Multicorp 5.2 Help

Institute for Corrosion and Multiphase Technology

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Multicorp 5 Help

Introduction

by Institute for Corrosion and Multiphase Technology

Multicorp is a corrosion prediction engine that can simulate corrosion in various conditions and environments. It was developed at the Institute for Corrosion and Multiphase Technology at Ohio University. It is available under contract to members of the Corrosion Center Joint Industry Project.

Multicorp 5 Help

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Special thanks to:

All the people who contributed to this project including all faculty, staff, students, and research fellows of the Institute for Corrosion and Multiphase Technology at Ohio University. We would also like to thank all of the sponsors who have given valuable feedback on Multicorp in order to make it better.

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I

1 Overview

Multicorp 5.2 Help

Multicorp is a corrosion and flow prediction engine that enables the simulation of corrosion and flow under various conditions and in various environments.

The overview of Multicorp consists of:

- System Requirements
- Availability
- Installation
- Modules
- Components and Structure
- Design

For more information about Multicorp, visit us online at CorrosionCenter.org or email us at Multicorp@CorrosionCenter.org

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1.1 System Requirements

Microsoft®
Windows®

Multicorp 5 has been tested on computers running Windows XP, Vista, and Win 7, both 32 bit and 64 bit. While it has been shown to run properly in those environments, there may be some cases that operating system configurations prevent it from running properly. **Microsoft's .Net Framework 4.0 is required for Multicorp to run, without it the program will fail to launch.** Administrative privileges should not be required to run Multicorp but are required to install the program. In order to run Multicorp please note the minimum and recommended specifications for your computer below.

Minimum System Requirements:

Software: Windows (Xp, Vista, 7, 8*) 32bit or 64bit, .Net Framework 4.0, Microsoft Office Excel 2003 or better

Hardware: 512MB RAM, 1.0GHz Processor, 25MB free space

Recommended System Requirements:

Software: Windows (Xp, Vista, 7, 8*) 32bit or 64bit, .Net Framework 4.0, Microsoft Office Excel 2003 or better

Hardware: 2GB RAM, 2.0GHz Dual-Core or better Processor, 250MB free space

*Testing for Windows 8 has been very limited and Compatibility Mode set to Windows 7 may be necessary.

1.2 Availability

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Multicorp is available to active members of the Corrosion Center Joint Industry Project, Top-of-the-Line Corrosion Joint Industry Project, or Water Wetting Joint Industry Project at Ohio University.

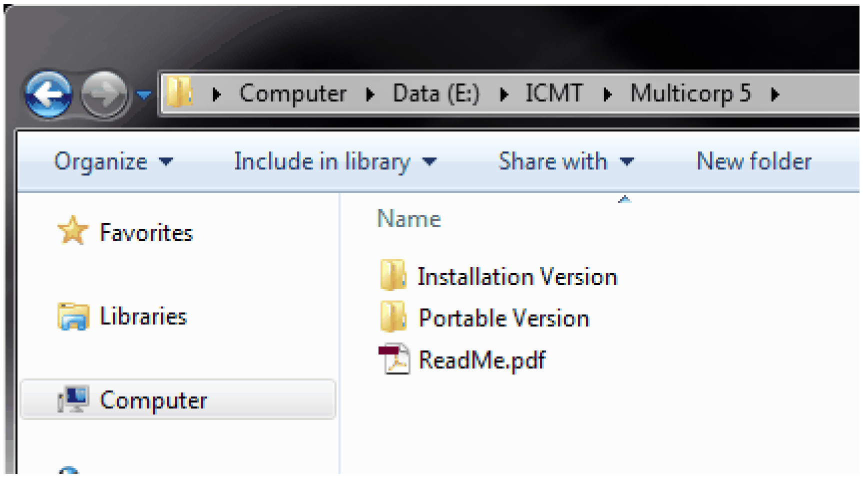
In order to download Multicorp software you must register for an account on the ICMT Secure Website.

Once you have been granted access to the website, click the software download link and choose the version of Multicorp you would like to download.

Proceed to the Installation help in order to run Multicorp on your computer.

1.3 Installation

Once Multicorp has been downloaded, extract the contents of the zip file to a location of your choosing.



Inside of the Multicorp-5 folder there are two folders (Run and Install).

The "Portable Version" folder contains a portable version of Multicorp and the "Installation Version" folder contains the installation version of Multicorp.

Installation version will make sure all prerequisites such as Microsoft's .Net Framework are installed prior to Multicorp running but may require administrative rights for installation.

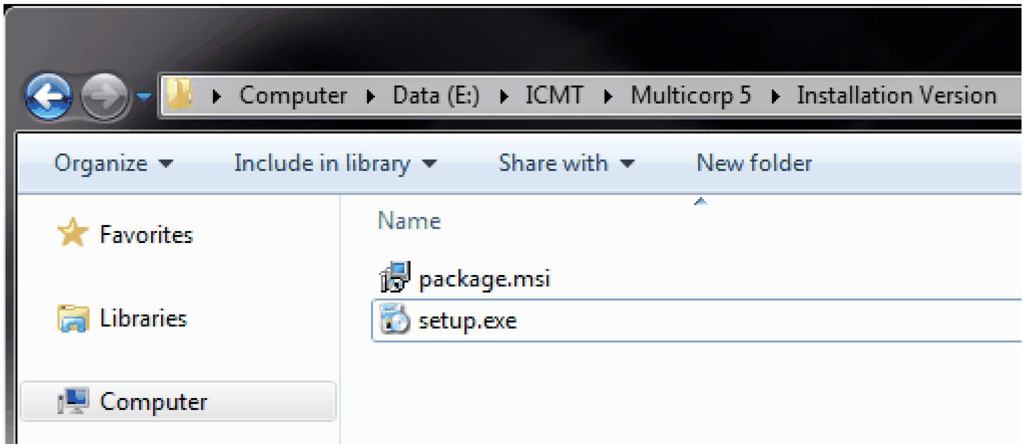
The portable version won't install any prerequisites therefore the program may not run if the prerequisites are not met but it does not require administrative rights to run.

After successfully installing and running the program please proceed to Multicorp tutorials or term definitions to learn how to use the program.

1.3.1 Install Version

Once the zip file has been decompressed and opened, open the installation version folder.

Inside there are two files: setup.exe and package.msi, double click the file named **setup.exe**.

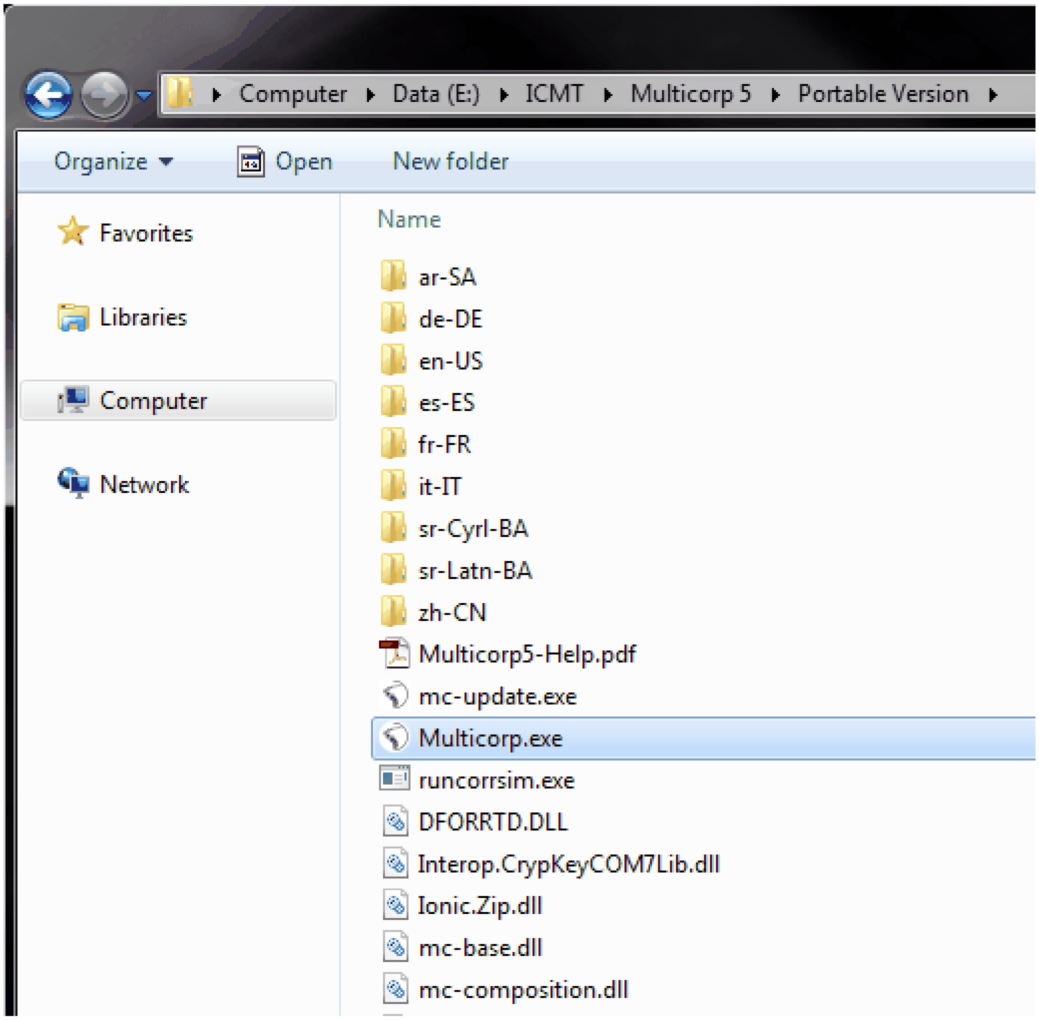


Follow the on screen instructions as installation of prerequisites may occur before Multicorp is installed.

1.3.2 Portable Version

Once the zip file has been decompressed and opened, open the portable version folder.

Inside the portable version folder there will be multiple files. Find the application file Multicorp.exe and double click it.



If you encounter and error window saying "**This application could not be started**" then please use the installation version as your computer has not met the software prerequisites needed for Multicorp to function.

1.4 Modules

Multicorp has various modules developed in their respective projects that are only available to members that are part of the associated project.

Currently there are four flavors of Multicorp available for download depending upon your project association:

Multicorp without any additional modules is available for those members who are a part of the Corrosion Center Joint Industry Project (CC-JIP)

- Multicorp 5

Water Wetting is available for those members who are a part of the Water Wetting Joint Industry Project (WW-JIP).

- Multicorp-WW 5

Topcorp is available for those members who are a part of the Top-of-the-Line Corrosion Joint Industry Project (TLC-JIP).

- Multicorp-Topcorp 5

Topcorp-WW is available for those members who are a part of the TLC-JIP and WW-JIP

- Multicorp-Topcorp-WW 5

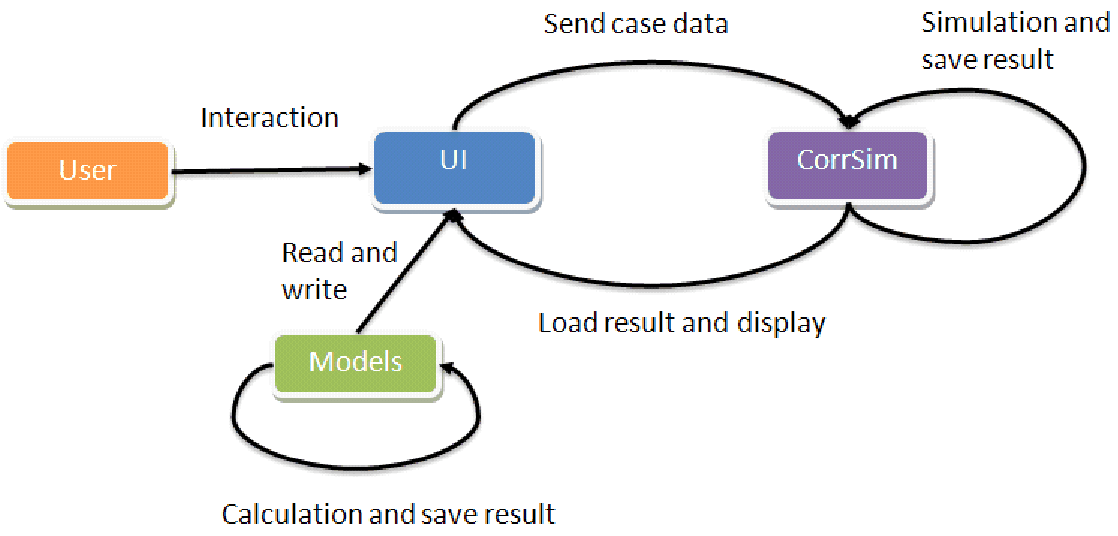
1.5 Components and Structure

Components

The whole Multicorp system consists of the following components:

- user interface (UI) and multicorp models (MM)
- corrosion simulation engine (CorrSim)

The functionality and relationship of the main components are explained in the figure below. As described, the UI interacts with the user to get input data, and then converts input as corrosion case data and send it to CorrSim to simulate. Through interfaces defined in CorrSim, UI controls the simulation process. During simulation, CorrSim saves calculation results into the output file from loop to loop; the UI then gets the result from CorrSim and displays the result.



UI and MM work together to execute chemical calculation based on the user input. UI is responsible for interacting with the user, including taking user input, validating data and displaying result. MM is responsible for data persistence, pre-calculation and interaction (send data and retrieve result) with the corrosion simulation engine.

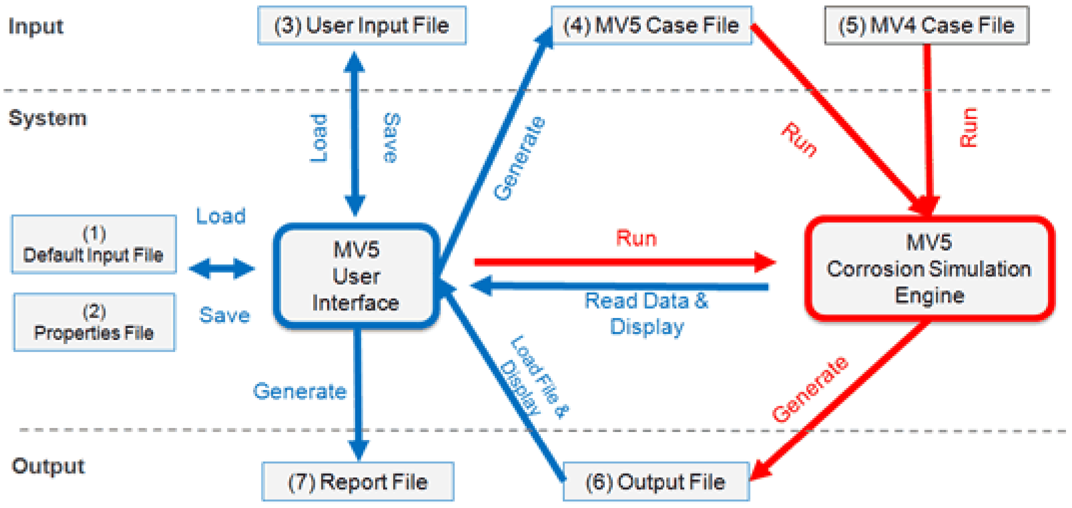
File Input/Output

The design of Multicorp 5 File system and communication between files and Multicorp 5 system are described in the figure below. As described, there are three types of files:

1) system files, including Default Input File (.xml) and Properties File (.xml);

2) input files, including User Input File (.mcinput), MV4 Case File and MV5 Case File (.mccase);

3) output files, including Output File (.output) and Report File.

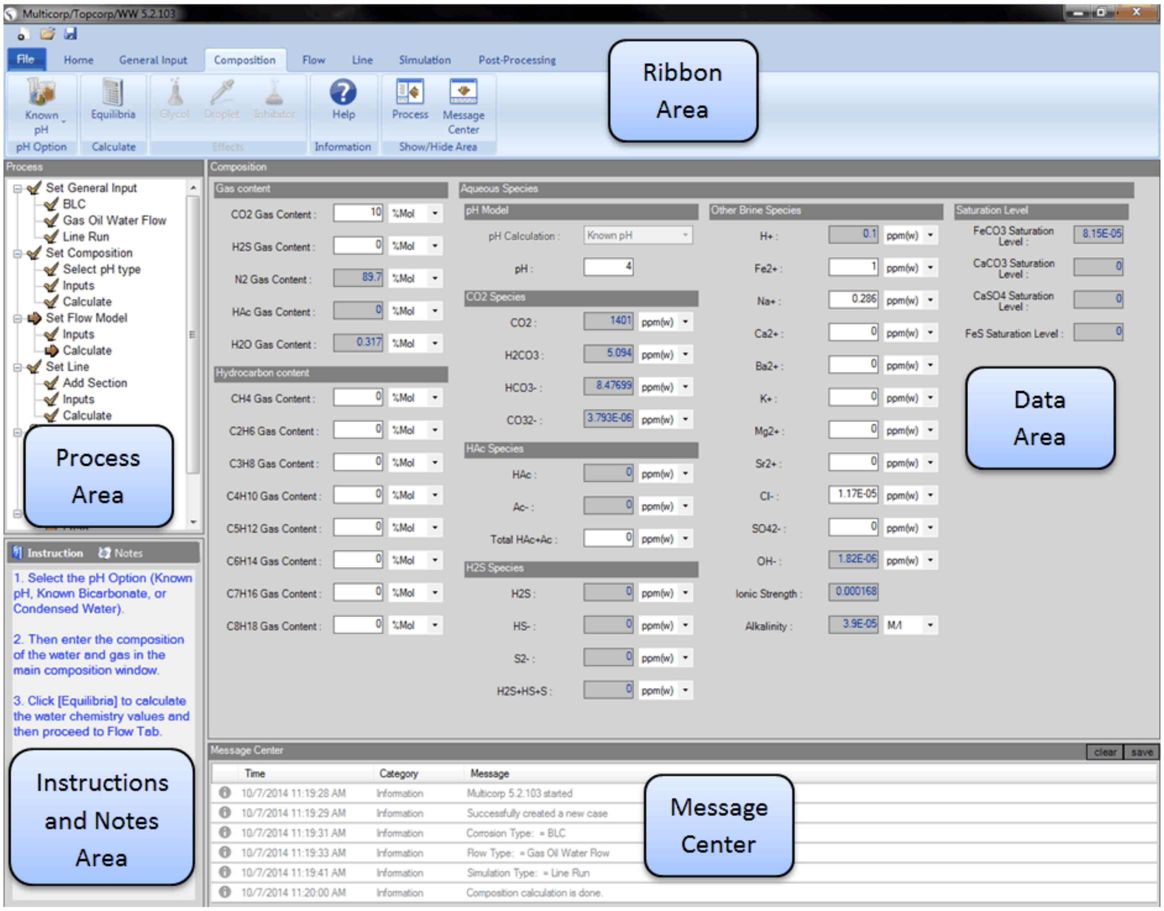


1.6 Design

Multicorp is broken into five different areas each with a specific function.

These areas are:

- **Ribbon Area** - The top menu bar that contains tabs as well as data panel specific buttons based on tab selected.
- **Data Area** - The main data area where all variables will be shown dependent upon tab selected.
- **Process Area** - The process state area where progress of the corrosion prediction process is shown.
- **Instruction and Notes Area** - The instruction and notes area that gives step by step instruction as well as user based notes dependent upon ribbon area tab chosen.
- **Message Center** - The messaging center that shows processing events as they happen and gives potential errors and warnings.



1. Select the pH Option (Known pH, Known Bicarbonate, or Condensed Water).

2. Then enter the composition of the water and gas in the main composition window.

3. Click [Equilibria] to calculate the water chemistry values and then proceed to Flow Tab.

Gas content

CO2 Gas Content : 10 %Mol
H2S Gas Content : 0 %Mol
N2 Gas Content : 89.7 %Mol
HAc Gas Content : 0 %Mol
H2O Gas Content : 0.317 %Mol

Hydrocarbon content

CH4 Gas Content : 0 %Mol
C2H6 Gas Content : 0 %Mol
C3H8 Gas Content : 0 %Mol
C4H10 Gas Content : 0 %Mol
C5H12 Gas Content : 0 %Mol
C6H14 Gas Content : 0 %Mol
C7H16 Gas Content : 0 %Mol
C8H18 Gas Content : 0 %Mol

pH Model

pH Calculation : Known pH
pH : 4

CO2 Species

CO2 : 1401 ppm(w)
H2CO3 : 5.094 ppm(w)
HCO3- : 8.47699 ppm(w)
CO32- : 3.793E-06 ppm(w)

HAc Species

HAc : 0 ppm(w)
Ac- : 0 ppm(w)
Total HAc+Ac : 0 ppm(w)

H2S Species

H2S : 0 ppm(w)
HS- : 0 ppm(w)
S2- : 0 ppm(w)
H2S+HS+S : 0 ppm(w)

Other Brine Species

H+ : 0.1 ppm(w)
Fe2+ : 1 ppm(w)
Na+ : 0.286 ppm(w)
Ca2+ : 0 ppm(w)
Ba2+ : 0 ppm(w)
K+ : 0 ppm(w)
Mg2+ : 0 ppm(w)
Sr2+ : 0 ppm(w)
Cl- : 1.17E-05 ppm(w)
SO42- : 0 ppm(w)
OH- : 1.82E-06 ppm(w)
Ionic Strength : 0.000168
Alkalinity : 3.9E-05 M/l

Saturation Level

FeCO3 Saturation Level : 8.15E-05
CaCO3 Saturation Level : 0
CaSO4 Saturation Level : 0
FeS Saturation Level : 0

Time	Category	Message
10/7/2014 11:19:28 AM	Information	Multicorp 5.2.103 started
10/7/2014 11:19:29 AM	Information	Successfully created a new case
10/7/2014 11:19:31 AM	Information	Corrosion Type: = BLC
10/7/2014 11:19:33 AM	Information	Flow Type: = Gas Oil Water Flow
10/7/2014 11:19:41 AM	Information	Simulation Type: = Line Run
10/7/2014 11:20:00 AM	Information	Composition calculation is done.

Process Area Icon Breakdown

The process tree has five different icons to represent different states of each process. In order for Multicorp to work, these processes must be done in order from top to bottom of the process tree.

Below you will find the meaning for each icon:

🔒 = Process is not yet available, finish prerequisite process(es) first.
➡ = Process is available but not yet finished, finish process before moving on.
▷ = Process is in progress, wait for process to finish.
✓ = Process is finished, okay to move on to next step.
⛔ = Process is not required, skip to next step.

Part

II

2 Technical Background

Multicorp employs various mathematical models in order to simulate system conditions.

Below are topics related to the technical background of the Multicorp software:

- Electrochemical Reactions at the Steel Surface
- Transport Processes in the Surface Film and in the Boundary Layer
- Chemical Reactions
- Growth of Iron Carbonate Films
- High Salt Concentration
- H_2S Model
- Growth of Mackinawite Films

2.1 Electrochemical Reactions at the Steel Surface

As the CO_2 corrosion process is electrochemical in nature, the corrosion rate can be explicitly determined by calculating the rate of the electrochemical reactions underlying it such as: iron oxidation as well as reductions of hydrogen ion, carbonic and acetic acid. The electrochemical reaction rate can be expressed as a current density, i (expressed in $A\ m^{-2}$), which is a function of the potential at the metal surface, E (expressed in V):

$$i = \pm i_o \cdot 10^{\pm \frac{E - E_{rev}}{b}} \cdot \prod_{s=1}^{n_s} (1 - \theta_s) \quad (1)$$

This equation is unique for each of the electrochemical reactions involved in a corrosion process such as hydrogen reduction, iron oxidation, etc. The “+” sign applies for anodic reactions while the “-” sign applies for cathodic reactions. θ_s is the fraction of the steel surface where a given electrochemical reaction does not occur because the surface is covered by a species s which could be an adsorbed inhibitor or a protective film. The product sign Π accounts for a compounding (additive) effect by more than one surface species. For each electrochemical reaction, Equation (1) is different because of the parameters defining it: i_o - the exchange current density in $A\ m^{-2}$, E_{rev} - the reversible potential in V, and b - the Tafel slope in V. These parameters have to be determined experimentally and are functions of temperature and in some cases species concentrations. An overview covering how these parameters are calculated in the present model is given in reference (1). The unknown electrical potential at the metal surface *E* in Equation (1), is also called the corrosion potential or open circuit potential, which can be found from the charge balance equation at the metal surface:

$$\sum_{a=1}^{n_a} i_a = \sum_{c=1}^{n_c} i_c \qquad (2)$$

where n_a and n_c are the total number of anodic and cathodic reactions respectively.

2.2 Transport Processes in the Surface Film and in the Boundary Layer

In corrosion, certain species in the solution are “produced” at the steel surface (e.g. Fe^{2+}) while others are depleted (e.g. H^+). This leads to concentration gradients and diffusion of these species to and from the surface. On the other hand the rate of the electrochemical reactions depends on the species concentrations at the steel surface. Therefore, there exists a two-way coupling between the electrochemical processes at the metal surface (corrosion) and transport processes in the adjacent solution layer (i.e. diffusion in the boundary layer). Flow (i.e. turbulent eddies) can penetrate deep into the boundary layer and significantly enhance the rate of species transport to and from the surface, hence leading to a higher corrosion rate. Conversely, when protective corrosion product layers form on the steel surface, they may slow down the diffusion of species and can reduce the corrosion rate.

In a model of uniform corrosion, a one-dimensional species transport domain is sufficient, stretching from the steel surface through the pores of a surface corrosion product layer and the mass transfer boundary layer, ending in the turbulent bulk of the solution. The concentration of each species is governed by a species conservation (mass balance) equation. A universal form of the equation which describes transport for species *j* in the presence of chemical reactions, which is valid both for the liquid boundary layer and the porous corrosion product layer, is:

$$\underbrace{\frac{\partial(\varepsilon c_j)}{\partial t}}_{\text{accumulation}} = \underbrace{\frac{\partial}{\partial x}\left(\varepsilon^{1.5} D_j^{eff} \frac{\partial c_j}{\partial x}\right)}_{\text{net flux}} + \underbrace{\varepsilon R_j}_{\substack{\text{source or sink}\\ \text{due to chemical reactions}}} \qquad (3)$$

where c_j is the concentration of species *j* in ${}^{kmol}/_{m^3}$, *e* is the porosity of the corrosion product layer, $D_j^{eff} = D_j^m + D_j^t$ is the effective diffusion coefficient of species *j,* in ${}^{m^2}/_{s}$, which includes both the molecular component, D^m_j, and the turbulent component, D^t_j. Turbulent convection has been modeled by *turbulent diffusion* as the former is difficult to determine explicitly. The source or sink, R_j of species *j*, is due to all the chemical reactions in which the particular species is involved in $kmol/m^3s$. *t* is time in *seconds* and *x* is the spatial coordinate in *meters*. It should be noted that, in the transport equation above, electromigration has been neglected as its contribution to the overall flux of species is small.

One equation of the form (3) is written for each species in the solution. The resulting set of equations is solved simultaneously in space and time. The boundary conditions for this set of partial differential equations are:

(a) flux of species at the steel surface determined from the rate of the electrochemical reactions as given by Equation (1) and
(b) equilibrium concentrations of species in the bulk.

The equilibrium is used also as the initial condition. Once the set of equations is solved for any given time step, the corrosion rate, *CR*, can be simply calculated as the flux of Fe^{2+} ions at the metal surface.

The details covering how to construct and solve the set of partial differential equations mentioned above are given in the references (1, 2).

2.3 Chemical Reactions

A variety of chemical reactions may accompany the corrosion process, some homogeneous (occurring everywhere in the solution) and others heterogeneous (occurring only at the metal surface). Hydration and dissociation are two typical homogenous chemical reactions accounted for in CO_2 and H_2S corrosion. Precipitation and dissolution of iron carbonate and iron sulfide are the heterogeneous chemical reactions considered in the present model. Also the solid state formation of mackinawite (FeS) is also considered in the model. A list of all the chemical reactions included in the model is given in reference (1). Most chemical reactions are very fast when compared to diffusion and electrochemical reactions (all occurring simultaneously in corrosion) and can maintain chemical equilibrium throughout the solution. Conversely, when some chemical reactions proceed slowly, other faster processes (such as electrochemical reactions or diffusion) can lead to local non-equilibrium in the solution. Either way, by affecting the surface concentrations of species, chemical reactions can significantly alter the rate of electrochemical processes at the steel surface and the rate of corrosion. This is particularly true when, due to high local concentrations of species, the solubility limit is exceeded and precipitation of surface corrosion product layers occurs.

Homogeneous Chemical Reactions

The rate of a homogeneous chemical reaction can be calculated, assuming ideal solutions and first order kinetics, as

$$R_j = k_f \prod_{r=1}^{n_r} c_r - k_b \prod_{p=1}^{n_p} c_p \qquad (4)$$

where K_f and K_b are the forward and backward reaction rate constants for the particular chemical reaction while c_r and c_p are the concentrations of reactants and products respectively. Generally, for any set of *k* chemical reactions involving *j* species one can write compactly:

$$R_j = a_{jk} r_k$$

(5)

where tensor notation applies for the subscripts, a_{jk} is the stoichiometric matrix where row *j* represents the *j*-th species, column *k* represents the *k*-th chemical reaction, and r_k is the reaction rate vector. Using this technique any number of homogenous chemical reactions can be added to the model with little effort.

Heterogeneous Chemical Reaction

The rate of precipitation of iron carbonate $R_{FeCO3(s)}$ can be described as a function of the saturation value *S*, the solubility limit K_{sp} , temperature *T* and surface area-to-volume ratio *A/V*:

$$R_{FeCO_{3(s)}} = \frac{A}{V} \cdot f(T) \cdot K_{sp} \cdot f(S)$$

(6)

Supersaturation is defined as:

$$S = \frac{c_{Fe^{2+}} c_{CO_3^{2-}}}{K_{sp}}$$

(7)

From the two different expressions describing the kinetics of iron carbonate precipitation proposed by references (4, 5), the latter is used because it is believed to give more realistic results especially at higher iron carbonate saturation values.

2.4 Growth of Iron Carbonate Films

When iron carbonate precipitates at the steel surface, it can slow down the corrosion process by:

- Presenting a diffusion barrier for the species involved in the corrosion process, i.e. by reducing the flux of species, accounted for by porosity *e* in Equation (3);
- Blocking (covering) a portion of the steel surface and preventing the electrochemical reactions from happening there, as accounted for by surface coverage q_S in equation

(1).

Iron carbonate layer growth depends primarily on the precipitation rate, R_{FeCO3}. As more iron carbonate precipitates the layer can grow in density as well as thickness. However, the steel surface corrodes under the layer, continuously creating a “void” between the corrosion product layer and the steel surface (here called “undermining”). As soon as it is created, the void starts filling up by the ongoing precipitation. When the rate of precipitation at the steel surface equals or exceeds the rate of corrosion (undermining) dense protective corrosion product layers form - sometimes very thin, but still protective. Vice versa, when the corrosion process undermines the newly formed corrosion product layer faster than precipitation can fill in the voids, a porous and unprotective corrosion product layer forms - which can be sometimes very thick, but still unprotective. On the other hand, a sudden change in condition (i.e. pH control) might cause the solution to become undersaturated ($S < 1$, Equation 7) and results in iron carbonate layer dissolution and an increase of corrosion rate.

In the context of the present model, a mass balance equation for solid iron carbonate which includes the effect of undermining and dissolution can be written and expressed in terms of volumetric corrosion product layer porosity *e* :

$$\underbrace{\frac{\partial \varepsilon}{\partial t}}_{\substack{layer\ porosity\\ change}} = \underbrace{-\frac{M_{FeCO_{3(s)}}}{\rho_{FeCO_{3(s)}}} R_{FeCO_3}}_{precipitation} - \underbrace{CR\frac{\partial \varepsilon}{\partial x}}_{undermining} + \underbrace{\frac{M_{FeCO_{3(s)}}}{\rho_{FeCO_{3(s)}}} DIS_{FeCO_3}}_{dissolution} \qquad \textbf{(8)}$$

Solution of this equation simultaneously with the transport Equation (3) for various species and electrochemical Equation (1) enables direct prediction of iron carbonate layer thickness and porosity as well as its protective properties. More details about the layer growth model are given elsewhere (1, 2, 3).

2.5 High Salt Concentration

It is observed that high content of salt not only retards the heterogeneous charge transfer reactions but also the homogenous chemical reactions and mass transfer reactions. Chloride ion was found to preferably adsorb on the metal surface and interfere with the reaction occurring at the metal surface. Therefore, the salt retardation effect on the charge transfer reaction can be modeled by using adsorption theory, which is commonly used to model the inhibitor effect. The Frumkin isotherm:

$$K_{a/d} c_{salt} = \left(\frac{\theta}{1-\theta}\right) e^{-f\theta} \qquad (14\ )$$

successfully captures the relation between the retardation factors and the salt concentration, where c_{salt} is the salt concentration and θ is the chloride surface coverage. Experimental data from high salt concentration testing has been used to identify the $K_{a/d}$ and f.

2.6 H2S Model

Dissolved H_2S is certainly a mild acid and, if present in high enough concentrations, has to be treated as another cathodic species, in a similar way as carbonic and acetic acids. The presence of H_2S can lead to formation of various forms of iron sulfides that can be very protective. There is always a very thin (<<1mm), but dense, film of mackinawite at the steel surface which acts as a solid state diffusion barrier for species involved in the corrosion reaction. Due to the presence of the inner mackinawite film and possibly the outer corrosion product layer it is assumed that the corrosion rate of steel in solutions containing H_2S is always under mass transfer control and the flux of species through the inner mackinawite film via solid state diffusion is calculated as:

$$Flux_i = A_i e^{-\frac{Bi}{RT_k}} \ln\left(\frac{c_{s,i}}{c_{R,i}}\right) \qquad (9\ )$$

where $Flux_i$ is the flux of species (such as $\mathbf{H_2S}$, $\mathbf{H^+}$, $\mathbf{CO_2}$) involved in the corrosion reaction, A_i, B_i are the Arrhenius constants, T_K is the temperature in Kelvin, $c_{s,i}$ is the concentration of species *i* on the steel surface, $c_{R,i}$ is the reference concentration.

The total corrosion rate in CO_2/H_2S corrosion environments is the sum of all fluxes:

$$CR = Flux_{H_2S} + Flux_{H^+} + Flux_{CO_2} \qquad (10)$$

2.7 Growth of Mackinawite Films

It is assumed that the amount of scale retained on the metal surface at any point in time depends on the balance of:

- scale formation (generated by spalling of the thin mackinawite film underneath it and by precipitation from the solution), and
- scale damage (by hydrodynamic stresses and/or by chemical dissolution)

$$\underbrace{SRR}_{\substack{\text{scale}\\\text{retention}\\\text{rate}}} = \underbrace{SFR}_{\substack{\text{scale}\\\text{formation}\\\text{rate}}} - \underbrace{SDR}_{\substack{\text{scale}\\\text{damage}\\\text{rate}}} \qquad (11)$$

where all the terms are expressed in mol/(m^2s). As in this study it was found that precipitation of iron sulfide did not play a significant role in maintaining a corrosion product layer, neither did chemical dissolution of the scale. The scale retention rate is written as:

$$\underbrace{SRR}_{\substack{\text{scale}\\\text{retention}\\\text{rate}}} = \underbrace{CR}_{\substack{\text{corrosion}\\\text{rate}}} - \underbrace{SDR_m}_{\substack{\text{mechanical}\\\text{scale damage}\\\text{rate}}} \qquad (12)$$

The corrosion rate, CR, is calculated by Equation (10). Due to the lack of experimental data, mechanical scale damage (SDR) is not used in the current model. When the scale retention rate *SRR* is known, then the change in mass of the mackinawite scale can be determined:

$$\Delta m_{os} = SRR \frac{M_{FeS}}{\rho_{FeS}} \frac{\Delta t}{\Delta x_{cv}} \qquad (13)$$

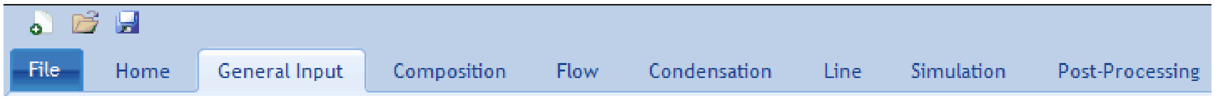
where M_{FeS} is the molar mass of iron sulfide in kg/mol, p_{FeS} is the density of iron sulfide in kg/m^3, Δt is the time interval in seconds and Δx_{cv} is the control volume width in meters.

A large number of carefully controlled corrosion experiments have been conducted in our laboratory over the past few years, at various temperatures (20-80°C), partial pressures of CO_2 (1-7 bar) and flow velocities (stagnant to 3 m/s) in both single and multiphase flow. All the data strongly suggest that the presence of even very small amounts of H_2S (10 ppm in the gas phase) leads to rapid and significant reduction in the CO_2 corrosion rate. At higher H_2S concentrations this trend is reversed. The effect seems to be universal and depends solely on the H_2S concentration, as all the data obtained at very different conditions follow the same trend.

Part

III

3 Tabs

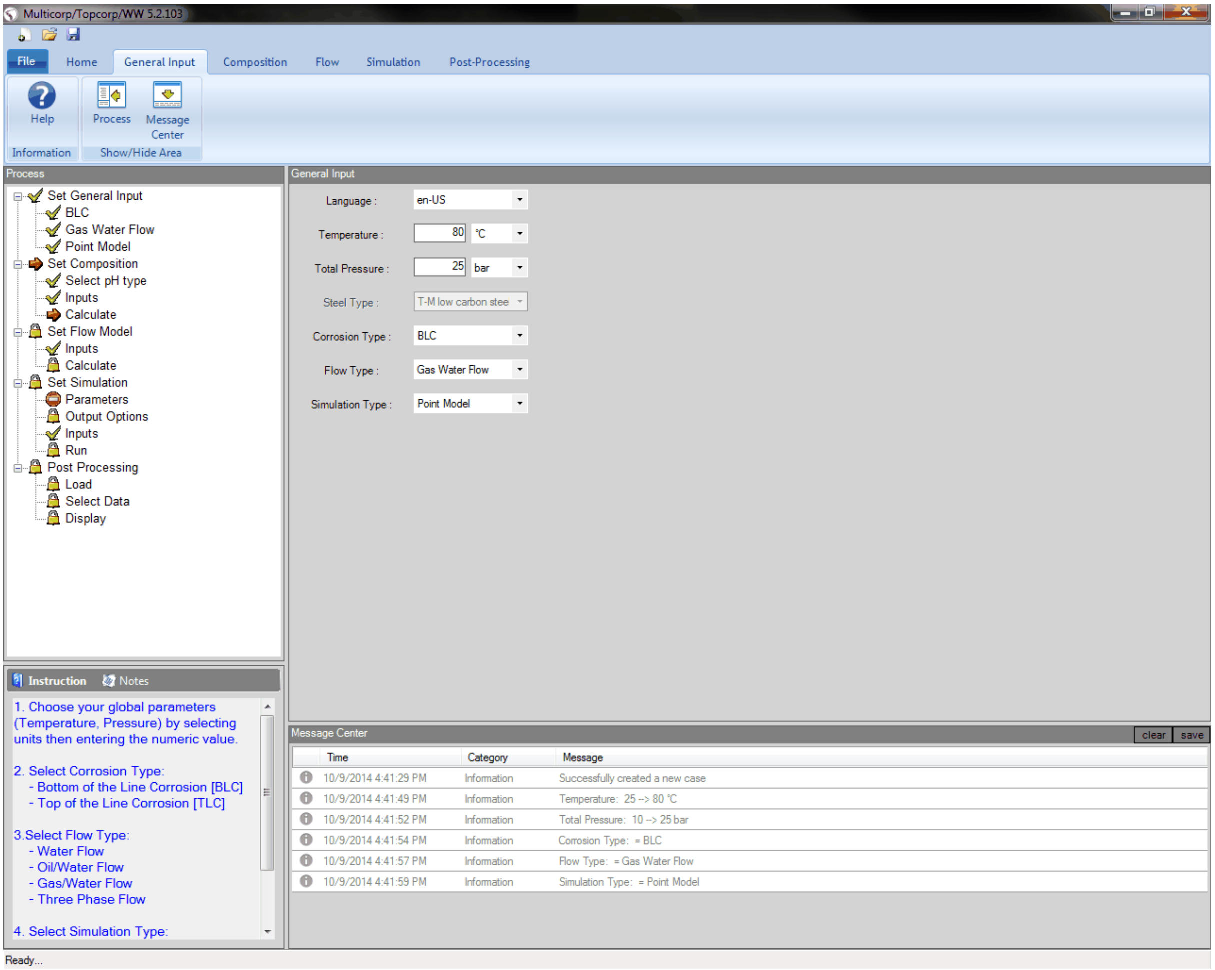


Multicorp is separated in multiple tabs to organize different system conditions such as composition and flow.

Below are the tabs of Multicorp:

- **General Input**
- **Composition**
- **Flow**
- **Condensation**
- **Line**
- **Simulation**
- **Post Processing**

3.1 General Input



Language : en-US
Temperature : 80 °C
Total Pressure : 25 bar
Steel Type : T-M low carbon stee
Corrosion Type : BLC
Flow Type : Gas Water Flow
Simulation Type : Point Model

1. Choose your global parameters (Temperature, Pressure) by selecting units then entering the numeric value.

2. Select Corrosion Type:
  - Bottom of the Line Corrosion [BLC]
  - Top of the Line Corrosion [TLC]

3.Select Flow Type:
  - Water Flow
  - Oil/Water Flow
  - Gas/Water Flow
  - Three Phase Flow

4. Select Simulation Type:

```
Time                   Category     Message
10/9/2014 4:41:29 PM   Information  Successfully created a new case
10/9/2014 4:41:49 PM   Information  Temperature:  25 --> 80 °C
10/9/2014 4:41:52 PM   Information  Total Pressure:  10 --> 25 bar
10/9/2014 4:41:54 PM   Information  Corrosion Type:  = BLC
10/9/2014 4:41:57 PM   Information  Flow Type:  = Gas Water Flow
10/9/2014 4:41:59 PM   Information  Simulation Type:  = Point Model
```

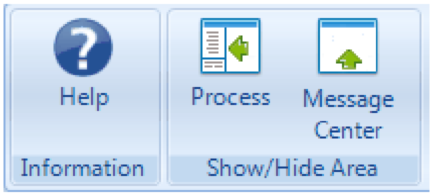
The General Input Tab allows you to define system wide variables such as culture, temperature, and total pressure.

Below are links to General Input tab's Ribbon Area and Data Area:

- Ribbon Area
- Data Area

Once the general input parameters have been defined, Composition parameters can be defined next.

3.1.1 Ribbon Area



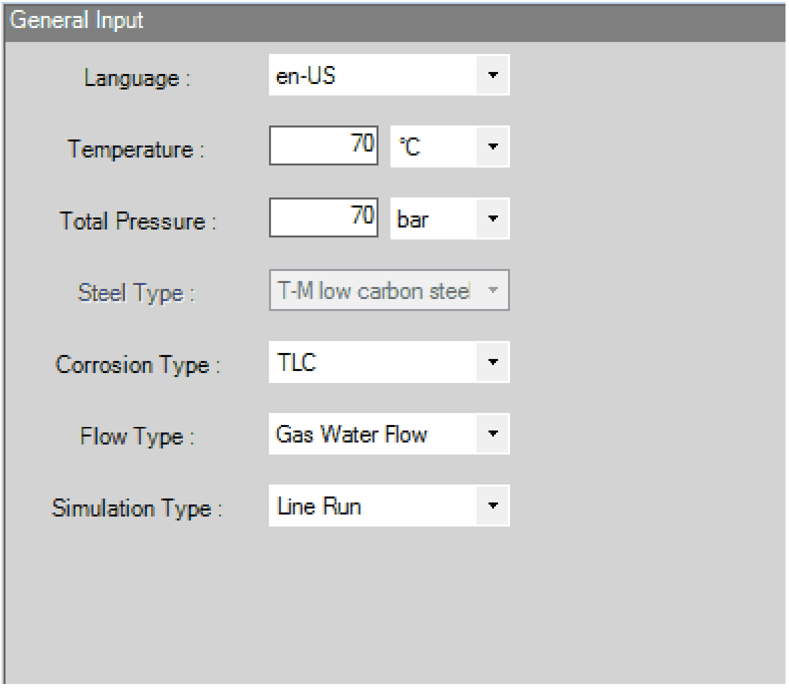
Information

- Clicking **Help** will open this help window for General Input.

Show/Hide Area

- **Process**: toggles the visibility of the left hand side Process Area and Instructions/Notes Area.
- **Message Center**: toggles the visibility of the bottom Message Center area. (Message Center will open if errors or warnings appear)

3.1.2 Data Area



General Input

Language : en-US

Temperature : 70 °C

Total Pressure : 70 bar

Steel Type : T-M low carbon steel

Corrosion Type : TLC

Flow Type : Gas Water Flow

Simulation Type : Line Run

Language: Preferred culture info format of Multicorp Case.

Temperature: Temperature of the system at operating condition.

Total Pressure: Total pressure of the system at operating condition.

Steel Type: The type of steel used in the system (currently unavailable)

Corrosion Type

Bottom-of-the-Line Corrosion (BLC)

Bottom of the line refers to the bottom of the pipeline which is usually in contact with liquid phase especially water phase. In oil and gas industry water phase is usually known as corrosive phase. In general, BLC refers to corrosion which happens at the bottom of the pipeline because of exposure to the liquid phase especially water phase.

Top-of-the-Line Corrosion (TLC)

Top-of-the-line corrosion is a phenomenon encountered in the oil and gas industry when problems of corrosion appear inside the pipe due to the condensation of water containing dissolved corrosive gases. TLC occurs exclusively in wet gas transportation and in a stratified flow regime. Condensation happens when the environment outside the pipeline is cooler than the saturated vapor flowing inside the pipe. The water vapor in the gas phase condenses on the pipe wall in two different ways:

- on the side walls of the pipe where the condensed liquid slides to the bottom of the line due to gravitational forces (BLC)
- at the top of the pipe where droplets of liquid form and remain attached at the metal surface for a longer time (TLC)

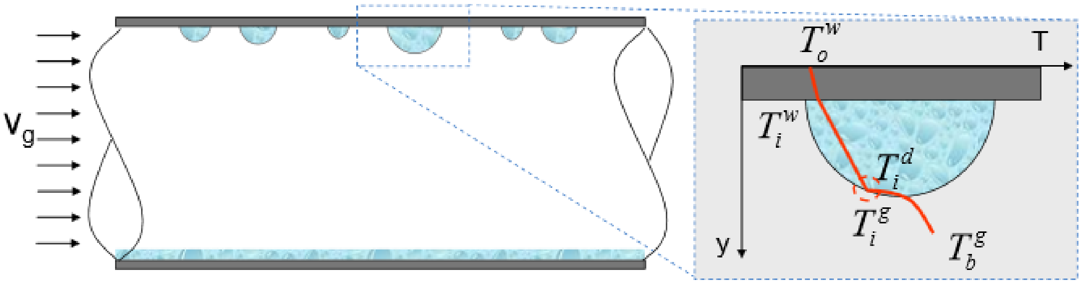


Figure 1 - Temperature gradient in a single droplet. T_o^w : outer wall temperature; T_i^w : inner wall temperature; T_i^d : interfacial temperature in the liquid side; T_i^g : interfacial temperature in the gas side; T_b^g : bulk gas temperature; V_g : gas velocity

(8)

Flow Type

Water Flow: Flow simulation with pipeline filled with water phase

Oil-water Flow: Flow simulation with pipeline filled with oil and water phases

Gas-water Flow: Flow simulation with pipeline filled with gas and water phases

Gas-oil-water Flow: Flow simulation with pipeline filled with gas, oil and water phases

Simulation Type

Point model: Corrosion simulation at one single location specified by input conditions.

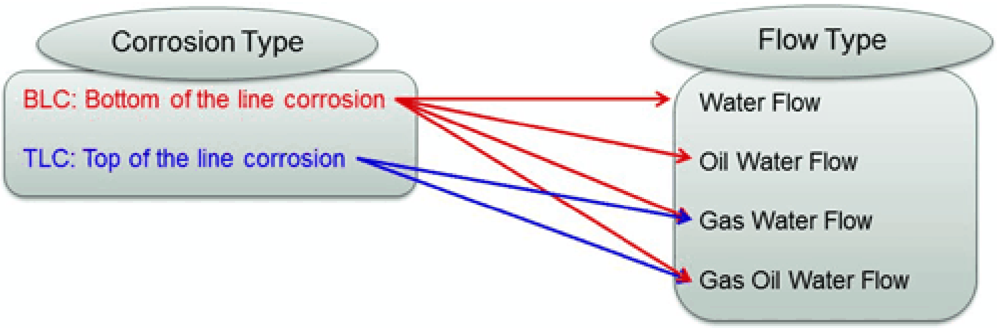
Parametric Run: A series of corrosion simulations by varying multiple parameters at specific intervals.

Line Run: A series of simulations (corrosion and/or flow) along a user defined line topography.

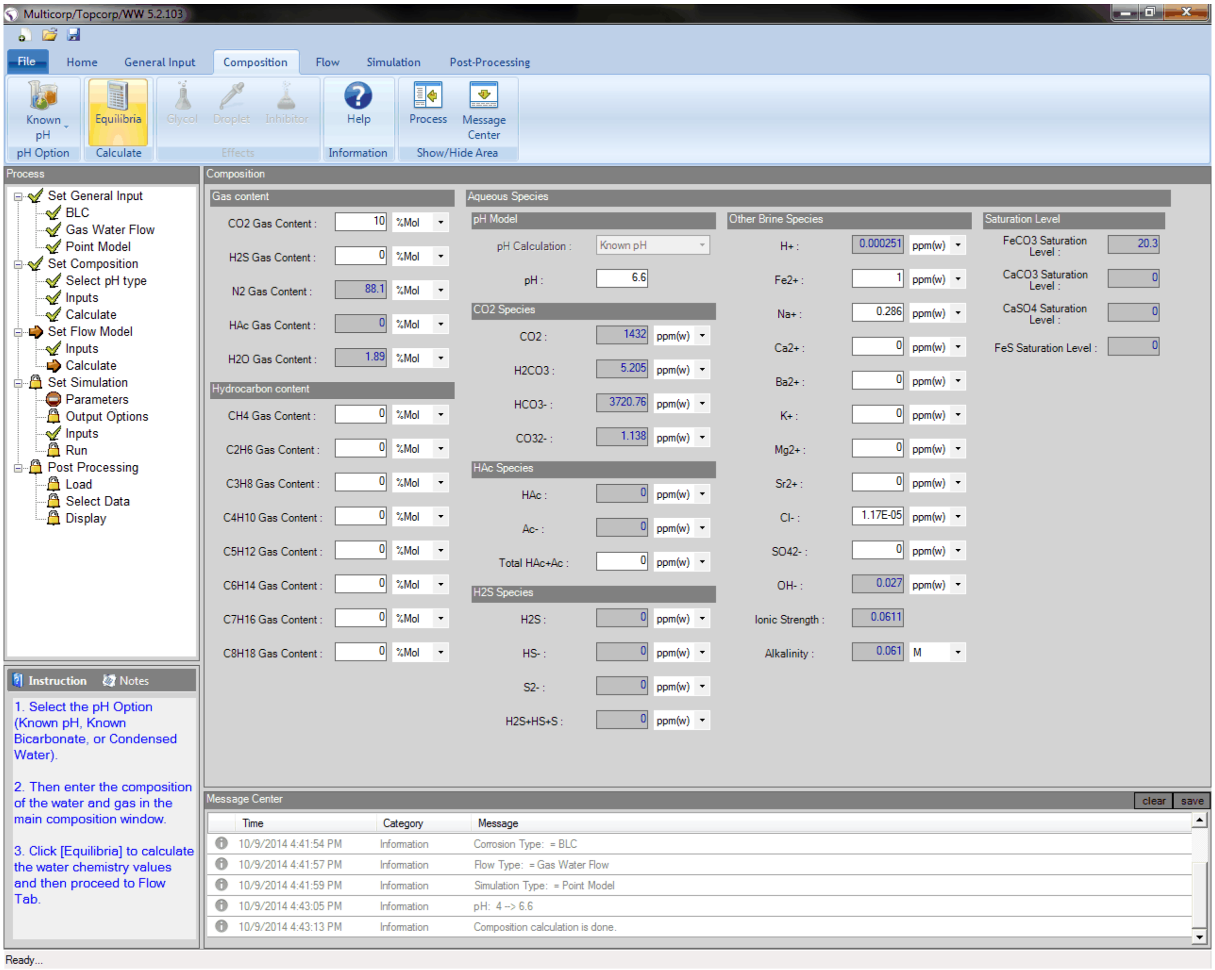
Dependency between Corrosion Type and Flow Type

For BLC, all 4 types of flow can be selected for simulation.

However, TLC requires a presence of gas in the flow so that it has to use either Gas-water or Gas-oil-water flow.



3.2 Composition



Composition

Gas content

CO2 Gas Content : 10 %Mol
H2S Gas Content : 0 %Mol
N2 Gas Content : 88.1 %Mol
HAc Gas Content : 0 %Mol
H2O Gas Content : 1.89 %Mol

Hydrocarbon content

CH4 Gas Content : 0 %Mol
C2H6 Gas Content : 0 %Mol
C3H8 Gas Content : 0 %Mol
C4H10 Gas Content : 0 %Mol
C5H12 Gas Content : 0 %Mol
C6H14 Gas Content : 0 %Mol
C7H16 Gas Content : 0 %Mol
C8H18 Gas Content : 0 %Mol

Aqueous Species

pH Model

pH Calculation : Known pH
pH : 6.6

CO2 Species

CO2 : 1432 ppm(w)
H2CO3 : 5.205 ppm(w)
HCO3- : 3720.76 ppm(w)
CO32- : 1.138 ppm(w)

HAc Species

HAc : 0 ppm(w)
Ac- : 0 ppm(w)
Total HAc+Ac : 0 ppm(w)

H2S Species

H2S : 0 ppm(w)
HS- : 0 ppm(w)
S2- : 0 ppm(w)
H2S+HS+S : 0 ppm(w)

Other Brine Species

H+ : 0.000251 ppm(w)
Fe2+ : 1 ppm(w)
Na+ : 0.286 ppm(w)
Ca2+ : 0 ppm(w)
Ba2+ : 0 ppm(w)
K+ : 0 ppm(w)
Mg2+ : 0 ppm(w)
Sr2+ : 0 ppm(w)
Cl- : 1.17E-05 ppm(w)
SO42- : 0 ppm(w)
OH- : 0.027 ppm(w)
Ionic Strength : 0.0611
Alkalinity : 0.061 M

Saturation Level

FeCO3 Saturation Level : 20.3
CaCO3 Saturation Level : 0
CaSO4 Saturation Level : 0
FeS Saturation Level : 0

1. Select the pH Option (Known pH, Known Bicarbonate, or Condensed Water).

2. Then enter the composition of the water and gas in the main composition window.

3. Click [Equilibria] to calculate the water chemistry values and then proceed to Flow Tab.

Message Center

Time	Category	Message
10/9/2014 4:41:54 PM	Information	Corrosion Type: = BLC
10/9/2014 4:41:57 PM	Information	Flow Type: = Gas Water Flow
10/9/2014 4:41:59 PM	Information	Simulation Type: = Point Model
10/9/2014 4:43:05 PM	Information	pH: 4 --> 6.6
10/9/2014 4:43:13 PM	Information	Composition calculation is done.

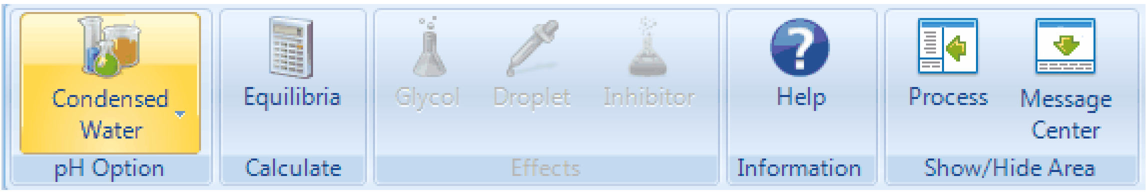
The composition tab allows you to define the aqueous species, as well as gas and hydrocarbon content of the system.

Below are links to the Composition tab's Ribbon Area and Data Area:

- Ribbon Area
- Data Area

Once the composition parameters have been defined and calculated, Flow parameters can be set.

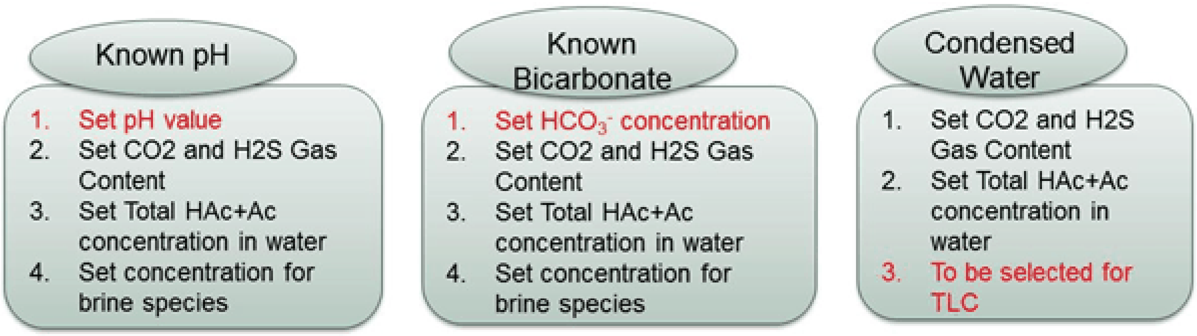
3.2.1 Ribbon Area



pH Option

Multicorp provides 3 different pH options for calculating water chemistry:

- **Known pH**: pH and other brine species are defined as inputs.
- **Known Bicarbonate**: pH is defined as an output while HCO3- and other brine species are defined as inputs.
- **Condensed Water**: pH and other brine species are defined as outputs.



Known pH

1. Set pH value
2. Set CO2 and H2S Gas Content
3. Set Total HAc+Ac concentration in water
4. Set concentration for brine species

Known Bicarbonate

1. Set HCO_3^- concentration
2. Set CO2 and H2S Gas Content
3. Set Total HAc+Ac concentration in water
4. Set concentration for brine species

Condensed Water

1. Set CO2 and H2S Gas Content
2. Set Total HAc+Ac concentration in water
3. To be selected for TLC

Calculate

- Water chemistry will be calculated by clicking **Equilibria**.

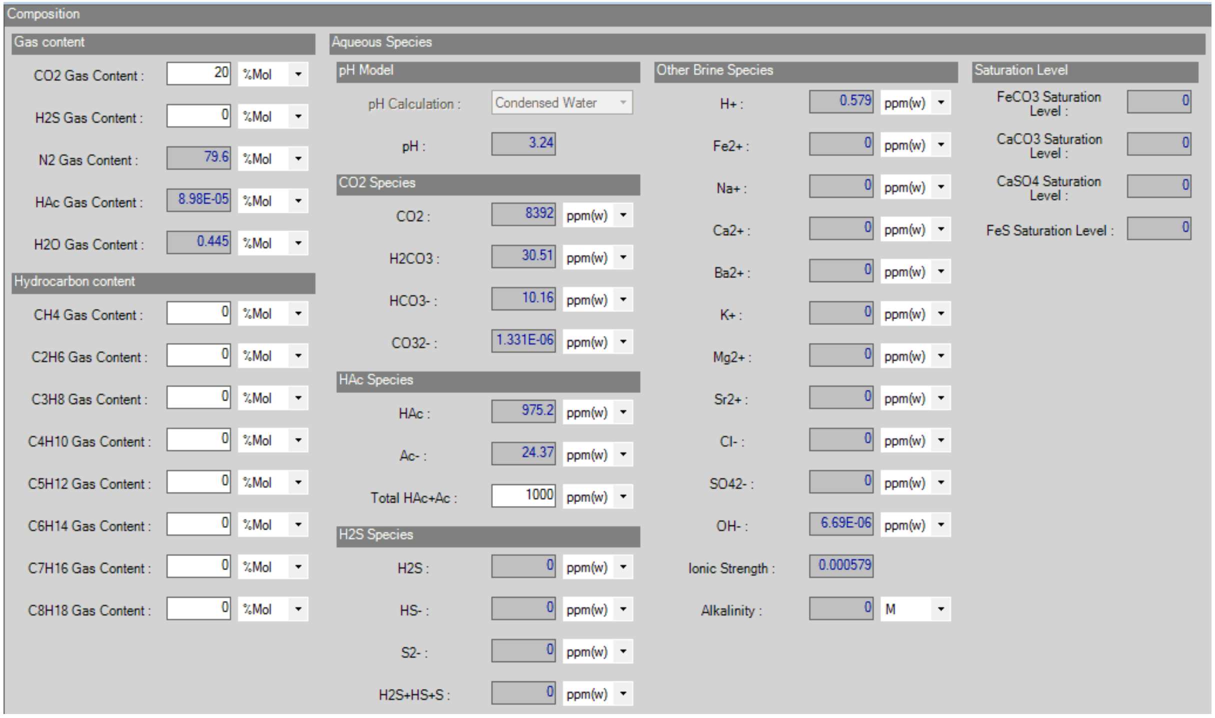
Information

- Clicking **Help** will open this help window for Composition.

Show/Hide Area

- **Process**: toggles the visibility of the left hand side Process Area and Instructions/Notes Area.
- **Message Center**: toggles the visibility of the bottom Message Center area. (Message Center will open if errors or warnings appear)

3.2.2 Data Area


Composition

Gas content

CO2 Gas Content : 20 %Mol
H2S Gas Content : 0 %Mol
N2 Gas Content : 79.6 %Mol
HAc Gas Content : 8.98E-05 %Mol
H2O Gas Content : 0.445 %Mol

Hydrocarbon content

CH4 Gas Content : 0 %Mol
C2H6 Gas Content : 0 %Mol
C3H8 Gas Content : 0 %Mol
C4H10 Gas Content : 0 %Mol
C5H12 Gas Content : 0 %Mol
C6H14 Gas Content : 0 %Mol
C7H16 Gas Content : 0 %Mol
C8H18 Gas Content : 0 %Mol

Aqueous Species

pH Model

pH Calculation : Condensed Water
pH : 3.24

CO2 Species

CO2 : 8392 ppm(w)
H2CO3 : 30.51 ppm(w)
HCO3- : 10.16 ppm(w)
CO32- : 1.331E-06 ppm(w)

HAc Species

HAc : 975.2 ppm(w)
Ac- : 24.37 ppm(w)
Total HAc+Ac : 1000 ppm(w)

H2S Species

H2S : 0 ppm(w)
HS- : 0 ppm(w)
S2- : 0 ppm(w)
H2S+HS+S : 0 ppm(w)

Other Brine Species

H+ : 0.579 ppm(w)
Fe2+ : 0 ppm(w)
Na+ : 0 ppm(w)
Ca2+ : 0 ppm(w)
Ba2+ : 0 ppm(w)
K+ : 0 ppm(w)
Mg2+ : 0 ppm(w)
Sr2+ : 0 ppm(w)
Cl- : 0 ppm(w)
SO42- : 0 ppm(w)
OH- : 6.69E-06 ppm(w)
Ionic Strength : 0.000579
Alkalinity : 0 M

Saturation Level

FeCO3 Saturation Level : 0
CaCO3 Saturation Level : 0
CaSO4 Saturation Level : 0
FeS Saturation Level : 0

Gas Content

- **CO_2 Gas Content** is the amount of Carbon Dioxide present in the gas phase.
- **H_2S Gas Content** is the amount of Hydrogen Sulfide present in the gas phase.
- **N_2 Gas Content** is the amount of Nitrogen present in the gas phase.
- **HAc Gas Content** is the amount of Acetic Acid present in the gas phase.
- **H_2O Gas Content** is the amount of Water present in the gas phase.

Hydrocarbon Content

- **CH_4 Gas Content** is the amount of Methane hydrocarbon present in the gas phase.
- **C_2H_6 Gas Content** is the amount of Ethane hydrocarbon present in the gas phase.
- **C_3H_8 Gas Content** is the amount of Propane hydrocarbon present in the gas phase.
- **C_4H_{10} Gas Content** is the amount of Butane hydrocarbon present in the gas phase.
- **C_5H_{12} Gas Content** is the amount of Pentane hydrocarbon present in the gas phase.

- **C_6H_{14} Gas Content** is the amount of Hexane hydrocarbon present in the gas phase.
- **C_7H_{16} Gas Content** is the amount of Heptane hydrocarbon present in the gas phase.
- **C_8H_{18} Gas Content** is the amount of Octane hydrocarbon present in the gas phase

Aqueous Species

pH Model:

- pH Calculation is calculation of hydrogen ion concentration in the solution based on chemical and electrochemical reactions in the system.
- pH is a measure of hydrogen ion concentration in the solution which represent the acidity and alkalinity of the solution.

CO_2 Species:

- CO_2 is the amount of carbon dioxide present in the aqueous phase as a result of CO_2 gas dissolution in the liquid phase.
- H_2CO_3 is the amount of carbonic acid present in the aqueous phase as a result of CO_2 hydration.
- HCO^{3-} is the amount of bicarbonate present in the aqueous phase as a the result of the H_2CO_3 dissociation reaction.
- CO_3^{2-} is the amount of carbonate ions present in the aqueous phase as a result of the HCO^{3-} dissociation reaction.

HAc Species:

- HAc is the abbreviation used for acetic acid with chemical formula of CH_3COOH which can be also written as CH_3CO_2H or $C_2H_4O_2$. Acetic acid is a weak monoprotic acid. In this part HAc means acetic acid concentration in aqueous phase.
- Ac- forms as a result of dissociation of acetic acid. In this part Ac- means acetate concentration in aqueous phase.
- Total HAc+Ac is total concentration of acetic acid and acetate concentration in the aqueous phase.

H2S Species:

- H_2S is the H_2S concentration in aqueous phase.

- HS^- is a product of H_2S dissociation. In this part, it means bisulfide concentration in aqueous phase.
- S^{2-} is a product of HS- dissociation. In this part, it means sulfide concentration in aqueous phase.
- H_2S+HS+S is total concentration of H_2S, HS and S^{2-} concentration in aqueous phase or total sulfides.

Other Brine Species:

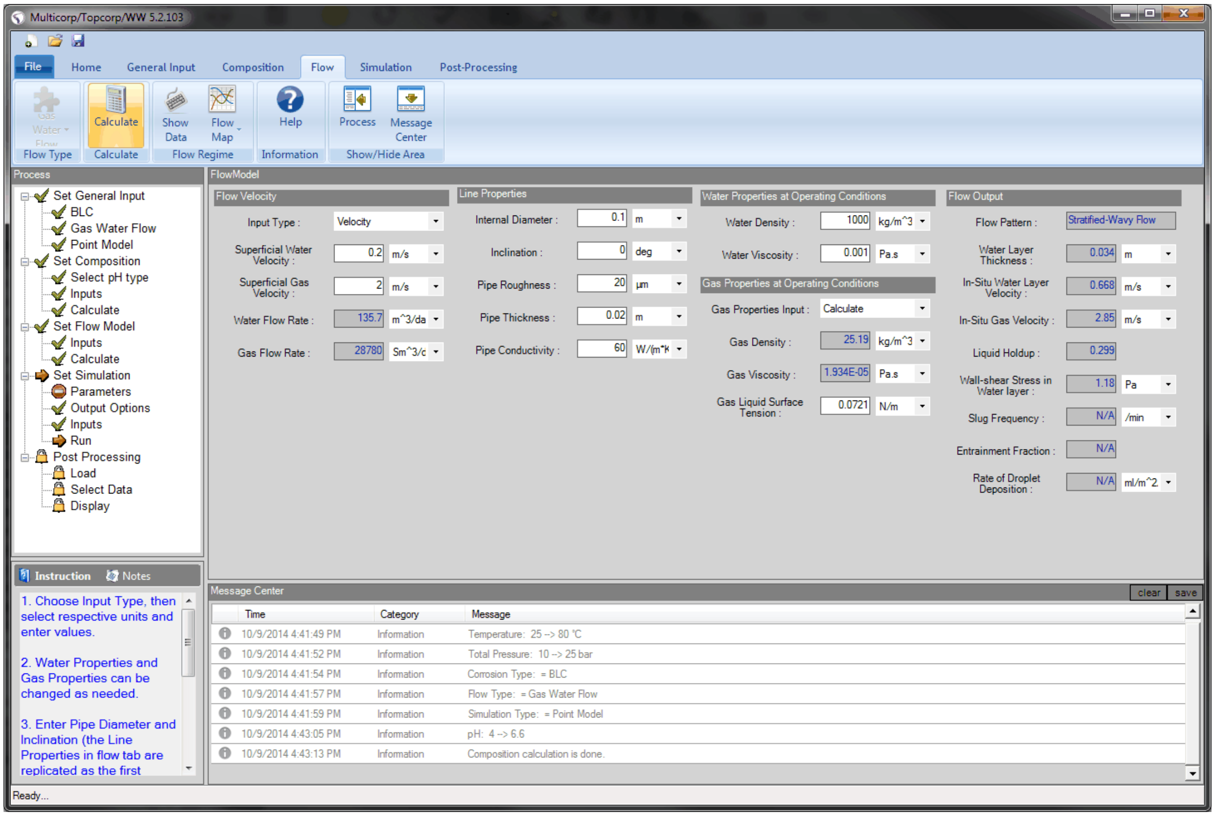
- H^+ is the concentration of hydrogen ions in the aqueous phase.
- Fe^{2+} is the concentration of iron ions (Fe^{2+}) in the aqueous phase.
- Na^+ is the concentration of sodium ions in the aqueous phase.
- Ca^{2+} is the concentration of calcium ions in the aqueous phase.
- Ba^{2+} is the concentration of barium ions in the aqueous phase.
- K^+ is the concentration of potassium ions in the aqueous phase.
- Mg^{2+} is the concentration of magnesium ions in the aqueous phase.
- Sr^{2+} is the concentration of strontium ions in the aqueous phase.
- Cl^- is the concentration of chloride ions in the aqueous phase.
- SO_4^{2-} is the concentration of sulfide ions in the aqueous phase.
- OH^- is the concentration of hydroxide ion in the aqueous phase.
- Ionic Strength is a measure of the concentration of ions in the solution.
- Alkalinity is the quantitative capacity of water to neutralize an acid.

Saturation Level:

- $FeCO_3$ Saturation Level is defined as multiplication of iron ion concentration by carbonate ions concentration in the system.
- $CaCO_3$ Saturation Level is defined as multiplication of calcium ion concentration by carbonate ions concentration in the system.

- ○ $CaSO_4$ Saturation Level is defined as multiplication of calcium ion concentration by sulfate ions concentration in the system.
- ○ FeS Saturation Level is defined as multiplication of iron ion concentration by sulfur ions concentration in the system.

3.3 Flow



Flow Velocity

Input Type : Velocity
Superficial Water Velocity : 0.2 m/s
Superficial Gas Velocity : 2 m/s
Water Flow Rate : 135.7 m^3/da
Gas Flow Rate : 28780 Sm^3/d

Line Properties

Internal Diameter : 0.1 m
Inclination : 0 deg
Pipe Roughness : 20 µm
Pipe Thickness : 0.02 m
Pipe Conductivity : 60 W/(m*K

Water Properties at Operating Conditions

Water Density : 1000 kg/m^3
Water Viscosity : 0.001 Pa.s

Gas Properties at Operating Conditions

Gas Properties Input : Calculate
Gas Density : 25.19 kg/m^3
Gas Viscosity : 1.934E-05 Pa.s
Gas Liquid Surface Tension : 0.0721 N/m

Flow Output

Flow Pattern : Stratified-Wavy Flow
Water Layer Thickness : 0.034 m
In-Situ Water Layer Velocity : 0.668 m/s
In-Situ Gas Velocity : 2.85 m/s
Liquid Holdup : 0.299
Wall-shear Stress in Water layer : 1.18 Pa
Slug Frequency : N/A /min
Entrainment Fraction : N/A
Rate of Droplet Deposition : N/A ml/m^2

Time	Category	Message
10/9/2014 4:41:49 PM	Information	Temperature: 25 --> 80 °C
10/9/2014 4:41:52 PM	Information	Total Pressure: 10 --> 25 bar
10/9/2014 4:41:54 PM	Information	Corrosion Type: = BLC
10/9/2014 4:41:57 PM	Information	Flow Type: = Gas Water Flow
10/9/2014 4:41:59 PM	Information	Simulation Type: = Point Model
10/9/2014 4:43:05 PM	Information	pH: 4 --> 6.6
10/9/2014 4:43:13 PM	Information	Composition calculation is done.

1. Choose Input Type, then select respective units and enter values.

2. Water Properties and Gas Properties can be changed as needed.

3. Enter Pipe Diameter and Inclination (the Line Properties in flow tab are replicated as the first

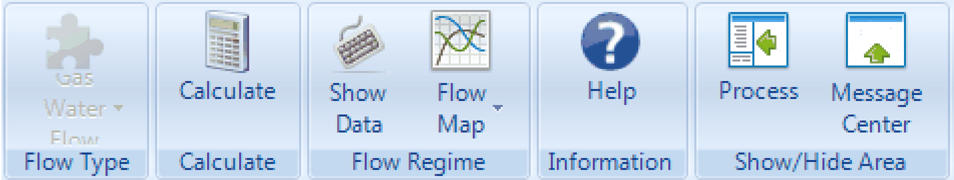
The flow tab allows you to set the flow parameters of the system including velocity as well as phase properties.

Below are links to the Flow tab's Ribbon Area and Data Area:

- Ribbon Area
- Data Area

Once flow parameters have been defined and calculated, depending upon the corrosion type chosen, either Condensation (TLC only), Pipeline (Line Model), or Simulation parameters must be defined.

3.3.1 Ribbon Area



Flow Type

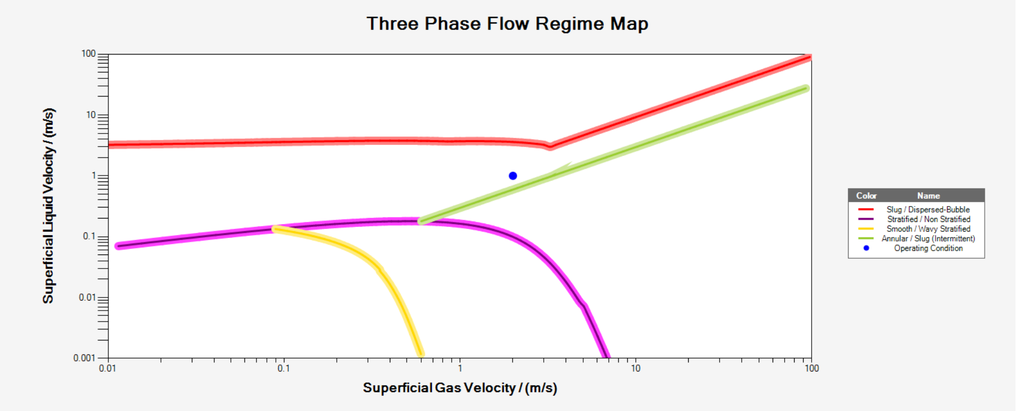
- Shows the currently chosen flow type defined in the General Input tab.

Flow Regime

- **Show Data** will make the Flow tab's Data Area visible.
- **Flow Map** displays a chosen flow map generated based on the current Flow tab's data and the chosen Flow type.

  Below are the various flow maps available based on Flow type:

  - Water flow:
    - No flow map available
  - Oil Water flow:
    - Superficial velocity: Superficial oil velocity vs. Superficial water velocity
    - Mixture velocity: Mixture velocity vs. Water cut
  - Gas Water flow:
    - Superficial velocity: Superficial gas velocity vs. Superficial water velocity
  - Gas Oil Water flow:
    - Superficial velocity: Superficial gas velocity vs. Superficial liquid (oil+water) velocity



(Three Phase Flow Map generated by choosing a Gas Oil Water flow)

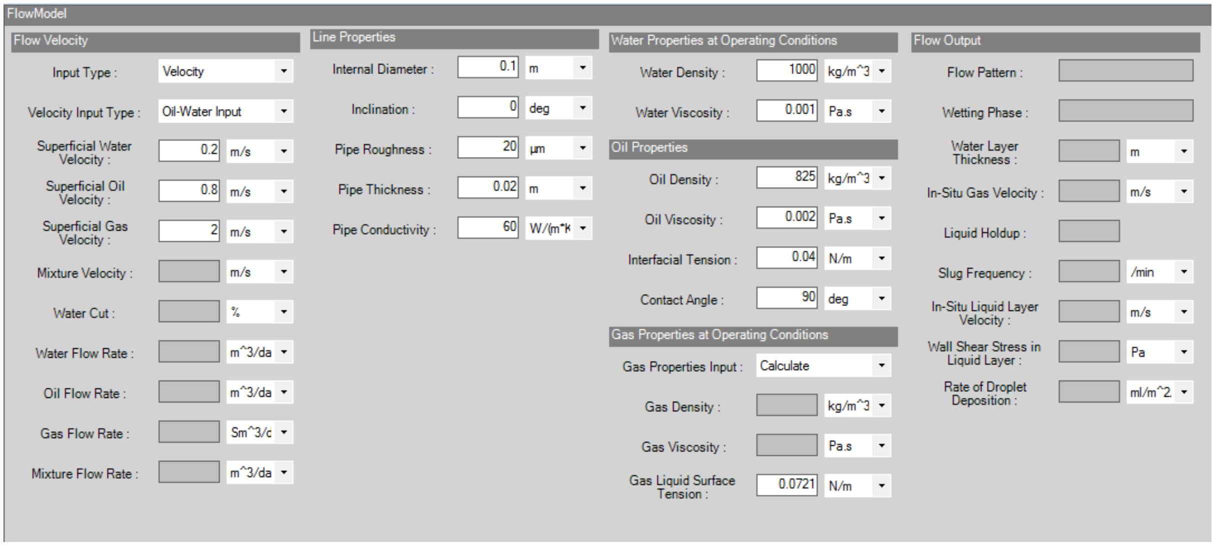
Information

- Clicking **Help** will open this help window for Flow.

Show/Hide Area

- **Process**: toggles the visibility of the left hand side Process Area and Instructions/Notes Area.
- **Message Center**: toggles the visibility of the bottom Message Center area. (Message Center will open if errors or warnings appear)

3.3.2 Data Area


FlowModel

Flow Velocity
Input Type : Velocity
Velocity Input Type : Oil-Water Input
Superficial Water Velocity : 0.2 m/s
Superficial Oil Velocity : 0.8 m/s
Superficial Gas Velocity : 2 m/s
Mixture Velocity : m/s
Water Cut : %
Water Flow Rate : m^3/da
Oil Flow Rate : m^3/da
Gas Flow Rate : Sm^3/c
Mixture Flow Rate : m^3/da

Line Properties
Internal Diameter : 0.1 m
Inclination : 0 deg
Pipe Roughness : 20 µm
Pipe Thickness : 0.02 m
Pipe Conductivity : 60 W/(m*K

Water Properties at Operating Conditions
Water Density : 1000 kg/m^3
Water Viscosity : 0.001 Pa.s

Oil Properties
Oil Density : 825 kg/m^3
Oil Viscosity : 0.002 Pa.s
Interfacial Tension : 0.04 N/m
Contact Angle : 90 deg

Gas Properties at Operating Conditions
Gas Properties Input : Calculate
Gas Density : kg/m^3
Gas Viscosity : Pa.s
Gas Liquid Surface Tension : 0.0721 N/m

Flow Output
Flow Pattern :
Wetting Phase :
Water Layer Thickness : m
In-Situ Gas Velocity : m/s
Liquid Holdup :
Slug Frequency : /min
In-Situ Liquid Layer Velocity : m/s
Wall Shear Stress in Liquid Layer : Pa
Rate of Droplet Deposition : ml/m^2.

(Above is a screen shot of the Flow tab's Data Area when a Gas Oil Water flow type is chosen)

The flow tab's Data Area will change based on Flow type chosen in General Input. Below is the input and output for different flow types:

Input/Output based on Flow Type

Oil-Water Flow:

Input type	Velocity input type	Input	Calculated Output
Velocity	Oil-water input	- Superficial water velocity - Superficial oil velocity	- Mixture velocity - Water cut - Water flow rate - Oil flow rate

			- Mixture flow rate
	Mixture input	- Mixture velocity - Water cut	- Superficial water velocity - Superficial oil velocity - Water flow rate - Oil flow rate - Mixture flow rate
Flow rate	Oil-water input	- Water flow rate - Oil flow rate	- Superficial water velocity - Superficial oil velocity - Mixture velocity - Water cut - Mixture flow rate
	Mixture input	- Water cut - Mixture flow rate	- Superficial water velocity - Superficial oil velocity - Mixture velocity - Water flow rate - Oil flow rate

<u>Gas-Water Flow:</u>

Input type	Input	Calculated Output
Velocity	- Superficial water velocity - Superficial gas velocity	- Water flow rate - Gas flow rate
Flow rate	- Water flow rate - Gas flow rate	- Superficial water velocity - Superficial gas velocity

<u>Gas-Oil-Water Flow:</u>

Input type	Velocity input type	Input	Calculated Output
Velocity	Oil-water input	- Superficial water velocity - Superficial oil velocity - Superficial gas velocity	- Mixture velocity - Water cut - Water flow rate - Oil flow rate - Gas flow rate - Mixture flow rate
	Mixture input	- Superficial gas velocity	- Superficial water velocity - Superficial oil velocity

		- Mixture velocity - Water cut	- Water flow rate - Oil flow rate - Gas flow rate - Mixture flow rate
Flow rate	Oil-water input	- Water flow rate - Oil flow rate - Gas flow rate	- Superficial water velocity - Superficial oil velocity - Superficial gas velocity - Mixture velocity - Water cut - Mixture flow rate
	Mixture input	- Water cut - Gas flow rate - Mixture flow rate	- Superficial water velocity - Superficial oil velocity - Superficial gas velocity - Mixture velocity - Water flow rate - Oil flow rate

Flow Velocity

- **Input Type**:
  - **Velocity**: based on superficial velocity input
  - **Flow Rate**: based on volumetric flow rate input
- **Velocity Input Type**:
  - **Oil-Water Input**: input based on superficial velocity for oil phase and water phase
  - **Mixture Input**: input based on the mixture (oil-water) superficial velocity and water cut
- **Superficial Water Velocity**: the velocity V_G calculated as if the water is the only phase filling the entire pipe cross section. It is equal to the water volumetric flow rate divided by the cross sectional flow area.
- **Superficial Oil Velocity**: the velocity V_O calculated as if the oil is the only phase filling the entire pipe cross section. It is equal to the oil volumetric flow rate divided by the cross sectional flow area.
- **Superficial Gas Velocity**: the velocity V_G calculated as if the gas is the only phase filling the entire pipe cross section. It is equal to the gas volumetric flow rate divided by the cross sectional flow area.
- **Mixture Velocity**: the sum of superficial water velocity and superficial oil velocity. It is equal to the total liquid volumetric flow rate divided by the cross sectional flow area.

- **Water Cut**: fraction of water in weight with respect to total liquid
- **Water Flow Rate**: volumetric flow rate of water
- **Oil Flow Rate**: volumetric flow rate of oil
- **Gas Flow Rate**: volumetric flow rate of gas
- **Mixture Flow Rate**: total liquid volumetric flow rate. It is the sum of volumetric flow rates of water and oil

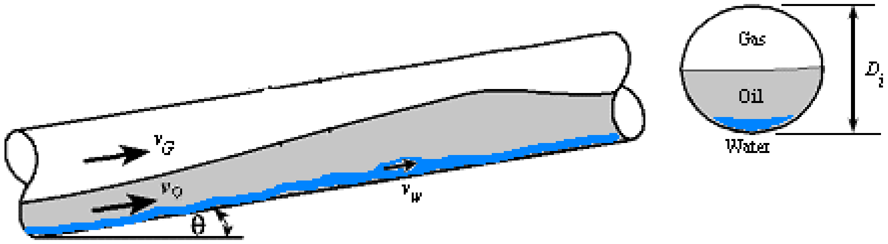


Figure 1. Schematic representation of gas-oil-water flow

Line Properties

- **Internal Diameter**: Internal pipe diameter Di.
- **Inclination**: the angle (θ, Figure 1) between the pipe and the horizontal plane.
- **Pipe Roughness**: a measure of the texture of the internal surface of the pipe.
- **Pipe Thickness**: a measure of the thickness of the pipe wall.
- **Pipe Conductivity**: a measure of the conductivity of the pipe wall.

Water Properties

- **Water Density**: density of water at operating condition
- **Water Viscosity**: dynamic viscosity of water at operating condition

Oil Properties

- **Oil Density**: density of oil at operating condition
- **Oil Viscosity**: dynamic viscosity of oil at operating condition
- **Interfacial Tension**: the surface tension measured at the interface between oil and water phase

- **Contact Angle** – the wetting angle formed at the water/oil boundary when water is in contact with steel surface. As shown in Figure 2, the wetting angle refers to the angle g the water droplet makes when it spreads on a steel surface in the bulk oil environment.

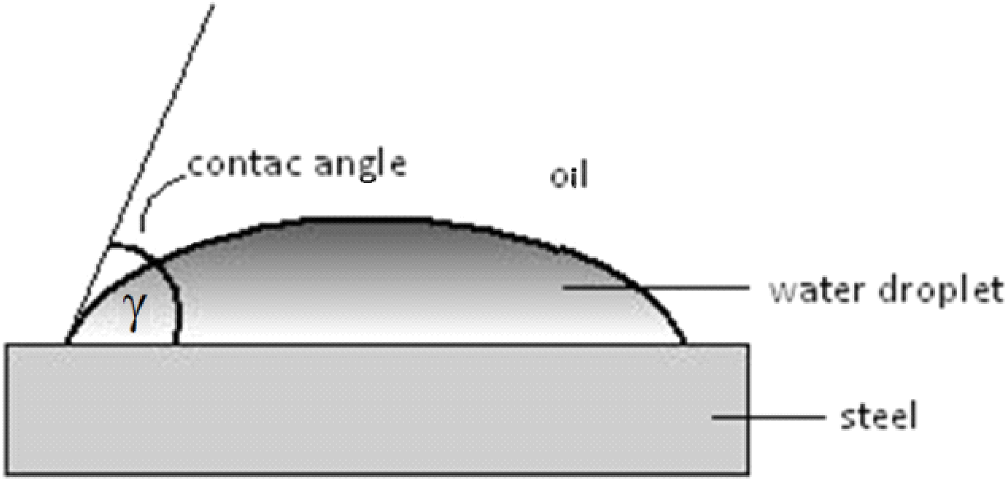
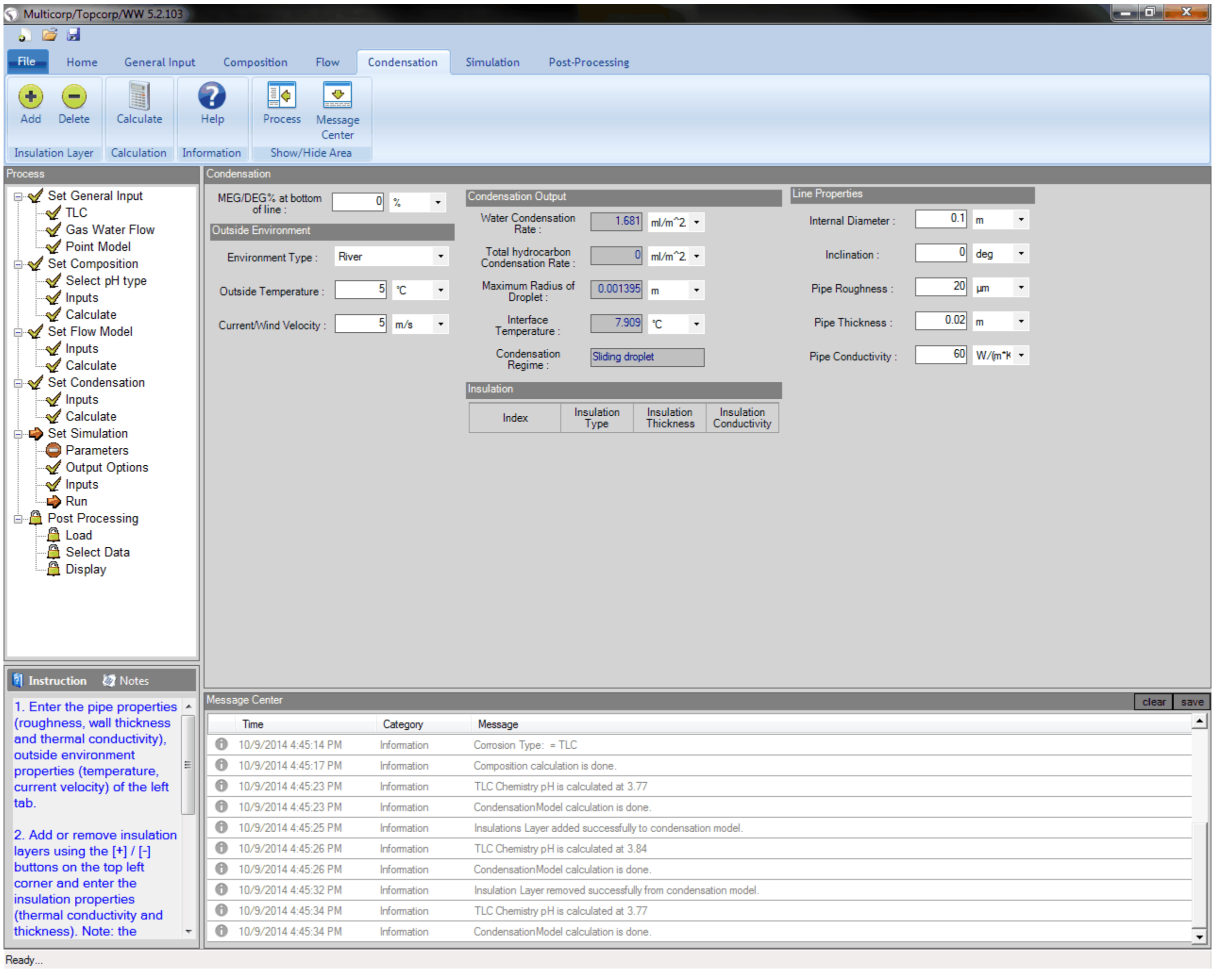


Figure 2. Schematic representation of a water droplet wetting the steel surface

Flow Output

- **Flow Pattern**: flow pattern of multiphase fluids in the pipeline at the operating conditions
- **Wetting Phase**: can be either oil wetting or water wetting which refers to the phase that comes in contact and wets the internal pipe wall
- **Water Layer Thickness**: the depth of water layer formed at the lower pipe section
- **In-Situ Water Layer Velocity**: the actual velocity of the water layer
- **In-Situ Gas Velocity**: the actual velocity of the gas phase
- **Liquid Holdup**: the in-situ area fraction of the liquid phase over the pipe cross section
- **Wall-shear Stress in Water Layer**: the shearing stress resulting from the water layer flow acting on contacting pipe wall
- **Slug Frequency**: the number of slugs that pass at a fixed point of the pipe per unit time.
- **Rate of Droplet Deposition**: the mass deposition rate of liquid droplet which were entrained in the gas phase. Only applicable to annular mixed flow.

3.4 Condensation



Condensation

MEG/DEG% at bottom of line : 0 %

Outside Environment

Environment Type : River

Outside Temperature : 5 °C

Current/Wind Velocity : 5 m/s

Condensation Output

Water Condensation Rate : 1.681 ml/m^2.

Total hydrocarbon Condensation Rate : 0 ml/m^2.

Maximum Radius of Droplet : 0.001395 m

Interface Temperature : 7.909 °C

Condensation Regime : Sliding droplet

Insulation

Index	Insulation Type	Insulation Thickness	Insulation Conductivity

Line Properties

Internal Diameter : 0.1 m

Inclination : 0 deg

Pipe Roughness : 20 µm

Pipe Thickness : 0.02 m

Pipe Conductivity : 60 W/(m*K

1. Enter the pipe properties (roughness, wall thickness and thermal conductivity), outside environment properties (temperature, current velocity) of the left tab.

2. Add or remove insulation layers using the [+] / [-] buttons on the top left corner and enter the insulation properties (thermal conductivity and thickness). Note: the

	Time	Category	Message
ⓘ	10/9/2014 4:45:14 PM	Information	Corrosion Type: = TLC
ⓘ	10/9/2014 4:45:17 PM	Information	Composition calculation is done.
ⓘ	10/9/2014 4:45:23 PM	Information	TLC Chemistry pH is calculated at 3.77
ⓘ	10/9/2014 4:45:23 PM	Information	CondensationModel calculation is done.
ⓘ	10/9/2014 4:45:25 PM	Information	Insulations Layer added successfully to condensation model.
ⓘ	10/9/2014 4:45:26 PM	Information	TLC Chemistry pH is calculated at 3.84
ⓘ	10/9/2014 4:45:26 PM	Information	CondensationModel calculation is done.
ⓘ	10/9/2014 4:45:32 PM	Information	Insulation Layer removed successfully from condensation model.
ⓘ	10/9/2014 4:45:34 PM	Information	TLC Chemistry pH is calculated at 3.77
ⓘ	10/9/2014 4:45:34 PM	Information	CondensationModel calculation is done.

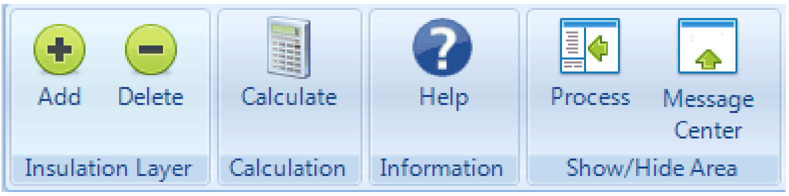
The condensation tab allows you to set condensation parameters pertaining to top of the line corrosion. This tab is only accessible when corrosion type is set to TLC.

Below are links to the Condensation tab's Ribbon Area and Data Area:

- Ribbon Area
- Data Area

Once condensation parameters have been defined and calculated, depending upon the corrosion type and simulation type, either Pipeline or Simulation parameters can be defined next.

3.4.1 Ribbon Area



Insulation Layer

- **Add**: adds an insulation layer to the condensation model.
- **Delete**: deletes the most recently added insulation layer from the model.

Calculate

- Condensation parameters will be calculated by clicking **Calculate**.

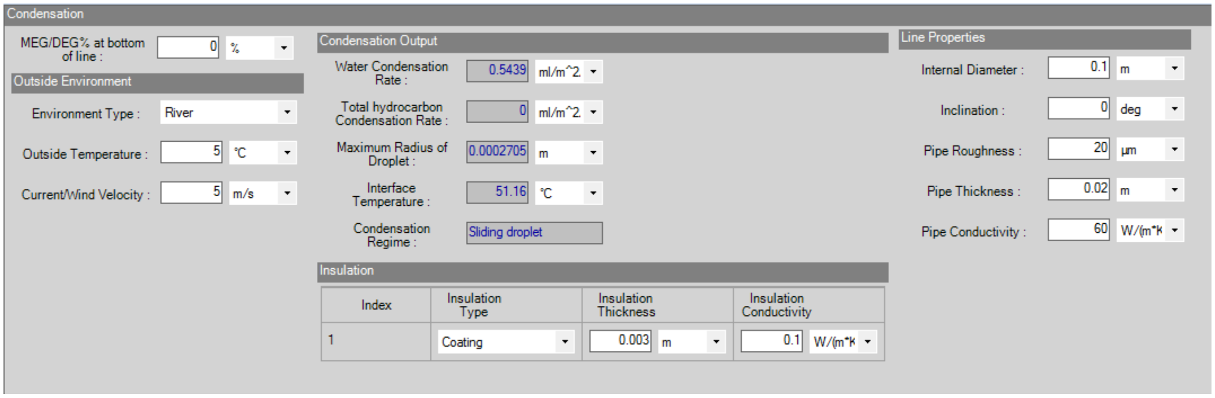
Information

- Clicking **Help** will open this help window for Condensation.

Show/Hide Area

- **Process**: toggles the visibility of the left hand side Process Area and Instructions/Notes Area.
- **Message Center**: toggles the visibility of the bottom Message Center area. (Message Center will open if errors or warnings appear)

3.4.2 Data Area


Condensation

MEG/DEG% at bottom of line : 0 %

Outside Environment

Environment Type : River

Outside Temperature : 5 °C

Current/Wind Velocity : 5 m/s

Condensation Output

Water Condensation Rate : 0.5439 ml/m^2.

Total hydrocarbon Condensation Rate : 0 ml/m^2.

Maximum Radius of Droplet : 0.0002705 m

Interface Temperature : 51.16 °C

Condensation Regime : Sliding droplet

Insulation

Index	Insulation Type	Insulation Thickness		Insulation Conductivity	
1	Coating	0.003	m	0.1	W/(m*K

Line Properties

Internal Diameter : 0.1 m

Inclination : 0 deg

Pipe Roughness : 20 µm

Pipe Thickness : 0.02 m

Pipe Conductivity : 60 W/(m*K

MEG/DEG% at Bottom of Line: MEG is Mono-Ethylene Glycol and DEG is Di- Ethylene Glycol. MEG and DEG are a common and economical means of water removal from natural gas and natural gas liquid systems.

Outside Environment

- **Environment Type**: Sea, river and air are different environments surrounding the pipeline.
  - **Sea**: Pipe is surrounded by sea water
  - **River**: Pipe is surrounded by fresh river water
  - **Air**: Pipe is surrounded by air
- **Outside Temperature**: Outside temperature is the temperature of environment surrounding the pipe line. It could be either sea, river, or air.
- **Current/Wind Velocity**: Current/wind velocity is the velocity of the environment surrounding the pipeline. If it is sea or river, it is considered as water current velocity and if it is air, it is considered as wind velocity.

Condensation Output

- **Water Condensation Rate** is the rate of change in physical state of water from gaseous phase into liquid phase.
- **Total Hydrocarbon Condensation Rate** is the rate of change in physical state of all the hydrocarbons in the system from gaseous phase into liquid phase.
- **Maximum Radius of Droplet** is the radius of the largest droplet forming during condensation process
- **Interface Temperature** is temperature at the pipeline internal diameter
- **Condensation Regime** is flow regime of condensed fluids on top of the line. There are different types of flow regime including sliding droplet.

Insulation

To add or remove an insulation layer from the Condensation tab see Condensation tab's Ribbon Area.

- **Index**: The unique identifier of the pipe section
- **Insulation Type**: There are different type of insulation used around the pipeline including coating, concrete and Soil. Each insulation can have different thermal and electrical conductivity properties set by the user.
  - **Coating:** A generic coating such as plastics or polymers

  - **Concrete:** A concrete insulation layer

- **Insulation Thickness** is the thickness of insulation surrounding the pipeline
- **Insulation Conductivity** is thermal conductivity of the insulation surrounding the pipeline. Different coatings, concrete and soils have different thermal conductivities.

Line Properties

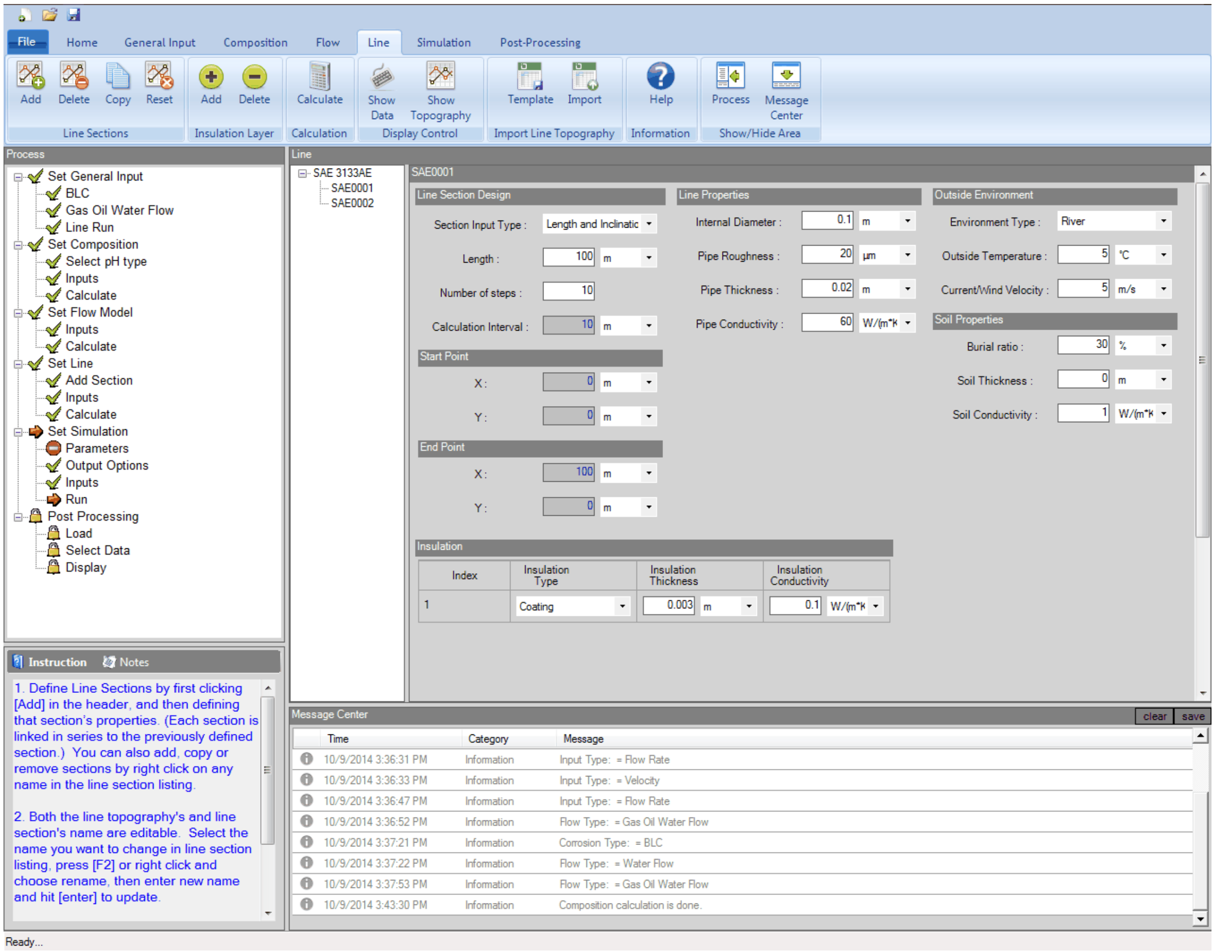
- **Pipe Roughness**: A measurement of the average height of peaks producing roughness on the internal surface of pipes. Roughness is measured in many locations and then averaged. It is usually defined in micro-inches RMS (root mean square). New steel has a surface roughness of 45µm, PVC/Acrylic, 1.5µm, Steel which lightly rusted, 300µm, and Rusty steel, 2mm.

Pipe absolute roughness values (RMS)		
Material	**Absolute roughness (in x 10^{-3})**	**Absolute roughness (micron or m x 10^{-6})**
Riveted steel[1]	36-360	915-9150
Concrete[1]	12-120	305-3050
Ductile iron[2]	102	2591
Wood stave[1]	3.6-7.2	91-183
Galvanized iron[1]	6	152
Cast iron – asphalt dipped[1]	4.8	122
Cast iron uncoated[1]	10	254
Carbon steel or wrought iron[1]	1.8	45
Stainless steel[1]	1.8	45
Fiberglass[3]	0.2	5
Drawn tubing – glass, brass, plastic[1]	0.06	1.5
Copper[2]	0.06	1.5
Aluminium[2]	0.06	1.5
PVC[2]	0.06	1.5
Red brass[2]	0.06	1.5

Sources: 1. Cameron Hydraulic Data Book, 2. Engineered Software's PIPE-FLO software www.engineeredsoftware.com, 3. Fiberglass Pipe Handbook, SPI Composites Institu

- **Pipe Thickness** is a value that indicates the thickness of the pipe wall.
- **Pipe Conductivity** is the degree to which a specific pipe conducts electricity.

3.5 Line



SAE0001

Line Section Design

Section Input Type : Length and Inclinatic
Length : 100 m
Number of steps : 10
Calculation Interval : 10 m

Start Point

X : 0 m
Y : 0 m

End Point

X : 100 m
Y : 0 m

Line Properties

Internal Diameter : 0.1 m
Pipe Roughness : 20 µm
Pipe Thickness : 0.02 m
Pipe Conductivity : 60 W/(m*K

Outside Environment

Environment Type : River
Outside Temperature : 5 °C
Current/Wind Velocity : 5 m/s

Soil Properties

Burial ratio : 30 %
Soil Thickness : 0 m
Soil Conductivity : 1 W/(m*K

Insulation

Index	Insulation Type	Insulation Thickness	Insulation Conductivity
1	Coating	0.003 m	0.1 W/(m*K

1. Define Line Sections by first clicking [Add] in the header, and then defining that section's properties. (Each section is linked in series to the previously defined section.) You can also add, copy or remove sections by right click on any name in the line section listing.

2. Both the line topography's and line section's name are editable. Select the name you want to change in line section listing, press [F2] or right click and choose rename, then enter new name and hit [enter] to update.

Message Center

```
Time                   Category     Message
10/9/2014 3:36:31 PM   Information  Input Type:  = Flow Rate
10/9/2014 3:36:33 PM   Information  Input Type:  = Velocity
10/9/2014 3:36:47 PM   Information  Input Type:  = Flow Rate
10/9/2014 3:36:52 PM   Information  Flow Type:  = Gas Oil Water Flow
10/9/2014 3:37:21 PM   Information  Corrosion Type:  = BLC
10/9/2014 3:37:22 PM   Information  Flow Type:  = Water Flow
10/9/2014 3:37:53 PM   Information  Flow Type:  = Gas Oil Water Flow
10/9/2014 3:43:30 PM   Information  Composition calculation is done.
```

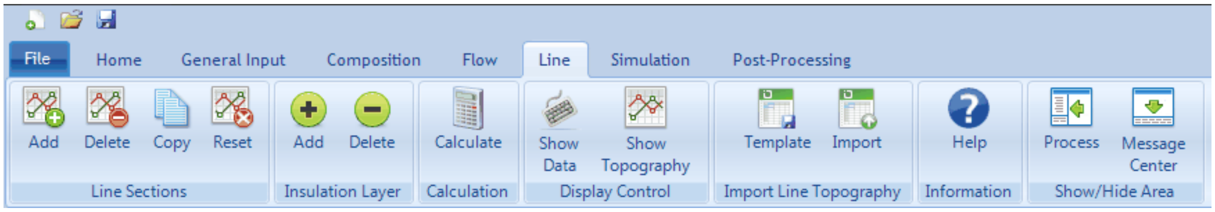
The pipeline tab allows you to define the topography of a pipeline. The pipeline is made up of line sections thus allowing for the properties of each pipe section such as diameter, length, insulation, etc to be set independently of each other. When a new section is added, it is automatically attached to the previous section's end point. This tab is only available when running a line model.

Below are links to the Line tab's Ribbon Area and Data Area:

- Ribbon Area
- Data Area

Once the pipeline parameters have been defined and calculated, Simulation parameters can be defined.

3.5.1 Ribbon Area

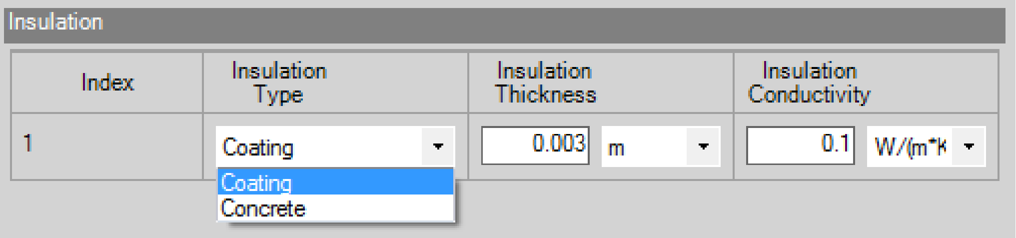


Line Sections

- Add: add new line section
- Delete: delete selected line section
- Copy: copy selected line section
- Reset: delete all existing line sections except the first section

Insulation Layer

- Add: add insulation layer, and then user can input information for the insulation (type, thickness and conductivity).


Insulation

Index	Insulation Type	Insulation Thickness	Insulation Conductivity
1	Coating	0.003 m	0.1 W/(m*K

- Delete: delete insulation layer

Calculation

- Calculate: calculates calculation interval and position for each section in the line

Display Control

- Show Data: shows the section data panel
- Show Topography: shows the line topography graph

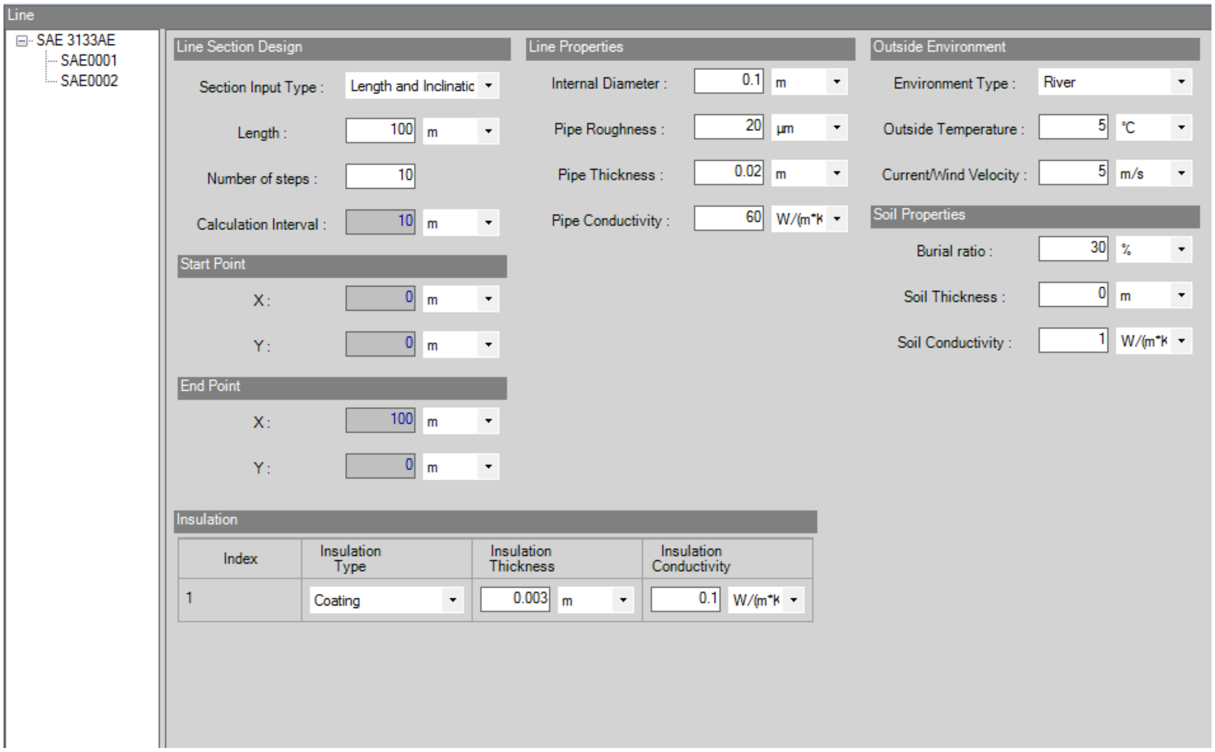
Import Line Topography (allows you to define your line topography and properties in excel and then import into Multicorp)

- Template: save an Excel-based default template (.xls or .csv) for line import of line topography and properties.

Detailed explanations are included in the file.

- Import: import line information from the template file updated with your line information inside.

3.5.2 Data Area



Line Section Design

Section Input Type : Length and Inclinatic

Length : 100 m

Number of steps : 10

Calculation Interval : 10 m

Start Point

X : 0 m

Y : 0 m

End Point

X : 100 m

Y : 0 m

Line Properties

Internal Diameter : 0.1 m

Pipe Roughness : 20 µm

Pipe Thickness : 0.02 m

Pipe Conductivity : 60 W/(m*K

Outside Environment

Environment Type : River

Outside Temperature : 5 °C

Current/Wind Velocity : 5 m/s

Soil Properties

Burial ratio : 30 %

Soil Thickness : 0 m

Soil Conductivity : 1 W/(m*K

Insulation

Index	Insulation Type	Insulation Thickness	Insulation Conductivity
1	Coating	0.003 m	0.1 W/(m*K

On the left side of the data area is the pipe section listing containing all pipe sections for the current line. Click on a pipe section name to load its pipe section data on the right side.

Line Section Design

- Section input type:

Section Input type	Input	Calculated Output
Length and inclination	- Inclination - Length - Number of steps	- Start point (X,Y) - End point (X,Y) - Calculation interval
Coordinates	- End point (X,Y) - Number of steps	- Inclination - Length - Start point (X,Y) - Calculation interval

- **Inclination**: defines the degree of line section inclination.
- **Length**: the length of the line section.

- **Number of steps**: the number of point model calculations per section. The more steps per section the higher degree of accuracy and but requires more calculation and therefore takes more time.
- **Calculation Interval**: distance for each point in the line section. It is simply calculated by length of the line / number of steps. It is highly recommended to have maximum 400 m of calculation interval for each line section.

Start Point

- **Start X** is the initial position of the pipe section in the x axis. For multiple sections it takes into account the inclination of the previous section.
- **Start Y** is the initial position of the pipe section in the y axis. For multiple sections it takes into account the inclination of the previous section.

End Point

- **End X** is the final position of the pipe section in the x axis, taking into account the inclination of the pipe section.
- **End Y** is the final position of the pipe section the y axis, taking into account the inclination of the pipe section.

Line Properties

- **Internal Diameter**: Internal pipe diameter Di.
- **Inclination**: the angle (q, Figure 1) between the pipe and the horizontal plane.
- **Pipe Roughness** is a measure of the texture of the internal surface of the pipe.
- **Pipe Thickness** is a measure of the thickness of the pipe wall.
- **Pipe Conductivity** is a measure of the conductivity of the pipe wall.

Outside Environment

- **Environment Type**
- **Outside Temperature**
- **Current/Wind Velocity**

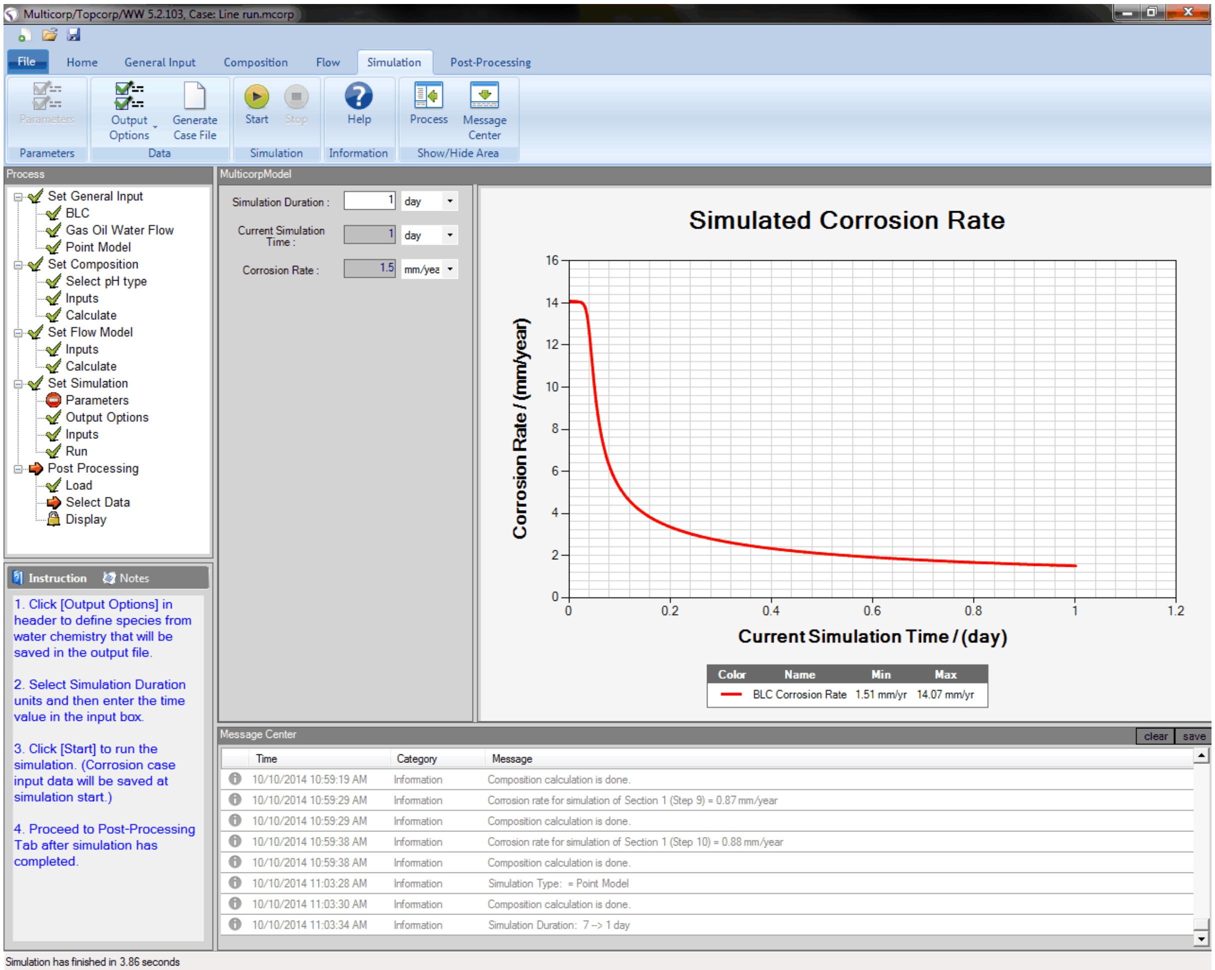
Soil Properties

- **Burial Ratio** is the percentage of the pipe being buried in soil.
- **Soil Thickness** is a measure of the thickness of the soil on top of the pipe.
- **Soil Conductivity** is a measure of the conductivity of the soil around or on top of the pipe.

Insulation

- Index
- Insulation Type
- Insulation Thickness
- Insulation Conductivity

3.6 Simulation



Simulation Duration : 1 day

Current Simulation Time : 1 day

Corrosion Rate : 1.5 mm/yea

Color	Name	Min	Max
▬	BLC Corrosion Rate	1.51 mm/yr	14.07 mm/yr

1. Click [Output Options] in header to define species from water chemistry that will be saved in the output file.

2. Select Simulation Duration units and then enter the time value in the input box.

3. Click [Start] to run the simulation. (Corrosion case input data will be saved at simulation start.)

4. Proceed to Post-Processing Tab after simulation has completed.

Time	Category	Message
10/10/2014 10:59:19 AM	Information	Composition calculation is done.
10/10/2014 10:59:29 AM	Information	Corrosion rate for simulation of Section 1 (Step 9) = 0.87 mm/year
10/10/2014 10:59:29 AM	Information	Composition calculation is done.
10/10/2014 10:59:38 AM	Information	Corrosion rate for simulation of Section 1 (Step 10) = 0.88 mm/year
10/10/2014 10:59:38 AM	Information	Composition calculation is done.
10/10/2014 11:03:28 AM	Information	Simulation Type: = Point Model
10/10/2014 11:03:30 AM	Information	Composition calculation is done.
10/10/2014 11:03:34 AM	Information	Simulation Duration: 7 --> 1 day

Simulation has finished in 3.86 seconds

The simulation tab enables the user to start or stop a simulation.

The simulation type chosen in the General Input tab determines the parameters available on this tab.

For all simulation types this tab will allow you to define the total duration of the simulation as well as see the current simulation time once simulation has been started.

Below are links to the Simulation tab's Ribbon Area and Data Area:

- Ribbon Area
- Data Area

Once simulation has completed, Post Processing of the simulation results can occur.

3.6.1 Ribbon Area

Parameters

- **Parameters**: this is where varying parameters for a parametric model simulation are chosen. (not required for Point model and Line run)

Data

- **Output Options**: Choose your output parameters for all models here. Simply select to include the parameter in post processing or deselect to not include in post processing.
  - Point Model: H^+, OH^-, CO_2, H_2CO_3, HCO_3^-, CO_3^{2-}, Na^+, Cl^-
  - Parametric Model: Inactive
  - Line Run: Temperature, Total Pressure, pH, Corrosion Rate, Flow Pattern
- **Generate Case File**: Generates an mccase file for running corrosion simulations directly in corrsim without the use of Multicorp (advanced users only)

Simulation

- **Start**: starts the simulation.
- **Stop**: stops the currently running simulation.

Information

- Clicking **Help** will open this help window for General Input.

Show/Hide Area

- **Process**: toggles the visibility of the left hand side Process Area and Instructions/Notes Area.
- **Message Center**: toggles the visibility of the bottom Message Center area. (Message Center will open if errors or warnings appear)

3.6.2 Data Area

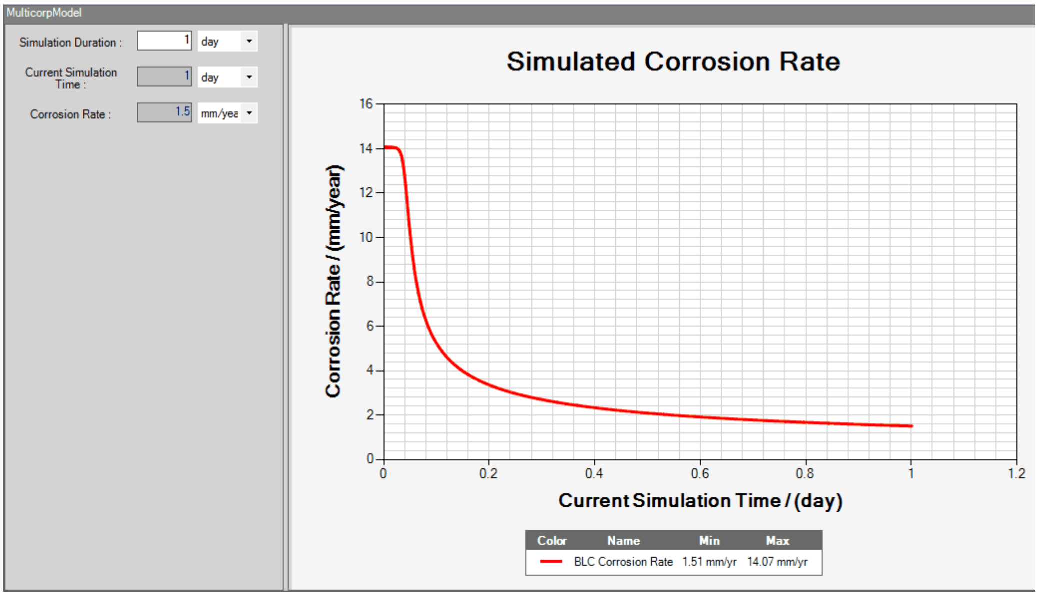
Based on the simulation type chosen in the General Input tab the Data Area for simulation tab will change.

All simulations do share three parameters, they are:

- **Total Simulation Count**: the total number of simulations to run along pipeline
- **Current Simulation Number:** the current simulation number that is running
- **Simulation Duration:** the duration of simulation for each corrosion rate prediction case

Below are what the data area's for the different simulation types look like:

Point Model

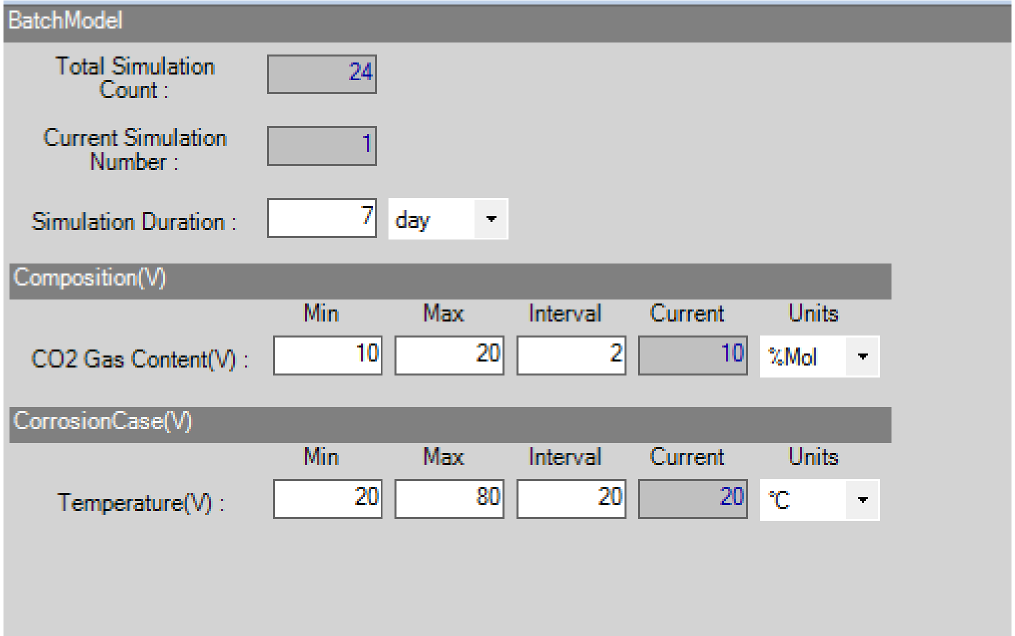


Simulation Duration : 1 day
Current Simulation Time : 1 day
Corrosion Rate : 1.5 mm/yea

Color	Name	Min	Max
🟥	BLC Corrosion Rate	1.51 mm/yr	14.07 mm/yr

Point Model simulation simulates corrosion at a single point for a defined length of time. The point model simulation tab shows the simulation duration, current simulation time, as well as current corrosion rate.
A real-time history curve of the simulated corrosion rate is shown on the right, with minimum and maximum corrosion rate listed in mm/yr.

Parametric Model (Batch Model)



BatchModel

Total Simulation Count : 24

Current Simulation Number : 1

Simulation Duration : 7 day

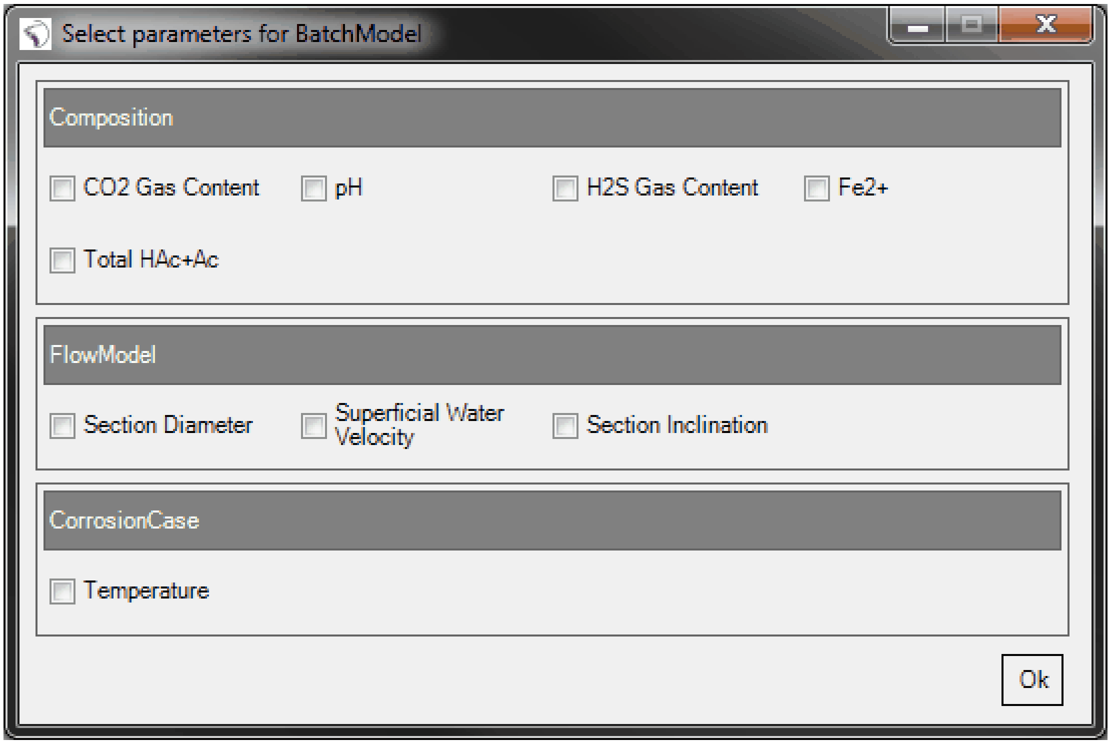
Composition(V)

	Min	Max	Interval	Current	Units
CO2 Gas Content(V) :	10	20	2	10	%Mol

CorrosionCase(V)

	Min	Max	Interval	Current	Units
Temperature(V) :	20	80	20	20	°C

Parametric model simulation simulates corrosion in a system by varying conditions over time. The parametric model simulation tab shows the simulation duration (the duration of each point model), current simulation number (the current point model being simulated), as well as total simulation count (the total point models to be run). This tab also shows the varying parameters required for the parametric model. Each varying parameter has a minimum, maximum, interval, and current value.



Select parameters for BatchModel

Composition

☐ CO2 Gas Content ☐ pH ☐ H2S Gas Content ☐ Fe2+

☐ Total HAc+Ac

FlowModel

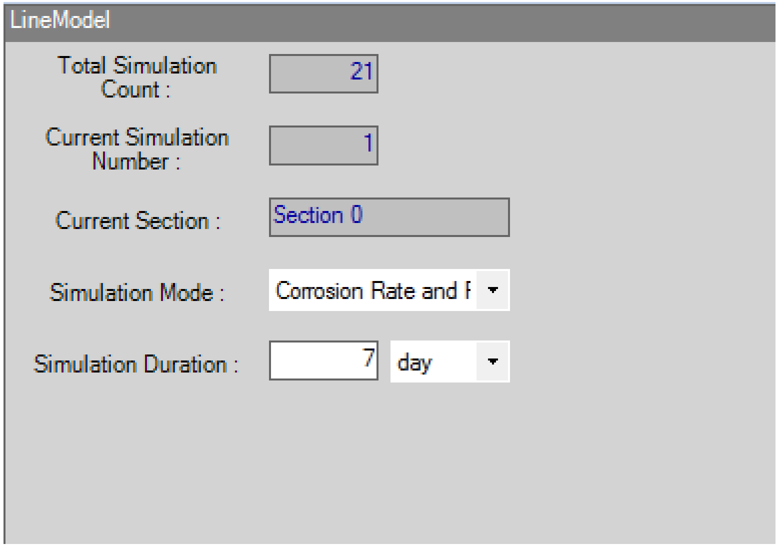
☐ Section Diameter ☐ Superficial Water Velocity ☐ Section Inclination

CorrosionCase

☐ Temperature

To add varying parameters to the model click on the Parameters button in the top left of the ribbon menu. Then select the parameters to be varied and click OK.

Line Model



Total Simulation Count : 21

Current Simulation Number : 1

Current Section : Section 0

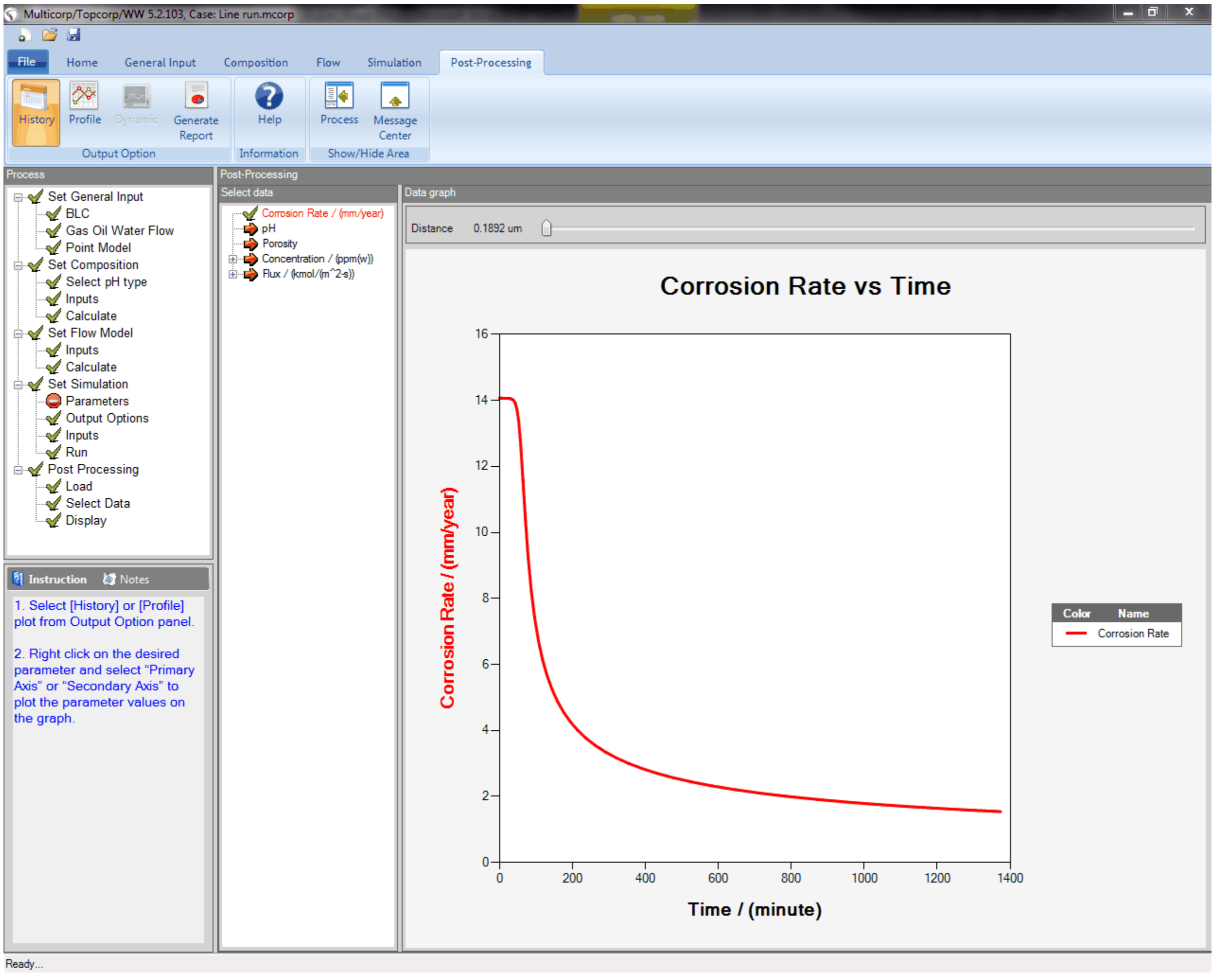
Simulation Mode : Corrosion Rate and F

Simulation Duration : 7 day

Line Model simulation simulates corrosion along the length of a pipe line broken down into pipe sections each with a discrete number of steps (point model calculations). The line model simulation tab shows the total simulation count (the total point models to be run along the pipeline), the current simulation number (the current point model being simulated), the current line section that is being simulation, the simulation mode, as well as the simulation duration (the duration of each point model simulation),.

- **Simulation Mode:** This selection will determine if a corrosion rate will be calculated for each point model simulation or if flow assurance or the guarantee of flow is the only calculation required.
    - **Corrosion Rate and Flow Calculation:** Both a corrosion rate and flow assurance will be calculated.
    - **Flow Calculation Only:** Only flow assurance will be calculated.

3.7 Post Processing



1. Select [History] or [Profile] plot from Output Option panel.

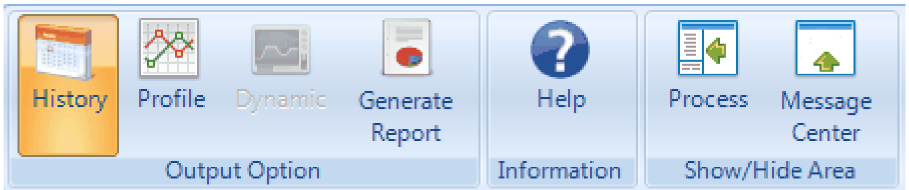
2. Right click on the desired parameter and select "Primary Axis" or "Secondary Axis" to plot the parameter values on the graph.

The post processing tab enables the user to analyze the simulation information returned after simulation has finished.
In order to analyze the data the user must first choose which parameters to analyze and the graph will automatically display them.

Below are links to the Post Processing tab's Ribbon Area and Data Area:

- Ribbon Area
- Data Area

3.7.1 Ribbon Area



Output Option

- **History**: Display variation of selected data vs. time at different distance (available only for Point Model)
- **Profile**: Display variation of selected data vs. distance from steel surface at different time (available only for Point Model)
- **Generate Report**: allows the user to export all case and simulation data to a Microsoft Excel based file.

Information

- Clicking **Help** will open this help window for General Input.

Show/Hide Area

- **Process**: toggles the visibility of the left hand side Process Area and Instructions/Notes Area.
- **Message Center**: toggles the visibility of the bottom Message Center area. (Message Center will open if errors or warnings appear)

3.7.2 Data Area

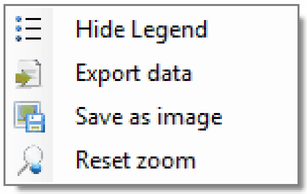
After simulation has finished, you can choose which simulation results to display in the post processing graph.

This is done by right clicking data in the Select Data window and choosing the axis on which it will be plotted.

Once data has been chosen for both the X-Axis and Primary Y-Axis, the data will automatically display on the graph.

Multicorp can plot data in multiple Y axes (Primary and Secondary Y-Axis) to allow for multiple scales.

Once this data has been plotted, right clicking on the data graph will display this menu:



Thus allowing the user to:

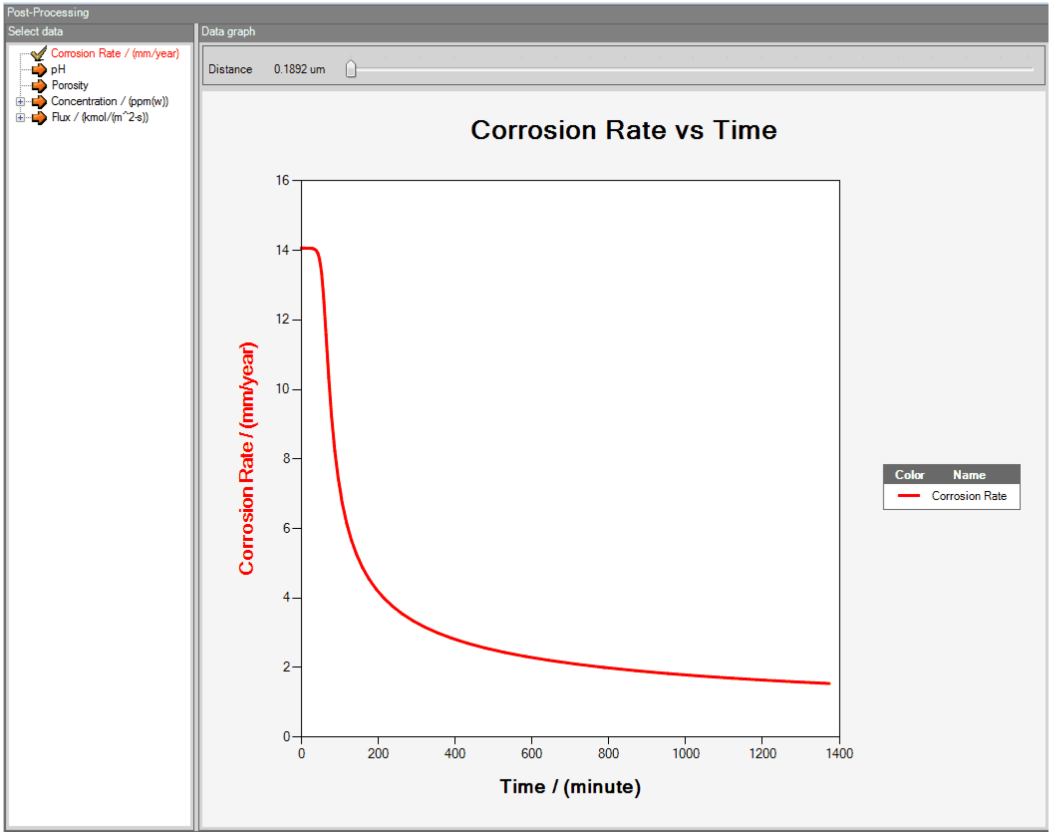
- show or hide the chart's legend
- export graph data to comma separated values file (Excel compliant)

- save the graph as a PNG image
- reset the zoom all the way out

Depending upon the simulation type chosen in General Input, the post processing data area will change.

Below are the data areas for different simulation types:

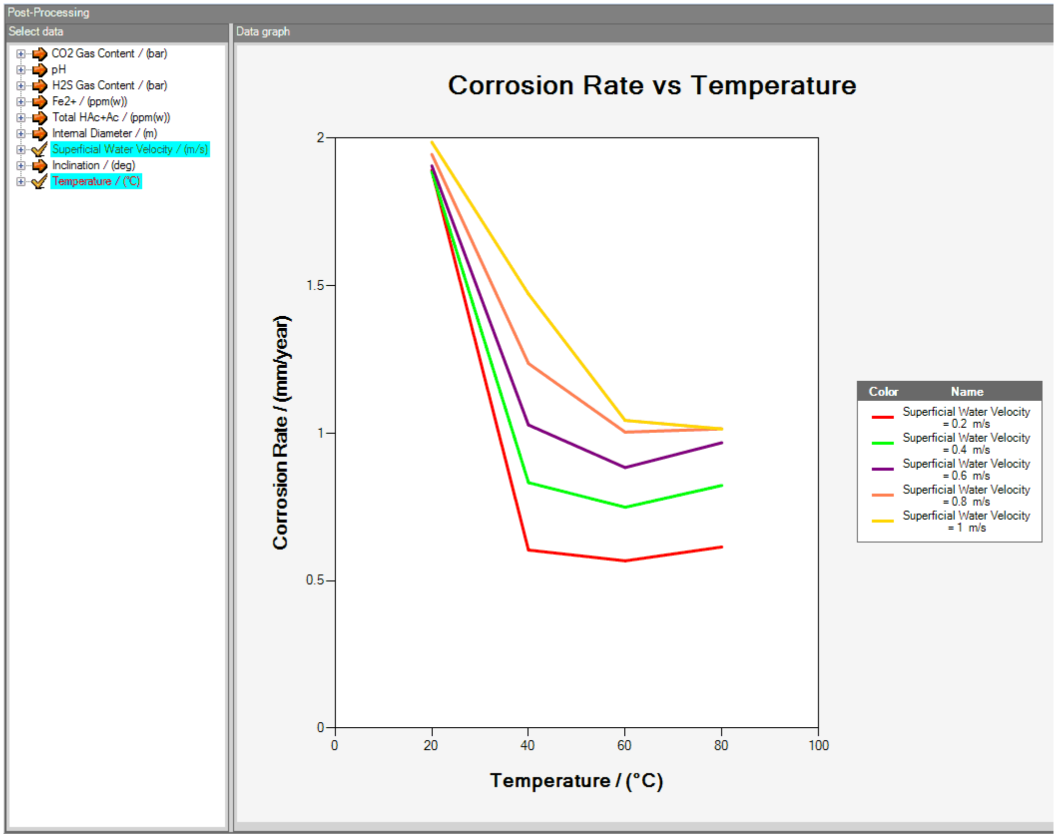
Point Model



Distance 0.1892 um

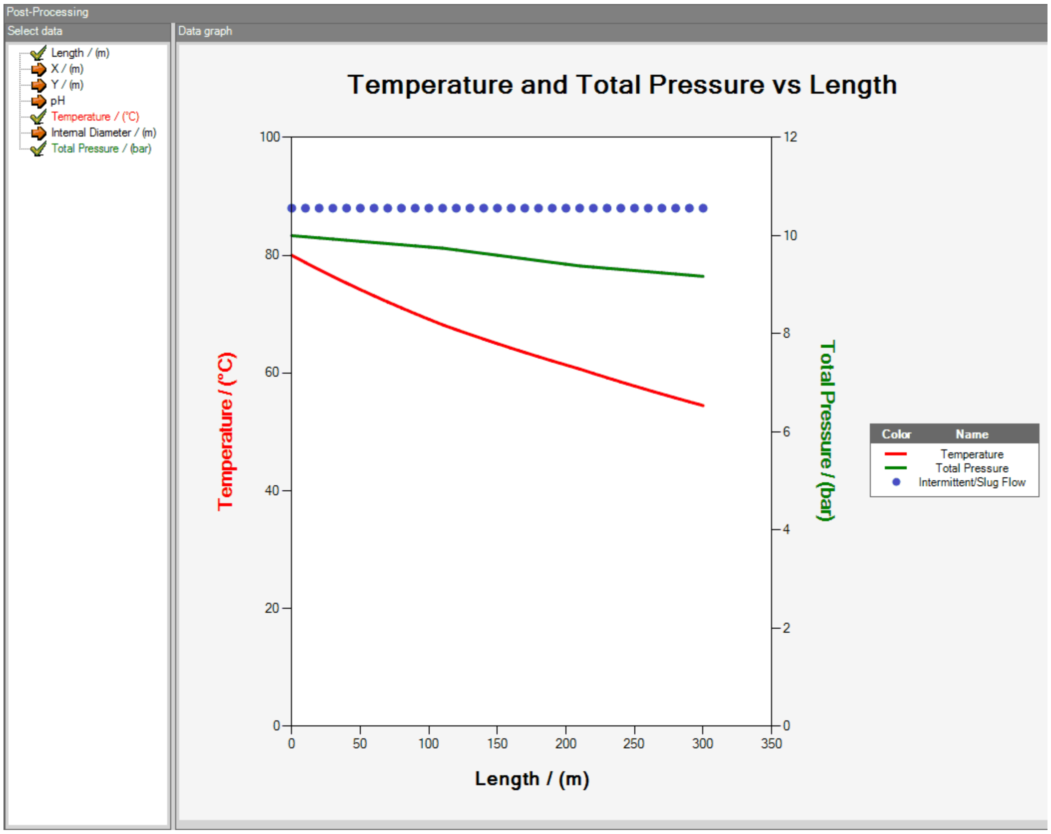
- Point Model (history): the user can select all parameters.
- Point Model (Profile): the user can select all parameters except Corrosion Rate and pH.

Parametric Model



- Parametric Run: the user can select only the varying parameters defined in the simulation tab (selectable parameters are shown with light blue color background).

Line Model



- Line Run: the user can select any parameters for primary y-axis and secondary y-axis, only Length or X can be plotted on the x-axis.

Part IV

4 Tutorials

Step by step tutorials of various Multicorp procedures are available on the ICMT Website at the link below:

- **Multicorp Tutorials**

Part

V

5 References

1 M. Nordsveen, S. Nesic, R. Nyborg and A. Stangeland, “A Mechanistic Model for Carbon Dioxide Corrosion of Mild Steel in the Presence of Protective Iron Carbonate Films - Part1: Theory and Verification”, Corrosion, Vol. 59, (2003): p. 443.

2 S. Nesic, M. Nordsveen, R. Nyborg and A. Stangeland, "A Mechanistic Model for CO_2 Corrosion of Mild Steel in the Presence of Protective Iron Carbonate Films - Part II: A Numerical Experiment", Corrosion, Vol. 59, (2003): p. 489.

3 S. Nesic, K.-L.J.Lee, "A Mechanistic Model for CO_2 Corrosion of Mild Steel in the Presence of Protective Iron Carbonate Films - Part III: Film Growth Model", Corrosion, Vol. 59, (2003): p. 616.

4 Johnson, M. L. & Tomson, M., “Ferrous carbonate precipitation kinetics and its impact on CO_2 corrosion, ”NACE Corrosion/91, paper no. 2689, (1991).

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