T H E R M O P T I M®

GETTING STARTED

JAVA VERSION

Refrigeration example

VERSION 1.5

CONTENTS

GETTING STARTED

This document intends to allow a user to get quickly used to THERMOPTIM (in less than half an hour), by using the basic elements of the software. Subsequently he or she will be able to deal with more complicated problems, especially those making use of nodes or heat exchangers.

You will find additional information in Thermoptim's reference manuals available through the Help menu of the simulator.

The following points will be addressed :

- presentation of some basic notions which must be understood before using the software

- analysis of a simple example: the calculation of a refrigeration cycle.

- plot of the cycle on a Vapor interactive chart.

- analysis of a more complex example: the total injection refrigeration cycle

Basic notions

The study of a thermodynamic system can be divided into five main tasks :

- 1) the analysis of the structure of the system under investigation, which identifies its main components and their connections: for instance, a thermal machine consists of heat exchangers, compressors, turbines or expansion devices, combustion chambers...

- 2) for each component, the identification of the thermodynamic fluids which are used: for instance, the fluid compressed in a gas turbine is air, which burns with a fuel in the combustion chamber. The resulting flue gases expand in a turbine.

- 3) for each component, the selection of the kind of system to be considered (open or closed): for instance, the study of the compression in a piston compressor must be made in closed system, while that of the expansion in a gas turbine is to be made in open system.

Let us recall that a closed system (respectively an open system) is characterized by the absence (respectively the existence) of mass transfer through its boundaries.

- 4) the description and the calculation of the processes undergone by the different fluids in the components, taking into account their interconnections.

- 5) the calculation of the overal balance of the system analysed.

THERMOPTIM has been designed in order to facilitate the calculation of complex thermodynamic systems, but it cannot replace the user for making the detailed analysis of the system under investigation, which corresponds to the three first steps above.

Before entering his project in the software, the user must have made this analysis. Otherwise there is a risk that the description will be done improperly.

Once this analysis is made, each component can be easily defined with the points, processes, nodes and heat exchangers described below, which together form a project.

THERMOPTIM makes use of four kinds of **substances**: pure ideal gases, composed ideal gases, condensable vapors (which are pure substances), and ext ernal substances. Perfect gases are ideal gases whose specific heat is independant of the temperature. A given substance may exist (under different names) as an ideal gas and a condensable vapor.

The substance can be pure, in which case its properties are predefined in the software, or it can be compound. In the case of gases, the user has to define the composition from the other gases present in the database, by indicating for each of them, its name and its molar or mass fraction. Properties of the composed substance are then determined from those of its constituents.

A **point** designates a particle of a substance and allows the user to define intensive state variables: pressure, temperature, specific heat, enthalpy, entropy, internal energy, exergy, and quality. A point is identified by its name and the name of the associated substance. To calculate it, one may either :

- enter the values of at least two state variables, generally its pressure and temperature for open systems, and its volume and temperature for closed systems.

- automatically calculate them by using for instance one of the processes defined below.

Processes correspond to thermodynamic evolutions undergone by a substance between two states. A process associates therefore two points such as defined previously, an inlet and an outlet point. Moreover, it indicates the mass flow rate involved, and therefore allows one to calculate extensive state variables, and notably to determine the variation of energy involved in the course of the process.

Processes can be of several types: compression, expansion, combustion, throttling, heat exchange, water vapor / gas mixtures (the latter includes six different categories of evolutions), and external ones. According to each case, various characteristics of the process have to be specified, for example, in a compression, its isentropic or polytropic efficiency.

A cycle can thus be described as a set of points connected by processes. To the extent that the mass flow rate fluid is the same in all the evolutions, processes and points are sufficient. If this is not the case, it may be necessary to at least partially describe the network of the fluids involved. Then the first elements to define are the network **nodes** which are described in the documentation.

Simple refrigeration cycle

Objective : a R134a compression refrigeration cycle operates between an evaporation pressure of 1 bar and a condenser pressure of 12 bar.
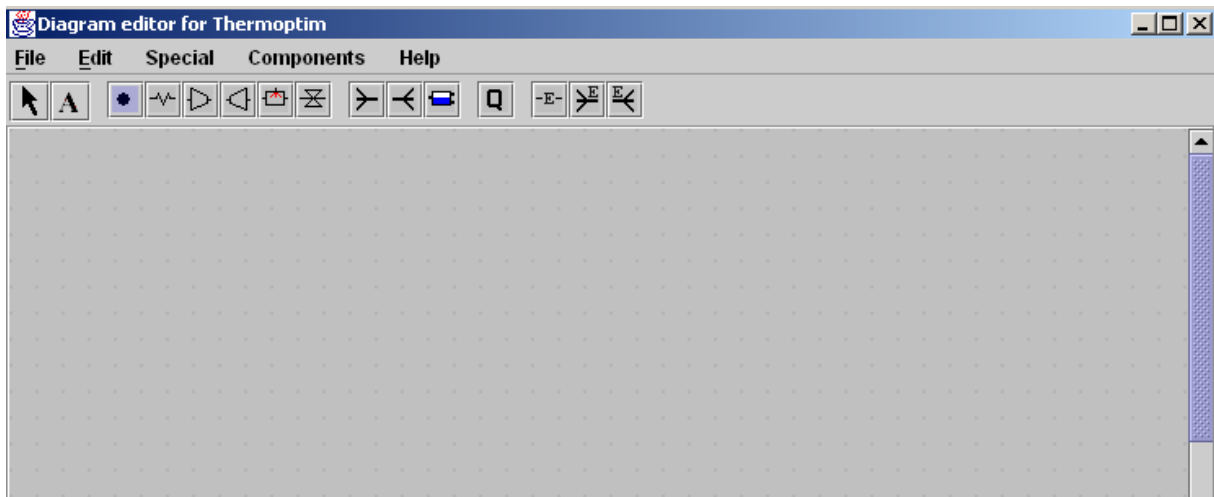
compression refrigeration cycle block diagram
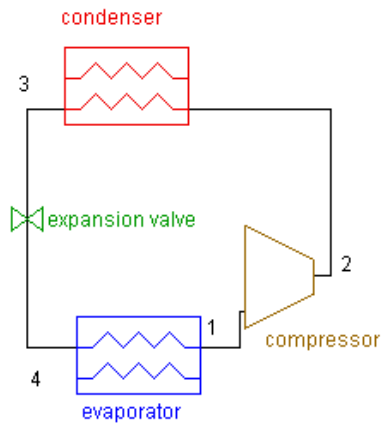
Before entering the compressor, the gas is superheated by 10 K above the saturation temperature, and before entering the expansion valve, the liquid is sub-cooled by 5 K. The compressor polytropic efficiency is 0.75.

Model the refrigeration cycle and calculate its efficiency

Creation of the diagram

Placement of the components

Run THERMOPTIM without loading a project, which displays the Diagram Editor screen:

On the palette appear the components available: process-points, exchange, compression, expansion and throttling processes, mixers, dividers, separators, external sources and external components.

The refrigeration cycle block diagram clearly shows which components should be selected : the compressor ▷, the condenser, which will be represented here by two exchange processes ⌁, one for desuperheating and one for the condenser itself, the expansion valve ⌧, and the refrigeration effect, which is an exchange process ⌁.

To represent the compressor, select a compressor component on the palette and place it on the editor by clicking the crosshair cursor at the appropriate location. A property editor is opened.

Name the compressor "compressor", then click on the "outlet port" tab:
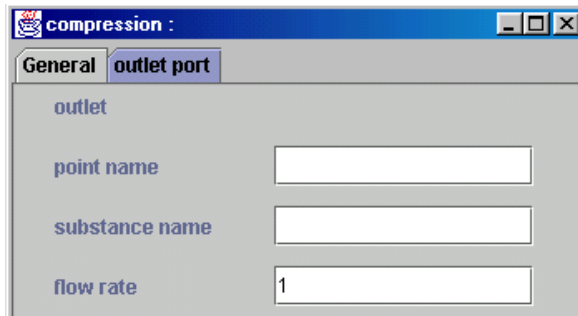
By default, the flow rate is set to 1. Name the point "2".

To enter the substance name, you may either type it if you know it, or get it from the list of available substances which can be displayed by double-clicking in the substance name field and expanding the type folder (here expand Vapors then click on « R134a »).
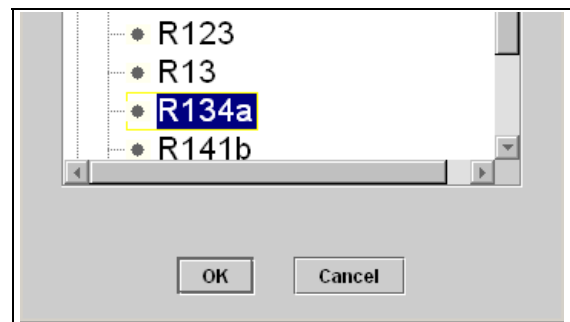
To validate and close the property editor, click on "Apply". The component appears on the diagram editor, with its name below it and the outlet point above on the right:

Similarly create one exchange component corresponding to the desuperheater (outlet point 3a). It is however not necessary in this case to select the substance again, as it will be automatically propagated when the components will be connected.

Connection of the components

To connect the two components, click on the outlet port of the compressor. The cursor becomes a crosshair and a line extends from the port if you drag the cursor. Drag the cursor to the inlet port the destination component (the desuperheater) while keeping the mouse clicked, and release the mouse. A link is established and the substance name of the desuperheater is updated, as you can check by displaying the component properties (menu Edit/Show properties or key F4).
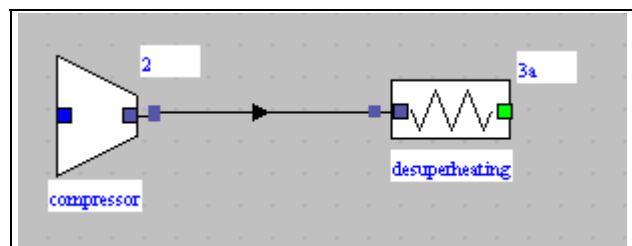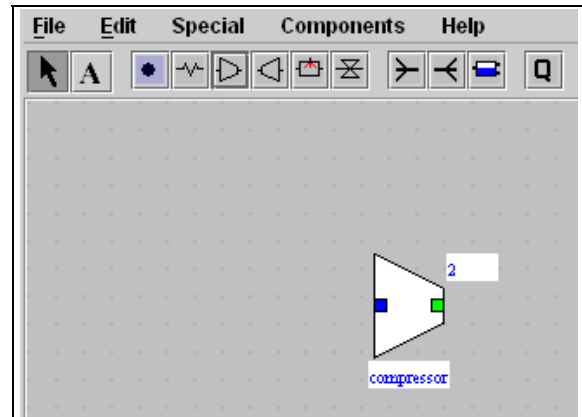
You can now create the other elements of the cycle, namely the condenser (outlet point 3), a throttling component (outlet point 4), and one exchange component corresponding to the refrigeration effect (outlet point 1).

When you have connected them, you obtain a diagram which looks like this:

By default, all components are oriented from the left to the right. When a loop appears in a diagram, it is convenient to orient some components from the right to the left. Here, you can change the desuperheating and condenser orientation by selecting them and selecting item "flip vertical" of menu Edition or pressing key F1. You obtain the following diagram, which can be refined by using the keyboard arrows to better align the components.

At this stage it is recommended that you save the diagram file as "refrig1.dia" by selecting item "Save As" of menu File of the Diagram Editor.
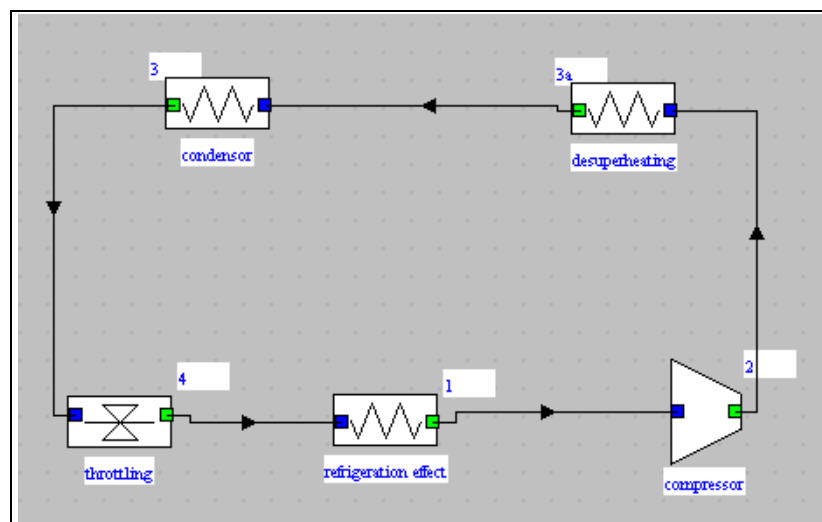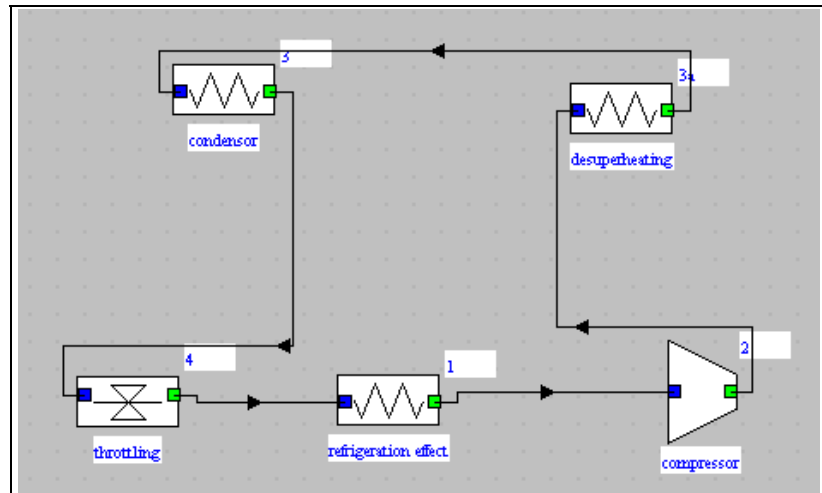
Transfer to the simulator

The diagram is now completed and you may transfer it in the simulator. To do that, select item "Interface Diagram/Simulator" in menu View, which opens a new frame. Click on button "Update the element table" :

component	type	simulator	Diagram	selected
compressor	compression		X	✔
desuperhe...	exchange		X	✔
condensor	exchange		X	✔
refrigeration...	exchange		X	✔
throttling	throttling		X	✔

The different components you have created appear in the table. A "x" in the " simulator" or "Diagram" column indicates that the element belongs to this environment (here all elements belong to the diagram, and none to the simulator).

Click the on button "Update the simulator from the diagram". As the project has not yet been named, the following message is prompted:
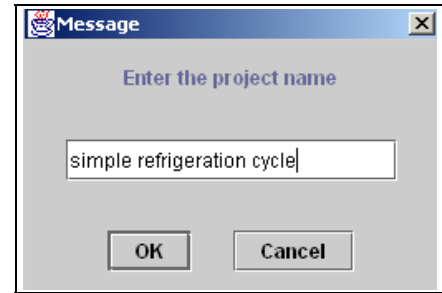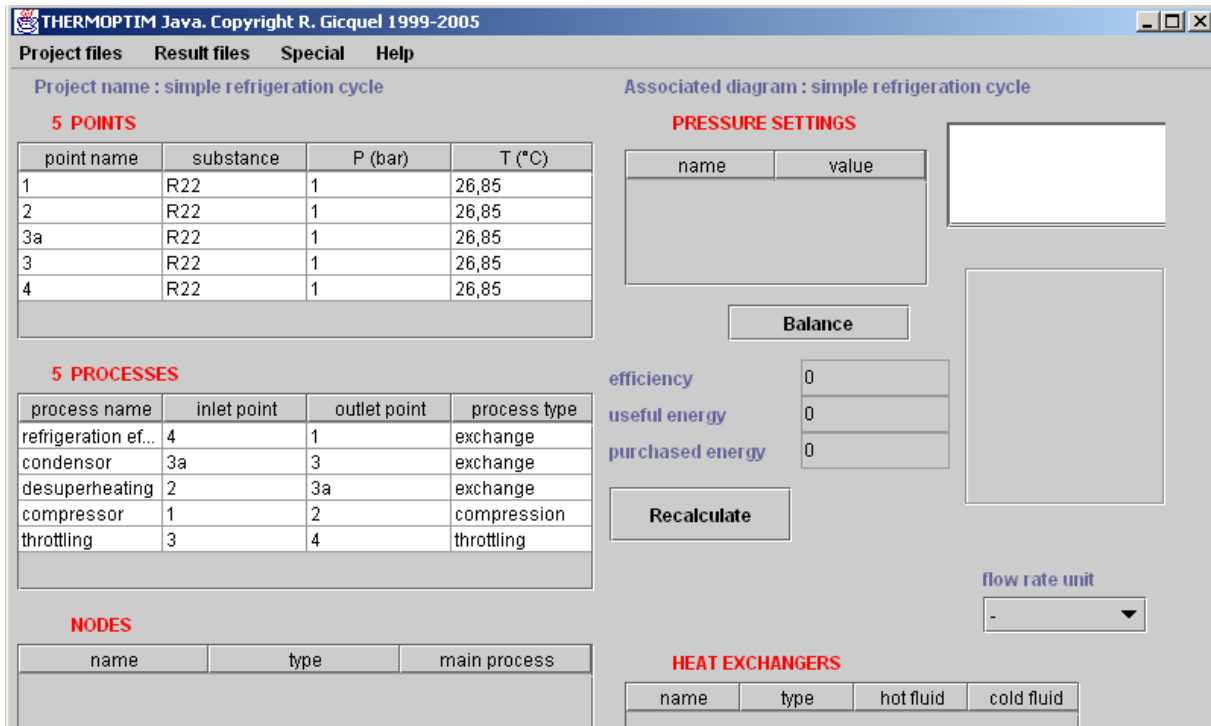
Name the project and click on "OK". The different points and processes are then created:

The whole structure of the project is created, but the detailed settings have still to be made (by default, all points have the same pressure (1 bar) and temperature (300 K)). First, select the flow rate unit in the list located in the lower right part of the screen (kg/s).
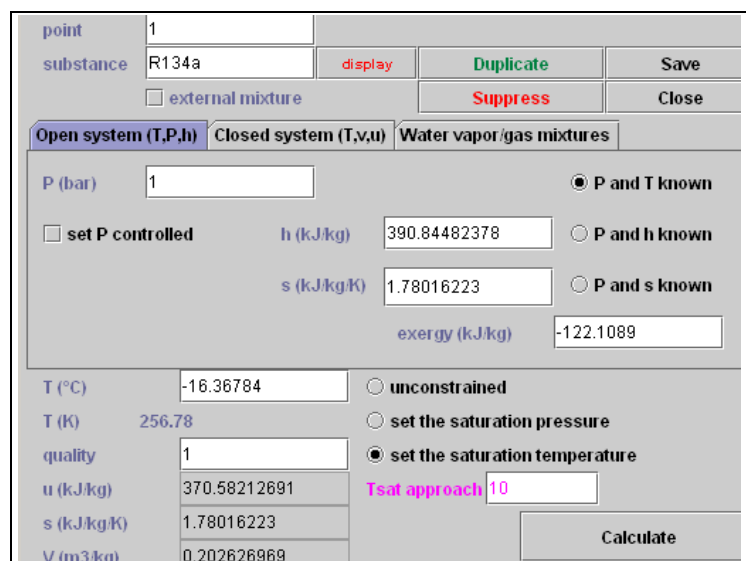
Definition of the points

To define point 1, double-click on it in the table or on the link between the refrigeration effetc and the compressor.

The point is calculated in open system, the pressure is 1 bar, and the saturation temperature set, with a Tsat approach equal to 10 K.

Point 1 is now defined. Similarly define the other points.

For point "2", indicate the only information known about it, the pressure is 12 bar. In the current definition state of the cycle, both its temperature and its enthalpy are not yet known.

Points 3a is at 12 bar and on the saturation curve, its quality being set to 1.

Point 3 is at 12 bar, subcooled by 5 K. It can also be calculated.

The last point to define is point 4. Only its pressure is known: 1 bar, and it is set to Tsat.

Definition of the processes

To define the processes, open their frames by double-clicking in the process table or in the diagram editor.

You have the choice between four modes of compression: adiabatic or polytropic, for open systems or for closed systems. For the first ones, the compression ratio is that of pressures, for second ones, that of volumes. It can be either calculated, as it is the case here, where the outlet pressure is known, or set, in which case the latter is calculated from the inlet pressure.

You can select two calculation modes. In the first case ("Set the efficiency and calculate the process"), the outlet point state is calculated from that of the inlet point and the efficiency value. For the second one ("Calculate the efficiency, the outlet point being known"), the efficiency value is calculated on the basis of both inlet and outlet points considered as set. Choose here the first case, which is selected by default.

Make your selection by clicking on the appropriate checkboxes, and enter the efficiency value (isentropic or polytropic) for compression. In the present case, the inlet point is liquid, and only ideal compressions are modeled for liquids, except for water. Choose here: isentropic, isentropic efficiency equal to 0.75, and open systems.

By default, the compressor energy type is "useful". Select the "purchased" energy type, as the compression power has to be provided to the cycle (see Reference Manual para. "Process screen").

Click on "Calculate ". Automatically, the state of point 2 is calculated, as well as the corresponding enthalpy variation. The value of the compression ratio is displayed (here 12).

Save the form.

As point 2 is known, you can now calculate the desuperheater, whose screen is the following:

Save the form. Similarly calculate the condensor (3a-3).

You can now define the throttling (3-4). The screen that is presented is the following:

The "refrigeration effect" is an exchange process of the "useful" energy type, as the evaporation effect is the useful one in this case.

Cycle plot

The cycle can now be plotted in the Interactive charts in the following way. In the simulator frame, select item Interactive Charts of menu Special, or type Ctrl C.

The following screen appears:

Double-click in the field labeled "Chart" and select "Vapors" from among the proposed list and the interactive chart frame is shown. If the substance selected is not R134a, select it in menu "Substance". Then go back to the "Interactive Chart" frame, and click on "Update the point table". All the project points are displayed in the table:

point name	substance	simulator	Chart	selected
1	R134a	X		✔
2	R134a	X		✔
3a	R134a	X		✔
3	R134a	X		✔
4	R134a	X		✔

The two first columns show the names and the substances of the points. When a point is part of the simulator project, a "X" appears in the third column, and when it is part of the Chart cycle points, a "X" appears in the fourth one. Here, there are only simulator points.

The last table column titled "selected" shows the point status: if a "X" appears, the point is selected for being taken into account in the transfers between the simulator and the charts, otherwise not. To change a point status, double-click on the corresponding line. Here we want to plot all points, so we keep them all selected.

Now, click on "Update the chart from the simulator " to have the points transferred to the chart. The points are transferred while trying to order them as well as possible, but it can be necessary to reorder them to obtain a correctly connected layout. The cycle point editor allows to do it in this case as we will see it.

Select "connected points" in menu Cycle. If necessary, change the axis layout in menu "Chart". You get the following result:

If you prefer to have the cycle plotted on a (h,p) chart, select this item in menu "Chart":
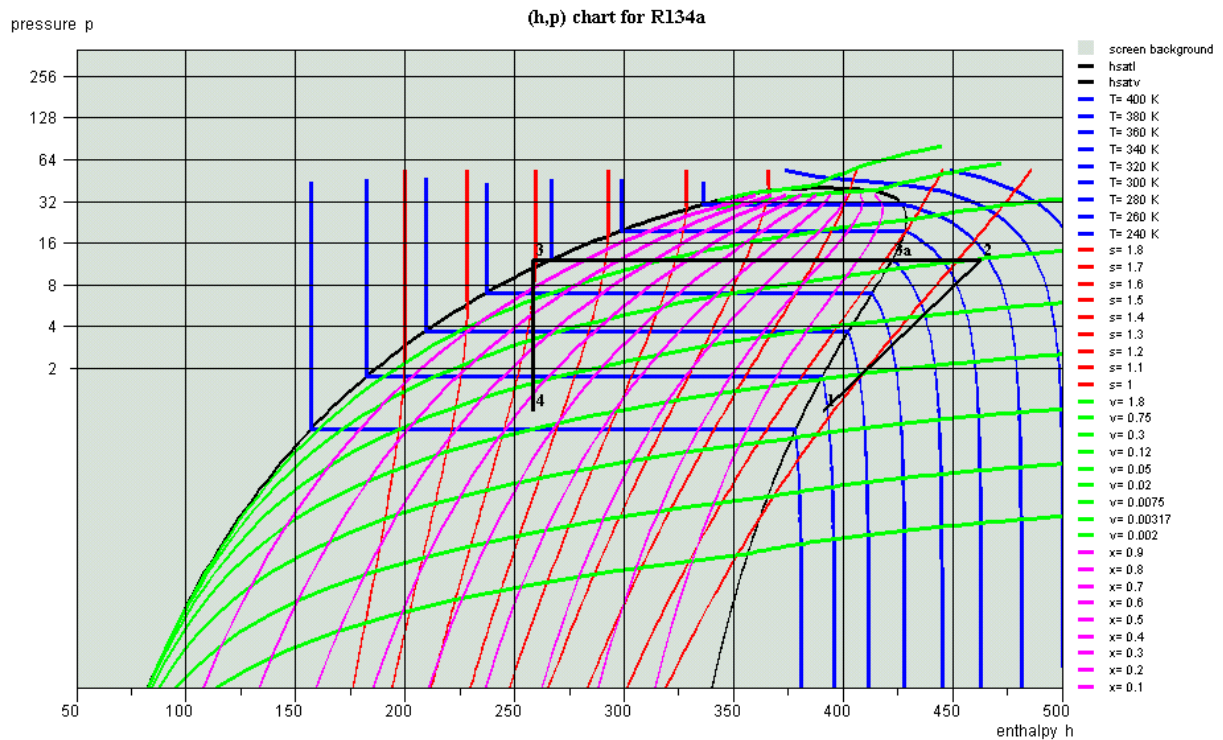
You can now use the features provided by the interactive charts, which are presented in the chart reference manual, such as editing the points in the cycle editor. In order to do that, select item "Edit a cycle" in the "Cycle" menu, or type Crtl C. The following frame appears:

The two first figure columns from the left define the input state variables for the calculations

point name	temperature T (°C)	pressure P	enthalpy h	entropy s	volume v	quality x
1	-16.36784	1	390.84482	1.78016	0.202627	1
2	83.10782	12	463.13399	1.83157	0.0206862	1
3a	46.32652	12	422.21063	1.70929	0.0167769	1
3	41.32652	12	258.39175	1.19619	0.000876682	0
4	-26.36784	1	258.39175	1.24408	0.0834521	0.428173

Insert   Copy   Suppress   Recalculate   Validate   Print   Cancel

You can now change the cycle, add new points, in particular in order to close the cycle… To do that, select line 1 and click on Insert, then select line 4 and click on Copy. Then select the line you have inserted and click on Paste. When you click on Validate, a new line between points 4 and 1 has been added.

Improvements in cycle plotting

A number of improvements have been recently made in the plotting of cycles:

- first, it is possible to link points by various iso-value lines (iso-pressure, isentropic...)
- second, each cycle color may be changed according to the user desire
- third, it is now possible to plot several cycles on the same chart

Linking points by iso-value lines

When the cycle is first plotted on a R134a (T, s) chart, the points are connected by straight lines. Opening the cycle point editor displays the cycle elements as shown in above.

It is now possible to connect points 3a and 3 by an iso-pressure line: select both lines 3a and 3 at the same time, and click on "Insert". A combo box with various iso-value choices is shown. Select "iso-pressure". You are requested to give the number of points you want to insert. The default value of 5 is adequate here. 5 new points are created in the cycle point editor. Click on "Validate": the plot now follows the 12 bar line.

Similarly you can connect points 4 and 1 with an iso-pressure line, and points 3 and 4 by an isenthalpic one. In order to add an isentropic line between points 1 and 2, you first have to insert a blank line before point 2, and to copy and paste point 1 line there. You then select the new line 1 and line 2, and insert the isentropic points. In the end the chart plot becomes as shown here.
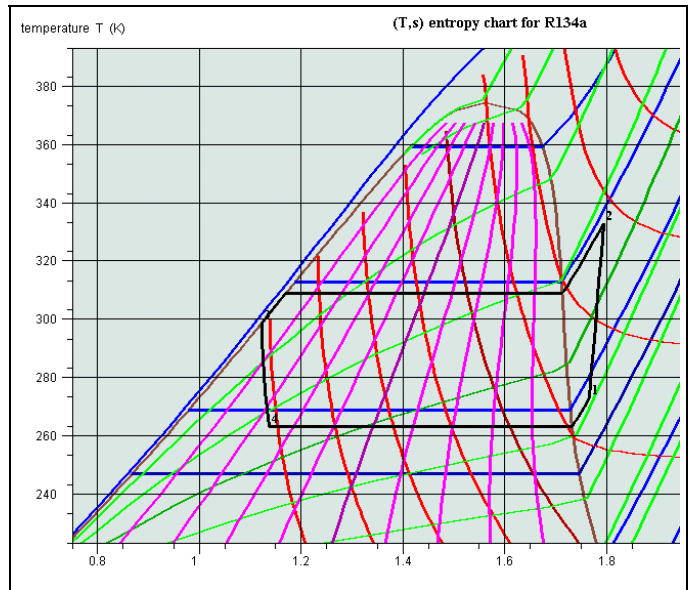
All the points inserted can be recalculated one by one if need be (i.e. if one of them does not exactly correspond to the user requirements). If need be they can be suppressed either one by one or as a group, by selecting them and clicking on "Suppress".

If you want to save this cycle, just open the cycle point editor, enter any title and description you may wish and save the cycle.

Changing cycle color

Until version 1.5, all cycles were plotted in black. It is now possible to select any color in the same way as you do it for the chart curves. In order to do that a new menu line named "Cycle manager" has been added in menu "Cycle". If you select it you open the frame shown here. If you click on "Update the cycle table", all cycles already loaded are displayed. Here, two cycles are loaded: the default one which is active, and a second one which has been loaded from a file.
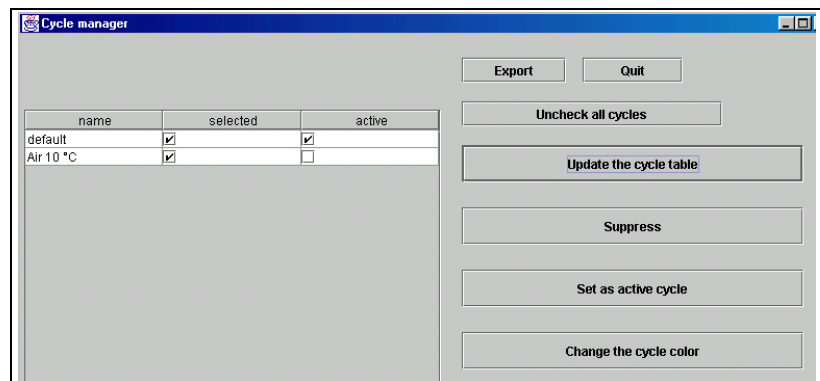
You select the active cycle by choosing its line and clicking on "Set as active cycle". The active cycle has the following properties:
- it is connected to the simulator
- it is the one on which the "Cycle" menu lines operate, i.e. it can be erased, saved, its points can be edited in the cycle point editor...
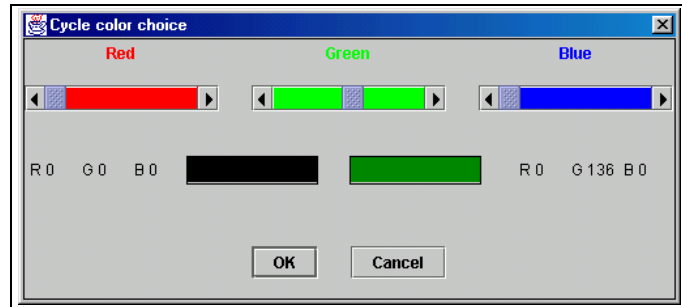
If you double-click on a line, you change the column "selected" status: if it is checked, the cycle is plotted on the chart, otherwise not. You can deselect all cycles by clicking on "Uncheck all cycles".

You can suppress a cycle in the list by selecting its line and clicking on "Suppress". Its plot is also suppressed from the chart.

To change a cycle color, select its line and click on "Change the cycle color". A frame allowing you to choose its color is displayed. If you want to save the new color, set the cycle as the active one and save it.

Suppressing the active cycle is equivalent to erasing it from the chart menu. You generate a new active cycle either by setting another cycle as the active one, or by interactively creating points in the chart, opening the cycle point editor and validating.

Superposition of several cycles on a chart

To plot several cycles on a chart, just load them together and set them as selected in the cycle manager screen. They automatically appear on the chart as shown here.

Two stage total injection refrigeration cycle

The refrigeration cycle that we have studied this far is a very simple one. It can be improved in several ways, one of which being named the two stage total injection cycle. In this cycle, a IP compressor pressurizes the refrigerant at an intermediate pressure in point 8. The IP gas is directed to a mixing bottle which acts as a separator. The bottle vapor is sucked by a HP compressor which pressurizes it at the HP pressure in point 2.

The hot gases are desuperheated, condensed and possibly subcooled, and the liquid is expanded at the IP before entering the mixing bottle where it mixes with the IP vapor.

The IP liquid at point 5 is expanded and vaporized to get the cooling effect.

**two stage total injection compression refrigeration cycle**
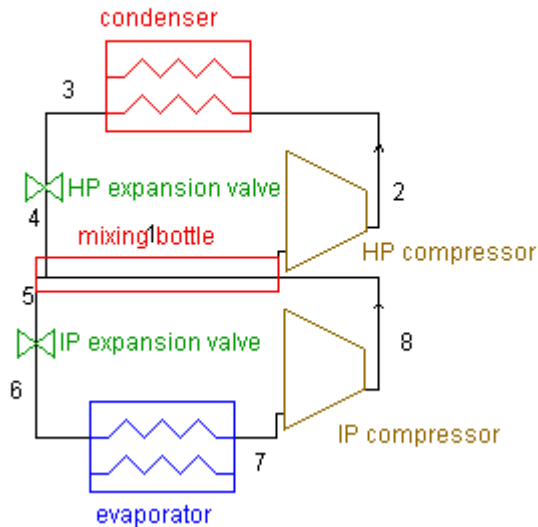
This cycle is an interesting example of how THERMOPTIM can easily solve complex problems. The flow distribution in this cycle depends on the enthalpy balance of the IP mixing bottle, which behaves as a mixer followed by a separator. Thus the liquid and vapor flow rates exiting the bottle vary as a function of the compressor efficiency, the compression ratio, the subcooling or superheating…

As the mass flow rates vary and the system is comprised if two loops, it is very difficult to make assumptions on realistic values, and one has to iterate a number of times to find a solution for a given set of parameters, whereas, with THERMOPTIM, it becomes very easy to make sensitivity studies.

To build the cycle, create the various processes as you did it in the simple refrigeration cycle by placing them on the working panel, and connect them together.

Then, you have to create the mixer and the separator :
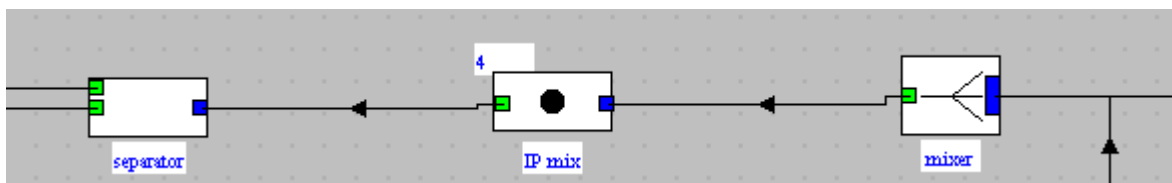
The mixing bottle behaves, as indicated above, as a mixer followed by a separator. The mixer mixes the liquid exiting the HP expansion valve and the vapor at the outlet of the IP compressor. The separator separates the resulting mix in two parts: the vapor is directed to the HP compressor, and the liquid to the IP expansion valve.

The process which connects the two nodes will be a process-point called "IP mix".
You end up with a diagram similar to this one:
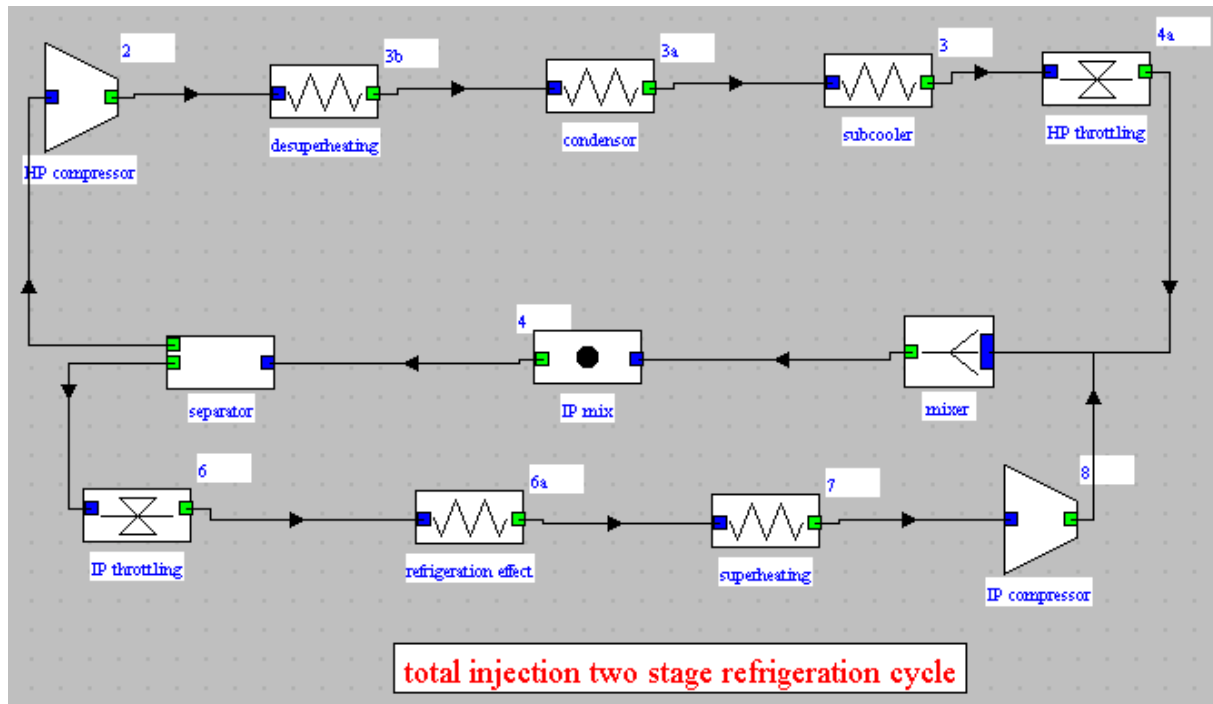
When creating the separator, make sure that the vapor connection corresponds to the upper outlet port and the liquid one to the bottom one. By default, the separation efficiency is set to one, which means that the separation of the liquid-vapor mix is complete, but you may change this value if you wish.

Now, to calculate the overall balance of the cycle, you have to make sure that the different elements which initialize it are correctly initialized.

As stated above, the calculation of this cycle is rather complicated: it is comprised of two loops which are interconnected by the mixing bottle, or if you prefer by a mixer and a separator. The main difficulty is that you do not know which are the flow rates in the two loops: they depend on the mixing bottle enthalpy balance, which itself depends on the rest of the cycle, and in particular on the enthalpy of the vapor exiting the IP compressor.

Thermoptim ensures the flow rate propagation, but if the flow rates are not correctly initialized, you are not sure that the recalculation engine will converge.

The solution is to set the flow rate in an appropriate process. In such conditions, the flow rate in the corresponding process will not react to the other flow rates changes, and the convergence will be guaranteed. For instance, you can check the "set flow" checkbox of the "IP compressor" process, and enter 1 in the flow rate field.

Then, if you click several times on the "Recalculate" button, until the global indicator values become stable, you get the cycle efficiency. If you look at the flow rate value in the "refrigeration effect" process which is directly connected to the IP compressor, you can check that Thermoptim succeeded in converging.

Balance	
efficiency	2.27373
useful energy	179.82
purchased energy	79.09

You can now easily make sensitivity studies by changing any parameter and recalculating the cycle.

The corresponding project file is named "refrig_2st.prj".

Plotting the cycle

As indicated previously open the Chart / Simulator interface and click on "Update the point table". All the project points are displayed in the table:

point name	substance	simulator	Chart	selected
1	R134a	X		✔
2	R134a	X		✔
3	R134a	X		✔
3a	R134a	X		✔
4	R134a	X		✔
4a	R134a	X		✔
5	R134a	X		✔
6	R134a	X		✔
7	R134a	X		✔
8	R134a	X		✔
3b	R134a	X		✔
6a	R134a	X		✔

Now, click on "Update the chart from the simulator" to have the points transferred to the chart, and select "Connected Points" in menu Cycle. If necessary, change the axis layout in menu "Chart". You get the following result:
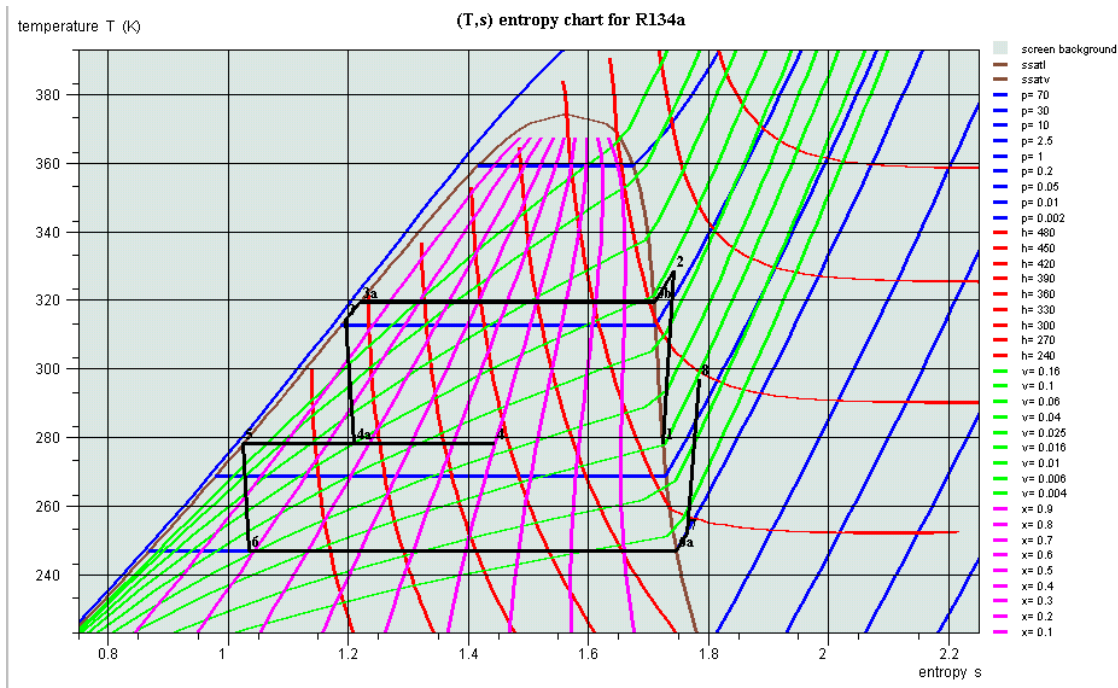
You may wish to edit the cycle points to refine the plot. Open the cycle point editor by selecting "Edit a cycle" in menu "Cycle". You get the following frame:

point name	temperature T (K)	pressure p	enthalpy h	entropy s	volume v	quality x
1	278.185	3.5	401.40532	1.72413	0.0588357	1
2	328.50657	12	432.9575	1.74274	0.0178142	1
3b	319.47652	12	422.21063	1.70929	0.0167769	1
3a	319.47652	12	265.89257	1.21999	0.00089492	0
3	314.47652	12	258.39175	1.19619	0.000876682	0
4a	278.185	3.5	258.39175	1.21003	0.0161569	0.264843
4	278.185	3.5	323.06485	1.44251	0.0354569	0.597293
5	278.185	3.5	206.87054	1.02483	0.000781646	0
6	246.78216	1	206.87054	1.03531	0.0375739	0.19072
6a	246.78216	1	382.4631	1.74683	0.193934	1
7	251.78216	1	386.69623	1.76388	0.198288	1
8	296.78248	3.5	418.98542	1.78533	0.0639915	1

You can add new lines: select the line above which you want to insert the new one, and click on "insert":

point name	temperature T (K)	pressure p	enthalpy h	entropy s	volume v	quality x
point	0	0	0	0	0	0
1	278.185	3.5	401.40532	1.72413	0.0588357	1
2	328.50657	12	432.9575	1.74274	0.0178142	1

You may then define the new point from scratch, entering two state variables and calculating the other ones. The chart considers that the data variables are those corresponding to the two first figure columns from the left. You can also copy and paste an existing line.

Here, in order to close the cycle, we would like to add point 4 above point 1. So we copy line 4 by selecting it and clicking on "Copy". The button title becomes "Paste". Select then the new line and click on "Paste".

point name	temperature T (K)	pressure p	enthalpy h	entropy s	volume v	quality x
4	278.185	3.5	323.06485	1.44251	0.0354569	0.597293
1	278.185	3.5	401.40532	1.72413	0.0588357	1
2	328.50657	12	432.9575	1.74274	0.0178142	1

Similarly, add a new connection between point 8 and point 1. When you are done with your modifications, they can be transferred on the chart by clicking on the button "Validate". Automatically, the editor table points are then repositionned on the screen.
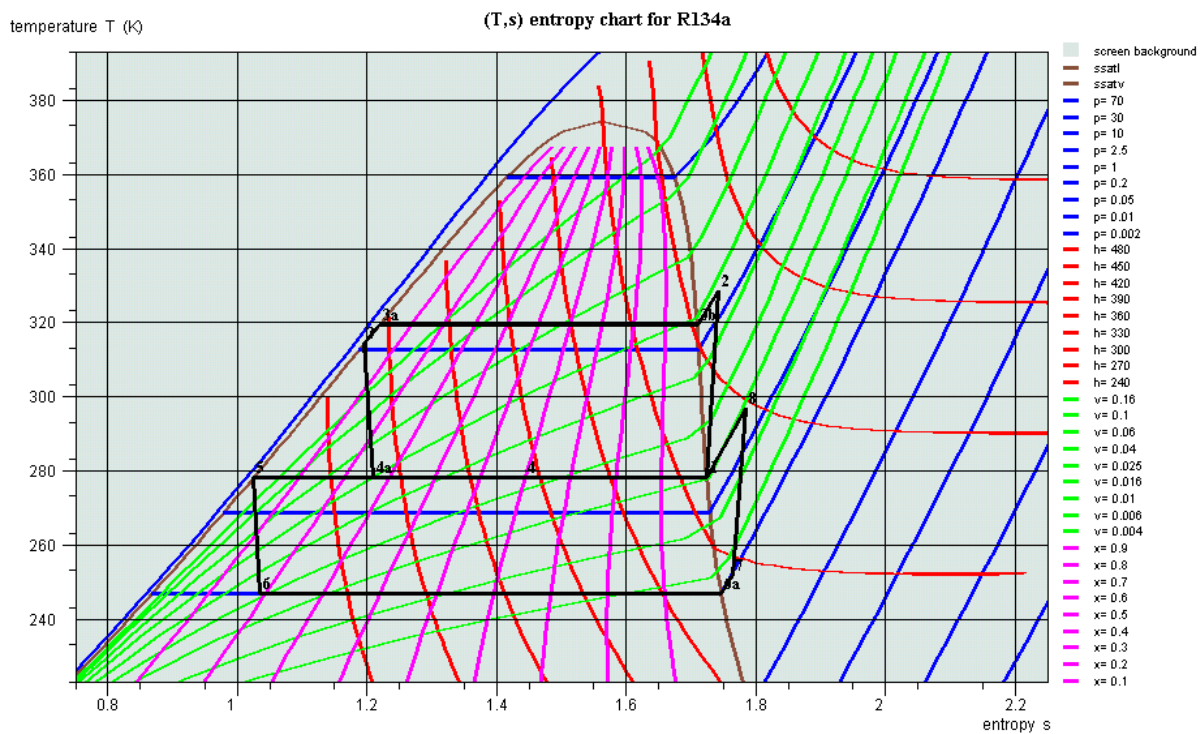
You can also plot the cycle on a (h, p) chart by selecting (h,p) in the Graph menu:
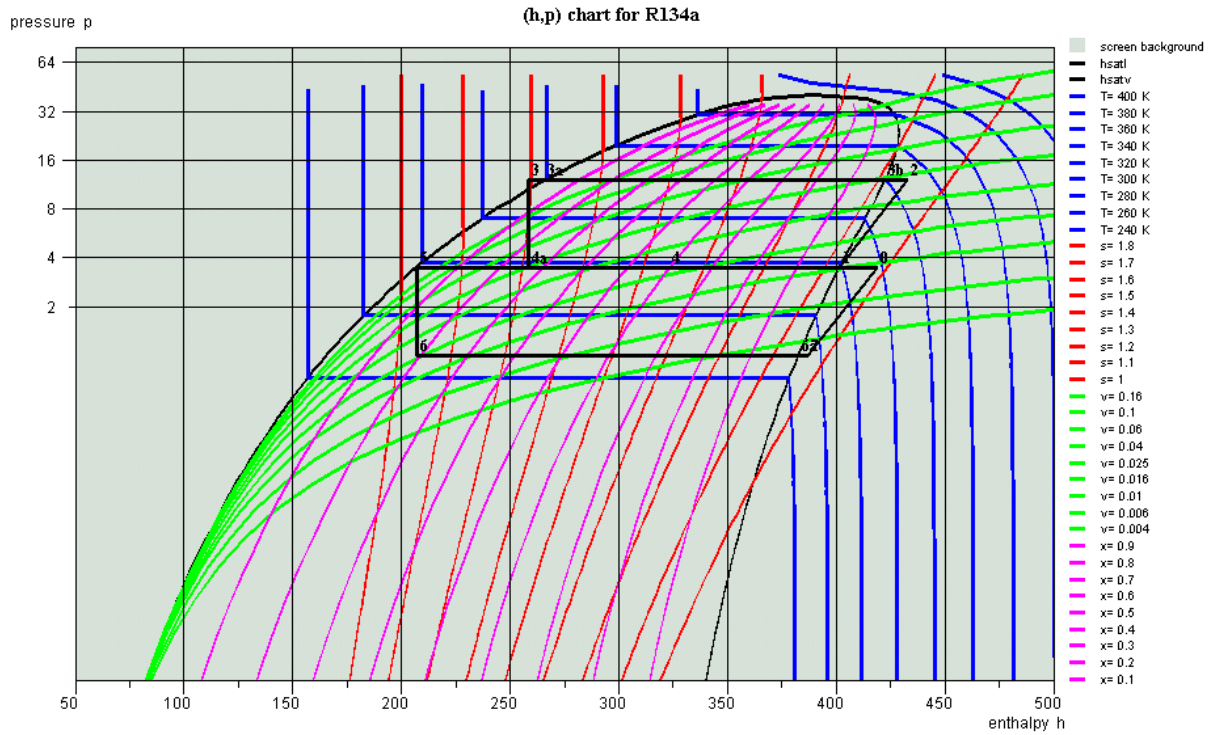
Viewing the point values in the diagram editor

You can also directly view the point state values on the diagram, by selecting item "Show values" in menu Special: