Sumo User Manual

BY

Sumo is a third generation wastewater process simulation software. It was put together by a dedicated team with professionalism and thousands of days of tender loving care. Enjoy, and please let us know if you find somewhere it is coming short of your expectations. We will do our best to improve it.

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1 Contact

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2 Installing Sumo

The following steps will help to guide you through the installation of Sumo.

2.1 Prepare Microsoft Windows for Sumo

Operating system

Make sure your computer is operating Microsoft Windows 7 or later. Sumo supports touch screen computers running Windows 8/8.1 and Windows 10.

Sumo can be used on a Mac with Windows installed or through an emulator like "Parallels".

Microsoft Office

Sumo requires Microsoft Excel 2007 or later installed.

.NET

Please make sure that your computer is running the Microsoft .NET 4.5 framework. You can check it in the list of installed applications (Control Panel / Programs / Programs and Features). If the .NET framework's 4.5 version is not installed, please download and install it from the following location:

http://www.microsoft.com/en-us/download/details.aspx?id=30653

Windows 10 comes with the required .NET environment. On other operating systems, if you have it already installed on your computer, the downloaded installer will not reinstall it. Proceed to the next step.

2.2 Installation of Sumo

You have received a link to the Sumo installer (or in rare cases the install file on a USB key). This is one file and contains everything necessary to install Sumo once Windows is prepared. Download it through the link provided to your computer. From the USB key you can install directly if desired, it is not required to copy the file to the computer.

Install Sumo by starting the install package and follow instructions. Administrator rights may be necessary during installation. For workstations, we recommend choosing the "Install just for me" option.

2.3 Obtaining a license

Obtaining a license is a two-step process.

1. After install, start Sumo from the Windows Start menu. Sumo will display a message providing multiple options. If you don't have the license file yet, Select "I need a new license". Sumo will display two additional buttons to show information about your hardware (Machine Identifier Code) and to copy this information directly to the clipboard. Please paste this code into an email and send it to support@dynamita.com. Dynamita will provide a license file for you according to our agreement.
2. Copy the license file Dynamita provided to a folder on your computer, start Sumo, choose the "I have a licence" option and navigate to load the license file. As long as the license file is not deleted or moved and it is valid, this validation does not have to be repeated. Other options, like using a license server or a hardlock, are also available.

Note: If you already have Sumo installed and running in demo mode, you can go to step 1 by choosing the "Home" icon and selecting the licensing button in the bottom left window pane.

3   Introduction

Sumo is a powerful, open process source, multipurpose simulation environment developed for environmental models, particularly municipal and industrial wastewater treatment plant modelling. A wide range of BNR plant configurations can be simulated in Sumo. Sumo models are written in an Excel based open process source code language called SumoSlang (Sumo Simulation Language, copyright Dynamita).

Sumo can simulate traditional biokinetic models dynamically or in steady-state, mixed equilibrium-kinetic models and direct algebraic models, depending on the simulation mode.

Sumo is supplied with internally researched and developed whole plant models as well as focus models (e.g. with focus on sulfur, high rate plants and the fate of nitrogen and GHG). The seven most widely known published models are also included in the Sumo Museum for N and P removal.

Sumo models can be run through several different interfaces. The most widely used is "Sumo", an intuitive graphical user interface (Figure 1)
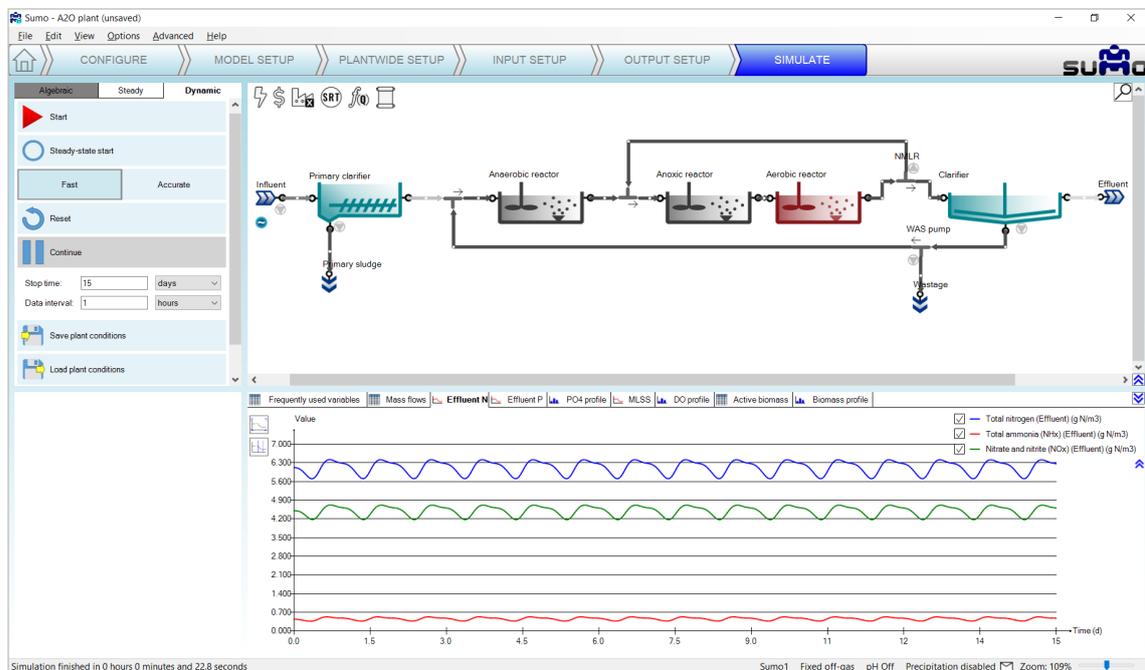
Figure 1 - The Sumo graphical user interface

Sumo21 is able to communicate with other programs through its Digital Twin Toolkit (DTT), such as Excel, Python, Matlab, etc. The Sumo21 install comes equipped with a couple of examples:

- Excel based "Operator interface". This can be customized to a certain plant configuration or SCADA for easy use of plant simulations.
- Sample Python scripts for sensitivity analysis and parameter optimization using Sumo.

More description about these advanced functionalities can be found in the Technical Reference document.

Please note that the Digital Twin Toolkit (DTT) will only work with a valid DTT license, which is available separately from the Sumo license.

4   How to use Sumo for simulations

4.1   Start Sumo

Start Sumo from the Start menu

On Windows 10 systems, you can use the start menu to launch Sumo. The installer places the software in a folder called "Dynamita". A quick way of locating the application is to start typing 'sumo' once the start screen is on (Windows 10 switches into application search mode in this case, showing the most relevant search results on the left). With drag and drop, you can also pin a Sumo21 quick launch icon to the Start menu tiles or to the Desktop of the computer as well. Note: right clicking on the program launcher icon allows you to open the recent project files.

Sumo will start with showing the Welcome Screen, as illustrated by Figure 2. Below the Menu Bar, you will see the Task Bar that guides you through the project workflow, all the way from configuration to simulation.
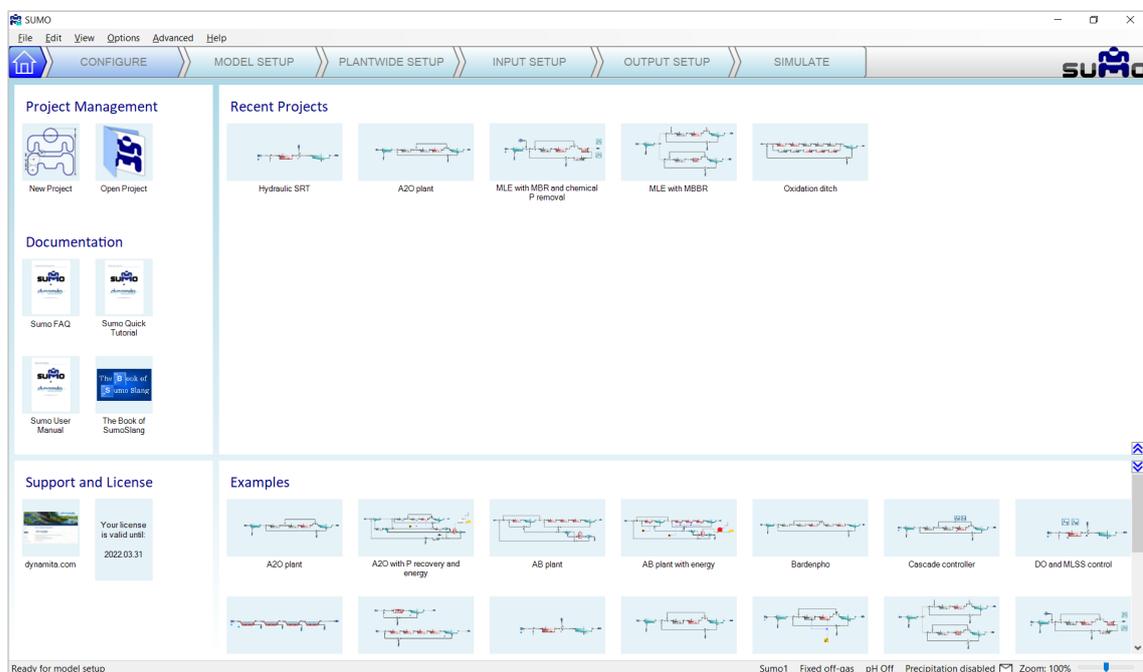
Figure 2 – Sumo21 startup screen

The central elements of the Sumo21 Welcome Screen are four screen panels, whose functions and roles are the following:

- Top left panel: – Project management and documentation
  Starting or opening a new project in a new window (*New Project*), opening a saved project from your own files (*Open Project*) and reaching various documents for how-to-use instructions.
- Top right panel: – Recent projects
  Your recently opened projects can be quickly reached from the welcome screen.
- Bottom left panel: – Support and license information
  Sumo21 support (link to our website) and the currently used license information can be reached from here.
- Bottom right panel: – Built-in example project repository
  All the built-in example configurations can be opened directly from this pane (they are also available from the Help menu).

These functions can be reached later at any point, by clicking either the *Home* icon (the first item of the Task Bar) or the Sumo logo (located at the right end of the Task Bar), which will bring you back to the Welcome Screen.

The screen panels can be resized anytime during the workflow to fit the actual needs of the job. In order to do that, just move the mouse to the padding between the panels and drag them to the desired position. The top right panel will always contain the plant configuration, while the content of the other panels depends on the actual task (*Configure*, *Model Setup*, *Plantwide Setup*, *Input Setup*, *Output Setup*, and *Simulate*). Please note that the runtime versions of Sumo are not meant for constructing new models and thus, the *Configure* and *Model Setup*, *Plantwide Setup* tabs are not available.

The Status Bar in the bottom of the screen provides model/simulation related information. In case of a system notification or model/simulation error, an exclamation mark will appear next to the mailbox icon (Figure 3). Red exclamation marks denote errors, while blue and yellow ones inform about warnings and notifications that need attention. Clicking on the mailbox icon will provide the description of the problem and hints about dealing with it.

Figure 3 - New notification

The following chapters will help you to understand the functions of each main tab of the Task Bar, and teach how to use them for building a project and performing various simulations.

4.2 Configure

To start your project, click on the *New Project* icon or the *Configure* tab. This task serves the building of the plant layout.

The roles of screen panels in *Configure* mode are the following:

- Top right panel: – Plant configuration drawing board
- Top left panel: – Process unit categories and process units
- Bottom right panel: – General comment panel – your notes, which will be saved with the project
- Bottom left panel: – Specific process unit options and information

While the *Configure* tab is selected, we will build a simple AO configuration (also available for reference from the built-in examples as *Tutorial plant*) using the *Flow elements*, *Bioreactors* and *Separators* categories from the top left element list. Select the desired process unit by opening the category and dragging the process unit to the drawing board. To drop the selected unit, just release the mouse button (Figure 6).

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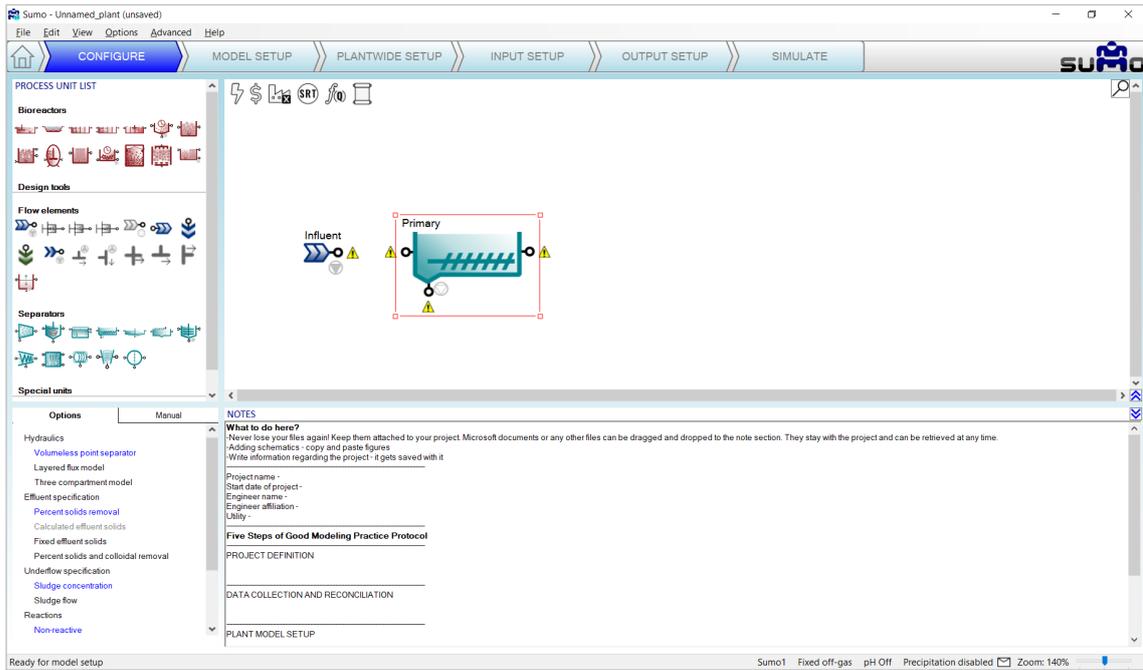
Figure 4 - Start building the plant layout

Pipes can be created using two methods. Sumo supports a handy way of establishing connections between process units, which can be triggered by positioning a process unit's output port on top of another process unit's input port (or vice versa) by moving one of the process units. Once the ports are positioned on top of each other, a pipe connection is automatically created, as it is demonstrated by Figure 5 with an Influent and a Primary clarifier. This method is especially useful when Sumo is commanded by fingers on a touch screen. Unconnected ports are indicated by yellow exclamation marks in the *Configure* and *Model Setup* tabs.
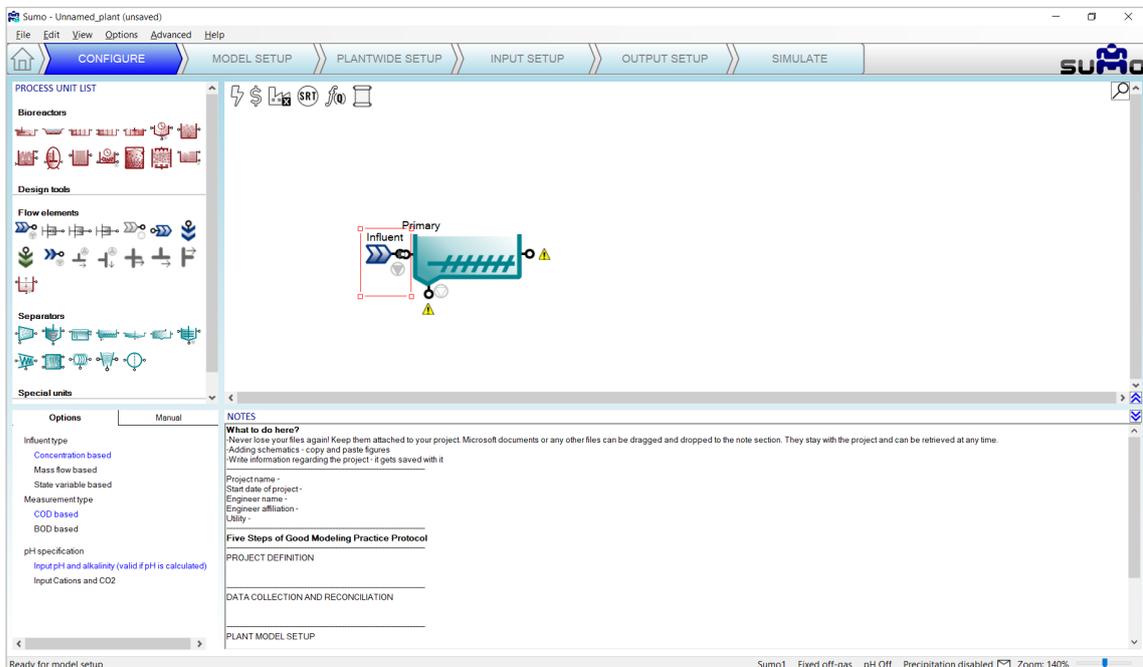

Figure 5 - Pipe being created by touching process units

The conventional way also works: position the mouse on an output port of a process unit, press the left mouse button, then move the mouse – and this way drag the pipe, denoted by a red line – to an input port of another

process unit (as illustrated in Figure 6) and finally release the mouse button to make the connection. Existing pipes can be removed by right clicking on them and selecting *Disconnect pipe* from the pop-up menu.
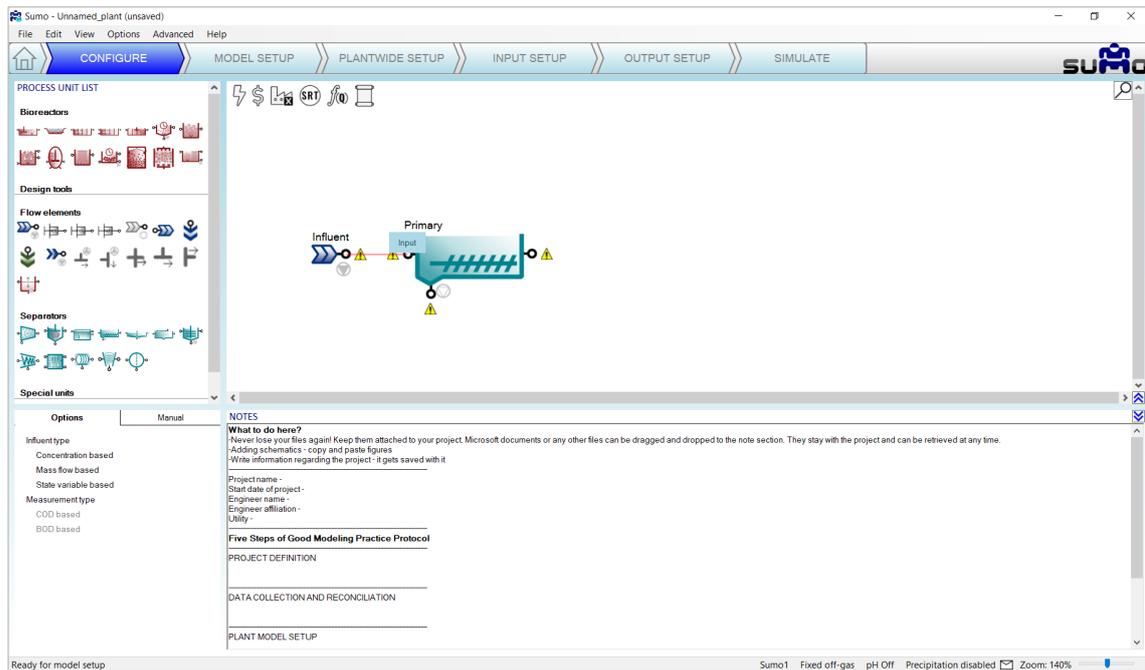
Figure 6 - Pipe being created the conventional way

Build the plant configuration and connect the pipes as shown by Figure 7. Tooltips provide hints about the purpose of a unit's connection point. This feature comes especially handy for the flow divider and flow combiner (make sure not to mix up these connections – their name is shown on a pop-up tooltip and flow direction is indicated by small arrows). Rotate the flow divider below the clarifier by swiveling the red selection rectangle (or with a right click pop-up menu option) and straighten the lines by grabbing process units or pipe corners. These maneuvers do not change the results of the simulation but will make working with the model a lot clearer.

Upon selecting a process unit on the drawing board, options appear in the bottom left panel, where the most suitable process unit can be chosen, fitted to the model. In this Tutorial we will use:

- Influent
    - Influent type: Concentration based
    - Measurement type: COD based
    - pH specification: Input pH and alkalinity (valid if pH is calculated)
- Primary
    - Hydraulics: Volumeless point separator
    - Effluent specification: Percent solids removal
    - Underflow specification: Solids concentration
    - Reactions: Non-reactive
- CSTR (both)
    - Dissolved oxygen: Input
    - Aeration: Diffused
    - Reactions: Reactive
    - Reactor type: Mainstream
    - α factor specification: Predicted α
    - Diffuser system specification: Membrane discs

- Clarifier
    - Hydraulics: Volumeless point separator
    - Effluent specification: Fixed effluent solids
    - Underflow specifications: Sludge flow
    - Reactions: Non-Reactive
- Side flow divider
    - Flow divider options: Side flow divider with side pump

Note: The flow divider's connection with the small pump symbol needs to be connected to the waste sludge and the other output (with the arrow) will be the recycled activated sludge.
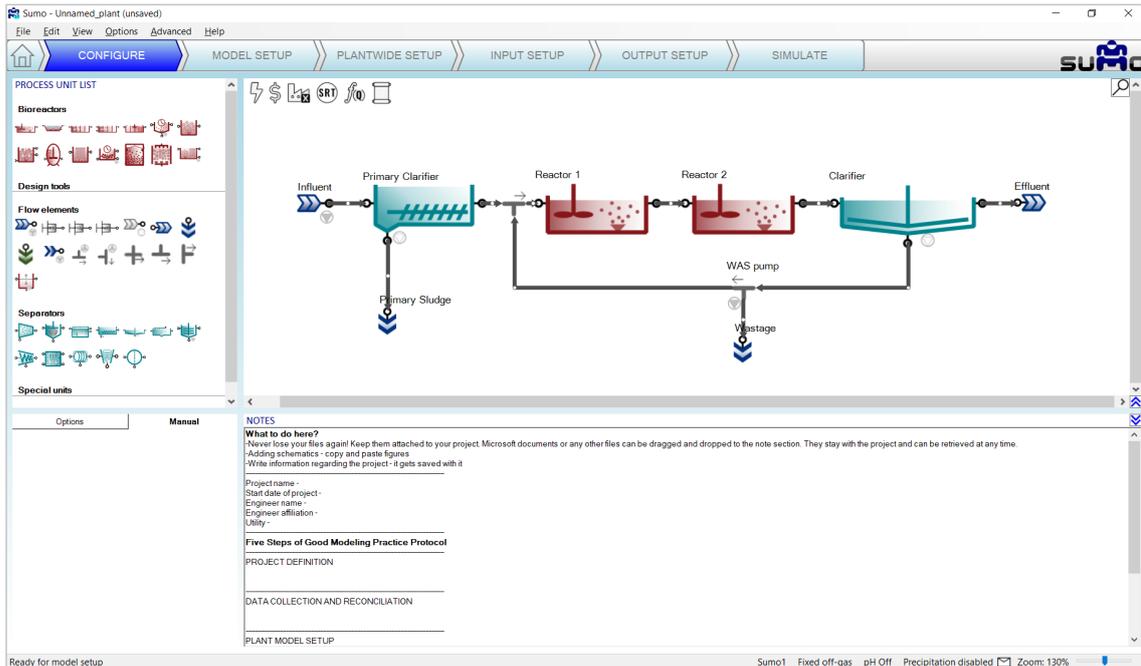

Figure 7 - The example layout

The drawing board can be easily zoomed in and out by holding down the CTRL key while scrolling with the mouse wheel, or alternatively by adjusting the zoom slider in the right end of the Status Bar. To move the configuration around the pane, hold down the CTRL key and the middle mouse button simultaneously while moving the mouse. To fit the actual configuration in the center of the viewport with the optimal zoom level, press CTRL+Home.

Rename the process units using the right-click pop-up menu, the F2 function key or double-click on the upper part of the unit. The pipes can be renamed as well, but this is usually not important – the pipe names are hidden by default (this can be changed in the *View* menu on the top). The visibility of process unit names can be controlled on a one-by-one basis. In order to obtain a clear example layout, hide the name of the 'Side flow combiner' process unit (this is the default setting).

Note: the above settings can only be modified in *Configuration* mode, but you can return and perform them at any point during your work. Changing the process unit names will not result in recompilation of the project model.

Note: other process units (e.g. Sewer network and Mobile carrier) may be available as add-ons. Please write to support@dynamita.com for information.

4.3   Model setup

In this **optional** task, the mathematical model describing the biological, chemical and physical processes can be selected. If no settings are changed, the default settings will be used – the model will be functional.

The role of screen panels in *Model Setup* mode are the following:

- Top right panel: – Plant configuration
- Top left panel: – Available model options or models in advanced mode
- Bottom right panel: – Model parameters
- Bottom left panel: – Model parameter categories (Note: for Sumo models, only selected parameters are shown by default; click on *Show all* to see the rest)

In this task, we can choose between using the various built-in models for our plant, as well as additional options like turning on or off gas phase, precipitation and different complexity levels of pH calculations.

The current package comes with the Sumo whole plant models listed in Table 1.

Table 1 – Description of Sumo Whole Plant models

General full plant models	
Mini_Sumo	Simplified One step whole-plant model Use "Mini_Sumo" for OUR and sludge production prediction.
Sumo1	One step whole-plant model Use "Sumo1" for activated sludge modeling, iron addition for P removal and with plants that have digesters but no iron addition
Sumo2	Two step whole-plant model Use "Sumo2" for activated sludge modeling and sidestreams, iron addition for P removal and with plants that have digesters but no iron addition
Focus models	
Sumo2S	Two step whole-plant model Use "Sumo2S" for whole plant modeling, (activated sludge, digesters, sidestreams), particularly if iron is dosed and is carried to the digester with the sludge. This is the only model which includes the full interaction of the sulfur and iron cycle.
Sumo2C	Two steps whole-plant model - High rate Use "Sumo2C" for high rate activated sludge modeling and sidestreams, iron addition for P removal and with plants that have digesters but no iron addition
Sumo4N	Four step whole-plant model Use "Sumo4N" for whole plant modeling, (activated sludge, digesters, sidestreams) when particularly interested in GHG emissions for carbon footprint estimations.

The general full plant models are available directly from the *Model selection* list (top left panel), while the focus models (and other custom models) are accessible either by choosing the *Museum, Focus and custom models* item, or by clicking the *Advanced* button (located in the bottom of the top left panel) – both will open up the complete *Model library* in the top left panel. When the *Model library* is shown, right-clicking on the model name will enable opening the source code in SumoSlang (Excel) format (Figure 8). To return to *Model Options* from here, just hit the *Back* button in the bottom part of the screen panel.

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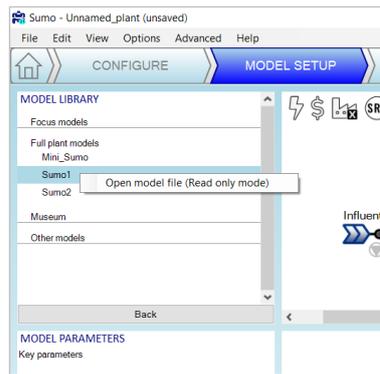
Figure 8 – Opening model source files

Table 2 lists the main processes included in the Sumo whole plant model family.

Table 2 - Main processes included in Sumo Whole Plant models

	General full plant models			Focus models		
	Mini_Sumo	**Sumo1**	**Sumo2**	**Sumo2S**	**Sumo2C**	**Sumo4N**
COD removal	X	X	X	X	Two populations: OHO and AHO	X
EPS production					X	
Denitrification	1-step	1-step	2-step	2-step	2-step	4-step
Hydrolysis	X	X	X	X	X	X
Fermentation	X	X	X	X	X	X
Anoxic methylotrophs		X	X	X	X	X
Nitrification	1-step	1-step	2-step	2-step	2-step	4-step
EBPR (PAO-GAO model)		X	X	X	X	X
Three-population anaerobic digestion	X	X	X	X	X	X
Temperature sensitivity	X	X	X	X	X	X
Precipitation		X	X	X	X	X
Chemical P removal	based on ASM2d approach	Kinetic approach	Kinetic approach	Kinetic approach	Kinetic approach	Kinetic approach
Sulfur cycle				X		
GHG emissions						X

Important comment on Mini_Sumo: unlike other Sumo whole plant models, Mini_Sumo does not include colloidal components. The user should pay careful attention on the influent fractionation and – if required – primary clarifier calibration, so that the primary effluent composition in term of BOD and TSS is in agreement with the expectations.

Note: other models (e.g. integrated Urban Water System model) may be available as add-ons. Please write to support@dynamita.com for information.

In our example we will use the default model setup with one step nitrification-denitrification model (Sumo1) with specified off-gas concentrations (gas transfer is approximated) and without pH calculation (therefore chemical precipitation is not calculated either), as shown in Figure 9.
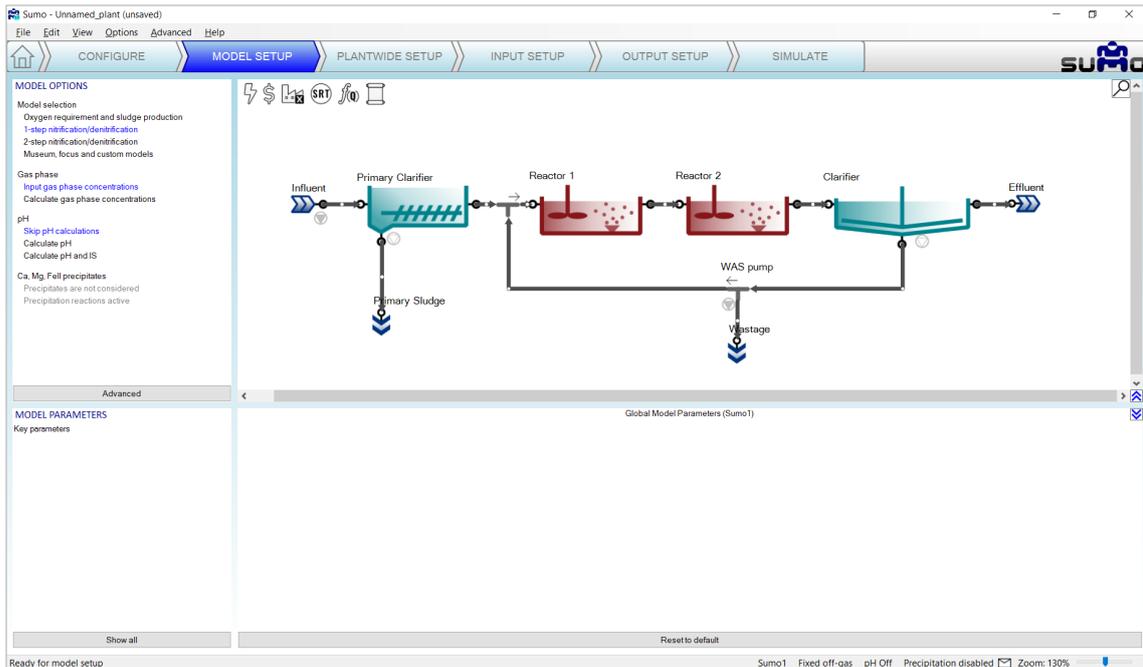

Figure 9 – Global model selection in Sumo

On the *Model Setup* tab, if none of the units are selected, clicking on the parameter categories listed in the bottom left panel (remember to click *Show all* in order to access all parameter tables in Sumo models), global kinetic and stoichiometric model parameters can be reviewed/modified. Each table will open up in the bottom right panel. This way the model parameters can be set globally, for the whole plant (Figure 10). These parameters will not be changed in this tutorial.

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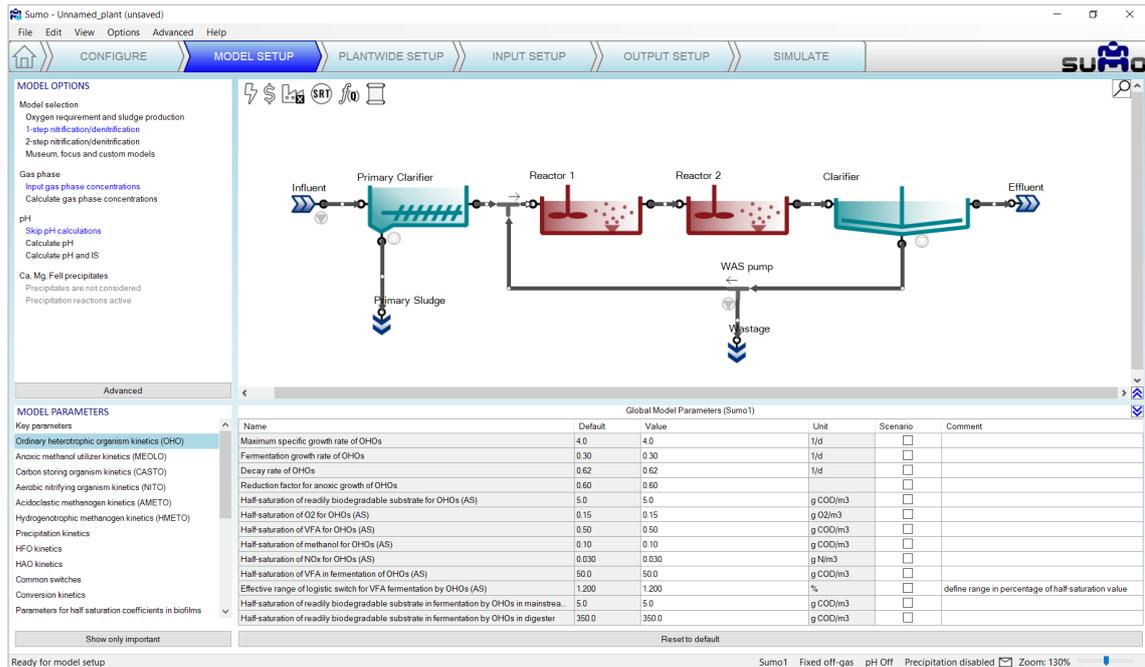
Figure 10 - Global model parameter setup in Sumo

Any model parameter can as well be set as a process unit specific "local parameter", by selecting the unit and dragging the desired parameter to the right side of the bottom right panel, as shown on Figure 11. In this case, the process unit will get a green "L" mark to remind the user for the local changes. Local model parameters will *NOT* be used in the current example, the aim of the above description was to explain this advanced functionality. You can remove local parameter selection by right clicking on the name of the parameter and selecting *Remove*.
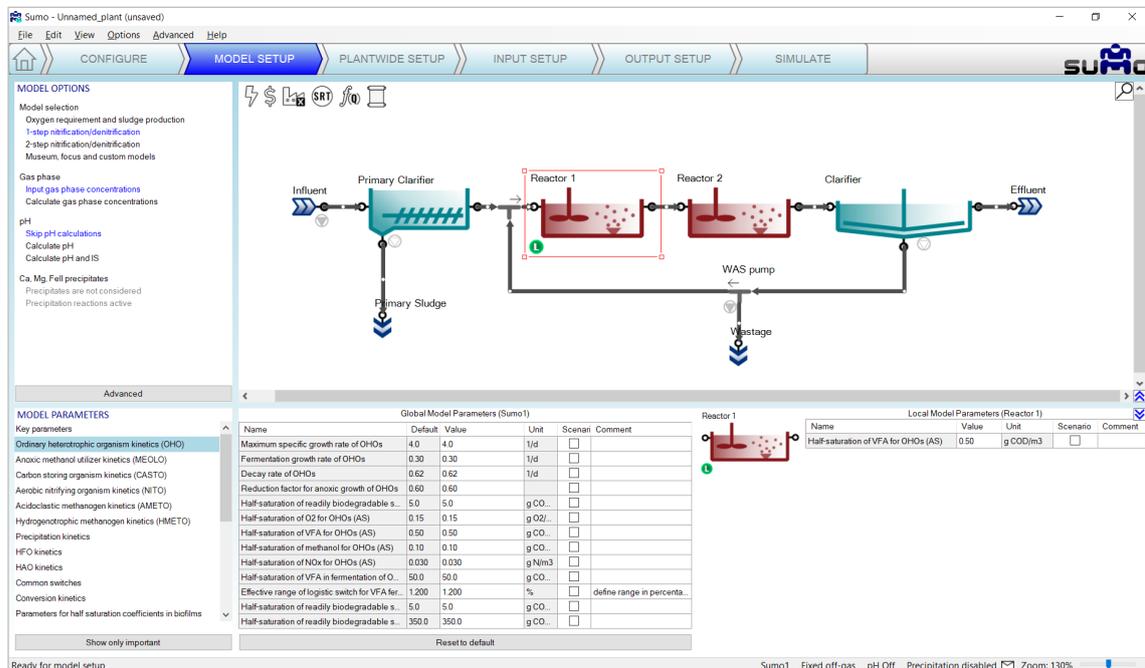

Figure 11 – Setting up process unit specific "local" model parameters in Sumo

4.4   Plantwide setup

Proceeding to the *Plantwide Setup* tab, complex plantwide calculations can be defined (Figure 12).
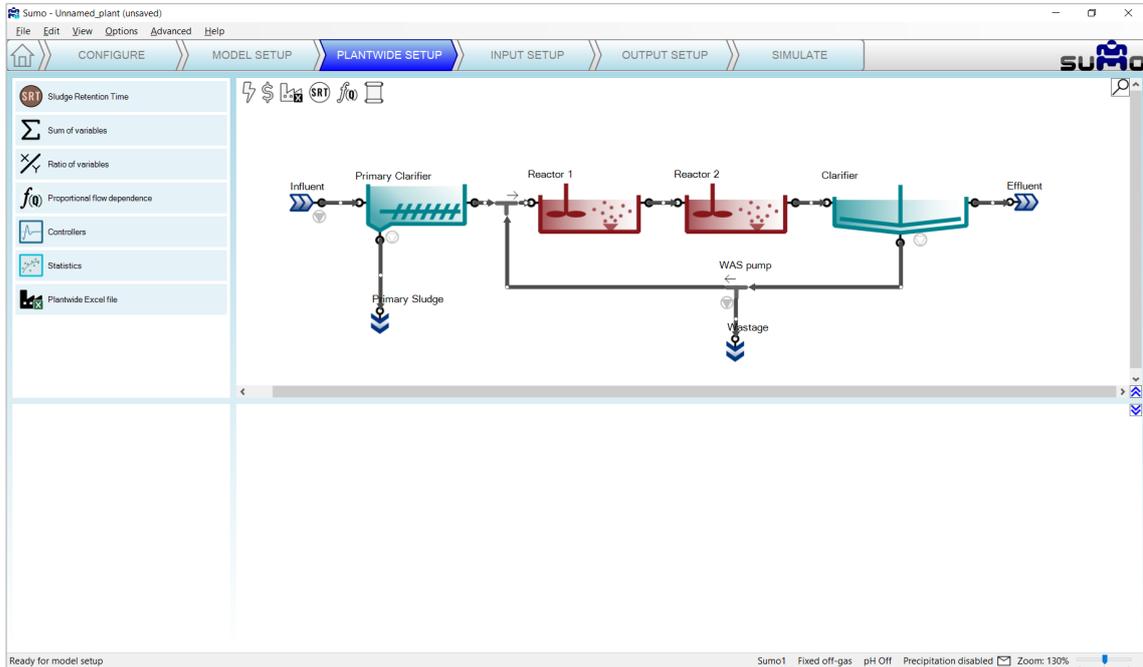

Figure 12 - Plantwide setup options

"Plantwide" means that the calculations are based on variables contained in several process units around the plant. The following calculations can be added to the simulation (listed in the top left panel):

- **Sludge Retention Time**
  Plant specific SRTs (total, aerobic, etc.) can be calculated.
- **Sum of variables**
  Variables (e.g. volumes, masses) can be summed up in the plant.
- **Ratio of variables**
  Variable ratios (e.g. N removal efficiency = effluent TN/influent TKN) can be defined for the plant.
- **Proportional flow dependence**
  Plant specific flow dependence (e.g. RAS flow as percentage of influent flow) can be defined.
- **Controllers**
  Controllers allow the user to configure automatic control (such as time based on/off, PID etc.) of process unit parameters.
- **Statistics**
  A few statistical options (Moving average, Noise generator) are available here.
- **Plantwide Excel file**
  The plantwide code is not confined to one process unit (PU) but can use variables from all over the plant model. The plantwide code file can be opened from the GUI directly. Further information and an example can be found in the Technical Reference document.

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4.4.1   Sludge Retention Time

The SRT calculation is set up the following way: drag reactors that contain sludge mass to the numerator and drag wastage – and if desired, effluent connections (ports) – in the denominator, as illustrated by Figure 13.
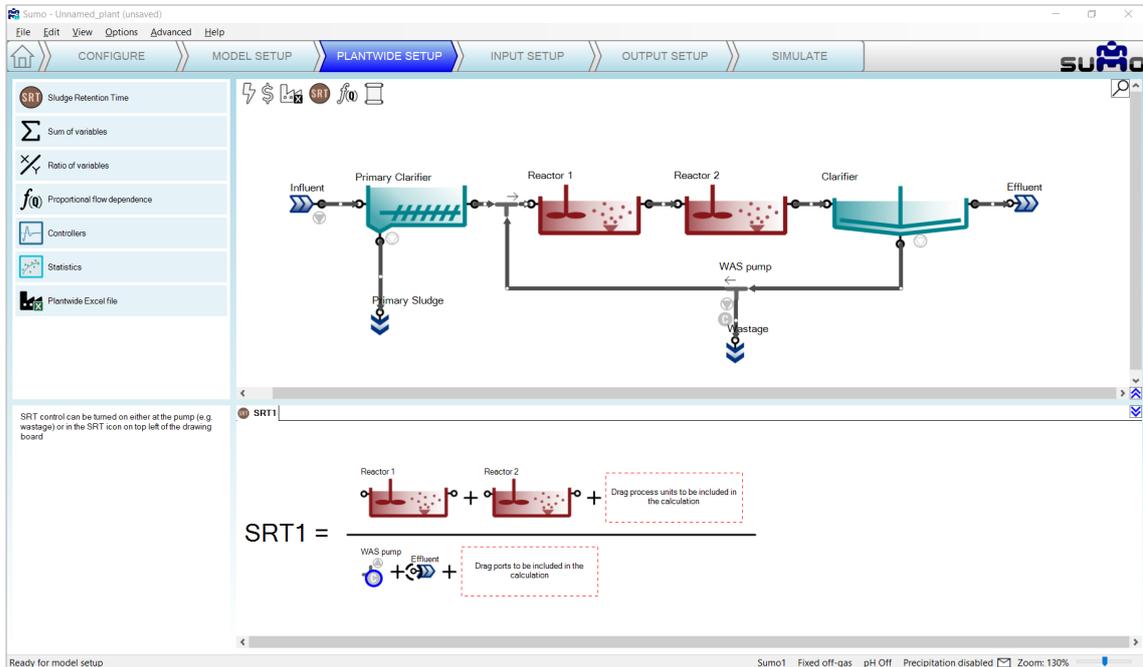

Figure 13 – Setting up SRT calculation

Several SRT calculations can be set up, e.g. total and aerobic, or North and South side SRT, etc. In this tutorial the total plant SRT will be calculated (as shown on Figure 13).

Note: When the project has an SRT calculation, the SRT icon on top of the drawing board gets a brown color.

Target SRT can be defined as well, by assigning a proper controlled port. These ports, such as the WAS pump in our example, are indicated by a "C" sign within a blue circle. A certain pump can only be used to control one SRT. Pumps can be selected and deselected for SRT control by right clicking their icon in the equation and choosing the desired option. When a pump is selected for control, *Remove Controlled* will deselect it (the "C" sign will disappear from the blue circle), while non-controlling pumps can be set to be controlling ones by choosing *Mark as Controlled* (Figure 16).
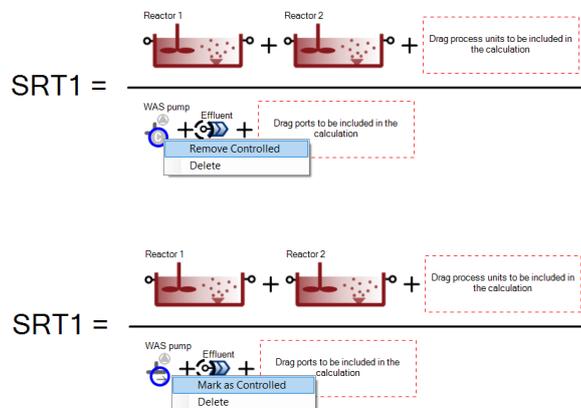

Figure 14 – Toggling between pump selection for target SRT control

Note that even though the wastage pump is selected for SRT control, it has not been designated yet for this role at the current stage (this is indicated in the plant layout by a grey "C" sign next to the pumped outflow pipe of the WAS pump). The activation of the SRT control can take place in a subsequent step (see Chapter 4.5.3 on page 27).

4.4.2   Sum of variables

For calculating the Sum of variables, a set of predefined items are available (organized into groups) from dropdown menus in the bottom left panel. If the desired variable cannot be found here, custom variable input can be used well (choosing the last item in the first dropdown menu). In the latter case, make sure that the correct symbol is used, otherwise the built-in GUI check will disallow the calculation. Symbols of variables can be figured out using various methods; details of the naming convention are described in the Technical Reference.

In this example, we will calculate the sum of Suspended solids mass in the reactors by entering "M_XTSS" as custom variable and dragging Reactor 1 and Reactor 2 into the equation from the layout (Figure 15).
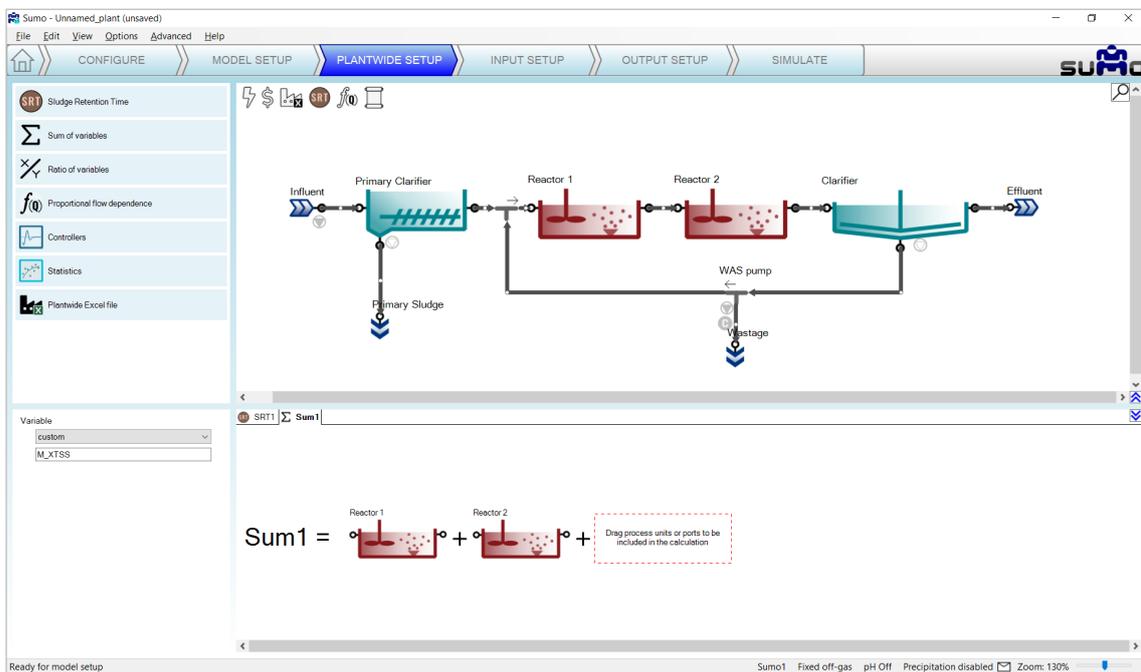

Figure 15 - Setting up Sum of variables calculation

4.4.3   Ratio of variables

Adding Ratio of variables can be done in a similar way as the Sum of variables. First select the variables to be used in the numerator and the denominator from the dropdown lists of the bottom left panel, then drag the desired process units to the ratio. In this example, we will calculate the removal ratio of Ammonia, as shown on Figure 16.
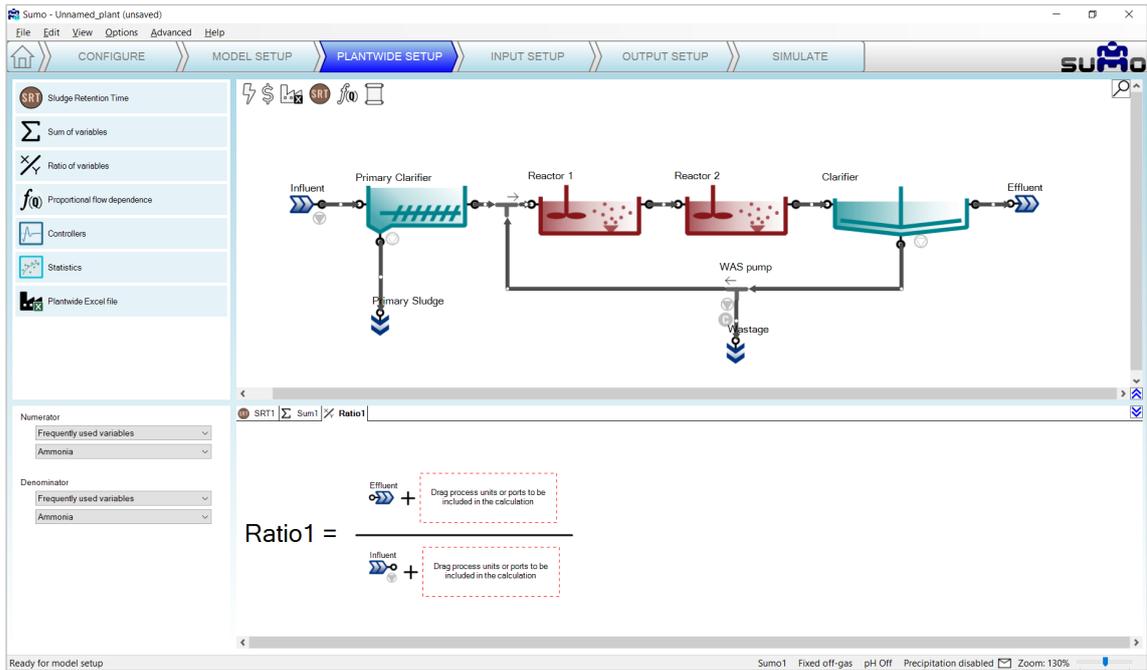
Figure 16 - Setting up Ratio of variables calculation

4.4.4 Proportional flow dependence

Adding Proportional flow dependence can be done by dragging the desired process units to the respective slots of the dependence equation. In this example, we are going to set the clarifier sludge recycle flow to be proportional to the influent flow rate, as shown on Figure 17. You will see a blue "C" sign showing up beside the clarifier on the drawing board, indicating that its sludge flow became a dependent parameter (controlled by the influent flow). The exact value of the proportional dependency will be set in a subsequent step (see Chapter 4.5.3 on page 27).

Note: When the project has a proportional flow dependency, the "Q" in the f(Q) icon on top of the drawing board gets a blue background.
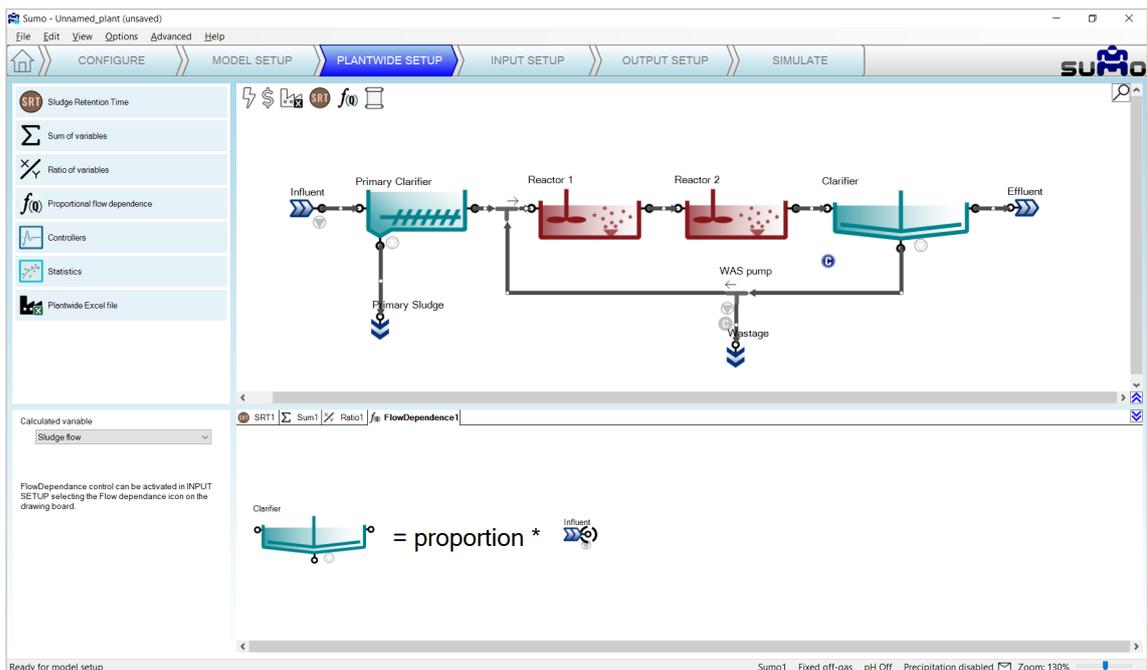

Figure 17 – Setting up Proportional flow dependence

4.4.5   Controllers

Controllers help to keep certain operational parameters of the selected process unit at a required setpoint or within a band. The following controllers are integrated into Sumo21 (Figure 18).
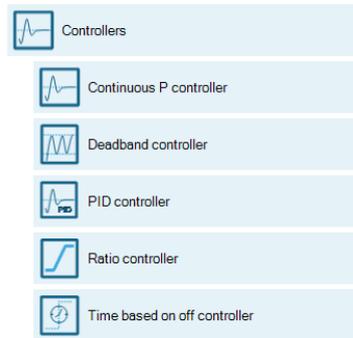
Figure 18 – Available controllers

In this example, we will use a *Deadband controller* to control the sludge wastage pump automatically, in order to maintain the MLSS between certain limits. Details about the further controller options can be found in Chapter 5 (Controllers, page 50).

4.4.5.1   *Deadband controller*

Adding a Deadband controller can be done in a similar way as the Sum of variables. First drag and drop the manipulated unit to the left side of the equation in the bottom right screen panel, and then the controlling unit to the right side of the equation. In the bottom left screen panel, you can now select the control variable (CV) and the manipulated variable (MV, a parameter) of the selected units. In this example, we will control the Wastage pump to achieve the desired MLSS range, see Figure 19. Note that the "C" sign by the wastage pump will change to blue color, indicating that we have just set up and designated a controller for it that took over the role of the previously defined (but not activated, hence the former grey color) SRT control.
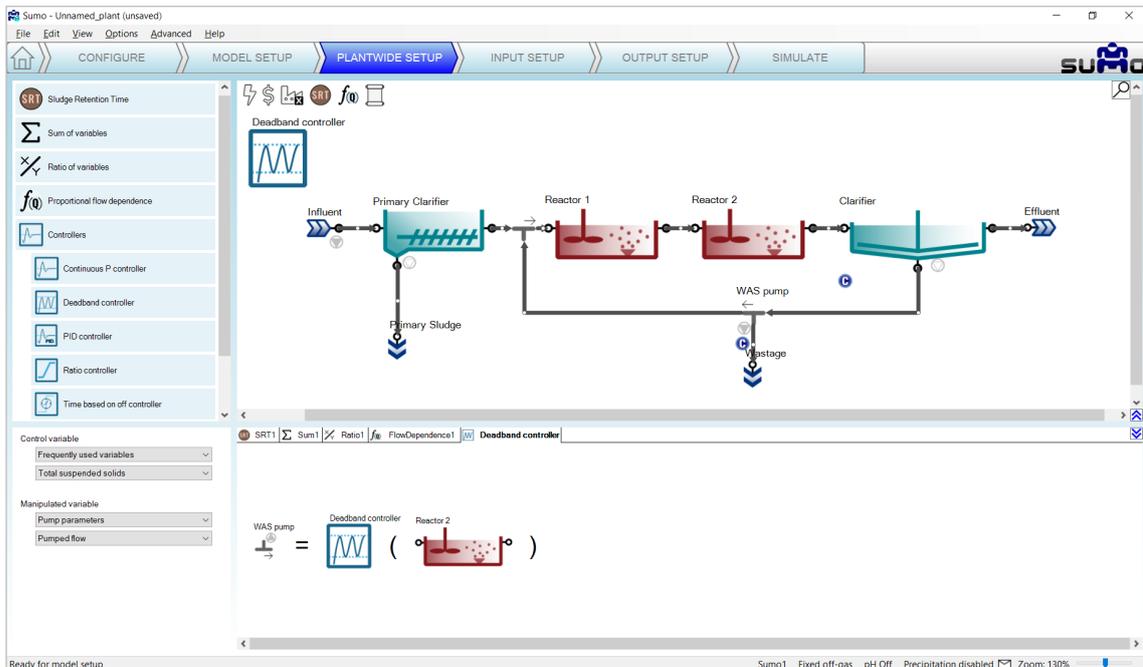

Figure 19 – Setting up a Deadband controller

The controller image that appears in the plant layout can be repositioned on the drawing board by holding the CTRL key while the icon is being dragged and moved, so the layout can be better understood. Move the controller icon above Reactor 2, then select it and hit F2 (or alternatively, right click on the tab header in the bottom right panel) to rename it to "MLSS control by WAS". This will rename the respective tab (or the controller icon) as well.

4.4.6   Statistics

The *Statistics* section contains calculations for easier understanding or presentation of the results, such as average calculations. The following statistical calculations are integrated into Sumo21 (Figure 18).

Figure 20 – Available statistical calculations

As an example, we will set up the average effluent concentration of the plant.

4.4.6.1   *Moving average calculation*

Moving average can be added in a similar way as Sum of variables. First drag and drop the process unit to which the calculation should apply, to the right side of the equation on the bottom right panel. In the bottom left panel you can now select the desired variable whose average should be calculated. In this example we will calculate the average effluent ammonia concentration, see Figure 21.

The statistical unit image can be repositioned on the drawing board and renamed similarly to controllers. Move the icon above the Effluent and rename it to "MA Ammonia".
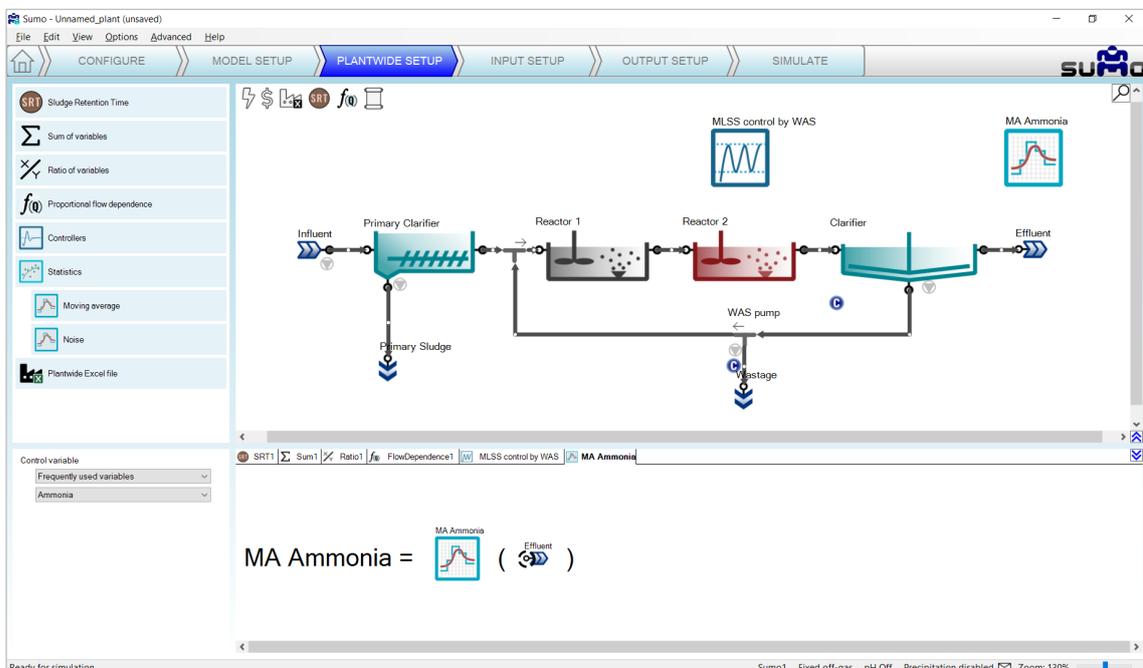

Figure 21 – Setting up a Moving average calculation

4.5   Input setup

Choosing the *Input Setup* task, the blue workflow tab above the drawing board automatically splits into *Constants* and *Dynamics*. According to this, different types of settings become available: we can set either constant inputs

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(e.g. fixed influent composition, reactor DO setpoints etc.) or dynamically changing inputs (e.g. variable influent flow, composition, shifting reactor DO setpoints etc.). At this point, Sumo will be compiling your model in the background (you can track the progress in the Status Bar). However, in most cases, you can already start providing information to Sumo. When your layout requires using arrays (e.g. layered clarifiers, biofilm), please wait until the model is fully compiled and loaded (status bar message: "Ready for Simulation"). For the initial plant setup, we will only need the *Constants*, as shown on Figure 22. Select each object one by one and enter the required values as shown below.
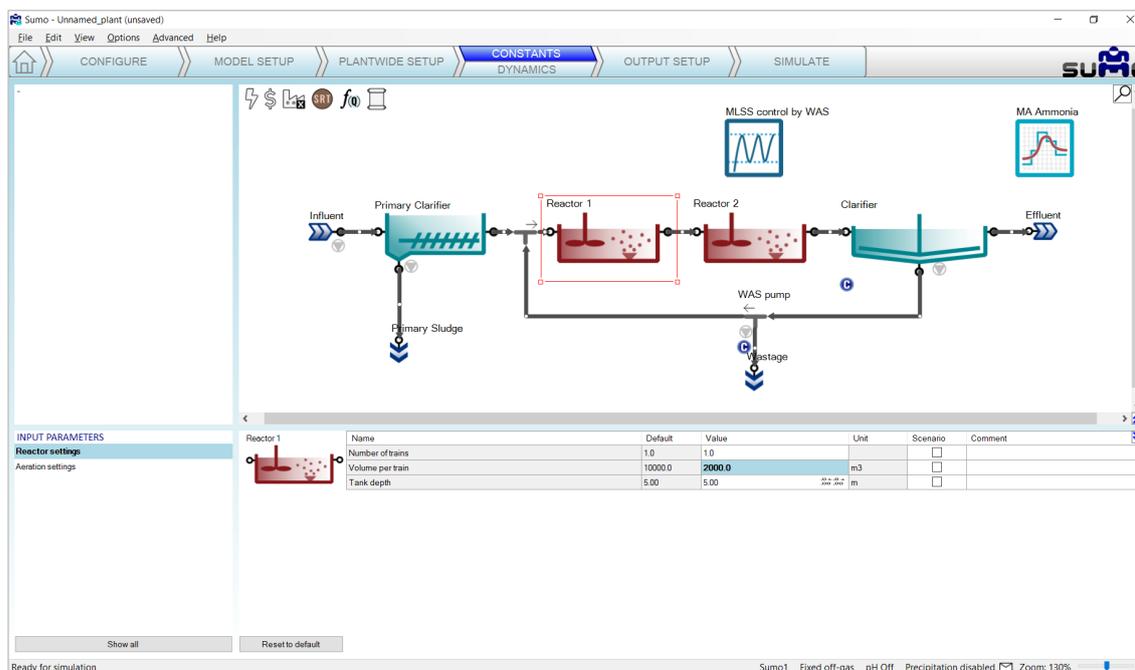
Figure 22 – Constant Input setup example

In this simple configuration, we only need to set a few values to build a realistic plant model, first for typical dry weather operation. Use the values from Table 3 for this example:

Table 3 - Input setup for AS plant

Process Unit	Parameter group	Parameter	Value	Unit
Reactor 1	Reactor settings	Volume per train	2000	m^3
Reactor 2	Reactor settings	Volume per train	8000	m^3
Influent	Influent specifications	Flow rate	20000	m^3/d
Influent	Influent specifications	Total COD	500	g COD/m^3
Influent	Influent specifications	Temperature	22	°C
Influent	Influent fractions	Fractions	Leave at default	

Enter these values by selecting the respective process unit on the drawing board and the parameter group in the *Input parameters* menu (bottom left panel) – the values can be edited in the bottom right panel (Figure 23). Each value that is different from the default will be highlighted with bold letter type. There is also a similar indication in the *Input parameters* menu for parameter groups that contain non-default values.

There is a unit conversion module for US units (MGD, scfm, etc.) in the *Options* menu item if necessary.

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Whenever the entered value is out of the allowed range specified in the model, Sumo will notify you with a prompt window and set the value to the nearest feasible bound, indicating the automatic choice by applying red color to the text. This value can be overridden manually with a valid number.

If needed, all changes applied to the values of the actual parameter group can be reverted to defaults by clicking the *Reset to default* button located in the bottom right screen panel (Figure 23).
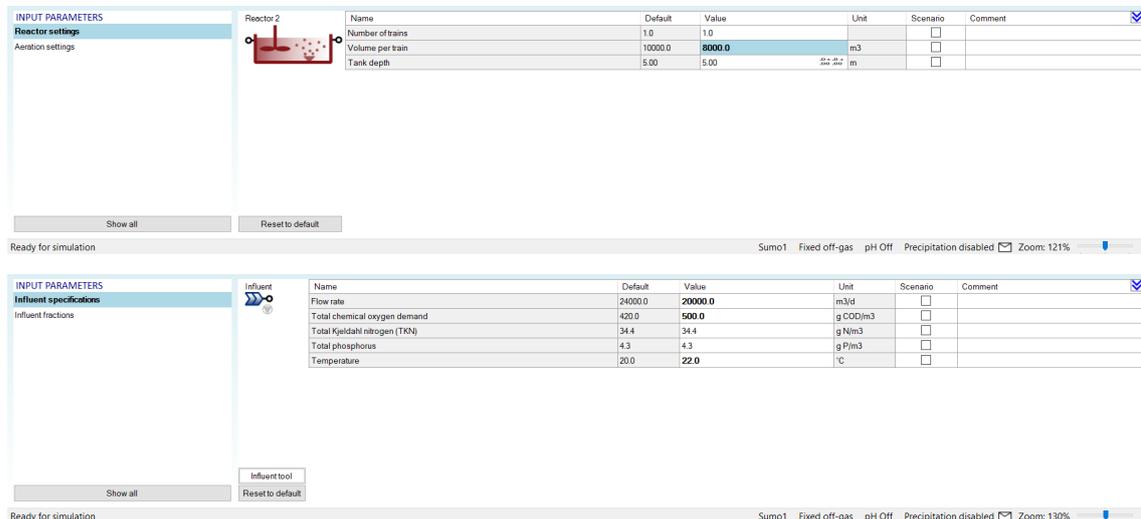
Figure 23 - Input parameter table examples

For setting the plant specific influent composition, the use of the *Influent tool* Excel file is recommended. The *Influent tool* can be reached directly from the input setup of the Influent, by clicking the button located in the bottom right screen panel (Figure 24).The details of the *Influent tool* are described in Chapter 4.5.1 (page 26). At this point, we will not alter the influent composition, so we will skip using the *Influent tool*.

Parameters for scenario analysis can be selected by using the checkboxes in the *Scenario* column. In this example, we will select the influent flow rate, total COD and the temperature (Figure 24).
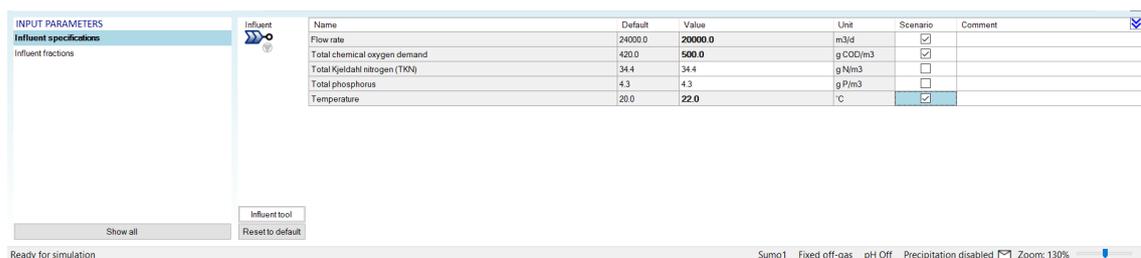
Figure 24 – Parameter selection for scenarios

The controller parameters can be setup at this stage as well. In this Deadband controller example, we will set:

- *Controller direction*: inverse (-1), since increasing wastage (MV) will decrease MLSS (CV), i.e. the CV responds inversely to MV change;
- 2600 mg/L as low value and 2800 mg/L as high value for the *Controlled variable* (MLSS in Reactor 2) range;
- 150 m^3/d as low value and 600 m^3/d as high value for the *Manipulated variable* range (the latter represents the physical pump capacity for the Wastage pumped flow);
- *Initial* value of manipulated variable to single pump capacity as 150 m^3/d.

See these settings on Figure 25.

The input setup of this wastewater treatment plant model is now ready.
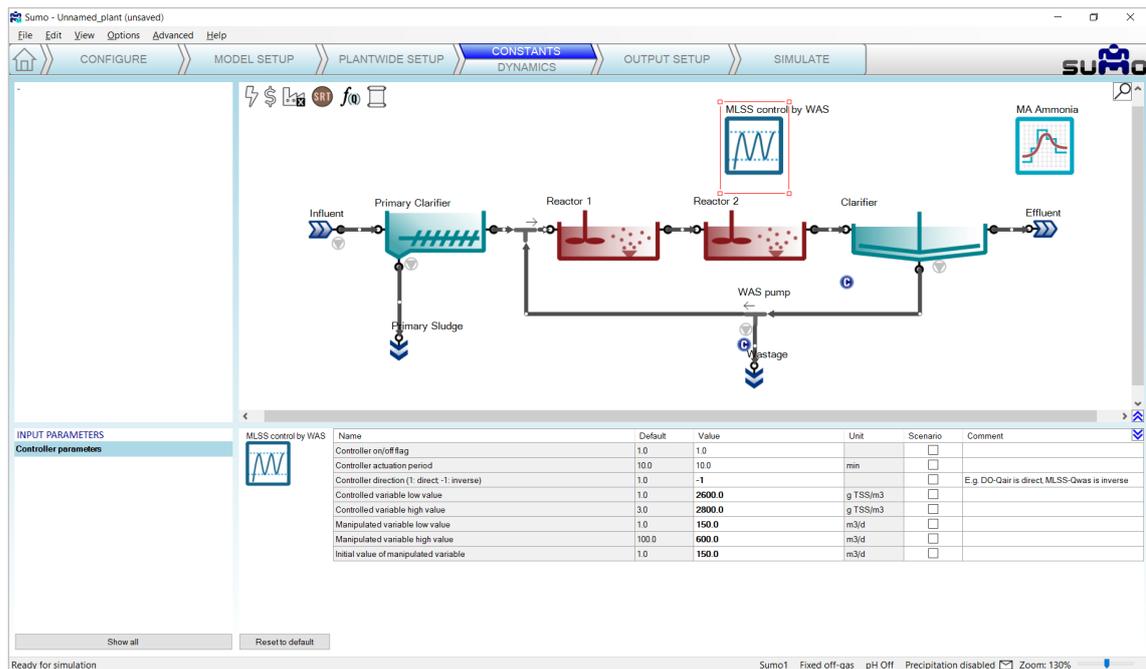
Figure 25 – Deadband controller input setup

4.5.1 Influent tool

The *Influent tool* is a multiple sheet Excel file to help to set up the proper influent composition. The role of each sheet is explained in Table 4 below.

Table 4 – Description of the Influent tool

Influent tool sheets	
Help	Short description of the file content
Data	Input of the available measurement data of the simulated plant or facility. This sheet provides help to estimate the missing data based on available information for municipal or industrial wastewater composition.
Check fractions	On the left side of the sheet, the estimation of key organic fractions is available, such as COD and N fractions, particulate COD/VSS ratios by component, yield on ultimate BOD and BOD fraction for soluble, colloid and particulate. On the right hand side, the calculated COD, BOD5 and TSS/VSS values can be checked if they match the measured values.
Sumo forms	This sheet gathers all the information that can be used to simply copy into the Sumo Model setup or Input setup tab of the Influent process unit.
Balances	On this sheet, the organic compounds can be checked (how the fractions add up to the total). The sheet will also provide warning when negative component concentrations result from the estimated fractions (such as not enough N for organic TKN if most of TKN is ammonia, and there are solids in the influent)
Diurnal flow	This sheet provides example and usual flow pattern for small, medium and large plants. Based on the influent value, the diurnal flow dynamic input tables are prepared for copy and paste into Sumo.
Calculations	This sheet contains the details of BOD calculation and the error tolerances used on Check fractions sheet.

4.5.2   Dynamic Inputs

This **optional** task can be used to enter dynamically changing input information, e.g. diurnal flows, DO schedules and more. To activate the dynamic input setup, click on the lower part of the Input setup tab on the Task Bar, labeled as *Dynamics*.

The role of screen panels in *Dynamic Input Setup* mode are the following:

- Top right panel   – Plant configuration
- Top left panel   – Unused in this mode
- Bottom right panel   – Data entry functionality
- Bottom left panel   – List of entered dynamic data tables

If we wish, we can copy and paste entire data tables from an Excel file into Sumo. This will be discussed later in Chapter 4.7.4 (page 39).
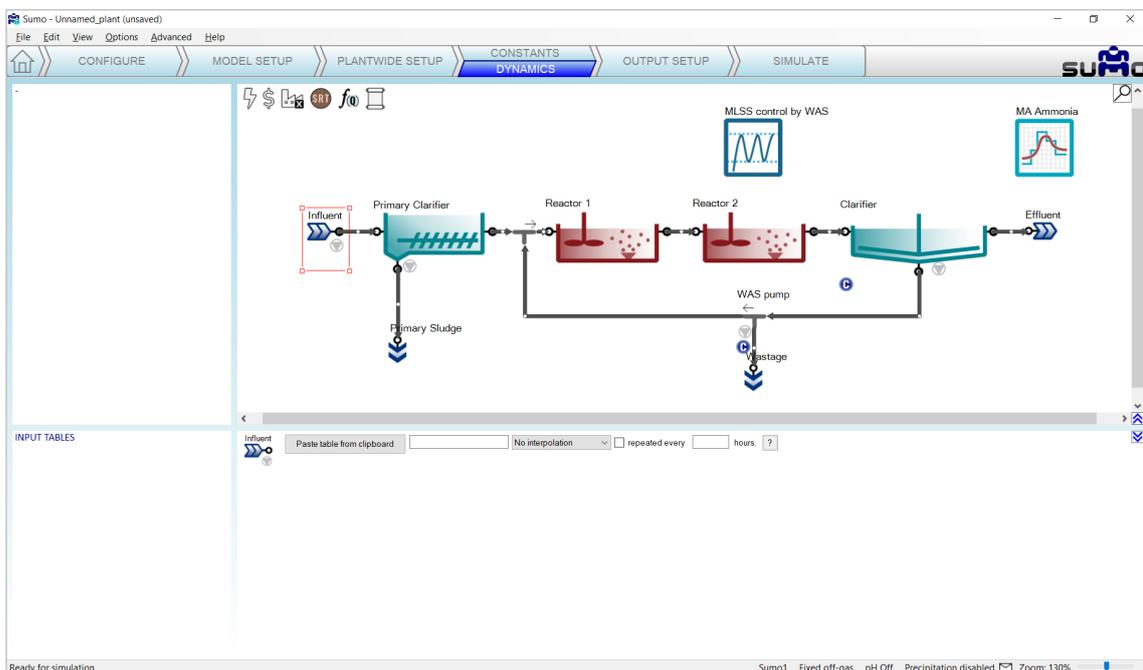

Figure 26 - Dynamic input setup

4.5.3   Plantwide inputs

Target SRT and proportional flow dependence input settings can be accessed by clicking on the respective icons listed on the top left part of the layout panel. In this simulation, we will not use the Target SRT controller, but will set up the proportional sludge flow of the clarifier to 100%, as shown on Figure 27. This will align the sludge flow rate with the influent flow as 1 to 1.

The plantwide parameters set in the Plantwide Excel file will appear in the Input setup when the plantwide (factory) icon is selected in the top section of the layout. These can also be changed dynamically, similarly to any other model parameter (for more detailed information on this feature, please consult the Technical Reference). In this simulation, we will not use plantwide parameters.

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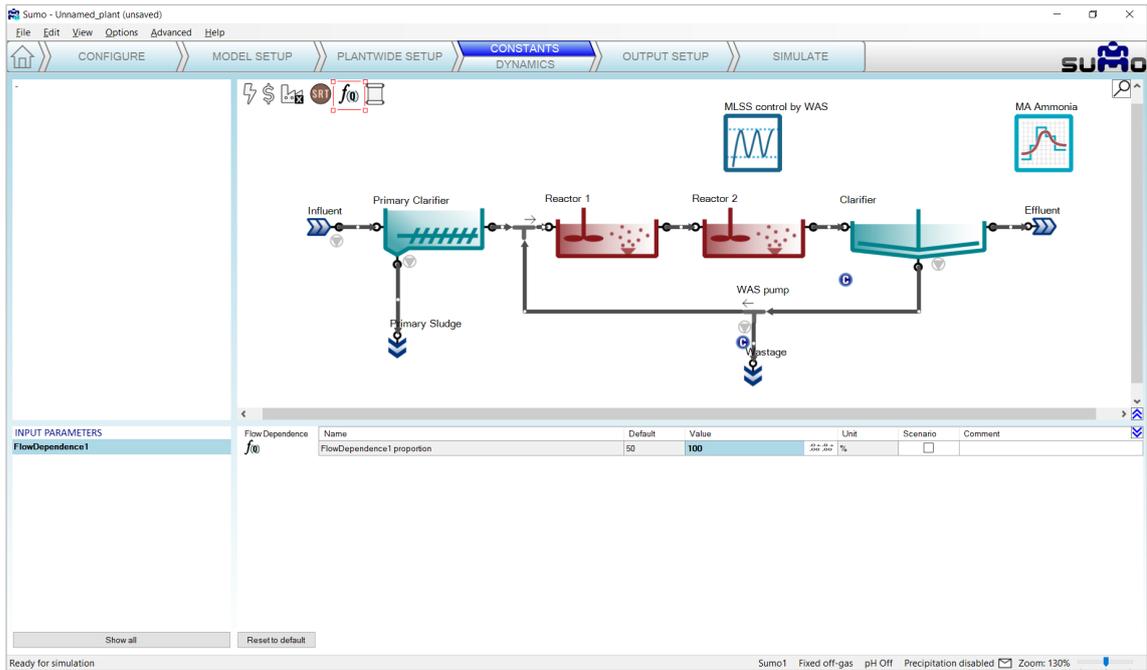
Figure 27 – Proportional flow input setup

4.6   Output setup

This task can be used to specify which variables and in what format should be displayed and/or saved during the simulation phase (Figure 28).
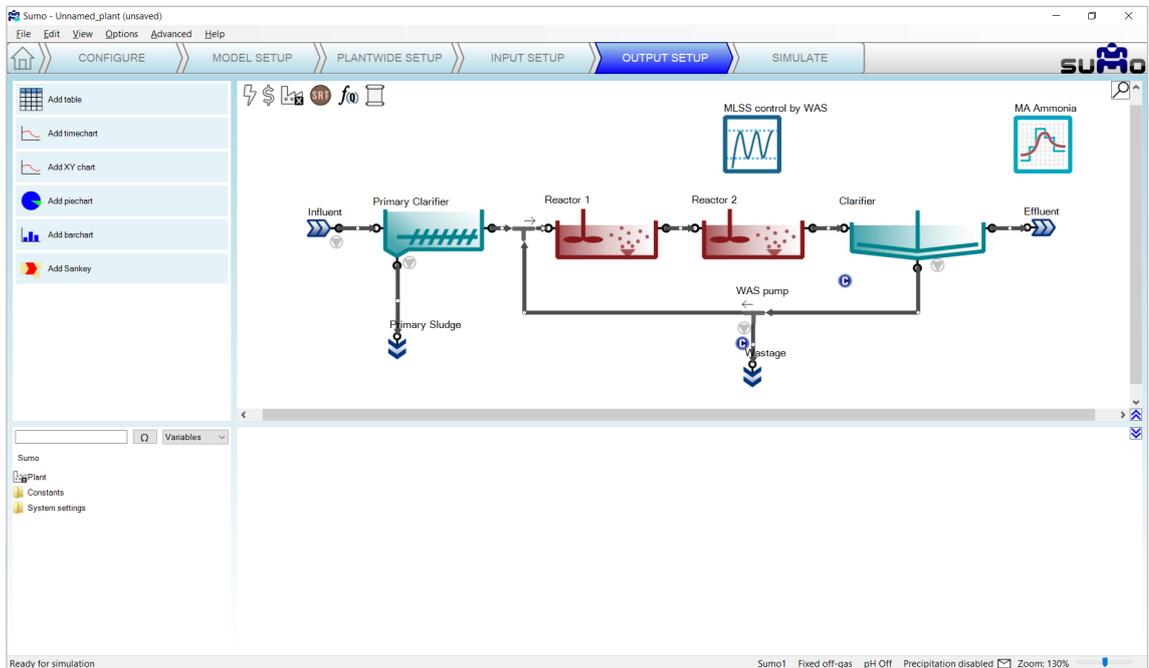

Figure 28 – Output setup

The role of screen panels in *Output Setup* mode are the following:

- Top right panel   – Plant configuration
- Top left panel   – Buttons for different diagram types (Table, Timechart etc.)
- Bottom right panel   – Added outputs in a series of tabs

- Bottom left panel — Output variable list for the selected unit and the connected pipes (available once the model is fully compiled). The user can browse the variables based on their name or symbol. There are also preselected categories (frequently used, operational variables etc.) available to help the work.

4.6.1   Adding a table

Click the *Add table* button in the top left panel: this will add a table to the bottom right panel. The table can be renamed (right click on the tab and choose *Rename* from the pop-out menu or simply just double-click on the tab) and several tables can be added. Name this table "Results". Add process units to the table by dragging them to the table (by selecting multiple units in the drawing board, they can be added in one go as well). Add variables to the table by selecting and dragging them from the bottom left panel (Figure 29). Entire display tables can be added at once by dragging the prepared table e.g. *Frequently used variables* (Note: if the table has not been renamed by the user, it is automatically renamed when a whole display table is added). The exact list of preselected variables may vary according to the process units. Initial values will appear in the cells.
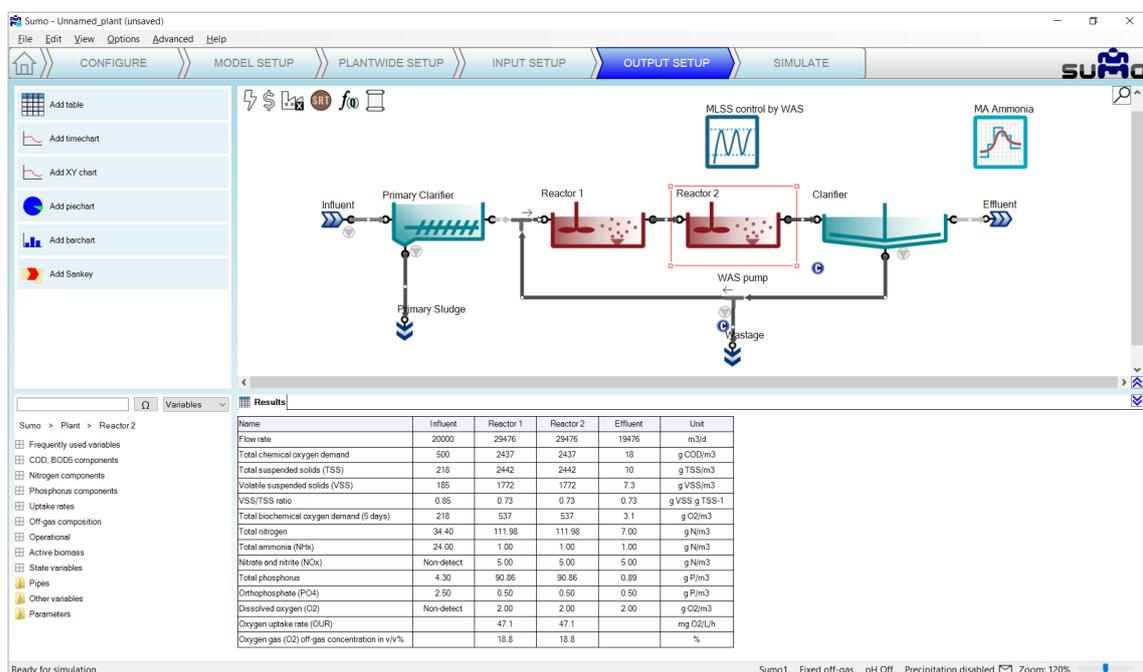

Figure 29 - Adding a table

You can add also the DO and Offgas O_2 content from the *Frequently used variables* of Reactor 1 (or 2).

Add another table and drag the *Active biomass* and *Uptake rates* for both reactors.

Note that the table columns (except for *Name* and *Unit*) can be reorganized by dragging the column header and dropping to the desired slot. Units can be changed by clicking and selecting from the dropdown list. The number of decimal digits displayed can be customized to show meaningful detail by hovering the mouse over the numbers and clicking the respective icons – the action will apply to all numbers in the active table row.

4.6.2   Adding a timechart

Click the *Add timechart* button in the top left panel: this will add a timechart to the bottom right panel as a new tab. Select a process unit on the layout and drag a variable from the bottom left panel on the timechart to be plotted (a legend will appear in the top right corner of the timechart). Several variables can be added to each timechart (new items will be appended to the legend), and several timecharts can be added as well (increasing the number of tabs). In this example we will plot MLSS in the reactors and wastage flow on one timechart (select the

reactors one by one and add TSS from *Frequently used variables*); and effluent total nitrogen, ammonia, as well as nitrate and nitrite (available from *Nitrogen components*) on the second one (see Figure 30). Graphs will be plotted during the simulation phase.
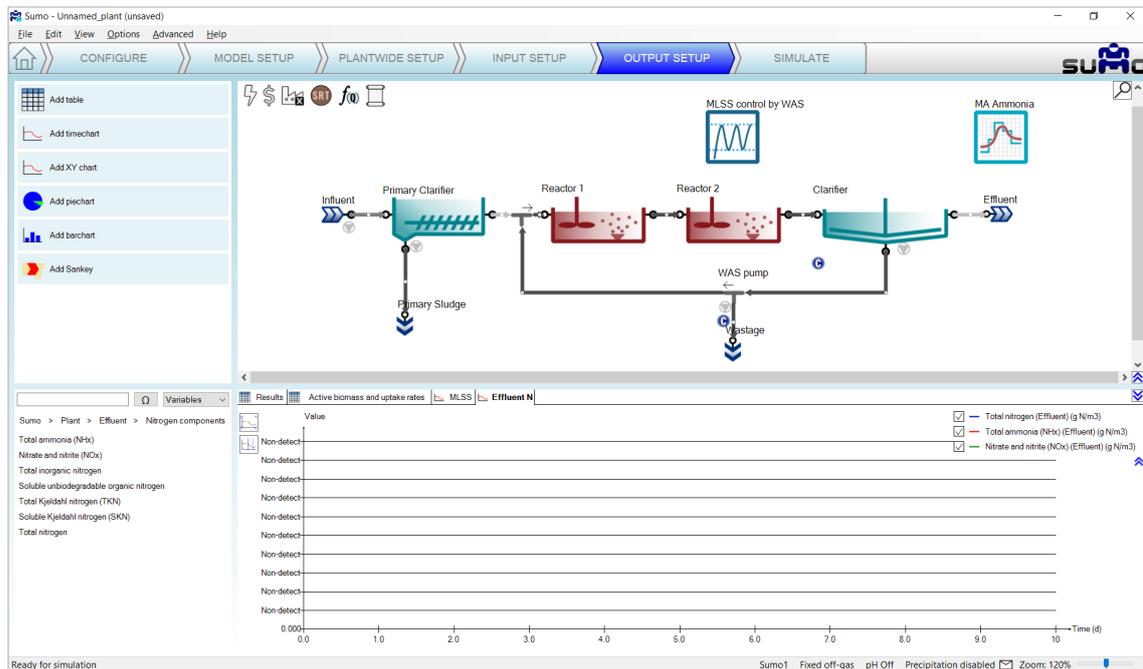

Figure 30 - Adding a timechart

4.6.3   Adding an X-Y chart

This type of diagram can be used to demonstrate the relation between selected variables (e.g. equilibrium species) depending on another variable (e.g. pH). A practical application is shown in the example Titration, in Chapter 7.23 (page 82).

4.6.4   Adding a piechart

Click the *Add piechart* button in the top left panel: a new tab for labeled piechart will appear in the bottom right panel. Select the desired process unit on the layout and drag the variables to be depicted from the bottom left panel to the – yet empty – bottom right panel (a legend will appear in the top right corner). For this example, we will use Total Kjeldahl Nitrogen along with Nitrate and nitrite (available from *Nitrogen components*) in the effluent. Rename the tab to "N fractions" (Figure 31). The piechart will be rendered during the simulation phase.

4.6.5   Adding a barchart

Click the *Add barchart* button in the top left panel: this will add a barchart to the bottom right panel as a new tab. Choose a process unit and drag variables from the bottom left panel to be shown on the barchart, just like in the previous chart types. Multiple variables can be added to each barchart, and several barcharts can be added as well. Dragging additional process units to the chart will add them with the actual set of variables and initial values will be shown. For this example, choose Total chemical oxygen demand and Total 5-day biochemical oxygen demand from the *Frequently used variables* in the influent and in the effluent (Figure 32). Rename the tab as "COD & BOD5". The barchart will be continuously updated with the changes during the simulation phase.
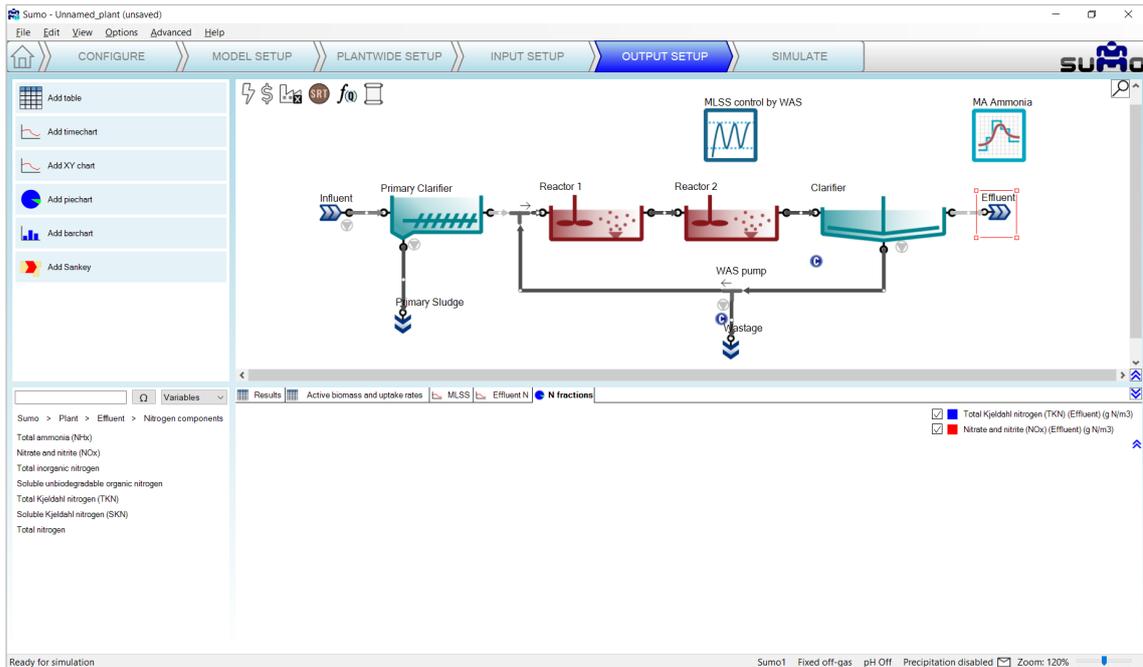
Figure 31 - Adding a piechart
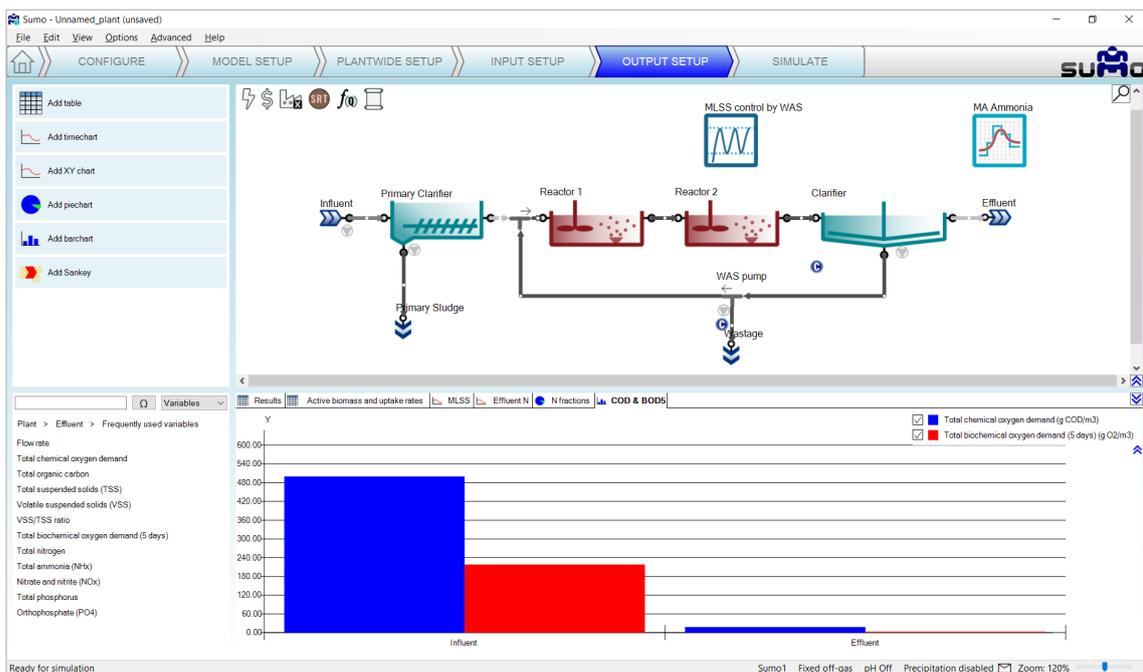
Figure 32 - Adding a barchart

4.6.6   Adding Sankey

Click the *Add Sankey* button in the top left panel: this will add the Sankey diagram of flow by default. The variable can be changed by dragging any other item from the bottom left panel over to the bottom right panel. Several Sankey diagrams can be added, with one variable plotted on each Sankey. This example will use one Sankey with the default setting (renamed as "Flow") and another one showing the mass flows of ammonia (renamed as "Ammonia mass flow") as shown on Figure 33. Use the search field in the bottom left panel to find the latter: type in "Total ammonia" and locate "Total Ammonia (NHx) mass flow" under the "Mass flows of frequently used variables" list item in the search results. The search field works with all of the other output options as well.
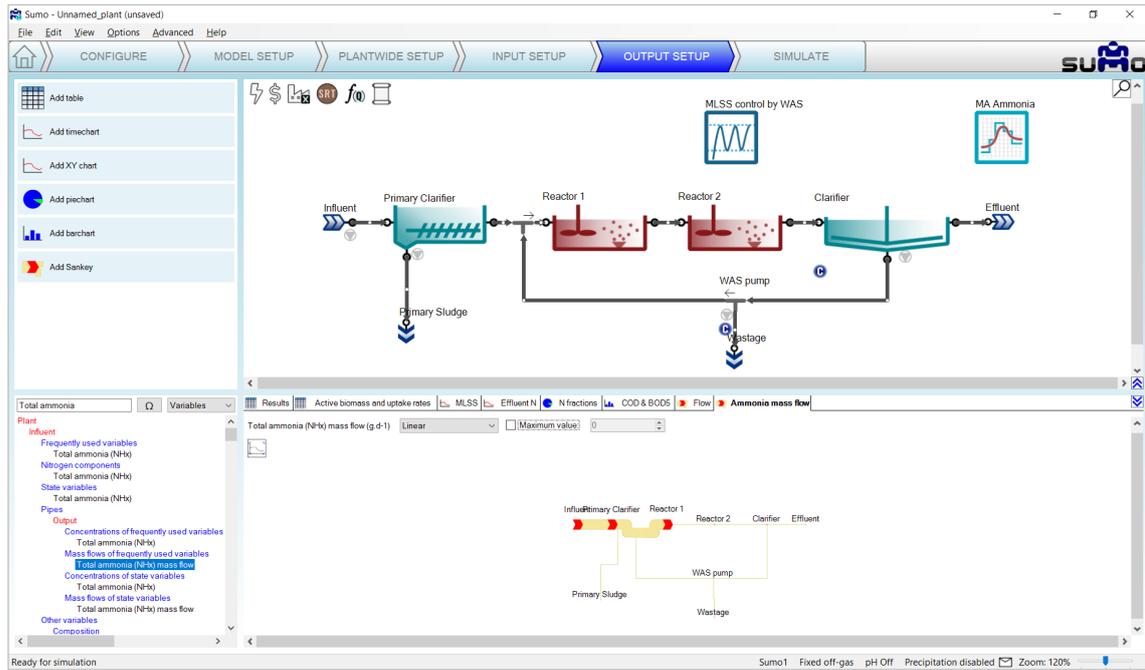
Figure 33 - Adding a Sankey diagram

At this point, the example is prepared for simulation with all the inputs and outputs provided. If desired, the output tabs can be reordered by dragging them to the aimed sequence. The file can be saved using the File menu (this function is not available in the demo version).

4.7   Simulate

The last item on the Task Bar can be used to run simulations and observe the results.

The role of screen panels in *Simulate* mode are the following:

- Top right panel   – Plant configuration
- Top left panel   – Simulation control panel (different function buttons for the simulation, including report preparation in Excel format)
- Bottom right panel   – Tabs for the previously defined outputs – display of results
- Bottom left panel   – Tabs for scenario definition

4.7.1   Simulation Control Panel

The top left screen panel enables operating the model, to run dynamic or steady-state simulations (as well as algebraic calculations, when being in design mode). *Steady* mode can be used to calculate directly the steady-state condition of the variables, whereas *Dynamic* mode will show the variations with time.

4.7.1.1   Steady mode

In systems theory, a system or a process is in a steady state if the variables which describe the behavior of the system or the process are unchanging in time. If a system is in steady state, then the recently observed behavior of the system will continue into the future.

After setting up the plant, all process units get a predefined initial value for each state variable (taken from the model defaults). However, most often this will not equal the values that can be observed in steady-state condition. The steady-state calculation will find the proper state variable values when the system is in steady state.

The steady-state simulation employs different solvers to look for the steady-state condition of the system. In this mode, all dynamic inputs are disabled and the controllers are turned into integrated controllers. Please note that steady-state simulation cannot be performed on inherently dynamic processes such as the SBR.

The roles of the control panel buttons on the *Steady* tab are the following:
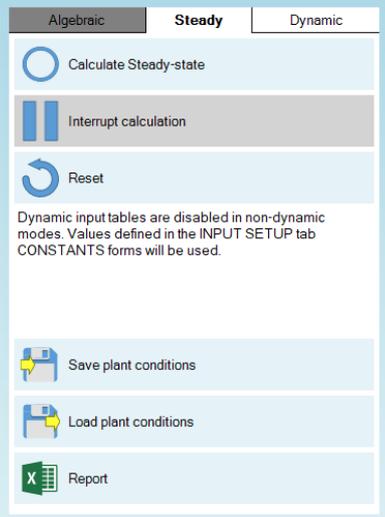
→ Start steady-state simulation from current system state

→ Interrupt simulation (or resume a previously interrupted one)

→ Reset the system to default initial conditions

→ Save actual conditions to a Sumo System State file

→ Load previously saved conditions from a Sumo System State file

→ Generate a report in Excel format

One should use the *Reset* button thoughtfully, especially when working with complex plants, for it will reinitiate the simulation with the default concentrations defined in the model and process units, and reaching steady-state again might be time-consuming in these cases. Saving plant conditions (especially if steady-state has been found) can be useful to restore system state in case the simulation is driven into an unwanted condition (e.g. accidentally having been reset).

4.7.1.2 Dynamic mode

Dynamic simulation will follow changes within the system as time passes, starting from the actual state of the system, and applying all dynamic inputs and behaviors that were defined during the setup process.

The roles of the control panel buttons on the *Dynamic* tab are the following:
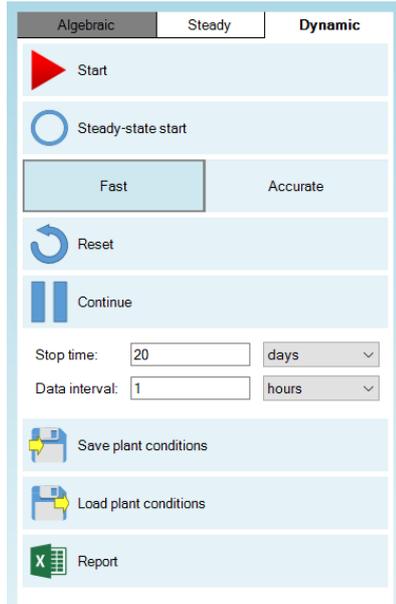
→ Start a simulation from actual conditions

→ Start a simulation from steady-state

→ Choose between Fast and Accurate modes

→ Reset default conditions

→ Continue/Pause simulation

→ Length of dynamic run
→ Data plotting/updating interval

→ Save actual conditions to a Sumo System State file

→ Load previously saved conditions from a Sumo System State file

→ Generate a report in Excel format

Dynamic simulation can be started by pressing the *Start* button. Upon first start, the simulation will be run from the initial conditions (defaults specified in the model file and in the process units). Every subsequent run will be initiated with the last system state. Pressing the *Steady-state start* button will run a steady-state simulation prior to starting the dynamic one (so that steady-state will be used as the initial condition). The role of the *Reset* button is the same as it is in the *Steady* mode – use it only if the goal is to restart the simulation process entirely from scratch.

The dynamic simulation will run until the end of the period defined by *Stop time* is reached (default setting: 1 day) and will plot/update results in the bottom right screen panel with the frequency described by the *Data interval* (default setting: 1 hour). The *Stop time* and *Data interval* can be modified before the simulation is started, or also when it is paused.

Choosing between *Fast* and *Accurate* modes translates to using different pre-configured solver settings. The differences between the two are described in Table 5. Usually the *Fast* mode is fast and accurate enough for most cases, and therefore its use is generally recommended. However, in certain situations (e.g. with biofilm models), the *Accurate* mode might provide faster simulation. If the plant seems to be complex and takes a long time to find a solution in *Fast* mode, then try switching over to *Accurate*. In such rare cases, it is the trial-and-error of coming to solver settings that lead to a speedy solution.

Table 5 – Explanation of Fast and Accurate solver settings

	Fast	Accurate
Type of configuration	Simple plant layouts will provide a speedy simulation	Best for complex plant layouts, specifically which have biofilm processes (MBBRs, and trickling filters) and several return or recycle streams.
Solver stop criteria	0.1 g/m3/d maximum error	0.1 g/m3/d maximum error
Solver types	GISA → Relaxation solver → Newton-Raphson	Relaxation solver → Newton-Raphson

Note that the mode selection will also have effect on the steady-state solver: GISA introduces a strong perturbance to the system state, therefore it is quite suitable for finding steady-state from a distant initial system state, while not so necessary when the system is already close to steady-state. There is no difference however in the stop criteria for the solvers; both will provide results below the maximum allowable error of 0.1 g/m3/d, and hence no difference in the outcome of the solution.

4.7.2   A process simulation example – aerobic plant

The plant configuration we have just built is an aerobic plant, with 12-hour hydraulic residence time:

$$HRT = \frac{10000 \; m^3 \; volume}{20000 \; m^3/d \; influent} \times 24\frac{h}{d}$$

A 10-day MLSS graph gives a good indication whether the system has settled into stable condition and the results are meaningful for typical dry weather summer operation, so let us start by setting the stop time to 10 days with 1-hour data interval and running a dynamic simulation. MLSS and effluent N plots are presented by Figure 34 and Figure 35, respectively. The effect of the MLSS control strategy can be observed as well.

In the bottom left screen panel rename the *Default scenario* to *Summer* (in order to differentiate from an another scenario that will be added later on).
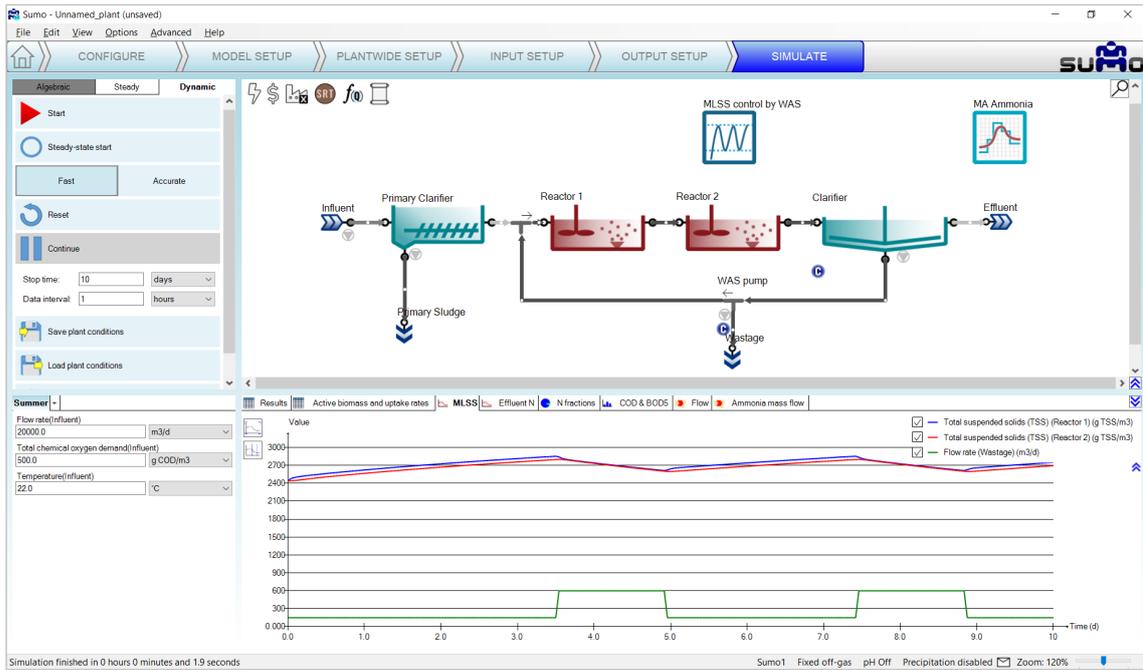
Figure 34 - Simulation results of the example plant with MLSS control
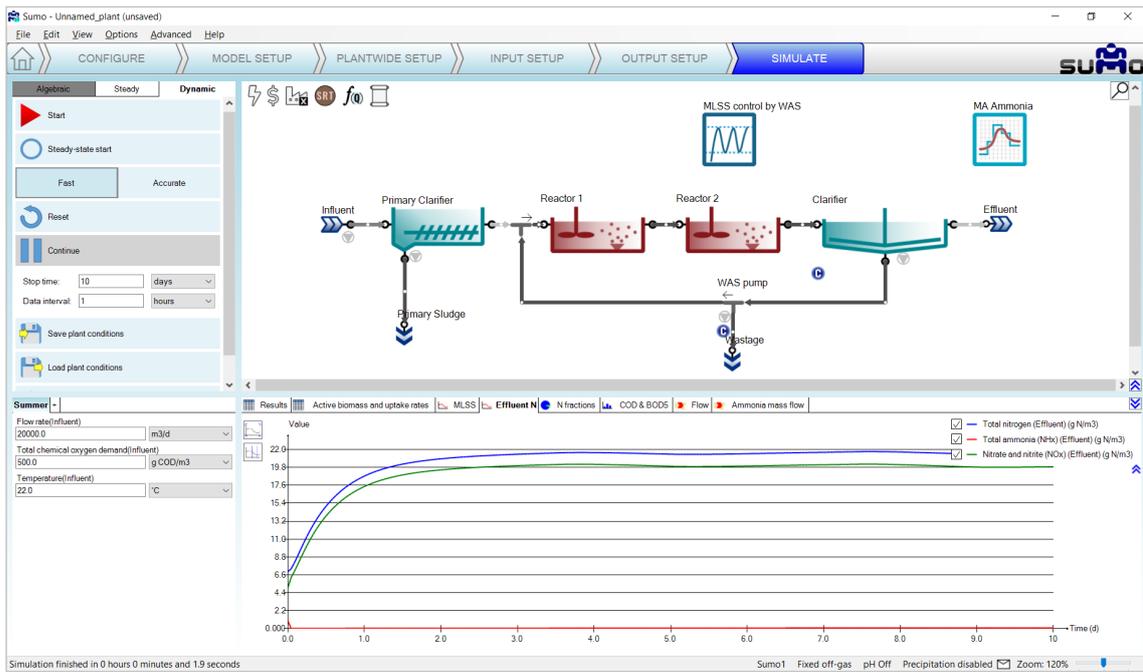

Figure 35 - Effluent total nitrogen, ammonia and nitrate at nitrification plant

The tabular results are shown in Figure 36.

Name	Influent	Reactor 1	Reactor 2	Effluent	Unit
Flow rate	20000	39327	39327	19327	m3/d
Total chemical oxygen demand	500	3033	2951	35	g COD/m3
Total organic carbon				9.4	g C.m-3
Total suspended solids (TSS)	218	2751	2696	10	g TSS/m3
Volatile suspended solids (VSS)	185	2188	2137	7.9	g VSS/m3
VSS/TSS ratio	0.85	0.80	0.79	0.79	g VSS.g TSS-1
Total biochemical oxygen demand (5 days)	218	594	558	2.7	g O2/m3
Total nitrogen	34	149	146	21	g N/m3
Total ammonia (NHx)	24	2.1	0.11	0.11	g N/m3
Nitrate and nitrite (NOx)	Non-detect	17	20	20	g N/m3
Total phosphorus	4.3	54	54	3.2	g P/m3
Orthophosphate (PO4)	2.5	2.2	3.0	3.0	g P/m3
Dissolved oxygen (O2)	Non-detect	2.0	2.0	2.0	g O2/m3
Oxygen uptake rate (OUR)		55	16		mg O2/L/h
Oxygen gas (O2) off-gas concentration in v/v%		19	19		%

Name	Reactor 1	Reactor 2	Unit
Ordinary heterotrophic organisms (OHO)	1022	992	g COD/m3
Carbon storing organisms (CASTO)	97	97	g COD/m3
PAO (Phosphate accumulating organisms) fraction of CASTO	17	17	g COD/m3
GAO (Glycogen accumulating organisms) fraction of CASTO	80	81	g COD/m3
Anoxic methanol utilizers (MEOLO)	0.69	0.68	g COD/m3
Aerobic nitrifying organisms (NITO)	54	53	g COD/m3
Acidoclastic methanogens (AMETO)	0.21	0.20	g COD/m3
Hydrogenotrophic methanogens (HMETO)	0.068	0.053	g COD/m3
Oxygen uptake rate (OUR)	55	16	mg O2/L/h
Carbonaceous oxygen uptake rate (COUR)	27	11	mg O2/L/h
Nitrification oxygen uptake rate (NOUR)	28	4.9	mg O2/L/h
Nitrate uptake rate (N3UR)	0.76	0.52	mg N/L/h
Ammonia uptake rate (AUR)	11	2.7	mg N/L/h
Phosphorus uptake rate (PUR)	1.2	0.46	mg P/L/h
Phosphorus uptake rate, biologically (PURBIO)	1.2	0.46	mg P/L/h
Phosphorus uptake rate, chemically (PURCHEM)	1.68E-21	2.13E-21	mg P/L/h
Phosphorus release rate (PRR)	0.74	0.61	mg P/L/h

Figure 36 - Tabular presentation of simulation results

These tables show:

- TSS and VSS profile from the influent through the reactors to the effluent;
- High effluent nitrate and low effluent ammonia (full nitrification);
- DO of 2 mg/L in both reactors (due to input settings);
- Oxygen Uptake Rate (OUR) in the two reactors: higher in the first one, lower in the second, as expected.

This fully aerobic plant does nitrify completely, producing low ammonia and high nitrate concentrations in the effluent. Both reactors are aerated to 2 mg/L DO, which requires energy and comes with costs.

4.7.3   Implementing denitrification

In the system above, the main electron acceptor for biochemical reactions is dissolved oxygen. We can use the abundant nitrate as electron acceptor, and with this process reduce our energy requirement and improve the effluent quality at the same time. For this, we need to reconfigure the plant – in this case simply creating an anoxic zone by switching off the aeration in Reactor 1. (In the actual plant, mixers would need to be installed in the anoxic zone to keep the MLSS in suspension, but in the model, the reactors are always ideally mixed.)

To implement this change, select *Input setup* on the Task Bar, switch to *Constants* mode, select Reactor 1 and select the *Aeration settings* item from the *Input parameters* (bottom left panel), then change the DO setpoint to zero in the bottom right panel (Figure 37).
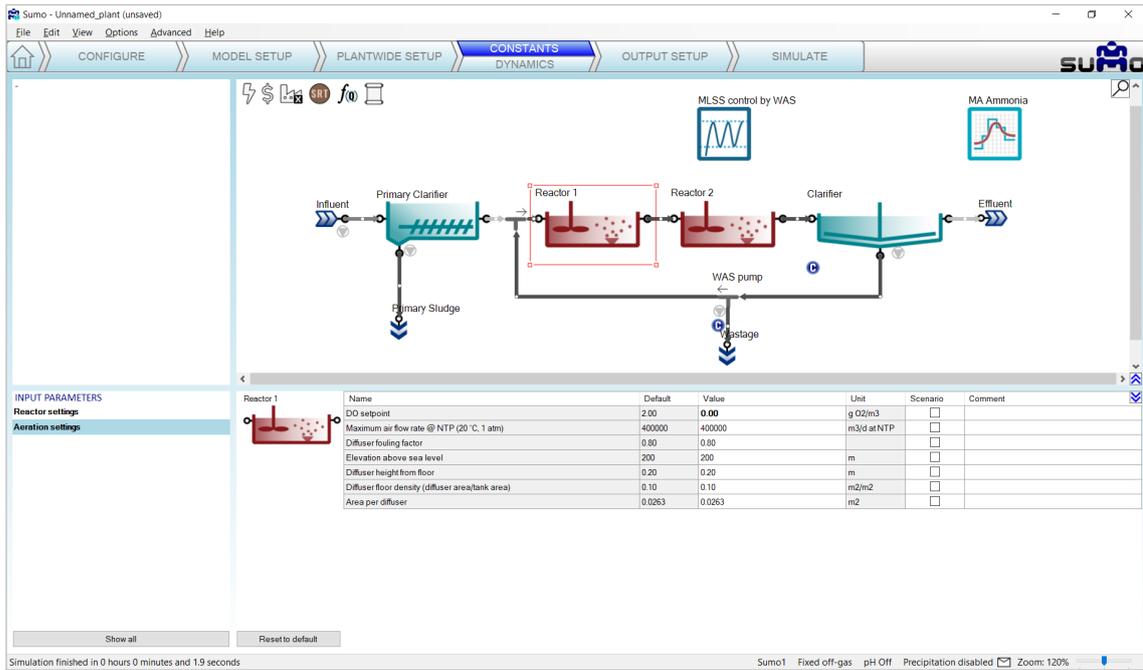
Figure 37 - Modifying DO setpoint in 'Reactor1'

Go back to the *Simulate* tab, set the *Stop time* to 20 day and click *Continue* to go on with the simulation while keeping the results of the previous 10 days in the graphs. Note that the color of the first tank will change to grey: this feature serves for easier visual identification of anoxic/anaerobic reactors. The effluent nitrate will be reduced because it is used up to oxidize organic material in Reactor 1 (the anoxic zone). On the contrary, effluent ammonia increases slightly as nitrification requires aerobic conditions and the aerobic reactor volume was reduced from 10000 m^3 to 8000 m^3. The effect of the DO setpoint change in the Reactor 1 can be followed on Figure 38. The drop in effluent nitrate concentration after 10 days is a due to the Reactor 1 having been turned anoxic. The time frame of the change can be followed as well: within 24 hours the nitrate concentration drops to the lower value.
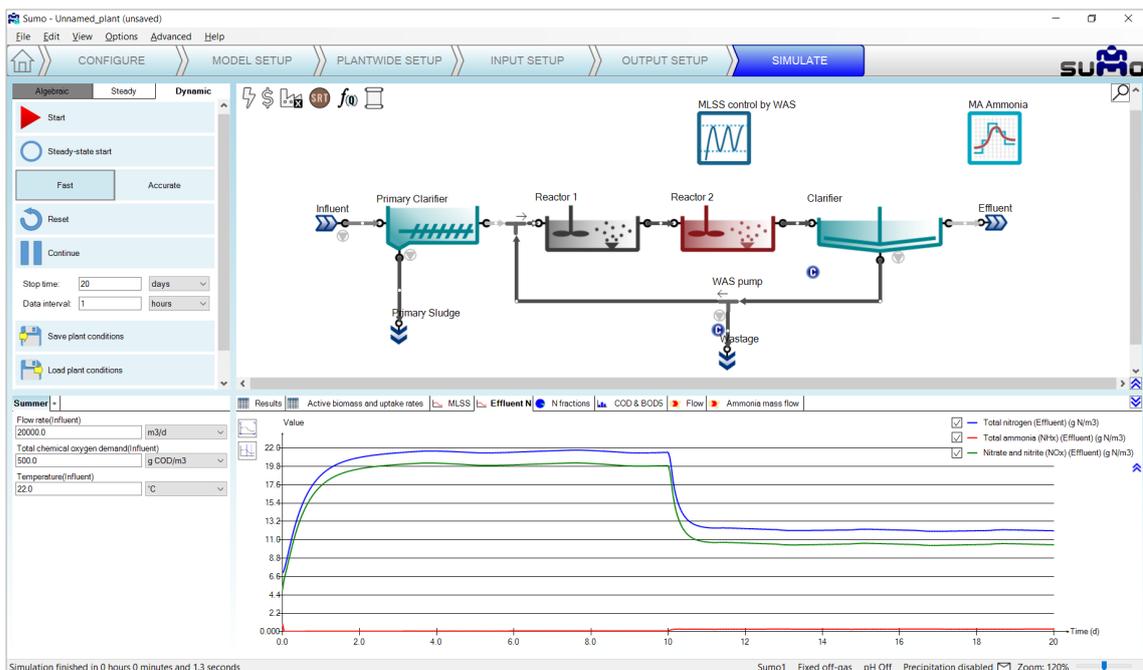
Figure 38 - Effluent ammonia and nitrate with denitrification

Name	Influent	Reactor 1	Reactor 2	Effluent	Unit
Flow rate	20000	38877	38877	18877	m3/d
Total chemical oxygen demand	500	2866	2821	35	g COD/m3
Total organic carbon				9.4	g C.m-3
Total suspended solids (TSS)	218	2564	2607	10	g TSS/m3
Volatile suspended solids (VSS)	185	2058	2042	7.8	g VSS/m3
VSS/TSS ratio	0.1	0.80	0.78	0.78	g VSS.g TSS-1
Total biochemical oxygen demand (5 days)	218	568	533	2.8	g O2/m3
Total nitrogen	34	130	130	12	g N/m3
Total ammonia (NHx)	24	13	0.32	0.32	g N/m3
Nitrate and nitrite (NOx)	Non-detect	0.0042	10	10	g N/m3
Total phosphorus	4.3	65	65	0.62	g P/m3
Orthophosphate (PO4)	2.5	16	0.30	0.30	g P/m3
Dissolved oxygen (O2)	Non-detect	0.0015	2.0	2.0	g O2/m3
Oxygen uptake rate (OUR)		1.3	24		mg O2/L/h
Oxygen gas (O2) off-gas concentration in v/v%		Non-detect	19		%

| Name	Reactor 1	Reactor 2	Unit
Ordinary heterotrophic organisms (OHO)	788	795	g COD/m3
Carbon storing organisms (CASTO)	230	237	g COD/m3
PAO (Phosphate accumulating organisms) fraction of CASTO	204	210	g COD/m3
GAO (Glycogen accumulating organisms) fraction of CASTO	26	27	g COD/m3
Anoxic methanol utilizers (MEOLO)	0.62	0.61	g COD/m3
Aerobic nitrifying organisms (NITO)	48	49	g COD/m3
Acidoclastic methanogens (AMETO)	0.24	0.22	g COD/m3
Hydrogenotrophic methanogens (HMETO)	0.11	0.084	g COD/m3
Oxygen uptake rate (OUR)	1.3	24	mg O2/L/h
Carbonaceous oxygen uptake rate (COUR)	1.1	13	mg O2/L/h
Nitrification oxygen uptake rate (NOUR)	0.21	11	mg O2/L/h
Nitrate uptake rate (N3UR)	4.3	0.37	mg N/L/h
Ammonia uptake rate (AUR)	1.2	4.2	mg N/L/h
Phosphorus uptake rate (PUR)	1.6	3.6	mg P/L/h
Phosphorus uptake rate, biologically (PURBIO)	1.6	3.6	mg P/L/h
Phosphorus uptake rate, chemically (PURCHEM)	1.27E-05	5.26E-05	mg P/L/h
Phosphorus release rate (PRR)	13	0.52	mg P/L/h

Figure 39 - Tabular presentation of simulation results with a denitrifying plant

Besides calculating air flow from a defined input DO, Sumo also offers the possibility to calculate DO levels based on specified input air flow. To select this model option, go back to the *Configure* tab and select Reactor 1, then in the *Dissolved oxygen* process unit option, switch from *Input* to *Calculated* (Figure 40). The calculated DO option will provide a better estimate of expected effluent values. In an aerobic reactor, instead of DO setpoint, the air flow is defined in the *Input setup*, and the concentration of the DO is calculated based on a mass transfer model. In anoxic (and anaerobic) reactors, with zero airflow specified, only the DO introduced by their input flow is considered.
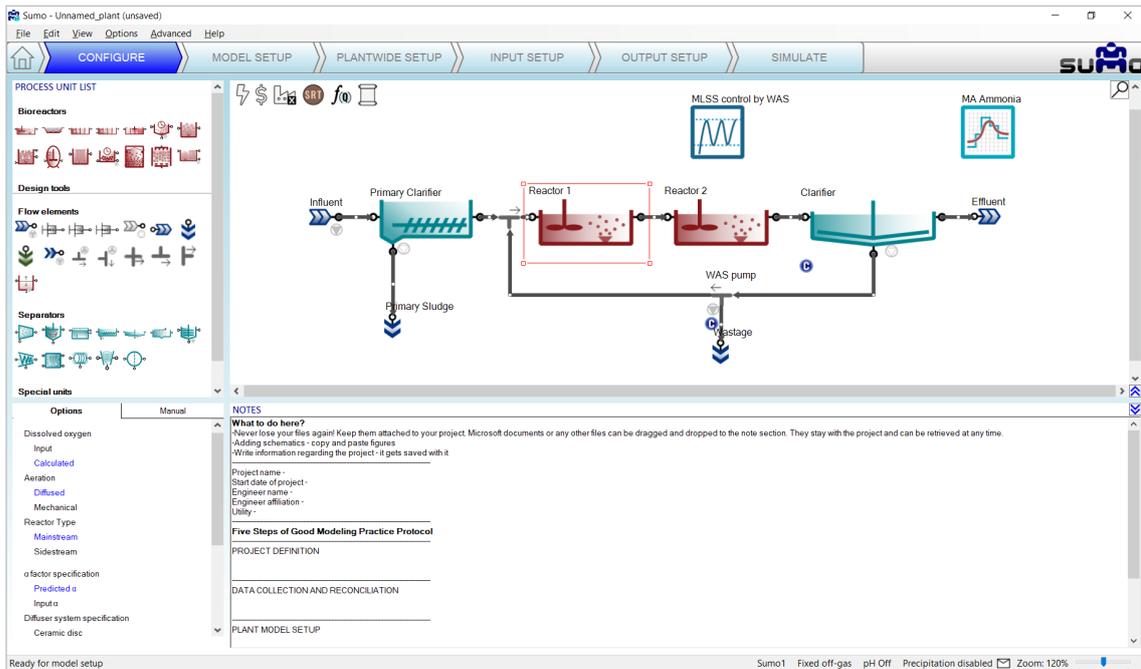
Figure 40 - Switching to "calculated DO" process unit option

The air flow can be provided on the *Input setup* tab. Let us change the blower airflow of Reactor 1 to 0 (Figure 41):

INPUT PARAMETERS — Reactor settings — Aeration settings — Reactor 1

Name	Default	Value	Unit	Scenario	Comment
Air flow @ standard conditions (NTP: 20 °C, 1 atm)	400000.0	0.0	m3/d at NTP		
Diffuser fouling factor	0.80	0.80			
Elevation above sea level	200	200	m		
Diffuser height from floor	0.20	0.20	m		
Diffuser floor density (diffuser area/tank area)	0.10	0.10	m2/m2		
Area per diffuser	0.0263	0.0263	m2		

Figure 41 - Changing air flow in 'Reactor 1'

After clicking on Reset, then running a 20-day simulation, you can compare the results of the plant operating with input DO (Figure 38 and Figure 39) and the plant operating with calculated DO (Figure 42 and Figure 43):

Name	Influent	Reactor 1	Reactor 2	Effluent	Unit
Flow rate	20000	39327	39327	19327	m3/d
Total chemical oxygen demand	500	2969	2875	35	g COD/m3
Total organic carbon				9.4	g C.m-3
Total suspended solids (TSS)	218	2716	2717	10	g TSS/m3
Volatile suspended solids (VSS)	185	2133	2080	7.7	g VSS/m3
VSS/TSS ratio	0.85	0.79	0.77	0.77	g VSS.g TSS-1
Total biochemical oxygen demand (5 days)	218	633	590	3.0	g O2/m3
Total nitrogen	34	137	135	12	g N/m3
Total ammonia (NHx)	24	12	0.31	0.31	g N/m3
Nitrate and nitrite (NOx)	Non-detect	0.0044	10	10	g N/m3
Total phosphorus	4.3	87	86	0.67	g P/m3
Orthophosphate (PO4)	2.5	17	0.29	0.29	g P/m3
Dissolved oxygen (O2)	Non-detect	0.0015	2.0	2.0	g O2/m3
Oxygen uptake rate (OUR)		1.3	24		mg O2/L/h
Oxygen gas (O2) off-gas concentration in v/v%		Non-detect	19		%

Name	Reactor 1	Reactor 2	Unit
Ordinary heterotrophic organisms (OHO)	819	811	g COD/m3
Carbon storing organisms (CASTO)	338	341	g COD/m3
PAO (Phosphate accumulating organisms) fraction of CASTO	302	304	g COD/m3
GAO (Glycogen accumulating organisms) fraction of CASTO	36	37	g COD/m3
Anoxic methanol utilizers (MEOLO)	0.66	0.65	g COD/m3
Aerobic nitrifying organisms (NITO)	51	51	g COD/m3
Acidoclastic methanogens (AMETO)	0.25	0.23	g COD/m3
Hydrogenotrophic methanogens (HMETO)	0.11	0.088	g COD/m3
Oxygen uptake rate (OUR)	1.3	24	mg O2/L/h
Carbonaceous oxygen uptake rate (COUR)	1.1	14	mg O2/L/h
Nitrification oxygen uptake rate (NOUR)	0.22	11	mg O2/L/h
Nitrate uptake rate (N3UR)	4.4	0.39	mg N/L/h
Ammonia uptake rate (AUR)	1.2	4.3	mg N/L/h
Phosphorus uptake rate (PUR)	1.6	4.0	mg P/L/h
Phosphorus uptake rate, biologically (PURBIO)	1.6	4.0	mg P/L/h
Phosphorus uptake rate, chemically (PURCHEM)	1.31E-05	5.16E-05	mg P/L/h
Phosphorus release rate (PRR)	14	0.60	mg P/L/h

Figure 42 - Tabular presentation of simulation results with a denitrifying plant with calculated DO
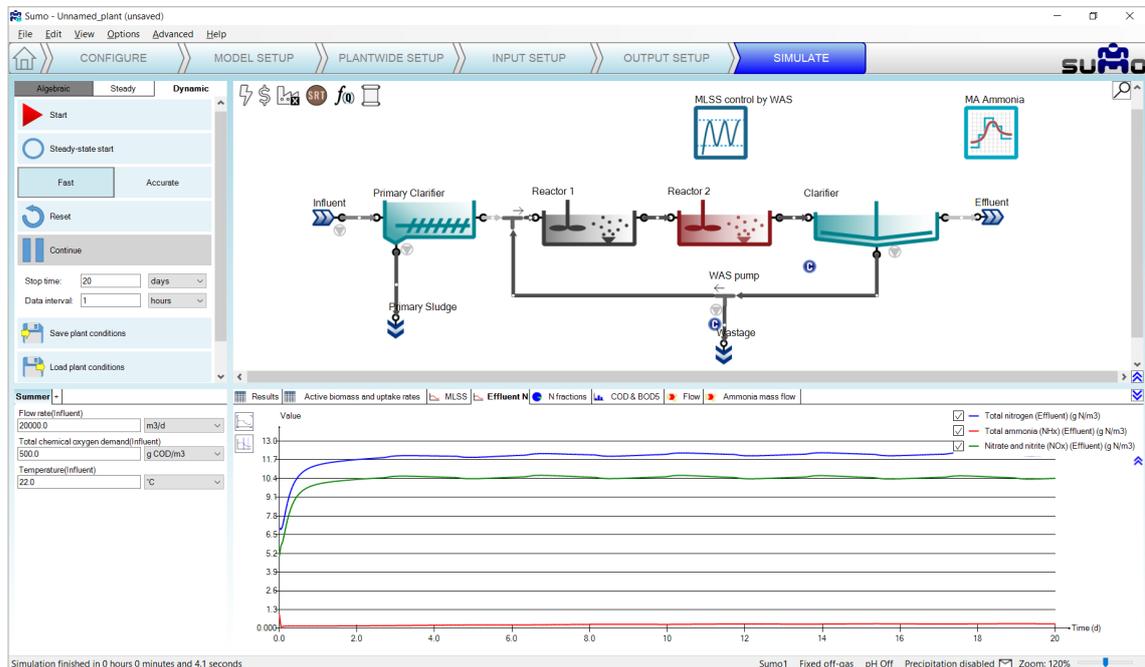
Figure 43 - Effluent ammonia and nitrate with calculated DO

4.7.4 Subjecting the plant to dynamics

Plants are usually subjected to diurnal variation and we might be interested not only in the average, but the peak effluent concentrations as well (e.g. in certain jurisdictions the effluent limits are based on grab samples never to exceed, daily maximum, etc.). This requires a dynamic simulation to investigate potential peaks during the day.

Select the *Input setup* tab, and the Influent process unit, where we will provide diurnal flow variation. In *Constants* mode, the *Influent tool* is available for Sumo models as an Excel file, containing typical fractions and diurnal variations with different plant sizes. Click on the button (located in the bottom right screen panel) to open this tool and copy the "medium plant" table from the *Diurnal flow* sheet to the Clipboard (Figure 44):
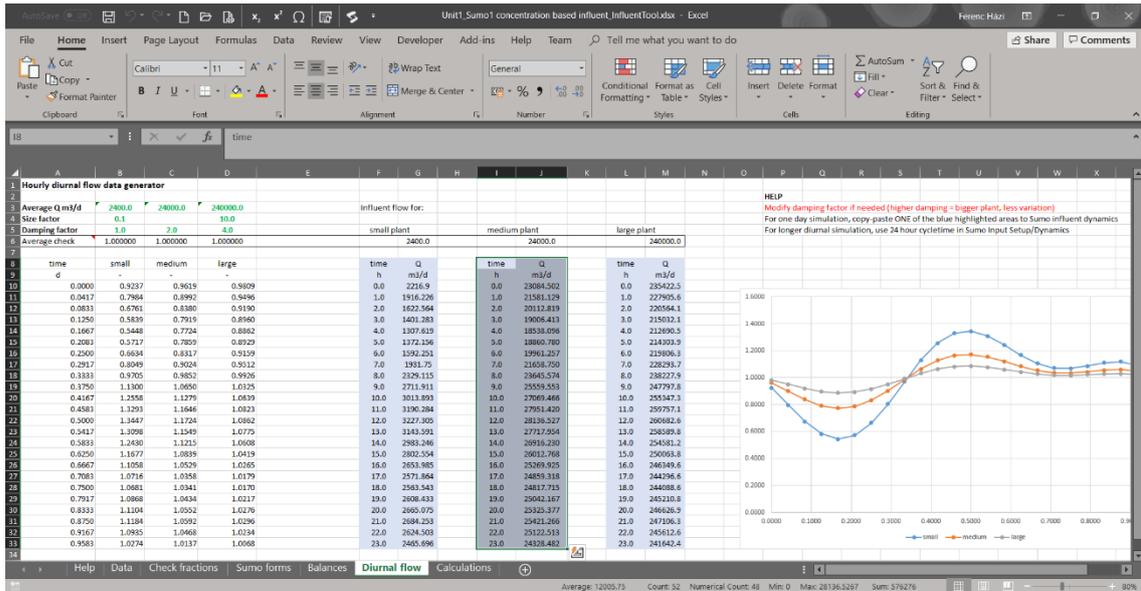
Figure 44 - Sumo1 Influent tool

Now switch to *Dynamics* mode in Sumo and paste your table by clicking on the *Paste table form clipboard* button (after this, you can close the *Influent tool* Excel file). On the drawing board, a small sign will appear below the Influent, showing that dynamic parameter input is used. These tables can be disabled/enabled or deleted by right-clicking on the name in the bottom left screen panel. Note that for a certain variable/parameter, only one dynamic table can remain enabled (Sumo will give you a warning if more than one tables are enabled for the same subject). The names of disabled tables (which are editable in the bottom right screen panel) will show up in grey, and in case all dynamic input tables are disabled, the sign beside the process unit will also turn to grey (indicating that there are dynamic inputs available, but not used). Linear interpolation and cycle repeat can also be set for dynamic input tables. Rename the newly inserted dynamic input table in the example to "Diurnal flow", check the box to repeat the contents of the table and provide the repeat frequency as 24 hours in this example, as depicted on Figure 45.
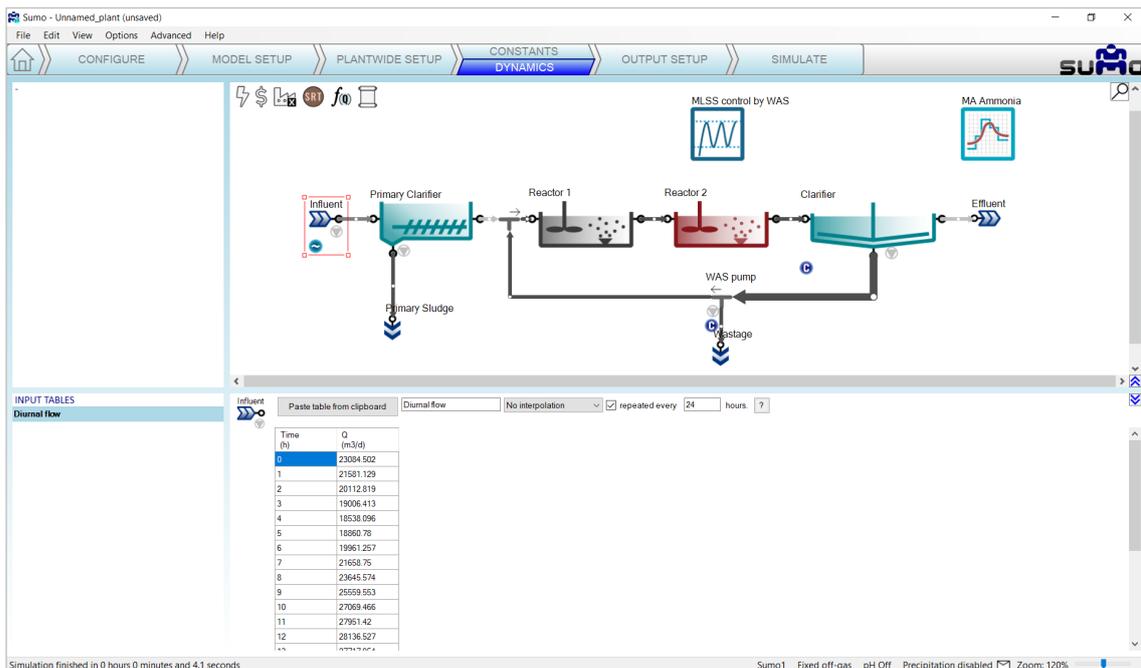
Figure 45 - Configuring dynamic input

If you can provide data from measurement, your input data (flow variation in this case) should be in Excel, in the following format: the header should be "Time" ("time" is also accepted) and the selected variable name as it is used by Sumo, in this case "Q" (denoting flow), with the respective units ("h" and "m3/d") in the second row, as illustrated by Table 6. To find out what is the internal identifier for a certain variable (or model parameter), you can just hover the mouse above the name of the specific item in the parameter tables of *Input setup – Constants* (or in the case of model parameters, the *Model setup*), and a popup will show you the cryptic name of your input variable that has to be used in the dynamic table (see Figure 46).

Table 6 – Dynamic input of influent flow pattern

time	Q
h	m3/d
0.0	23084.502
1.0	21581.129
2.0	20112.819
3.0	19006.413
4.0	18538.096
5.0	18860.780
6.0	19961.257
7.0	21658.750
8.0	23645.574
9.0	25559.553
10.0	27069.466
11.0	27951.420
12.0	28136.527
13.0	27717.954
14.0	26916.230
15.0	26012.768
16.0	25269.925
17.0	24859.318
18.0	24817.715
19.0	25042.167
20.0	25325.377
21.0	25421.266
22.0	25122.513
23.0	24328.482

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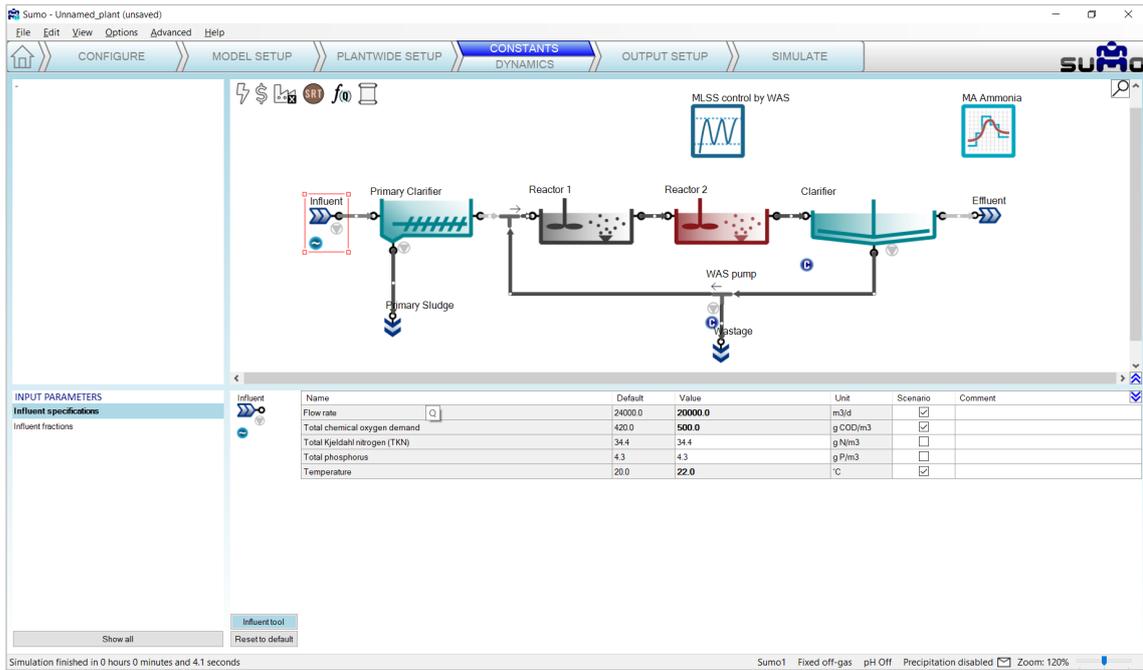
Figure 46 – Variable name pop-up message at the Input setup

Having set up the diurnal flow, go to the *Simulate* tab and start a new dynamic simulation of 5 days duration: In this case, the result of the last simulation will be used as initial values. The variation in loading should have an effect on effluent quality, as shown by Figure 47.
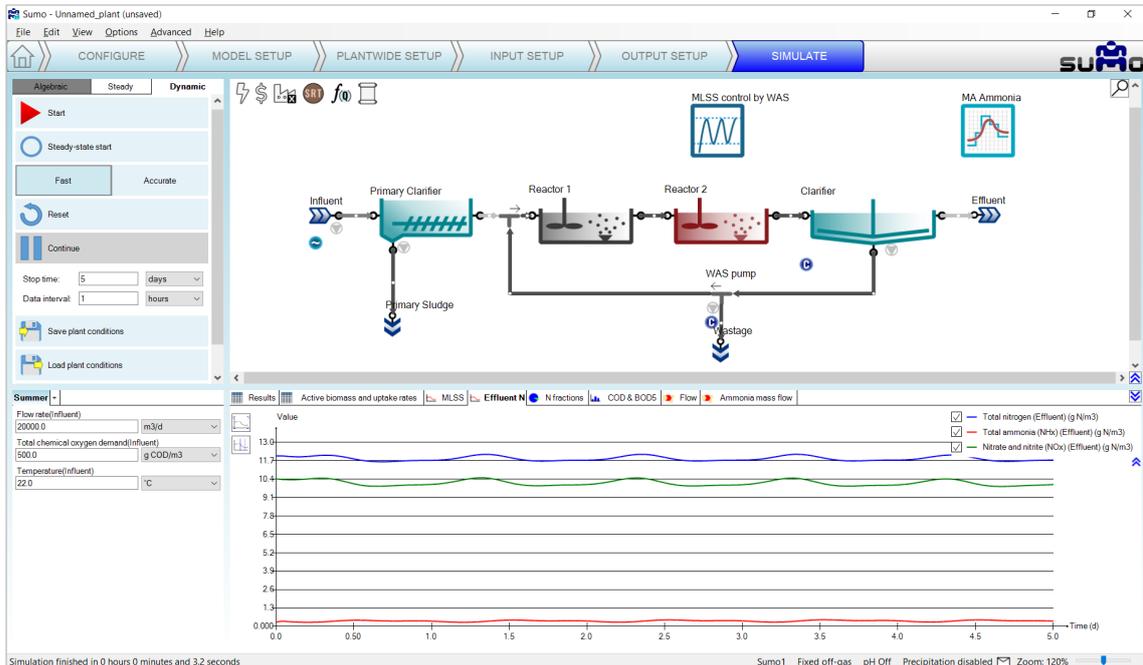
Figure 47 - Effluent ammonia and nitrate variation with changing influent flow

We can observe higher ammonia concentrations during the high loaded periods, and lower nitrate concentrations, due to lower nitrification and the abundance of organic substrate for denitrification.

We can of course always turn on our aerators in the first reactor (not so easy in an actual plant) by going to the *Input Setup* tab, selecting Reactor 1 and changing the air flow to 150000 Nm^3/d. In the *Simulate* tab, we can extend the length of the run for 10 days and hit *Continue*.
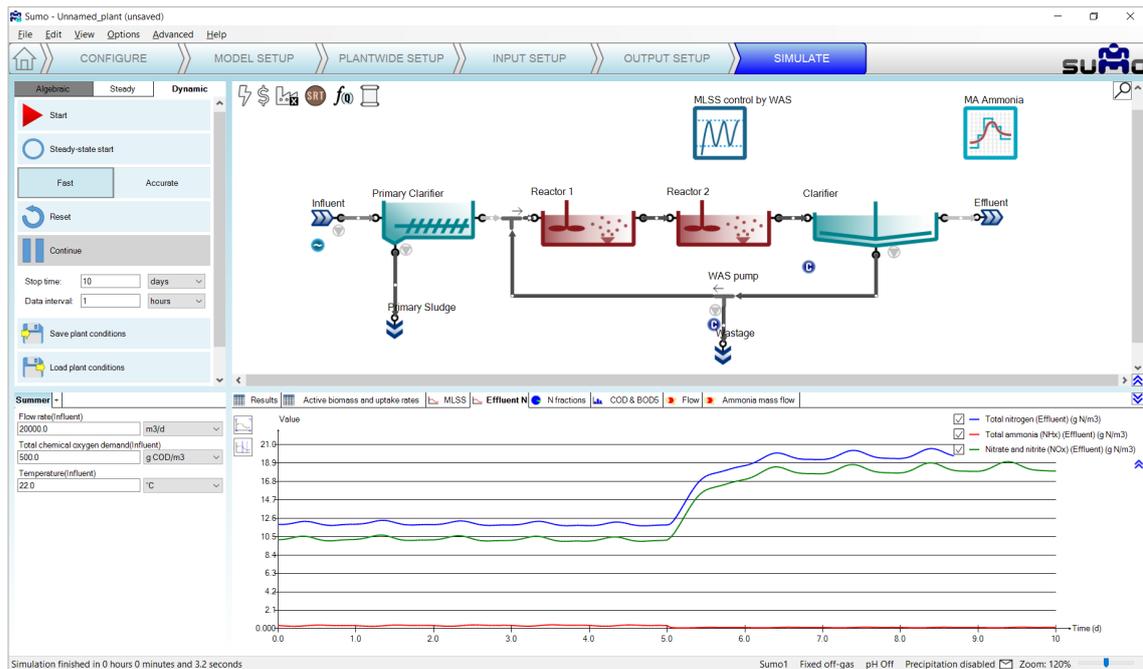
Figure 48 - Effluent ammonia and nitrate variation – aeration switched back in 'Reactor1'

Nitrate concentration will increase, and the ammonia peaks will get much reduced from day 10, when the aerators were turned back on. After this exercise, reset the air flow in Reactor 1 to 0 Nm³/d and run a 10 d simulation to get back to denitrifying plant.

4.7.5   Model parameter dynamic input

Model parameters and plantwide parameters can be added as dynamic inputs as well – in these cases, the plantwide (factory) icon should be selected on the drawing board in the *Input setup – Dynamics* tab, and extended descriptions of the model parameters are to be used in the dynamic input tables, as described below.

The incode name of model parameters can be found as popup by hovering the mouse over the desired parameter on the *Model setup* tab. See the example of *Maximum specific growth rate of the NITOs* (nitrifier organisms) on Figure 49: μNITO is the name of the parameter in the active model, which is the Sumo1 model in this tutorial. The model name of the parameter is the compound of the model name and the parameter name, separated by two dots. So in our example, **Sumo1..μNITO** will be the correct model parameter name to be used in the dynamic input table (Table 7).

Table 7 – Model parameter dynamic input table

time	Sumo1..μNITO
h	1/d
0.0	0.9
6.0	0.4

Inserting the dynamic input table is done the same way as it was done in the diurnal flow – just copy the prepared table from Excel and paste using the button in the *Input setup – Dynamics* tab (remember that the factory icon shall be selected for showing this functionality). The presence of the dynamic global model parameter input will be indicated by a blue circle with a wave inside on the drawing board, below the factory icon (see Figure 50).
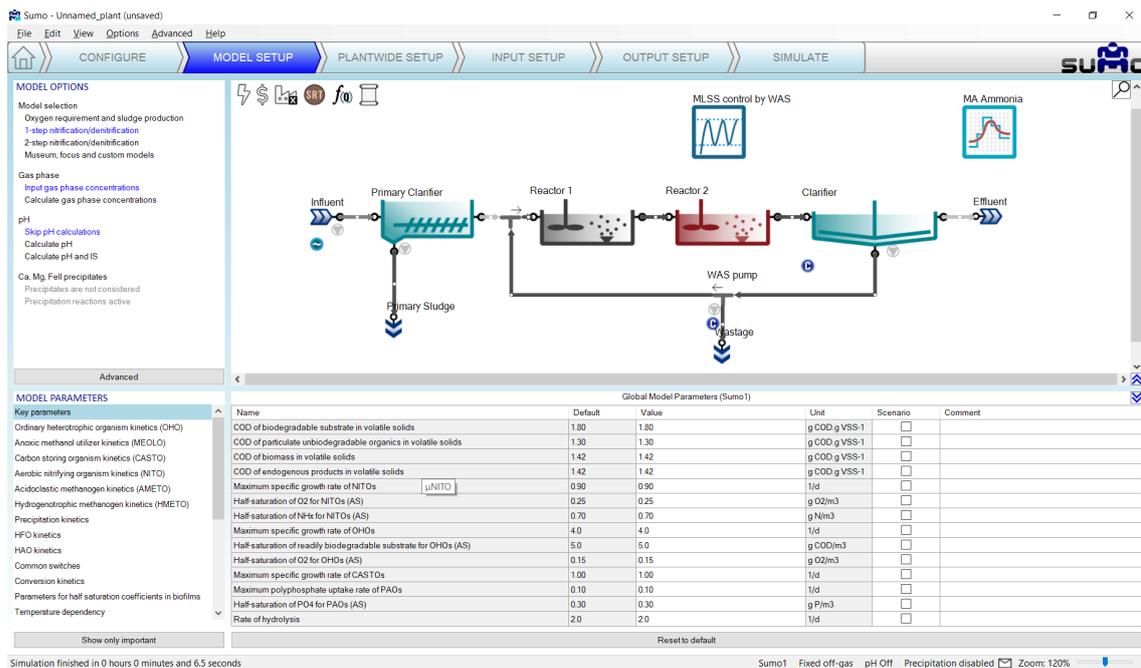
Figure 49 – Model parameter name
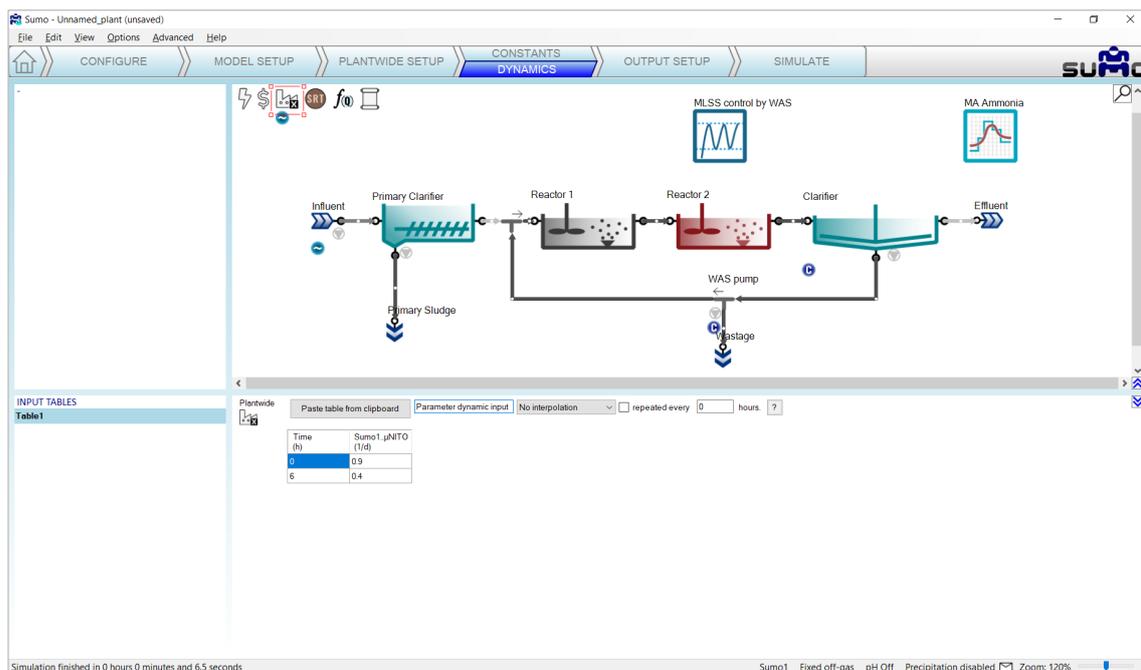
Figure 50 – Dynamic global model parameter input

Now let us go to the *Simulate* tab and start a 2-day simulation with an hourly data interval. The decrease in nitrifier maximum growth rate (caused by i.e. a toxic substance in the influent) should have an effect on effluent quality as shown in Figure 51: we can observe higher ammonia concentrations after the decrease in the NITO growth rate.
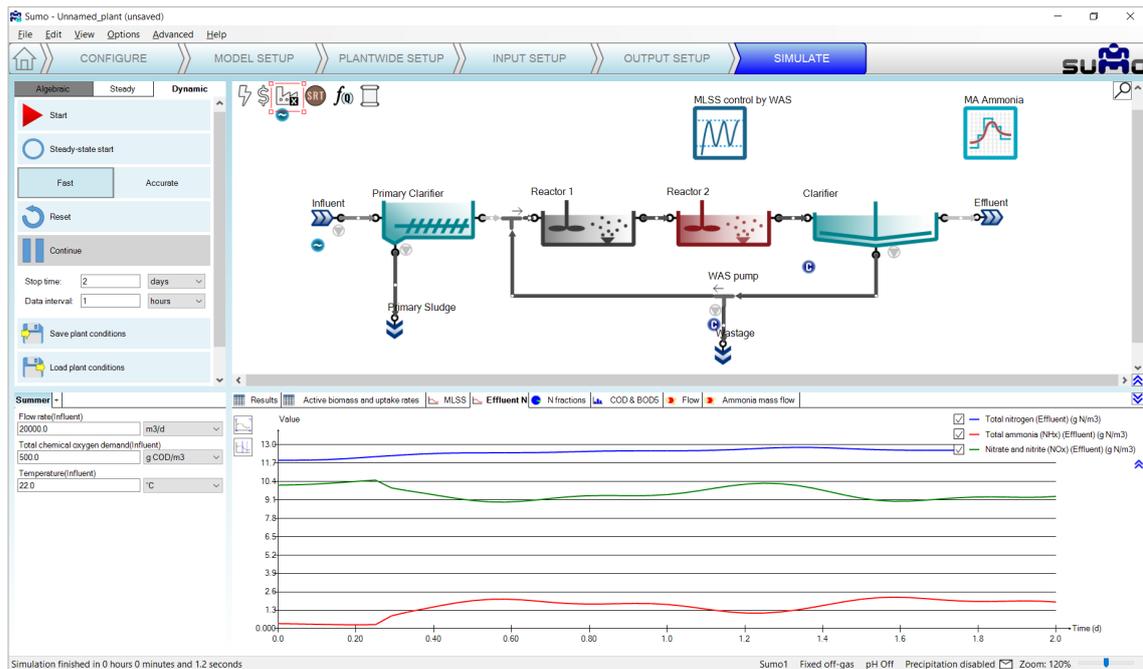
Figure 51 - Effluent ammonia and nitrate variation with NITO growth rate decrease

During the following exercises, we will not use the dynamic input for model parameters any more. In the bottom left screen panel of the *Input setup/Dynamics* tab, right click on the name of this table and choose *Delete* to remove the table. Alternatively, you can just use the *Disable* option as well, in order to keep the table but not to use it during the subsequent simulation. Let us try this option for switching off the diurnal flow (the indicator below the Influent icon will turn to light grey).

4.7.6   Adding measured data to the charts

Plants do collect information and one important task in process simulation is to compare measured data with simulation results (and potentially using the information to calibrate the model). Let us assume that this plant has MLSS grab samples once a day in Reactor 2 (TSS Reactor 2). The collected data is shown in Table 8 below.

Table 8 - Measured TSS data for the example plant

Time	XTSS (Reactor2)
d	g/m3
0	2800
1	2700
2	2600
3	2700
4	2780
5	2700
6	2750
7	2725
8	2775
9	2600
10	2750

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Copy this table into an Excel sheet (e.g. named Plant Data.xlsx) and rename the sheet "Measured TSS" (Actual names are irrelevant and flexible).

Switch Sumo to *Simulate* mode, click on *Reset,* then run a 10-day simulation to let the system settle into stable condition. Then run another 10-day simulation for evaluating the MLSS trend due to the deadband controller.

Switch Sumo to 'Output setup' mode, right click on the MLSS timechart tab and select *Import data*. The data import is carried out the same way as the dynamic input table: simply paste from the clipboard (Figure 52).
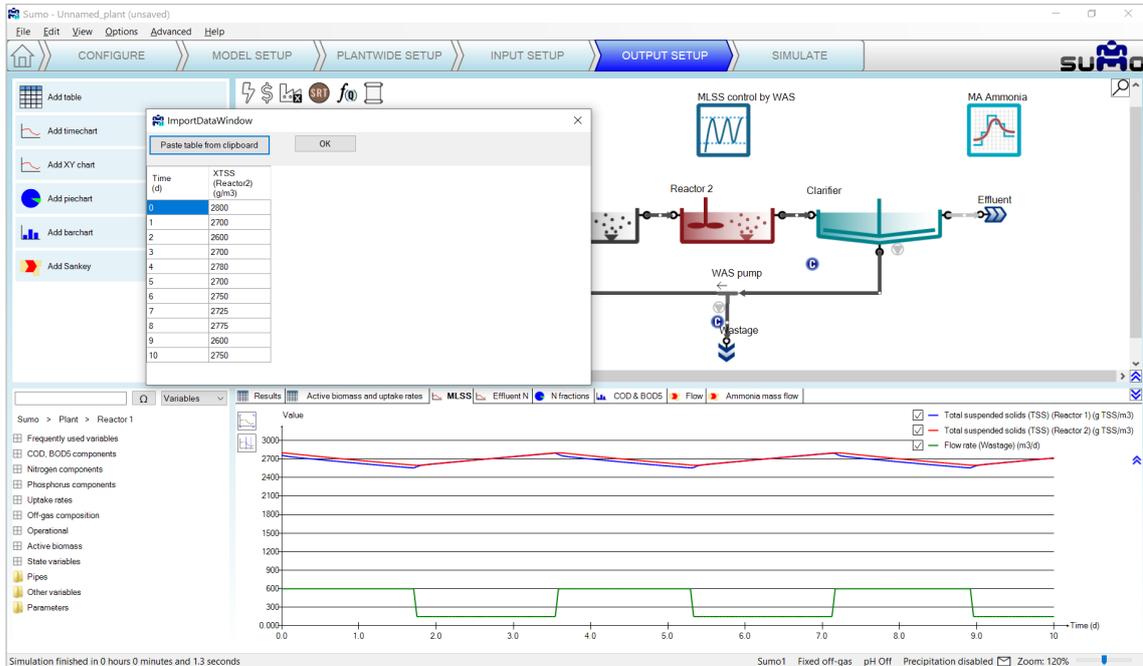
Figure 52 - The data import dialog

Pressing *OK* the data is plotted along the simulation results (Figure 53):
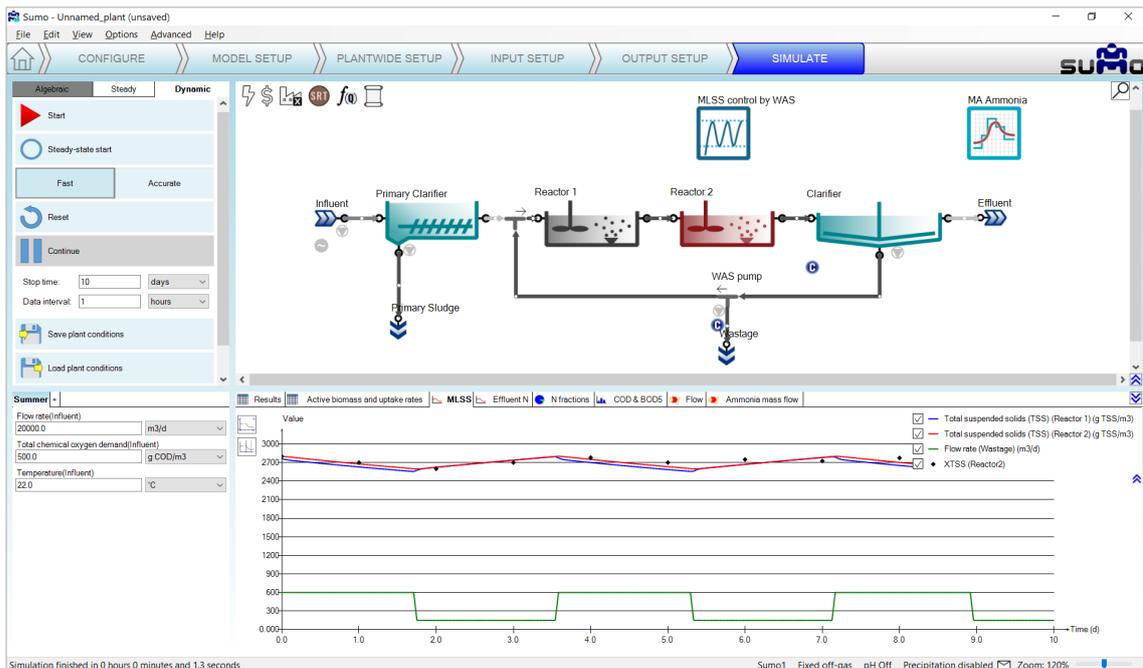
Figure 53 - Measured and simulated data in the same chart

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The project can be saved any time during the configuration and project development using the *File* menu and reloaded at a later point in time to continue the work.

Many other operational scenarios can be simulated with Sumo, including more complex reactor configurations and more elaborate operational scenarios. Please see *Examples* under the *Help* menu and for further description in Chapter 6 (page 67).

4.7.7 Scenarios

By default, the simulation is using the input parameters defined in *Input setup*, such as the influent flow rate, the influent Total Chemical Oxygen Demand and the influent temperature, which we have also selected for scenario analysis at an earlier stage. On the bottom left screen panel of the *Simulate* tab, further scenarios can be defined by clicking on the Add Scenario (+) tab. Add a new scenario, rename it to Winter and set 14°C, 26000 m^3/d flow rate and 460 mg O$_2$/l COD as input parameters instead of the default parameter set provided in the Summer tab. (Figure 54). With this simple setup the simulation will now use (as long as the *Winter* tab is active) 14°C as influent wastewater temperature, modified influent flow and COD composition and the results can be compared.
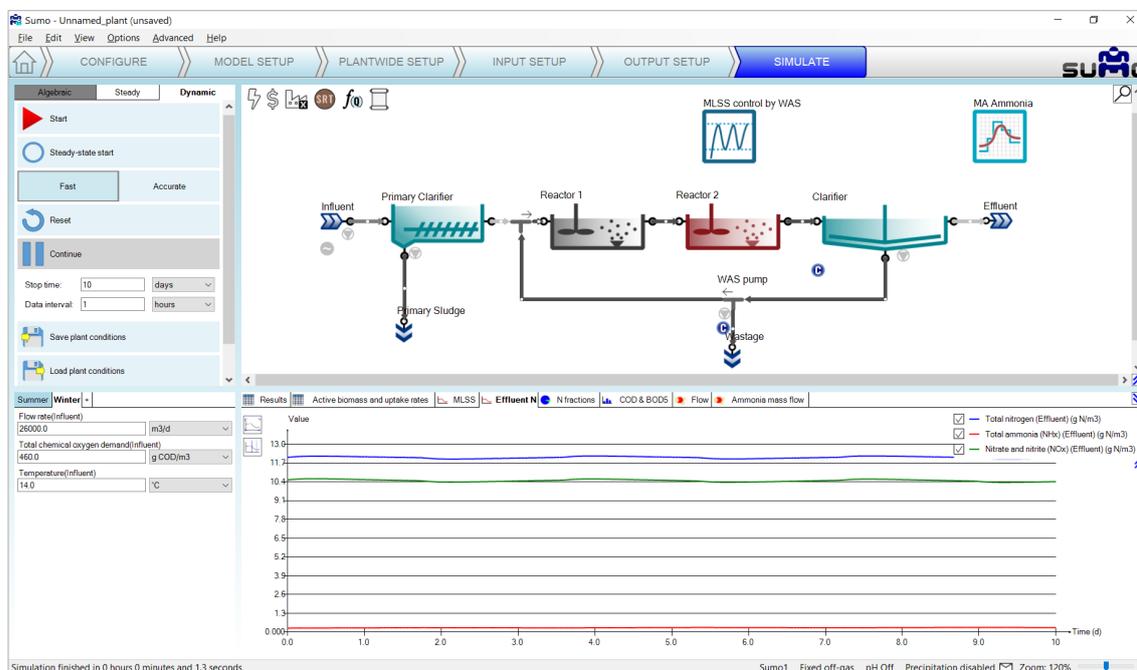
Figure 54 – Scenario definition for Winter conditions

After clicking on *Reset* and running two consecutive 10-day dynamic simulations (in order to get the system to a characteristic winter operation), activate the *Summer* scenario by clicking on its tab, modify the simulation stop time to 20 day and hit *Continue*. The change due to new influent conditions can be seen quickly (Figure 55):
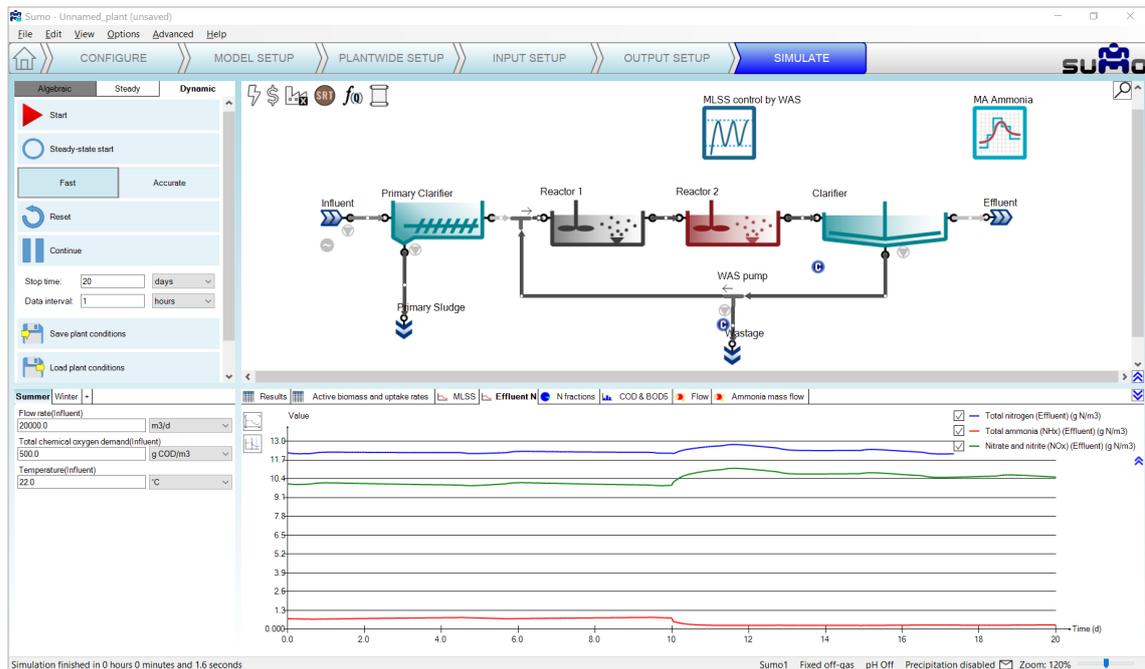
Figure 55 – Low temperature scenario results followed by summer conditions at 10 days

If you want to add further parameters, just go back to the *Input setup* tab and select the desired parameters of the desired process unit. Model parameters can be selected as well for scenario analysis and the *Model setup* tab.

4.7.8   Writing a report

On the Control panel of the *Simulate* tab, a *Report* button is available. When clicked, results will be written to an Excel file, available for further processing. The resulting Excel file is named the same as the sumo project file by default (Figure 56). This function creates an Excel file with the following sheets:

- Project overview: contains the configuration layout and basic project information
- Notes: the contents of the *Notes* screen panel from the *Configuration* tab
- Modified parameters: values of all parameters in the project that were changed from default
- Simulation results: all results of the output tabs get saved to separate sheets, including data tables for the diagrams
- Model: contains all parameter values for the used model (in this example: Sumo1)
- Plantwide calculations: Plantwide, Energy center, Cost center, SRT and Flow dependence settings are saved on separate sheets
- Process Units: all settings and PU parameters are displayed on separate sheets for each unit, including pipes.
- Controllers: all settings and parameters of the controllers employed in the project (if any).

Please keep in mind that if there are multiple scenarios defined in the project, only the parameters for the one that was last run will be saved to the report.

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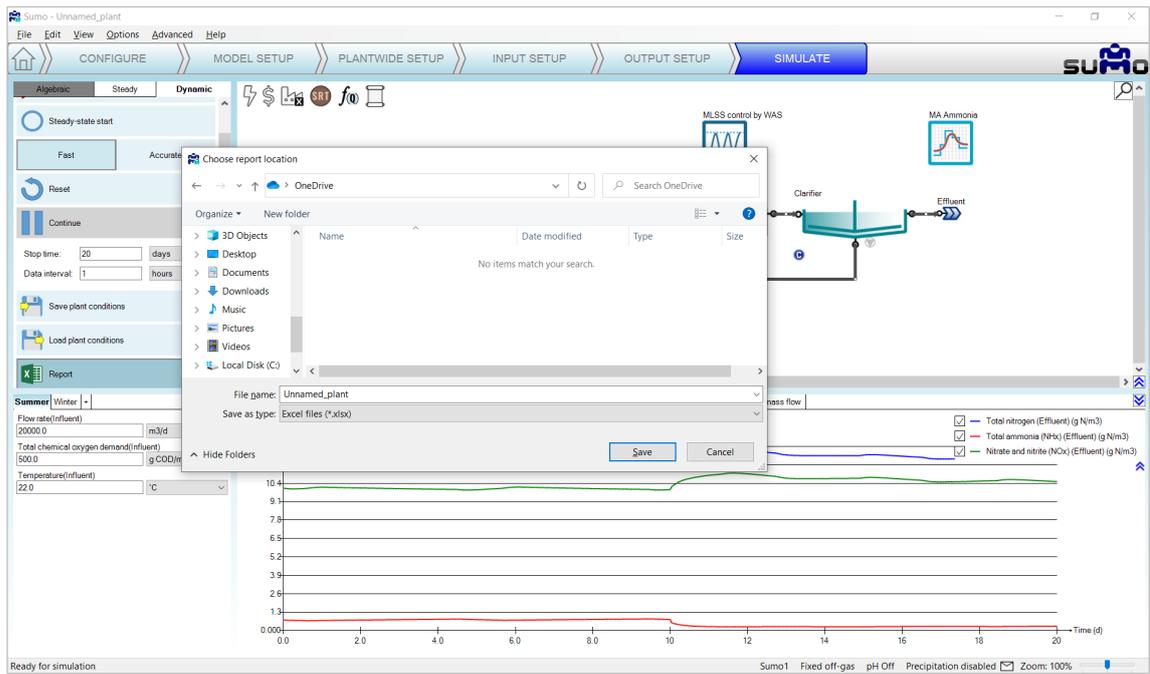
Figure 56 - Saving the Report

5   Controllers

Controllers are used to set operational parameters based on measured values during the operation of the plant. In Sumo, the controlled values are calculated variables from the simulation. The on-off controller has no controlled variable. The manipulated parameters are input values for the controlled process unit. For example this way the reactor MLSS can be automatically controlled by manipulating the wastage sludge flow. Another example is setting the air flow into the aerated reactor to maintain a certain dissolved oxygen level.

There are 5 different type of controllers implemented in Sumo, which can be added at the *Plantwide setup* tab (Figure 57):
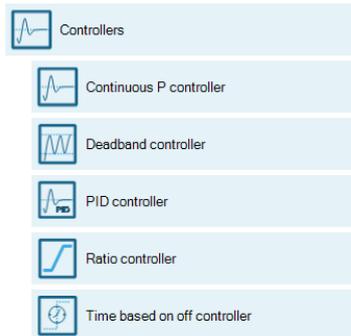
Figure 57 – Available controllers

In *Plantwide setup* you can add the Controller and configure the control variable (CV) and the manipulated variable (MV) which is a parameter in the model, while in the *Input setup* you can fine tune the controller settings. In this chapter, the setup possibilities will be presented for each available controller one by one, based on the example project built in Chapter 4 (page 9).

5.1   Continuous P controller

The Continuous P controller is a model controller that continuously sets (integrates) the input parameter (Manipulated variable) of the desired unit to meet the control variable value setpoint (as opposed to discrete controllers).

Add this controller to the layout from the *Plantwide setup* and configure it as follows. First drag and drop the manipulated process unit (Reactor 2) to the left side of the equation in the bottom right screen panel and the controlled unit (Effluent) to the right side of the equation. On the bottom left screen panel, you can now select the control variable and the manipulated variable in the respective units. In this example, we control the requested DO setpoint to maintain the desired ammonium concentration in the effluent. Rename the unit (using F2 or right click) to "Ammonia control" (Figure 58).
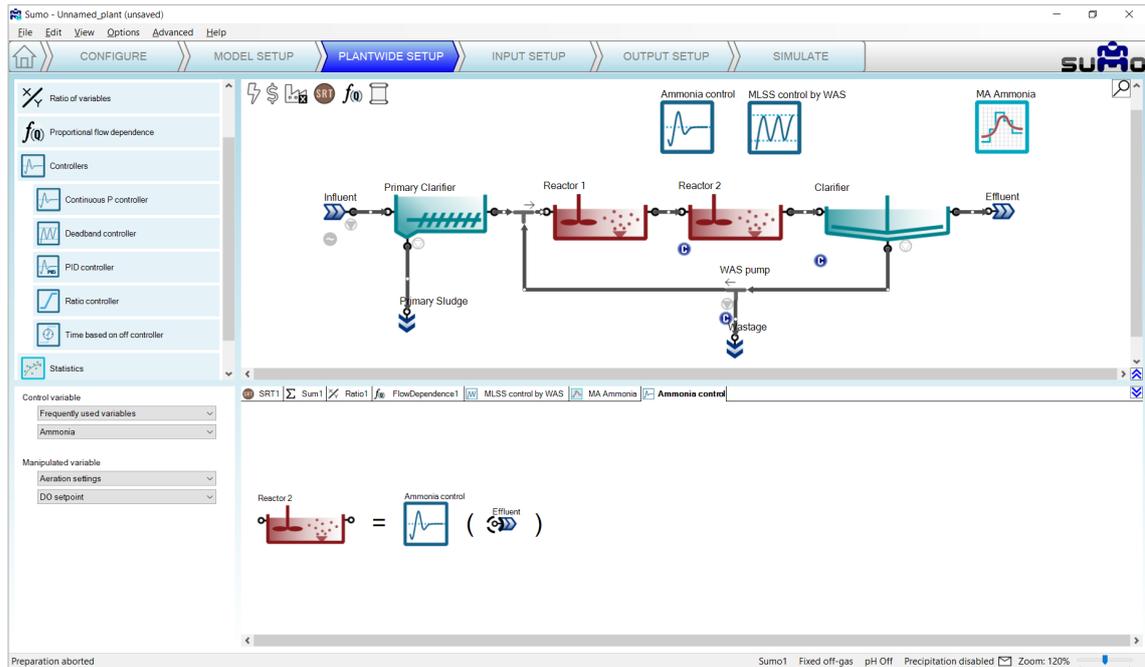
Figure 58 – Configuration of the continuous P controller

At the *Input setup* tab, select the newly added controller. In the *Controller parameter* table, enter the following settings:

- *Controlled variable setpoint* to 0.5 g N/m^3 (target effluent ammonia concentration);
- the *Maximum of the manipulated variable* value to 3 g O$_2$/m^3;
- the *Controller direction* to -1, because it is an inverse controller (to decrease the ammonia concentration the DO setpoint has to be increased).

At the *Controller initialization* table, set the *Initial value of manipulated variable* to 2 g O$_2$/m^3 (Input DO setpoint in Reactor 2). Leave the other parameters default (Figure 59).

Figure 59 – Setting continuous P controller input parameters

To follow the effect of the controller, you can add the setpoint to the *Effluent N* timechart at the *Output setup* tab: select the *Ammonia control* controller and from the bottom left screen panel, go to *Parameters > Controller parameter*s menu and add *Controlled variable setpoint* to the timechart. (Figure 60).
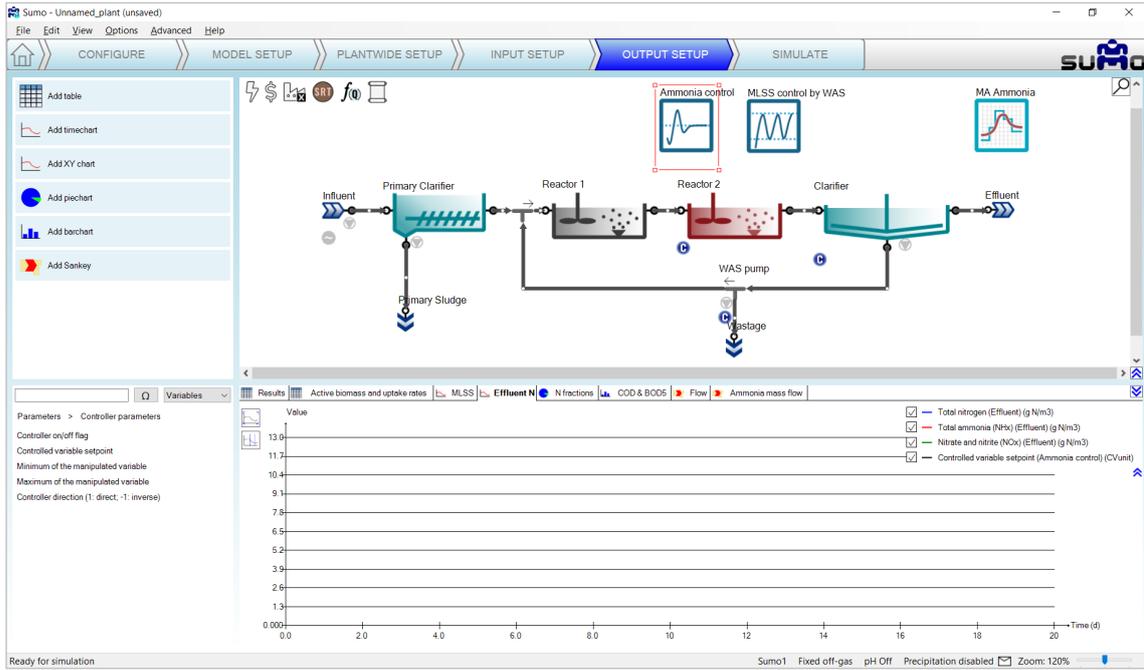
Figure 60 – Add controlled variable setpoint to timechart

Before starting the simulation, go to the *Input setup/Dynamics* tab and enable the Diurnal flow dynamic input table of the Influent to have changes in the ammonia load (see Figure 61).
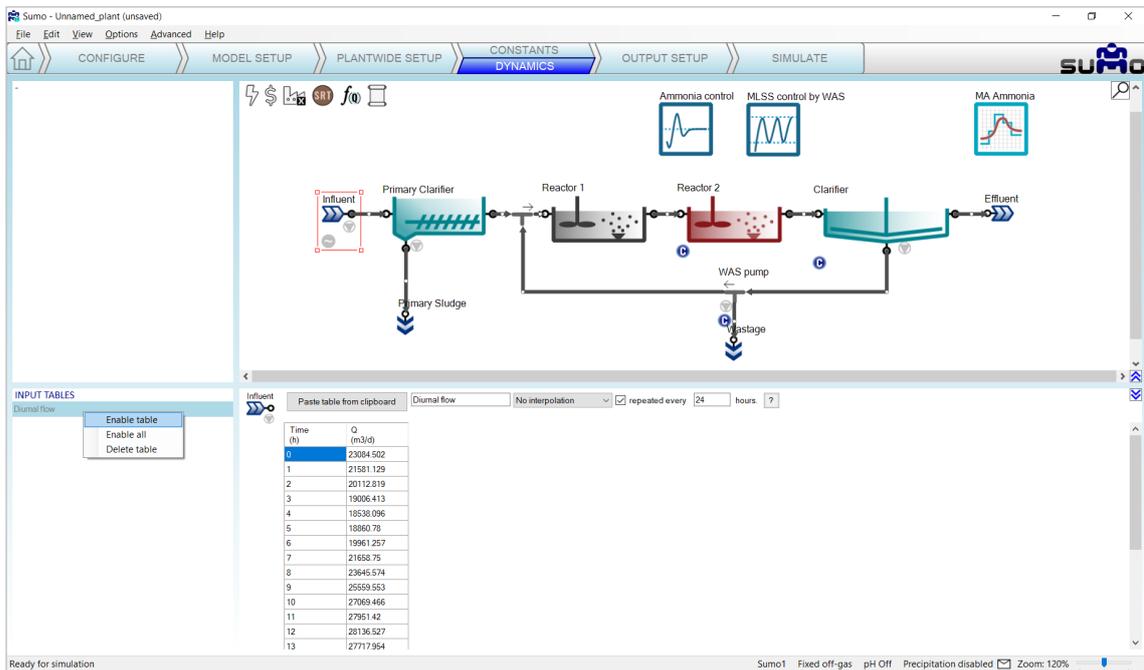
Figure 61 – Enable diurnal flow dynamic input for the influent

Finally go to the *Simulate* tab, set the *Stop time* to 1 day and the *Data interval* to 1 minute (to see finer details of the operation of the controller) and run the simulation. During the calculation, you can follow the change of the effluent ammonium along with nitrate and nitrite on the previously extended chart (Figure 62).
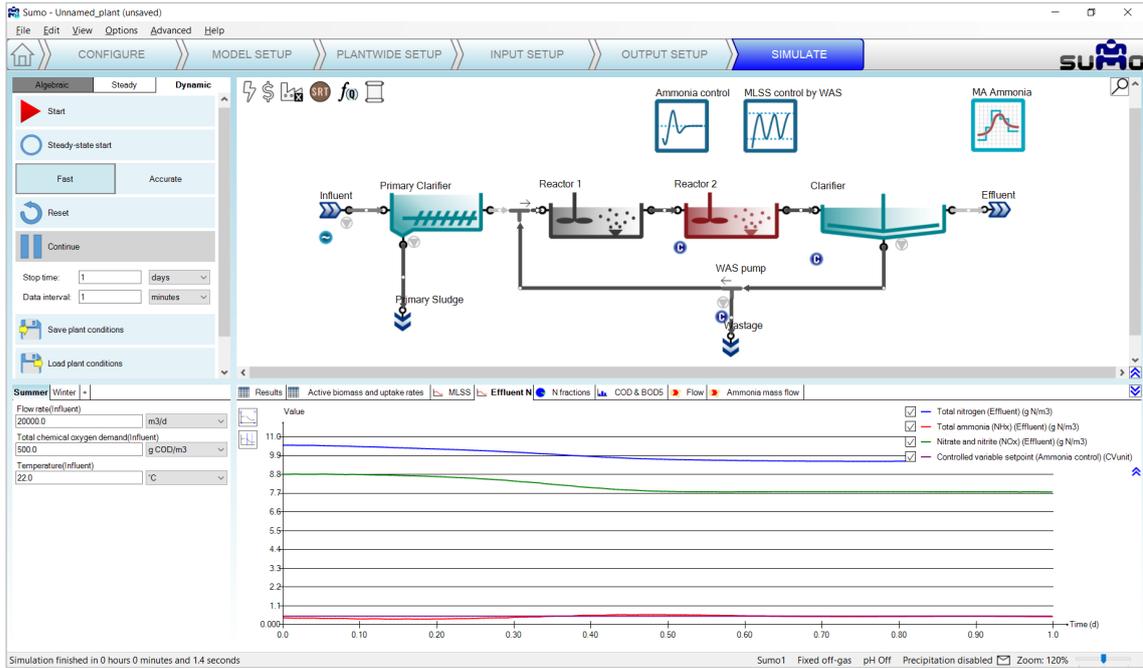
Figure 62 - Simulation results with DO setpoint based on effluent ammonium continuous P control

To modify the setpoint of the controller go to the *Input setup* tab, select the *Ammonia control* controller and modify the setpoint to 1.0 g/m³ (effluent ammonia concentration). On the *Simulate* tab increase the *Stop time* for 2 days and continue the simulation (Figure 63).

Note: Keep in mind that the effluent fluctuation is caused by the influent diurnal flow and the MLSS deadband controller, which are independent of the continuous P controller.
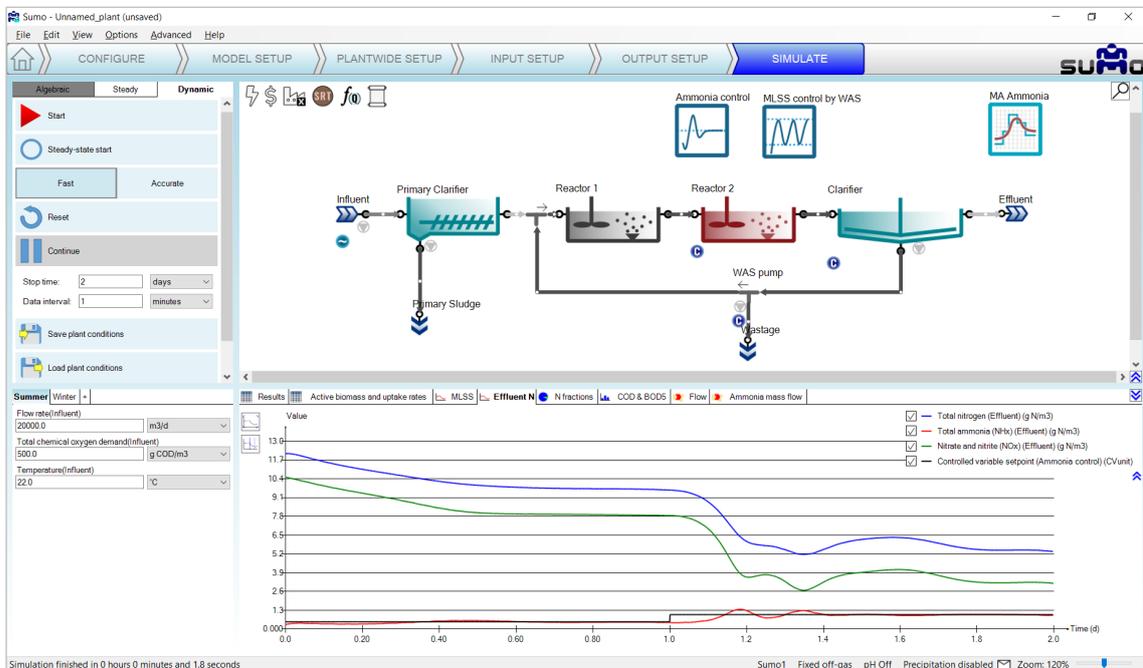
Figure 63 - Effect of Controller setpoint modification

The *Total nitrogen* and the *Nitrate and nitrite* (NOₓ) curves can be unchecked in the graph legend, thus the smooth changes in the effluent caused by the controller DO setpoint modification can be seen in detail. (Figure 64)
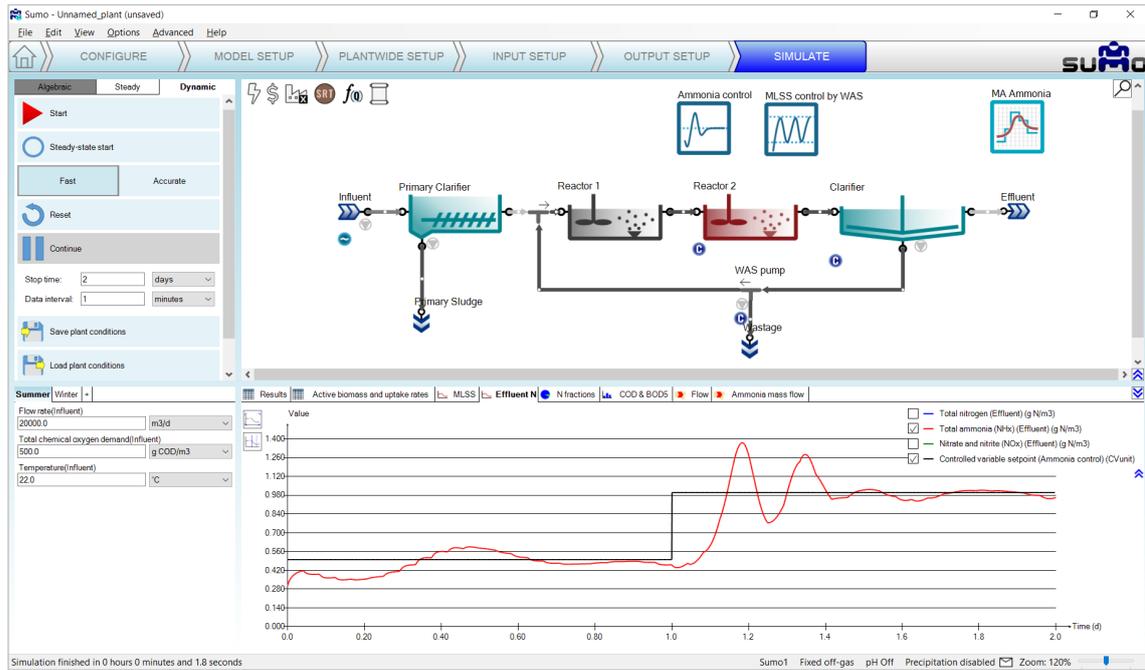
Figure 64 - Simulation results with DO setpoint Continuous P controller based on effluent ammonium (without NO$_x$)

5.2   Deadband controller

In Chapter 4.4.5 (page 22) we added a Deadband controller to manage the MLSS in the reactors.

5.3   PID controller

The PID controller is using a discrete time step to set the input parameter (manipulated variable) of the desired unit to meet the controlled variable setpoint.

To demonstrate the capabilities of this controller, let us set Reactor 2 to use the *Calculated* option for Dissolved oxygen (*Configure* tab). Then add the controller and configure in *Plantwide setup* as follows. First drag and drop the manipulated unit (Reactor 2) to the left side of the equation in the bottom right screen panel and the control unit (also Reactor 2) to the right side of the of the equation. In the bottom left screen panel, you can now select the control variable and the manipulated variable of the selected unit. In this example, we are going to control the requested air flow rate to maintain the desired dissolved oxygen concentration. Rename the controller unit (using F2 or right click) to "DO control by Air flow" – this will rename the tab as well (see Figure 65).
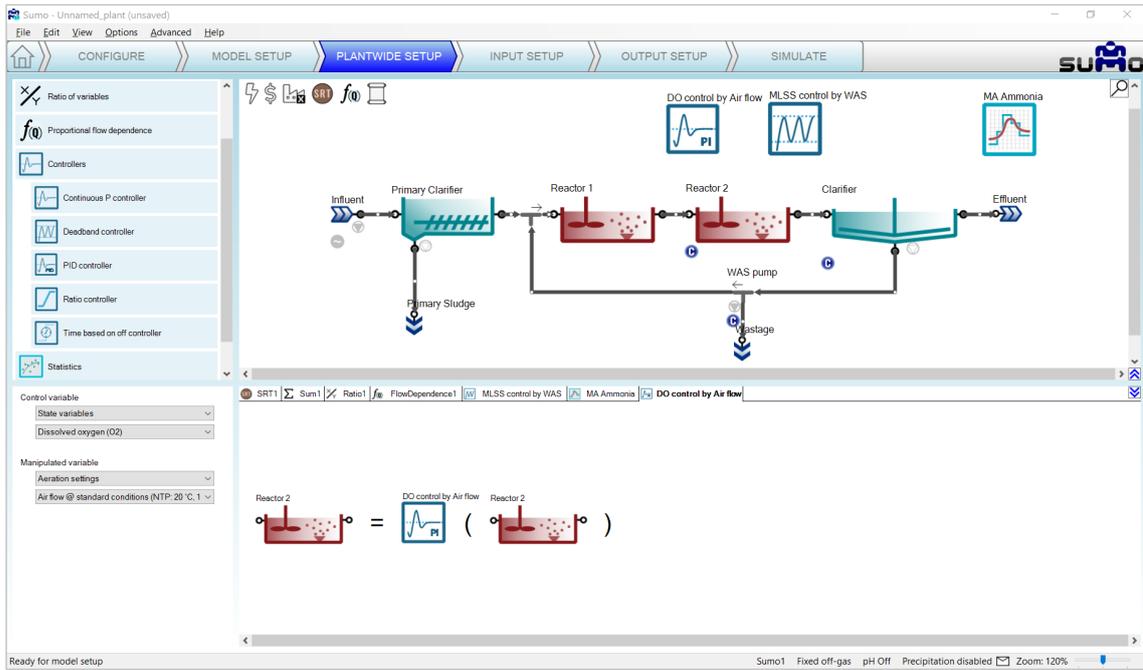
Figure 65 – PID controller configuration

On the *Input setup* tab, select the newly added *DO control by Air flow* controller. In the *Controller parameter* menu set the following:

- the *Controlled variable setpoint* to 2.0 g O_2/m^3 (maintained DO concentration),
- the *Initial value of manipulated variable* to 75000 Nm^3/d (Input air flow of Reactor 2),
- the *Minimum of manipulated variable* to 30000 Nm^3/d, and
- the *Maximum of manipulated variable* to 200000 Nm^3/d.

Within the *Gains* menu set the *Proportional gain* to 50000, the *Integral gain* to 1000 and the *Derivative gain* to 125 (Figure 66).

Figure 66 - Setup PID controller parameters

Note: The proper tuning of the controller needs attention. In every situation, the best gains for the controller depend on the combination of the controlled and manipulated variable. In this case, the controlled variable is set to 2, while the manipulated variable can change between 30,000 and 200,000. Properly operated controllers react quickly to the change of the controlled variable, depending on the inertia of the system. As a rule of thumb, the gain is related to the MV/CV ratio. The proportional gain in this specific case should turn the error derived from small numbers (DO) into large air flow ranges. As it was seen at the Continuous P controller, if both the controlled and the manipulated variables are in the same range, the most suitable proportional gain will be a small number.

Note: Controllers use units for the controlled and manipulated variable from the internal code of the system (called "in code unit"). To make sure that the controller is set up properly, change the *Unit system*s in the *Options* menu

to "in code", so that on the *Input setup* tab the respective units for the controlled and the manipulated variables can be verified.

To follow the changes in the aeration of Reactor 2, add a timechart in the *Output setup* tab and rename it to "Air flow and DO". Select Reactor 2 and drop *Dissolved oxygen* and *Input air flow* from *Operational* menu (Figure 67). Then select the *DO control by Air flow* controller and add the *Controlled variable setpoint* from the *Controller parameters* menu under the *Parameters* group (Figure 68).
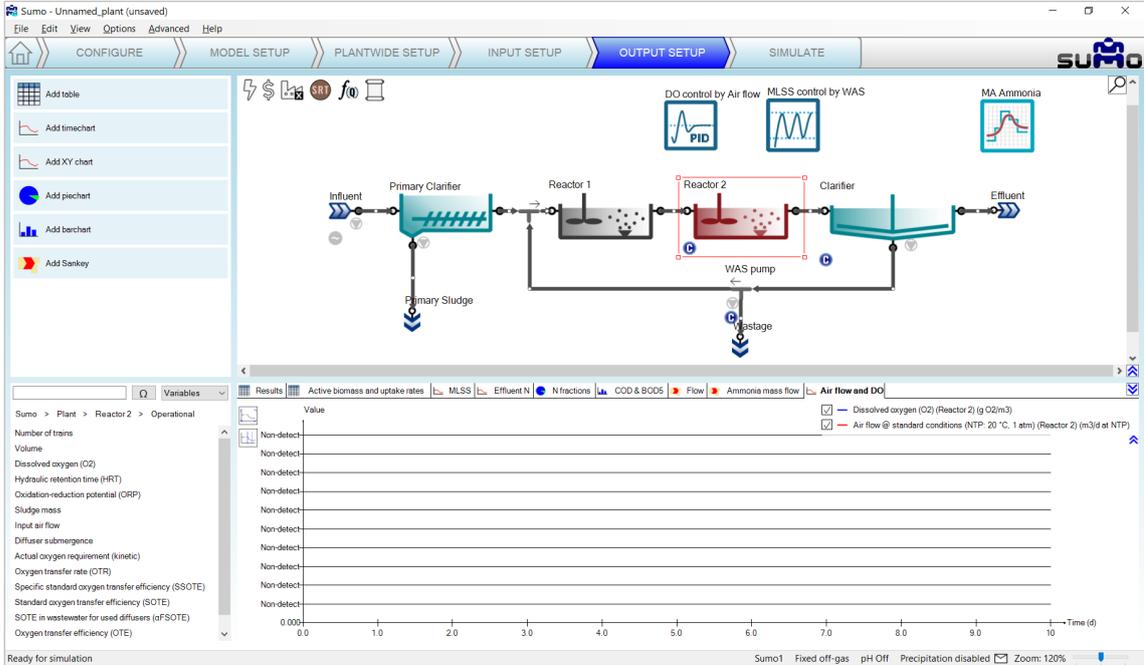
Figure 67 – Timechart setup for Input air flow and Dissolved oxygen
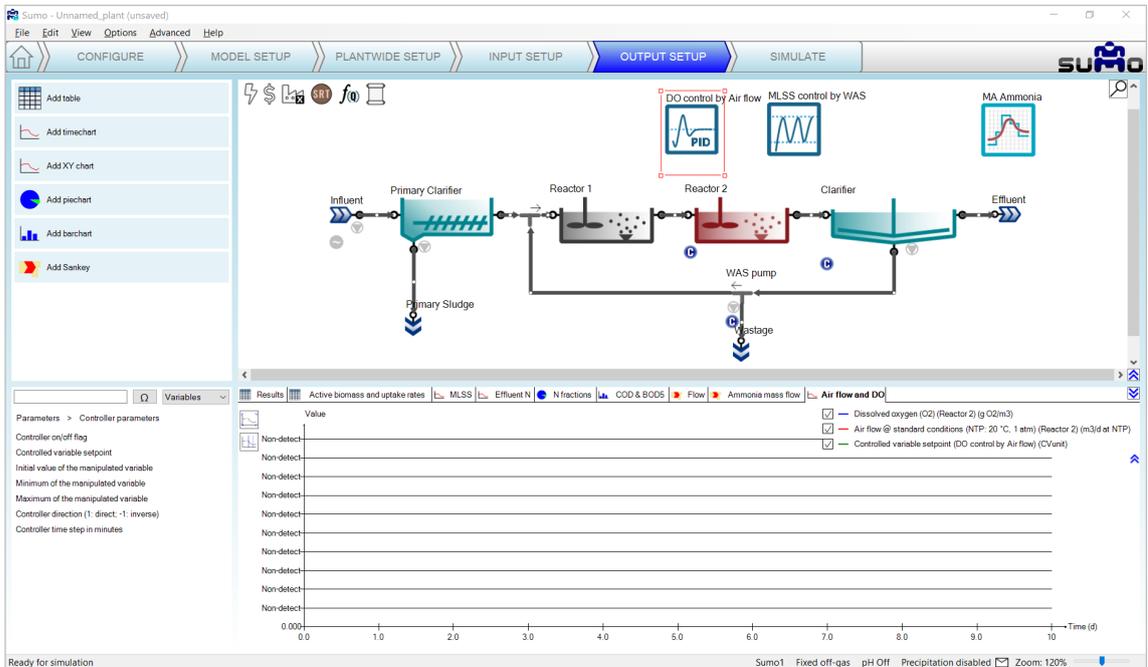
Figure 68 – Timechart setup for Controlled variable setpoint

Switch on the diurnal flow dynamic input table for the influent on the *Input setup/Dynamics* tab, then go to the *Simulate* tab and set the stop time to 2 day, then run a dynamic simulation. During the calculation, you can follow

the change of the air flow on the *Air flow and DO* timechart (Figure 69). Unchecking the *Air flow* item on the timechart, only the dissolved oxygen setpoint and the predicted DO will be shown (Figure 70). Using these gain settings, the controller can keep a strict fit to the setpoint without oscillation or overshoot (this be verified by hovering the mouse on the graph and checking the values on the popup that appears on the timechart).
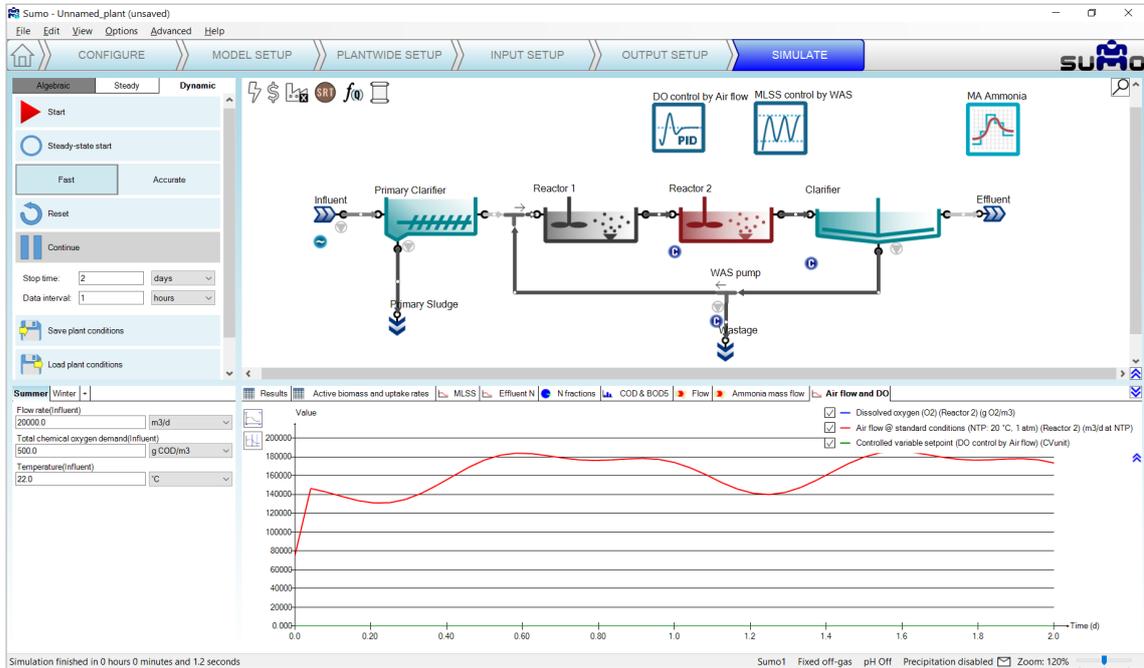
Figure 69 - Change of Input air flow PID controller set for DO control

Note: It is good to keep in mind that this plant is subjected to dynamic influent load and a *Deadband MLSS* controller, thus the system never reaches steady state conditions.
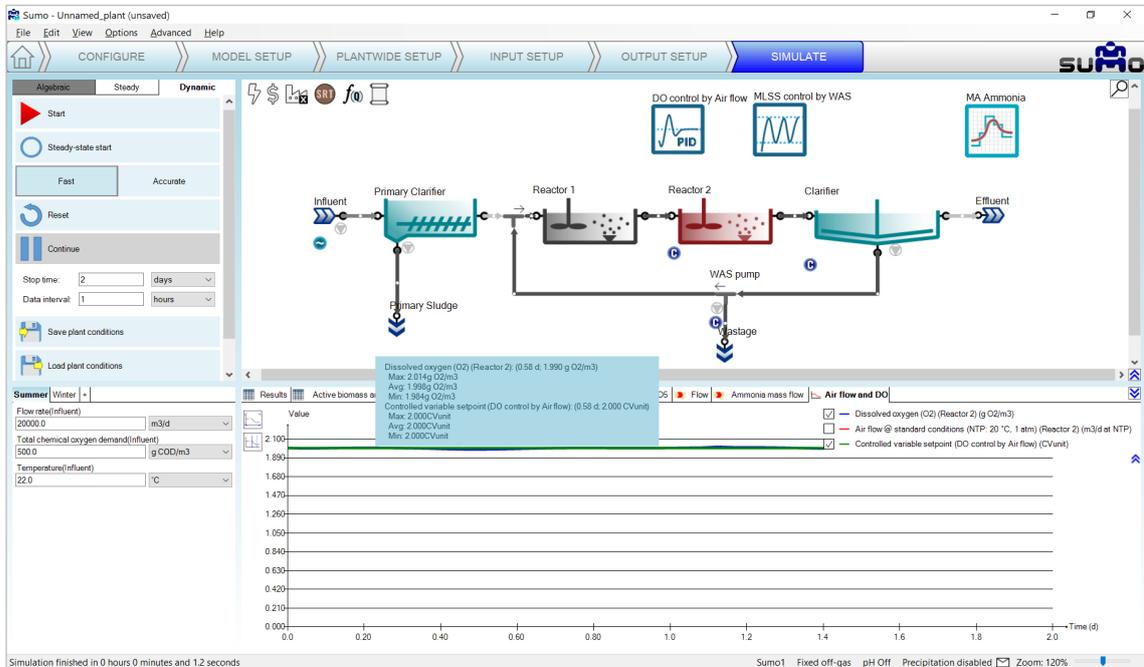
Figure 70 - Simulation results with Input air flow PID controller set for DO control

5.4   Ratio controller

The Ratio controller is using a ratio as multiplier for the manipulated variable, thus keeping the ratio of the manipulated and the control variable constant during the operation of the facility. To test this function, add a *Carbon dosage* unit (choose the mass flow based & methanol options) using a flow combiner before Reactor 1 of the previously used example layout, as shown by Figure 71 (renaming the new unit to "Methanol dosage").
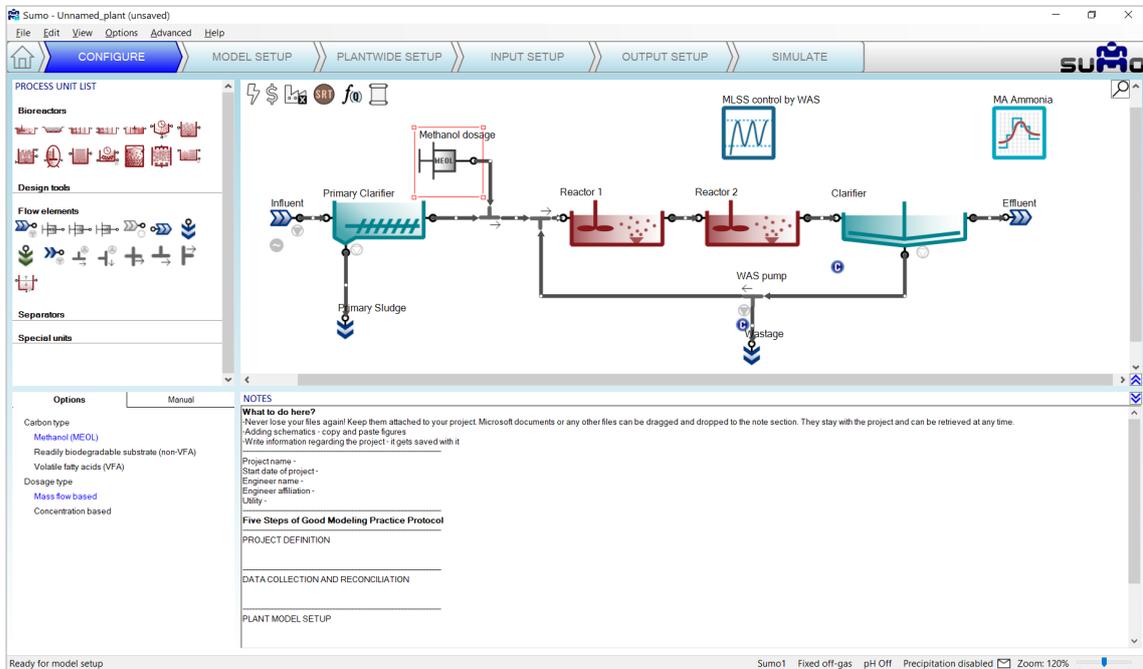
Figure 71 – Adding Carbon dosage to the layout

Now add the controller on the *Plantwide setup* as follows: first drag and drop the manipulated unit to the left side of the equation on the bottom right screen panel and the control unit to the right side of the of the equation. On the bottom left screen panel, you can now select the control variable and the manipulated variable of the selected units. In this example, we will manipulate the methanol dosage unit flow rate, depending on the ratio to the influent flow rate. Rename the controller (using F2 or right click) to "Methanol dosage control" (Figure 72).
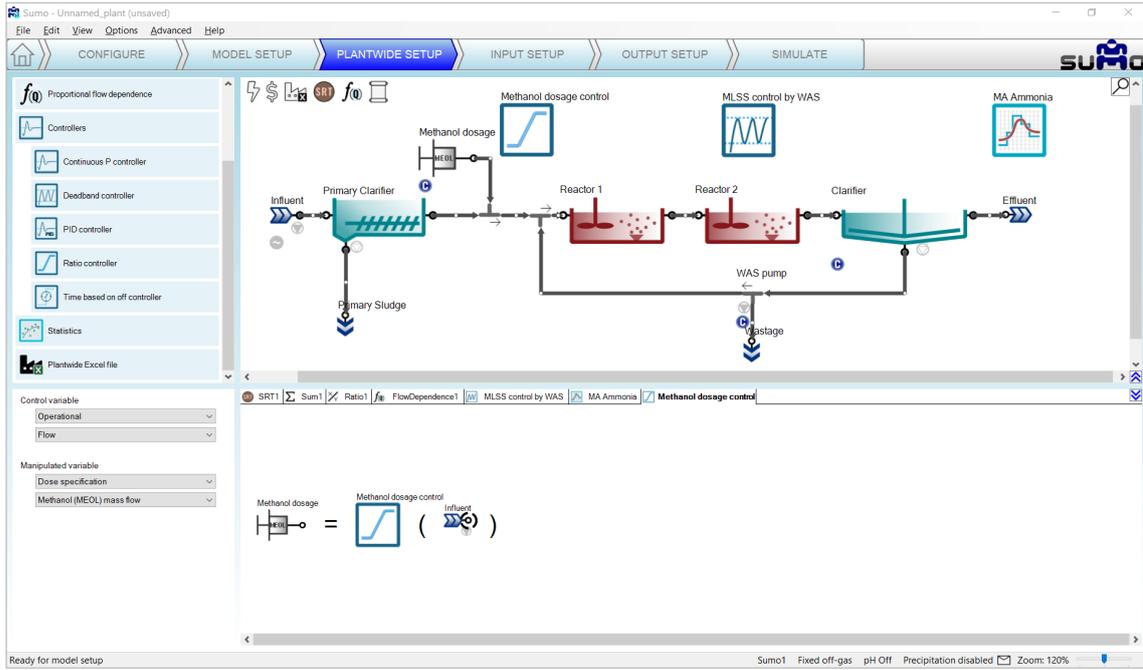
Figure 72 – Adding Ratio controller for Methanol dosage control

To properly set the controller parameters, the Unit system selection should be turned to "in code" in the *Options* menu > *Unit systems*. On the *Input setup* tab select the *Methanol dosage* and check the Unit of the mass flow – it is g COD/d (Figure 73). Select the new *Methanol dosage controller*. In the *Ratio controller parameters* table set the *Ratio* to 50, thus every influent m³ wastewater triggers 50 g of COD equivalent methanol dosage. Set the *Minimum value of manipulated variable* to 0, the *Maximum value* to 2.844E07 (equals the capacity of a dosage pump of 1 m³/h) and the *Initial value* to 1000000 (Figure 73). Turn on the dynamic input table for the Influent and leave other settings as they were set previously (Figure 73).

Figure 73 - Setup Ratio controller parameters with Unit check

To follow the change of the Methanol dosage before Reactor 1, add a timechart on the *Output setup* tab and name it as "Methanol dosage". Select the *Methanol dosage* process unit and drop *Flow rate* from the *Operational parameters* group (Figure 74).
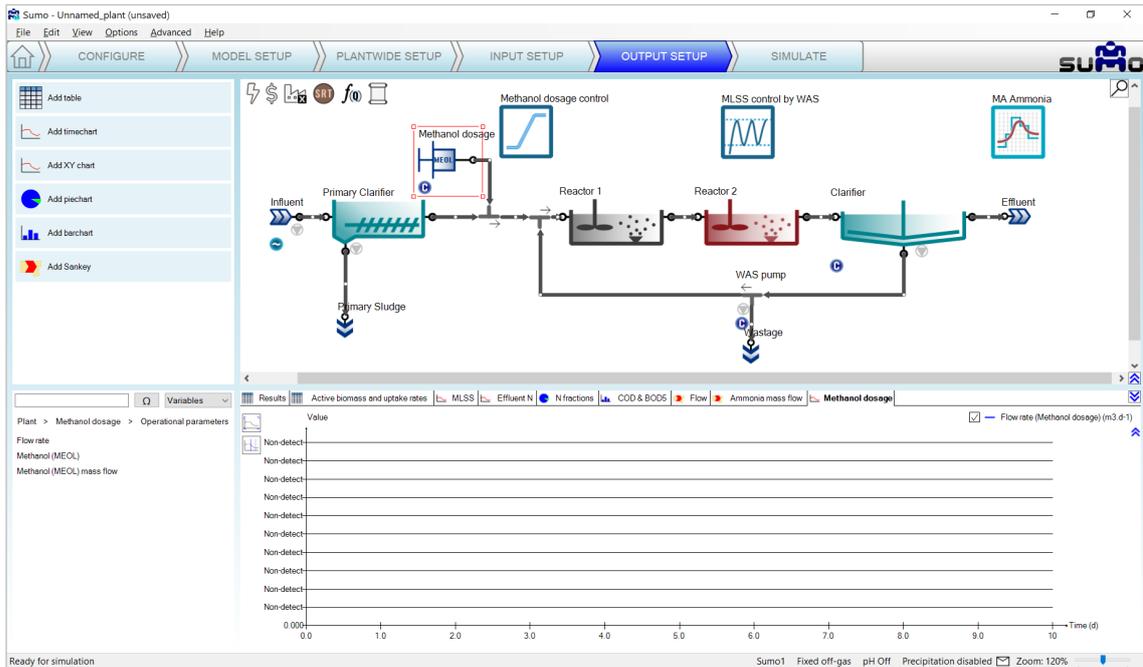
Figure 74 – Timechart setup for Methanol dosage flow rate

Go to the *Simulate* tab, set the stop time to 1 day with a data interval of 10 min and run a dynamic simulation. You can follow on the *Methanol dosage* timechart how the methanol dosage flow rate changes during the calculation, responding to the diurnal flow (Figure 75).
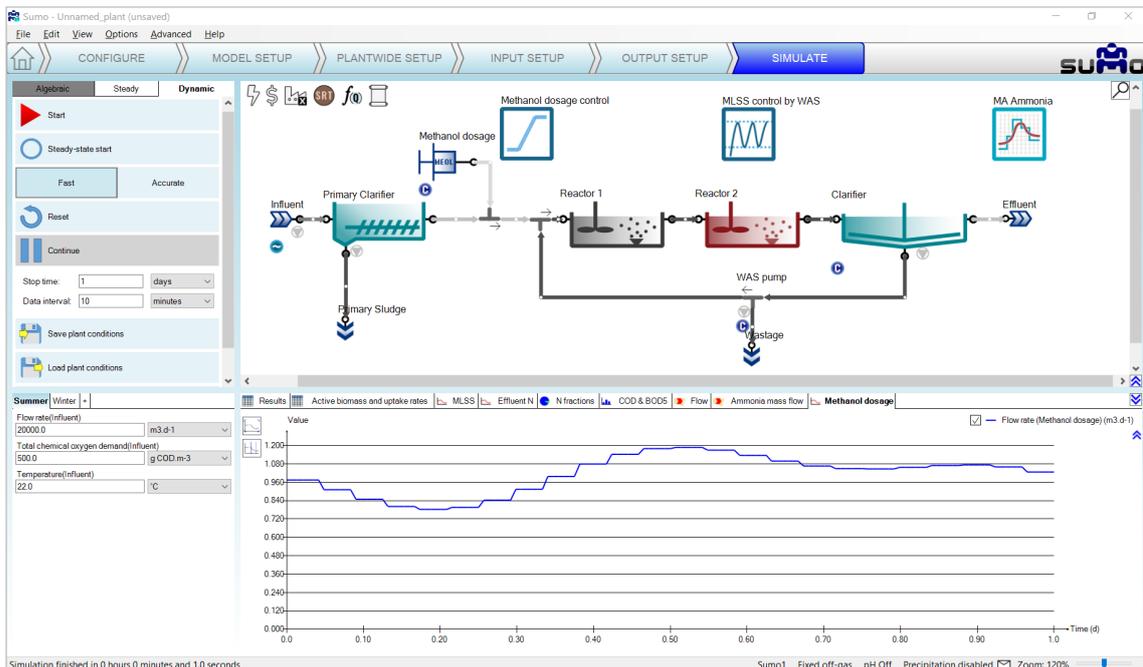
Figure 75 - Change of Methanol dosage set by Ratio controller based on Influent flow rate

Go to the *Input setup* and set the *Controller on-off flag* to 0 for the *Methanol dosage control* unit (Figure 76).

Figure 76 - Turn off Methanol dosage control

Go to the *Simulate* tab, set the stop time 2 days and hit *Continue*. The flow rate of the methanol dosage pump will drop to 0 m³/d, which corresponds to the value given at the *Input setup/Constants* tab as 0 g COD/d dosage rate (Figure 77). Note that the GUI turns the controller color to grey in order to inform the user that it is turned off.
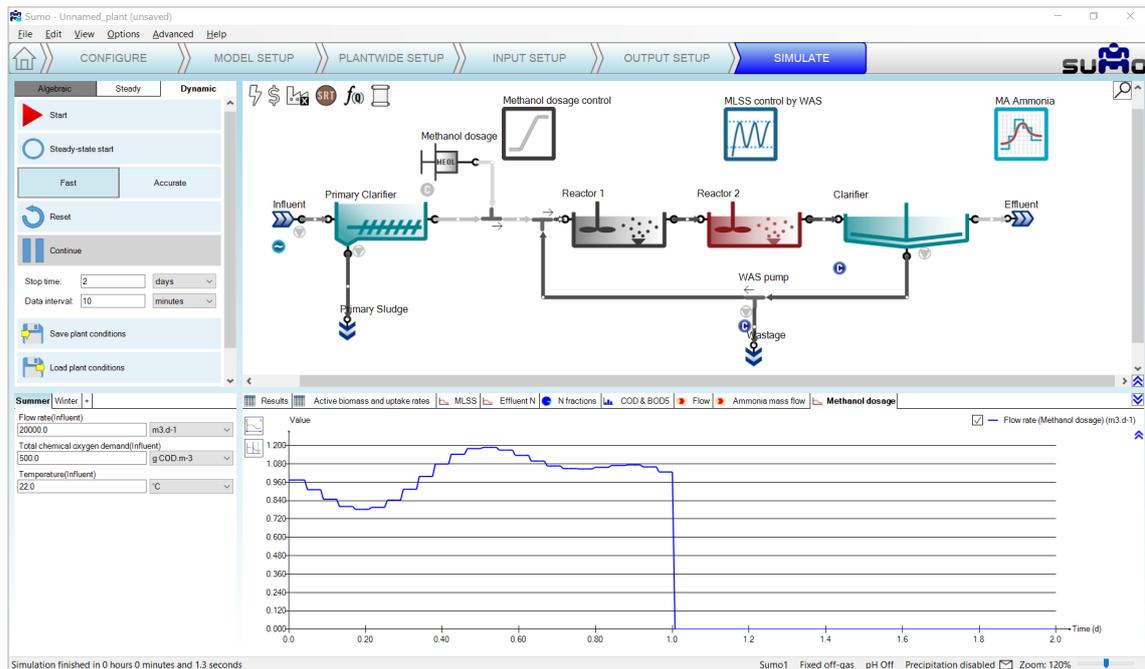
Figure 77 - Methanol dosage control shut down

5.5   Time based on-off controller

The Time based on-off controller is a controller that sets the input parameter (manipulated variable) of the desired process unit based on a time step between a defined high and low value. This controller has no measured variable input (no control variable).

To demonstrate the capabilities of this controller, let us set Reactor 2 to use the *Calculated* option for Dissolved oxygen (*Configure* tab). Then add the controller and configure in *Plantwide setup* as follows. First drag and drop the manipulated process unit (Reactor 2) to the left side of the equation in the bottom right screen panel. On the bottom left screen panel, you can now select the manipulated parameter of the selected unit. In this example, we will generate intermittent aeration in the chosen reactor by changing the air flow. Rename the controller (using F2 or right click) to "Intermittent aeration" (Figure 78). This will rename the tab as well.
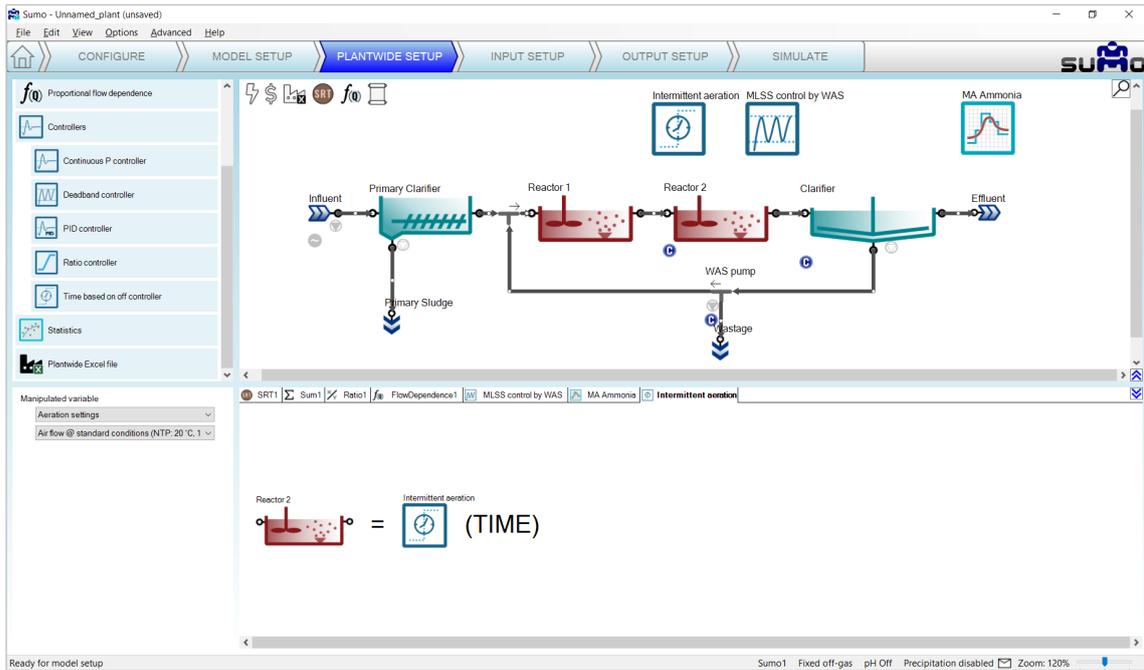
Figure 78 – Adding a Time based on-off controller

On the *Input setup* tab, select the new *Intermittent aeration* controller and review the *Time based on-off controller parameters* table. Set the *Cycle length* to 1 h, the *Duration while the manipulated variable is set to high* parameter to 0.5 h (aeration will be turned on for 30 min) and the *High value of the manipulated variable parameter* to 250000 m³/d, leaving the other parameters at default (Figure 79).


Figure 79 - Setup Time based on-off controller parameters

Before moving on, also make sure that the diurnal flow dynamic input table is turned on for the influent.

To follow the changes in the aeration of Reactor 2, add a timechart in the *Output setup* tab and rename it to "Air flow and DO". Select Reactor 2 and drop *Dissolved oxygen* and *Input air flow* from *Operational* menu (same method as described in Chapter 5.3, see Figure 67).

Now go to the *Simulate* tab, set the stop time to 1 day with 1 minute data interval and run a dynamic simulation from steady state. During the calculation, you can follow the periodic changes in the air flow on the timechart (Figure 80).
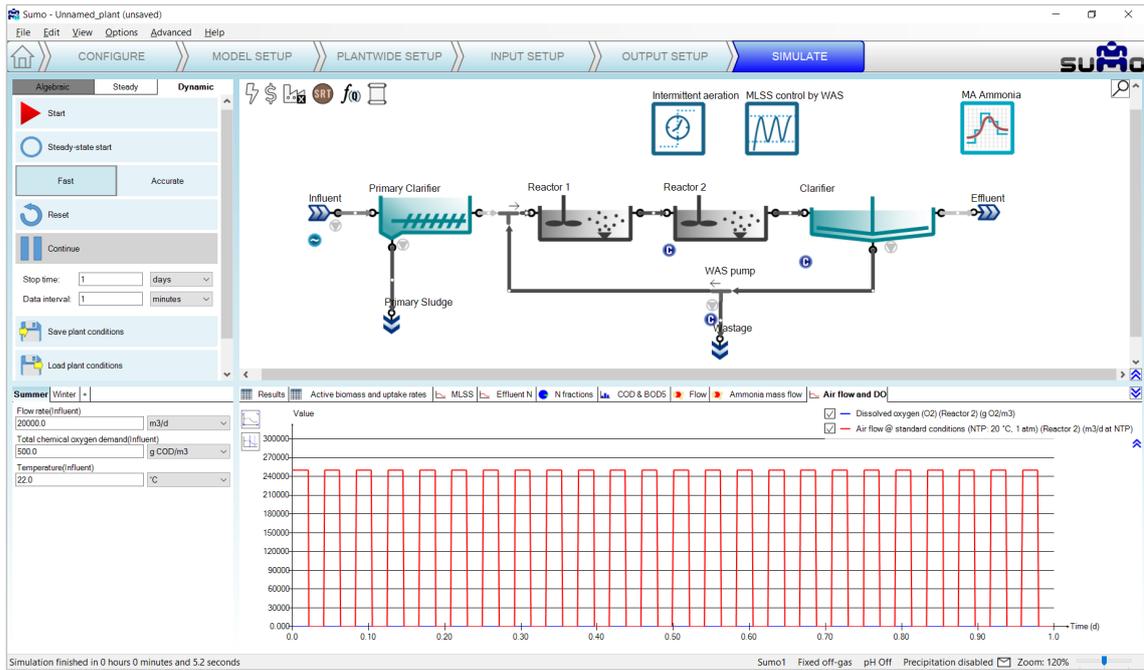
Figure 80 - Change of Input air flow set by Time based on-off controller

Unchecking the curve for the *Air flow*, the resulting periodic changes in the dissolved oxygen can be seen in details. (Figure 81). The effect of the diurnal flow pattern can also be observed.
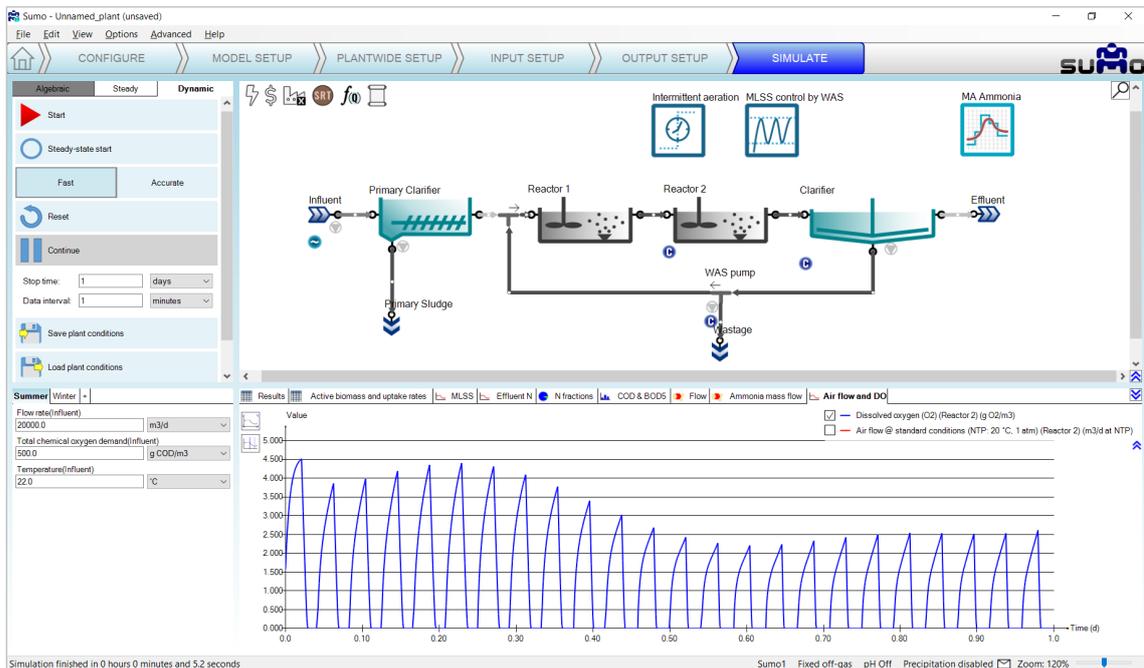
Figure 81 - Changes in DO resulting from the Time based on-off controller and the diurnal flow pattern

5.6   Cascade controller

Cascade controllers can as well be set up in Sumo21, using the methods described above. To set up a cascade controller example, a PID and a Time-based on-off controller will be used. Based on the time-based controller example it can be easily shown how the DO calculation effects the process in the reactors. To see the effect of calculated DO, the example prepared with the PID controller in chapter 5.3 (page 54) will be continued. In that example, the DO is calculated in Reactor 2.
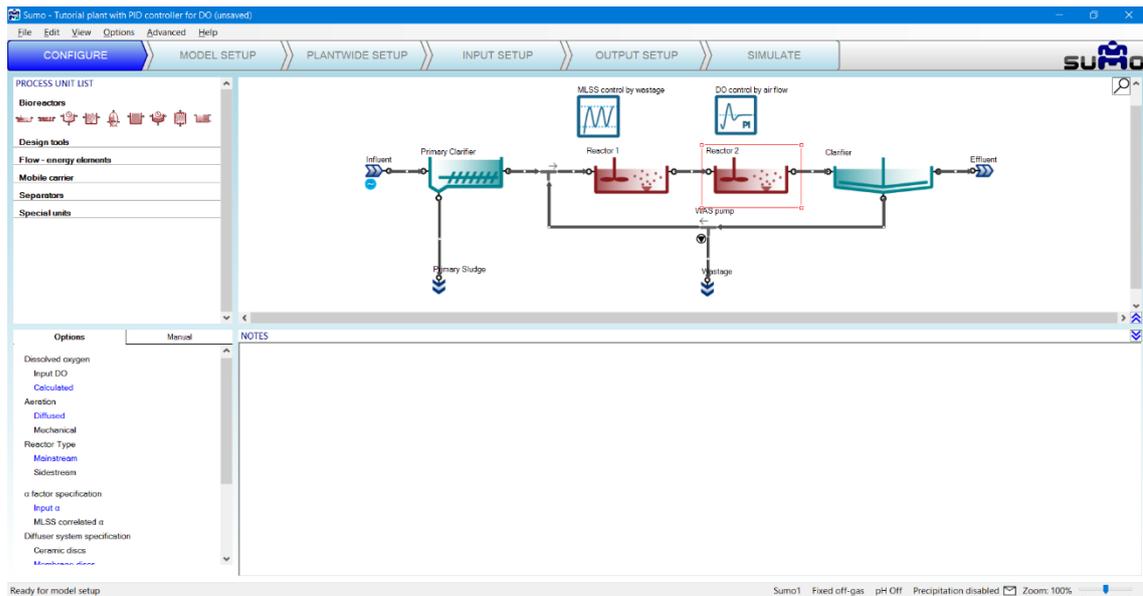
Figure 82 - Reactor 2 with Calculated DO and PID controller

Go to the *Plantwide setup* tab and add a Time based on-off controller. In this example, we will generate a high-low setpoint, time-based aeration, by changing the DO setpoint, which is controller setpoint of the PID controller. Rename the unit (using F2 or right click) – along with the tab – to "High-low setpoint aeration". (Figure 83)
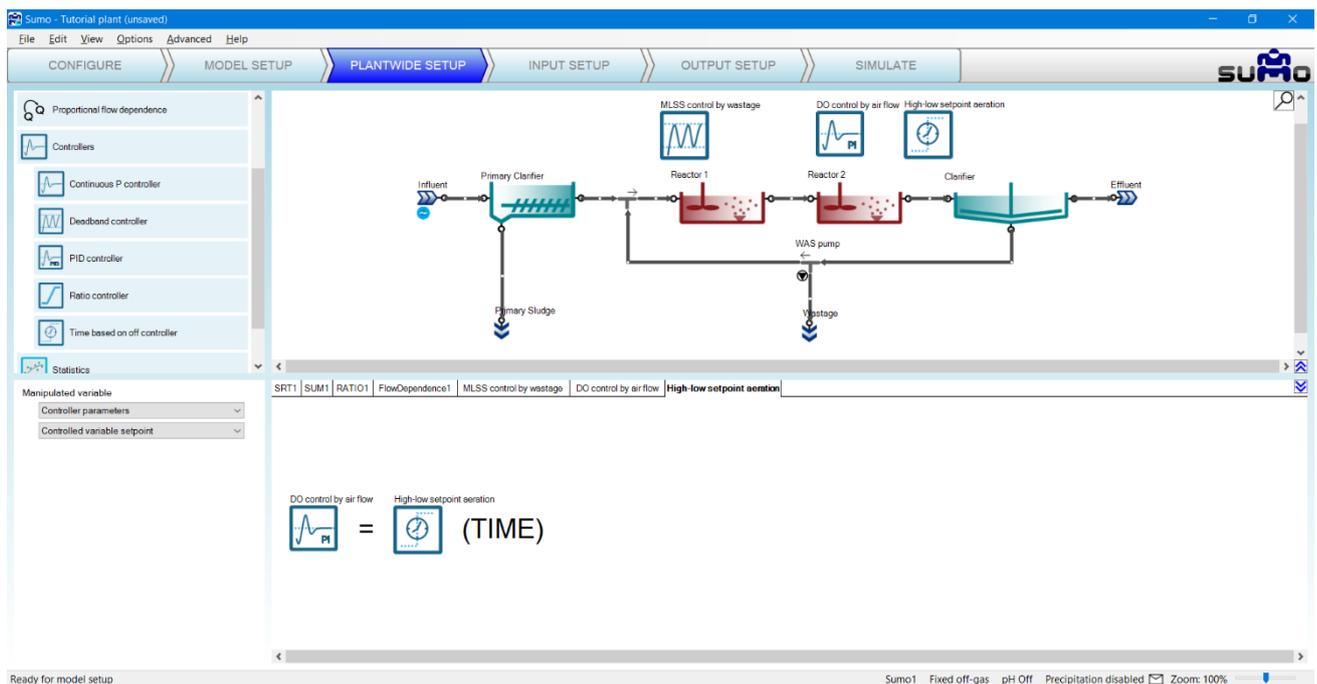
Figure 83 - Time based on-off controller setup

On the *Input setup* tab, select the new *High-low setpoint aeration controller* and in the *Time based on-off controller parameters* menu set the following:

- the *Cycle length* to 2 h,
- the *Duration while the manipulated variable is set to high* to 1 h (higher setpoint for 1 h),
- *Low value of the manipulated variable* to 50% (or 0.5 without unit, depending on the *Unit system* settings), this equals 0.5 g O_2/m^3 as dissolved oxygen setpoint, and leave the other parameters as default.

Now select the *DO control by Airflow* controller and in the Controller parameters menu, set the *Controller time step* to 1 min (see Figure 84).

INPUT PARAMETERS	High-low setpoint aeration	Name	Default	Value	Unit	Scenario	Comment
Time based on-off controller parameters		Controller on/off flag	1.0	1.0		☐	
		Cycle length	2.0	2.0	h	☐	
		Duration while the manipulated variable (MV) is set to high	1.0	1.0	h	☐	
		Start offset	0.0	0.0	h	☐	
		High value of the manipulated variable	200.0	200.0	%	☐	
		Low value of the manipulated variable	0.0	50.0	%	☐	

INPUT PARAMETERS	DO contor by Air flow	Name	Default	Value	Unit	Scenario	Comment
Controller parameters		Controller on/off flag	1.0	1.0		☐	1 - controller is on. 0 - controller is off
Gains		Controlled variable setpoint	1.5	2.0	g O2/m3	☐	
		Initial value of the manipulated variable	1.0	75000.0	m3/d at NTP	☐	
		Minimum of the manipulated variable	0.0	30000.0	m3/d at NTP	☐	
		Maximum of the manipulated variable	1.00E10	200000.0	m3/d at NTP	☐	
		Controller direction (1: direct; -1: inverse)	1.0	1.0		☐	E.g. DO-Qair is direct, MLSS-Qwas is inverse
		Controller time step in minutes	10.0	1.0	min	☐	

Figure 84 - Cascade controller setup for intermittent aeration

Go to the *Simulate* tab, set the stop time to 1 d and the data interval to 1 minute and start simulation. Select the "Air flow and DO" timechart. The change of DO follows the aeration change controlled by the PID controller (Figure 85). Compare the new results with the results of the previous exercise on Figure 81.
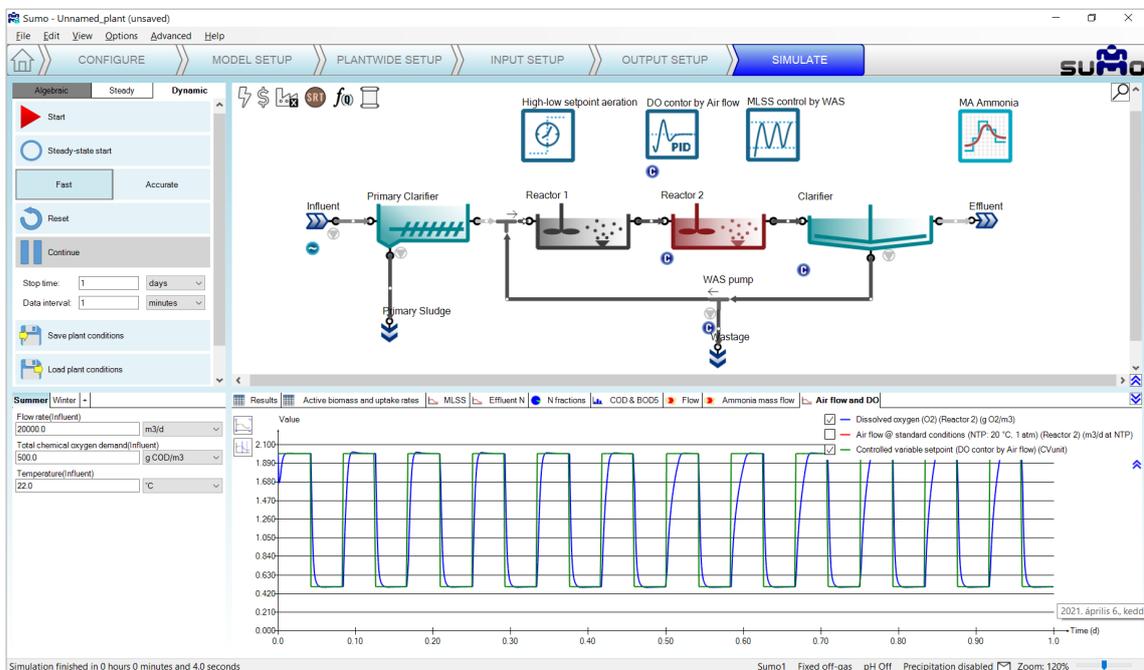
Figure 85 - The change of DO at Reactor 2 with PID aeration control of intermittent aeration.

The change of Input air flow (Figure 86) shows a really different profile compared with the previous exercise (Figure 80).
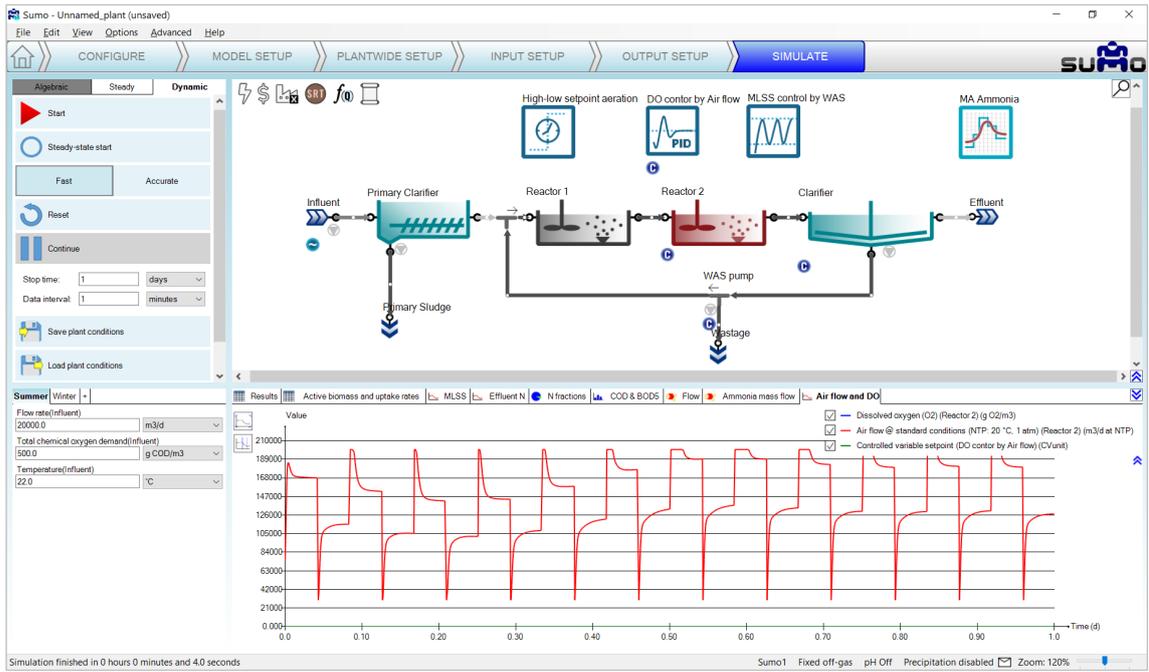
Figure 86 - Input air flow dynamics of Reactor 2 with PID aeration control of intermittent aeration

6   Energy and cost calculations

Sumo features additional layers of energy and cost calculations, based on the process model. The energy mode can be used to assess the electricity demand of aeration, mixing, pumping and other equipment operation, as well as the available potential to produce electricity from biogas produced in digesters (enabling self-sufficiency survey and scenario analysis for energy savings). The cost layer can be useful for evaluating and improving plant operation from an economic standpoint, by comparing the various cost items associated with the components of the energy balance and the usage of chemicals. In this chapter, an overview of the possibilities will be presented, based on the example project built in Chapter 4 (page 9).

The status of the energy and cost layers is indicated by the first two icons in the top left corner of the plant layout screen panel (Figure 87). By default, the energy mode is inactive and cost calculations are limited to basic inputs. While the energy mode is inactive, the cost center can be supplied with input data by selecting the **$** icon in the *Input setup* tab. At this level, simple specific prices can be defined for electricity, water and polymer usage, as well as disposal fees and product sales (Figure 88).

Figure 87 - The 'Energy center' and 'Cost center' icons precede the 'Plantwide' icon
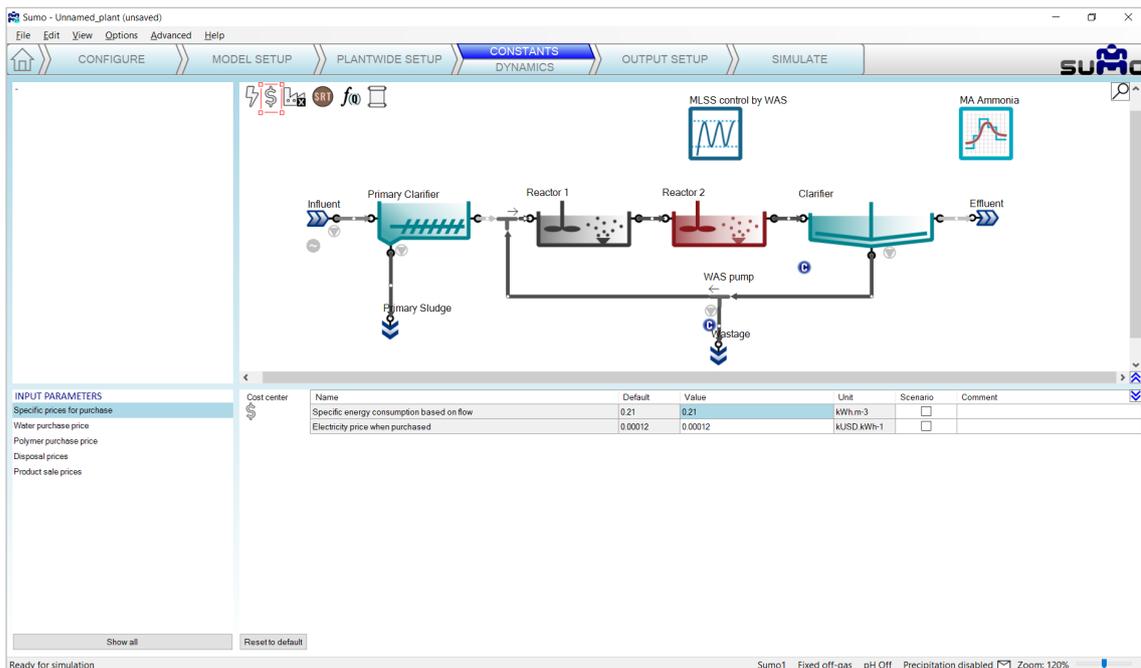
Figure 88 – Basic settings available for the 'Cost center' in the Input setup

In order to fully exploit the capabilities of cost calculation, the energy mode shall be activated. This can be done by double-clicking on the *Energy center* icon (which will turn to yellow) or right-clicking and selecting "Turn Energy On". Along with this, the *Cost center* icon will turn to black from hollow, and the specific price input options will also adapt to the energy mode (as well as the underlying cost calculations).

The *Energy center* plantwide input parameters are also available on the *Input setup* tab, by selecting the lightning bolt icon (Figure 89). Here you can specify general energy consumers that are grouped into periphery consumers

6 Energy and cost calculations

(ventilation, water supply and miscellaneous), other variable and fixed consumers, as well as PV and other on-site electricity producers.
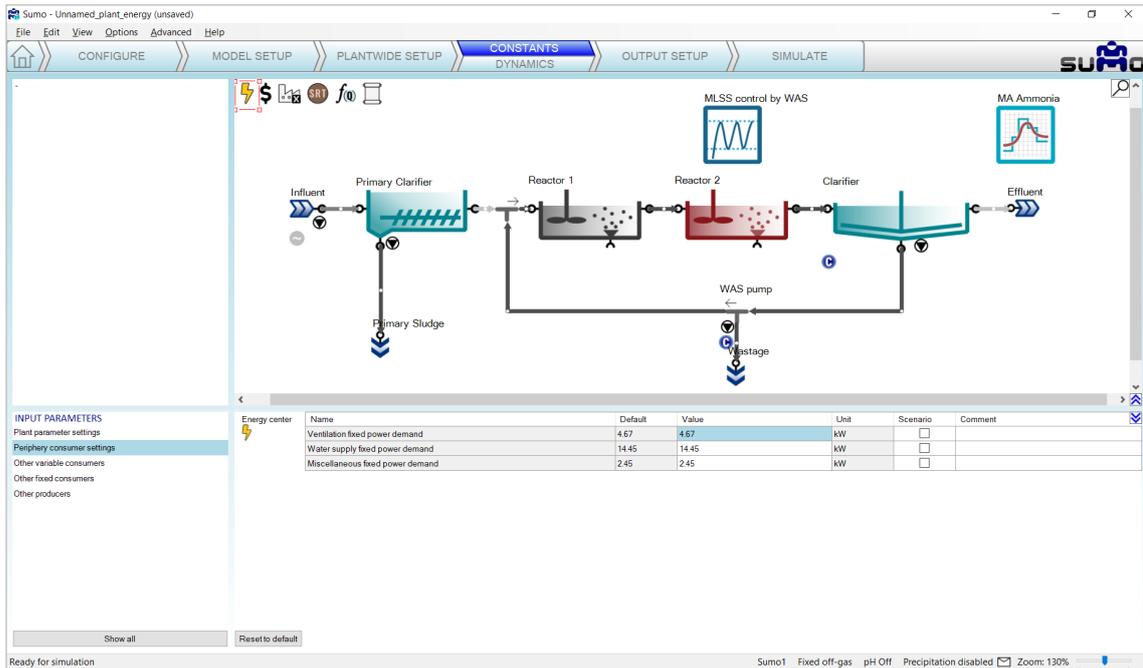
Figure 89 – Basic settings available for the 'Energy center' in the Input setup

Apart from the plantwide inputs, the *Energy center* has a lot more to offer. Moving over to the *Configure* tab, you will see that the process unit library got extended with three new categories: *Aeration units* (blower), *Connectors* (for gaseous phase flows – air and biogas) and *Production units* (biogas tank, CHP unit and flare). It is also on this page (in the bottom left screen panel), where you can specify whether the periphery power demands should be calculated based on PE load, flow or entered directly in kW; as well as indicate whether the plant has PV units or batteries installed as on-site electricity production and storage options. (Figure 90).
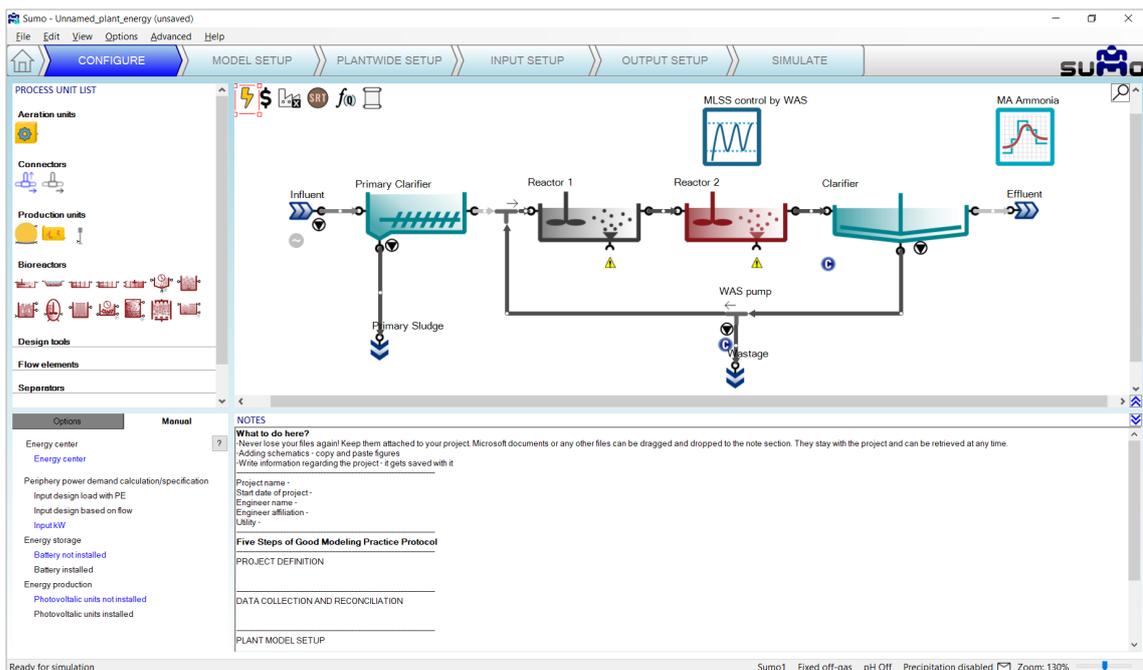
Figure 90 – Energy related process units and energy center specification on the Configure tab

While on the *Configure* tab, let us extend the plant layout by adding a blower unit to the second reactor, connecting it to the air input port that appeared at the bottom of the reactor (Figure 91). Technically, we could attach another blower unit to the first reactor as well (or use an air connector unit to split the air flow from one blower to the two tanks), however, since it is not aerated, the air flow demand would be zero, thus there is no need for a blower there.

In the process unit options, you can specify between simple empirical (default), positive displacement and turbo blowers. The latter two come with delicate calibration tools that are available from the *Input setup* tab (just like the Influent tool), which offer full customization capabilities, based on blower manufacturer data. These tools are described in more detail in the Technical Reference. For our example, we will stick with the empirical blower.
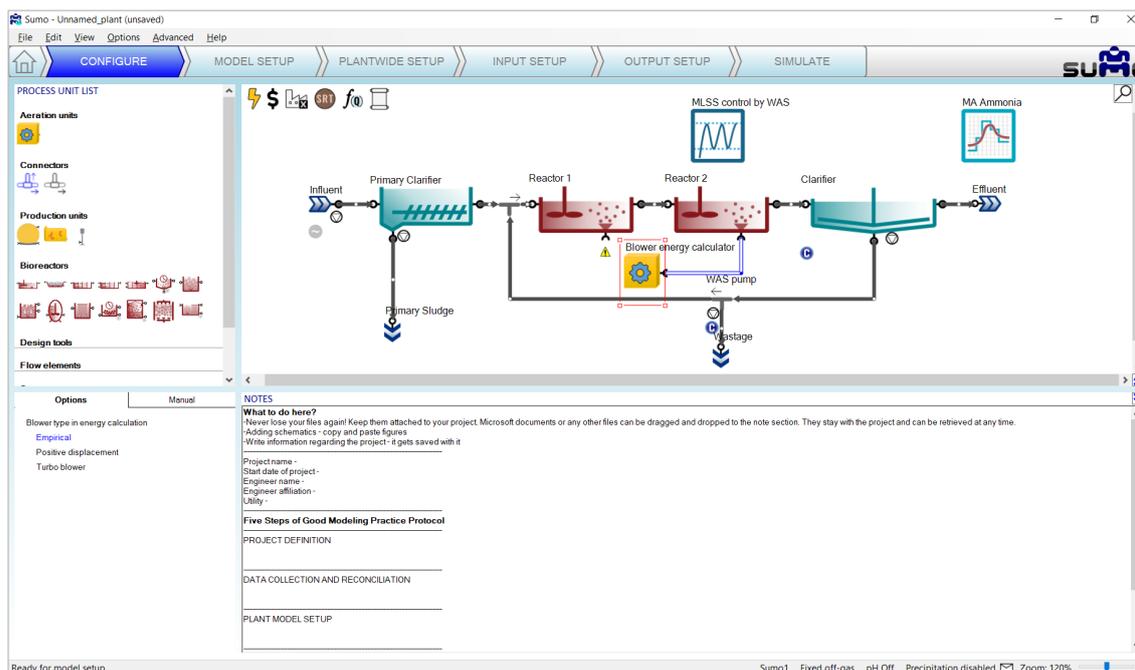
Figure 91 – Connecting a blower unit to a reactor

You may also have noticed that the appearance of the pump icons by the influent, the clarifier and the flow splitter process units has slightly changed. When the energy mode is active, you can specify different pumping options for these process units in the bottom left screen panel; including gravitational flow (no pumping), empirical pump model (default), as well as more detailed centrifugal, displacement and screw pump models (Figure 92). The latter ones feature elaborate tools that are available from the *Input setup* tab, offering detailed pump customization based on manufacturer data. To learn more about these tools, the reader is referred to the Technical Reference. For this simple example, we will keep all pumps with the simple empirical model. It is also possible to assign pumps to the individual pipes by selecting them and specifying the pump type (there will be no visual notation of these pumps on the drawing board, but they will be included in the energy and cost calculations).

Moving over to the *Input setup* tab, the plant model will start to be recompiled (which is necessary for adding the extended features of the energy mode). The appearance of the pump icons will change from 'not in operation' to 'in operation' and the pump settings (in our example the efficiency) can be specified in the input parameters of the respective process units, one by one (as demonstrated for the influent on Figure 93). When using one of the detailed pump models, an extensive set of parameters will be available, to be used in conjunction of the respective pump tool.
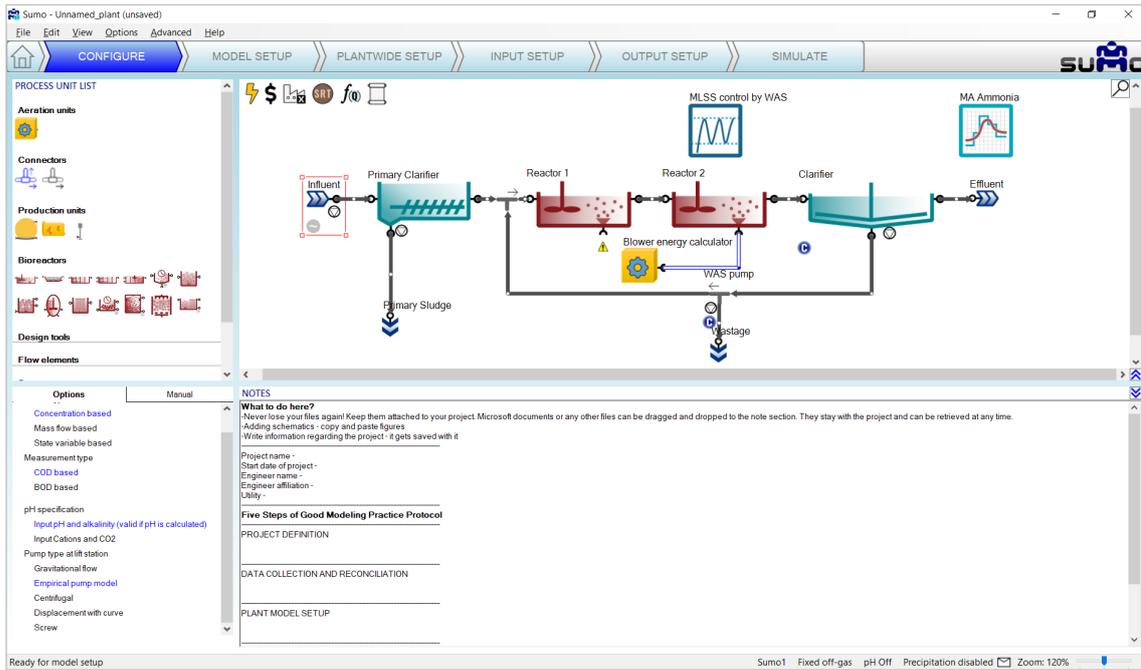
Figure 92 – Pump type specification for the influent in the process unit options
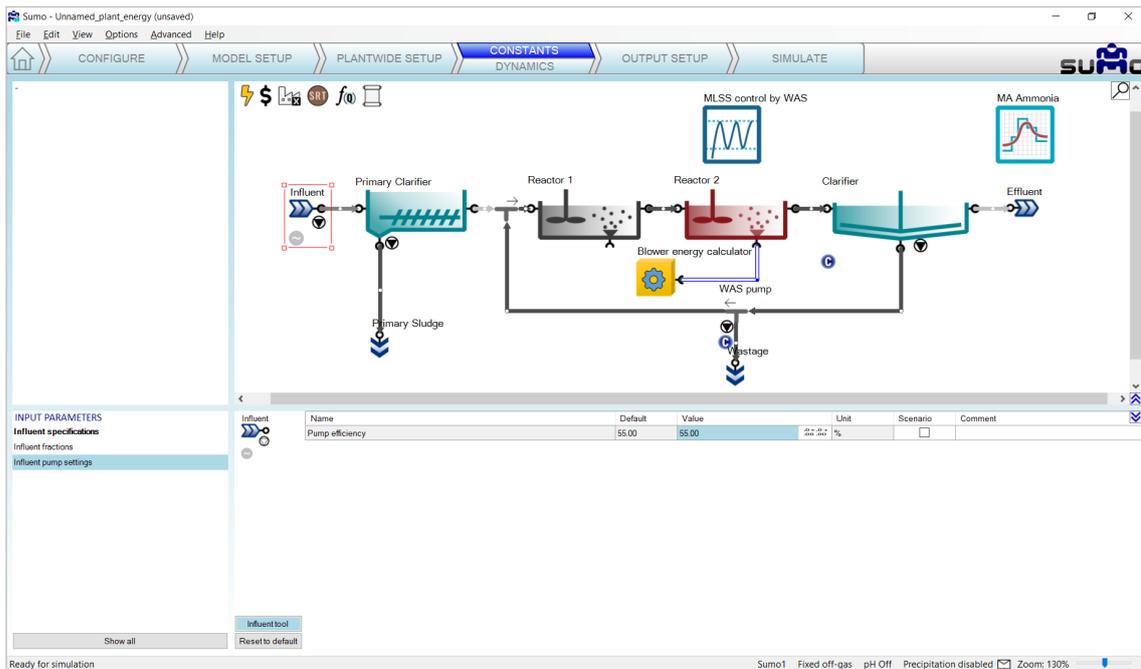
Figure 93 – Empirical pump settings for the influent in the Input setup

Similarly, the main input parameter for the blower in our example will be the efficiency, while selecting one of the more detailed blower models will require a range of additional parameters, whose proper calibration shall be performed using the respective blower tool.

Moving over to the *Output setup* tab, we can add various energy and cost related output information; such as a blower variables table by selecting the blower unit, adding a table and dragging over the variable group (Figure 94); an overview table of plant operation costs for the given simulation period by selecting the *Cost center* icon, adding a table and pulling the relevant variable group over on it (Figure 95); or piecharts showing the share of different energy consumer groups and categories in the plant by selecting the *Energy center* icon, adding piecharts and dragging over the respective variable groups to the charts.
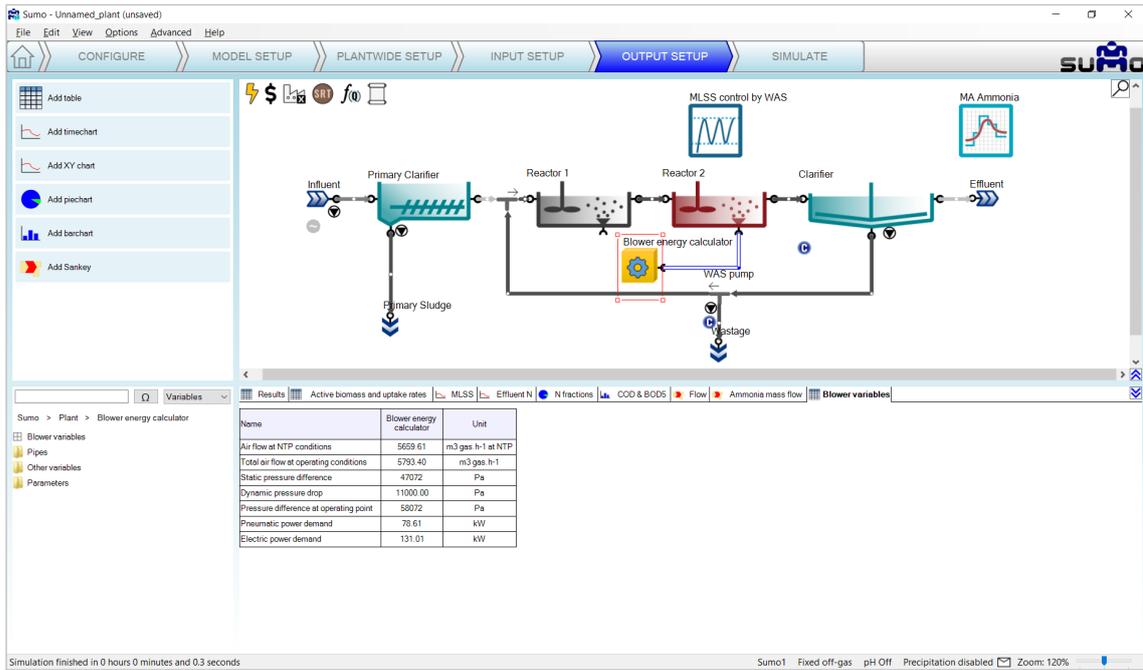
Figure 94 – Adding blower variables table in the Output setup
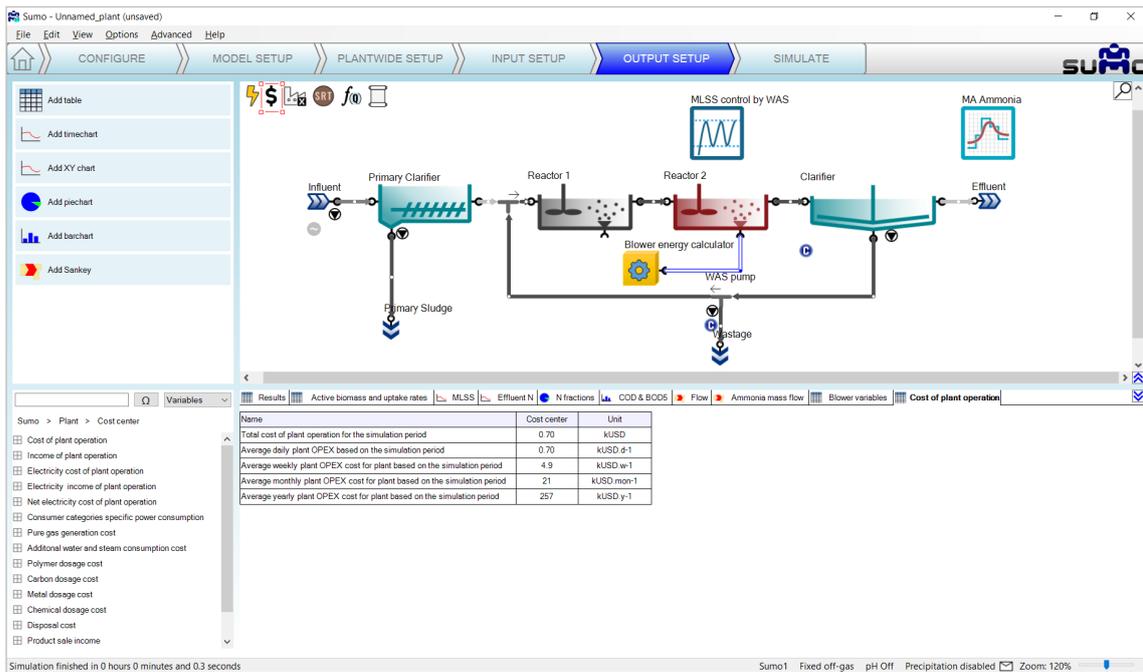
Figure 95 – Adding plant operation cost table in the Output setup

On the *Simulate* tab, after running a 30-day simulation from steady-state, you can review the energy and cost related information calculated by the model for this period. For example, it can be seen that most of the energy demand in this simple tutorial example comes from the electricity consumption of the biological treatment (Figure 99); basically aeration and mixing (Figure 97).

You can add various other energy and cost related outputs to analyze the performance of the plant in more detail, as well as extend the blower/pump models by specifying and calibrating the more detailed model options.

6 Energy and cost calculations
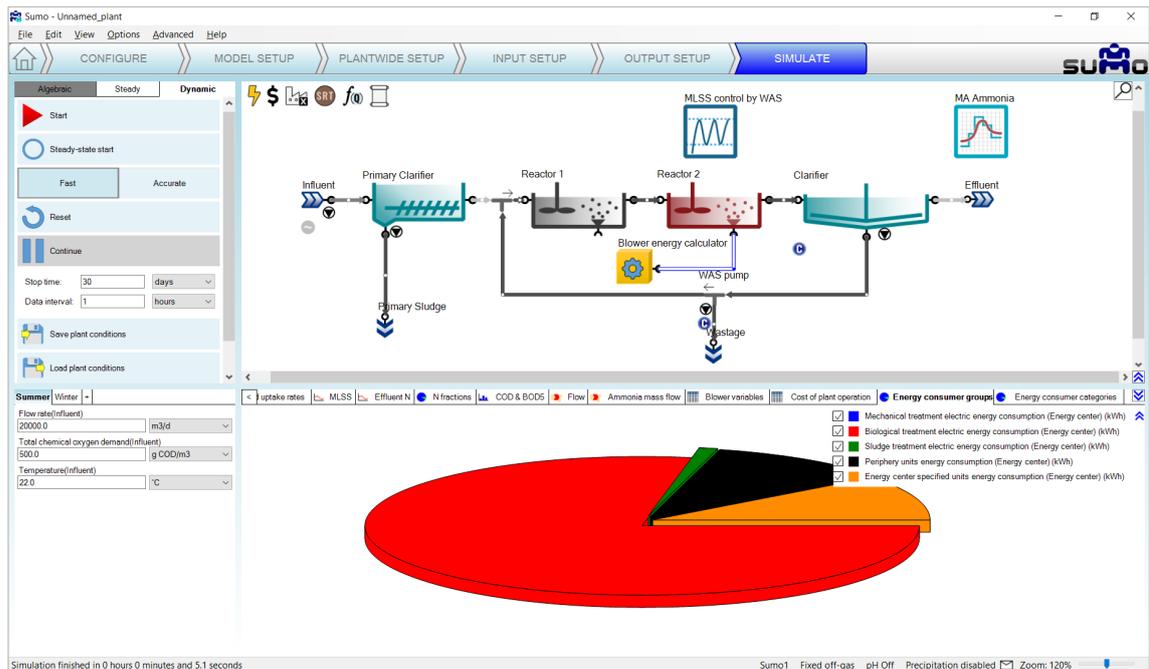
Figure 96 – Simulation results regarding the relative share of energy consumer groups
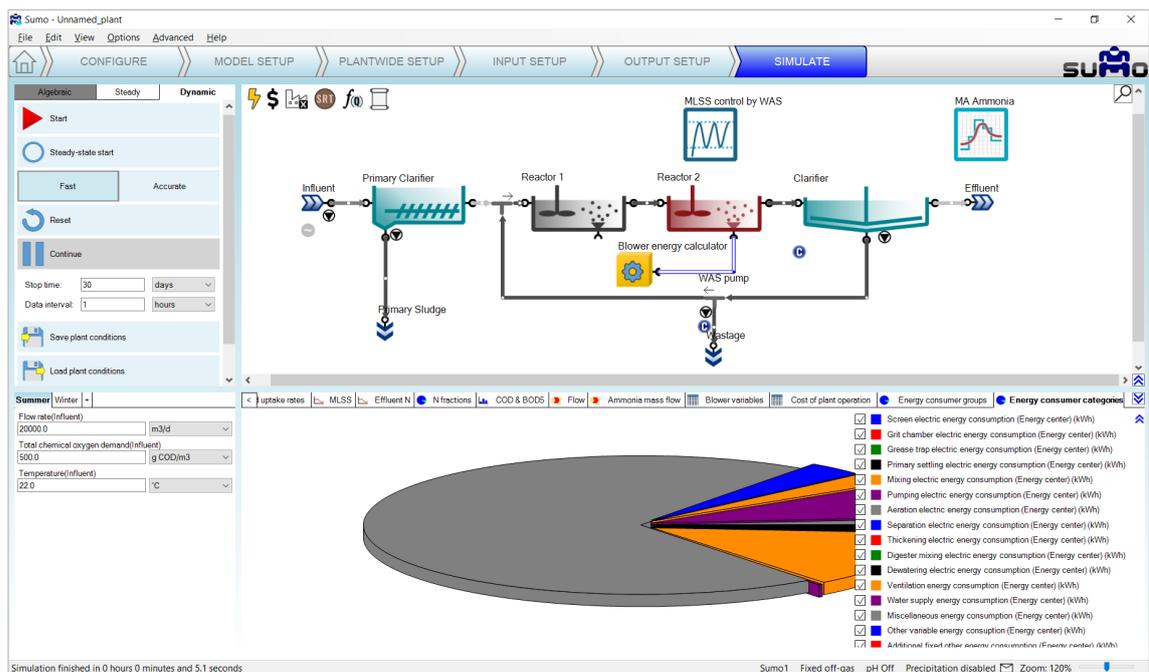
Figure 97 – Simulation results regarding the relative share of energy consumer categories

The usage of energy units associated with sidestream treatment (biogas tank, CHP unit, flare) is demonstrated by three of the factory examples: Tutorial Plant 2 with energy, AB plant with energy, UASB plant with energy.

7   Examples

In this chapter, the built-in example configurations are presented covering various process technologies. These examples can be selected from the Welcome Screen, as well as from the *Help* menu. They are located in the install directory.

7.1   Tutorial plant

This is the example layout used in this manual.
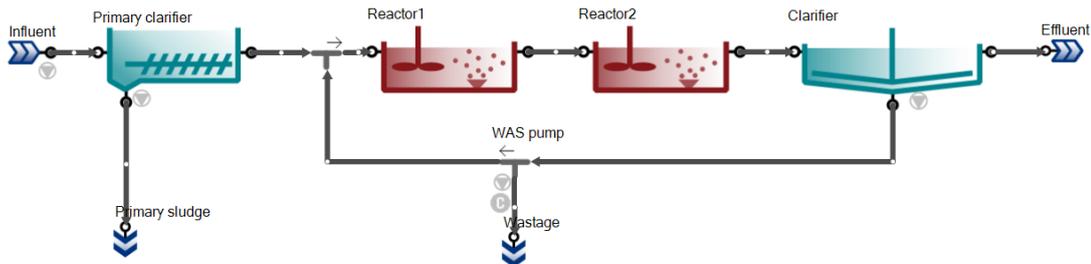
Figure 98 - The 'Tutorial plant' example layout

7.2   Tutorial plant 2

Tutorial Plant 2 is the extended configuration of Tutorial plant, including mesophilic digestion. Off-gas and pH calculations are turned on.
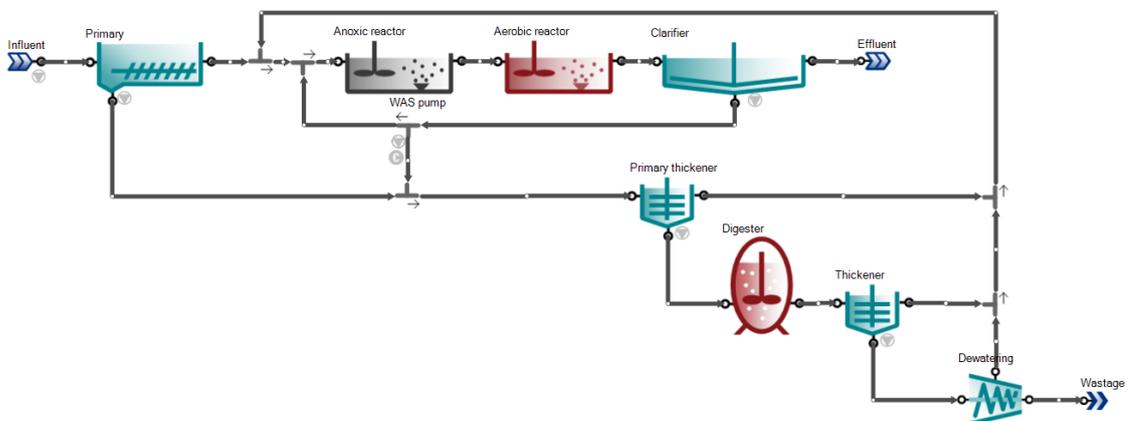
Figure 99 - The 'Tutorial Plant 2' configuration

7.3 Tutorial plant 2 with energy

Tutorial Plant 2 with energy calculations turned on.
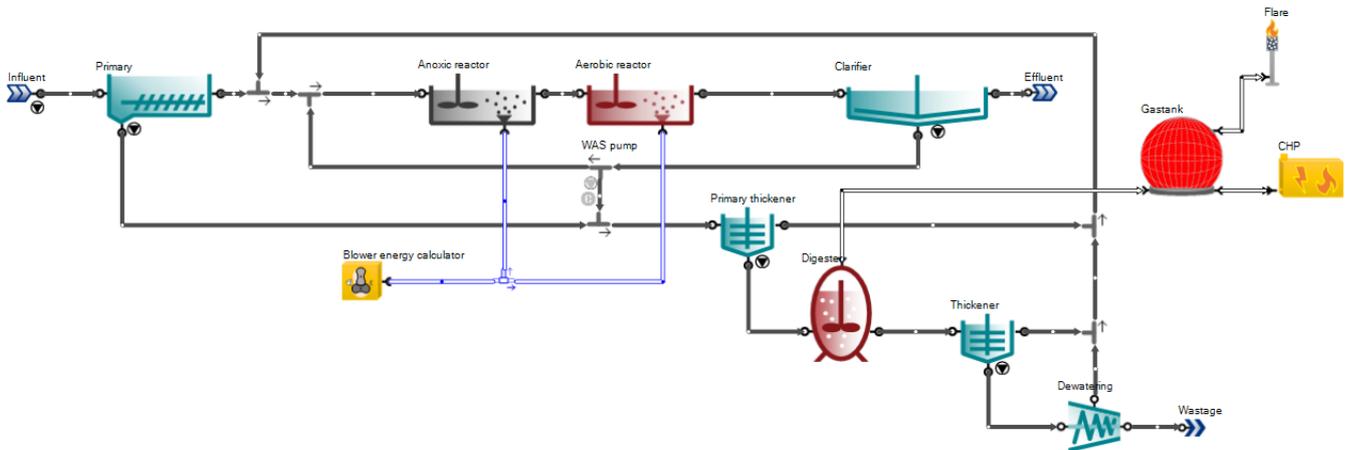
Figure 100 - The 'Tutorial Plant 2 with energy' configuration

7.4 Tutorial plant 3

Tutorial plant 3 is the extended version of Tutorial plant 2 with sidestream treatment (nitritation and denitritation). This configuration is simulated using the two-step nitrification/denitrification model with Sulfur (Sumo2S). Off-gas, pH and precipitation calculations are turned on.
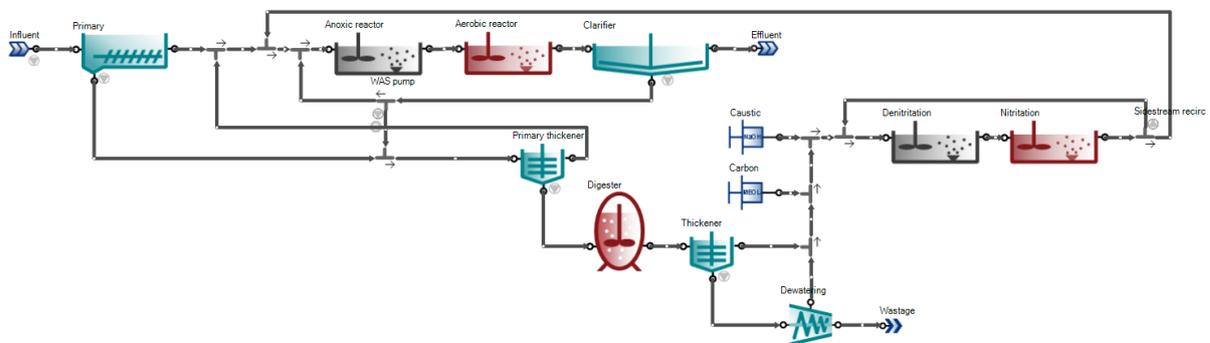
Figure 101 - The 'Tutorial plant 3' configuration

7.5   Tutorial plant 4

Tutorial plant 4 is the extended version of Tutorial plant 2 with a different sidestream treatment (partial nitritation and anammox). This configuration is simulated using the two-step nitrification/denitrification model. Off-gas, pH and precipitation calculations are turned on.
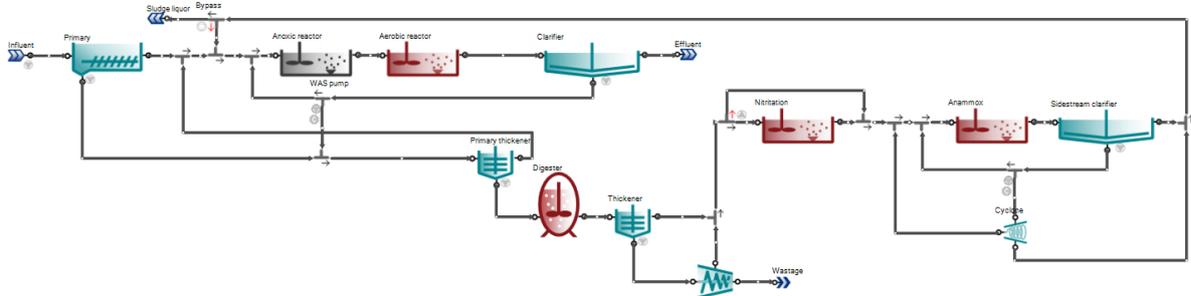
Figure 102 - The 'Tutorial plant 4' configuration

7.6   A2O plant

A2O configuration with one-step nitrification/denitrification model.
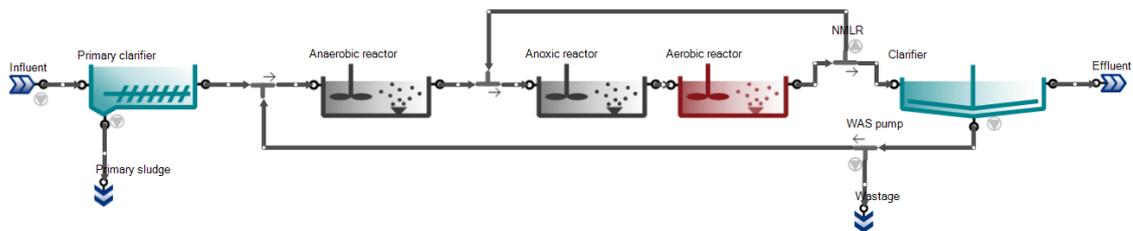
Figure 103 - The 'A2O plant' example layout

7.7   A2O with P recovery and energy

This layout is the extended version of the A2O configuration with primary sludge fermentation, digestion and P recovery (struvite precipitation). Off-gas, pH and precipitation calculations, as well as energy calculations, are turned on.
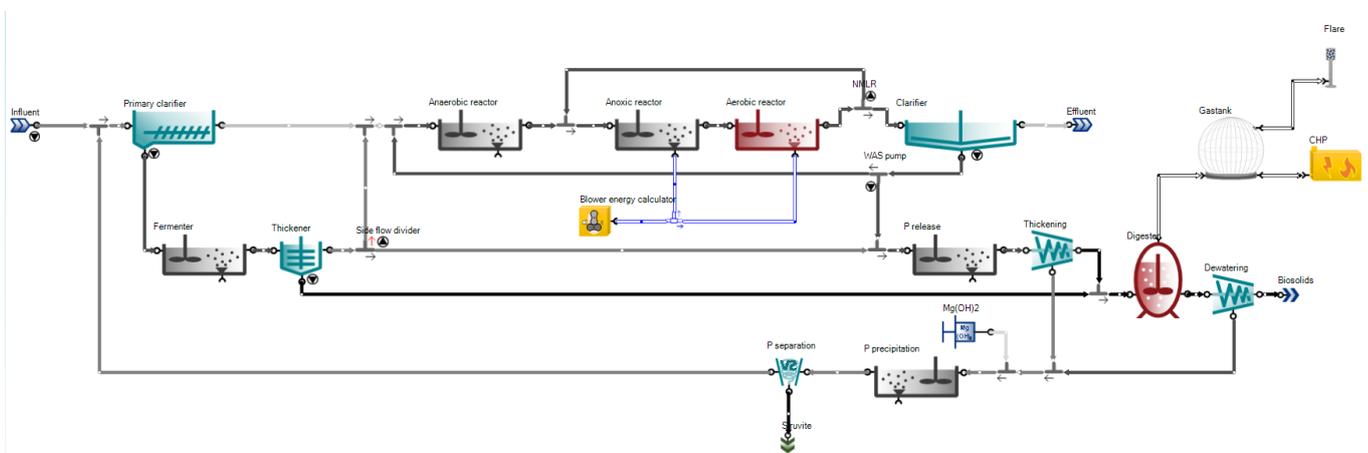
Figure 104 – The 'A2O with P recovery and energy' configuration

7 Examples

7.8　AB plant

This layout features an adsorption/bio-oxidation process configuration, known for enhanced carbon capture.
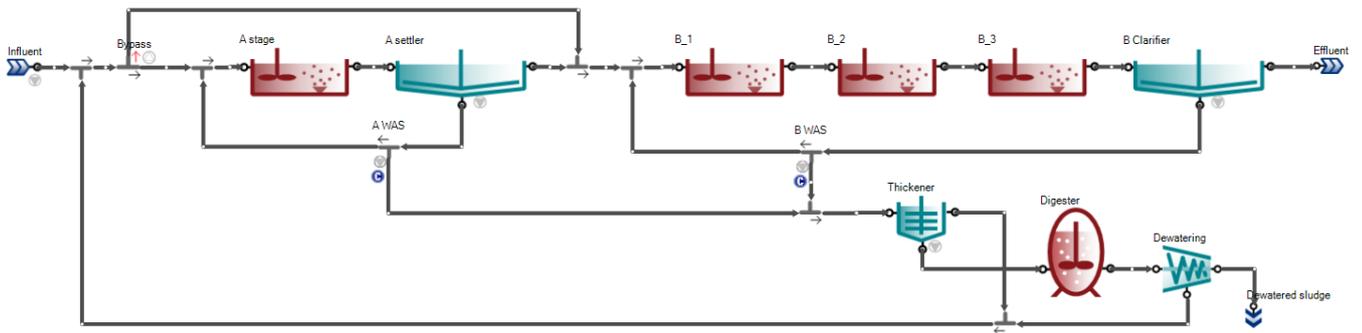
Figure 105 - The 'AB plant' configuration

7.9　AB plant with energy

AB plant with energy calculations turned on.
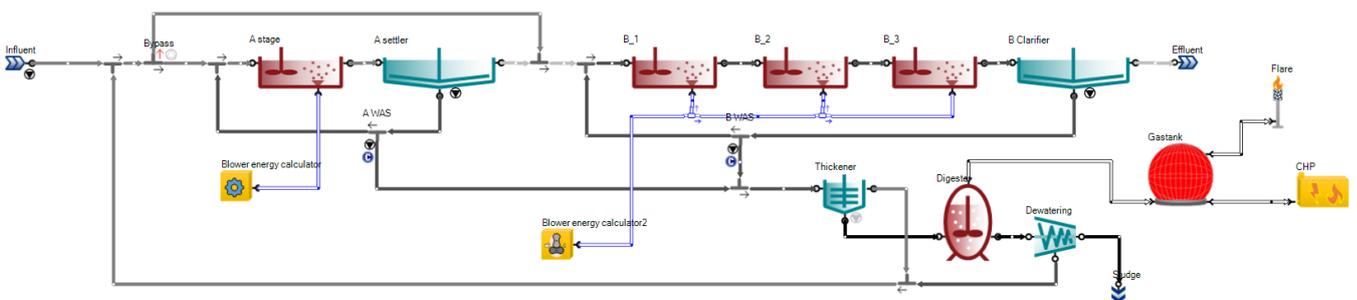
Figure 106 - The 'AB plant with energy' configuration

7.10　BAF plant

This layout features a treatment plant configuration employing upflow biological aerated filters.
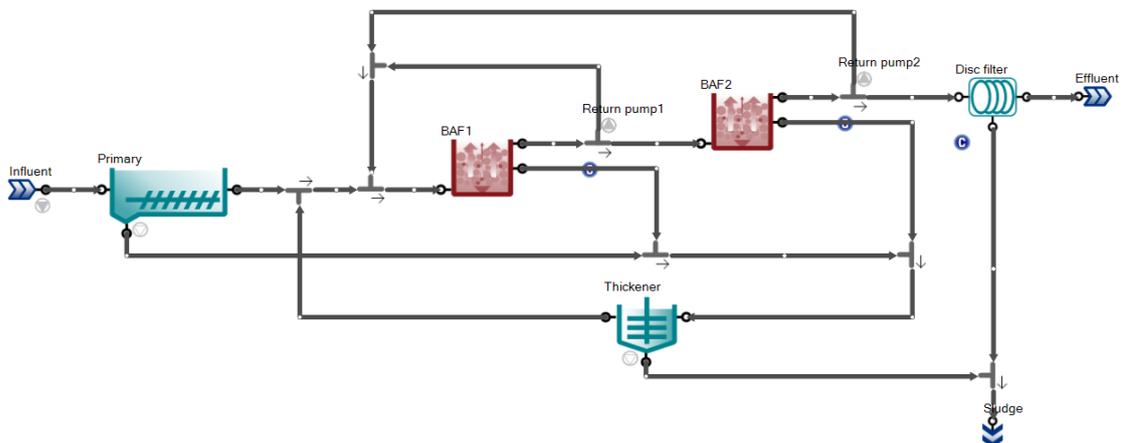
Figure 107 - The 'BAF plant' configuration

7.11 HPO configuration

This plant demonstrates the application of high purity oxygen to intensify biological wastewater treatment.
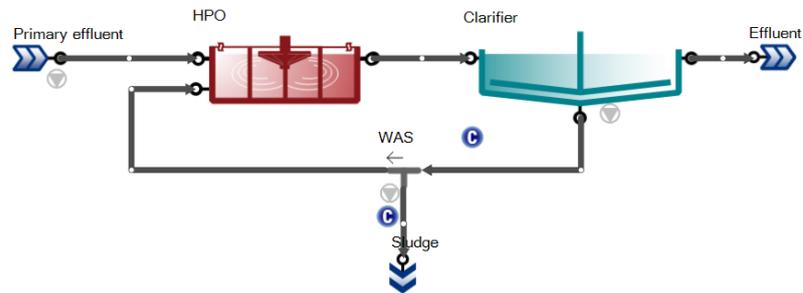
Figure 108 - The 'HPO' configuration

7.12 Hydraulic SRT

This plant is a demonstration of hydraulic SRT control. The wastage is removed from the reactor itself, and SRT (irrespective of the MLSS content) will be V/Q_{WAS}. Since the reactor volume is 10,000 m^3, 3000 m^3/d wastage will result in 3.3 d of SRT and loss of nitrification at 12°C.
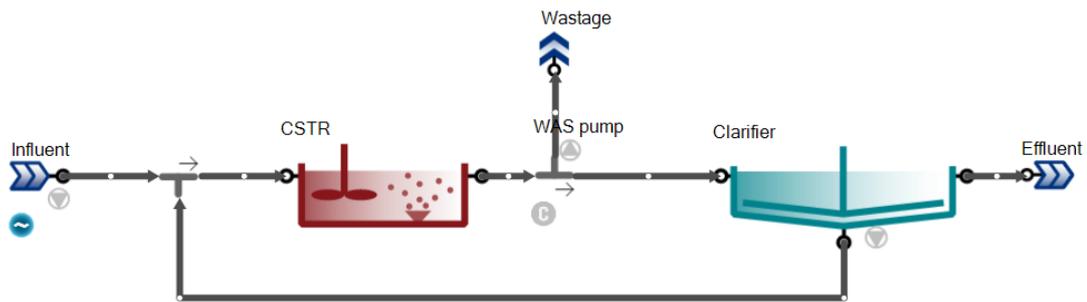
Figure 109 - The 'Hydraulic SRT' configuration

7.13 MLE configuration

Modified Ludzack-Ettinger configuration with one-step nitrification/denitrification.
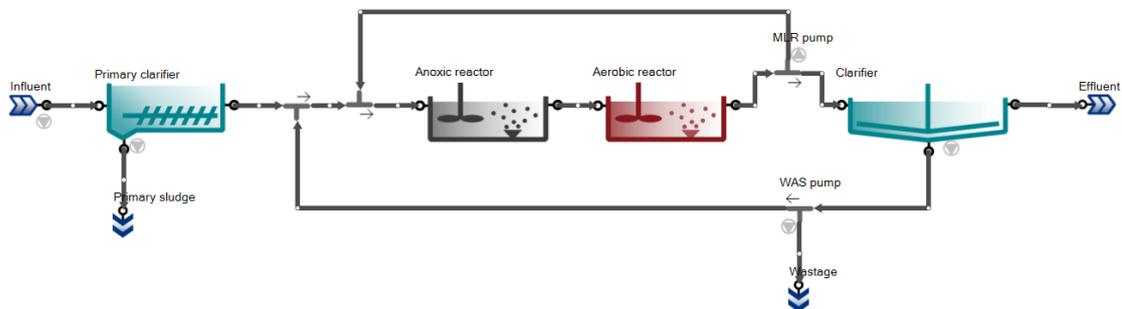
Figure 110 – The 'MLE' configuration

7.14 MLE with energy

This layout is the MLE configuration extended with energy calculations.

Figure 111 – The 'MLE with energy' configuration

7.15 MLE with MBBR

This layout has two parallel MLE trains with wintertime influent to demonstrate the benefits of upgrading the aerobic reactor with media for enhanced N removal.

Figure 112 – The 'MLE with MBBR' configuration

7.16   MLE with MBR and chemical P removal

This layout is the extended version of the MLE configuration with chemical P removal, using aerated membrane bioreactor as phase separator.
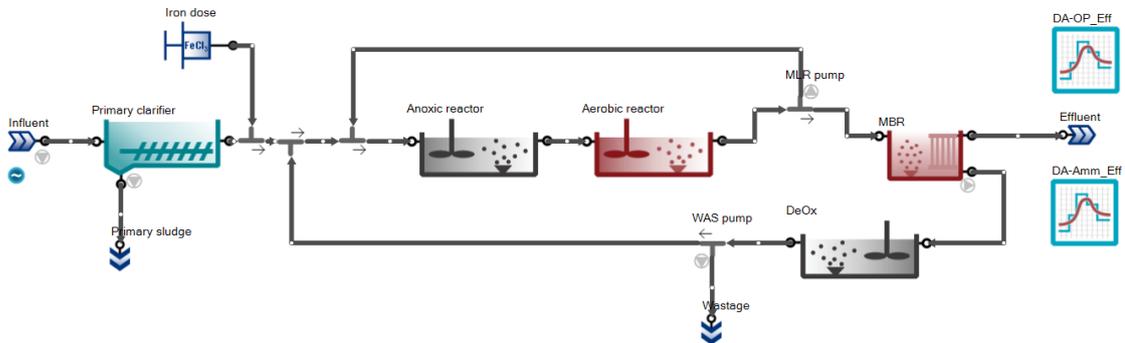
Figure 113 – The 'MLE with MBR and chemical P removal' configuration

7.17   Bardenpho

Five-stage Bardenpho configuration with one-step nitrification/denitrification model.
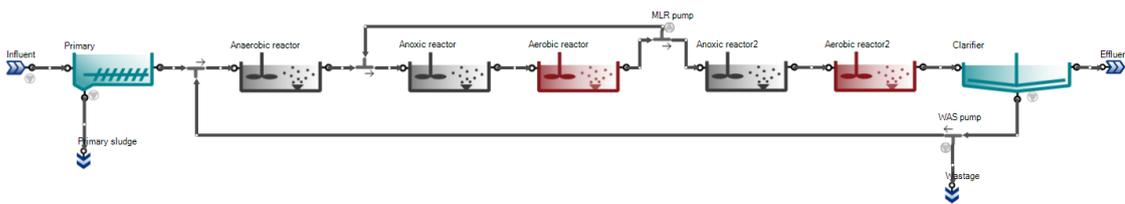
Figure 114 – The 'Bardenpho' configuration

7.18   Oxidation ditch

Oxidation ditch example with surface aeration. The ditch is essentially a flow loop and the incoming flow must leave so the outgoing flow must exactly match the influent. The solution to do this in a model is to force the internal flow loop and the rest of the flow overflows to the clarifier. The flow forcing pump does the internal 'recirculation' in the oxidation ditch, while the overflow port automatically equals the input flow rate to the ditch.

To calculate the internal flow (which is usually 50-100 times the influent flow) one needs to multiply the forward linear velocity (usually 0.3-0.6 m/s or 1-2 ft/s) in the ditch with the cross sectional area, which will give a m3/d or MGD flow value. This is the value that should be set in the pump.
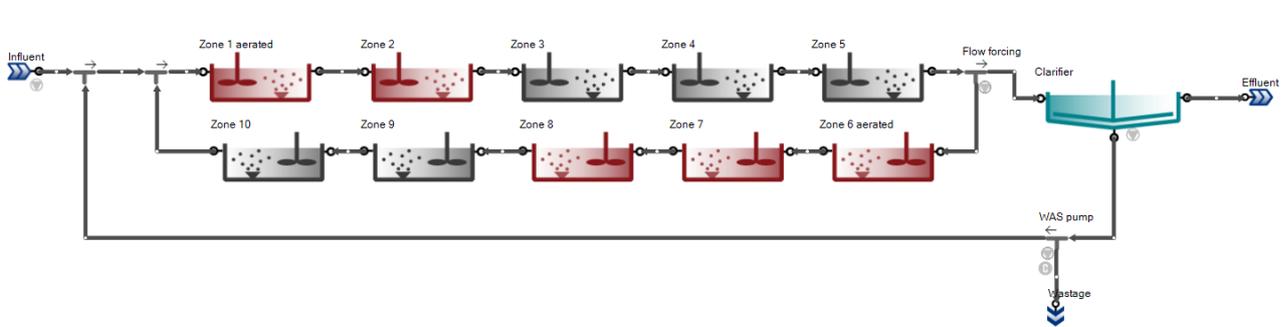
Figure 115 – The 'Oxidation ditch' configuration

The Oxidation ditch can be considered ideally mixed as a CSTR for all variables except DO. See the DO profile of the Oxidation ditch on Figure 116.
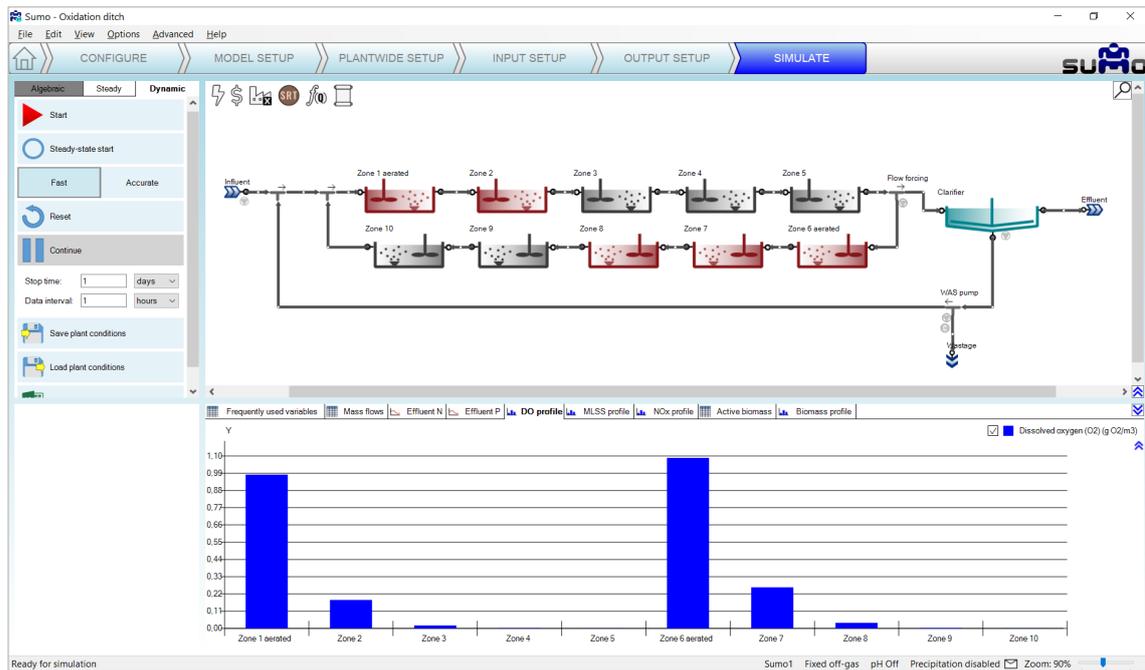
Figure 116 – Oxygen profile along the Oxidation ditch

7.19   SBR plant

Sequencing batch reactor example with one-step nitrification/denitrification.
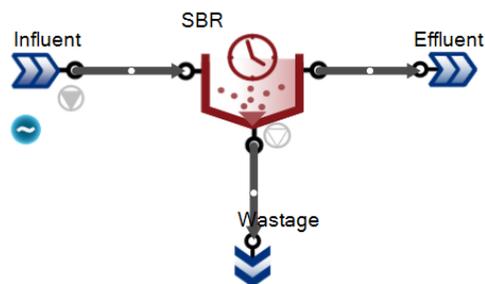
Figure 117 - The 'SBR plant' example layout.

7.20 Trickling filter configuration

Simple trickling filter plant example with biofilm model.
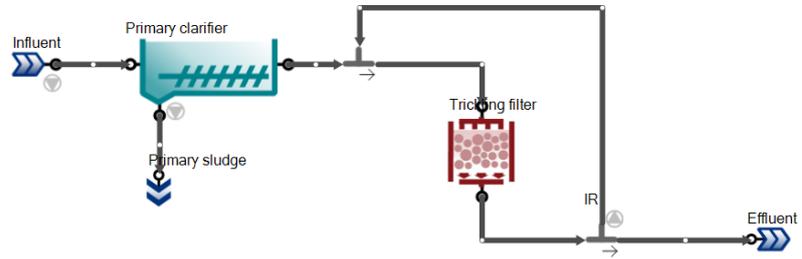
Figure 118 - The 'Trickling filter' example layout.

7.21 THP plant

UCT plant with THP sludge pretreatment stage before digestion. Off-gas and pH calculations are turned on.
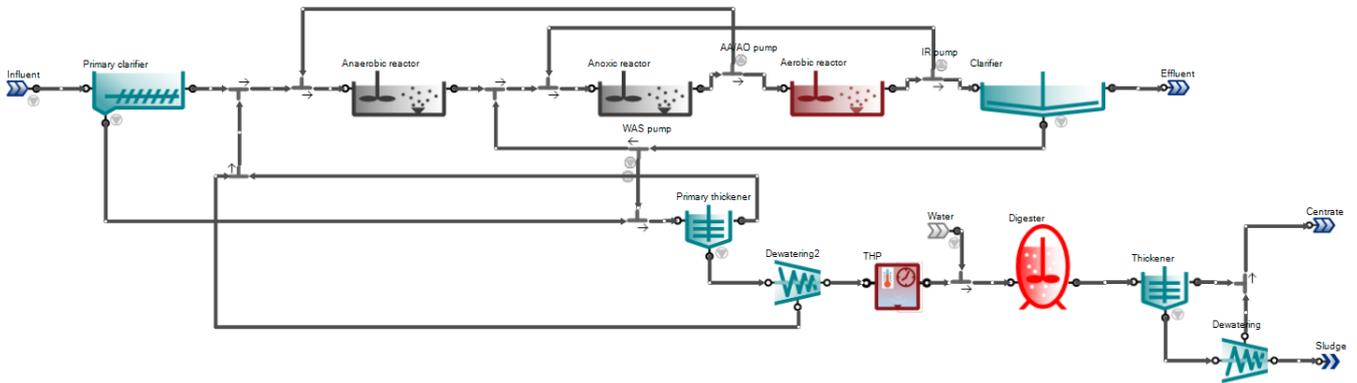
Figure 119 – The 'THP plant' configuration

7.22   UASB plant with energy

This example layout features a plant with upflow anaerobic sludge blanket reactor with post-aeration and energy calculations turned on.
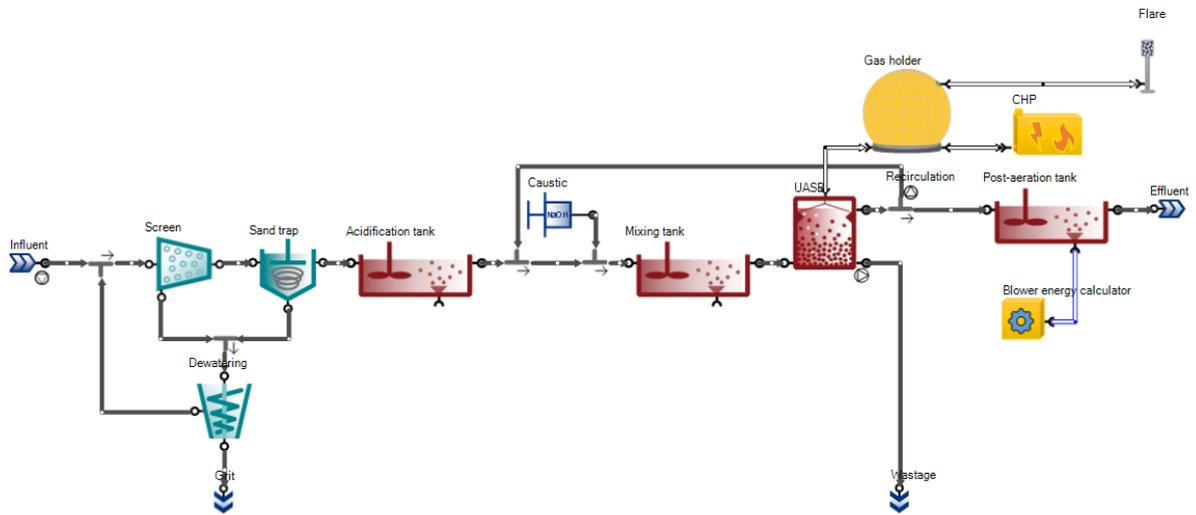
Figure 120 – The 'UASB plant with energy' configuration

7.23   Four lagoons in series

This example demonstrates the long-term behavior of aerated facultative lagoons.
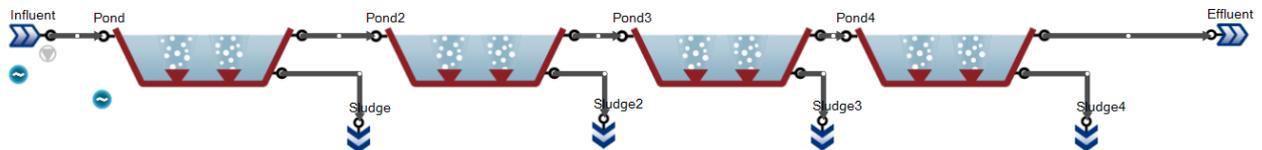
Figure 121 – The 'Four lagoons in series' configuration

7.24 Titration of ammonia solution

This example demonstrates the ammonium/ammonia relationship depending on pH, using an XY diagram, added from the *Output tab* by dropping pH on the X axis and choosing the NH_4^+ and NH_3 in the tank for the Y axis (Figure 122).
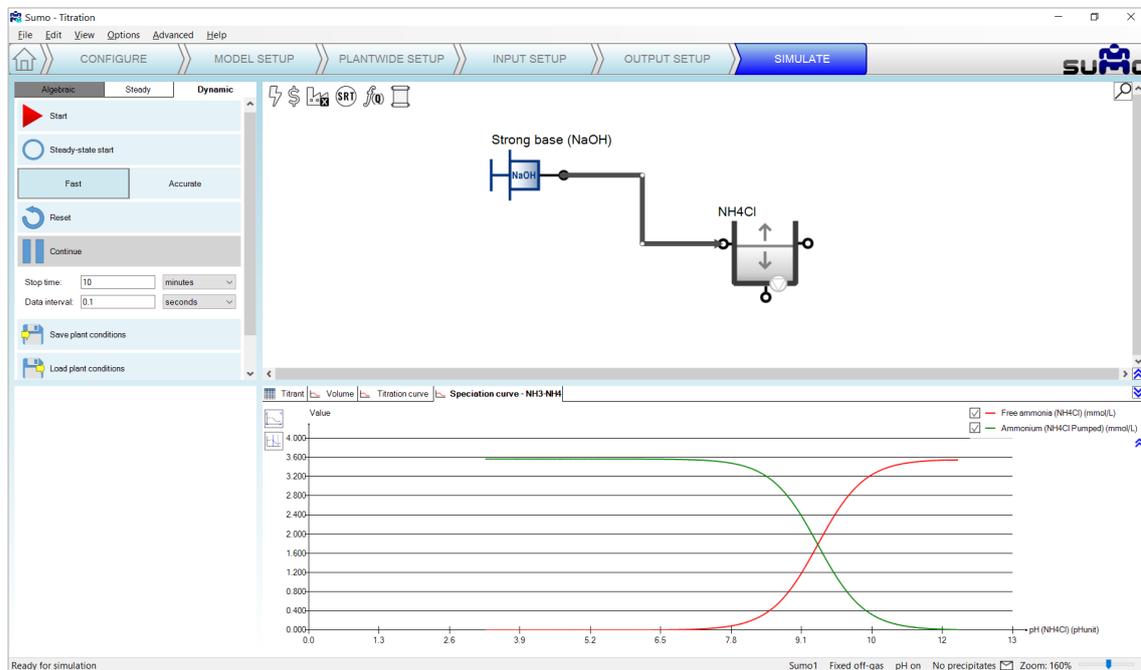
Figure 122 – 'Titration example' with simulation

7.25 Precipitation

This example demonstrates how the precipitate concentration depends on pH, using the Sumo2S model and an XY diagram, added from the *Output tab* by dropping pH on the X axis and choosing the available precipitates

(Calcium carbonate as *CaCO3*, Amorphous calcium phosphate as *ACP*, Struvite as *STR*, Vivianite as *Vivi* and Iron sulfide as *FeS*) in the tank for the Y axis. (Figure 123)
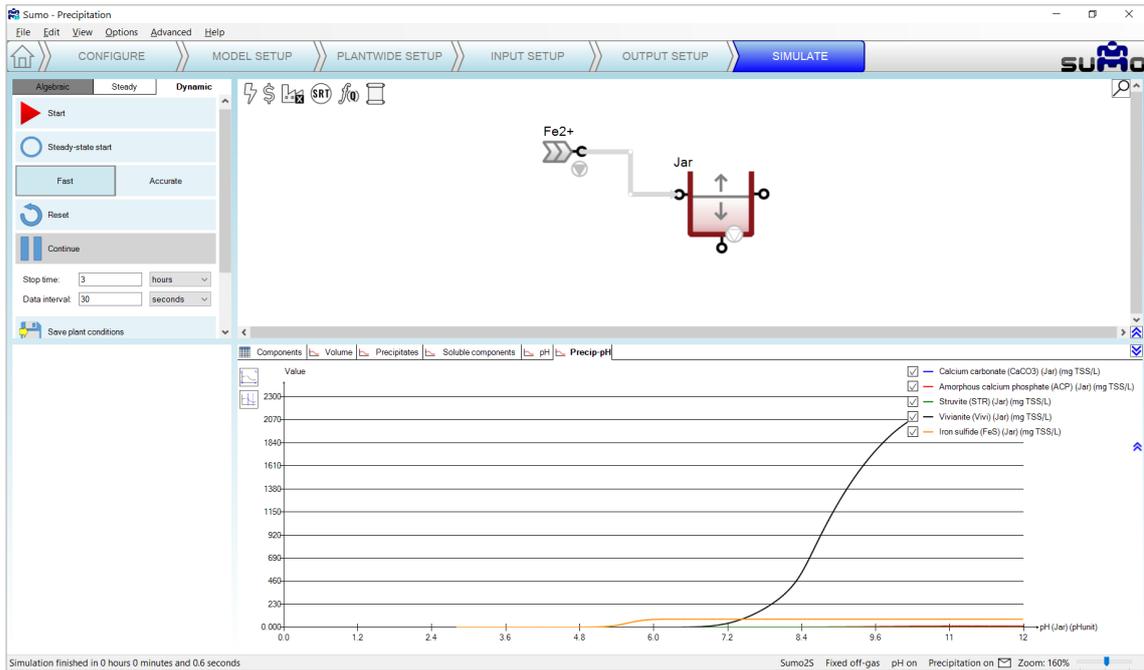
Figure 123 – 'Precipitation example' with simulation

7.26 Respirometer

This example demonstrates the possibility of simulating a respirometer (Figure 124).
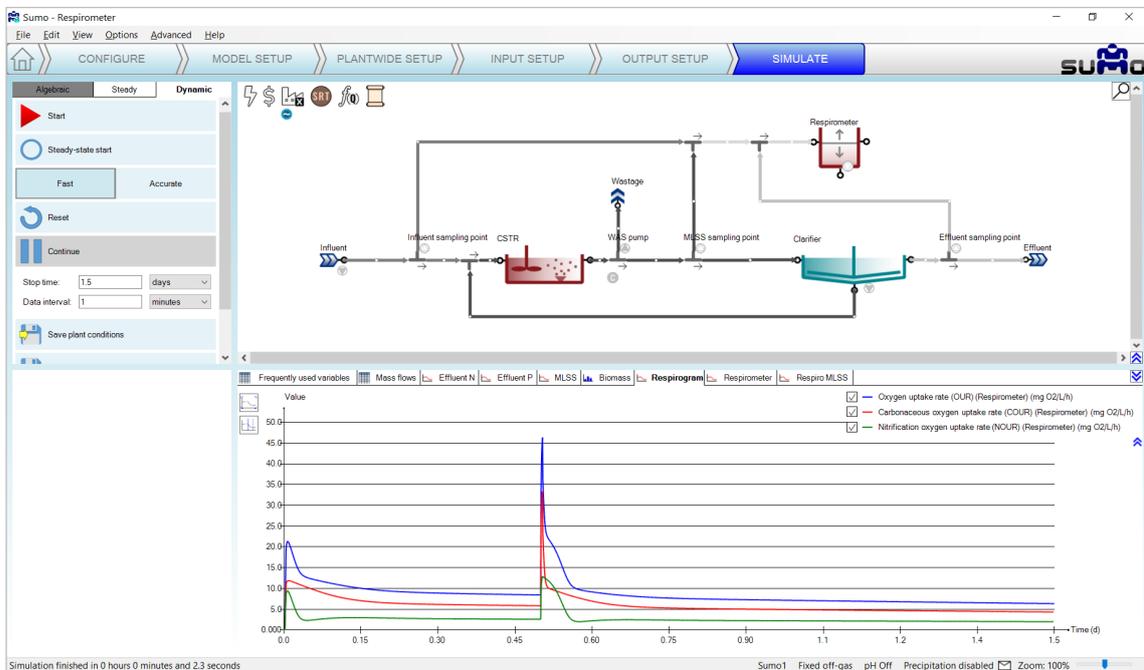
Figure 124 – 'Respirometer' example with simulation

7.27 P uptake-release test

This example demonstrates the possibility of simulating a P uptake-release jar test using a sample taken from a plant configuration (Figure 125).
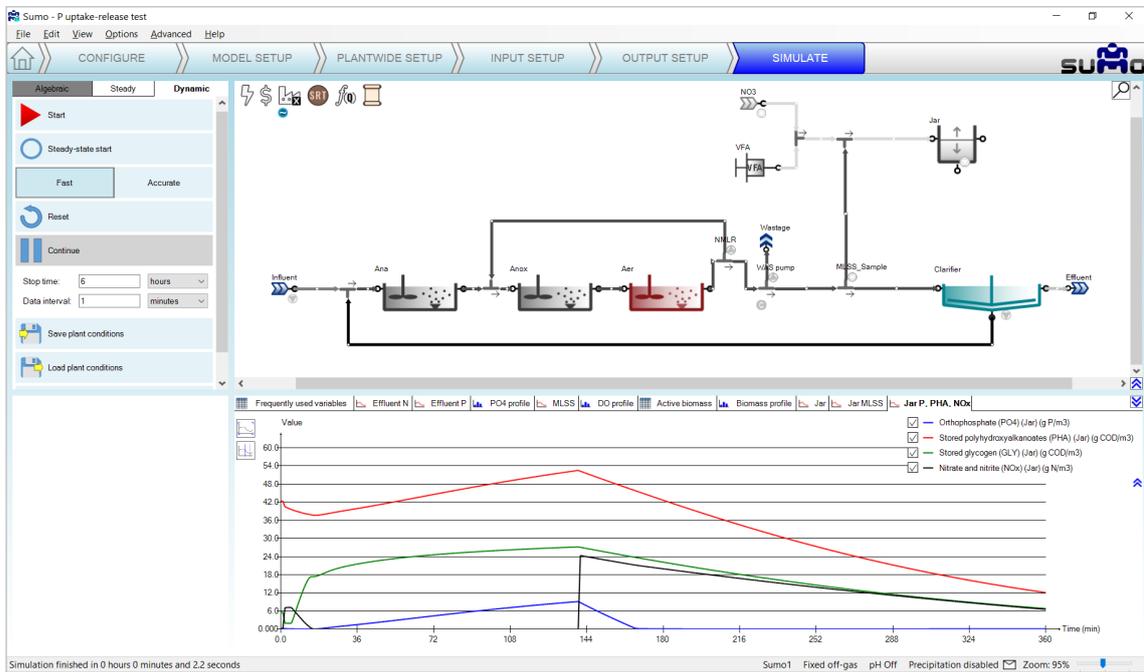
Figure 125 – 'P uptake-release test' example with simulation

7.28 DO and MLSS control

This example demonstrates the implementation of parallel control strategy for MLSS and DO, relying on two PID controllers (Figure 128 and Figure 127).
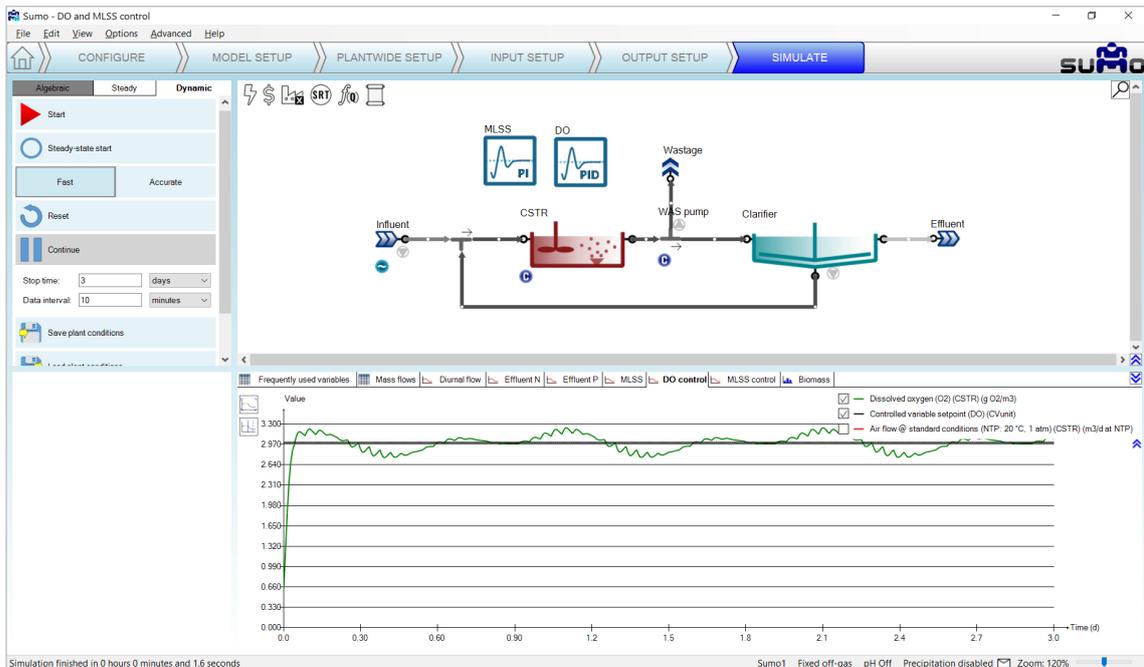
Figure 126 – 'DO and MLSS control' example with simulation (DO control)

7 Examples
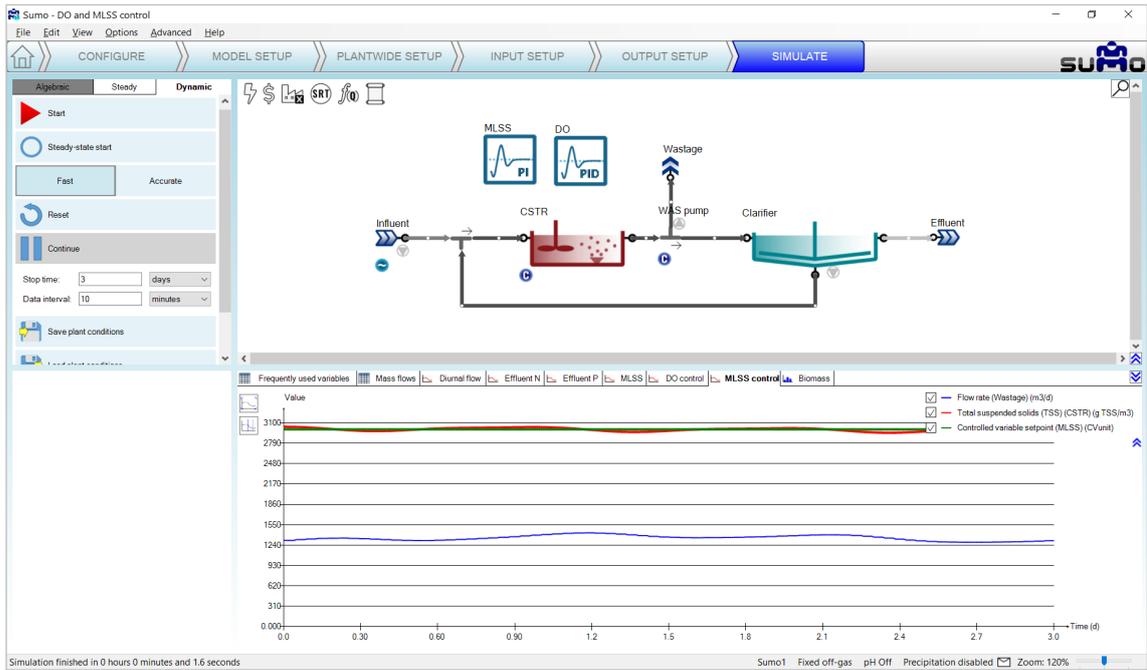
Figure 127 – 'DO and MLSS control' example with simulation (MLSS control)

7.29 Cascade controller

This example demonstrates the application of the cascade controller strategy for ammonia-based aeration control (ABAC) using two PID controllers (Figure 128).
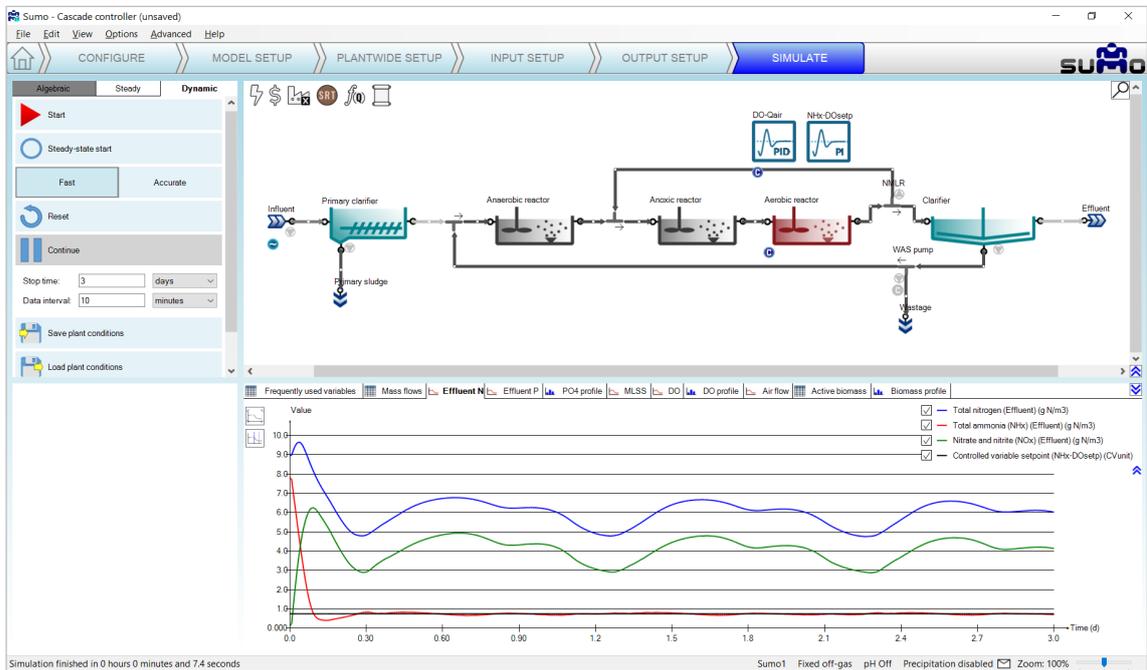
Figure 128 – 'Cascade controller' example with simulation

7.30   Optimal TN control

This example demonstrates the application of the cascade controller strategy to aerate a reactor according to a setpoint of the sum of effluent ammonia and nitrate concentrations, by using a combination of a PID and a time based on/off controller (Figure 129).
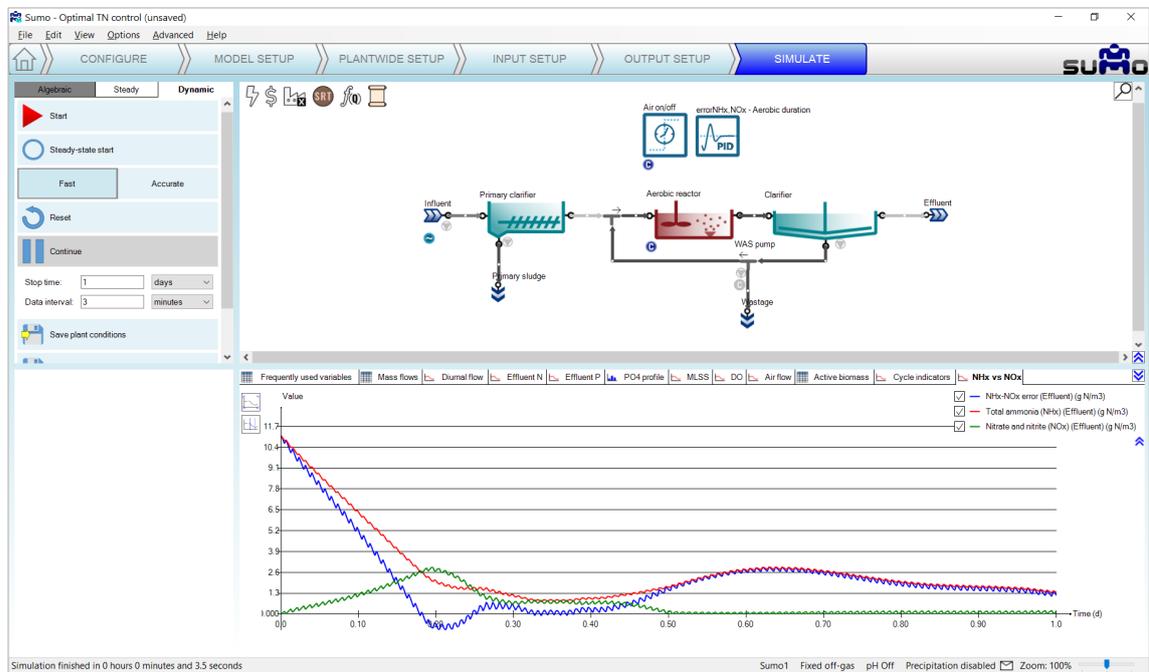
Figure 129 – 'Optimal TN control' example with simulation

8   How to use Sumo for plant design

Sumo can be used for plant design as well, based on simple algebraic calculations. This version includes a design tool for AS plants.

AS design calculates the required reactor volume based on design SRT and MLSS.

To set up a plant design example, please follow the steps described below.

8.1   Configure

Just like with dynamic configurations, to start the project, the relevant process unit has to be chosen on the *Configure* tab. For the current exercise, this will be the *AS design* from the *Design tools* group. This unit is restricted to be only available for the design model. As the selection of the latter will take place in the model setup, at this point the unit will be indicated as invalid, crossed out with red lines (Figure 130).
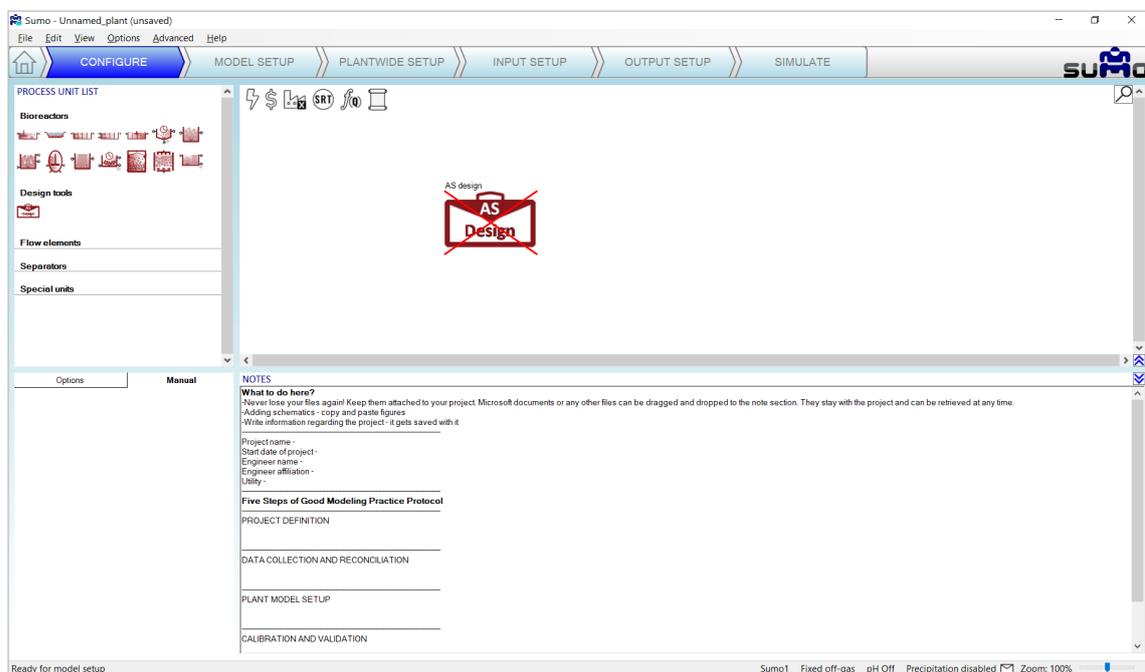
Figure 130 - Configuration of AS design

8.2   Model setup

On the *Model setup* tab, please choose the *Design model* from the model option, available under *Model selection/Museum, focus and custom models/Other models/Design*. The process unit will become indicated as valid (Figure 131).
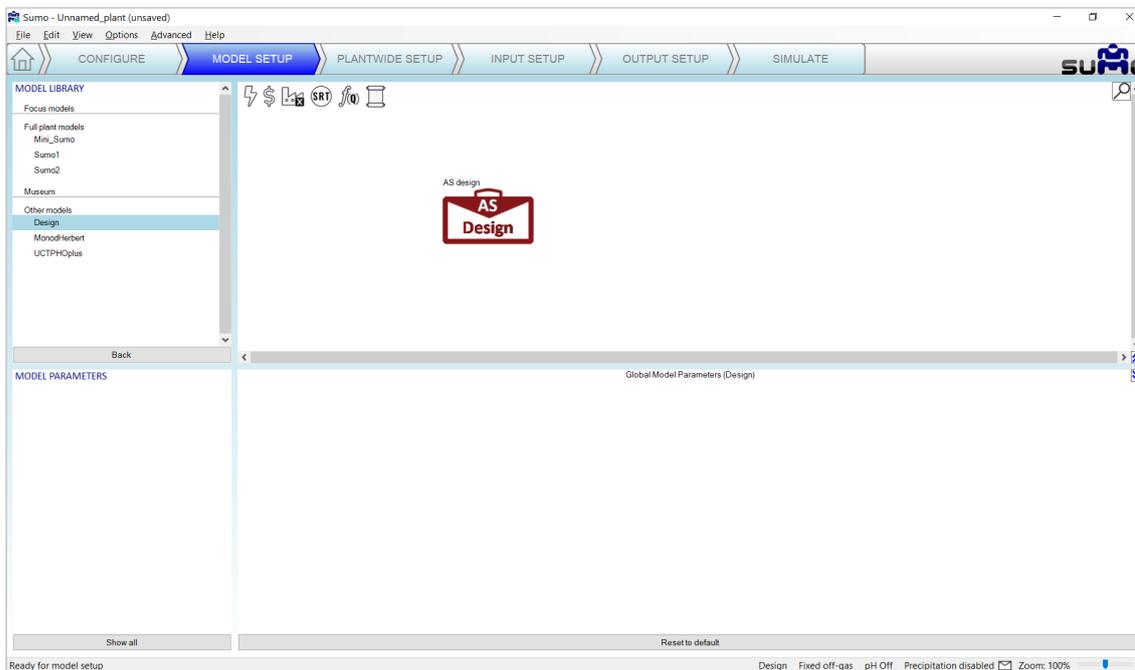

Figure 131 - AS design model selection

8.3   Input setup

On the *Input setup* tab, the main influent and design parameters can be set (Figure 132). By clicking on the *Show all* button, further details (such as COD and biomass fractions) can be added.
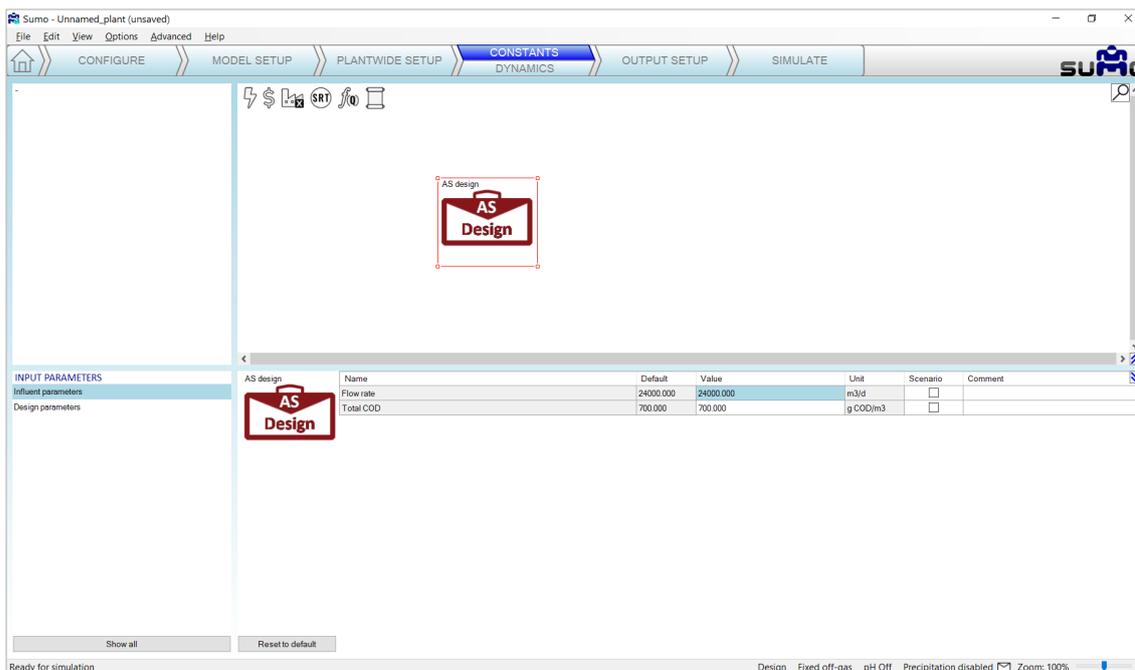
Figure 132 - AS design input setup

8.4   Output setup

Tables can be added here, similarly to the dynamic configurations (Figure 133).
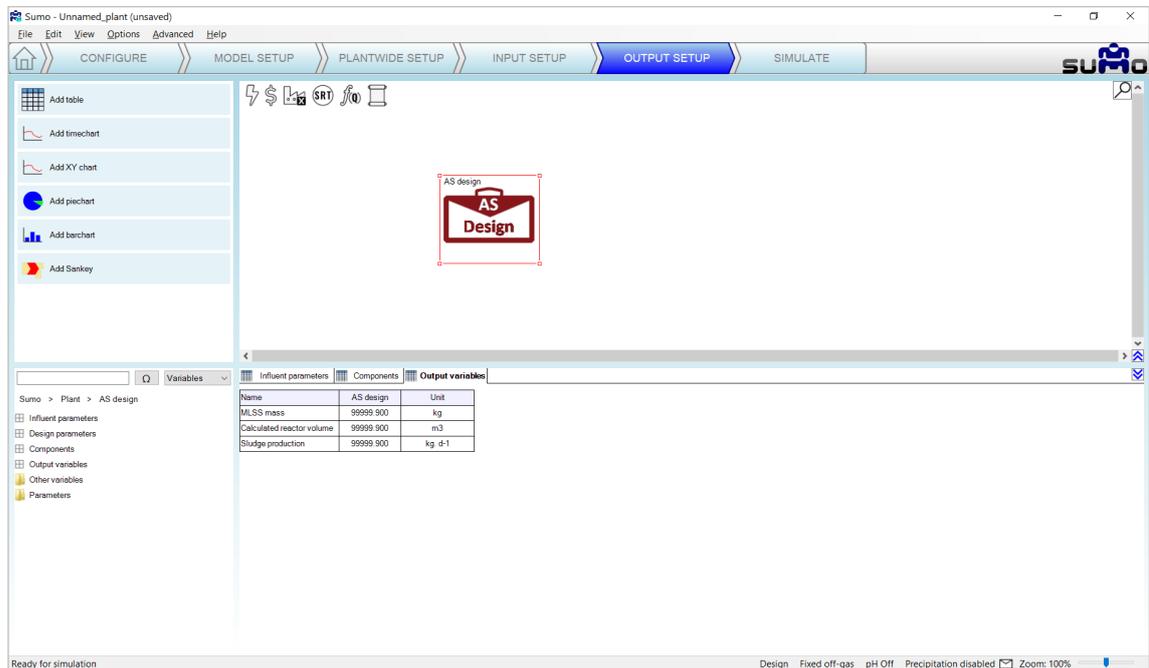
Figure 133 - AS design output setup

8.5   Simulate

On the *Simulation* tab, the *Algebraic* mode becomes active. Switching to this tab and clicking *Start Algebraic*, the desired calculations will be executed and a report can be written of the results. (Figure 134)
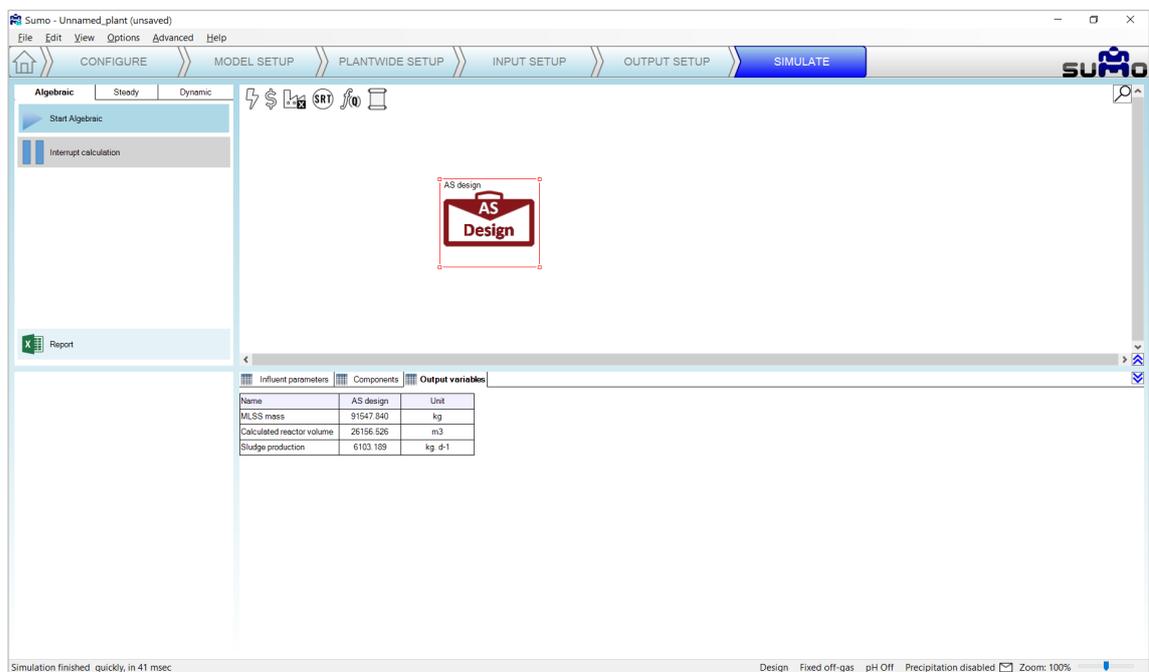
Figure 134 - AS design simulation