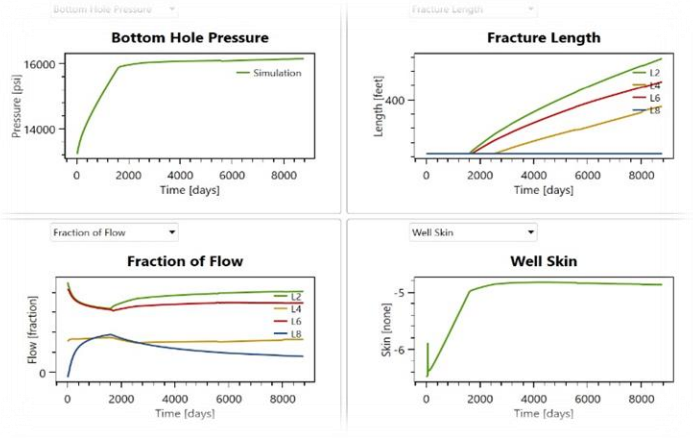
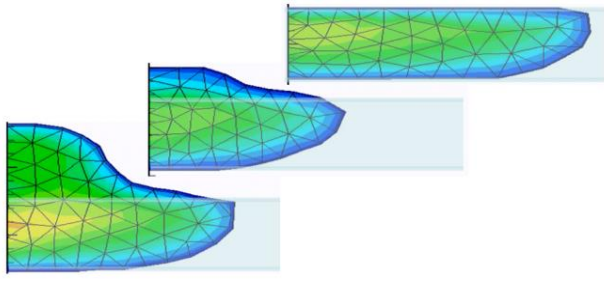
WID

Water Injectivity Decline Simulator

User Guide





- ✓ 2-D and 3-D Induced Fracture Propagation Simulation
- ✓ Injectivity, Fraction of Flow in Vertical & Horizontal Injectors
- ✓ Comprehensive Filtration Physics for Injection Wells
- ✓ History Match Injection Well Performance

Last updated February 14, 2018 for WID3D 18.01

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Chapter 1: What is WID?

1.1 About this Version

WID is a PC-based simulator to predict and monitor injection well performance (well injectivity and induced fracture growth) in water/polymer injection wells from inception to abandonment.

1.2 Current Capabilites

The current version has the following features/modeling capabilities:

1.2.3 Vertical Wells

WID can model the injectivity and induced fracture growth in vertical injection wells. The vertical wells in WID can have the following options – 1) open-hole (with or without a hydraulic fracture), 2) cased-hole and perforated (with or without a hydraulic fracture) and 3) frac-packed injector with detailed plugging of the gravel in the frac-pack and widening of the frac-pack. However, this more comprehensive option for frac-packed injectors does not allow any lengthening of the frac-pack. For vertical wells, 3D fracture growth can also be modelled for evaluating height containment issues.

Model Description Summary: The model is capable of handling injection into non-communicating multi-layered reservoirs. The present version has the capability to model thermally and hydraulically induced fractures (with asymmetric growth of the fracture in case of a dipping reservoir) around a single, vertical or horizontal well. The model predicts the initiation and growth of a two-winged fracture in the near wellbore region due to the combined influence of injection pressure, pore pressure and thermal stresses due to the injection of cold water, and an additional pressure increase due to well and fracture face plugging. The modeling of fracture initiation and propagation is based on the PKN model (Perkins and Gonzalez, 1985). The fracture face plugging due to particle filtration and the resulting filter-cake build-up on the fracture face are modeled using filtration theory (Rajagopalan and Tien, 1976; Wennberg and Sharma, 1997). Fracture growth and fracture face plugging are modeled as dynamically coupled phenomena, with the continuously growing fracture face area being plugged with the influx of injected particles.

1.2.2 Horizontal Wells

WID can model the injectivity and induced fracture growth in horizontal injection wells. The horizontal wells can be open-hole or cased-hole with perforations. A model similar to that proposed by Joshi (1988) is used to estimate the injectivity. In this model, the 3-dimensional flow is divided into two 1-dimensional flows. The induced fracture growth can have two orientations:

- Transverse
- Longitudinal

1.3 Injectivity Calculation

WID determines how the injectivity in an injection well changes with time as a result of 1) plugging due to particles present in the injection water, and 2) mobility changes in the reservoir. The simulator utilizes the following steps to accomplish this:

- Determine the concentration of deposited particles around the well as a function of time and distance from the well, (by solving the filtration equations in that region).
- Calculate the transition time, i.e. the time where an external cake starts building on the wellbore. Prior to the transition time, only internal filtration is considered (reduction of formation permeability). After the transition time is reached, only external cake build-up is considered.
- Calculate the reduced permeability of the near-well zone or the near fracture zone due to deposited particles.
- Determine how this near-well damage changes the injectivity of the well by calculating the additional pressure drop due to this region.
- Calculate the change in minimum horizontal stress due to thermal stresses and pore pressure changes as water at temperature T_1 is injected into a formation at temperature T_2.
- Iterate to calculate the length of the damaged fracture by properly accounting for fracture plugging and changes in the stress field.
- Calculate the distribution of flow and fracture growth in non- communicating multi-layered reservoirs with a vertical well.

1.4 Chapters overview

This manual, which focuses on the effective use of WID, is organized as follows:

WID: Software User Guide

Section 1 is the User Guide and describes how to run the WID software. The user's guide assumes that you have a general knowledge of the windows operating system.

- Chapter 2 covers the installation of WID.
- Chapter 3 is a quick tutorial on WID.
- Chapter 4 covers the common input variables.
- Chapter 5 discusses loading and saving of data
- Chapter 6 describes the units used in the simulator.

WID: Technical Documentation

Section 2 is the description of the mathematical models that are used to calculate the injectivity and fracture length. For a description of the underlying mathematical models, you can also refer to the key references listed below:

1.5 Key References

1. Sharma, M.M., Pang, S., Wennberg, K.E. “Injectivity Decline in Water Injection Wells: An Offshore Gulf of Mexico Case Study” SPE Production & Facilities, February 2000
2. Sharma, M.M., Wennberg, K.E. “Determination of the Dynamic Filtration Coefficient and transition time for Water Injection Wells”, SPE 38181 presented at the European Formation Damage Conference, The Hague, 1997.
3. Perkins, T.K. and Gonzalez, J.A. “The Effect of Thermoelastic Stresses on Injection Well Fracturing,” SPE Journal, February 1985, 78-88.
4. K. Prasad Saripalli, Phani B. Gadde, M. M. Sharma and S. L. Bryant (1999) “Role of Fracture Face and Formation Plugging in Injection Well Fracturing and Injectivity Decline”, SPE 52731 presented at the 1999 SPE/EPA Exploration and Production Environmental Conference, Austin, February 28 – March 3.
5. Pang, S. and Sharma, M.M.: “A Model for Predicting Injectivity Decline in Water-Injection Wells”, paper SPE 28489 presented at the 1994 SPE Annual Technical Conference and Exhibition, New Orleans.
6. Pang, S. and Sharma, M.M.: “Evaluating the Performance of Open-Hole, Perforated and Fractured Water Injection Wells”, paper SPE 30127 presented at the SPE European Formation Damage Control Conference, May 1995, The Hague.
7. Wennberg, K.E.: “Particle Retention in Porous Media”, Ph.D. dissertation, The Norwegian University of Science and Technology, Trondheim, 1998.
8. Rajagopalan, R. and Tien, C.: “Trajectory Analysis of Deep-Bed Filtration with Sphere- in-Cell Porous Media Model”, AICHE Journal, 1976.
9. Joshi, S.D., “Augmentation of Well Productivity with Slant and Horizontal Wells”, JPT 729-739, 1988.
10. Svendsen, A. P., et al.: “Thermally Induced Fracturing of Ula Water Injectors” SPE Production Engineering, November 1991.
11. Martins, J. P., et al.: “Long-Term Performance of Injection Wells at Prudhoe Bay: The Observed Effects of Thermal Fracturing and Produced Water Re-Injection” SPE 28936 presented at the SPE 69th ATCE held in New Orleans, LA, U.S.A., 25-28 September 1994.
12. Perkins, T. K. and Krech, W. W. “The Energy Balance Concept of Hydraulic Fracturing,” SPE Journal (March 1968) 1-12; Trans., AIME, 243.
13. Pang, S. and Sharma, M.M.: “Evaluating the Performance of Open-Hole, Perforated and Fractured Water Injection Wells”, paper SPE 30127 presented at the SPE European Formation Damage Control Conference, May 1995, The Hague.
14. McCarty, R.A. et al. 2006. The Resiliency of Frac-Packed Subsea Injection Wells. Paper SPE 102990 presented at the SPE ATCE, San Antonio, Texas, USA, 24-27 September.
15. Suárez-Rivera, R. et al. 2002. An Experimental Investigation of Fracture Propagation during Water Injection. Paper SPE 73740 presented at the SPE International Symposium and Exhibition on Formation Damage Control, Lafayette, Louisiana, 20–21 February.
16. Suri, A., Sharma, M.M. 2007. A Model for Water Injection into Frac-Packed Wells. Paper SPE 110084 presented at the SPE ATCE, Anaheim, California, U.S.A., 11–14 November.

17. Suri, A., Sharma, M.M. 2009. Fracture Growth in Horizontal Injectors. Paper SPE 119379 presented at the SPE HFTC, The Woodlands, Texas, U.S.A., 19–21 January.
18. Friehauf, K.E. et al. 2009. A Simple and Accurate Model for Productivity of Hydraulically Fractured Wells. Paper SPE 119264 presented at the SPE HFTC, The Woodlands, Texas, 19-21 January.
19. Iwasaki, I. 1937. Some Notes on Sand Filtration. Paper J. Am. Waterworks Assoc., 29 (10), 1591-1602. 12.
20. Schechter, R. S. 1992 Oil Well Stimulation. Pg. 262. Englewood Cliffs, New Jersey: Prentice-Hall.
21. Khatib, Z.I. 1994. Prediction of Formation Damage Due to Suspended Solids: Modeling Approach of Filter Cake Buildup in Injectors. Paper SPE 28488 presented at the 69th SPE ATCE, New Orleans, LA, USA, 25-28 September.
22. Perkins, T.K. and Kern, L.R. 1961. Widths of Hydraulic Fractures. SPE 89-PA.
23. Prats, M. 1960. Effect of Vertical Fractures on Reservoir Behavior – Incompressible Fluid Case. Paper SPE 1575-G presented at 35th Annual Fall Meeting, Denver, 2-5 October.
24. Saripalli, K.P., et al. 1999. Role of Fracture Face and Formation Plugging in Injection Well Fracturing and Injectivity Decline. Paper SPE 52731 presented at the SPE/EPA Exploration and Production Environmental Conference, Austin, February 28 – March 3.
25. Hwang, J., & Sharma, M. M. 2013. A 3-Dimensional Fracture Propagation Model for Long-Term Water Injection. Presented at the 47th U.S. Rock Mechanics/Geomechanics Symposium, 23-26 June, San Francisco, California, Paper ARMA 13-575. https://www.onepetro.org/conference-paper/ARMA-2013-575

Chapter 2: Installing WID

2.1 Installation

WID is a 32 bit application that runs on Windows 7, 8 and 10. To install it, double click the Setup.exe program.

Follow the instructions that appear on the screen. WID will appear on the program menu as WID.

2.2 Using Non-English Versions of Windows

If you are using a non-English version of Windows and the program is crashing, it is possible that it is due the regional settings. Change the settings on your computer to English. To do so,

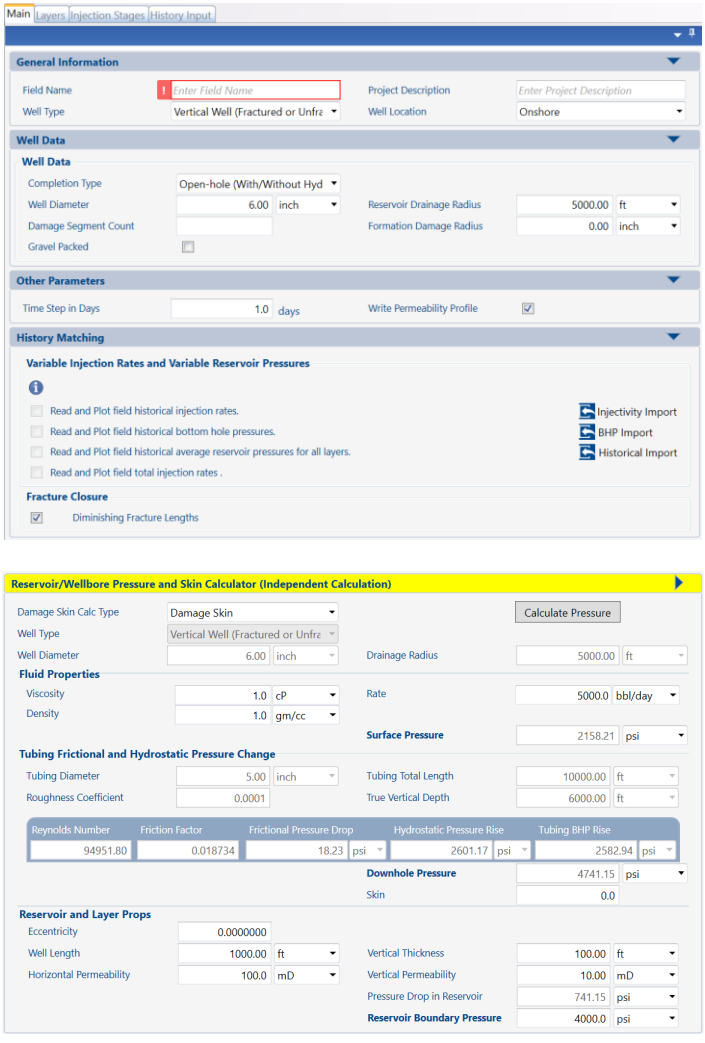
1. From the Windows Start menu select *Settings*
2. Select the *Control Panel*
3. Select the *Regional Settings* folder and select the *Regional Settings* Tab.
4. Select *English (United States)* from the Combo Box
5. Restart the computer for the settings to take effect

Chapter 3: Getting Started

This chapter provides a summary of the process and steps involved in setting up a simulation in WID. A more detailed explanation is provided in the following chapters of this text.

3.1 Main Tab

On starting WID, the first window that opens is the Main Tab, which is the first step for setting up the simulation.



3.2 File Options

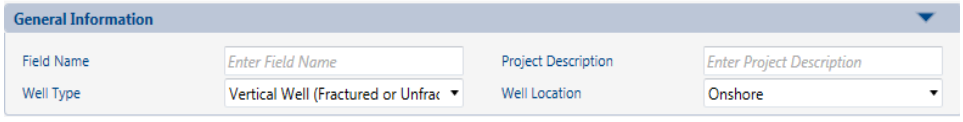
The user may want to:

- Create a New Input File : Click File>New
- Open an Existing Input File : File >Open
- Import .dat input file : File>Import

3.3 Setting up a simulation

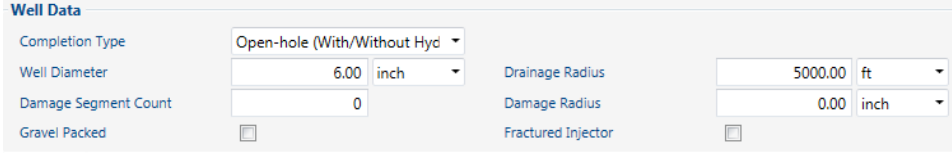
3.3.1 General Information:

In this section the user must may enter the details of the project such as Field Name, well location and project description. Well Type must be selected from the drop down box which gives options for vertical, horizontal and linear core flood injection.



3.3.2 Well Data:

The following section is important for setting up the correct default input parameters for the simulation. For each well type, there are several Completion Type options which the user must choose from:

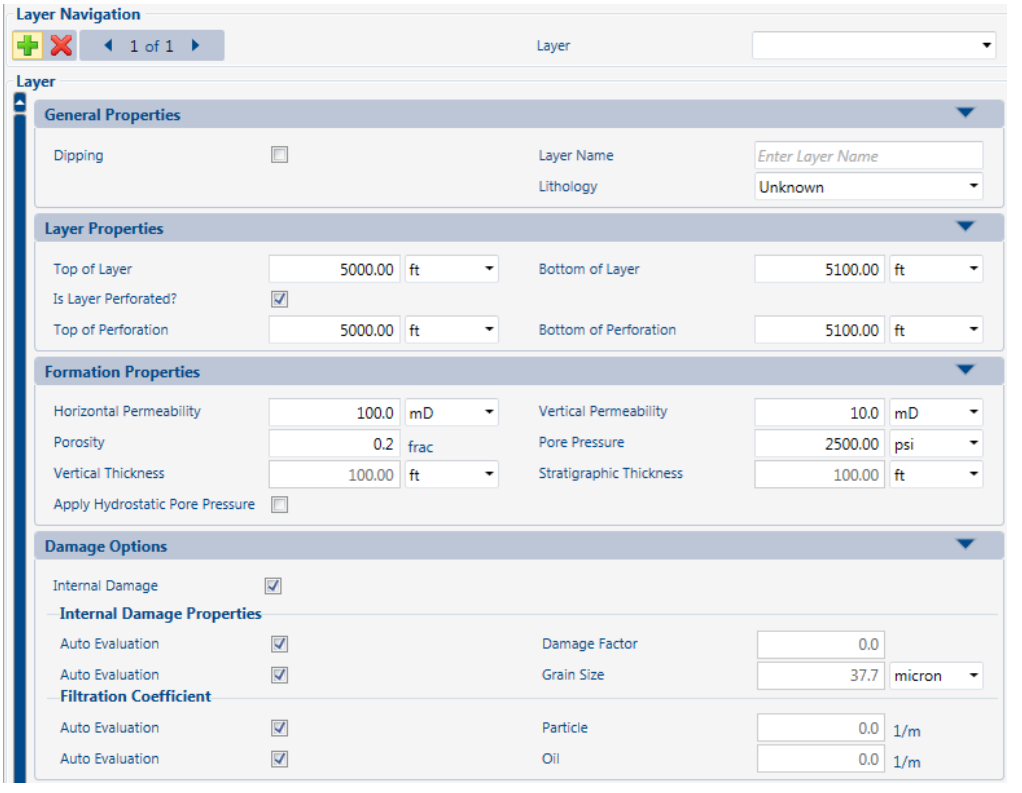


Vertical Well	Open-hole (With/Without Hydraulic Fracture) Perforated (With/Without Hydraulic Fracture) FracPacked (Comprehensive but No Lengthening) 3-D Fracture Growth
Horizontal Well	Open Hole Injector (2-D Longitudinal Fracture) Perforated Injector (2-D Longitudinal Fracture) Open-hole Injector (2-D Transverse Fracture) Perforated Injector (2-D Transverse Fracture)
Linear Core Flood Injection	-

- Choose one of the options for the completion type compatible with the Well Type selected.
- The input data window will appear filled with the default input data and modify the required input parameters according to the selections made by the user in the above options.
- Input the corresponding well data and click the ‘Layers’ tab.

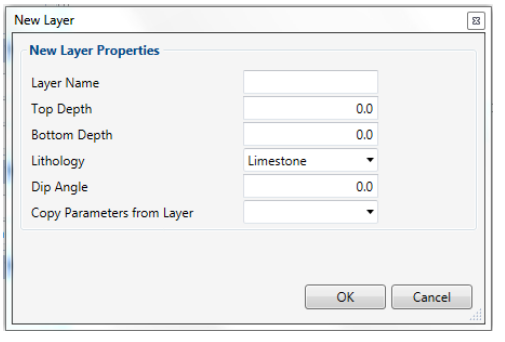
3.3.3 Layers Tab:

The layers tab allows the user to add multiple layers in the simulation. However, only one layer can be perforated or have fracture growth.



- New Layers can be added or deleted using the green '+' button and red 'x' button respectively. Upon click the '+' button the following dialogue box appears, which also allows the user to copy layer properties from a pre-existing layer.

Note : Providing a unique layer name is necessary



- Layer and Formation properties take the basic inputs for the formation, and whether the current layer is perforated or not. The user must select the check box for 'Is layer perforated' for the layer in which the induced fracture propagation is to be modelled. For the Damage options the user can decide to use the in-built auto evaluation functionality, in case of unavailability of sufficent relevant data.

Note : Only one layer can be perforated at a time for the 3-D simulations. The program will not run for more than one layer perforated.



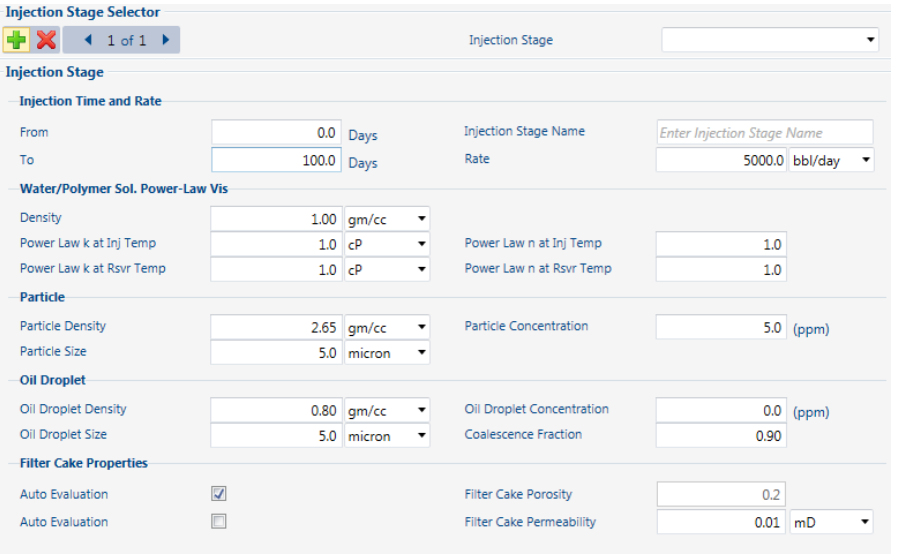
- Fluid properties :
    - Physical properties
    - Thermal Properties
    - Fluid Flow properties
- Rock properties :
    - Rock Mechanical Properties
    - Rock Thermal Properties

The above properties are input of the second half of the layers section. Default values are provided for each parameter. Two unit systems are provided in the interface :

- SI units
- Field units

Click on Tools>Settings>Default Units to change units or simply choose from the drop down box located on top of the window as shown below :





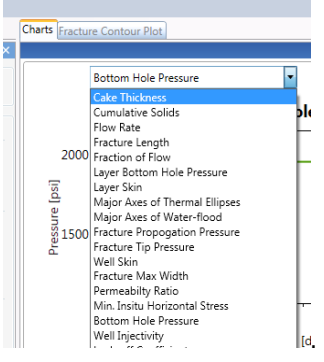
3.4 Simulation Run Button

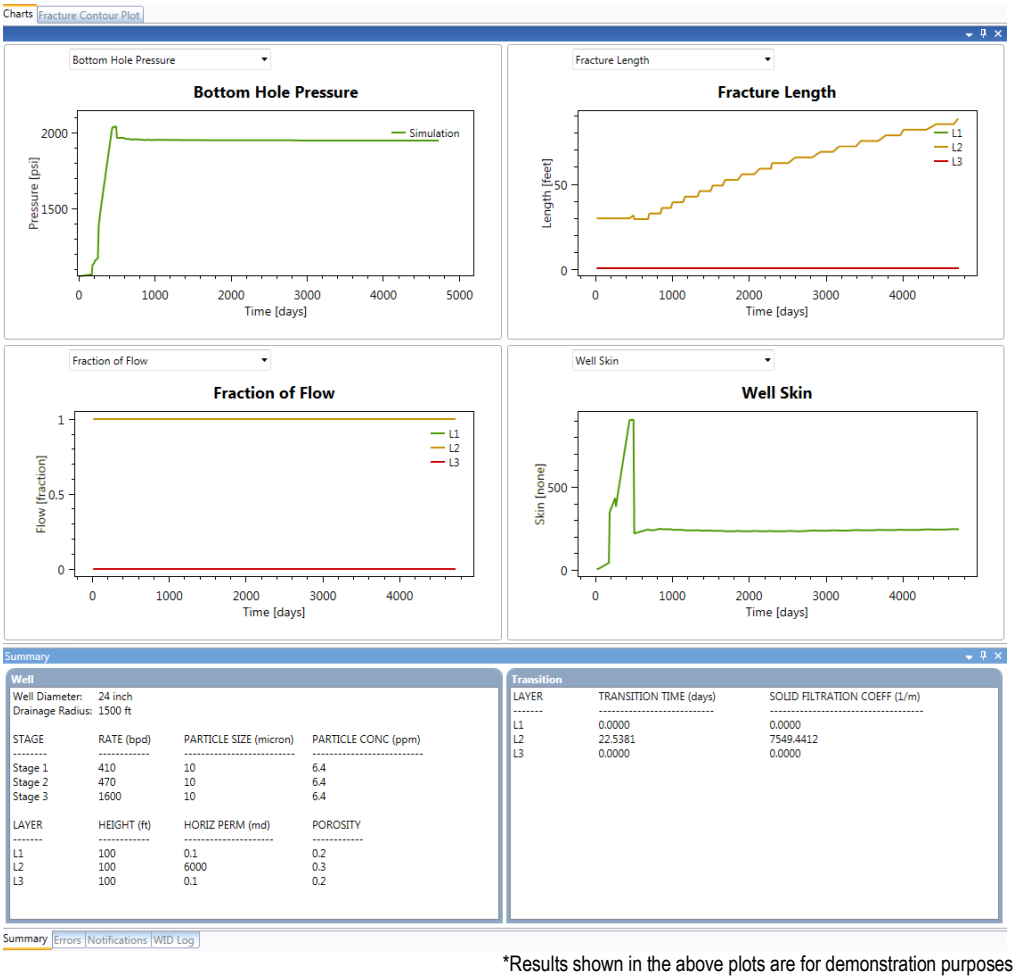


Click the play button (circled in red in figure) after you are sure you want to run the simulation. After a few seconds to few minutes, depending on the injection period and type of completion under evaluation, the results window will appear.

The Charts Tab shows plots which can be selected from the drop down box for the parameters shown in the given figure. WID log, Summary, Errors and Notification tabs appear on the bottom-left of the results window which can be used to check runtime messages.

Note: Fracture Contour Plot is only for 3-D simulation.





*Results shown in the above plots are for demonstration purposes only

Plot manipulation options:

- Right click and drag on plot axis will scale the axis values accordingly
- Hovering the pointer over the plots gives the x, y coordinates.
- The mouse-wheel can be used to zoom-in and zoom-out of the plot.
- Holding mouse-wheel button and drawing a rectangle zooms in on that portion of the plot.

Close the *Results* window. Try to change some input data in the input windows to see how it affects the result for any sensitivity analysis.

Chapter 4: Input Windows

The WID input frames are organized into four tabs, containing the Main, Layer, Injection and History data. The main tab contains the general information of the simulation and the well completion type which further decides the input parameters required for the particular case. The input options under these tabs are described in this chapter.



4.1 Main: Well Data

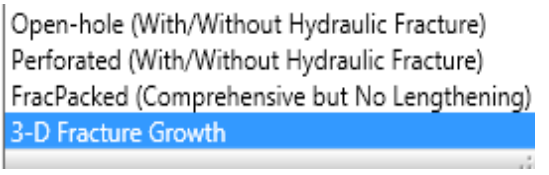
The 'Well Data' input section, has several fields. Each is described below.

4.1.1 Completion Type

Vertical well: The program allows 4 options for vertical injection wells: 1) open-hole injector (with or without a hydraulic fracture), 2) perforated injector (with or without a hydraulic fracture) and 3) frac-packed injector with in-depth modeling of the frac-pack and 4)3-D Fracture Growth. The fracture in all three is assumed to be vertical with a constant height equal to the layer height.

- In the first two options, a 2-D fracture growth is modeled with widening and lengthening of the fracture. The fracture initiation and growth is based on 2-D PKN constant height model with fracture growth caused by the damage due to solids in the injected fluid and due to any thermal stresses. Note that the model for the hydraulic fracture in the first two options does not explicitly model the proppant pack but considers it to be an infinitely conductive fracture.
- The third option, with the frac-packed injector option, allows for plugging of the proppant in the frac-pack and is a comprehensive model for frac-packed vertical injectors. However, the frac-packed injector option run results are valid only up to a few months or a maximum of few years as it allows only widening of the frac-pack but no lengthening.
- The fourth option, allows for 3-D fracture growth and can capture height growth of the fracture. If late time lengthening of the frac-pack is to occur and modeled, the first two options allow an approximate model for the frac-pack as an infinitely conductive fracture that can lengthen with time.

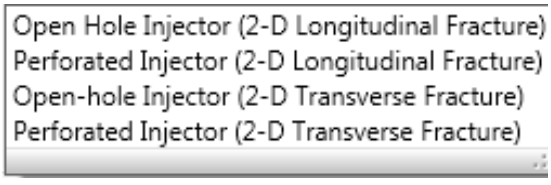
The downside of the options without frac-pack is that they do not allow plugging of the proppant in the frac-pack and assume uniform plugging of the fracture faces. Details of these models are discussed in the 'Technical Documentation' section later in this manual. The following window shows the three options for the vertical injectors:



Well radius
The radius of the well. Units: cm [metric], inches [field].

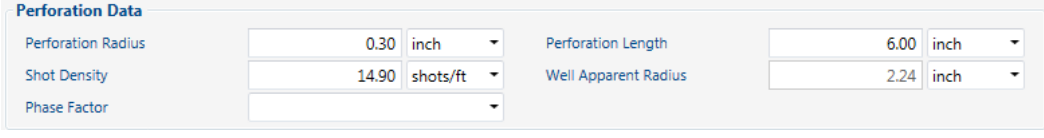
Drainage radius
For a single production or injection well, this radius is the distance over which fluid flow is impacted by the well. This is determined by well spacing. In a reservoir that has both production and injection wells, it will typically be half the distance between the production and the injection well. The results are relatively insensitive to drainage radius. Units: meters [metric], ft [field].
1 m=3.28 ft.

Horizontal well: The program allows for a open-hole injector (with or without a hydraulic fracture) and a perforated injector (with or without a hydraulic fracture) with two fracture growth orientations (longitudinal and transverse). In the longitudinal fracture growth option, a fracture is grown upward and downward vertically aligned with the horizontal well with the entire wellbore fractured. The height of the fracture is assumed to be the horizontal well length with maximum length allowable is equal to the layer height. Once the fracture reaches the layer upper or lower bound, the results are not valid thereafter. In the transverse fracture growth option, a vertical fracture is grown from the center of the horizontal well perpendicular to the well with fracture height constant and equal to the layer height.



The longitudinal and transverse options provide limiting cases for fracture length. The transverse case usually provides an upper bound to the fracture length while the longitudinal case provides a lower bound to the created fracture length. Fractures are likely to be oriented at some angle to the horizontal wellbore and their response will lie somewhere in between these two limiting cases. The following window shows the four options for horizontal injectors:

4.1.2 Parameters for Perforated Completion



Perforation radius
Perforations are assumed to be cylindrical in shape. Typical range: 0.25 – 0.5 inches. Units: cm [metric], inches [field]. 1 cm = 0.3937 inch

Perforation Length
The length of the perforation is from wellbore wall to perforation tip into the formation. This can be estimated from specifications for the shaped charge (API RP53). Units: cm [metric], inches [field].
1 cm = 0.3937 inch

Perforation Shot Density

Number of perforations per unit length of the perforated well interval. Typical value: 8 shots/ft. Units: shots/m [metric], shots/ft [field]. 1 spm = 0.3048 spf

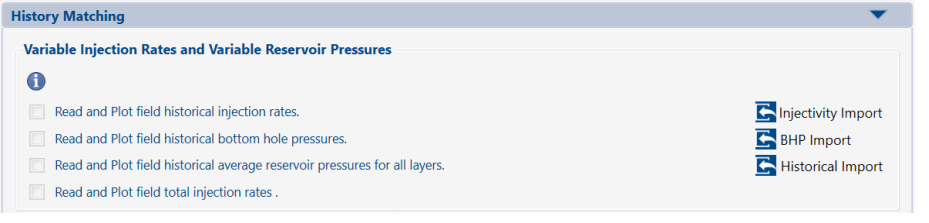
Well Apparent Radius

The flow through perforations is modeled as an additional pressure drop in the reservoir. An equivalent open-hole well with an apparent well radius based on the perforation radius, length and the shot density is calculated for the cased and perforated hole (Eq. 2.47, chapter 2, technical documentation).

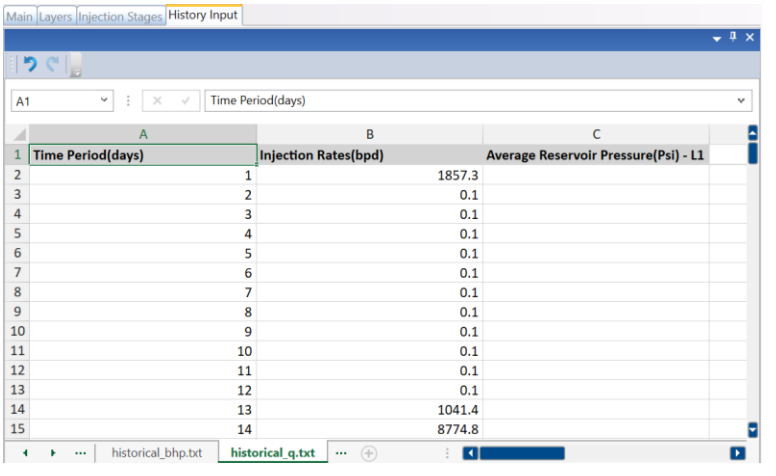
4.1.3 History Matching

WID can use historical field data for its simulation. WID allows user to import either:

- Historical total injection rate to the well
  - To import injection rate, "Read and Plot field total injection rates" option must be selected.
- Historical total injection rate to the well and the boundary reservoir pressure of each layer
  - To import injection rate and reservoir pressures, both options "Read and Plot field total injection rates" and "Read Plot field historical average reservoir pressures for all layers" must be selected.



The field data in text file can be imported by Historical Import button. The text file must be in a format with a header row and data from the second row. From the second row, the first column should be time in days and second column must be the total injection rate in the unit of barrel per day. When the reservoir pressures are imported as well, the third column and on should have reservoir boundary pressures in psi from the top to bottom layers respectively. The imported data can be verified in the "historical_q.txt" sub-tab of the "History Input" tab as below.



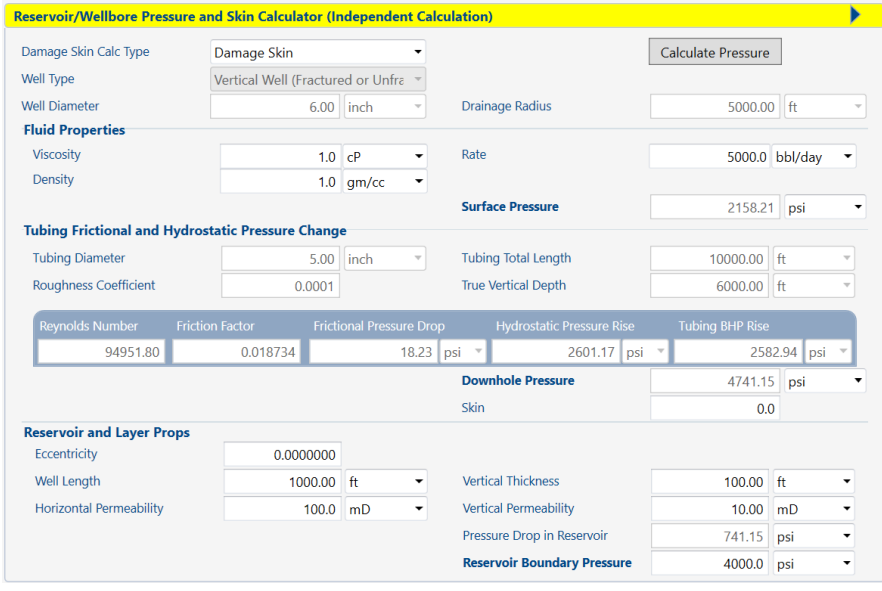
	A	B	C
1	Time Period(days)	Injection Rates(bpd)	Average Reservoir Pressure(Psi) - L1
2	1	1857.3	
3	2	0.1	
4	3	0.1	
5	4	0.1	
6	5	0.1	
7	6	0.1	
8	7	0.1	
9	8	0.1	
10	9	0.1	
11	10	0.1	
12	11	0.1	
13	12	0.1	
14	13	1041.4	
15	14	8774.8	

User can also import historical injectivity and/or historical bottom hole pressures. The imported data for injectivity and bottomhole pressures are not used as simulation input, but are only used to compare with simulation results in x-y plots. “Read and Plot field historical injectivity” and/or “Read and Plot field historical bottom hole pressures” options are to be selected as necessary.

To import historical injectivity and BHP data, Injectivity Import and BHP Import buttons must be used to choose text files. The format of the text files must have a header row, and data from the second row. The fist column needs to be time in days, and second column historical injectivity (bpd/psi) or BHP (psi). Once data files are imported, they can be displayed in the “Historical Input” tab in a spreadsheet format.

4.1.4 Skin Calculator

If the well has skin (reduced near-well permeability) from drilling workover or completion operations, this must be accounted for when determining the initial injectivity of the well. This skin will influence the behavior of the injection well until a fracture is induced. First, the well has a higher flow resistance due to this skin. This means that additional flow resistance added e.g. by an external filter cake in the well has less relative effect on the injectivity. A filter cake that reduced the injectivity in an undamaged well by 50% may only reduce the injectivity in a damaged well by 10%.



WID accounts for this by allowing the user to specify initial skin. This can be done in three different ways:

i. **“Downhole Pressure”** option: Downhole flowing pressure and average reservoir pressure is specified. Skin values are calculated on the basis of initial down hole pressure and formation data.
ii. **“Damage Skin”** option: The damage skin is specified directly. Steady-state downhole pressure is calculated.
iii. **“Surface Pressure”** option: Surface initial pumping pressure, reservoir pressure and injection tubing data are specified. Downhole pressure and skin values are calculated

based on pumping pressure, hydrostatic pressure head (ρgh) and frictional pressure drop.

The friction factor (*f*) inside well bore tubings (steel pipes) is calculated using Chen's correlation (Economides and Hill, 1992):

$$\sqrt{1/f} = -4\lg\left\{\frac{\varepsilon}{3.7065} - \frac{5.04}{N_{\mathrm{Re}}}\lg\left[\frac{\varepsilon^{1.1098}}{2.8275} + \left(\frac{7.149}{N_{\mathrm{Re}}}\right)^{0.8981}\right]\right\}$$

Here, $N_{Re} = \rho ud/m$ and ε is the roughness coefficient for the steel pipe, typically between 0.001 and 0.003. When the friction coefficient is known, the frictional pressure drop is given as:

$$\Delta p_{rf} = 2 f \rho_l u^2 L_w / d$$

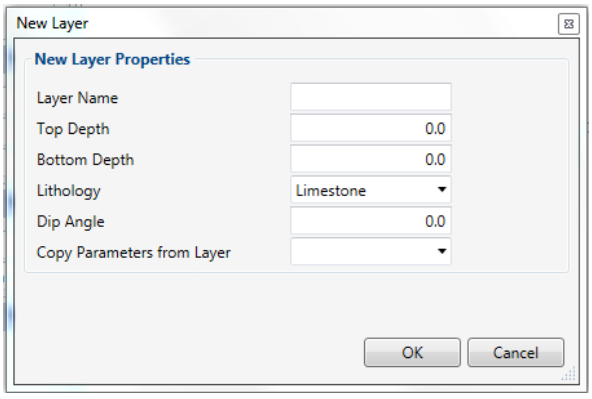
Caution
Since this Skin Calculator section in the program is designed to provide initial skin to the main WID simulation, calculation in this section is mostly independent of the rest of the program. Whenever any parameter is updated in this section, Calculate Pressure button must be clicked to update the result.

4.2 Layers

In WID, one can have as many as 10 layers for vertical wells. Note that the model assumes no cross flow between layers. The basic parameters for each layer are displayed in the grid in the bottom of the input frame. Note that although the name layer may be a misnomer for lab cores, the properties of the rock need to be entered in the layer data. For horizontal wells and cores, only one layer is allowed.

Adding a Layer
To add a new layer, click the green '+' button located on top-left corner. This opens the 'New Layer' dialogue box. The layer is inserted at the bottom by default. The layer number of the layer to be added or in other words the position where the new layer is added can be adjusted by clicking on the arrows next to the number.

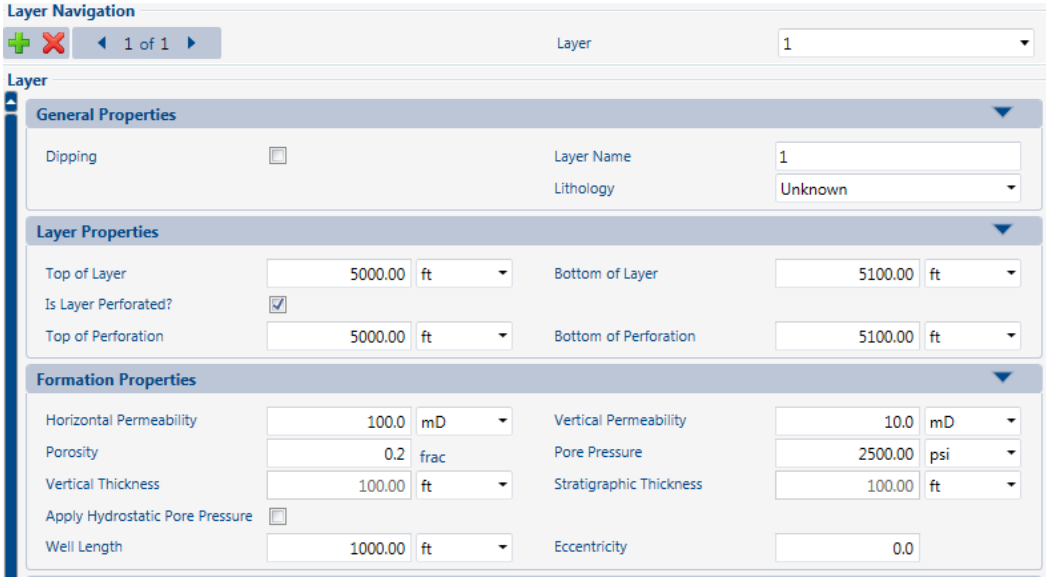
***Note**: The layers need to be added in the sequence of occurrence with the shallowest layer entered first and the deepest layer entered last. The vertical scroll bar is provided to change the sequence for the new layer to be added (default sequence is addition to the bottom).*



Clicking OK brings up the *Formation and Filtration Properties* window.

Removing a Layer
To remove a layer, select the appropriate layer in the Layer display grid and press the red 'x' button on top left corner. The last layer cannot be removed.

4.2.1 Formation and Filtration Properties



Layer Name
The layer name is important and needs to be entered. The fluid and reservoir properties in the Reservoir Fluid Rock Thermal Fracture Data frames are displayed and set based on the layer name entered here.

Top of Layer
Enter the depth to the top of the layer.

Bottom of Layer
Enter the depth to the top of the layer.

Perforated
This option is only available in perforated completed well options and not in the Open-Hole completion well option. By default all layers in the cased and perforated well option are assumed to have perforations. However, if one or more layers are not perforated then injected fluid will not enter directly into this layer from the wellbore. Uncheck the box in this case. Approximate vertical flow is modeled that will result in flow entering into this layers from the other perforated layers. Refer to Chapter 5 in the Technical Documentation section for details.

Top of Perforations
This option is only active in the cased and perforated well completion.

Bottom of Perforations
This option is only active in the cased and perforated well completion. However the depths of the perforations are not used in any calculation.

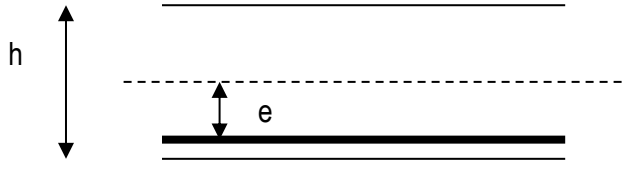
Horizontal permeability
The permeability in the horizontal plane. The horizontal permeability is assumed to be isotropic in the horizontal direction.

Vertical permeability
The permeability in the vertical plane is needed for horizontal wells and for unperforated layers in vertical wells.

Porosity
The porosity of the layer, must lie between 0 and 1.

Height/Vertical Thickness
The formation height. WID assumes a uniform height for each layer/formation. If the height varies, the height in the near well area is most appropriate. If the layers are dipping, the formation height refers to the layer thickness (minimum distance between the layer boundaries).

Eccentricity and Well Length(Horizontal Wells only)
This is enabled for the horizontal well only. This is a ratio = e / (h/2), where h is the formation thickness and e is the vertical distance from the center of the formation to the axis of the horizontal well. A value of 0 means the well is in the center of the layer with no eccentricity and a value of 1 means that the well is at the top or bottom of the formation.



Note*: The layers need to be added in the sequence of occurrence with the shallowest layer entered first and the deepest layer entered last. However the depths of the layers are not used in any calculation.*

4.2.2 Internal Damage Parameters Frame

This frame contains the parameters needed to calculate internal damage due to particle deposition. The default is for WID to evaluate all these parameters, but the user can change them.

Internal Damage Check Box
If the internal damage period is very short or the user knows that an external cakes starts to form at once, the program can be forced to skip the internal damage period by leaving this box unchecked. Parameters related to internal damage and transition time are then irrelevant. This option is currently inactive. Contact Dr. Mukul Sharma if needed.

Damage factor, β
The permeability reduction as a result of particle deposition is calculated on the basis of the Kozeny equation (SPE 38180). Changes in porosity and specific surface area are accounted for.

Increased tortuosity may cause a larger permeability reduction than predicted by this equation. This extra damage can be accounted for by specifying a positive value for the damage factor, β. The default value for β is 0.

Filtration coefficient, λ
The filtration coefficient (λ) describes the rate of particle deposition via the equation:

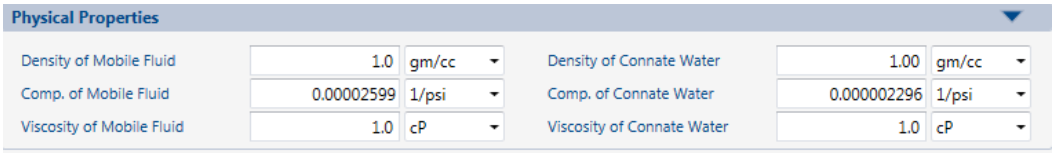
$$\frac{d\sigma}{dt} = \lambda v c$$

where σ is the deposited concentration, *v* is the velocity and *c* is the suspended concentration. The filtration coefficient can either be automatically evaluated or entered for oil and water. It depends on a large number of parameters. In WID 7.2, the filtration coefficient is calculated on the basis of a correlation by Rajagopalan and Tien, which assumes negligible double layer repulsion between particles and grains. For typical water injection conditions, the correlation predicts values in the range of 0.1 to 10 cm^{-1}. The calculated value is shown in the results window.

Formation grain size
The grain size is evaluated by the Kozeny equation, using the formation permeability and porosity. The grain size obtained form this equation can sometimes be incorrect for extreme cases, and the user can specify a value obtained from thin sections or grain size analysis.

4.2.3 Reservoir Fluid, Rock, Thermal and Fracture Data

PHYSICAL PROPERTIES



Density of mobile fluid (oil/water) in reservoir
This is the density of mobile fluid in an undisturbed formation. The mobile fluid is water in case of injection into aquifers and oil in case of oil reservoirs. Units: kg/meter^3, lbm/cu ft.

Density of connate water in reservoir
This is the density of the connate water in the reservoir. Units: kg/meter^3, lbm/cu ft.

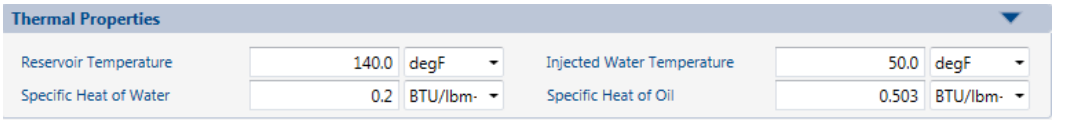
Compressibility of connate water
This is the compressibility of water. Units: 1/Kpa, 1/psi

Compressibility of mobile fluid (oil/water) in reservoir
This is the compressibility of the mobile fluid in an undisturbed formation. This is water in case injection into aquifers and oil in case of oil reservoirs. Units: 1/Kpa, 1/psi

Viscosity of mobile fluid (oil/water) in reservoir
This is the viscosity of the mobile fluid in an undisturbed formation. This is water in case injection into aquifers and oil in case of oil reservoirs. Units: Pas, cp.

Viscosity of connate water
This is the viscosity of the connate water at the reservoir temperature. Units: Pa-s, cp.

THERMAL PROPERTIES



Reservoir Temperature
This is the initial temperature of the undisturbed reservoir. Units: ^{0}C, ^{0}F

Injected Water Temperature
This is the temperature of the injected water. Units: ^{0}C, ^{0}F

Specific heat of Injected Fluid and Connate Water
This is the specific heat of water. Note this value is also used for the specific heat of injected fluid and the connate water. Units: KJ/Kg-K, Btu/Lbm.

Specific heat of mobile fluid (oil/water) in reservoir
This is the specific heat of the mobile fluid in an undisturbed formation. This is water in case injection into aquifers and oil in case of oil reservoirs.

FLUID FLOW PROPERTIES

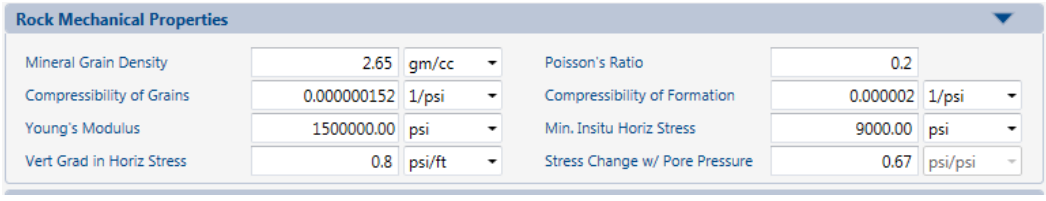


Residual mobile fluid (oil/water) saturation in reservoir
If the water is being injected into an oil bearing zone, then this is the residual oil saturation. In the case of injection into an aquifer, it is 0.

Initial water saturation
This is 1 for injection into aquifers and the appropriate value for injection into oil bearing zones.

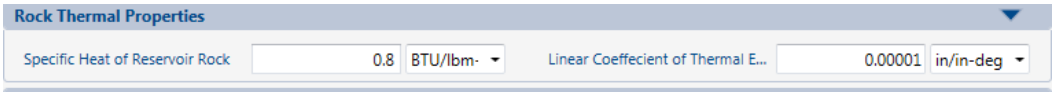
Relative permeability to water at residual saturation of mobile fluid
If the water is being injected into an oil bearing zone, this is the relative permeability of water at the residual oil saturation. For injection into aquifers, this value should be 1.
Relative permeability to mobile fluid (oil/water) in virgin reservoir
If the water is being injected into an oil bearing zone, this is the relative permeability of the oil. It should be taken as 1 for injection into an aquifer.

4.2.4 Rock Mechanical Properties



The appropriate mechanical properties need to be entered in consistent units.

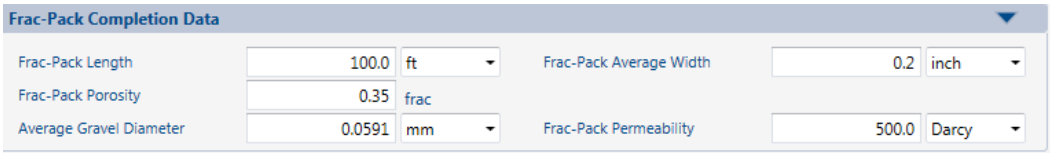
4.2.5 Rock Thermal Properties



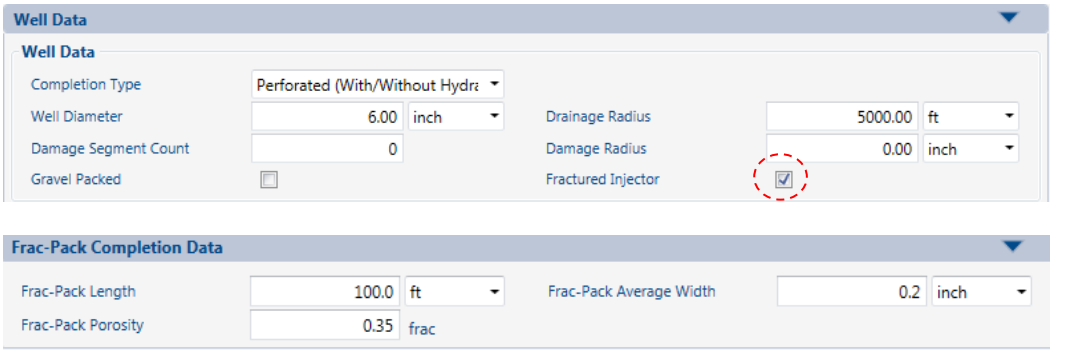
The appropriate thermal properties need to be entered in consistent units.

4.2.6 Hydraulic Fracture Data for Fractured Injectors

For approximate but long-term injectivity and fracture growth modeling of initially hydraulically fractured injectors, the following data is needed. The Fractured injector check box must be. For accurate but short term injectivity modeling of hydraulically fractured vertical injectors, the following data is needed under the frac-Packed Vertical Injector option:

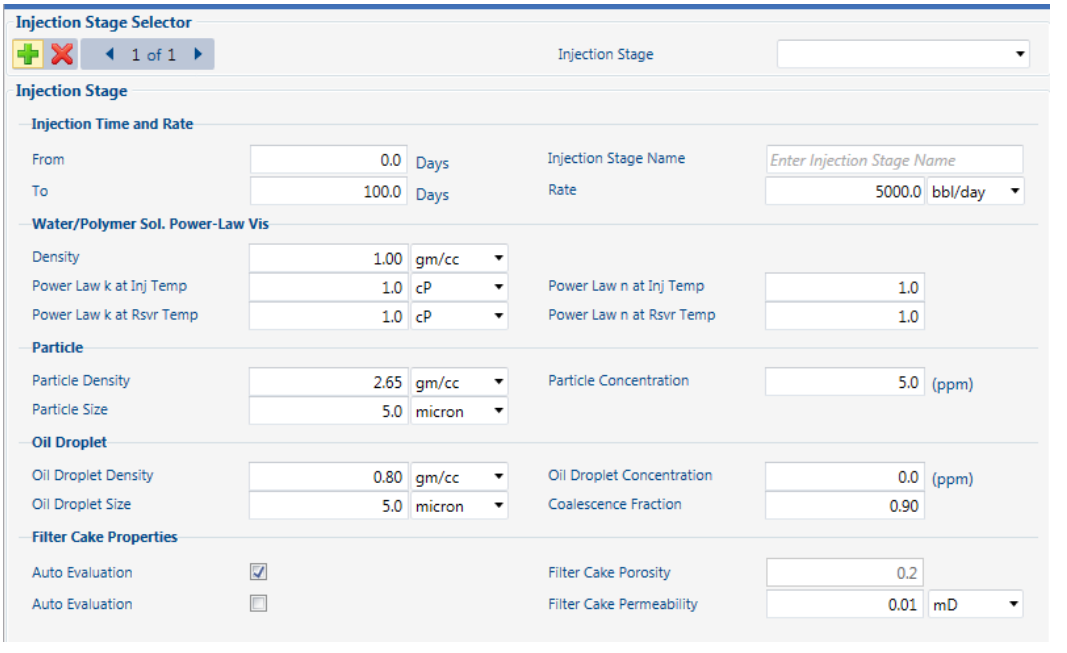


For fractured injector without comprehensive frac-pack model, but allows frac pack extension the following input is required:



4.3 Injection Stages

Click the 'Injection Fluid and Rate Data' button. The program allows for multiple injection stages with varying injection fluid rheology, injection rates and water quality (solids and oil ppm).



Initial Time

Ten stages of injection are allowed. To enter multiple injection stages, click on the checkbox for the stage and enter the end time (number of days or pore volumes for core case) for that stage of injection. Note if you enter an end time less than the start time, you will be prompted to change it.

Initial Injection rate

This is the initial rate at the start of the injection. If the user chooses '*constant pressure injection*' in the 'Core Flood Option' (not provided in modeling injection via wells) as the flow constraint, the rate will decrease as injection proceeds. Units: m^3/day [metric], bbl/day [field]. 1 m^3/day = 6.2898224 bpd

Water density
The density of the injection water. Units: kg/$meter^3$ [metric], g/cc [field]. 1 kg/m^3 = 0.001 g/cc

Viscosity
The injection fluid viscosity can be shear rate dependent (applicable to polymer injection wells). A power law model is used to represent the viscosity. A power law coefficient (k) and a power law exponent (n) at injection water temperature and at reservoir temperature are needed as inputs. For Newtonian fluids such as water, enter n = 1. Units for k: cp.s^{n-1} [field]; n has no units. Please refer to 'Enhanced Oil Recovery' textbook by Larry W. Lake for reference.

Particle Density
The density of particles in the injection water. Particles of high density have a settling velocity when migrating through the pores, and their likelihood of being trapped is therefore, bigger. Organic materials (bacteria etc.) will have densities close to that of the water (~1.05 to 1.1 g/cc). Clay and mineral particles typically have densities between 2 and 3 g/cc. Units: kg/m^3, g/cc.

Solids Concentration
The volume fraction of suspended solids given in ppm. (parts per million, volume fraction of solids to the fluid). Units: ppm.

Particle Size
The particle size is a very important parameter in determining the filtration coefficient (deposition rate). If a particle size distribution is known, we suggest that a volume average be used. Units: μm.

Oil Droplet Density
The density of oil droplets suspended in the injection water.

Oil Droplet Concentration
The volume fraction of suspended oil droplets given in ppm. (parts per million, volume fraction). Units: ppm.

Oil Droplet Size
The suspended droplet size is an important parameter in determining the filtration coefficient (deposition rate). If a droplet size distribution is known, we suggest that a volume average be used to find the average droplet size. Units: μm.

Coalascent Fraction
This is the fraction of injected oil droplets coalescing with the residual oil in the reservoir. The entrained oil droplets in the injected water behave differently from particles. All the particles entrained in the injected fluid contribute to plugging the formation. The oil droplets on the other hand can coalesce with the residual oil or may act like solid paticles by plugging the formation. The fraction of oil droplets coalescing with the residual oil do not contribute towards plugging. Hence,

only the remaining fraction of oil droplets are accounted for in particle plugging and permeability decline. The coalascent fraction depends on the interfacial properties of the rock and the fluids and can be estimated by history matching core flow tests.

Filter Cake Properties

In almost all the cases, a filter cake will ultimately start to build on the formation face after some time during injection. The properties (porosity and permeability) of the filter cake are assumed and are constant with time. The user can specify the porosity and permeability of the external filter cake. In case the data is unavailable, these can be calculated by the program by selecting the *Automatic Evaluation* box. The default value for the filter cake porosity is 0.25 and a corresponding permeability is calculated from the particle size using the modified Carman-Kozeny equation. Since the particles are treated as spheres, the permeability calculated is found to be an overestimate. Therefore, the calculated permeability is multiplied by 0.1 and used in the program. It is recommended that the estimates of external filter cake permeability be made by filtering the injection water through a 0.2 μm filter paper.



The program allows for multiple injection stages with varying water quality. Therefore, the filter cake properties need to be input for each stage. The number of stages corresponds to the number of stages selected previously in the Water and Particle Properties window.

Chapter 5: Saving and Loading Data – File Menu

5.1 Saving and Loading Data – File Menu

The file menu in WID is similar to the file menu in most Windows programs. A description of each menu choice is given below.

New
When the users choose *New,* they are first asked to specify the well type (Vertical, horizontal or core flow test). Then a data input window appears.

Open
A dialog box where the user can select previously saved data files is displayed. Only one file can be open at a time.

Save
Saves the current input file to the default location. The first time a user chooses save, a default file name untitled.WID is used. Later *save* will use the previously chosen file name and will not prompt.

Caution

The default location for the data file is
C:\Users\[userName]\Documents\WID\Datafiles

The default location for the actual working folder is
C:\Users\[userName]\Documents\WID\Output

Save As
Using this option always prompts the user for a file name and location.

Close Project
Closes the current file.

Exit
Exits WID.

Chapter 6: WID Units: Metric and Field

The WID user interface allows a user to input parameters in either metric or oil field units.

6.1 Metric Units

The metric units are based on the decimal system such as: centimeters, meters, and kilometers for length measurement; milligrams, grams, and kilograms for weight measurements; and cubic millimeters, cubic centimeters, and cubic meters for volume measurements. The metric units are evolving to SI units and are to be accepted internationally. However since the petroleum industry still uses metric system in its scientific literature that we are using metric units.

6.2 Field Units

The field units are the units used in the oil field industry. Some of the typical field units are as followed: barrel or gallon for volume measurement, ft or inches for length measurements, md or darcy for permeability measurements.

6.3 Unit Conversion

Below is the list of metric and field units used by the program along with their conversion factor.

Unit Type	Metric Units	Field Units	Metric to Field Conversion *
Length	Meters	Inches	39.370079
Length	Meters	Feet	3.2808398
Length	Meters	Microns	1e+6
Perf. shot density	Shots per meter	Shots per foot	0.3047999
Injection flow rate	$meter^3/sec$	Bbl/day	543440.6587
Density	Kg/m^3	g/cc	0.001
Density	kg/m^3	lb/cu.ft	0.06242796
Viscosity	Pascal second	Centipoise	1000
Concentration	m^3/m^3	ppm	1e+6
Permeability	m^2	md	1e+15
Pressure	Pascal	psi	0.000145038
Filtration coefficient	1/meter	1/cm	0.01
Compressibility	1/Pascal	1/psi	6894.757
Temperature	Celsius	Fahrenheit	1.8*C+32
Specific heat	KJ/Kg-K	Btu/lbm-F	0.238186596

* Multiply the conversion factor with the values in metric units to obtain the corresponding value in field units. To obtain values in metric units from values in field units, multiply with the reciprocal of the conversion factor.