WATER HAMMER SIMULATOR

User Guide

Abstract

Water hammer signature can provide diagnostic information on fracture geometry. Water Hammer Simulator solves the transient flow problem in a wellbore-fracture system to match the water hammer signature, and the solution provides the fracture dimensions based on the resistance-capacitance-inertance (R-C-I) circuit analogy.

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Summary

This User Guide for Water Hammer simulator is prepared to help users install and run the program for hydraulic fracture diagnostics by water hammer simulation. For the background information, theories, and application examples, please refer to the Technical Documentation of this program.

Key References

- Mondal, S. (2010). Pressure Transients in Wellbores: Water Hammer Effects and Implications for Fracture Diagnostics. Thesis, The University of Texas at Austin. http://www.pge.utexas.edu/images/pdfs/theses10/mondal.pdf
- Carey, M. A. (2014). Water Hammer Fracture Diagnostics. Thesis, The University of Texas at Austin. http://www.pge.utexas.edu/images/pdfs/theses14/carey.pdf
- Carey, M. A., Mondal, S., & Sharma, M. M. (2015). Analysis of Water Hammer Signatures for Fracture Diagnostics. Presented at the SPE Annual Technical Conference and Exhibition, 28-30 September, Houston, Texas, USA, Paper SPE 174866. https://doi.org/10.2118/174866-MS
- Carey, M. A., Mondal, S., Sharma, M. M., & Hebert, D. B. (2016). Correlating Water Hammer Signatures with Production Log and Microseismic Data in Fractured Horizontal Wells. Presented at the SPE Hydraulic Fracturing Technology Conference, 9-11 February, The Woodlands, Texas, USA, Paper SPE 179108. https://doi.org/10.2118/179108-MS
- Hwang, J., Szabian, M., & Sharma, M. M. (2017). Hydraulic Fracture Diagnostics and Stress Interference Analysis by Water Hammer Signatures in Multi-Stage Pumping Data. Presented at the Unconventional Resources Technology Conference held in Austin, Texas, USA, 24-26 July 2017, Paper URTeC 2687423. https://doi.org/10.15530/urtec-2017-2687423

Last Updated

on Aug 9, 2017 for Water Hammer Simulator 17.01

License Information

Contents

Chapter 1 : Introduction

1.1 About The Software

Water Hammer simulator is a fracture diagnostic tool for multi-stage hydraulic fracture treatments. Water Hammer provides an estimate of fracture dimensions by simulating water hammer signature data that is readily available for any fracture treatment.

1.2 Current Capabilites

Water Hammer solves a transient flow problem in a Wellhead-Wellbore-Fracture system, which allows a user to address questions such as:

- What are the induced fracture dimensions including length, height, and width?
- What are the fracture dimensions when multiple fractures are growing in a stage?
- How does the stimulated reservoir volume change in each stage from toe to heel?
- How do other fracture diagnostic data compare with water hammer analysis? (Microseismic, long-term production, DTS/DAS, and so on)
- How does fracture treatment design impact water hammer signature and predicted fracture dimensions?
- How do ISIP, net pressure and near-well pressure drop change over stages?

1.3 Simulation Results

The simulation results from Water Hammer consist of graphs, charts, and tables including:

- Simulated and field-observed surface pressures for each stage (water hammer signature).
- Pressure drops caused by near-well and wellbore friction, net fracturing pressures, ISIP
- Fracture dimensions for single “effective” fracture and multiple fractures in a stage
- Sensitivity study results for the optimization of pressure match

All output data can be saved in an Excel format for your own workflow for fracture treatment data management.

1.4 Chapters Overview

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

WATER HAMMER: Software User Guide

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

- Chapter 2 covers the installation of WATER HAMMER.
- Chapter 3 is a main tutorial to run WATER HAMMER.
- Chapter 4 covers the sensitivity study.
- Chapter 5 discusses loading and saving of data.
- Chapter 6 describes the units used in the simulator.

WATER HAMMER: Technical Documentation

Section 2 is the description of the mathematical models that are used to solve momentum balance in the wellbore-fracture system and fracture diagnostics. For a description of the underlying mathematical models, you can also refer to the key references in the summary page.

Chapter 2 : Installing WATER HAMMER

2.1 Installation

WATER HAMMER 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. WATER HAMMER will appear on the program menu as WATER HAMMER.

The installation program will attempt to create a working folder named “WaterHammer” in the “Documents” folder of the current user. Please refer to the location of folder in Chapter 5.

2.1.1 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 to 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 Water Hammer simulator.

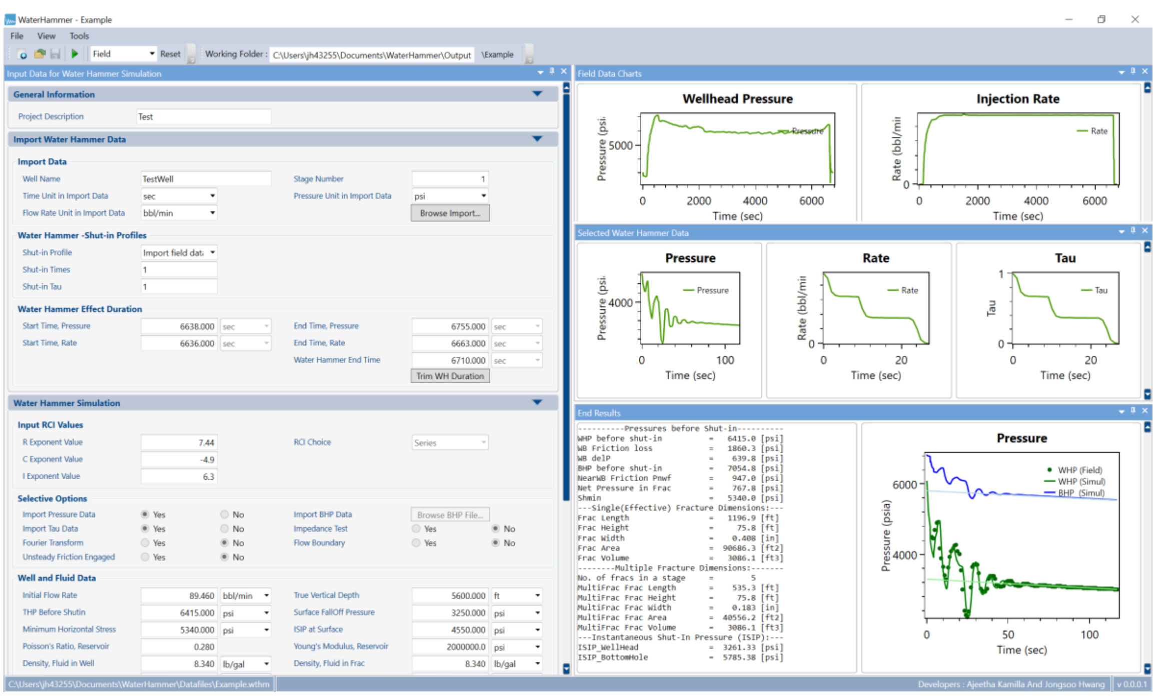
3.1 Raw Data Requirement

First, create a new .xlsx spreadsheet, and copy the Time, Pressure, and Rate data into columns A, B, and C respectively from the data source. Be sure there are no headers, as shown below. You will want to create a separate excel file for each stage.

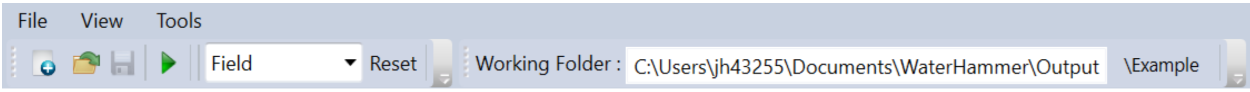
	A	B	C	D
1	0.017	48	0	
2	0.033	48	0	
3	0.05	48	0	
4	0.067	48	0	
5	0.083	48	0	
6	0.1	48	0	
7	0.117	48	0	
8	0.133	48	0	
9	0.15	47	0	

3.2 Main Input and Output Window

On starting Water Hammer, the first window that opens is the Main Tab, where user can specify input parameters, run program, and check simulation results.



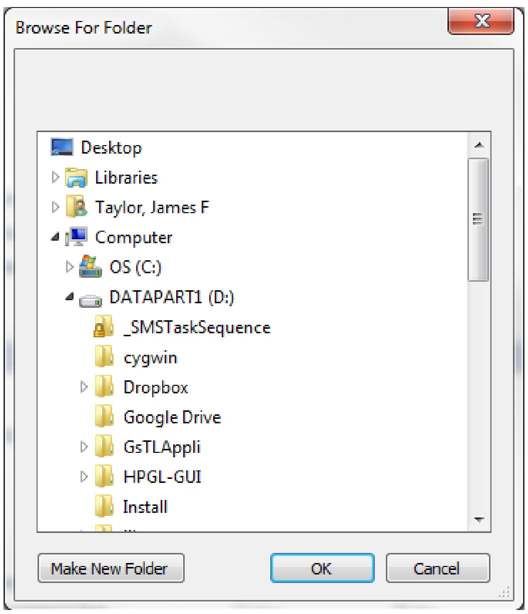
3.3 File Options



The user may want to:

- Create a New Input File : Click File > New
- Open an Existing Input File : Click File > Open
- Close an Open File : Click File > Close Project

The user may specify the location in which the data will be saved called the “Working Folder”. The default working folder will be ‘Users\[username]\Documents\UTWaterHammer\Output’. This location can be changed by inputting a new location or by clicking the “Working Folder” button to browse for a folder.

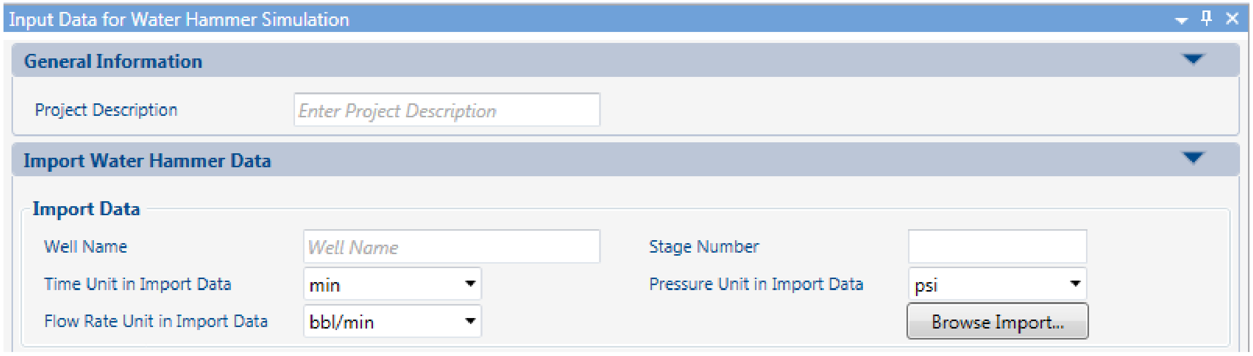


In the specified working folder, a sub-folder with the current data file name will be created once the program runs. Input and output files for the current simulation will be stored in this sub-folder.

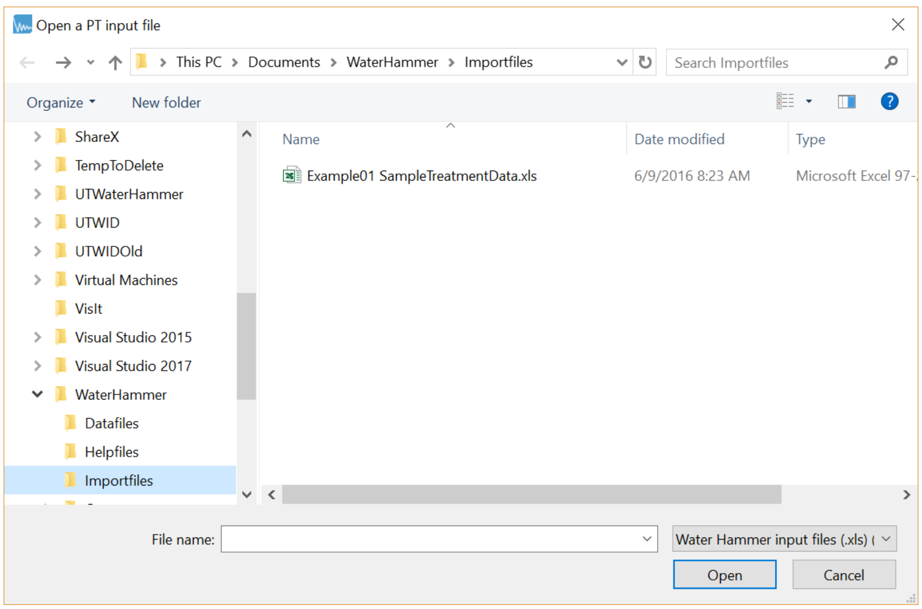
3.4 Importing Treatment Data

3.4.1 Input Data for Water Hammer Simulation

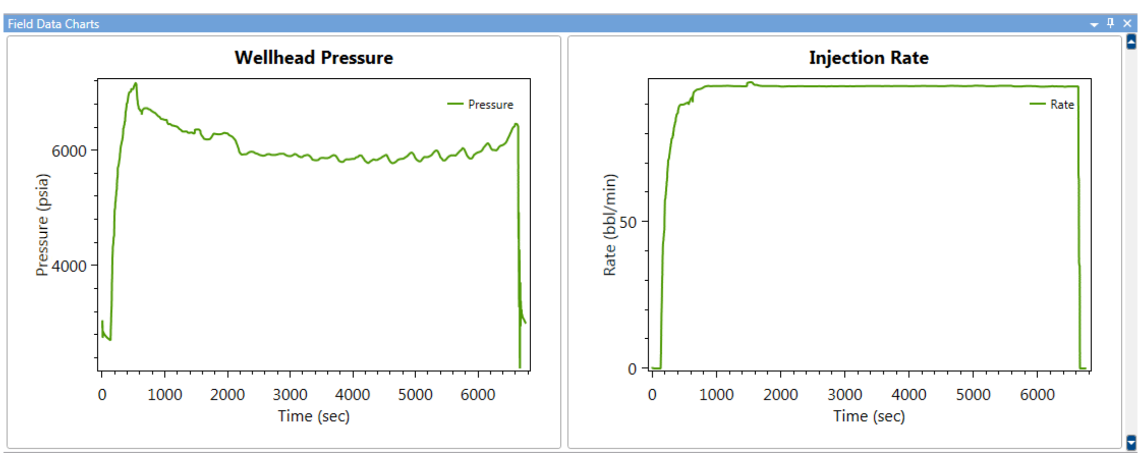
In this section the user first enters the Project Description, Well Name, and Stage Number. Stage data is imported through the “Browse Import…” button. Upon importing the data, ensure that the Time Unit in Import Data, Pressure Unit in Import Data, and Flow Rate Unit in Import Data match the units of the Data File.



Field Data must be imported as an .xlsx or .xls spreadsheet formatted as shown in section 1. Data for each stage can then be selected for the simulation.

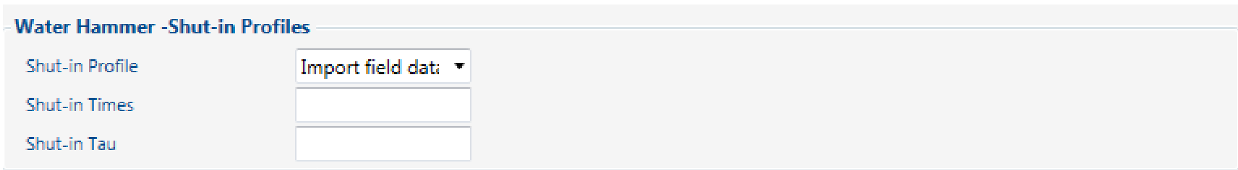


After the Field Data is imported, the Field Data Charts will appear.



3.4.2 WATER HAMMER SHUT-IN PROFILES:

This section allows the user to select a Shut-in Profile, enter Shut-in Times, and enter Shut-in Tau. Options for the Shut-in Profile include Import field data, Step-wise, Linear, and S-curve. The Shut-in profile should remain "Import field data" by default to use the field injection rate data as an input.

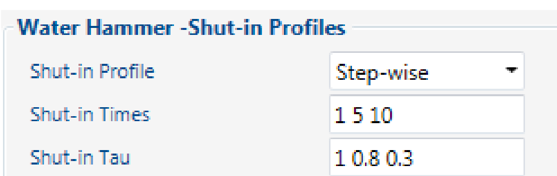


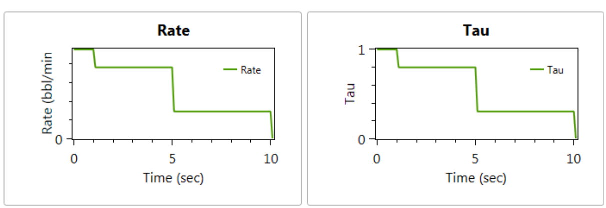
3.4.2.1 Import field data

With the "Import field data" option, the flowrate data during shut-in in the field data from the spreadsheet will be used as is. Shut-in Times and Shut-in Tau are not used for simulation, and may be left blank. The following options are for an artificial injection schemes.

3.4.2.2 Step-wise

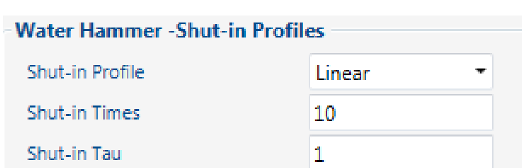
The user may choose a Step-wise profile in which multiple Shut-in Times and Shut-in Tau's are chosen. The values must be separated by spaces.

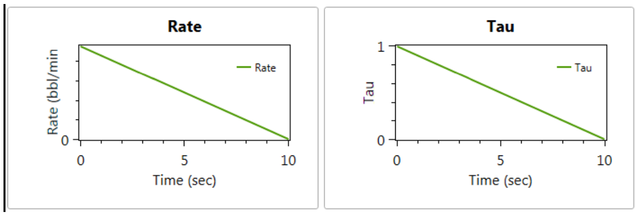




3.4.2.3 Linear

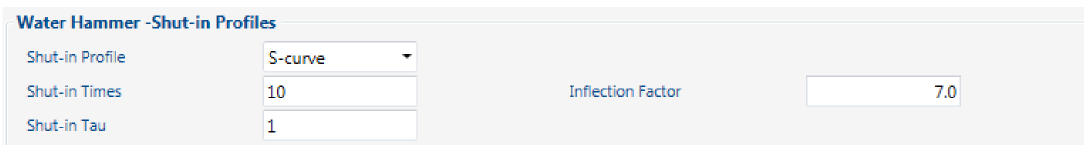
The user may choose a Linear profile in which a Shut-in time is chosen and the Shut-in Tau is equal to 1.

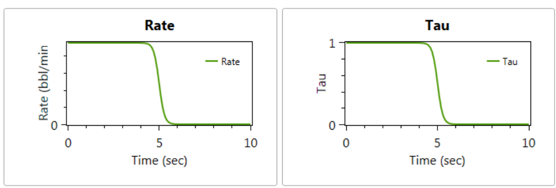




3.4.2.4 *S-Curve*

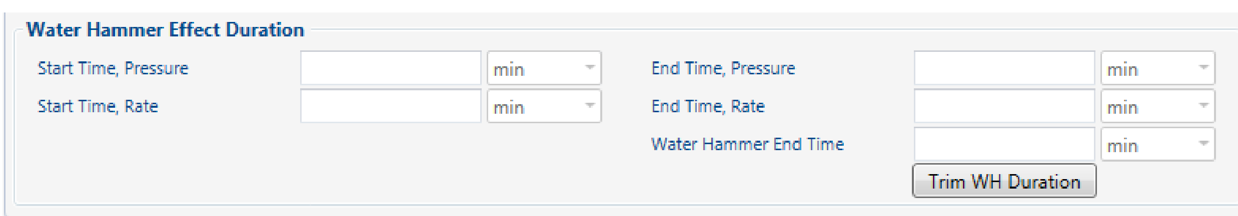
The user may choose an S-Curve profile in which a Shut-in time is chosen and the Shut-in Tau is equal to 1. In addition, an Inflection Factor value is chosen ranging from 4 to 10.





3.5 Trimming Water Hammer Data

3.5.1 WATER HAMMER EFFECT DURATION



This section allows the user to select the Duration of the Water Hammer Effect from the Field Data Charts. A more selective view of the Water Hammer portion of the Field Data can be obtained by using the right click to move the graph up or down.

- Holding down Ctrl+right click will allow the user to make a box around the area of the graph that the user would like to zoom in on.
- Using the mouse and left clicking on a spot on the Field Data line will show the respective Pressure/Rate and Time of that point.

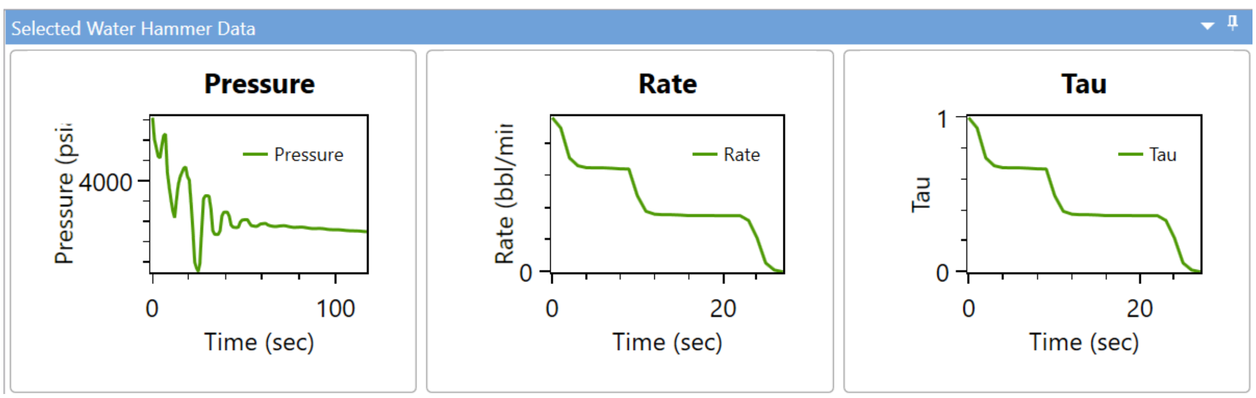
The definition of start and end times are as follows:

- Start Time, Pressure = Time on the pressure graph right before the pumps are stopped and the pressure drops

- End Time, Pressure = Last data point you want to collect. End of simulation time.
- Start Time, Rate = Time right before the rate drops, from the rate graph (Sometimes the rate and pressure graphs are slightly off-time between them. When this temporal discrepancy between rate and pressure data is encountered, it is recommended to adjust Start Time, Pressure to match simulated pressure to the field pressure data.)
- End Time, Rate = Time when the rate goes to 0
- Water Hammer End Time = Time at which the oscillations cease. This time should be earlier than End Time, Pressure

3.5.2 Trimming Water Hammer Data

Once the start and end times are specified, click "Trim WH Duration" Button. This will trim the water hammer data from the entire raw data. Only the trimmed data will be used for the next step. Once the water hammer data is successfully trimmed, the selected data will be plotted as below. Tau is dimensionless rate.



3.6 Water Hammer Simulation

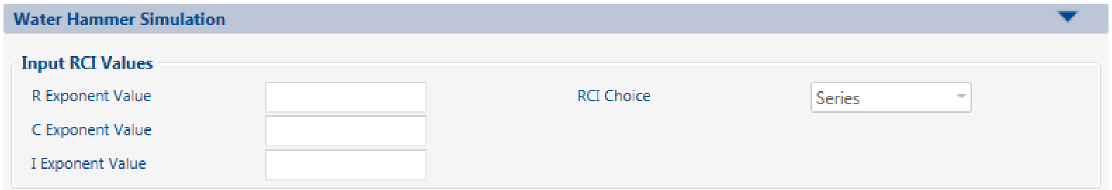
3.6.1 Input RCI Values

This section allows for the user to input the exponent values for the Resistance, Capacitance, and the Inertance. If no vales have been selected yet, arbitrary values may need to be input in order for the simulation to run. Since actual RCI values span a large range, the RCI are calculated by taking 10 to the power of the specified exponents (If R exponent is 7.2, R is $10^{7.2}$ in SI units). These are the values that must be adjusted in order to history match the field treatment data.

First, R must be fit by matching the amplitudes and the decay, and higher R values typically lead to a more dampened signal.

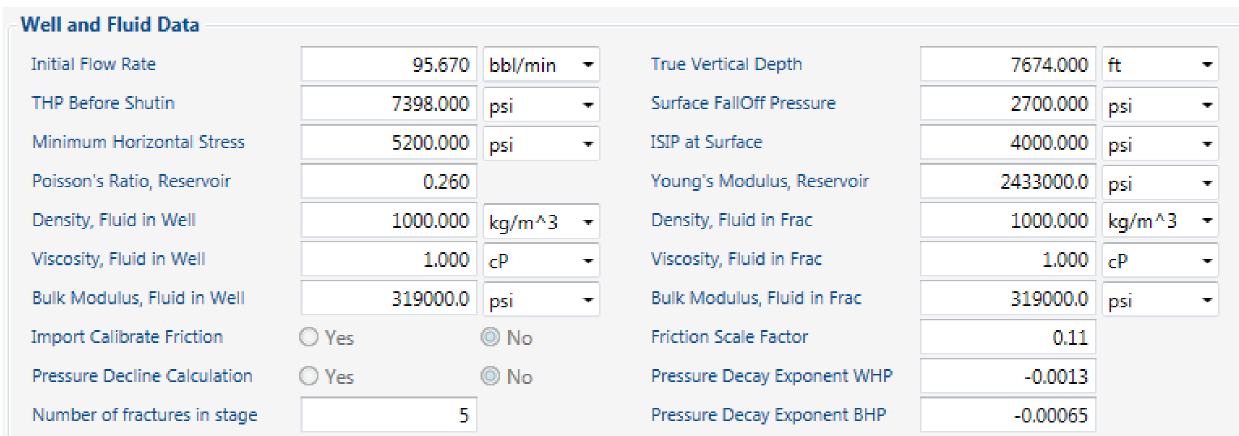
Next, C is fit by matching the frequency and the pressures.

Finally, I is obtained by altering I until the correct fracture height is calculated (fracture dimension will be seen on the output text).



3.6.2 Well and Fluid Data

Before being able to run the simulation, the well and fluid data must be input. The Flow Rate Before Shutin, THP Before Shutin, and Surface FallOff Pressure can be selected from the Field Data charts.



"***Initial Flow Rate***" is the injection rate immediately before shut-in. It can be read from the beginning value of the trimmed injection rate data.

"***THP Before Shut-in***" is the wellhead pressure immediately before shut-in. It can be read from the beginning value of the trimmed wellhead pressure data.

"***Surface FallOff Pressure***" is the wellhead pressure at the end of water hammer duration. The trendline of pressure decay will be extrapolated from this pressure.

"***Friction Scale Factor***" is multiplied to the friction factor calculated by correlation (Barr, 1981) to get a friction factor used in simulator. If experimental data for frictional pressure drop is available, the ratio of experimental frictional pressure drop in the wellbore to the calculated frictional pressure drop can be used for the friction scale factor. If experimental data is not available, 0.1 to 0.5 is generally a good estimation for the friction scale factor.

"***ISIP at Surface***" is the instantaneous shut-in pressure at the surface condition. This is used as an estimation purposes only in simulations. Calculated ISIP's at surface and bottomhole conditions will be calculated as simulation results.

"***Pressure Decay Exponent WHP***" is an exponent for the (extrapolated) trendline of wellhead pressure decay. Values between -0.0001 and -0.001 can be tried to approximate the wellhead pressure decay.

"***Pressure Decay Exponent BHP***" is an exponent for the (extrapolated) trendline of wellhead pressure decay. Values slightly larger than Pressure Decay Exponent WHP is recommended.

"***Number of fractures in stage***" is a number of perforation clusters in a stage or any number of fractures that user expects to have in a stage.

3.6.3 Wellbore Data

Information about the well is entered here. If the well is also horizontal, multiple sections can be entered with the respective Deviation from Horizontal of the well trajectory.

Wellbore Data

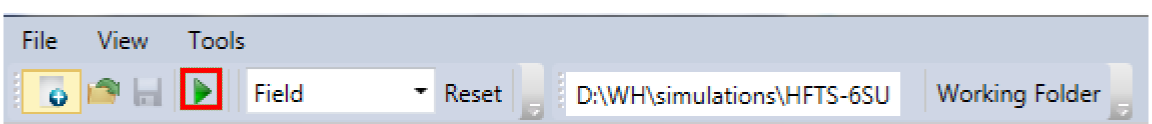
Section Length (ft)	Inner Diameter (inch)	Outer Diameter (inch)	Deviation from Horiz. (deg)	Youngs Modulus (psi)	Poisson's Ratio	Roughness Factor
7000.0	4.892	5.5	90.0	29000000.0	0.25	0.00006
500.0	4.892	5.5	60.0	29000000.0	0.25	0.00006
500.0	4.892	5.5	30.0	29000000.0	0.25	0.00006
9806.0	4.892	5.5	0.0	29000000.0	0.25	0.00006

Based on the number of pipe sections user wish to model (different pipe IDs or in this case a horizontal well with different angle deviations), pipe lengths, ID, OD, and the deviation are required. The pipe roughness (RF), Young's modulus and Poisson's ratio (v) values can be taken from the actual pipe data or standard values for steel.

For the first row in the table, the deviation from horizontal can be 90 deg for the vertical section of pipe, and the last row with 0 deg can represent the horizontal section of pipe.

3.7 Simulation Run

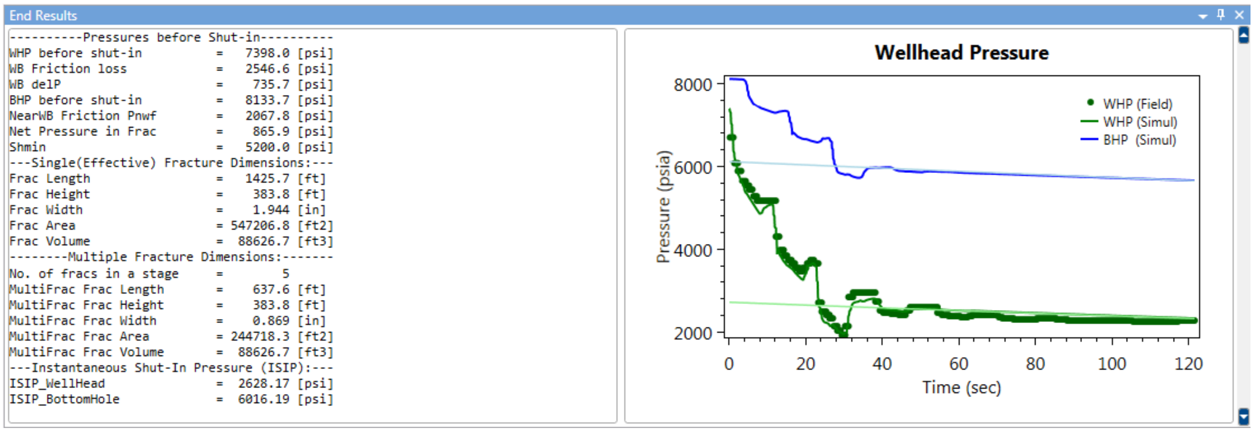
To run the simulation, click the green play button at the top left of the screen.



3.8 Simulation Output

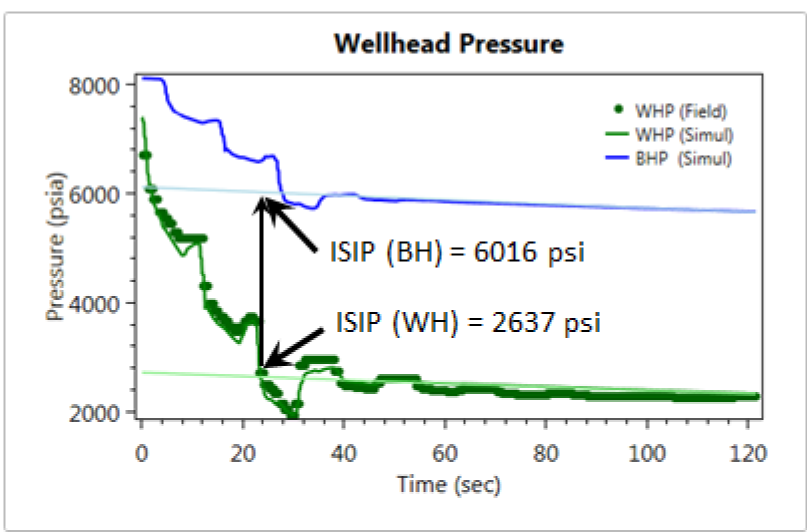
The output consists of several parameters that can be checked to ensure the reasonable simulation result. RCI values are displayed in SI and oilfield units, and the fracture parameters including the fracture half-length, height, and width are displayed in oilfield units along with the calculated net pressure in the fracture and the calculated near-wellbore frictional pressure drop. They are saved in both result.dat and result.csv files. The files can be found at:

C:\Users\<<username>>\Documents\WaterHammer\Output\<<casename>>



Once the simulation has completed running, the simulated data will also be plotted versus the field treatment data. Based on the differences in the two sets of data, R, C, and I should be adjusted to match the field treatment data.

One aspect to put focus into is the Instantaneous Shut-In Pressure (ISIP) at wellhead and bottom-hole conditions. A trendline can be formed based on the behavior of the field pressure data after the water hammer has attenuated. This trendline can be extrapolated back to earlier times to find the specific pressure at which the pressure data decreases below the trendline. This is the wellhead ISIP.

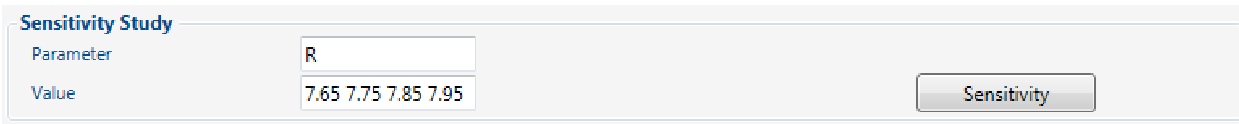


At that exact same time at bottom-hole conditions, the ISIP can also be found from the bottom-hole pressure data.

Chapter 4 : Sensitivity Study (To be implemented in program)

4.1 Running Sensitivity Study

After having run the simulation once with the specified parameters, the user can choose to go back and single out a parameter to explore the effects of changing the values.



The user must enter one parameter as well as the values that the user would like separated by a space. The combined results with all of the parameters for each value will appear in an excel file as seen below.

	A	B	C	D	E
1	Well	6SU	6SU	6SU	6SU
2	Stage	10	10	10	10
3	R exponen	7.65	7.75	7.85	7.95
4	C exponen	-3.55	-3.55	-3.55	-3.55
5	I exponen	5.25	5.25	5.25	5.25
6	R [Pa-s/m	4.47E+07	5.62E+07	7.08E+07	8.91E+07
7	C [m3/Pa]	2.82E-04	2.82E-04	2.82E-04	2.82E-04
8	I [Pa-s2/m	1.78E+05	1.78E+05	1.78E+05	1.78E+05
9	R [psi/bpc	1.19E-02	1.50E-02	1.89E-02	2.38E-02
10	C [bbl/psi	1.22E+01	1.22E+01	1.22E+01	1.22E+01
11	I [psi/(bbl	5.49E-10	5.49E-10	5.49E-10	5.49E-10
12	WHP_Fall	3000	3000	3000	3000
13	Fall_Time	50	50	50	50
14	WHP befo	7878	7878	7878	7878
15	WB Frictic	2585.9	2585.9	2585.9	2585.9
16	WB delP [	696.4	696.4	696.4	696.4
17	BHP befor	8574.4	8574.4	8574.4	8574.4
18	NearWB F	1552	1953.9	2459.8	3096.7
19	Net Press	1629.4	1227.5	721.6	84.7
20	Shmin [ps	5393	5393	5393	5393
21	ISIP [psi]	3427	3427	3427	3427

Chapter 5 : Saving and Loading Data – File Menu

5.1 Saving and Loading Data – File Menu

The file menu in WATER HAMMER 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*, 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.wthm is used. Later *save* will use the previously chosen file name and will not prompt.

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

Close Project
Closes the current file.

Exit
Exits WATER HAMMER.

Attention
The default location for the data file is C:\Users\[userName]\Documents\UTWaterHammer\Datafiles The default location for the actual working folder is C:\Users\[userName]\Documents\UTWaterHammer\Output

Chapter 6 : Units – Metric and Field

The Water Hammer 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. 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.

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
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
Permeability	m^2	md	1e+15
Pressure	Pascal	psi	0.000145038
Compressibility	1/Pascal	1/psi	6894.757