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# Design and numerical simulations of the thermohydraulic systems in Simulink®

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*Recent developments in designing of the thermohydraulic systems have heightened the need for special software tools. Possibility of incorporating the measured data, easy and quick rearrangement of the system and short simulation time play a key role in successful progress in designing of the thermohydraulic systems. Commercial software sometimes does not fit to our special tasks or it lacks some utilities. This paper attempts to show usefulness of MATLAB® and Simulink in the development of the "drag and drop" software.*

**Keywords:** thermohydraulic systems, Simulink, simulation

## 1. Introduction

One of the most significant current field of interest in the industry is focused on thermohydraulic systems as air conditioning, coolant circuits and many similar systems dealing with heat transfer. A lot of suitable "drag and drop" commercial software is able to design and simulate different thermohydraulic systems. But sometimes there is a demand for solving very special task. In such cases we may lack some utilities such as development of new components, integration of measured data etc.

The purpose of this paper is to review possibilities of MATLAB and Simulink in the case we need to develop "drag and drop" software (library) for design and simulation of the thermohydraulic systems. Developed library can contain graphical blocks representing real components of the thermohydraulic system such as pipes, pumps, heat exchangers etc. These blocks can be consequently connected to each other and thus create the simulation model of the real thermohydraulic system. MATLAB and Simulink has been chosen as a development tool because it is well-known for many engineers and this software can be found in almost every academic environment. The procedures and information given below can be used also for development of libraries concerning also in other fields than thermohydraulic systems.

## 2. Physical and mathematical background

There is no need to introduce MATLAB and Simulink widely. Briefly it can be said, that MATLAB includes a lot of functions and methods for solving mathematical problems numerically. Simulink then serves as a "graphical interface" for some methods from MATLAB. Using the Simulink makes the calculations more transparent. Methods, functions etc. in Simulink are represented graphically as blocks. These blocks can be connected in the right way to each other. Thus can be easily graphically created mathematical model of any dynamical system. Consequently the user can set up the special properties of the blocks and the simulation time and then can run the simulation.

In thermohydraulic systems we usually deal with physical variables such as temperature, heat, pressure, fluid flow rate etc. The relationships among these variables are described by physical or empirical laws/relations in the dependence of system parts. These laws/relations in the mathematical form create background of every computational software. Matlab and Simulink offer a few tools for developing mathematical background of the graphical blocks. It is worth to notice that Simulink already contains several blocks capable of integration of simply relationships (for instance *Fcn* block, *Interpreted MATLAB Function* block). Also more complex MATLAB code can be easily used in Simulink using the *MATLAB function* block. Using all of these blocks do not require extra knowledge of MATLAB programming language.

In this paper it is supposed we need to develop the whole new library containing such elements as pipes, pumps, heat exchangers, temperature sensors, pressure sensors etc. There is more than one practical ways of developing special libraries. Basically we can choose between *physical network approach* (Simscape see [1],[2]) and *signal approach* (Simulink). For the purpose of the considered phenomena was chosen signal approach using **Level-2 MATLAB S-Function**. In this approach the blocks have unidirectional connecting ports – inputs and outputs ports. The input ports contain information about incoming signal in each simulation step. This signal is then transformed according to some physical law or empiric relationship $\boldsymbol{Y} = \boldsymbol{f}(\boldsymbol{X})$, where X is the input signal, Y is the output signal (see Fig. 1).

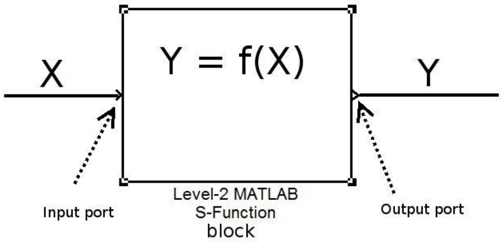


**Fig. 1:** Signal transformation scheme

The Using 2-level Matlab function block is one of the more practical ways of developing special blocks. However there is already assumption about some object oriented programming knowledge. Templates files (*msfuntmpl_basic.m*, *msfuntmpl.m*) offered in MATLAB help can be recommended for introduction in programming 2-level Matlab function block. 2-level Matlab function files has common suffix ".m". Their inner structure is exactly given. Among required methods in these files is method *function Outputs(block)*. In this section is possible to incorporate physical laws and other relationships in mathematical form. Especially it is possible to include algebraic-differential equations (DAEs). The mathematical models consisting only of DAEs are often denoted as 1-D models, because there is taken into account at most one spatial variable and also one time variable. Partial differential equations can be also included, but then the libraries lose their the main advantage in comparison with FEM/CFD solvers, i.e. short computational time.

2-level Matlab function allows to use MATLAB functions. Through these functions it is possible to integrate measured data and consequently interpolate from this data, read data from Excel sheets etc. It is also possible to program delays of physical variables transport.

## 3. Thermohydraulic system consisting of the blocks

The main idea of proposed work is to develop library containing blocks representing real components of thermohydraulic systems. The user then does not have to take a care about computational methods because it is integrated and set in the blocks. The user can consequently treat with the blocks as with real components of the thermohydraulic system, i.e. user can connect heat exchangers with pumps by pipes, set up diameters of a pipe, set characteristic parameters of pump, etc. as in the real system. Thus can be arranged the whole thermohydraulic system. If the rearrangement of the system is necessary due to optimalization or development, it can be done in a short time only by dragging the blocks to the new positions. New simulation can be computed then. Look and feel of the blocks can be also adapted, which makes the model more well-arranged. Not only colours of the blocks can be changed to distinguish among the blocks, but also the pictures can be set as background of the blocks – see the Fig. 2, where is on the heat exchanger block set the picture of "used" heat exchanger.

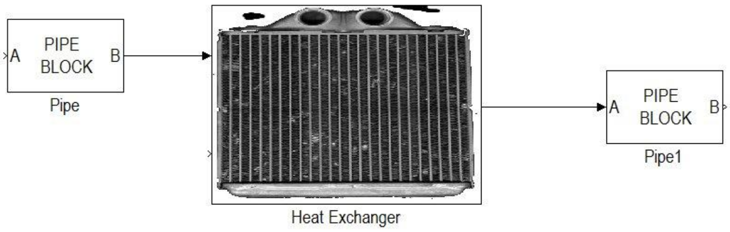


**Fig. 2:** Heat Exchanger block with a picture of the used heat exchanger on the background

## 6. Results

Although development of the library is still in progress, some simulations are done. Several blocks are prepared and can be easily set up for simulations – see the Fig. 3, where is the example of easy pipe setting.

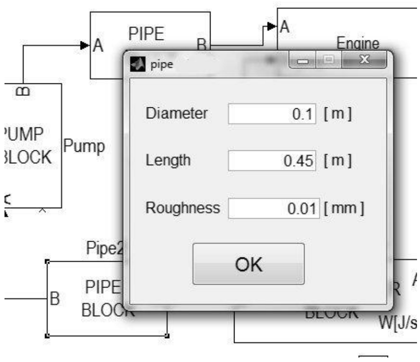


**Fig. 3:** Component (pipe in this case) setup by double-click

On the Fig. 4 is shown part of library containing sensors. As seen in menu there are another groups of elements with similar features as basic elements of thermohydraulic systems, different pipes, sensors, sources (heat sources, fluid flow source ...), utilities (displays, graphs, ..).

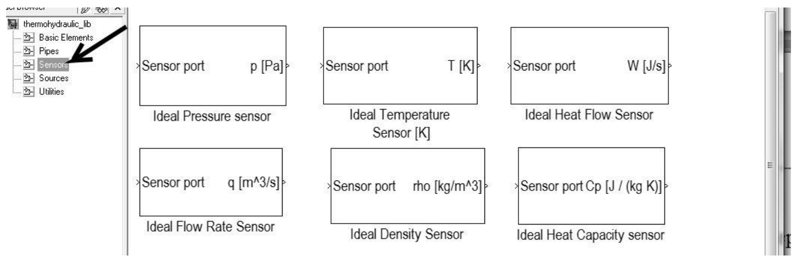


**Fig. 4** Example of the part of library containing Ideal sensors

Finally the last Fig. 5 shows the example of some simple cooling circuit design. This example should examine cooling of selected engine by cooling fluid flowing through the system. It is possible to optimize this circuit easily by changing the properties of used elements as pipes diameters, pump characteristic, heat exanger (cooler) characteristic etc. The results are possible to view during the simulatons in displays blocks or the results can be ploted in the graphs.

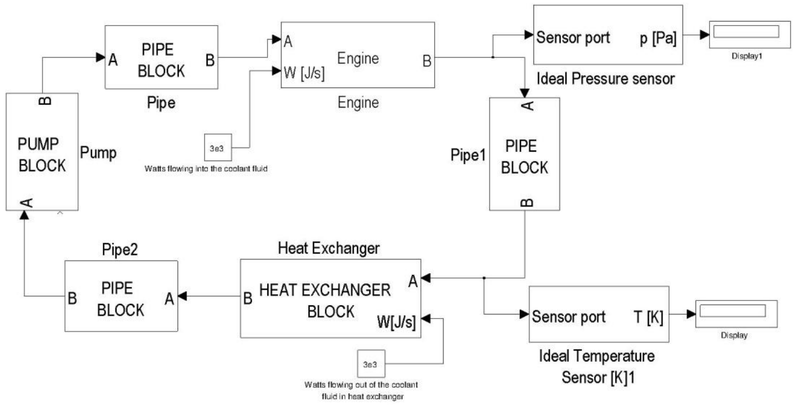


**Fig. 5:** Easy example of the cooling circuit design

## 7. Conclusion

MATLAB with Simulink offer more than one tool for developing specialized libraries and “drag and drop“ software. Its advantage in comparison with commercial software is, that we can change source code of the components. New components can be added in a short time. This paper has given an account of and the reasons for the widespread use of 2-level Matlab function. Thus is possible to make the library more flexible in the cases we need to solve special task.

Easy simulations have been already computed with the thermohydraulic library. Easy cooling circuits and systems containig heat exchanger were computed. Results are in a good agreement with real thermohydraulic systems and measurement. To date the library is restricted only for simulating easy systems..

A number of different elements can be still added to the library. Further development should therefore concentrate on the investigation of the new elements integration. It would be also interesting to think about how to spare more computational time.

## Literature

[1] MATLAB Version R2011a user guide

[2] http://www.mathworks.com/support/

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