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REFTOOLBOX - REFRIGERATION TOOLBOX FOR MATLAB/SIMULINK

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Abstract: RefToolbox is an useful utility for MATLAB/Simulink, which adds support of thermodynamic data export and ph diagram plotting. It is based on CoolProp and supports large number of refrigerants and other mediums. Using graphical user interface it is possible to gain thermodynamic dependencies of state variables and export them into lookup tables. Also ph diagrams can be assembled using this tool and then used during simulations and measurements of heat pump and other refrigeration applications.

Keywords: refrigeration, heat pump, MATLAB/Simulink, ph diagram

1 INTRODUCTION

Modeling, simulations and control of refrigeration systems require measurement of thermodynamics variables. However, some of the variables can not be directly measured (for example specific enthalpy, superheat, quality, mass density etc.). These variables can be acquired using equation of state, an equation employing pressure, temperature and specific volume. The simplest equation of state is an ideal gas equation of state [1]

$$pV = nRT \quad (1)$$

where p is vapor pressure, V is the vapor volume, n is amount of vapor (number of moles), R is the gas constant and T is temperature. This equation holds also for real gases (with some accuracy), but only in limited range of state variables (superheated vapor). As in refrigeration systems the medium usually change its phase, the ideal gas equation of state can not be used for computations in whole state variables range.

There are several other (usually quite complicated) formulaes of equation of state, e.g. Van der Waals equation of state, Redlich–Kwong equation, Beattie–Bridgeman equation, Benedict–Webb–Rubin equation, Virial Equation of State, Helmholtz energy equation and others [1, 2]. Some of these equations can handle all phase regions (gas, two-phase, liquid) needed in refrigeration computations and thus can be used for this purpose. However, most of them are very complex and thus not useful for fast computations during simulations, real-time estimation or control.

That is the reason why we developed RefToolbox, which is able to generate the dependencies of thermodynamic variables into lookup tables for later usage. Moreover it provides ability of presentation refrigeration cycle in ph diagram (even dynamically during simulations or measurement).

2 REFTOOLBOX

Reftoolbox is a toolbox, which adds support of refrigeration computations and visualizations into MATLAB/Simulink environment. It is focused on two main tasks, refrigeration data export and visualization of refrigeration diagrams. The overview of RefToolbox principle is shown in Fig. 1.

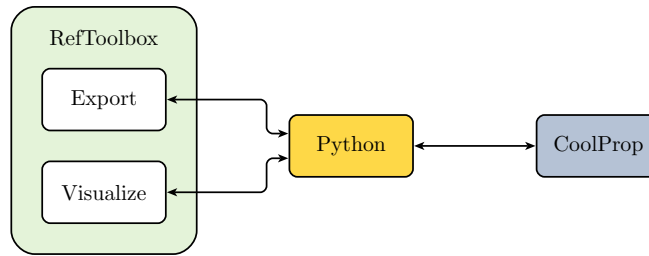


Figure 1: RefToolbox principle diagram

RefToolbox was developed under MATLAB environment, especially App Designer. The toolbox is based on CoolProp [3], a library providing equations of state based on Helmholtz energy formulations [4] for all generally used refrigerants (and other fluids). CoolProp is accessible from MATLAB via Python interface, which can be easily added into MATLAB by installing the Python (one of supported versions - 2.7, 3.5, or 3.6). To bring the Python into operation, it might be needed to configure it by command

```
>> pyversion '<path>'
```

where <path> stands for Python executable file. After successful configuration the same command can be used for validation of Python configuration:

```
>> pyversion
    version: '3.6'
    executable: 'C:\Python\Python36\python.exe'
    library: 'C:\Python\Python36\python36.dll'
    home: 'C:\Python\Python36'
    isloaded: 1
```

CoolProp can be then installed by invoking

```
>> [v,e] = pyversion; system([e,' -m pip install --user -U CoolProp '])
```

and then it is ready to use. To simplify the commands and improve their readability we can run

```
>> import py.CoolProp.CoolProp.PropsSI
```

what will allow us to use directly the PropsSI function. For example, the temperature of R1234yf refrigerant under pressure of 3 bar and quality of 0.5 can be obtained by

```
>> T = PropsSI('T','P',300000,'Q',0.5,'R1234yf')
T =
    2.716436975593448e+02
```

Honestly, the quality value is not important in this case, as refrigerant temperature is dependent only on its pressure in two phase area. But as an example it is quite well suitable.

2.1 DATA EXPORT

RefToolbox provides data export of three main types of dependencies:

- Single variable dependency, e.g. $T = f(h)$ for $p = const$.

- Two variables dependency, e.g. $T = f(h, p)$
- Partial derivatives approximation $\left(\frac{\partial p}{\partial p}\right)_h = f(h, p)$

All of the dependencies can be exported as vectors of values or MATLAB/Simulink Lookup Table (an object of Simulink. lookuptable class) for further use within Simulink models. The user is expected to provide the range and the step of independent variables and the data are automatically obtained, saved into desired format and also plotted in GUI. In Fig. 2 there is an example of two variables dependency in RefToolbox GUI.

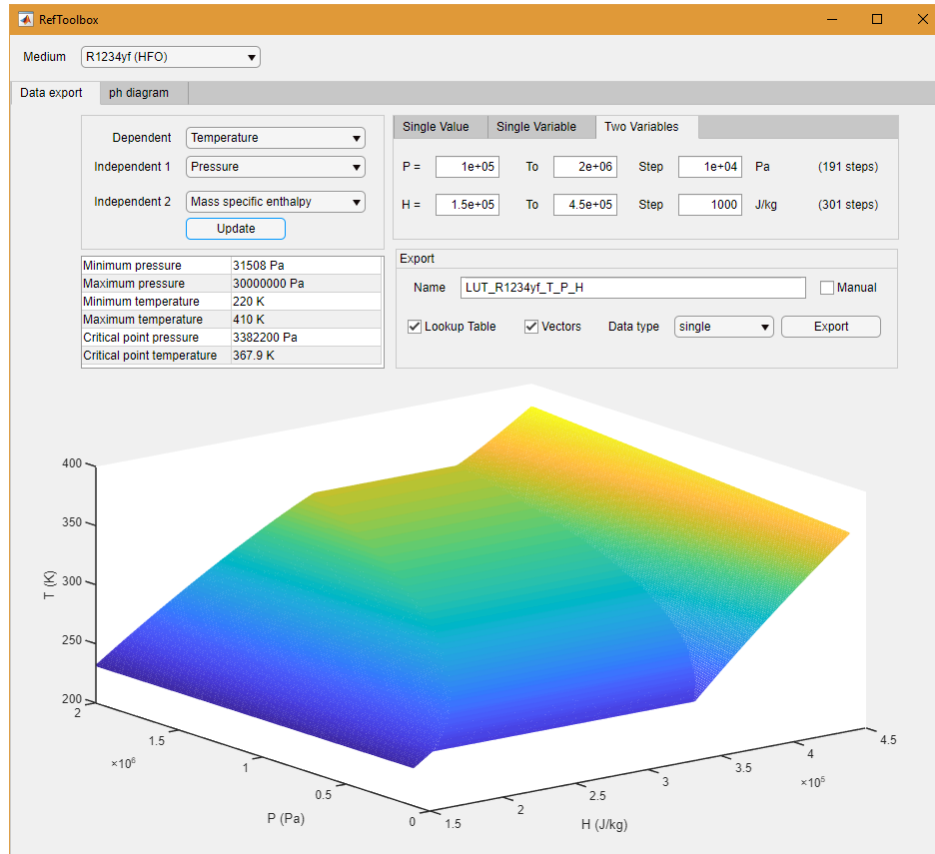


Figure 2: RefToolbox two variable dependency

2.2 PH DIAGRAM DRAWING

Drawing a ph diagram requires two parts, a diagram background and the data to be presented. Diagram background usually consist of two axes, specific enthalpy as x axis and pressure as y axis. There are also isotherms, isentropic and isochoric curves shown to allow better orientation. Moreover the boundaries of phases are usually presented. Thus it is quite complicated to correctly print the diagram background with keeping its clarity. The ph diagram preview is shown in Fig. 3.

The second part of ph diagram are the presented data. It can consist of single point in diagram, representing a state of medium at steady-state situation, or a cycle, which can describe state changes in some technologic process (usually in heat pump or other refrigeration device).

Sometimes it is convenient to see the ph diagram in time, so we developed a Simulink library, which

is capable to update the cycle or point in ph diagram during simulation of MATLAB/Simulink model.

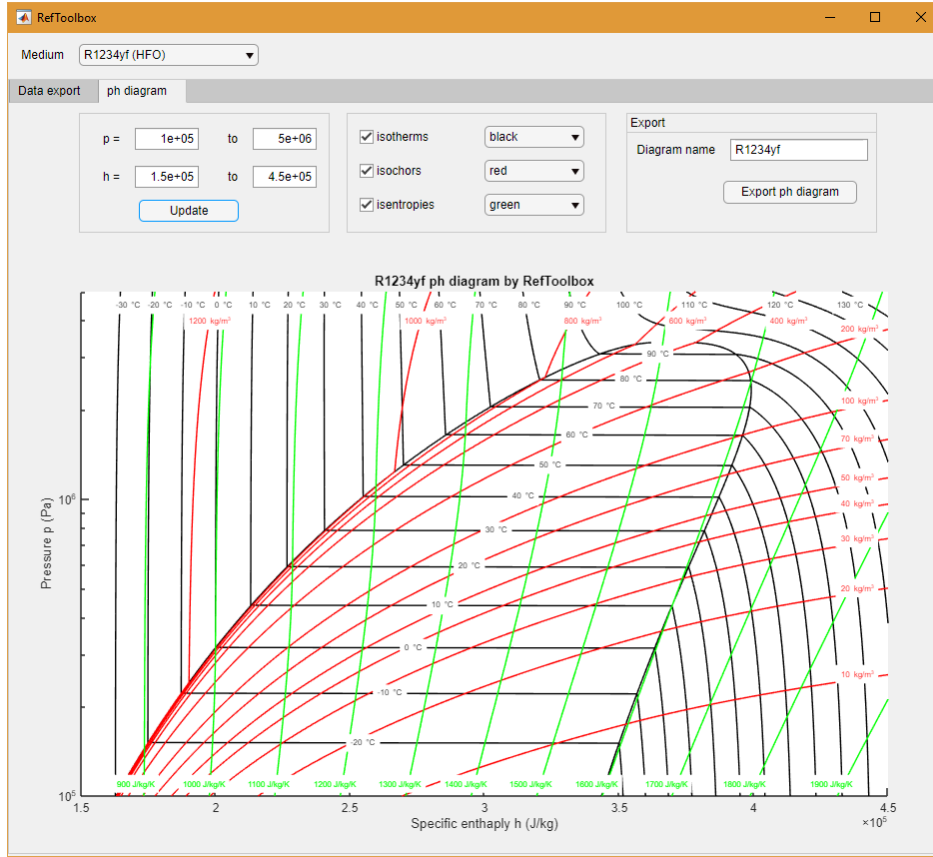


Figure 3: RefToolbox ph diagram presentation

3 USAGE EXAMPLES

3.1 LOOKUP TABLES

Exported lookup tables can be used for real-time computations or in simulations. As an example we take computation of refrigerant superheat (SH), which is defined as a difference between the actual temperature of the refrigerant vapor (T) and the saturation temperature of the refrigerant (T_{sat}) at that same point

$$SH = T - T_{sat}. \quad (2)$$

The saturation temperature can be obtained from pressure measurement

$$T_{sat} = f(p), \quad (3)$$

where $f(p)$ is function returning saturation temperature based on pressure and implemented by lookup table exported from RefToolbox.

3.2 HEAT PUMP SIMULATIONS AND MEASUREMENTS

RefToolbox was successfully utilized during measurement on heat pump testbench, where the refrigeration circuit is controlled by Infineon AURIX Tricore based control unit, which sends the measured

pressures and temperatures via CAN bus to MATLAB/Simulink. RefToolbox is then used for real-time visualization of ph diagram of refrigeration cycle based on received measurement data as shown in Fig. 4.

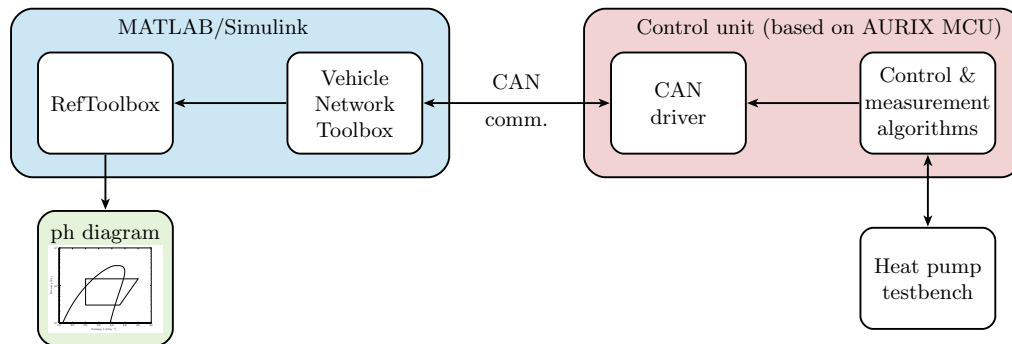


Figure 4: Usage of RefToolbox during measurements on heat pump testbench

4 CONCLUSION

Within this paper a toolbox for MATLAB/Simulink named RefToolbox was described. It was developed to allow thermodynamic computations, data export and visualisations particularly for refrigeration systems. The paper presents the principle of the RefToolbox as well as the examples of toolbox outputs and even the toolbox practical applications.

There are multiple possible improvements, like GUI enhancements, units settings (now fixed for basic SI), additional mediums and others, what will be implemented in the second version of RefToolbox.

ACKNOWLEDGEMENT

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