Energized Fractures in Shales / Tight Gas Sands

EFRAC-3D : Compositional Hydraulic Fracturing Model



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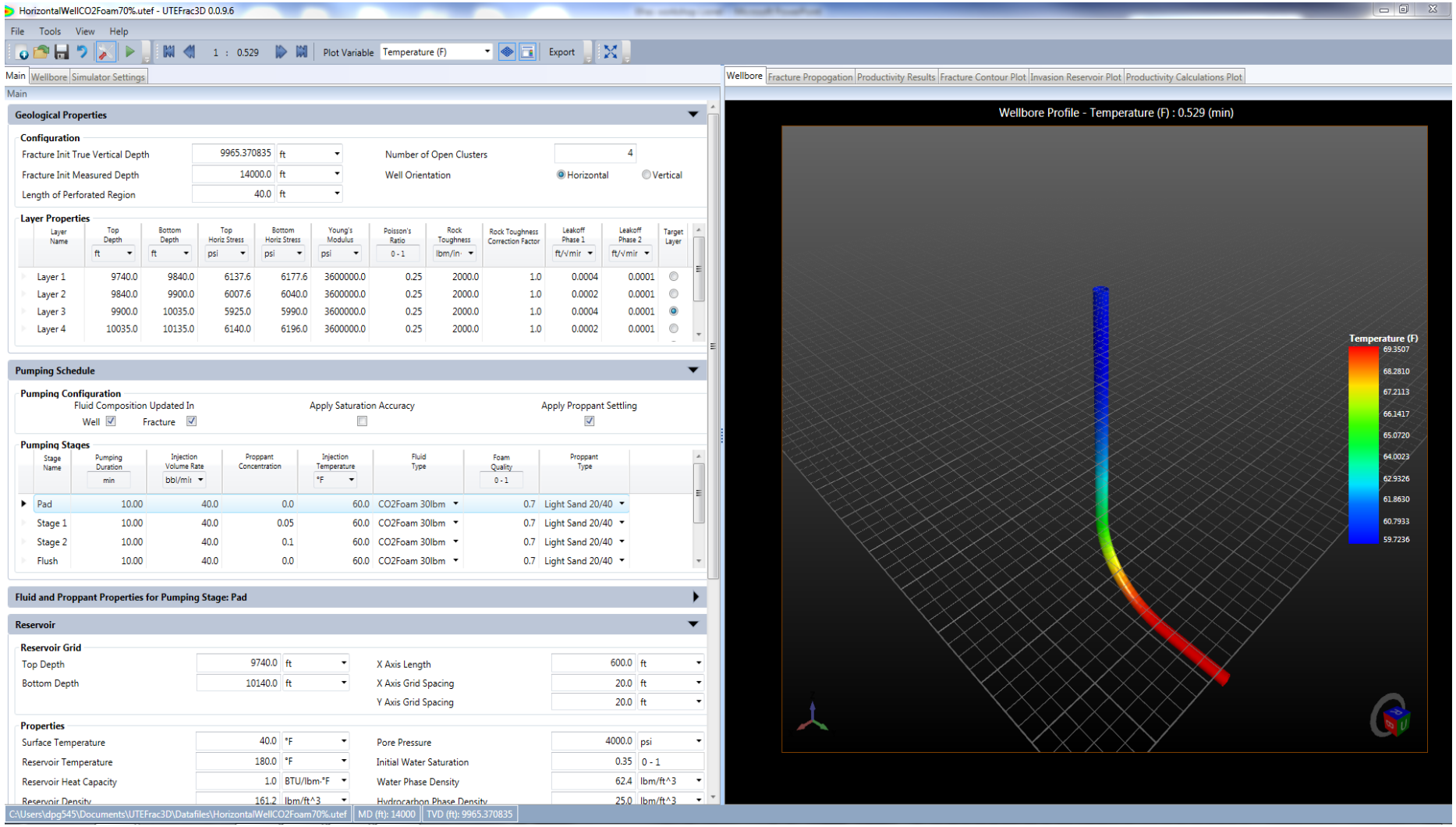
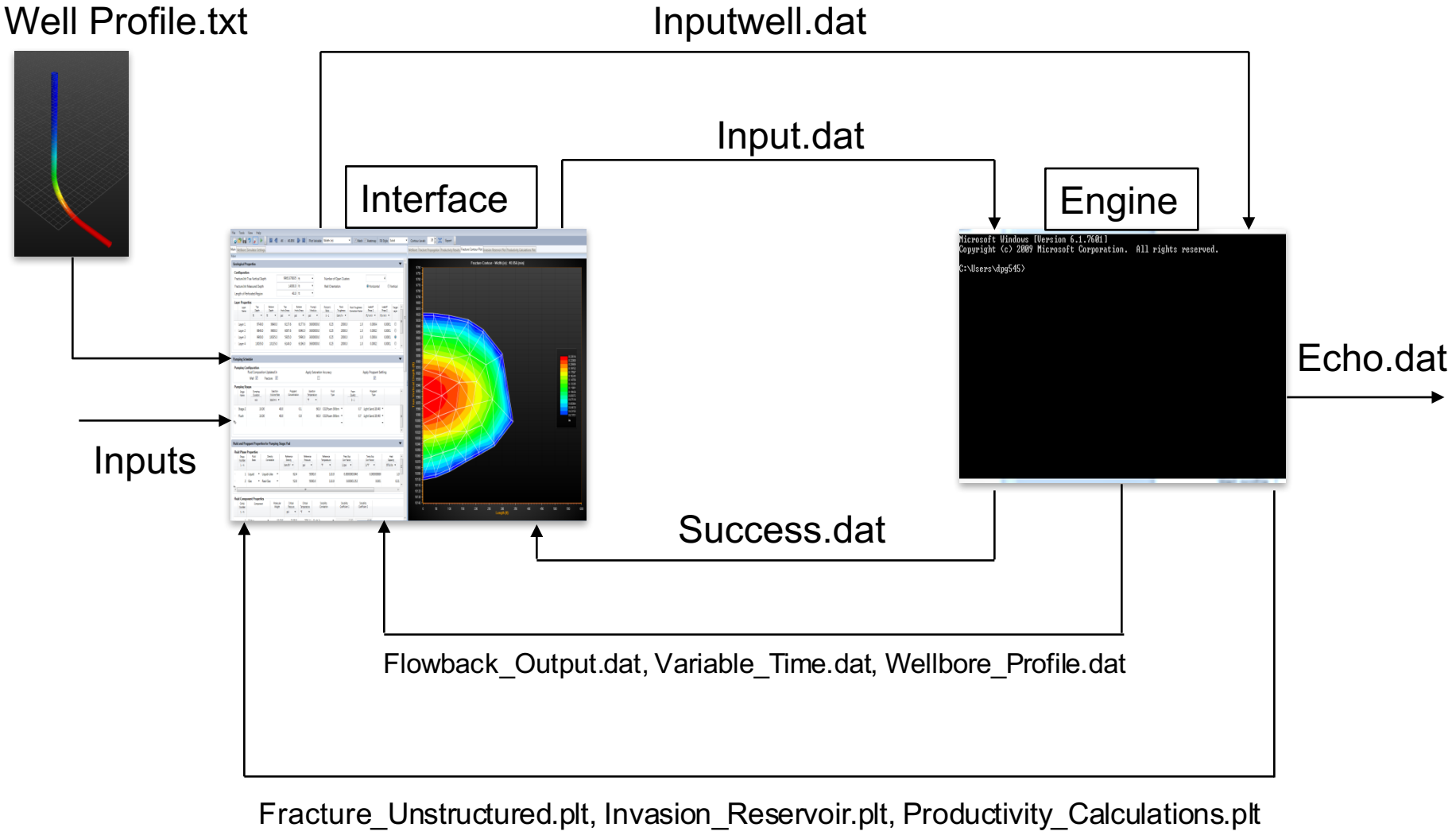
EFRAC-3D User Interface



EFRAC-3D Working Scheme



Creating Wellbore Profile

Steps:

- Text document format (.txt)
- Consists of 4 columns
- Only first (MD in ft), second (inclination angle in degrees) and last column (TVD in ft) are useful.
- Entries in third column not used in calculations
- The first row should have non-zero MD and TVD
- Save it in C:\Users\Documents\UTEFrac3D\ImportFiles

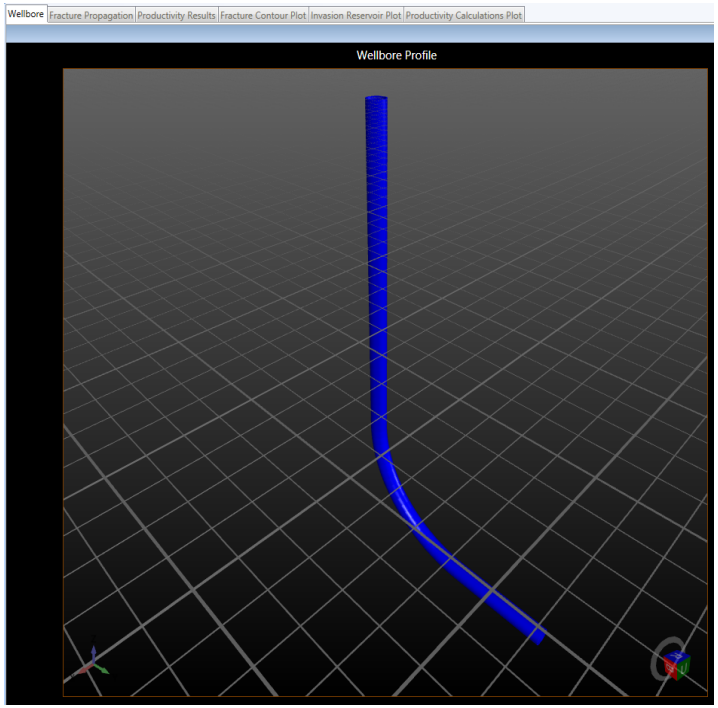
Sample vertical and horizontal wellbore profiles can be found at: C:\Users\Documents\UTEFrac3D\ImportFiles

200	0	0	200
400	0	0	400
600	0	0	600
800	0	0	800
1000	0	0	1000
1200	0	0	1200
1400	0	0	1400
1600	0	0	1600
1800	0	0	1800
2000	0	0	2000
2200	0	0	2200
2400	0	0	2400
2600	0	0	2600
2800	0	0	2800
3000	0	0	3000
3200	0	0	3200
3400	0	0	3400
3600	0	0	3600
3800	0	0	3800
4000	0	0	4000
4200	0	0	4200
4400	0	0	4400
4600	0	0	4600
4800	0	0	4800
5000	0	0	5000
5200	0	0	5200
5400	0	0	5400
5600	0	0	5600
5800	0	0	5800
6000	0	0	6000
6200	0	0	6200
6400	0	0	6400
6600	0	0	6600
6800	0	0	6800
7000	0	0	7000
7200	0	0	7200
7400	4	0	7399.51281
7600	8	0	7597.566424
7800	12	0	7793.195944

Uploading Wellbore Profile

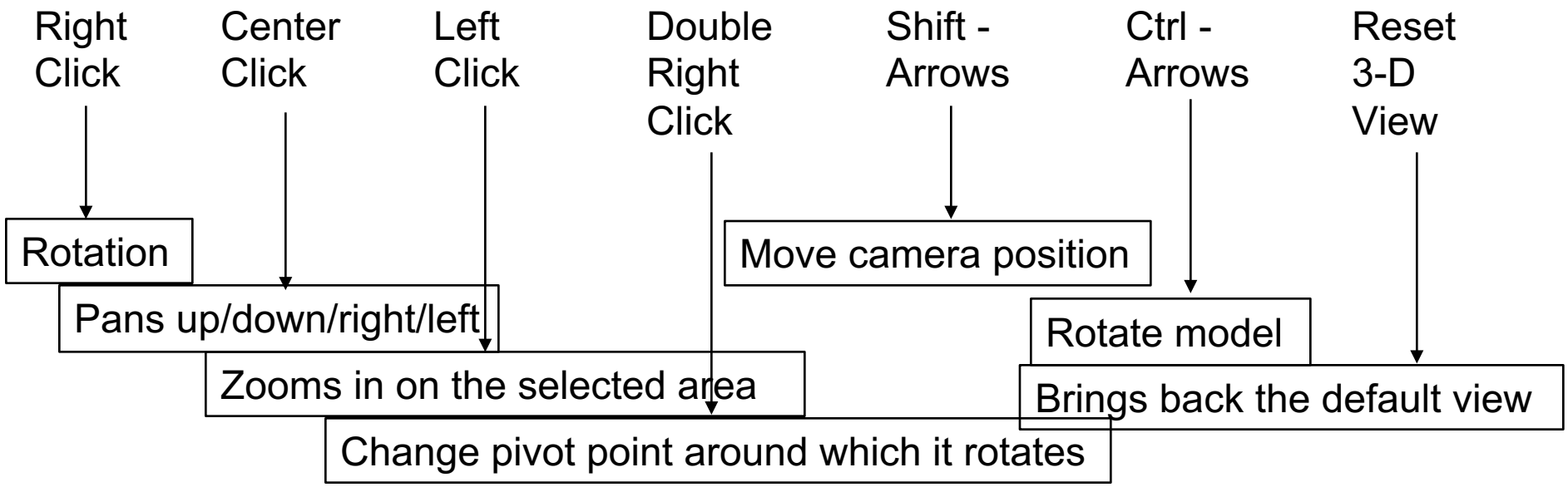
Steps:

- Go to File
- Click on “Import Wellbore Profile”
- Upload the file from C:\Users\Documents\UTEFrac3D\ImportFiles
- The wellbore appears in the Wellbore tab on right hand side of the interface



Wellbore Profile

Display Options:



Fluid and Proppant Library

Fluid Library

1. Slick Water
2. Linear Gelled
3. Cross-Linked Gelled
4. LPG gelled
5. CO_2 Foams (30% and 70%) Quality
6. N_2 Foams (30% and 70%) Quality
7. CO_2 gelled
8. Binary Foams
9. Mixed Fluids (CO_2 + gelled water)

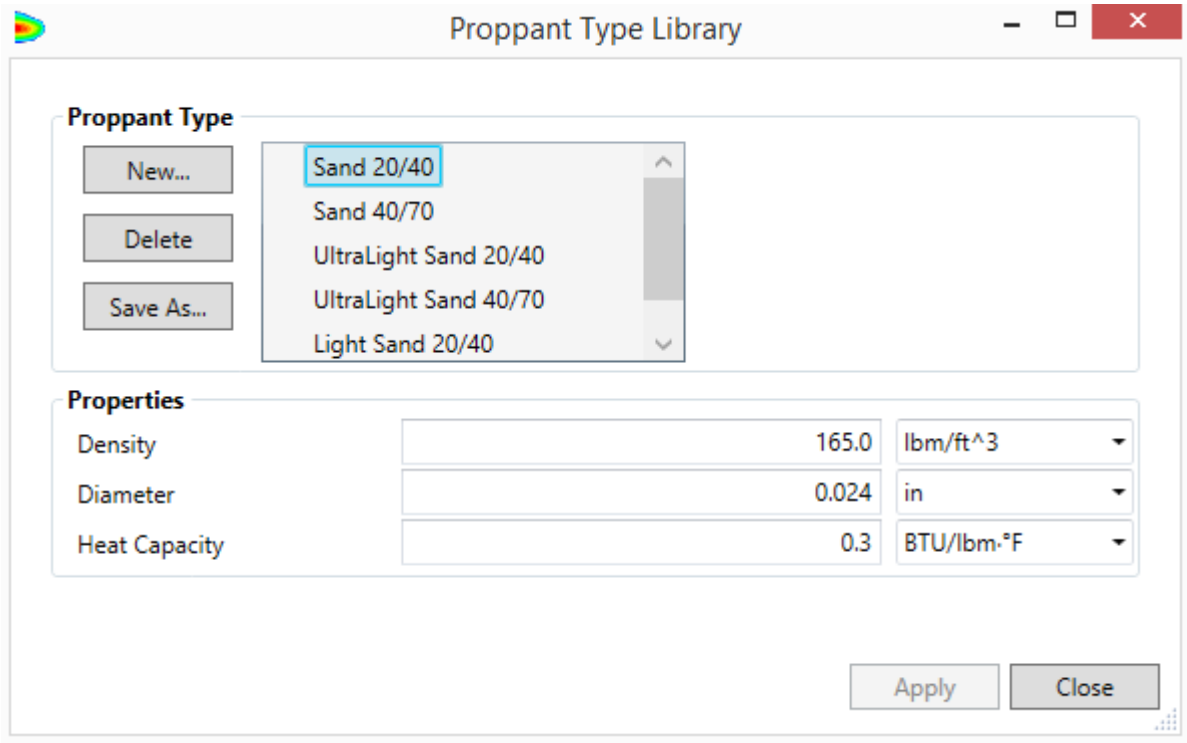
Proppant Library

1. Sand 20/40
2. Sand 40/70

Steps:

- Go to Tools
- Select Libraries
- Click on Fluid or Proppant Types

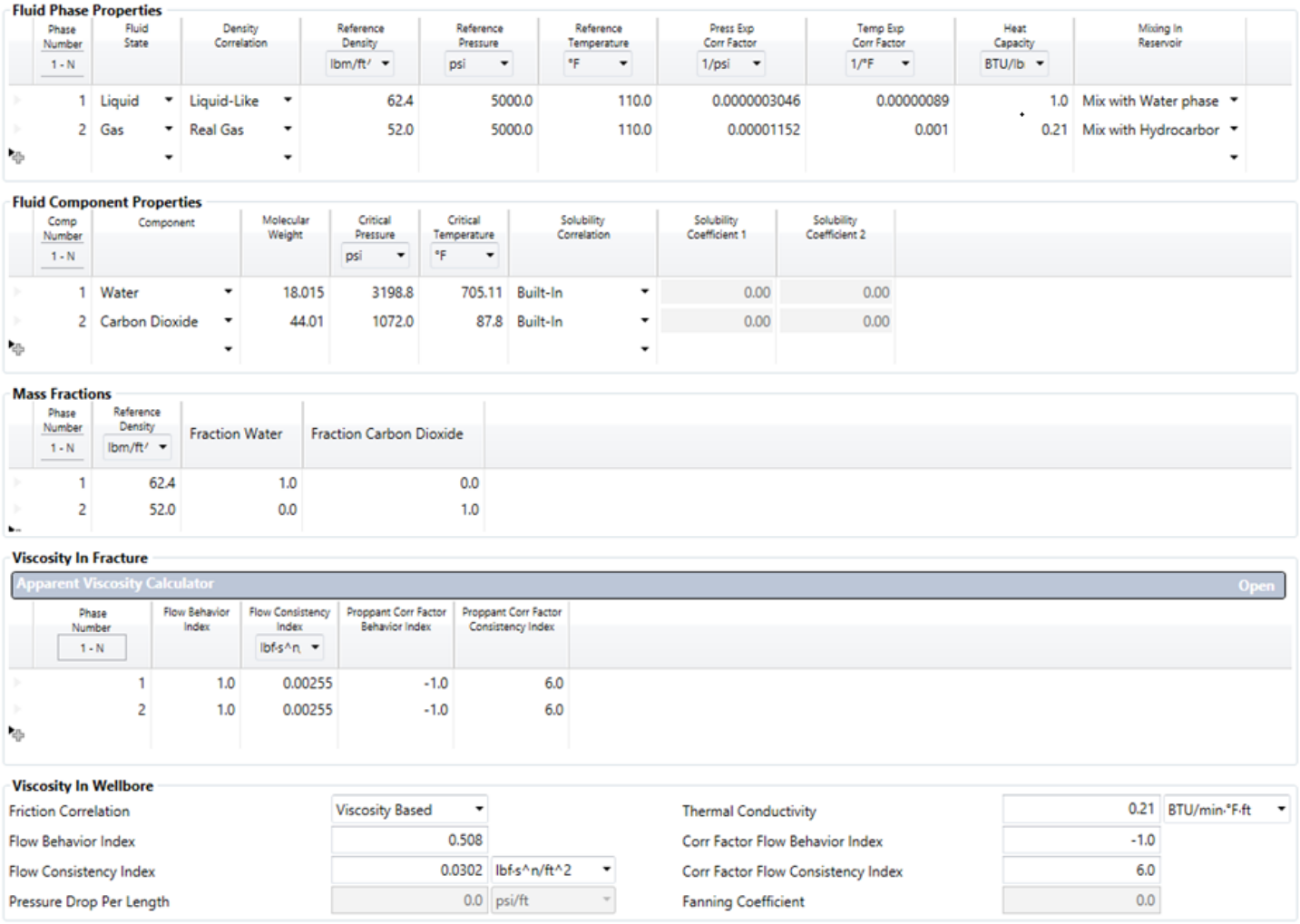
Proppant Library



Properties:

- Density of proppant
- Diameter of proppant
- Heat Capacity

Fluid Library



Fluid Phase Properties

Phase Number (1 - N)	Fluid State	Density Correlation	Reference Density (lbm/ft³)	Reference Pressure (psi)	Reference Temperature (°F)	Press Exp Corr Factor (1/psi)	Temp Exp Corr Factor (1/°F)	Heat Capacity (BTU/lb)	Mixing In Reservoir
1	Liquid	Liquid-Like	62.4	5000.0	110.0	0.0000003046	0.00000089	1.0	Mix with Water phase
2	Gas	Real Gas	52.0	5000.0	110.0	0.00001152	0.001	0.21	Mix with Hydrocarbor

Fluid Component Properties

Comp Number (1 - N)	Component	Molecular Weight	Critical Pressure (psi)	Critical Temperature (°F)	Solubility Correlation	Solubility Coefficient 1	Solubility Coefficient 2
1	Water	18.015	3198.8	705.11	Built-In	0.00	0.00
2	Carbon Dioxide	44.01	1072.0	87.8	Built-In	0.00	0.00

Mass Fractions

Phase Number (1 - N)	Reference Density (lbm/ft³)	Fraction Water	Fraction Carbon Dioxide
1	62.4	1.0	0.0
2	52.0	0.0	1.0

Viscosity In Fracture

Apparent Viscosity Calculator — Open

Phase Number (1 - N)	Flow Behavior Index	Flow Consistency Index (lbf·s^n/ft²)	Proppant Corr Factor Behavior Index	Proppant Corr Factor Consistency Index
1	1.0	0.00255	-1.0	6.0
2	1.0	0.00255	-1.0	6.0

Viscosity In Wellbore

Friction Correlation	Viscosity Based	Thermal Conductivity	0.21 BTU/min·°F·ft
Flow Behavior Index	0.508	Corr Factor Flow Behavior Index	-1.0
Flow Consistency Index	0.0302 lbf·s^n/ft^2	Corr Factor Flow Consistency Index	6.0
Pressure Drop Per Length	0.0 psi/ft	Fanning Coefficient	0.0

Fluid Properties

Density Calculations

$$\rho(P,T) = \rho_0(P_0,T_0) \times e^{[-\alpha_T(T-T_0)]} \times e^{[\beta_P(P-P_0)]}$$

ρ_0 - Reference Density
P_0 - Reference Pressure
T_0 - Reference Temperature
α_T - Temp Exp Corr Factor
β_P - Press Exp Corr factor

Solubility Calculations

$$x_{i,sol} = \beta(T)\frac{\alpha(T)P}{1+\alpha(T)P} \quad \text{and} \quad x_i = \frac{x_{i,sol}}{100 + x_{i,sol}}$$

$\alpha(T)$ - Solubility Coefficient 1
$\beta(T)$ - Solubility Coefficient 2

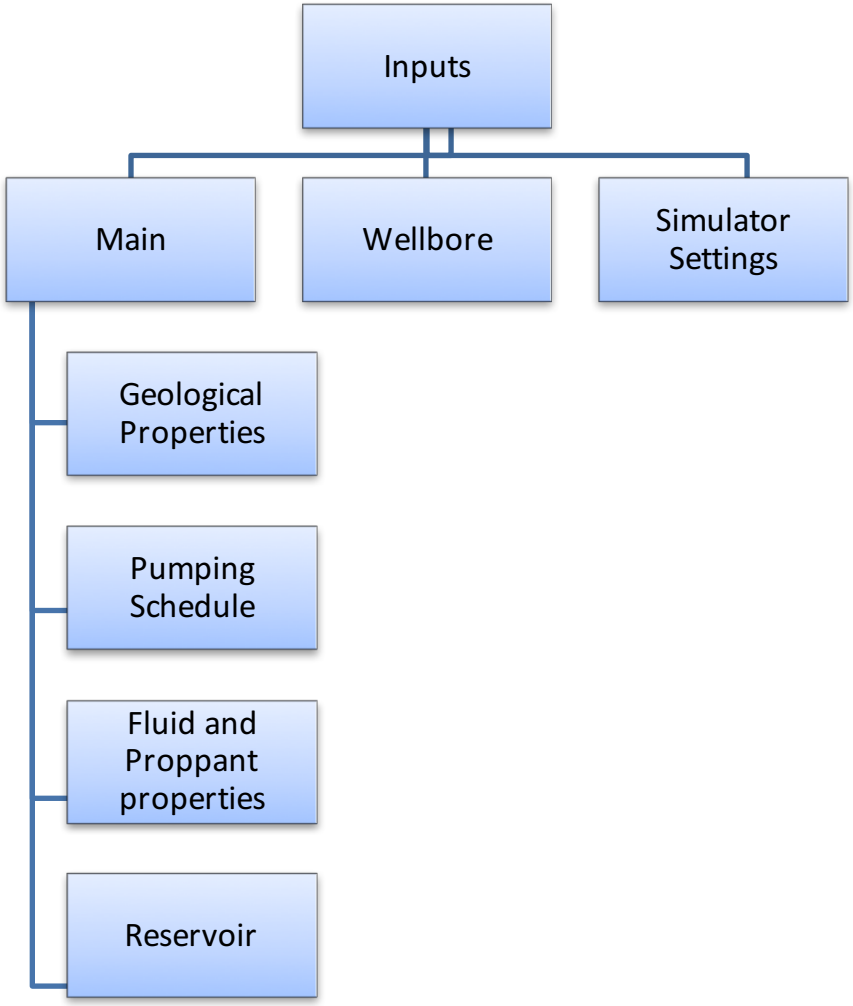
Viscosity Calculations

$$\mu_{eff} = K\left(\frac{du}{dy}\right)^{n-1}$$

$$\begin{cases} n_{prop} = n_{fluid}\exp(n_c \times c) \\ K_{prop} = K_{fluid}\exp(k_c \times c) \end{cases}$$

n_{fluid} - Flow Behavior Index
K_{fluid} - Flow Consistency Index
n_c - Proppant Corr Factor Behavior Index
k_c - Proppant Corr Factor Consistency Index
$\frac{du}{dy}$ - shear rate

Inputs


Inputs
Main
Wellbore
Simulator Settings
Geological Properties
Pumping Schedule
Fluid and Proppant properties
Reservoir

Geological Properties

Geological Properties

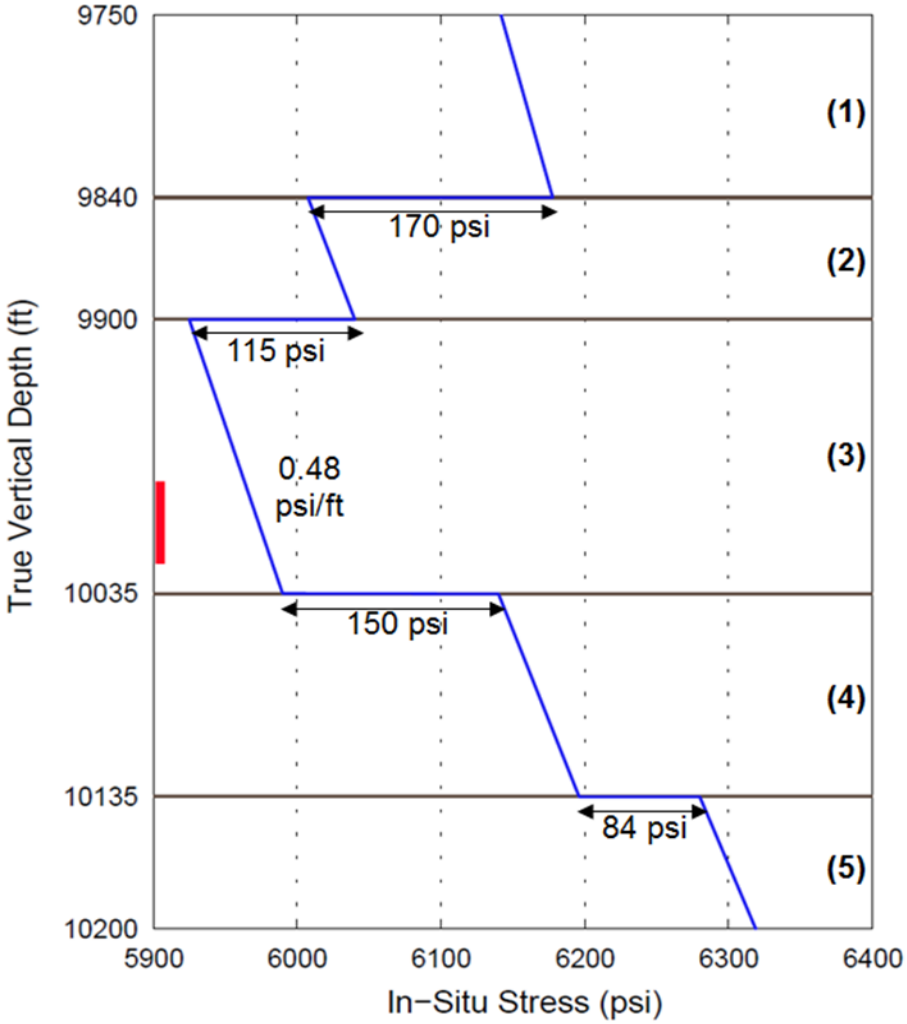
Configuration

Fracture Init True Vertical Depth	10000.0	ft	Number of Open Clusters	1	
Fracture Init Measured Depth	10000.0	ft	Well Orientation	○ Horizontal	◉ Vertical
Length of Perforated Region	40.0	ft			

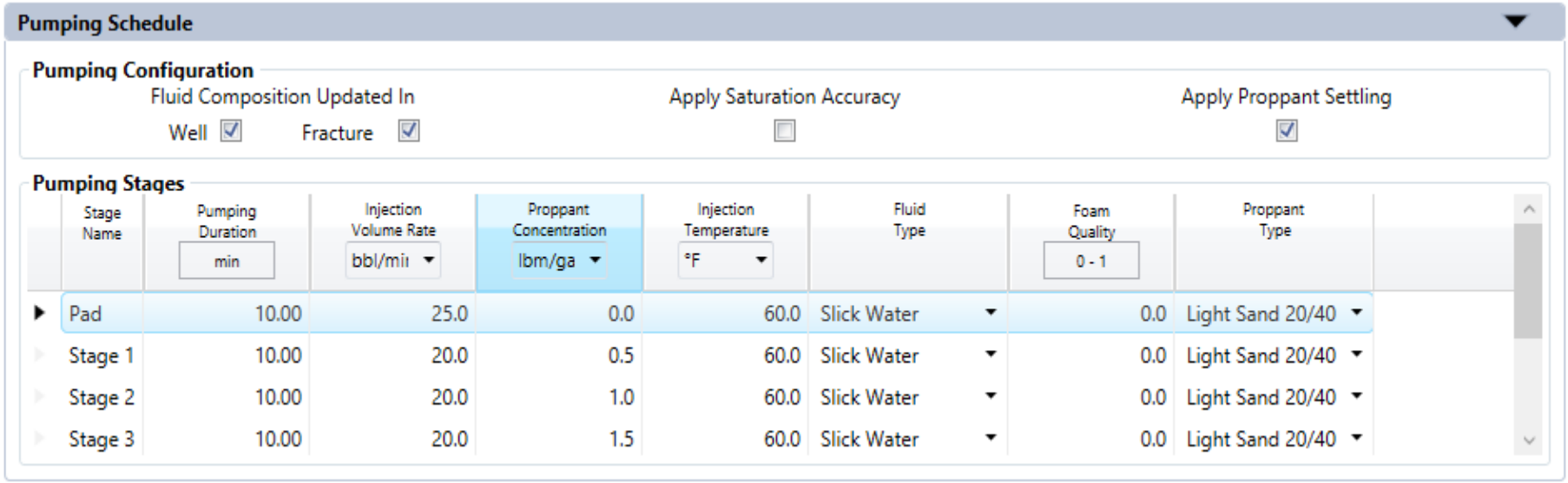
Layer Properties

Layer Name	Top Depth (ft)	Bottom Depth (ft)	Top Horiz Stress (psi)	Bottom Horiz Stress (psi)	Young's Modulus (psi)	Poisson's Ratio (0 - 1)	Rock Toughness (lbm/in·)	Rock Toughness Correction Factor	Leakoff Phase 1 (ft/√min)	Leakoff Phase 2 (ft/√min)	Target Layer
Layer 1	9740.0	9840.0	6137.6	6177.6	3600000.0	0.25	2000.0	1.0	0.0008	0.0	○
Layer 2	9840.0	9900.0	6007.6	6040.0	3600000.0	0.25	2000.0	1.0	0.0008	0.0	○
Layer 3	9900.0	10035.0	5925.0	5990.0	3600000.0	0.25	2000.0	1.0	0.0016	0.0	◉
Layer 4	10035.0	10135.0	6140.0	6196.0	3600000.0	0.25	2000.0	1.0	0.0008	0.0	○

Geological Properties



Pumping Schedule



Pumping Schedule

Pumping Configuration

Fluid Composition Updated In — Well ☑ Fracture ☑

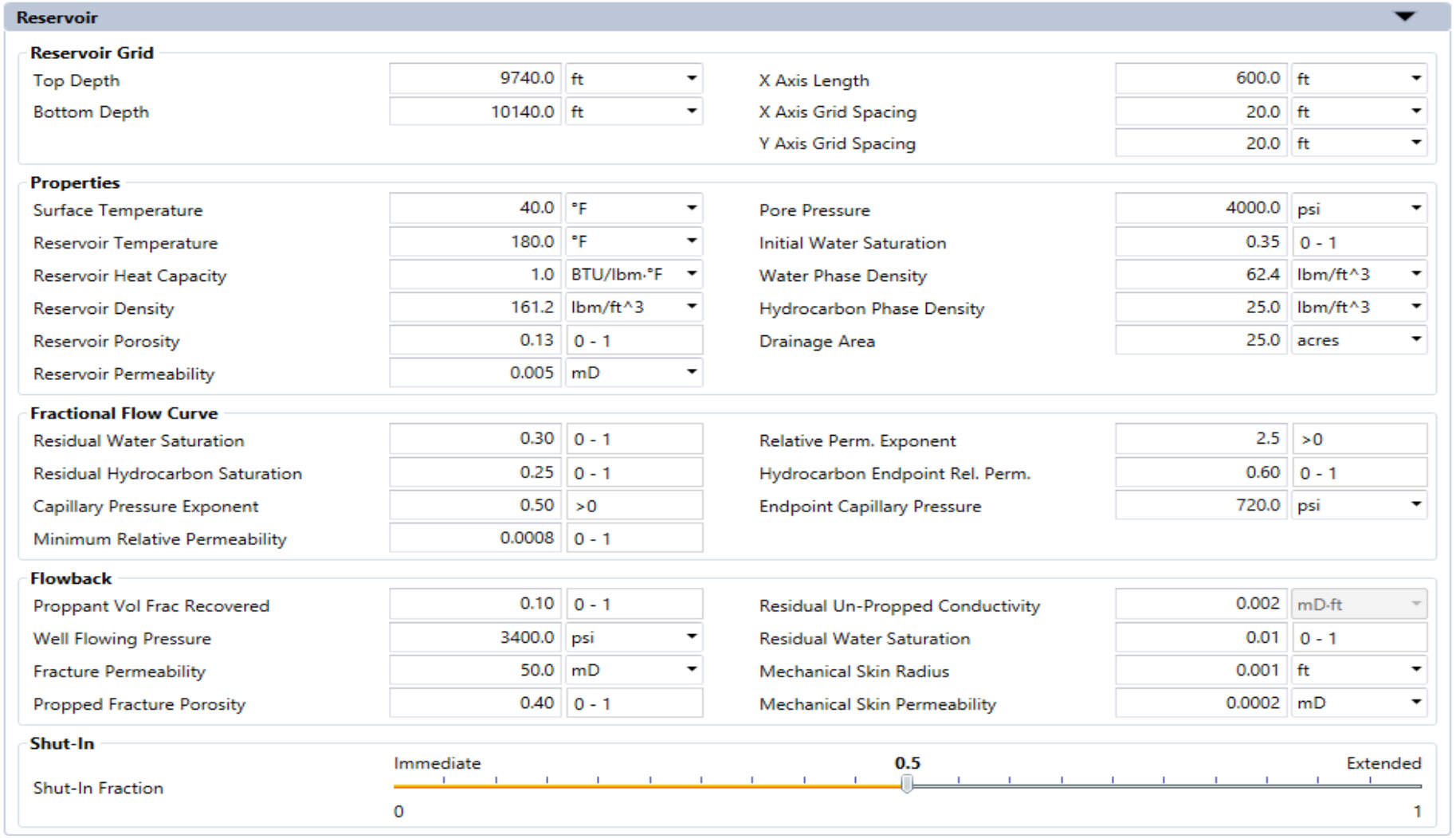
Apply Saturation Accuracy ☐

Apply Proppant Settling ☑

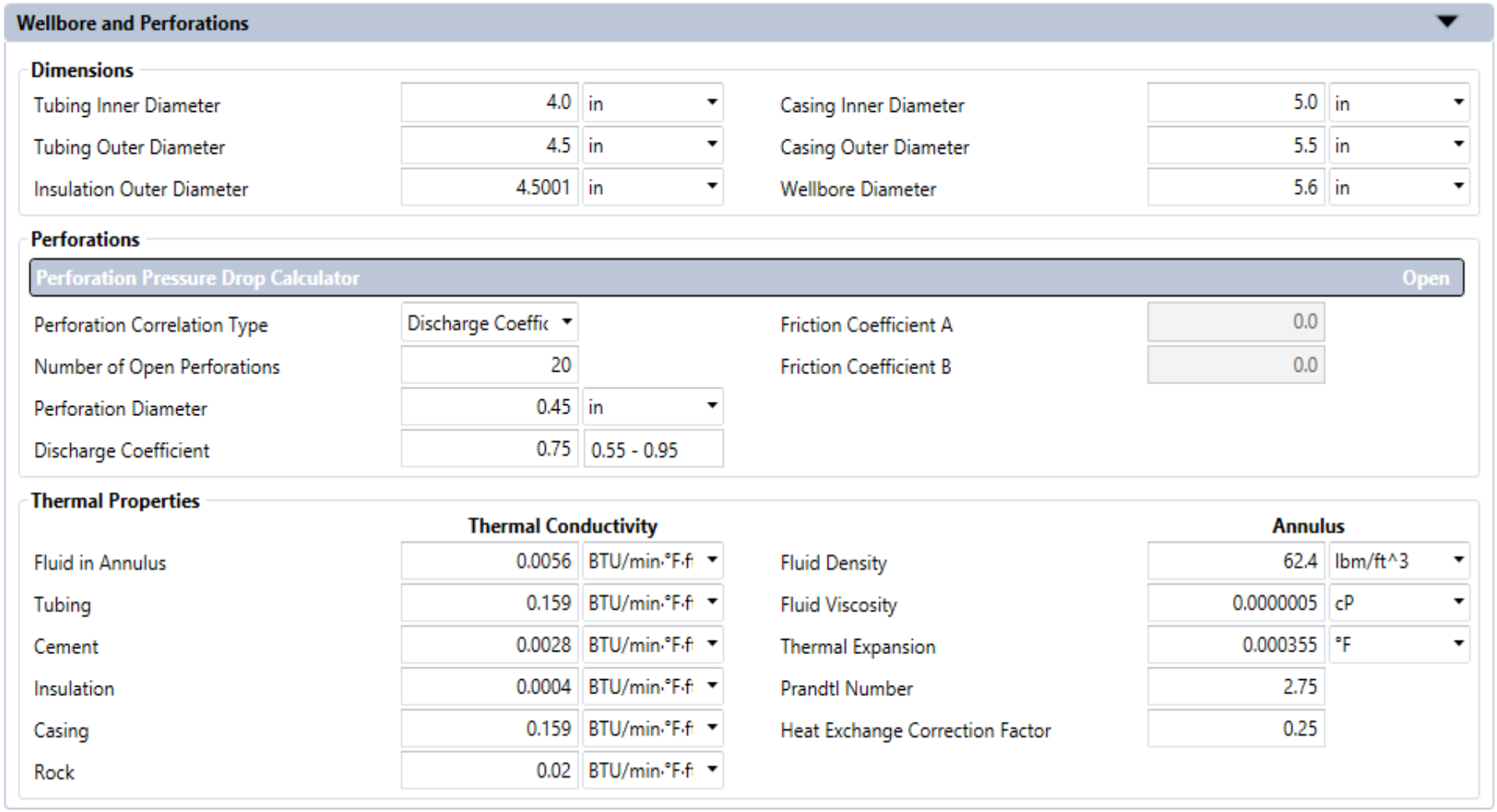
Pumping Stages

Stage Name	Pumping Duration (min)	Injection Volume Rate (bbl/mi)	Proppant Concentration (lbm/ga)	Injection Temperature (°F)	Fluid Type	Foam Quality (0 - 1)	Proppant Type
Pad	10.00	25.0	0.0	60.0	Slick Water	0.0	Light Sand 20/40
Stage 1	10.00	20.0	0.5	60.0	Slick Water	0.0	Light Sand 20/40
Stage 2	10.00	20.0	1.0	60.0	Slick Water	0.0	Light Sand 20/40
Stage 3	10.00	20.0	1.5	60.0	Slick Water	0.0	Light Sand 20/40

Reservoir Properties



Wellbore



Wellbore and Perforations

Dimensions

Tubing Inner Diameter	4.0	in	Casing Inner Diameter	5.0	in
Tubing Outer Diameter	4.5	in	Casing Outer Diameter	5.5	in
Insulation Outer Diameter	4.5001	in	Wellbore Diameter	5.6	in

Perforations

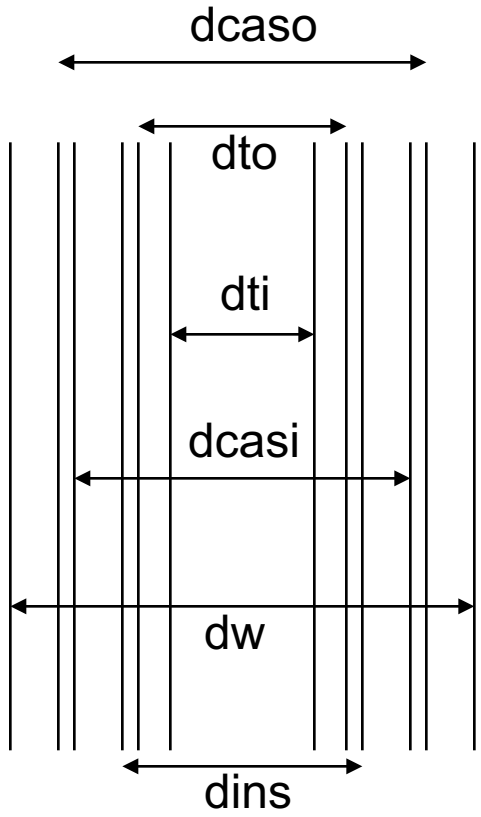
Perforation Pressure Drop Calculator — Open

Perforation Correlation Type	Discharge Coeffic		Friction Coefficient A	0.0	
Number of Open Perforations	20		Friction Coefficient B	0.0	
Perforation Diameter	0.45	in			
Discharge Coefficient	0.75	0.55 - 0.95			

Thermal Properties

	Thermal Conductivity			Annulus	
Fluid in Annulus	0.0056	BTU/min·°F·f	Fluid Density	62.4	lbm/ft^3
Tubing	0.159	BTU/min·°F·f	Fluid Viscosity	0.0000005	cP
Cement	0.0028	BTU/min·°F·f	Thermal Expansion	0.000355	°F
Insulation	0.0004	BTU/min·°F·f	Prandtl Number	2.75	
Casing	0.159	BTU/min·°F·f	Heat Exchange Correction Factor	0.25	
Rock	0.02	BTU/min·°F·f			

Wellbore Dimensions



Tubing Inner diameter (d_{ti})

Tubing Outer diameter (dto)

Insulation Outer diameter (dins)

Casing Inner diameter (dcasi)

Casing Outer diameter (dcaso)

Wellbore diameter (dw)

Perforation Pressure Drop

Direct Correlation

$$\Delta P_{perf} = a_{perf} q^{b_{perf}}$$

a_{perf} - Friction Coefficient A
b_{perf} - Friction Coefficient B
q – Fluid Flow Rate

Discharge Coefficient

$$\Delta P_{perf} = 0.2369 \frac{\rho q^2}{d_{perf}^4 N^2 C_{disc}^2}$$

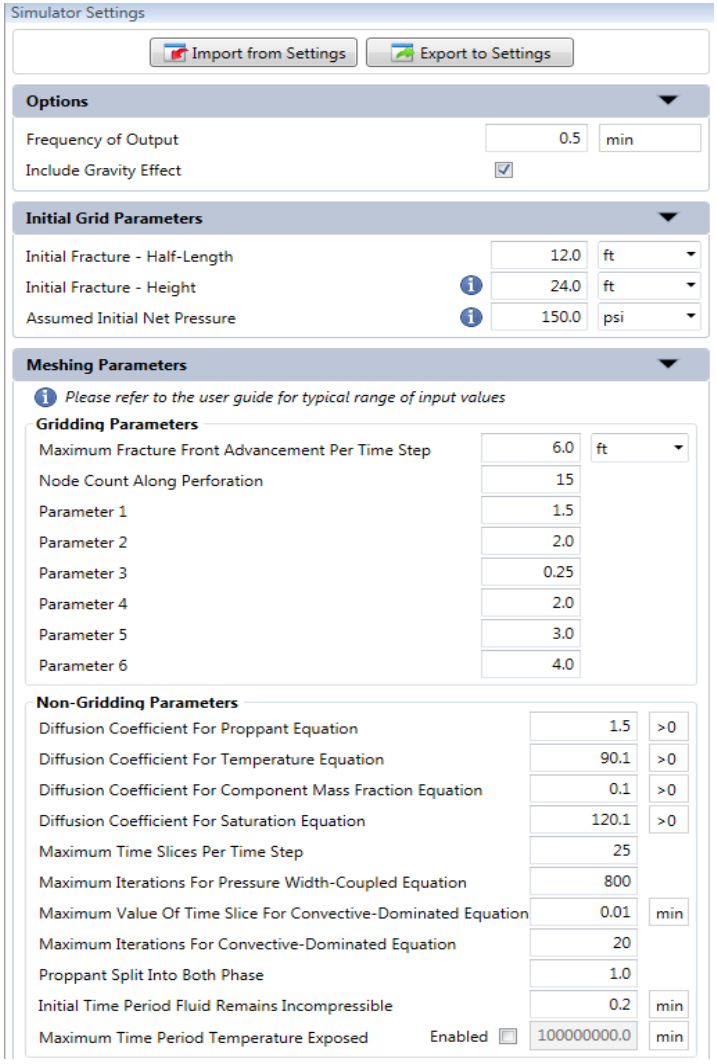
d_{perf} - Perforation Diameter
N – Number of Open Perforations
C_{disc} - Discharge Coefficient
ρ – Fluid Density
q – Fluid Flow Rate

Sand Erosion

$$C_{disc} = \min\left(0.56 + 1.65 \times 10^{-4} m_{sand,cum}; 0.95\right)$$

$m_{sand,cum}$ is the cumulative amount of proppant (sand) pumped through the wellbore.
It is calculated directly by the code.

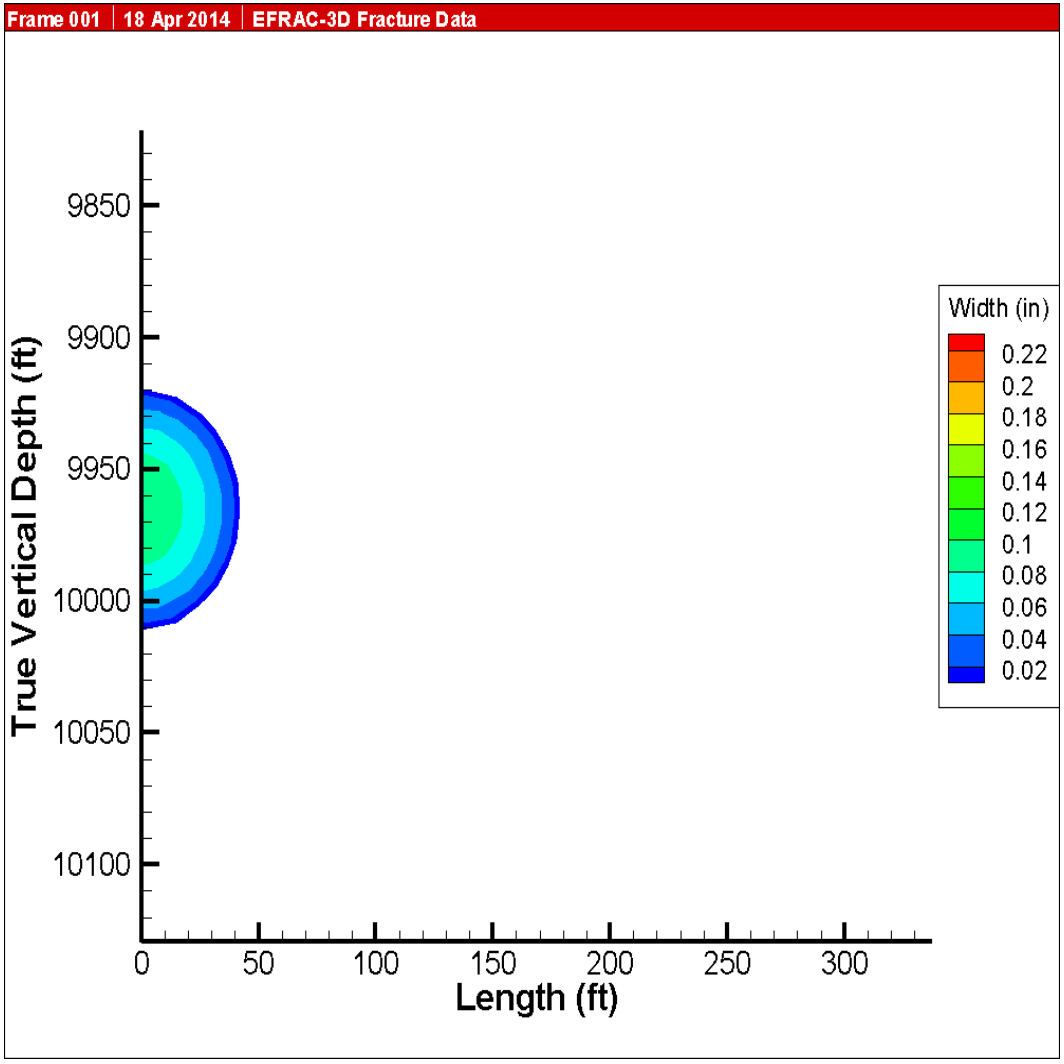
Inputs – Simulator Settings



Results / Outputs

1. Wellbore ⟷ Wellbore_Profile.dat
2. Fracture Contour Plot ⟷ Fracture_Unstructured.plt
3. Fracture Propagation ⟷ Variable_Time.dat
4. Invasion Reservoir Plot ⟷ Invasion_Reservoir.plt
5. Productivity Calculations Plot ⟷ Productivity_Calculations.plt
6. Productivity Results ⟷ Flowback_Output.dat

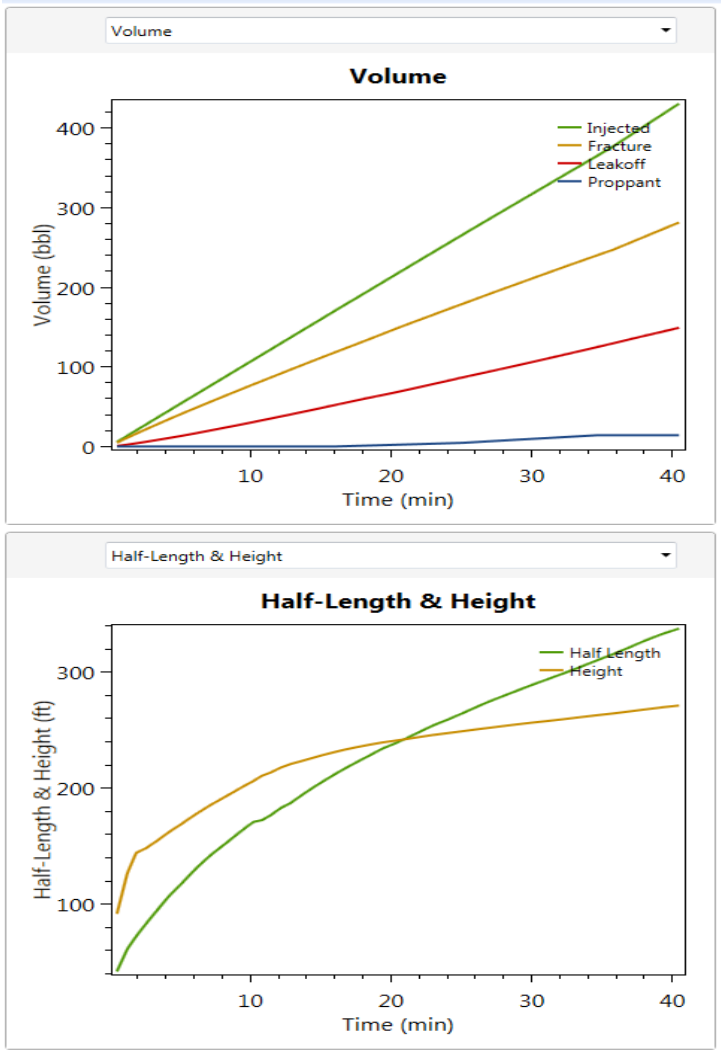
Results/Output – Fracture Contour Plots



Plot Variables:

- Width
- Net Pressure
- Volumetric proppant concentration
- Proppant mass per area
- Temperature
- Fluid Pressure
- Density of phases, slurry
- Saturation of phases
- Proppant concentration
- Component mass fractions

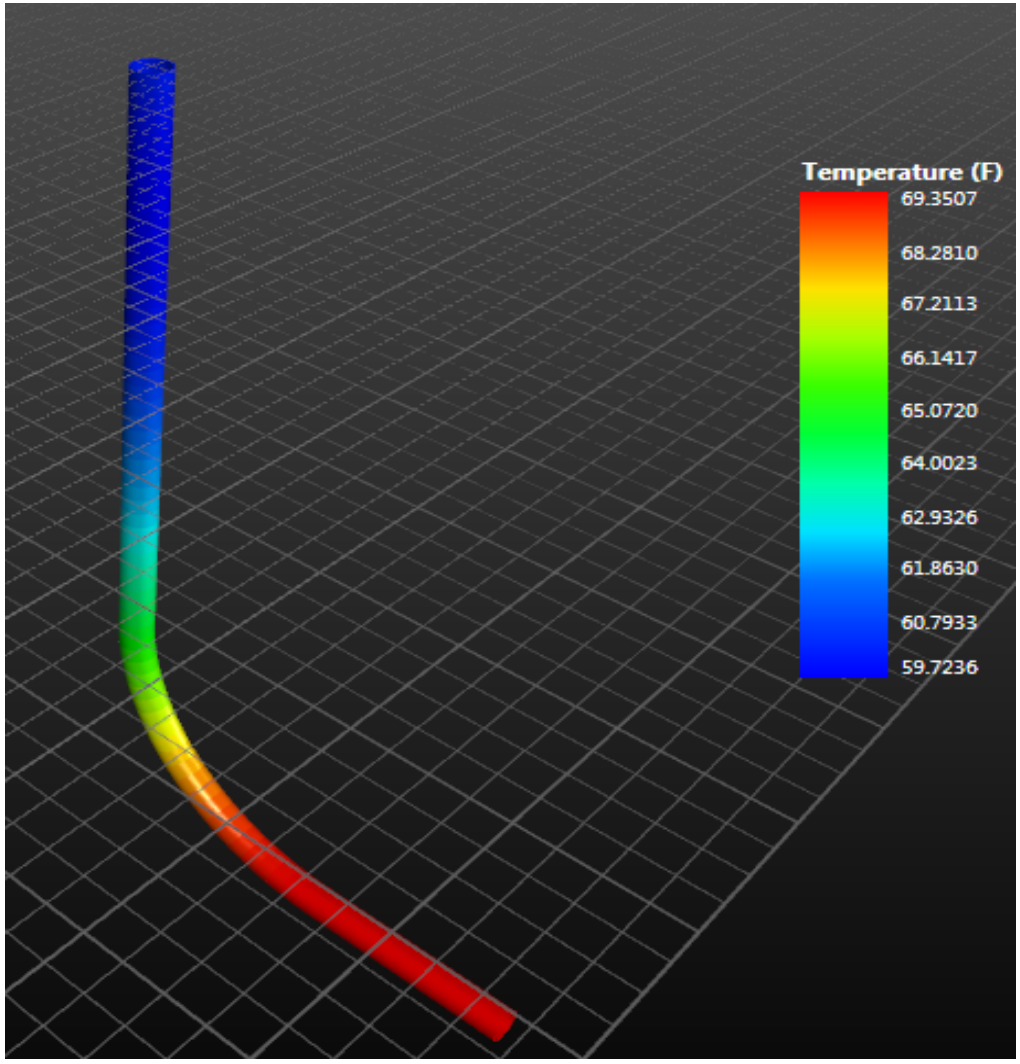
Results/Output – Fracture Propagation Plots



Plot Variables:

- Half-length and Height
- Average and Maximum Width
- Net Pressure
- Pressure Drop in fracture and Perforation
- Pressure at perforation, bottomhole and surface
- Temperature at bottomhole and surface
- TVD below and above injection
- Volume (injected, fracture, leak-off and proppant)
- Efficiency
- Cumulative mass of each components and proppant
- Injection rates of each phase and proppant in fracture and at surface
- Proppant Concentration in fracture and at surface
- Saturation in fracture and at surface

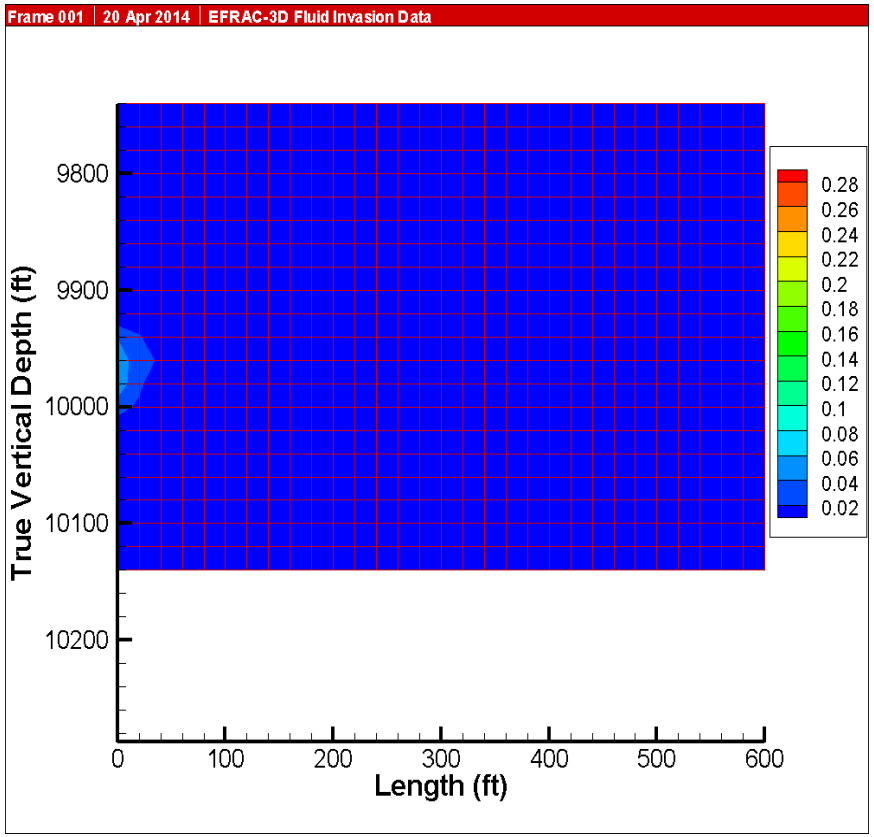
Results/Output - Wellbore



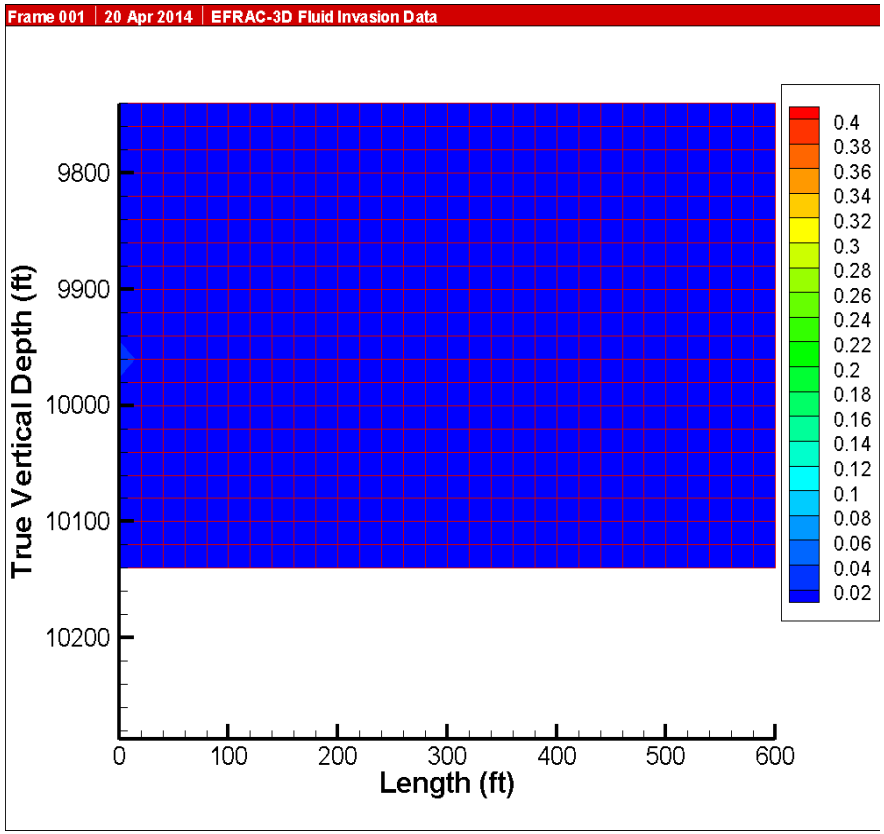
Plot Variables:

- Temperature
- Pressure
- Density of phases, slurry
- Saturation of phases
- Proppant concentration
- Velocity
- Reynolds Number
- Viscosity
- Pressure Drop
- Component mass fractions

Results/Output – Invasion Reservoir Plot

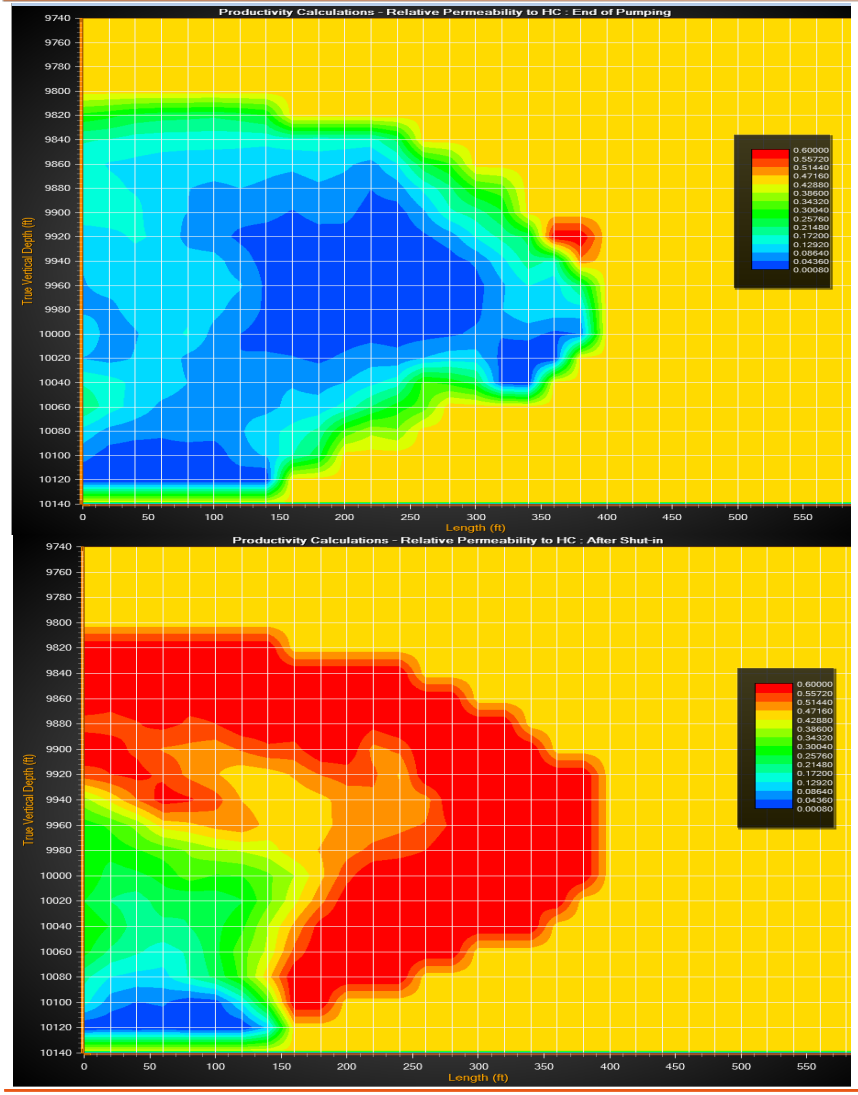


Mass Leak-off of Water (lbm/ft^2)



Mass Leak-off of CO_2 (lbm/ft^2)

Results/Output – Productivity Calculations



Plot Variables:

- Width
- Pressure
- Mass Invasion in Water and HC phases
- Water and HC saturation
- Relative Permeability to HC
- Invaded Zone Length

Time Options:

- Initial
- End of Pumping
- After Shut-In
- Flowback

Results/Output – Productivity Results

Main Results

Length *	Height Correction *	Width (in)	Invaded Zone Length (ft)	Conductivity *	Relative Permeability *	Invaded Zone Length *	Productivity Index *
0.679	0.967	0.03382	0.072	0.09457	0.4797	25.402	2.304

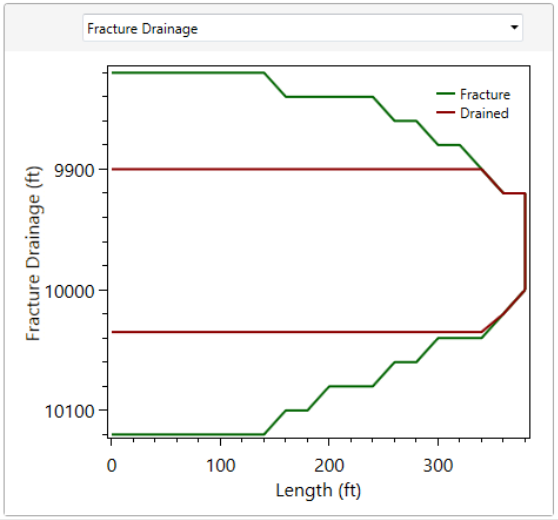
* Denotes a dimensionless property

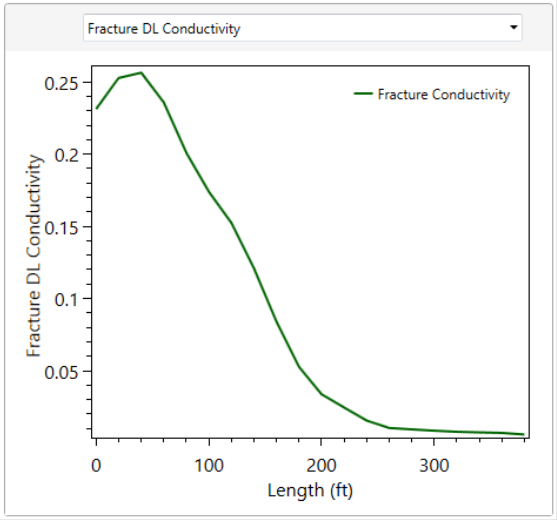
Proppant

Pumped (lbm)	Placed (lbm)	Recovered (lbm)
24697	22227	2470

Water

Pumped (lbm)	Leaked (lbm)
37238	34679





Plot Variables:

- Fracture Drainage
- Fracture DL Conductivity
- Conductive Width
- Invaded Zone Length
- Relative Permeability
- Invaded Zone Saturation
- Height

Thank You

Questions or Comments?

Backup Slides

Reservoir Inputs

Fractional Flow Curve

$$\frac{k_d}{k} = k_{rnwo}\left(1 - \frac{(1 - S_{wr})\left(\frac{\Delta P}{P_c{}^o}\right)^{-b}}{1 - S_{nwr} - S_{wr}}\right)^n$$

Swr – residual water saturation
Snwr – residual hydrocarbon saturation
krnwo – hydrocarbon endpoint relative permeability
b – capillary pressure exponent
n – relative permeability exponent
Pc^o – endpoint capillary pressure

