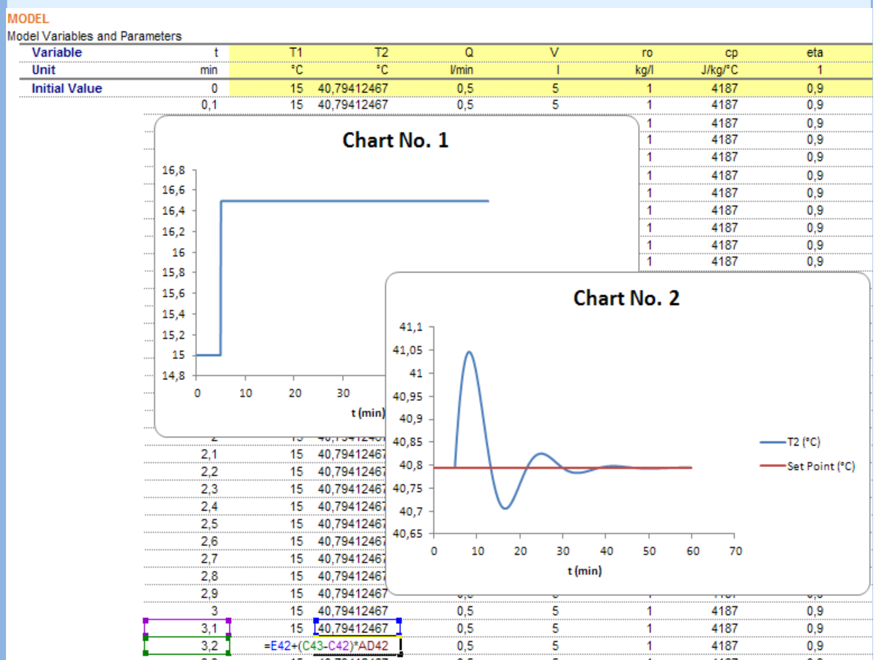
PROCESS SIMULATION AND CONTROL

PSIC User's Guide



PSIC

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1 About PSIC Add-in

Process Simulation and Control (PSIC) is an Excel add-in that lets you to

- Create mathematical models of chemical engineering systems and simulate their behavior,
- Create control loops and simulate their behavior.

The add-in assumes models of max. 10 ordinary differential equations of the first order (the 1^{st} ODEs) of max. 25 quantities, and solves the 1^{st} ODEs using Euler's method. The add-in allows you to configure and tune feedback regulatory control loops with a single PID controller.

Add-in consists of a file PSIC.xlam which complements this user's guide.

1.1 Software Requirements

The PSIC.xlam file of the add-in contains codes of Visual Basic for Application (VBA) that extends the built-in Excel commands and functions and provides additional features and commands for inserting and checking quantities and ODEs of models, running simulations, configuring regulatory loops, tuning controllers, etc. The PSIC add-in requires the installation of Excel 2007+ and authorized the execution of macros permanently in the Trust Center, or temporarily in the Message Bar when starting Excel – see **Enable or disable macros in Office files** [1].

1.2 Adding and Activation

Adding and activation the PSIC add-in consists of following steps:

1. In Excel 2007, click the **Microsoft Office** button, click the **Excel Options**. In Excel 2010+, click the **File** tab, click the **Options**.
2. Click the **Add-Ins** category.
3. In the **Manage** box, select the **Excel Add-ins** and then click the **Go** button. The Add-Ins available box appears (see Figure 1):

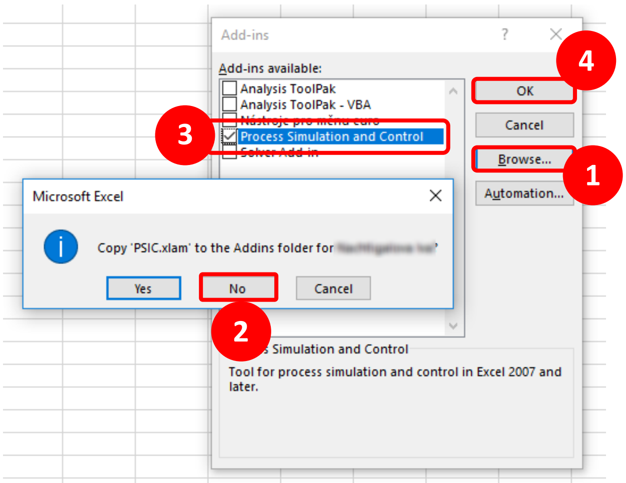

Figure 1: Add-Ins dialog box

4. Click the **Browse** button ❶, find the file PSIC.xlam in the file system and open it, choose the **No** button ❷ to disable copy the file into the system Addins folder**,** select the checkbox of the **Process Simulation and Control** add-in ❸ and click the **OK** button ❹.

After activation, the new **PSIC** ribbon tab with the new commands will be available (see Chapter 1.3).

Note: After clicking the **Yes** button ❷ the file will copy into the Windows Addins folder C:\Users\»your-username«\AppData\Roaming\Microsoft\Addins. If updated, the file must be manually copied to this folder.

Note: Do not add the PSIC add-in by double-clicking on the file PSIC.xlam in the file manager. After this, the add-in can be opened only as an ordinary workbook (you do not have to be asked to install) and the add-in does not have to be added to Excel in a fair manner. It is necessary to restart Excel and follow instructions 1 – 4 as above.

Note: The add-in can be inactivated at any time by clearing the checkbox in the Add-Ins dialog box (see ❸ in Figure 1). Inactivating the add-in does not remove its file from your computer, it only inactivate the add-in features and commands (including changes in the user interface).

If you want to remove the PSIC add-in file from Excel, follow these steps:

1. Remove the file PSIC.xlam from its folder (see Note above).
2. Start Excel, confirm warning about unavailable add-in file and follow steps 1 – 3 as when you add the add-in to Excel.
3. In the Add-Ins available box (see Figure 1), clear the checkbox of the **Process Simulation and Control** add-in, confirm the query to remove the add-in and then click the **OK** button.

Note: Warning about unavailable add-in file can appear even if file PSIC.xlam moves or renames after its activation. Then follow instructions above, uninstall the add-in and add it again.

1.3 Features and User Interface

The works with the PSIC add-in is simple: for the first you create a mathematical model (see Chapters 2 and 2.1) or a feedback loop (see Chapters 3 and 0), for the second, you run a simulation (see Chapters 2.2 and 2.3, or 3.2 and 3.3) or rerun a simulation after adjustment of controller constants (see Chapter 3.5). The PSIC add-in generates modified worksheets and graphics sheets with that you can manipulate in the standard way, and informs or guides user through sheet messages (see Chapter 0). All models, loops and simulation results you can save in standard Excel documents (see Chapter 5).

Commands for creating models and loops, simulations and controller tuning are available on the PSIC ribbon tab through controls in groups **Design**, **Simulation**, **Controller** and **Configuration** (see Figure 2). The functions of commands are as follows:

- **New Model**
  Button which generates the new worksheet named *Model #* for inserting input data of model and setting of simulation parameters and outputs.
- **New Loop**
  Button which generates the new worksheet (or sheet with chosen model) named *Loop #* for configuring feedback regulatory control loop and setting of simulation parameters and outputs.
- **Mode**
  Dropdown list which changes controller mode (direct or reverse) in simulated feedback regulatory control loop.

- **Action**
  Dropdown list which changes control action (P, PI, PD or PID) in simulated feedback regulatory control loop.
- **Gain r0**
  Text field which changes controller gain r_0 in simulated feedback regulatory control loop.
- **Integral Time Ti**
  Text field which changes controller integral time T_i in simulated feedback regulatory control loop.
- **Derivative Time Td**
  Text field which changes controller derivative time T_d in simulated feedback regulatory control loop.
- **Reset**
  Button which enables return back changes in controls in the ribbon group **Controller** (i.e. to restore controller settings used in the last simulation).
- **Run**
  Button which generates the new worksheet named *Report #* with results of simulation of model behavior or feedback regulatory control loop behavior.
- **Rerun**
  Button which recalculates simulation of behavior of feedback regulatory control loop after changing controller settings.
- **Update Add Link**
  Button which update link to PSIC add-in in a workbook (it is necessary if you use the add-in and related workbooks on computers with the different add-in folder or, if you rename or change the add-in file or folder).

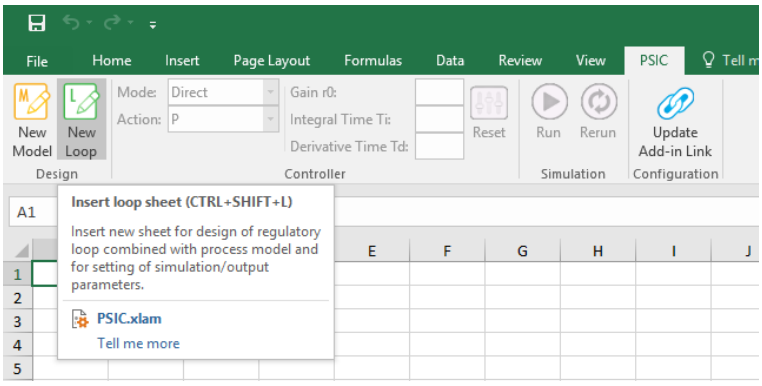

Figure 2: The PSIC tab and its controls

Note: Actions associated with controls on the PSIC tab can be run by keyboard shortcuts that are displayed in tooltips (see tooltip of the **New Loop** button in Figure 2).

1.4 Updating Link

In general, if Excel workbook use user-defined functions (UDFs) implemented in an add-in, Excel always saves an add-in path, i.e. a link to an add-in location in a file system, in a workbook. Unfortunately, Excel does not automatically update it if you rename or change an add-in file or its folder (only if you open workbook with an add-in path different from the saved one you receive a warning message about the need to update a link).

The PSIC add-in has built-in several UDFs that are used in Excel formulae of data and output sheets. Due to bad add-in link, it is not possible to view, insert or modify model equations, to insert the simulation step size, to insert values of controller parameters, etc. For these cases, repair or update the PSIC add-in link manually by the **Update Add-in Link** button (see Chapter 1.3).

2 Model

Quantities and equations of a model are entered in the yellow cells of the *Model #* worksheet that is generated by the **New Model** button (see Chapter 1.3). On the same sheet, simulation parameters (in blue cells) and desired outputs simulation (in gray cells) are entered too.

> Note: A Model # worksheet is protected so the user cannot enter data of other values or types than requested. If you copy data, insert them as values using the **Paste Special** command.

2.1 Model Design

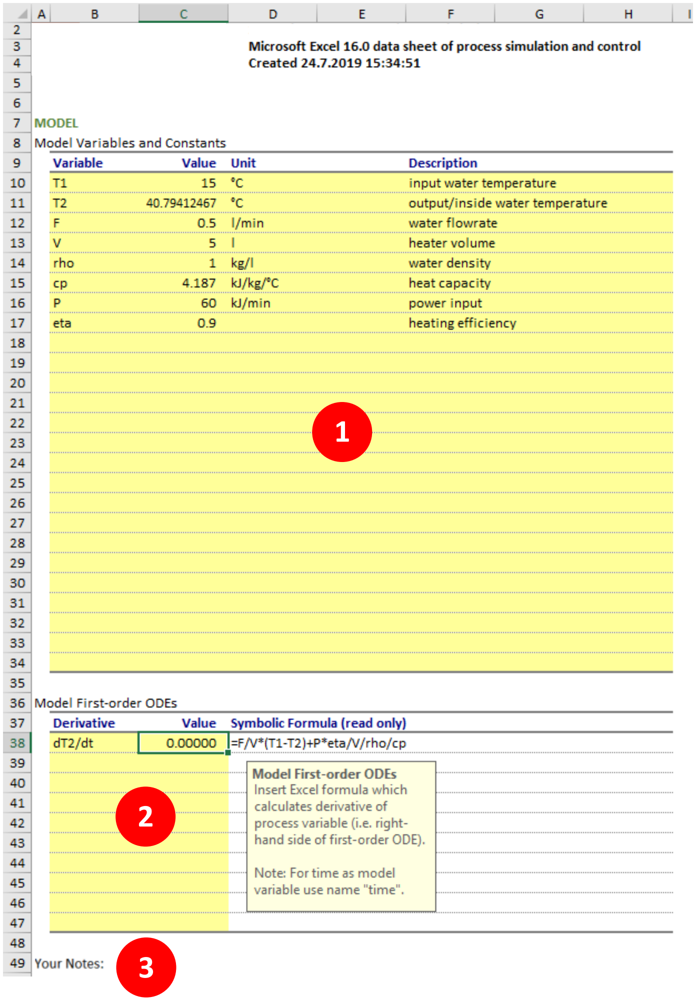

Figure 3: A Model # datasheet – model design

If you design a model, complete the *Model #* worksheet by following tables (see Figure 3):

- *Model Variables and Constants* ❶
  Enter marks of quantities of model (*Variable* column), their values at the beginning of the simulation (*Value* column), their physical units (*Unit* column) and their descriptions (*Description* column).

- *Model First-order ODEs* ❷
  Select variables of which the first derivative occurs in the left-hand sides of the 1st ODEs (*Derivative* column), and insert Excel formulae which calculate derivatives i.e. the right-hand sides of the 1st ODEs (*Value* column). Arguments of Excel formulae must be cell references from the column *Value* of the table *Model Variables and Constants*.

In addition to these mandatory data, you can fill cells labeled *Your Notes* ❸ by your optional notes.

Note: After inserting Excel formulae of the right-hand sides of the 1st ODEs formulae values of derivatives will be calculated in the *Value* column and symbolic shapes of ODEs will be displayed in the *Symbolic Formula (read only)* column. Red-highlighted values of formulae need not indicate errors in the formulae, but the unsteady-state values.

Note: If a system is described by higher-order ODE you can convert it into a system of the 1st ODEs by means of new subsidiary variables. Therefore, the add-in enables insert variables into *Derivative* column which do not occur directly in the model, too.

2.2 Settings Simulation and Outputs Parameters

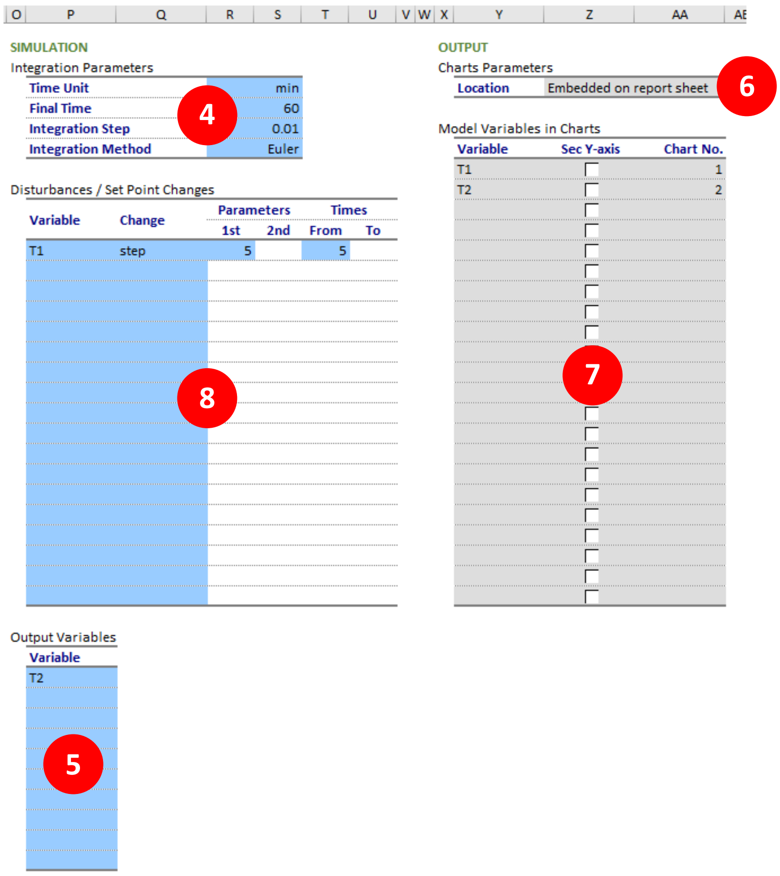

Figure 4: A Model # data sheet – setting simulation, disturbances and output parameters

Before running the simulation fill parameters in the following tables (see Figure 4):

- *Integration parameters* ❹
  Enter the final simulation time (*Final Time* cell) and the simulation step size (*Integration Step* cell), select the numerical method for solving ODE (*Integration Method* cell) and select the time unit of a final time and a simulation step (*Time Unit* cell). The time unit must be the same as in the model.

- *Output Variable* ❺
  Select the output variable of the model which you want to observe (*Variable* column).
- *Charts Parameters* ❻
  Select the location of simulation charts (embedded in worksheet or separated chart sheets) in which model variables will be displayed (*Location* cell).
- *Model Variables in Charts* ❼
  In chosen table row, select the variable of the model which you want to display in the chart (*Variable* column), chart number (*Chart No.* column) and if it is needed to check secondary y-axis (*Sec Y-axis* checkbox).

2.3 Generating Disturbances

If you want to simulate model response to disturbances in input (also load) variables, fill the table *Disturbances* ❽ (see Figure 4):

- *Variable* column
  Select input model variable which you want to change.
- *Change* column
  Select type of change. You can select *step*, *ramp* or *sinus* change.
- *Parameters* columns
  Fill size of change (or amplitude for sinus change) in the column *1^st^* and number of periods for sinus change.
- *Times* columns
  Fill initial time of change (or time of change for step change) in the column *From* and the final time of change (for ramp or sinus changes) in the column *To*.

Note: The PSIC add-in does not enable to select impulse disturbance in the column *Change*. However, you can generate it by two step changes with the same size but the different unary sign (+ or -).

2.4 Simulation and Results

Activate a datasheet *Model #* with a finished mathematical model and run simulation by the **Run** button (see Chapter 1.3).

Note: If other than the datasheet *Model #* is active, the **Run** button is not enabled.

The results are saved in an output sheet *Report #* in the following tables and charts (see Figure 5):

- *Model Variables and Parameters* ❾
  In each table row, the time instants of simulation and correspondent values (or Excel formulae) of model quantities are saved.
- *Model First-order ODEs* ❿
  In each table row, values (or Excel formulae) of derivative of quantities (i.e. the left-hand sides of the 1st ODEs) at a given time instant of simulation are saved.
- *Chart No. #* ⓫
  In each chart, quantities set in the table *Model Variables in Charts* are plotted.

Note: Yellow cells of an output sheet *Report #* indicate data taken from a data sheet *Model #*.

Note: Although an output sheet *Report #* prevents change or delete results, Excel formulae can be viewed and tables and charts can be formatted in a standard way.

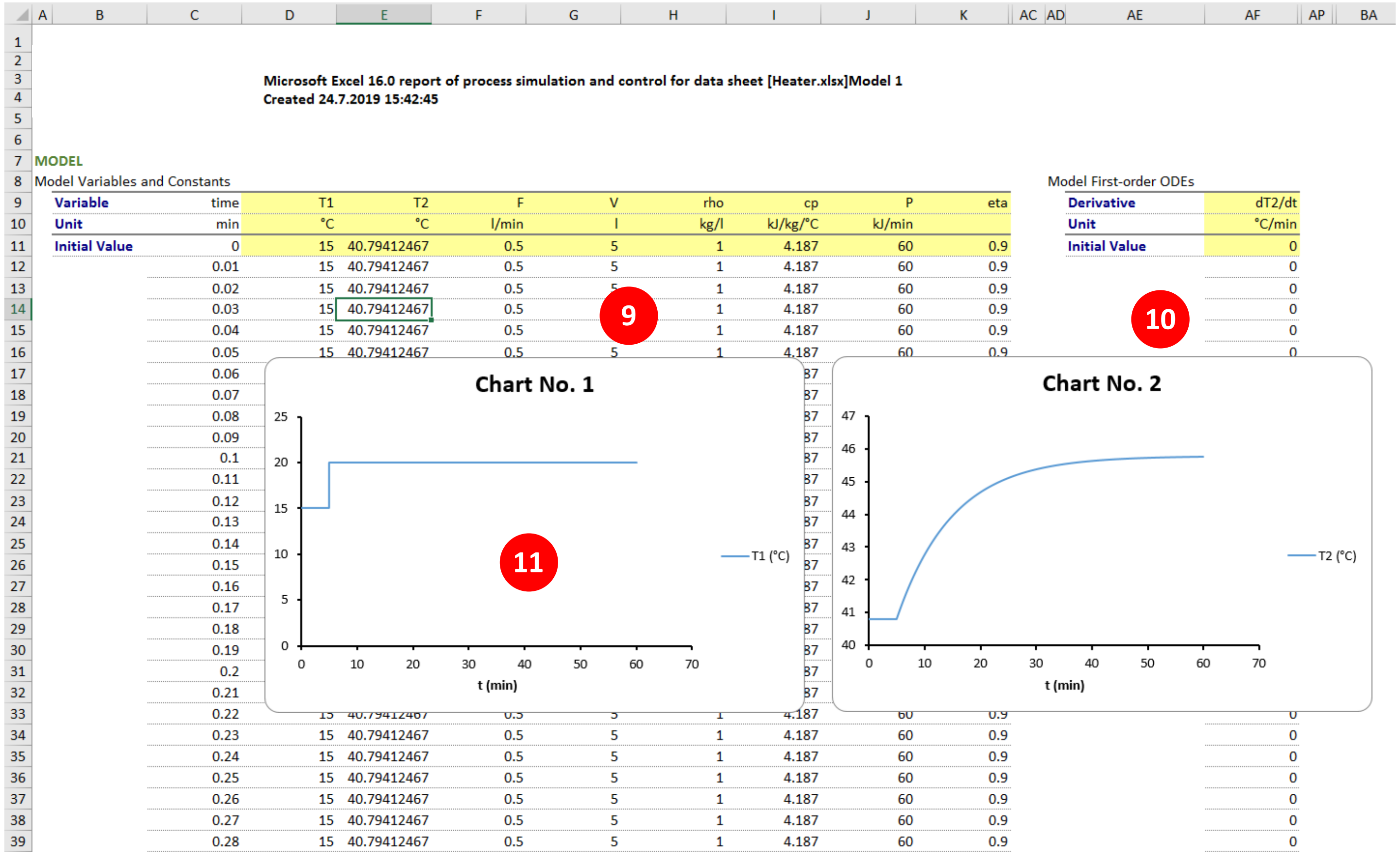

Figure 5: A Report # output sheet - table of model quantities, table of derivatives of the 1st ODEs and charts

3 Closed-Loop Feedback Control

Closed-loop feedback control is configured in green cells on a data sheet *Loop #* that is generated by the **New Loop** button (see Chapter 1.3). The new mathematical model of controlled system (in the yellow cells), simulation parameters (in the blue cells) and simulation outputs (in the gray cells) are entered in the same sheet.

> Note: To configure a control loop with an already finished model, activate completed datasheet *Model #* before using the **New Loop** button. The PSIC add-in will offer to take a model from a completed datasheet.
>
> Note: A datasheet *Loop #* is protected so the user cannot enter data of other values or types than requested. You cannot copy data from other worksheets, files, or programs.

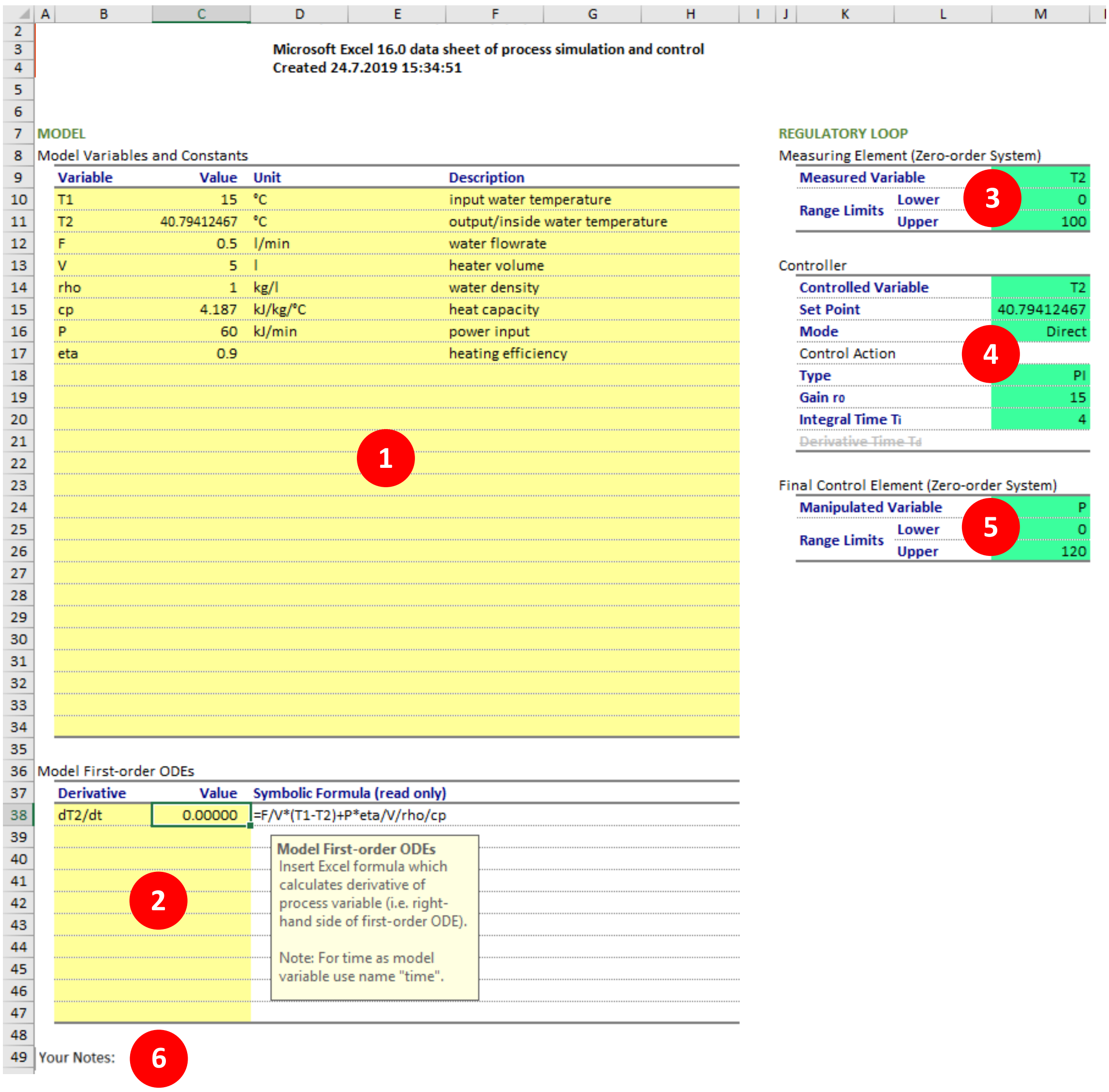

Figure 6: A Loop # data sheet – design of closed-loop feedback control

3.1 Loop Design

If you design a feedback control loop, complete the following table in a data sheet *Loop #* (see Figure 6):

> Note: If you configure a feedback control loop with an already finished model skip filling tables ❶ and ❷.

- *Model Variables and Constants* ❶
  Enter marks of quantities of model (*Variable* column), their values at the beginning of the simulation (*Value* column), their physical units (*Unit* column) and their descriptions (*Description* column).
- *Model First-order ODEs* ❷
  Select variables of which the first derivatives occur in the left-hand sides of the 1st ODEs (*Derivative* column), and insert Excel formulae which calculate derivatives i.e. the right-hand sides of the 1st ODEs (*Value* column). Arguments of Excel formulae must be addresses from the column *Value* of the table *Model Variables and Constants*.
- *Measuring Element (Zero-order System)* ❸
  Select the measured variable (*Measured Variable* cell) and insert measured limits (*Limits: Lower* and *Higher* cells).
- *Controller* ❹
  Select the controlled variable (*Controlled Variable* cell) and insert its desired value (*Set Point* cell). Next, insert controller mode (*Mode* cell), select type of control action (*Type* cell) and insert values of adjustable controller constants (*Gain r0*, *Integral Time Ti* and *Derivative Time Td* cells).
- *Final Control Element (Zero-order System)* ❺
  Select the manipulated variable (*Manipulated Variable* cell) and insert adjustable limits (*Limits: Lower* and *Higher* cells).

In addition to these mandatory data, you can fill cells labeled *Your Notes* ❻ by your optional notes.

3.2 Settings Simulation and Outputs Parameters

Before running the simulation fill simulation and output parameters in the following tables (see Figure 7):

- *Integration parameters* ❼
  Enter the final simulation time (*Final Time* cell) and the simulation step size (*Integration Step* cell), select the numerical method for solving ODE (*Integration Method* cell) and select the time unit of a simulation step (*Time Unit* cell). The time unit must be the same as in the model.
- *Output Variable* ❽
  Select the output variable of the model that you want to observe and control (*Variable* column).
- *Charts Parameters* ❾
  Select the location of simulation charts (embedded in worksheet or as separated chart sheets) in which results of simulation will be displayed (*Location* cell).
- *Model Variables in Charts* ❿
  In chosen table row, select variable of model which you want to display in chart (*Variable* column), chart number (*Chart No.* column) and if it is needed check secondary y-axis for the variable (*Sec Y-axis* checkbox).
- *Regulatory Loop Variables in Charts* ⓫
  In chosen table row, select variable of control loop (setpoint, control deviation, output from controller) which you want to display in chart (*Variable* column), chart number (*Chart No.* column) and if it is needed check secondary y-axis for the variable (*Sec Y-axis* checkbox).

Note: Model variables and regulatory loop variables can be arbitrary combined in charts.

3.3 Generating Disturbances or Set Point Change

If you want to simulate model response to disturbances in input (also load) variables or changes in the setpoint, fill the table *Disturbances / Set Point Changes* ⓬ (see Figure 7):

- *Variable* column
  Select input model variable or set point which you want to change.
- *Change* column
  Select type of change. You can select *step*, *ramp* or *sinus* change.
- *Parameters* columns
  Fill size of change (or amplitude for sinus change) in the column *1st* and number of periods for sinus change.
- *Times* columns
  Fill initial time of change (or time of change for step change) in the column *From* and the final time of change (for ramp or sinus changes) in the column *To*.

Note: The PSIC add-in does not enable to select impulse disturbance in the column *Change*. However, you can generate it by two step changes with the same size but the different unary sign (+ or -).

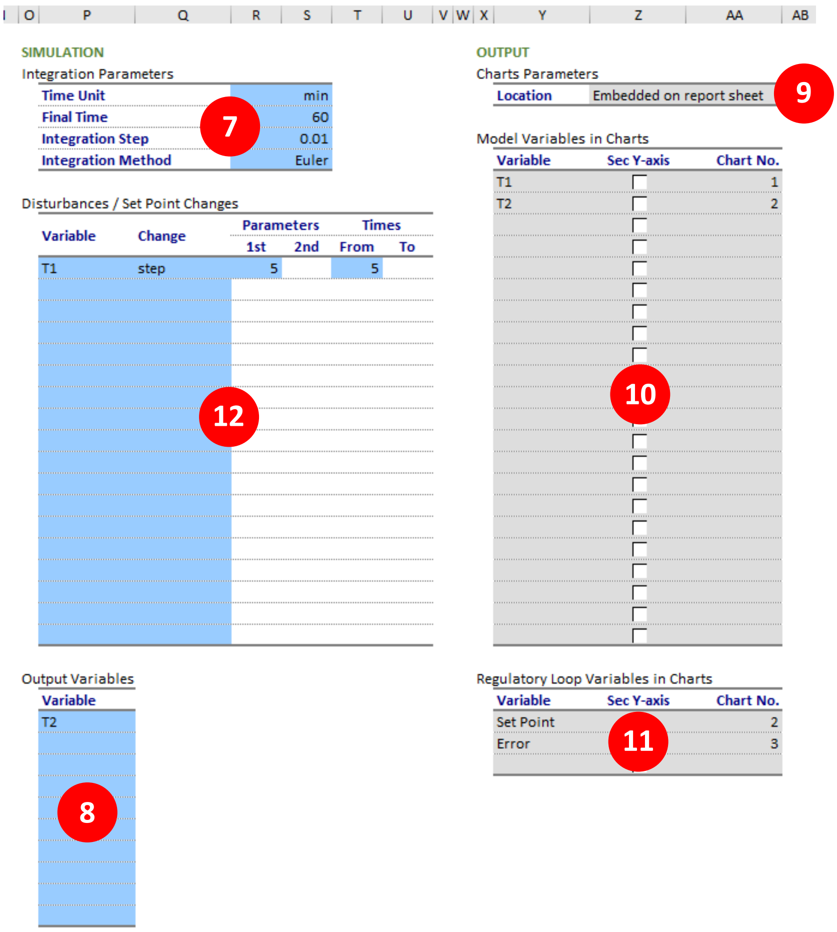

Figure 7: A Loop #data sheet – setting of simulation, disturbances and output parameters

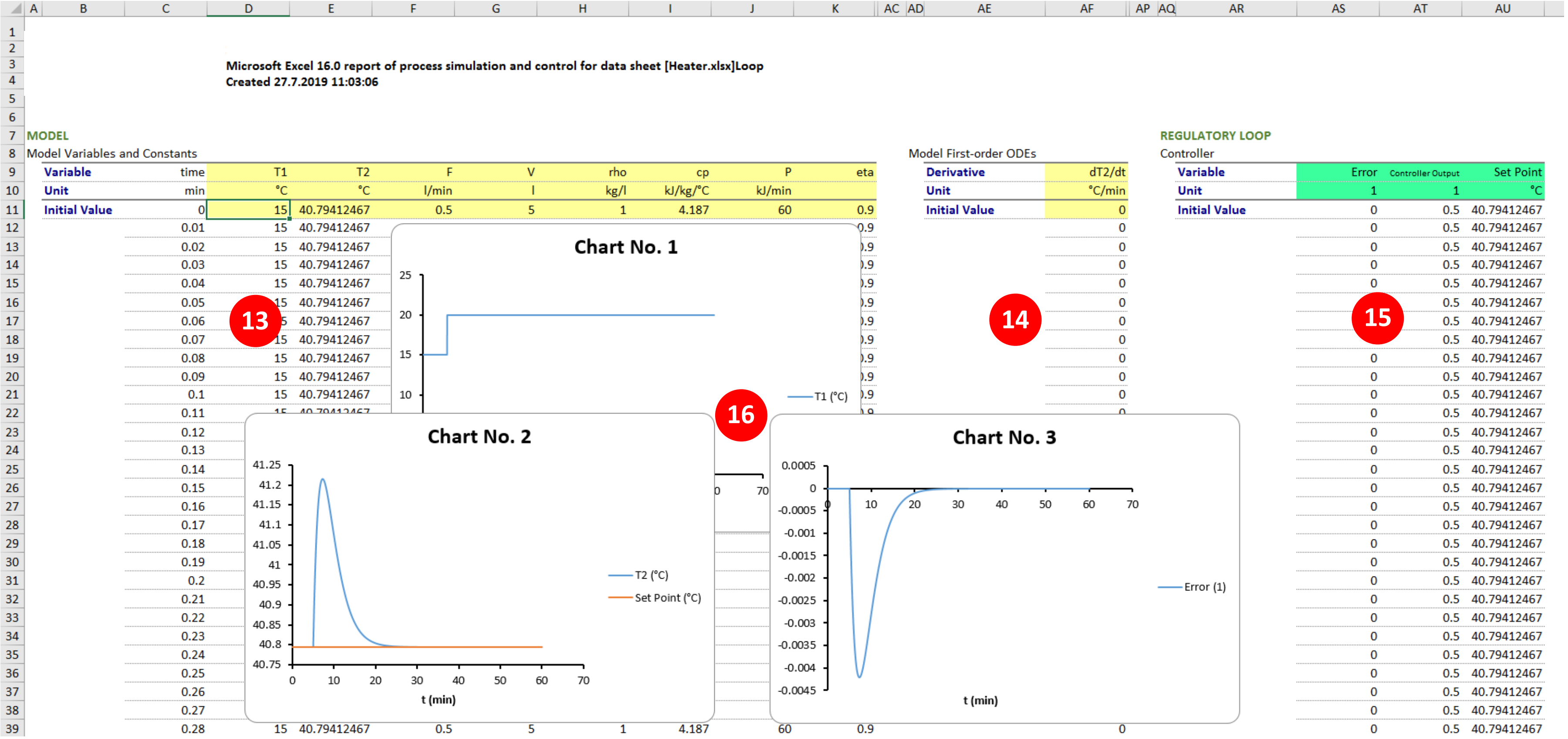

Figure 8: A Report # output sheet - table of model quantities, table of derivatives of the 1st ODEs, table of loop quantities and charts

3.4 Simulation and Results

Activate a datasheet *Loop #* with a feedback control loop and start simulation by the **Run** button (see Chapter 1.3).

> Note: If other than the datasheet *Loop #* is active, the **Run** button is not enabled.

The results are saved in an output sheet *Report #* in the following tables and charts (see Figure 8):

- *Model Variables and Parameters* ⓭
  In each table row, the time instants of simulation and correspondent values (or Excel formulae) of model quantities are saved.
- *Model First-order ODEs* ⓮
  In each table row, values (or Excel formulae) of derivative of quantities (i.e. the left-hand sides of the 1st ODEs) at a given time instant of simulation are saved.
- *Controller* ⓯
  In each table row, values (or Excel formulae) of loop variables (set point, control deviation, controller output) at a given time instant of simulation are saved.
- *Chart No. #* ⓰
  In each chart, quantities from the table *Model Variables in Charts* are plotted.

> Note: Yellow cells indicate data taken from a data sheet *Loop #*.
>
> Note: Although an output sheet *Report #* prevents change or delete results, Excel formulae can be viewed and tables and charts can be formatted in a standard way.

3.5 Controller Setting and Tuning

If you activate an output sheet *Report #* with results of a simulation of a closed-loop feedback control the **Mode**, **Action**, **Gain r0**, **Integral Time Ti** and the **Derivative Time Td** buttons (see Chapter 1.3) becomes enable. They can be used to change controller mode, control action and to sensitively tune controller adjustable constants. Changed or tuned values always confirm by the **Rerun** button in order to recalculate simulation results and redraw simulation charts.

> Note: If other than an output sheet *Report #* with simulation results of regulation is active, buttons for controller setting and tuning are not enabled.
>
> Note: If the simulation has not yet recalculated by the **Rerun** button it is possible to take changed values back by the **Reset** button (see Chapter 1.3).

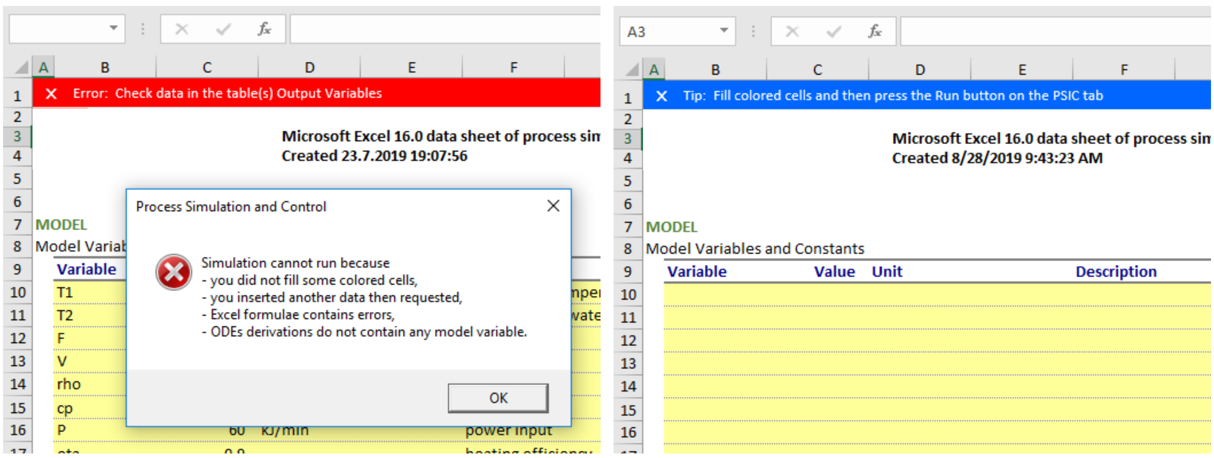

Figure 9: A sheet message highlighting error (red row) and providing tip (blue row)

4 Sheet Messages

In addition to information in dialog boxes and the status bar, the PSIC add-in highlights errors and provides tips using colored sheet messages that are always displayed above the sheet identification header (see Figure 9). If you want to hide the message, click on the message.

5 Saving Results

Workbooks with sheets generated by PSIC add-in can be stored into standard Excel document, i.e. XLSX file.

> Note: Sheets with simulation results significantly slow down opening and saving the workbook and increase file size due to the large amount of data and formulae. When you design more models and control loops is therefore recommended to work with multiple workbooks (each workbook for one model and loop).

Resources

[1] Enable or disable macros in Office files. MICROSOFT. *Office Online* [online]. © 2014 [cit. 2015-01-08]. Available from: https://support.office.com/en-au/article/Enable-or-disable-macros-in-Office-files-12b036fd-d140-4e74-b45e-16fed1a7e5c6.