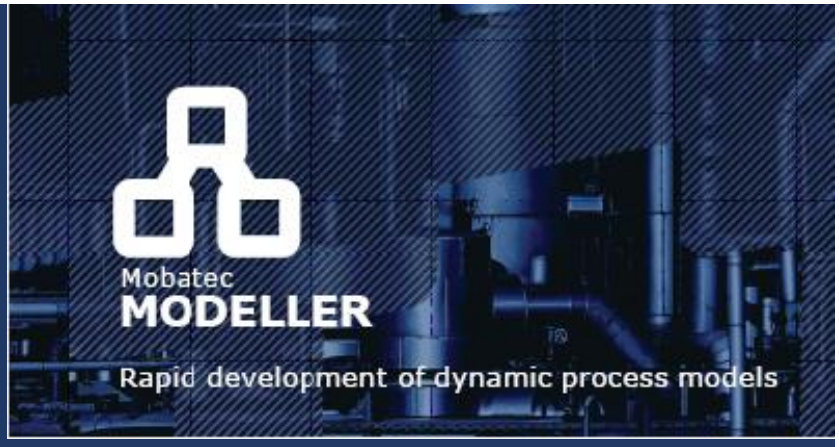
Mobatec
model-based technology



Mobatec Modeller

INTRODUCTION COURSE

Model Developer I

Advanced Equation-Based Modelling

Mobatec Modeller Intro Course – Model developer I

1 Modelling and Simulation of a Buffer Tank

1.1 Objectives

By the end of this exercise, you will know:

- How to build a model from scratch.
- How to write equations and add them to your model.
- How to monitor variable & parameter values using var. & par. tables.
- How to add parameters value access displays & filled rectangle displays.

1.2 Model description

We want to model a dynamic operation of a buffer tank:

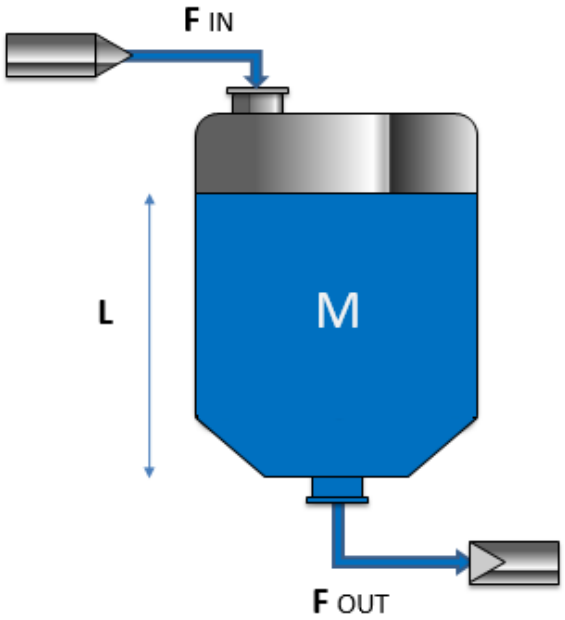


Figure 1 Single tray – Buffer Tank

The tank has a single inlet at the top and single outlet at the bottom. The geometry of the tank and the inlet flow will be provided as model inputs. The outlet flowrate is driven by gravity (hydrostatic pressure) and is dependent on the liquid level in the tank.

In MM (Mobatec Modeller) language, (topologically) this model consists of 2 "Battery Limit" system objects for the liquid source and sink, "Capacity" system object for the buffer tank and inlet and outlet mass connection.

1.3 Assumptions

- The tank is well-stirred (ideally mixed).
- The cross-section area is constant along the height of the tank.
- The operation of the tank is isothermal.
- The tank contains single component in the liquid phase, water - H_2O.

1.4 Model Equations

Buffer Tank model equations

Mass balance (system equation - generated automatically)

- $\mathrm{d}\frac{\mathrm{m_i}}{\mathrm{dt}} = Fin_i - Fout_i \qquad , i \in COMP$

Buffer cross-section area (system equation)

- $\mathrm{A} = \pi \cdot \frac{D^2}{4}$

Total mass holdup (system equation)

- $M = \sum(m_i)$

Liquid level (system equation)

- $M = \rho \cdot A \cdot L$

Liquid lines equations

Inlet mass flowrate (mass connection equation)

- $\mathrm{Fin} = \alpha \cdot Fm$

Inlet component mass flowrate (mass connection equation)

- $\mathrm{Fm_i} = Fin \cdot_{(or)} Xm_i$

Outlet component mass flowrate (mass connection equation)

- $\mathrm{Fm_i} = \beta \cdot \sqrt{_{(or)} L}$

1.5 Parameters

Symbol	Name	Model object	Units
D	**Diameter**	System	[m]
ρ	**Liquid density**	System	[kg/ m^3]
Fm	**Inlet mass flow**	In. Connection	[kg/s]
α	**Inl. line valve position**	In. Connection	[-]
β	**Outlet flowrate coeff.**	Out. Connection	[kg/s/m^(1/2)]
Xm_i	**Species mass fraction**	System	[-]

Table 1 Model parameters

1.6 Variables

Symbol	Name	Model Object	Units
A	**Horizontal cross-section area**	System	[m^2]
M	**Amount of the liquid contained**	System	[kg]
L	**Liquid level**	System	[m]
Fin	**Inlet mass flow**	In. Connection	[kg/s]
Fm_i	**In. com. mass flow**	In. Connection	[kg/s]
Fm_i	**Out com. mass flow**	Out. Connection	[kg/s]

Table 2 Model variables

1.7 Things to do

1. Create a New Model

Open a new model, by clicking on a "New Model" button, or click on *File/New Model*. A new model called "untitled1" will open. Save your model with a different name by clicking on a save as icon, or click File/Save Model as, choose appropriate location for your model.

2. Building model physical topology

Now that you have blank MM model on your screen you can start building the model physical topology. Go to *Property Browser/Insert Objects/Objects/ Systems from the scratch,* or press "SHIFT+s". From available options, choose **mass based "Capacity"** for the model parts that should store mass and energy. Choose **mass based "Battery Limit"** system for the mass & heat sources and sinks. Select appropriate system and then just click anywhere in MM modelling environment and the system will be inserted. Do that for all the model parts as they are described in the paragraph 1.2. Choose battery limits systems for the liquid source & liquid sink. Choose capacity system for the buffer tank.

Now that you have placed the model systems to resemble Figure 1, you should make physical mass connections. Go to *Property Browser/Insert Objects/Objects/Connections from Scratch* (shortcut, "SHIFT+c") and choose **"Uni-Directional Mass" connection**. Connect the liquid source battery limit to the buffer tank, and then make a mass connection from the buffer tank capacity system to the liquid sink battery limit system as illustrated in Figure 2.

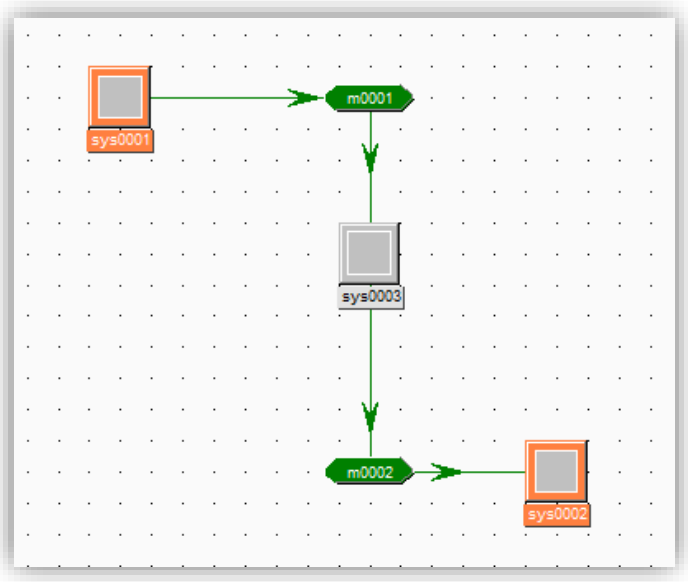


Figure 2 Buffer Tank Mobatec Modeller physical topology

In MM you can choose to use either **molar** or **mass** based balanced calculation for the capacity systems. In this model our input parameter is in mass units (kg/s) so a mass based balance calculation should be chosen. If needed this setting can be changed always by selecting the system and going to *Properties Browser/Selected Objects/System/Equations,* then click on *Equation Sorting* button and under "Equation Class" drop-down menu (left bottom corner of the tab) one can choose between "**System (mass based balances)**" & "**System (mole based balances)**".

3. Adding Icons to systems and connections

After connecting all the model parts, we can add specific icons to each part. Go to ***Properties Browser/General/Icons***. You will see that the "Plant Icons" box is empty. In "Available Plant Icons" select "Exercises Icons" folder and find "Ex_Buffer_tank" icon and click "Add Plant Icon" button, now this icon is available in the "Plant Icons" box above, do so for the "Ex_Liquid_Source", "Ex_Liquid_Sink" & "Ex_Valve" icons. Note: all icons related to all the exercises have "Ex_" prefix before their name.

Now all four icons are available. Select the buffer tank system in MM working space, then go to ***Properties Browser/Selected Object/System/Graphics*** select the "Ex_Buffer_tank" icon in the "Plant Icons" and click "Change Icon" button. Do so for other two objects accordingly (Sink & Source). Use corner active points on the icons to resize the icons. To add icons to connections, go to ***Properties Browser/Selected Object/Connection/Graphics*** then do the same as for the systems (add valve icon). Now your model should look similar like presented in Figure 3.

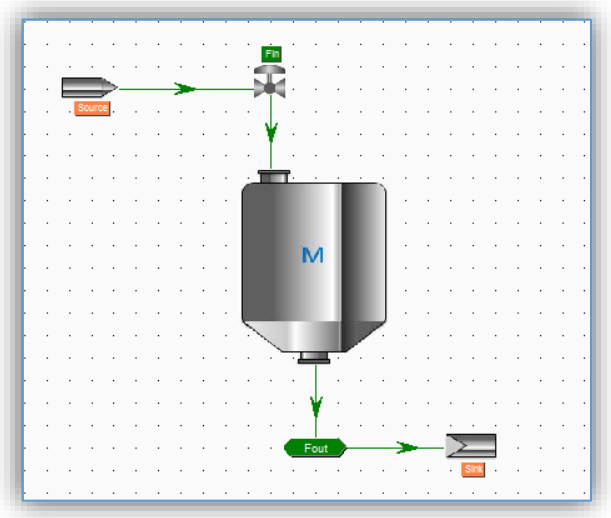


Figure 3 Buffer Tank model with icons added

When a system is selected, within the "Graphics" tab in the right bottom corner you can choose the position of the system label (name). You can "hide label" (keyboard shortcut: 6), place label it under the system (7), above the system (8) or in the system (9). When connection is selected choose "Attributes" subtab of the "Graphics" tab to access the options (keyboard shortcuts are the same). To **rename the system or connection** select the object, press "**F2**" or do right click/rename. Try out these operations.

4. Adding Species to your model

Inject H_2O to Liquid Source battery limit. Procedure is the same as performed in Exercise 2.

5. Writing & Adding Equations in Mobatec Modeller - MM syntax

Writing Equations

By making physical topology of the model and species topology (injecting species) of the model in Mobatec Modeller you have already created the mass balance equations of all your model systems (in this case one system). As you are making mass and heat connections Mobatec Modeller is generating mass & energy balance equations automatically in the systems, based on the connections you have made. Select the Buffer Tank system object and go to Properties/Selected Object/System and select the Equations tab.

In the upper section of the tab you will be able to see the automatically generated mass balance (Figure 4) as it is given in the **Model Equations** paragraph. Energy balance is not present as the buffer tank is modelled to have isothermal operation and no heat flow (HF) equation is present in the mass connections, and no heat connection(s) are included in the model as well. You will never have to define the balances equations! Mobatec Modeller will always take care of that for you, and will update the balances automatically as you change each system mass or heat connections!

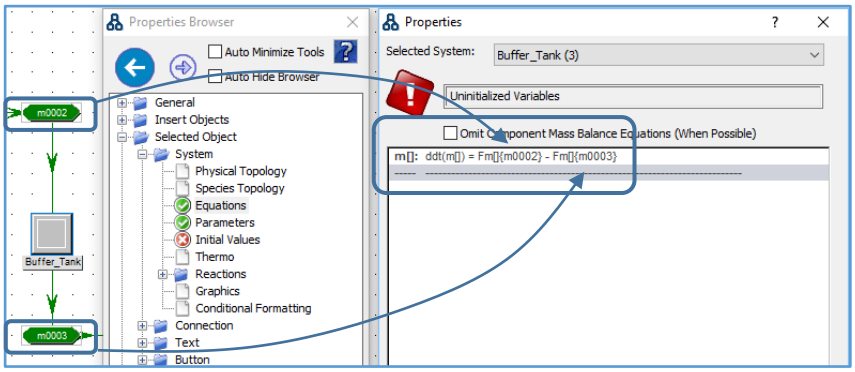


Figure 4 Automatically generated mass balance

Next step is to create the (algebraic) equations and add them to your systems & connections. First, let us create and add the Inlet connection equations.

Inlet connection equations *(MM syntax):*

Equation name:	**Function:**	**Equation Class:**
Inlet_Mass_Flowrate	`Fin = Alpha * Fm`	***Mass Connection***
Inlet_Comp_Mass_Flowrate	`Fm[] = Fin * or.Xm[]`	***Mass Connection***

(`or.Xm[] calls the variable Xm[] from the origin source system`)

Select the active point of inlet mass connection (not source battery limit system) go to ***Selected Object/Connection/Equations*** tab and click on "Define Equations" button (left bottom corner), "Define Equations" tab will open. To create a new equation, click on "Define New Equation" button. The "Define New Equation" tab will appear.

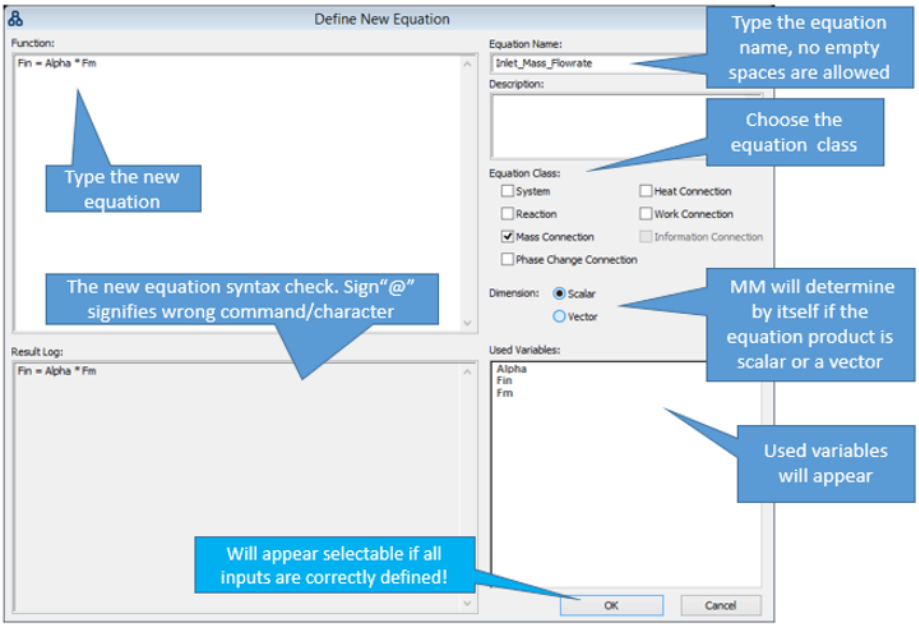


Figure 5 Define New Equation Window – Creating "Inlet Mass Flowrate" equation of Inlet mass connection.

Write the equation name according to the equations list. There should not be empty spaces in defined name, as then MM will report “illegal character” and will not let you create the equation (e.g. “Inlet_Mass_Flowrate” is correct). Under the “**Equation Class**” select “**Mass Connection**” (every time you want to create a mass connection equation). You can choose to use the equation for more than one system type by selecting two or more equation classes.

Under “Function:” write the equation for the inlet mass flowrate as shown in Figure 5. As you typed the equation, MM will determine automatically whether the equation is a “scalar” or “vector” under the “Dimension”. Press “OK” to create (save) the equation. Use the same procedure to make the second equation for the inlet connection, i.e. “Inlet component mass flowrate”.

After you created both equations you should add those equations to the inlet mass connection. Already opened Define Equation tab now has two equations in its “Database Equations:” list-box, equation you have created. Select one, equation and press “Add” button to add it to the inlet mass connection. Do the same for the other equation.

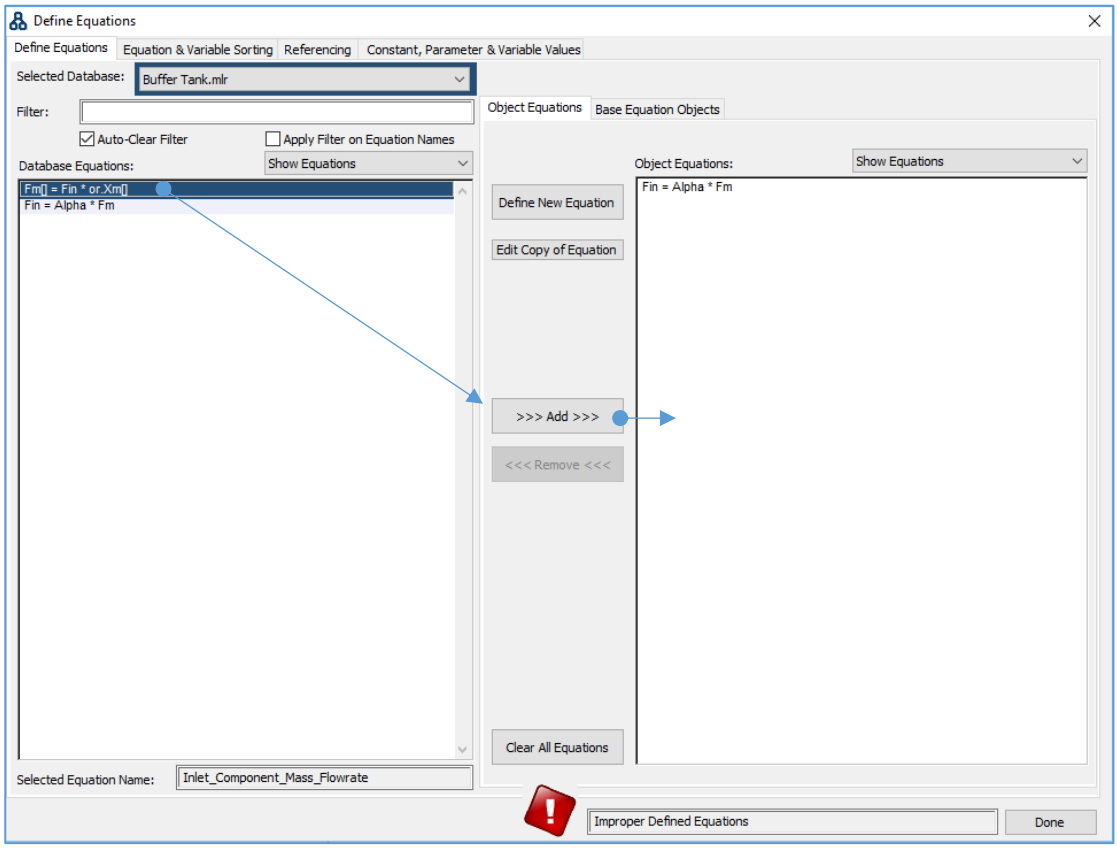


Figure 6 Adding the equations of Inlet mass connection

Use the same procedure to create and add the equations to Buffer tank system. In this case choose “**System**” type under equation class. Create and add following three equations to the buffer tank system.

Buffer tank system equations *(MM syntax):*

Equation name:	**Function:**	**Equation Class:**
Area	`A = D^2 * PI() / 4`	***System***
Total_mass_holdup	`M = SUM(m[])`	***System***
Liquid_level	`M = rho * A * L`	***System***

Create and add, the equation to the outlet mass connection on the exact same way as you did for the Inlet mass connection. After doing that, your model parts should hold all the equations needed.

Outlet connection equations *(MM syntax):*

Equation name:	**Function:**	**Equation Class:**
Outlet_comp_mass_flowrate	`Fm[] = Beta * SQRT(or.L)`	***Mass Connection***

(`or.X calls the variable X from the origin system, tar.X calls the variable X from the target system of the connection`)

Equations can also be created and deleted (you can remove any previously created equation from the database) by using the Main Editor. You can open it by using the "" icon in the toolbar (or just press "d"). Main editor will open. You will be able to see: ***Equations, Variables, Species, Reactions, Equation Objects, User Routines*** *and* ***External functions*** tabs. For now, we will only focus on Equations and Variables tabs. Go to Equations tab of the main editor and follow the exact same procedure to add equations to the model database as described when adding the equations directly **when having selected a model object.** Adding equations is done by selecting a model object and adding the equations from the available selected database. *Note: Select your model database and not the "Default Database".*

IMPORTANT: If some equations are repeating in different systems or connections, there is no need to create them again, every equation needs to be created ONLY ONCE, it will become a part of equation database and it can be used where ever you need them as many times as needed. This is possible due to equation physical topology distribution in Mobatec Modeller.

6. Declaring variables dimensions (units)

After you have entered the equations you need to declare the dimensions of the variables used. Open the main editor tab, select the main editor icon "" in the toolbar (or just press "d") and select the "Variables" tab. There you will find listed all the variables that you have used in your equations (some other MM predefined variables will be listed there as well, don't mind them at this point). Select any variable and you will be able to "Edit Variable", chose the variable "Unit Category" from available drop down many and by doing that the "Engineering Unit" will be filled automatically. Set the variable upper & lower bound. Do this for all the variables according to Table 3 below. If variable does not belong to any available unit category, like "Beta" in this case, use "_Undefined" unit category and input the unit into the "Engineering Unit" box.

Symbol	Name	Unit Category	Eng. Unit	Bounds
D	**Diameter**	Length	m	[0 – 100]
rho	**Density**	Density	kg/m^3	[0 – 3000]
Fm	**Inlet mass flow**	Mass flow	kg/s	[0 – 1000]
Alpha	**Inlet line valve position**	Fraction	(-)	[0 – 1]
Beta	**Outlet flowrate coefficient**	-	kg/s/m^(1/2)	[0 – 100]
Xm[]	**Species mass fraction**	Fraction	(-)	[0 – 1]
A	**Area**	Area	m^2	[0 – 100]
M	**Total mass holdup**	Mass	kg	[0 – 3000]
L	**Level**	Length	m	[0 – 100]
Fin	**Inlet mass flow**	Mass flow	kg/s	[0 – 1000]
Fm[]	**Component mass flow**	Mass flow	kg/s	[0 – 1000]

Table 3 Variable dimension declaration

7. Sorting the equations

What is a well posed system?

There should be identical number of equations and variables to make a well posed system, i.e.

(nº variables = nº equations)

To assure a well posed system in each model object every time, Mobatec has developed **equation sorting** to ensure maximal certainty with this important step of model building. Let's take a look on how the "Buffer_Tank" system should be "sorted". First select the system and go to *Property Browser/Selected Objects/Systems/Equations* then click *Equation Sorting* button.

If you added all the equations correctly you will see the picture presented in Figure 7. You can see that some equations are marked with "***" sign. This sign in front of the equation indicates that specific equation cannot calculate value of any of the variables within that equation. This is time to define the parameters (inputs) of the "Buffer Tank" model.

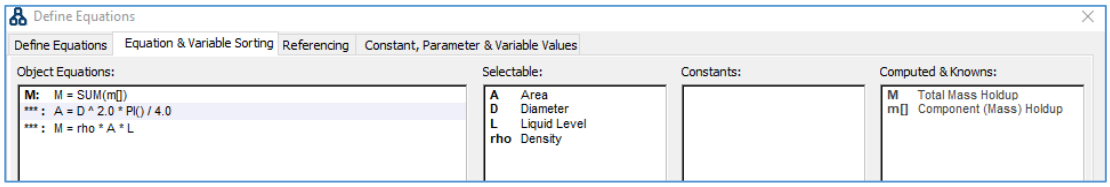


Figure 7 Buffer tank system – unsorted – not well posed

Next to the "**Object Equations**" box in the "Equation & Variable Sorting" tab you can see three groups "**Selectable:**", "**Constants:**" and "**Computed & Knowns:**". In Computed & Knowns box are the variables that can be calculated or are known from the provided equations. In the Selectable box, Mobatec Modeller will list the variables that cannot be calculated from the given system of equations.

Now check the model parameter Table 1 and define the parameters (*D,rho*) of the "Buffer_Tank" system. By clicking on the variable in the selectable box the variable will move to constants box (user changeable constant) and becomes a parameter (model input). After this system will become well posed, as shown in Figure 8.

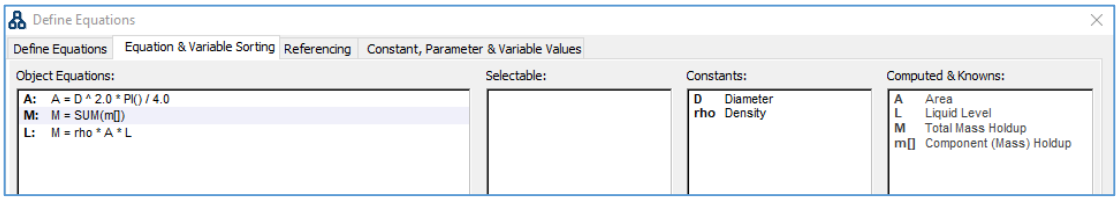


Figure 8 Buffer tank system - sorted - well posed

At the bottom of the "Equation & Variable Sorting" tab as well as on the top of selected model object "Equations" tab, the visual sign with message of the current state of the model object system of equations will be displayed, example showed in Figure 9.



Figure 9 System of Equations CHECK message – unsorted (left) & sorted (right)

Select the Source battery limit system and open "Equation & Variable Sorting" tab (the same as for the buffer tank system). There will be no equations present in this system as we did not add any, but variable "Xm[]" will be present (Figure 10 n. p.) in the selectable box list as this

variable was “called” using prefix “or.” in “Fm[]= Fin * or.Xm[]” equation of the inlet connection. Sort variable “Xm[]” as parameter according to Table 1.

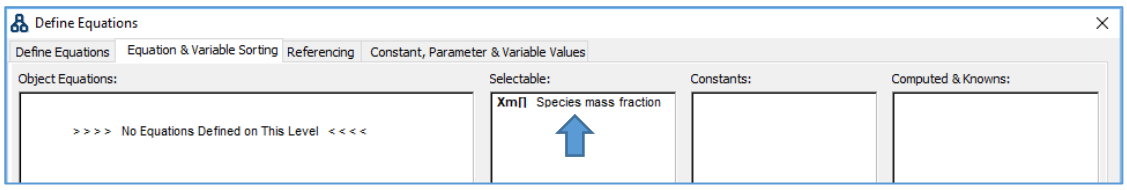


Figure 10 Battery Limit Source system sorting

Sort the equations of the inlet and outlet liquid line following the exact same procedure.

8. Initializing the “Buffer Tank” model

Insert the given parameters values to the “Buffer Tank” system & inlet and outlet connection according to Table 4 in **Appendix 1**. Do that by selecting the desired system/connection then go to the *Properties Browser/Selected Object/ System or Connection/Parameters* and in the “Constants & Parameters Values” tab enter the value under the “Value” column for each parameter defined for the selected object.

Now you need to enter the initial values of a certain variables in the capacity systems (system that can store mass & energy), in our case “Buffer_Tank” system, so that you can initialize the model.

Select buffer tank system, go to *Properties Browser/Selected Object/ System/Initial Values* tab. Check the “I” box for the “L” (level) variable as shown in Figure 11 and click “Calculate Initial Values”. You could also specify “M” or “m[]” as well (try that too). After, you have successfully initialized the “Buffer_Tank” system, initialize the Inlet & Outlet mass connections by clicking on “Calculate Initial Values” as they do not require the initial variable values because they are not capacities.

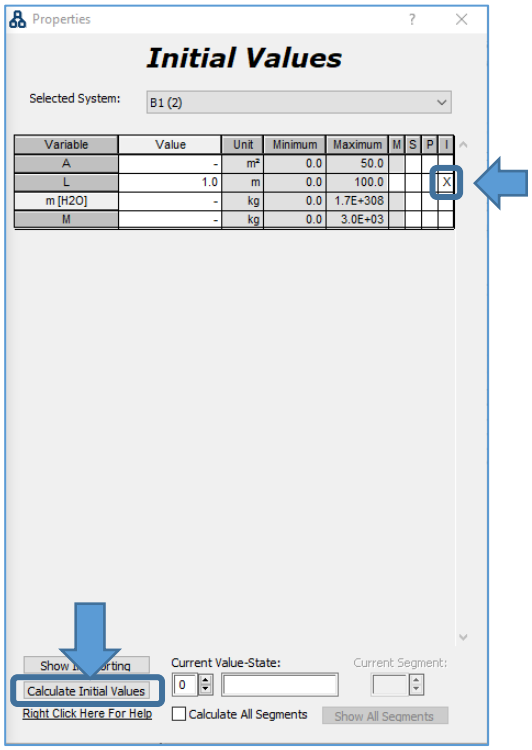


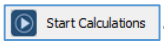
Figure 11 Buffer Tank system initialization

To learn all on **first principles model building** in MM and **mass balance formulation/definition** read **Chapter 5**. To learn all on **degrees of freedom and initial conditions** read **Chapter 6**. in Mobatec Modeller handbook for beginning and advanced users.

9. Running a Dynamic Simulation & monitoring variable values

Before running a model simulation, the model compilation is required. Compilation is a model code generation process where all the "programming" is done by Mobatec Modeller, after which the model is ready to be solved by the solver. To Compile the model, press *"Compile Model and Switch to Simulation Environment"* icon in the toolbar "" (shortcut - F12), or go to *Property Browser/General/Basic Commands* and press *"Compile Model and Switch to Simulation Environment"* button. When your Model is compiled you will get a message that compilation was successful!

Go to *Property Browser/General/Basic Commands* in Simulation environment and select *"Dynamic"* under the *"Simulation type"*. Under "Integration Method" select "Fix Step Size" and enter "1" (sec), you can also choose bigger or smaller time steps. Under *"Calculation Delay (in ms)"* enter "1000" if you want a Real Time simulation, if not leave "0".

Click the ***"Start Calculation"*** button "

" and run a dynamic simulation of the model. If there are no errors your model should be running the simulation and you are able to follow the *"Simulation time"* in seconds on the Basic Commands tab, or at the left bottom corner of the screen.

Monitoring variables values

You can monitor your variables and monitor & change parameter values of any model object by selecting the object, doing the right click and choosing "Show Variable Table" or "Show Parameters Table", or just select object and press numbers from 1-5 for variable tables or numbers from 6-9 & 0 for parameter tables. You can have up to 5 variable & 5 parameter separate tables open in the same time. You can open just one variable table and then just click on another model object to inspect the variable values of those objects (try it). If you want one table to always show only one object variable values, select "Lock Selection Filter" check box and then the shown variables are locked to that specific table as shown in Figure 12. The same holds for parameter tables. If you make no selection and open a table all model variables or parameters (depending on opened table) will be displayed.

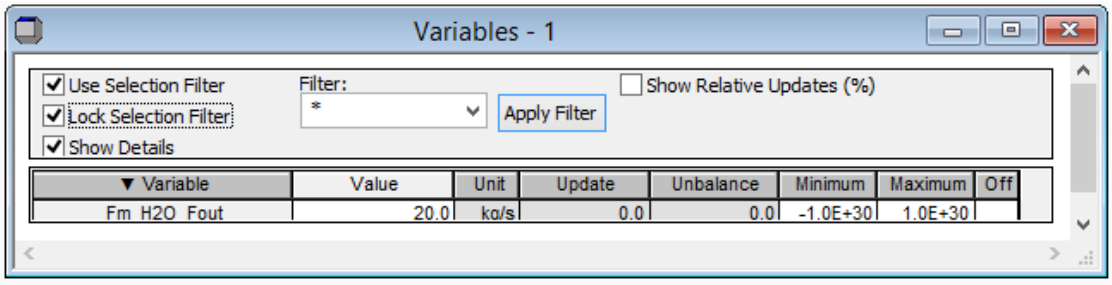


Figure 12 Variable Table with Locked Selection Filter

10. Adding variables & parameter displays

Now, that your model is running, lets "display" some variable and parameter values to be visible at all time for easy process variables monitoring and parameter value monitoring and change.

In MM you can display the variable value in two ways, graphically in a form of a filled rectangle where filled area corresponds to a value of the variable with respect to its min/max values or digitally with numbers, as used in Exercise 2.

Add mass flow value display object (**kg/s**) for "**Fin**" variable of the inlet connection. Do the same for the outlet mass connection where you should display "**Fm_H2O**" variable. This variable appears as "Fm[H2O]" in the modelling environment but after compilation in the Simulation environment it will always appear in "Fm_H2O" form.

Make a value display object to monitor the liquid level (simulation variable "**L**") in the tank. Also make a rectangle filled display (Figure 13) to graphically represent the liquid level (same simulation variable "**L**"), use 10 m as max value (upper bound). Use your mouse pointer to re-shape the rectangle display to desired form.

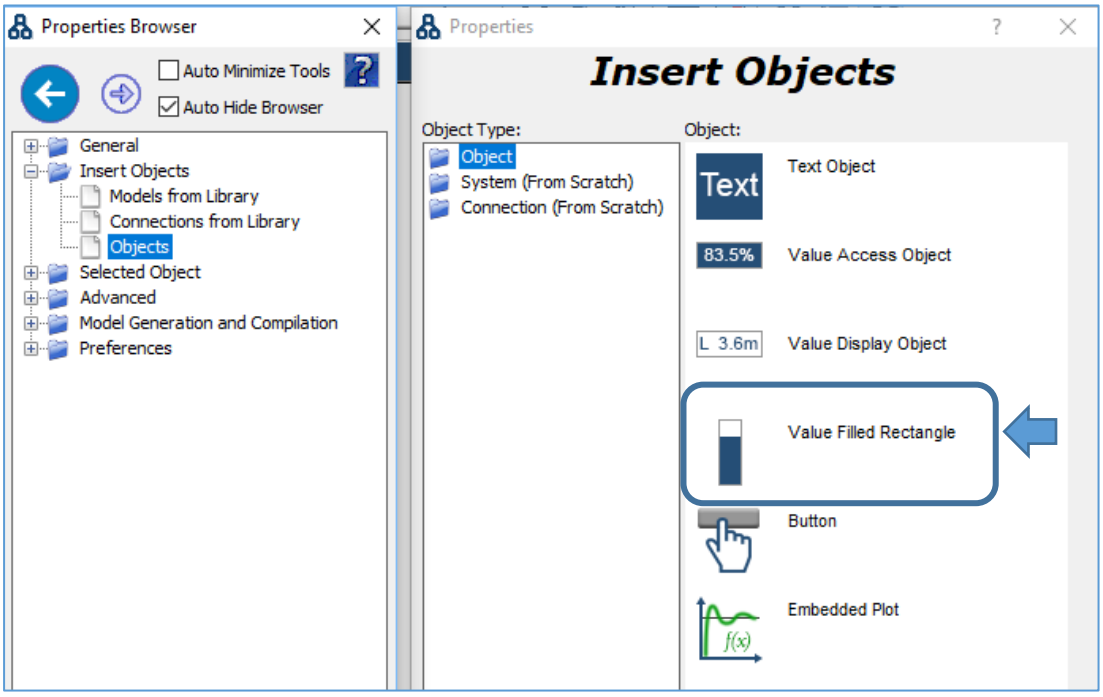


Figure 13 Value Filled Rectangle

Now, let's make some parameter display so that parameter values could be changed directly while simulation is running. For this purpose, **Value Access Objects** are used. The procedure is the same as for value display objects but now in "Simulation Variable" box of the value access object display you will type the parameter exact name (parameter full name from simulation). When in simulation click on the display and a small pop-up window "Set New Value" will open allowing you to change the parameter value directly as shown in Figure 14.

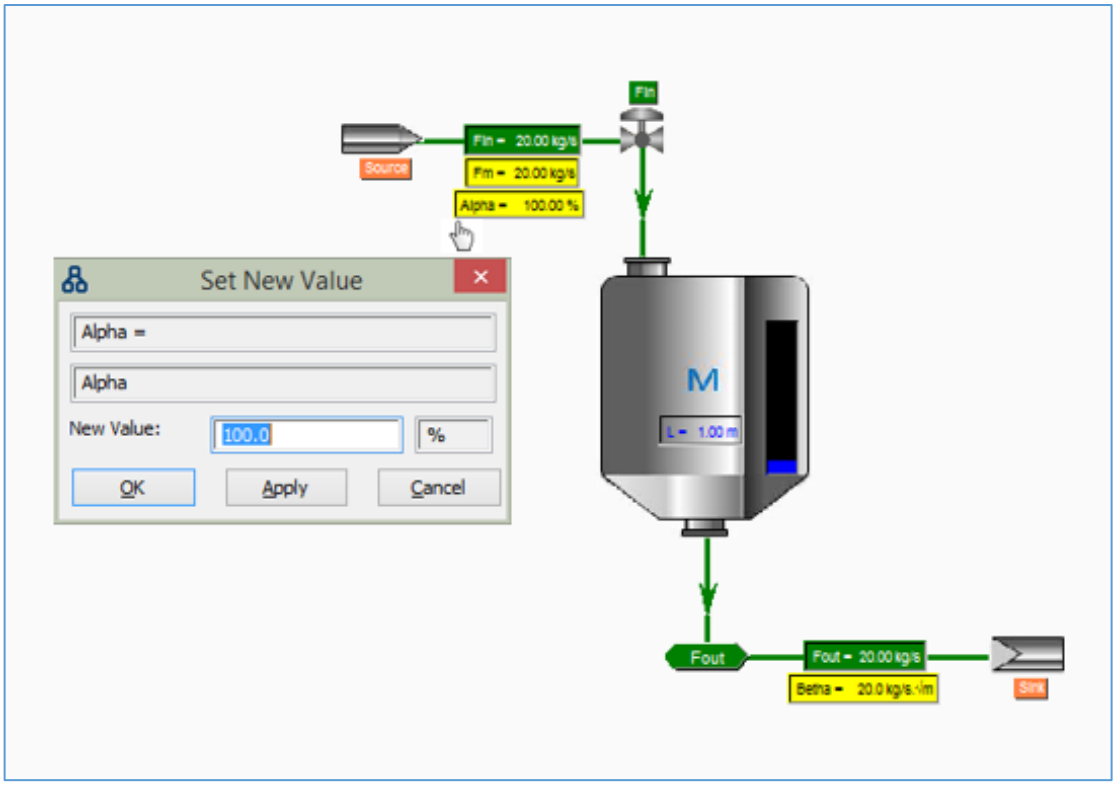


Figure 14 Buffer Tank model parameter change using display

1.8 Questions:

Question1:

What should be the "Beta" - outlet flowrate coefficient so that the liquid level in the tank is L = 4 m & L = 6 m?

Beta (4m) = ___.

Beta (6m) = ___.

Question 2:

Make a cascade of 3 buffer tanks in series by copying and reconnecting model parts from the existing model. Rename the tanks to B1, B2 & B3. Rename the connections to "B1, B2 & B3_Fout".

What should be the "Beta" - outlet flowrate coefficients values of the outlet lines so that the liquid level in tank B1 is L = 6 m in tank B2, L = 4 m and tank B3, L = 2 m?

Beta_B1_Fout (6m) = ___.

Beta_B2_Fout (4m) = ___.

Beta_B3_Fout (2m) = ___.

Appendix 1

1. Model parameter values

Symbol	Topology	Name	Value	Units
D	**Tank**	**Diameter**	0.15	[m]
ρ	**Tank**	**Liquid density**	1000	[kg/ m^3]
Fm	**Inlet conn.**	**Inlet mass flow**	20	[kg/s]
α	**Inlet conn.**	**Inl. line valve position**	1	[-]
Xm	**Source system**	**Species mass fraction**	1	[-]
β	**Outlet conn.**	**Outlet flowrate coeff.**	20	[kg/s.√m]

Table 4 Buffer Tank model parameters