: Normalized Root Mean Square Error.

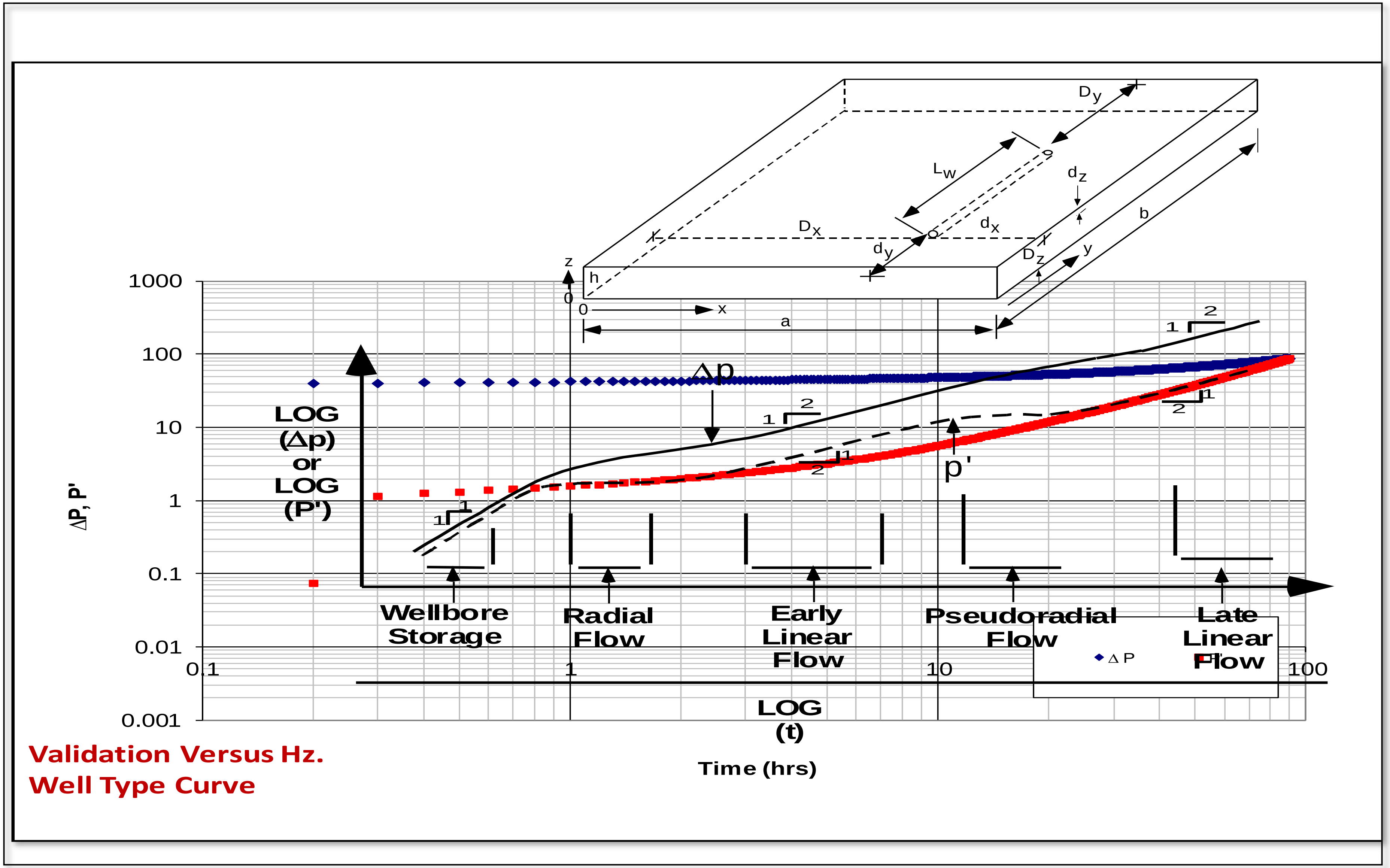




Sensitivity over # of Well Segments to Give Minimum Error:

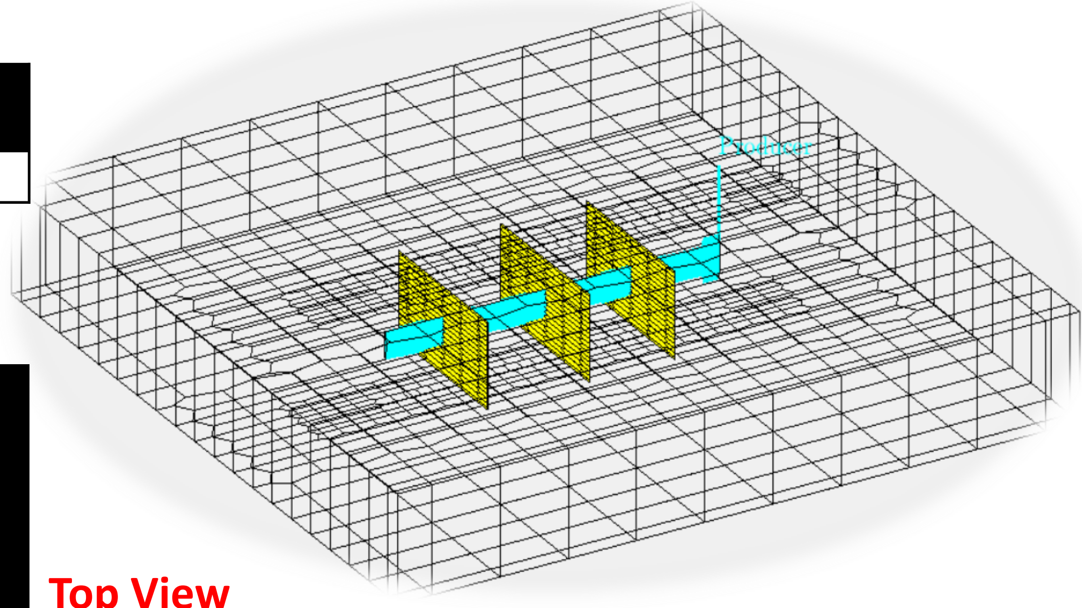
1- Analytical Solution, #= N/A
2- Model , # = 25

Case_11: Validation Versus The Analytical Solution

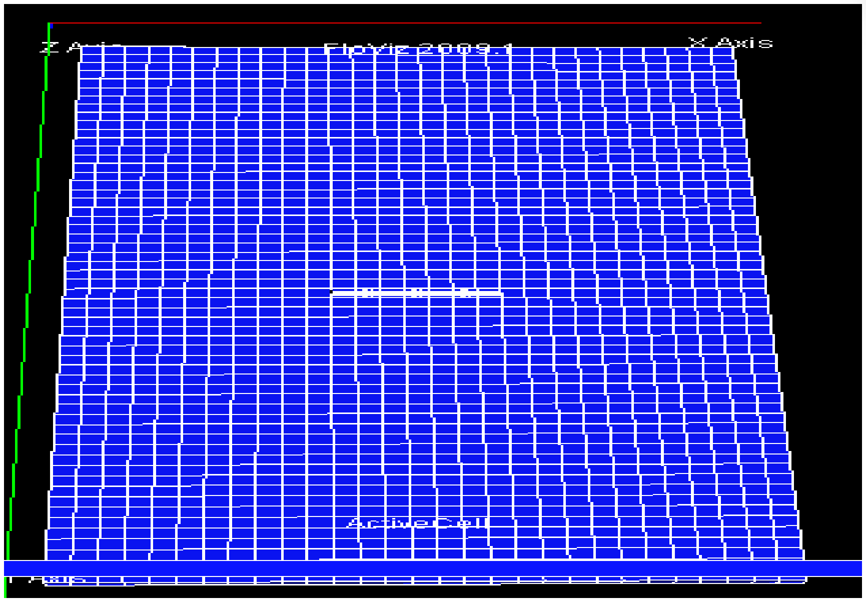


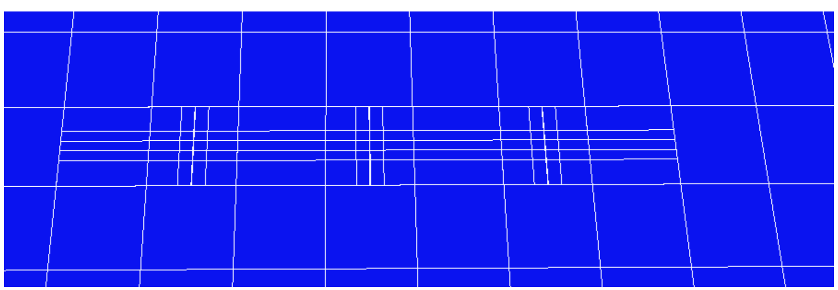
Hybrid Grid, Single Well , 'Hz. Well + 3 Transverse Fractures', 1 Case Compared to Eclipse Cartesian Grid

Case	Test Type	Phase
12_Hypothetical	Draw Down	Oil

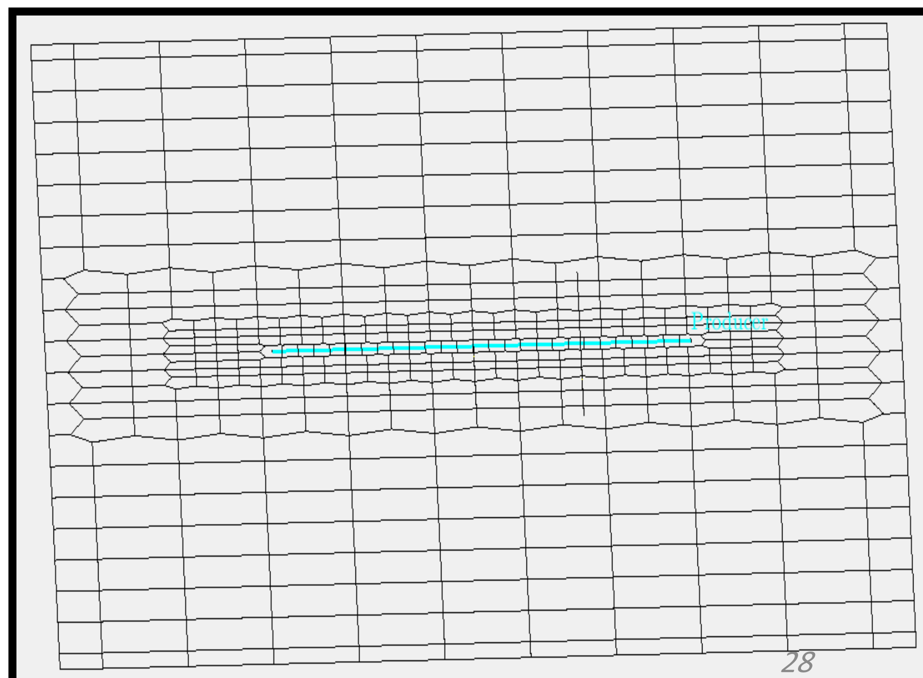


Eclipse Cartesian LGR Grid,



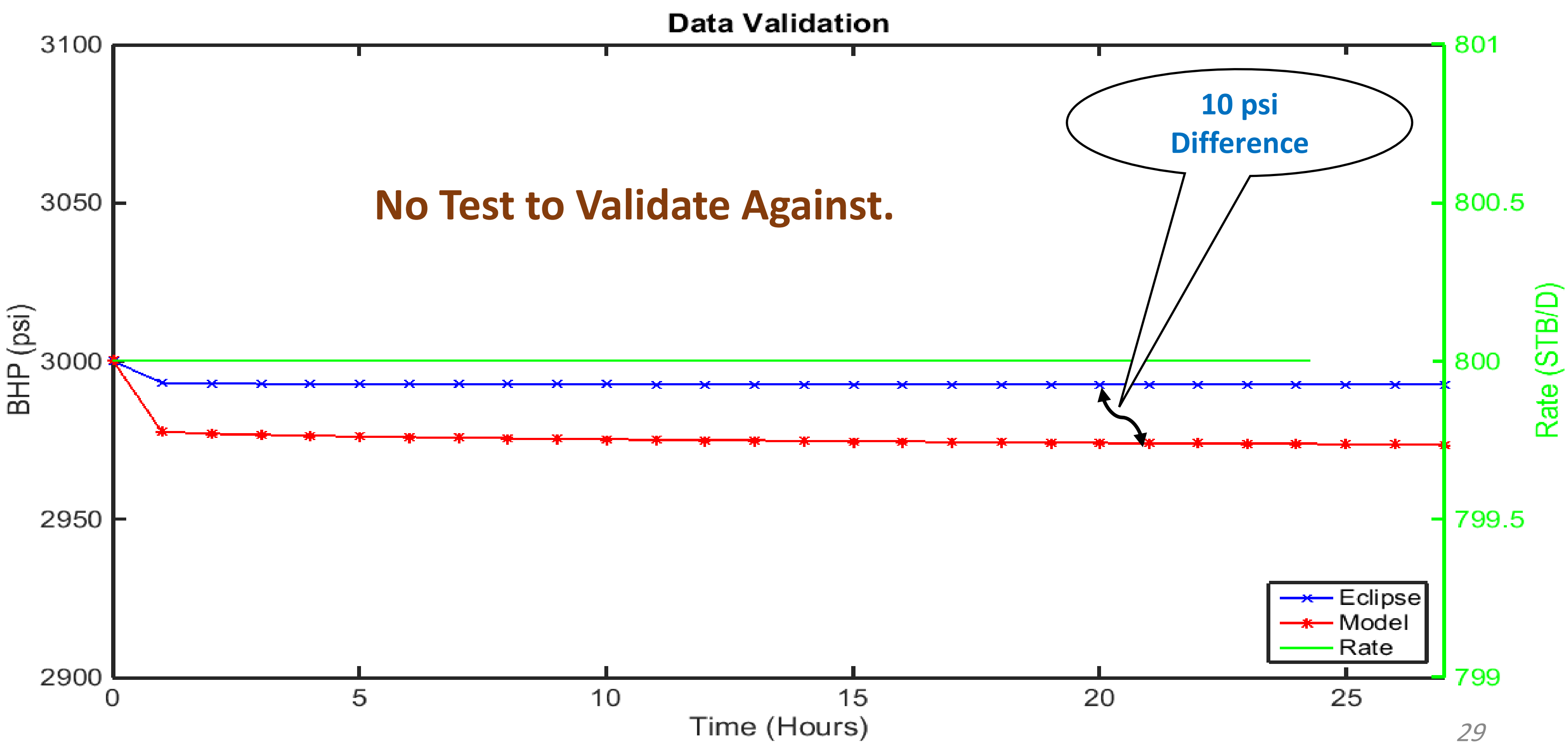


Top View



Case_12: DD-Oil, 'Hz. Well + 3 Transverse Fractures'

Givens (Model Parameters)
Qo = 800 STB/D , h = 200 ft, φ = 0.2, Bo = 1.25 RB/STB, Pi = 3000 psia, Ct = 15 x 10-6 psi-1, rw = 0.25 ft, and μ = 1 cp Centered in box-shaped drainage area. a = 4,000 ft, and b = 2,000 ft. Lw= 1,000 ft kx = 200 md



Contribution (Added Value): NWT, **SPE 105271/2007**

SPE 105271

Linking Well-Test Interpretations to Full Field Simulations

Faisal M. Al-Thawad, SPE, and Jim S. Liu, SPE, Saudi Aramco, and Raj Banerjee, SPE, and Dominic Agyapong, SPE, Schlumberger

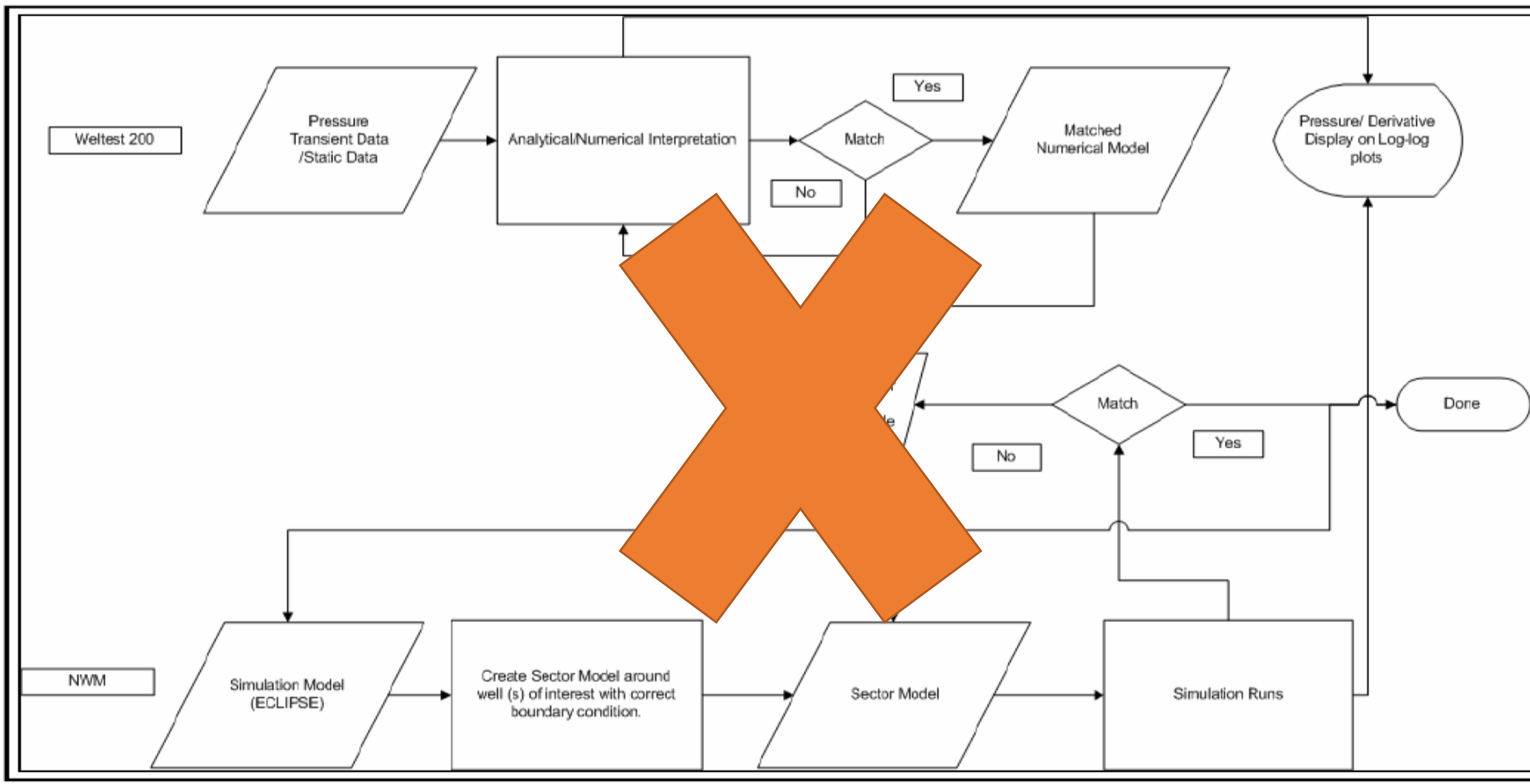


Figure 2: Study Workflow

Thank You