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1 The condenser

In this chapter the modelling of the condenser with Cycle-Tempo is treated. There are two condenser models to be used in Cycle-Tempo. First the general condenser model is discussed. This model is restricted to design situations as no knowledge of the mechanical layout of the condenser is needed. Secondly the steam condenser model is discussed. This model is suitable for design and off-design calculations and requires input of the geometry of the condenser. This model is restricted to steam for the condensing side and water for the cooling side.

All calculations are executed with Cycle-Tempo version 4.14 and a relative accuracy of 1×10^{-6} .

1.1 General condenser model

The general condenser model has the following properties:

- free choice of condensing fluid
- free choice of cooling fluid
- only suitable for design calculations ($U \times A$ is not calculated)
- it makes no use of heat-transfer relations
- superheating and subcooling are allowed

Figure 1 shows the scheme for the calculations.

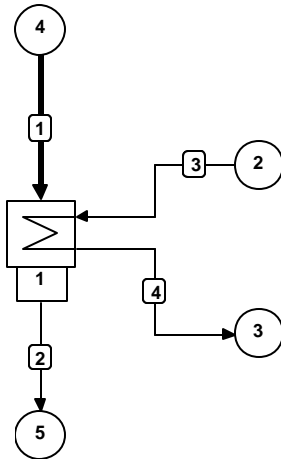


Figure 1 Scheme of the condenser calculation configuration

The user can choose between two kinds of calculations, a calculation with the *EEQCOD* (Energy Equation CODE) = 1 and a calculation with the *EEQCOD* = 2. The first means that the energy equation is used to calculate an unknown mass-flow, and the latter means that the energy equation is used to calculate an unknown temperature. Paragraph 1.1.1 shows the calculation with *EEQCOD* = 1.

1.1.1 Input for the calculation of an unknown mass-flow

In this example steam with a mass-flow of 100 kg/s and a steam quality of 90% is condensed in the condenser. The pressure in the condenser is equal to 0.03 bar. The cooling fluid is water with an inlet temperature of 12° Celsius, and an outlet temperature of 19° Celsius. Cycle-Tempo will calculate the unknown mass-flow of the cooling water. A pressure loss of 2 bar is assumed for the cooling water side and no pressure loss is assumed at the condensing side. The *SATCOD* (SATuration CODE) is set to 0, to indicate that the secondary (condensate) outlet is saturated. The input parameters are shown in Table 1.

Table 1 Input parameters for the calculation of the unknown mass-flow

Input parameters	
Condenser (apparatus Nr.1)	
<i>EEQCOD</i>	1
<i>DELP1</i>	2
<i>DELTI</i>	7
<i>PIN2</i>	0.03
<i>DELP2</i>	0
<i>SATCOD</i>	0
Sink/Source (apparatus Nr.2)	
<i>POUT</i>	4
<i>TOUT</i>	12
Sink/Source (apparatus Nr.3)	
	-
Sink/Source (apparatus Nr.4)	
<i>DELM</i>	-100
<i>XOUT</i>	0.9
Sink/Source (apparatus Nr.5)	
	-

1.1.2 Results of the calculation of an unknown mass-flow

Figure 2 shows the results of the design load calculation.

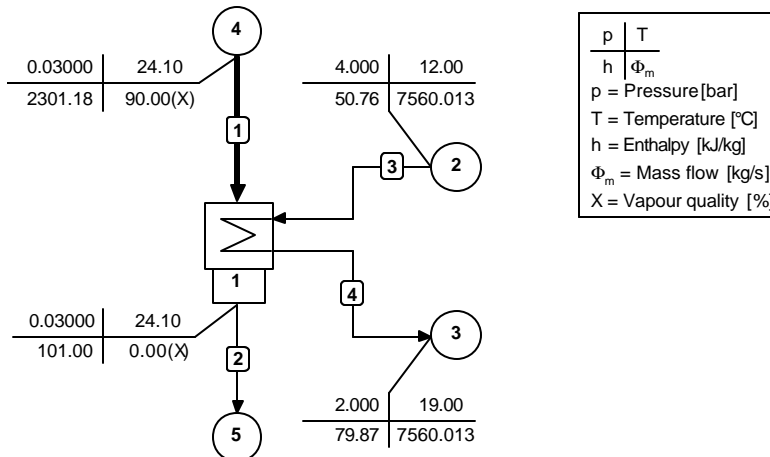


Figure 2 Results of the calculation

Cycle-Tempo calculated the inlet steam temperature using the pressure in the condenser and the steam quality specified by the user. The energy equation code was set to be 1 in this example and so Cycle-Tempo calculated the required cooling water mass-flow.

1.1.3 Q, T diagram

The user can use Cycle-Tempo to make a Q, T -diagram of the condenser. Figure 3 shows an example of such a Q, T -diagram for the design load calculation example.

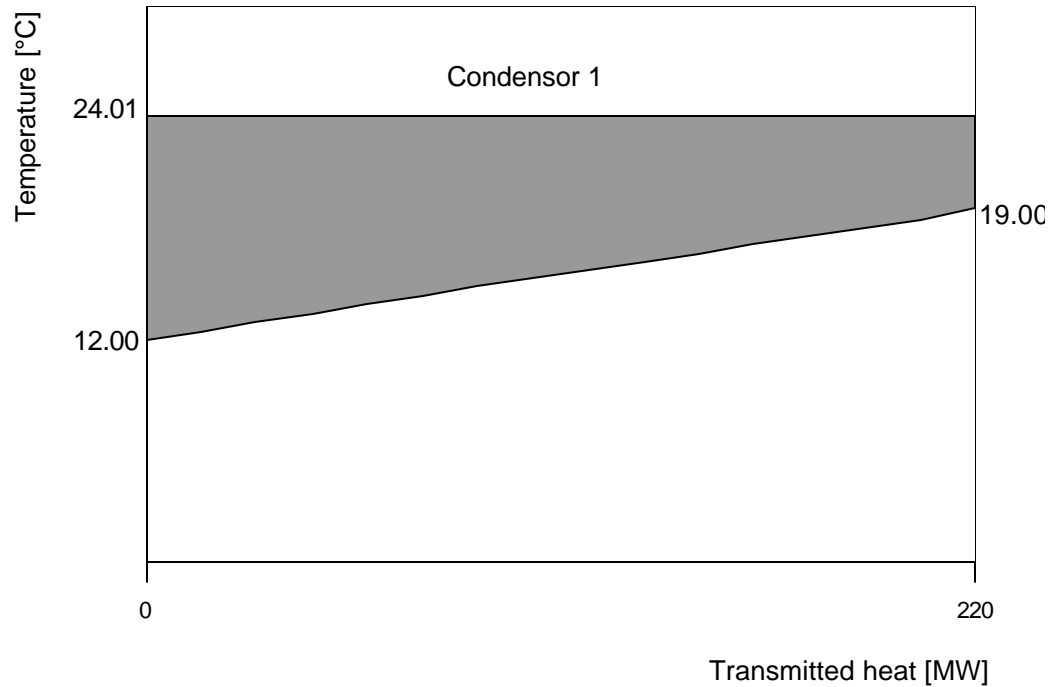


Figure 3 Q, T - diagram for the condenser

1.1.4 Energy and exergy in the system

A table of the energy and exergy flows can be made after setting the environment definitions in the general data menu. The exergy of a medium is relative to that of the environment chosen, so Cycle-Tempo needs this information to perform an exergy calculation. In this example the environmental conditions are set equal to the conditions of the incoming cooling water, i.e. $T= 12^\circ$ and $p= 4$ bar. Table 2 shows the exergy values in the system and Table 3 shows the energy and exergy flows.

Table 2 Exergy values in the system

No.	Name	Type	Exergy transmitted from system [kW]			Rel. Ex.	Univ.	Func.
			Total	Power/Heat	Losses	Loss	Exergy eff.	Exergy eff.
						[%]	[%]	[%]
1	Condenser	4	7796.79	0.00	7796.79	86.41	12.97	13.59
2	Sink/Source	10	0.00	0.00	0.00	0.00		
3	Sink/Source	10	1161.66	0.00	1161.66	12.87		
4	Sink/Source	10	-9023.16	0.00	-9023.16	-100.00		
5	Sink/Source	10	64.71	0.00	64.71	0.72		
	Total:		0.00	0.00	0.00	0.00		

Table 3 Energy and exergy flows

<i>Pipe no.</i>	<i>Total Energy flow</i>	<i>Total Exergy flow [kW]</i>
1	225042.06	9023.16
2	5023.99	64.71
3	0.00	0.00
4	220018.06	1161.66

The user should note that the value for the exergy in pipe 3 is equal to zero. This is a direct consequence of the choice of the environmental conditions at the same conditions as the cooling water in pipe 3. All other exergy values are relative to this environmental condition.

In the Cycle-Tempo manual in chapter 5 (technical notes), paragraph 5.2.3, definitions are given of exergy efficiencies. For this example the efficiencies are calculated as follows:

The universal exergy efficiency:

$$h_{Ex,u} = \frac{\Delta\Phi_{Ex,out}}{\Delta\Phi_{Ex,in}} = \frac{\Phi_{Ex,2} + \Phi_{Ex,4}}{\Phi_{Ex,1} + \Phi_{Ex,3}}$$

The functional exergy efficiency:

$$h_{Ex,f} = \frac{\Phi_{Ex,primary,out} - \Phi_{Ex,primary,in}}{\Phi_{Ex,secondary,in} - \Phi_{Ex,secondary,out}}$$

1.1.5 Input for the calculation of the unknown temperature

In this example again steam with a mass-flow of 100 kg/s and a steam quality of 90% is condensed at a pressure of 0.03 bar. To illustrate the free choice of cooling fluid not water is used but environmental air, with a temperature of 18° Celsius. This is achieved by substitution of the water pipes by air pipes and by editing the composition of the inlet air pipe to standard air. Cycle-Tempo will now use its library with air properties.

The energy equation code for this example is set to 2, so Cycle-Tempo will calculate an unknown temperature, which is the outlet temperature of the cooling air. In this case the user has to specify a cooling fluid mass-flow. In this example a mass-flow of 5000 kg/s is chosen.

Table 4 shows the input parameters for this example.

Table 4 Input parameters for the calculation of the unknown temperature

Input parameters	
Condenser (apparatus Nr.1)	
EEQCOD	2
DELP1	2
PIN2	0.03
DELP2	0
SATCOD	0
Sink/Source (apparatus Nr.2)	
POUT	4
TOUT	18
DELM	-5000
Sink/Source (apparatus Nr.3)	
-	
Sink/Source (apparatus Nr.4)	
DELM	-100
XOUT	0.9
Sink/Source (apparatus Nr.5)	
-	

1.1.6 Results of the calculation of the unknown temperature

Figure 4 shows the plot of the results for the design load calculation.

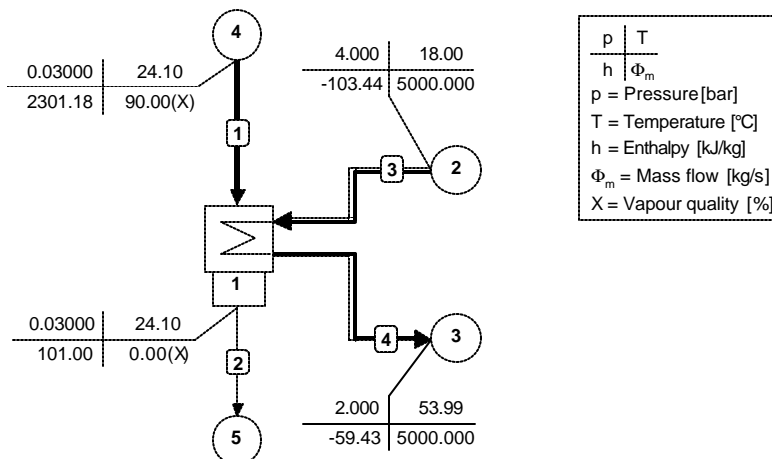


Figure 4 Results of the calculation

Cycle-Tempo has calculated an outlet cooling air temperature of 53.99° Celsius.

1.2 Steam condenser model

The steam condenser model has the following properties:

- The choice for the condensing fluid is restricted to steam
- The choice for the cooling fluid is restricted to water
- The model can be used for design load and off-design calculations
- The heat transfer coefficient is calculated (with the use of the mechanical layout)
- Superheating and aftercooling are not permitted

In this paragraph calculations with $EEQCOD=1$ and with $EEQCOD=2$ will be discussed for design load situations and for off-design situations. First the method of the heat transfer calculations will be discussed here.

The layout for the next examples is the same as the layout shown in Figure 1.

1.2.1 Method of the heat transfer calculation

In addition to the two mass equations and the energy equation the overall heat transfer equation is now also available to calculate an extra unknown. The overall heat transfer equation is as follows:

$$Q = U \times A \times \Delta T_{\ln}$$

where:

Q	Heat transferred	[kW]
U	Overall heat transfer coefficient	[kW/m ² K]
A	Heat transfer surface	[m ²]
? T _{ln}	Log-mean temperature difference	[K]

The overall heat transfer coefficient U is calculated using the instructions as stated in the V.D.I.-Wärmeatlas:

$$\frac{1}{U} = \frac{1}{a_{cw}} \times \frac{d_{out}}{d_{in}} + \frac{d_{out}}{2 \times l_w} \times \ln \left(\frac{d_{out}}{d_{in}} \right) + \frac{1}{a_{st}}$$

where:

a _{cw}	Cooling water coefficient	[kW/m ² K]
d _{out}	Tube outside diameter	[m]
d _{in}	Tube inside diameter	[m]
? l _w	Thermal conductivity of the tube wall material	[kW/mK]
a _{st}	Steam coefficient	[kW/m ² K]

1.2.2 Input for the design load calculation of an unknown mass-flow

For this example the same conditions are used as in the example of paragraph 1.1.1, with the difference that geometry input data are added in order to let Cycle-Tempo make an off-design calculation. The input data for this example are shown in Table 5.

Table 5 Input data for the design calculation of an unknown mass-flow

Input parameters	
Condenser (apparatus Nr.1)	
<i>EEQCOD</i>	1
<i>DELP1</i>	2
<i>DELTI</i>	7
<i>PIN2</i>	0.03
<i>DELP2</i>	0
<i>SATCOD</i>	0
Geometry input data	
<i>DIAIN</i>	0.018
<i>DIAOUT</i>	0.020
<i>PITCH</i>	0.030
<i>NPIPES</i>	35500
<i>NEDGE</i>	3550
<i>LAMBDW</i>	0.085
<i>RFOUL</i>	0.045
<i>AIRFAC</i>	1.4
Sink/Source (apparatus Nr.2)	
<i>POUT</i>	4
<i>TOUT</i>	12
Sink/Source (apparatus Nr.3)	
	-
Sink/Source (apparatus Nr.4)	
<i>DELM</i>	-100
<i>XOUT</i>	0.9
Sink/Source (apparatus Nr.5)	
	-

1.2.3 Results for the design calculation of the unknown mass-flow

Figure 5 shows the results for the design calculation.

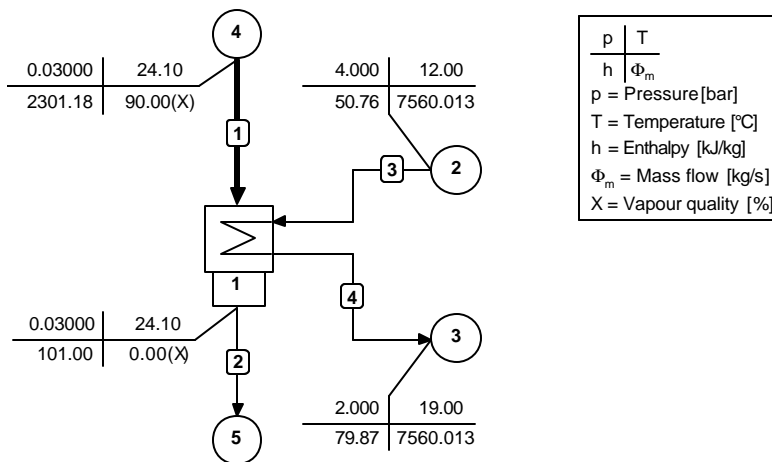


Figure 5 Results for the design calculation of an unknown mass-flow

The user should note that the results are the same as the results of the example of paragraph 1.1.2. The difference is that we can now let Cycle-Tempo make an off-design calculation.

1.2.4 Input for the off-design calculation of an unknown mass-flow

In this example the off-design calculation will be discussed. The condenser will be used to condense a steam flow with a mass-flow which is 60% of the original mass-flow of 100 kg/s. The input and output temperature of the cooling water are held constant and Cycle-Tempo has to calculate the new cooling water mass-flow. The input data are given in Table 6.

Table 6 Input data for the off-design calculation of an unknown mass-flow

Input parameters	
Condenser (apparatus Nr.1)	
<i>EEQCOD</i>	1
<i>DELP1</i>	2
<i>DELTI</i>	7
<i>PIN2</i>	0.03
<i>DELP2</i>	0
<i>SATCOD</i>	0
Geometry input data	
<i>DIAIN</i>	0.018
<i>DIAOUT</i>	0.020
<i>PITCH</i>	0.030
<i>NPIPES</i>	35500
<i>NEDGE</i>	3550
<i>PRISEC</i>	1
<i>LAMBDW</i>	0.085
<i>RFOUL</i>	0.045
<i>AIRFAC</i>	1.4
Off-design input data	
<i>A</i>	pasted from design situation
Sink/Source (apparatus Nr.2)	
<i>POUT</i>	4
<i>TOUT</i>	12
Sink/Source (apparatus Nr.3)	
	-
Sink/Source (apparatus Nr.4)	
<i>DELM</i>	-60
<i>XOUT</i>	0.9
Sink/Source (apparatus Nr.5)	
	-

Cycle-Tempo uses the geometry input data to calculate the off-design results with the method of the VDI-Wärmeatlas. The explanation of the codes is given in the Cycle-Tempo manual, reference guide, pages 2-27 & 2-29.

1.2.5 Results of the off-design calculation of an unknown mass-flow

Figure 6 shows the results of the calculation.

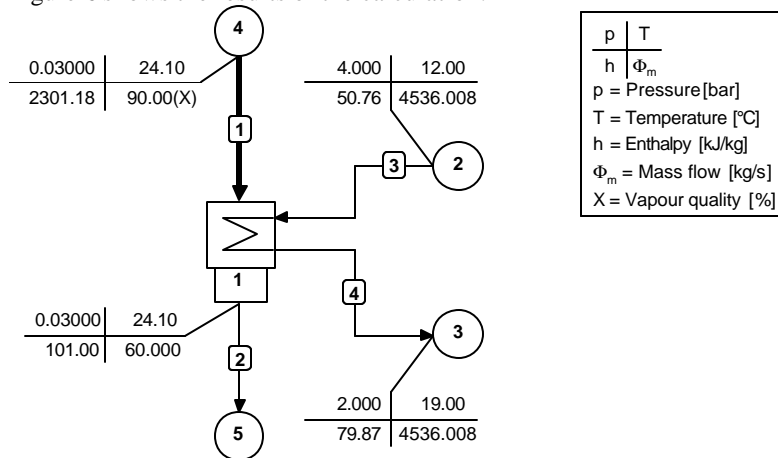


Figure 6 Results of the calculation of the off-design calculation of an unknown mass-flow

1.2.6 Input for the design calculation of an unknown temperature

Steam with a mass flow of 100 kg/s, a pressure of 0.03 bar and a steam quality of 90% is condensed in a condenser. Cooling water with an inlet temperature of 12° Celsius and a pressure of 4 bar is used. The mass-flow of the cooling water is set to 5000 kg/s and Cycle-Tempo has to calculate the outlet cooling water temperature. A temperature calculation has to be executed, so the Energy Equation Code is set equal to 2. The input parameters are given in Table 7.

Table 7 Input data for the design calculation of an unknown temperature

Input parameters	
Condenser (apparatus Nr.1)	
EEQCOD	2
DELP1	2
PIN2	0.03
DELP2	0
SATCOD	0
Geometry input data	
DIAIN	0.018
DIAOUT	0.020
PITCH	0.030
NPIPES	35500
NEDGE	3550
LAMBDW	0.085
RFOUL	0.045
AIRFAC	1.4
Sink/Source (apparatus Nr.2)	
POUT	4
TOUT	12
DELM	-5000
Sink/Source (apparatus Nr.3)	
	-
Sink/Source (apparatus Nr.4)	
DELM	-100
XOUT	0.9
Sink/Source (apparatus Nr.5)	
	-

Cycle-Tempo will calculate the cooling water temperature at the outlet of the condenser.

1.2.7 Results of the design calculation of an unknown temperature

Figure 7 shows the results of the calculation with the input data of Table 7.

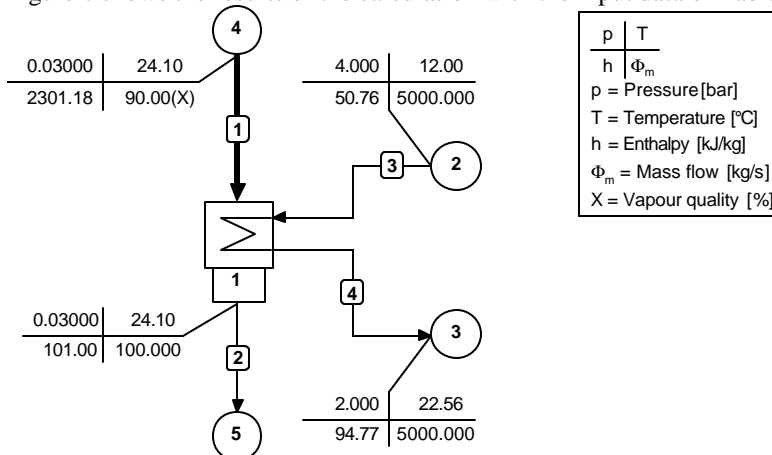


Figure 7 Results of the design calculation of an unknown temperature

1.2.8 Q,T diagram

A Q,T diagram has been made for the design calculation, see Figure 8.

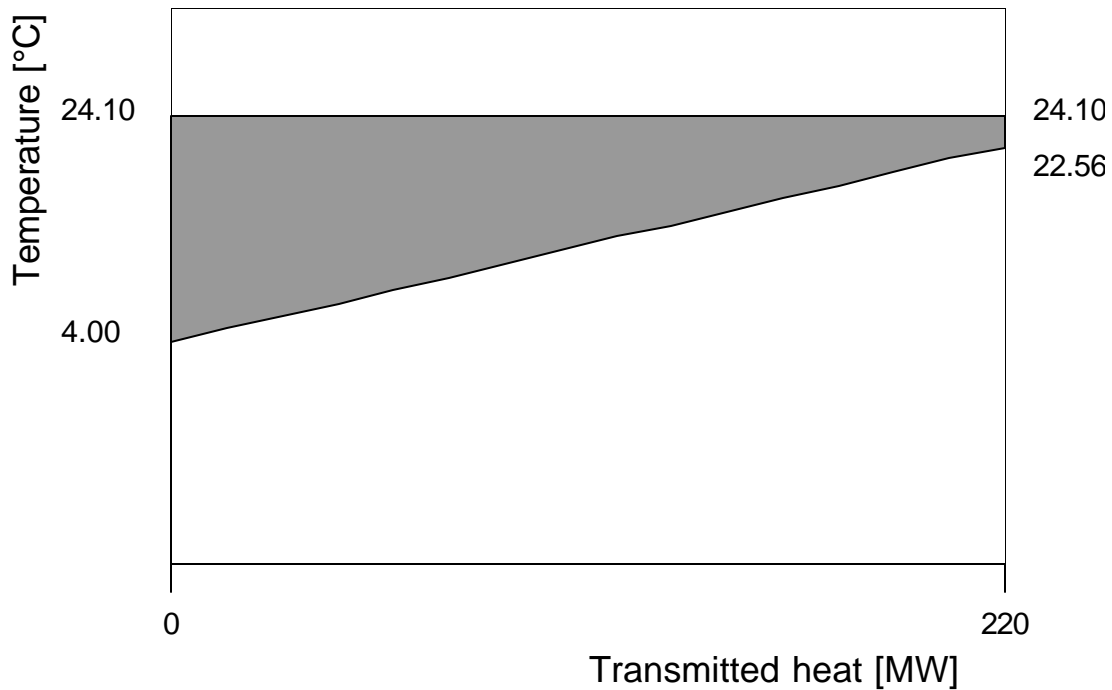


Figure 8 Q,T diagram for the design calculation

A total amount of 220 MW of heat is exchanged between the water/steam and the cooling water. Cycle-Tempo has calculated an outlet cooling water temperature of 22.56° Celsius.

1.2.9 Energy and exergy in the system

A table of the energy and exergy flows can be made after setting the environment definitions in the general data menu. The exergy of a medium is relative to that of the environment chosen, so Cycle-Tempo needs this information to perform an exergy calculation. In this example the environmental conditions are set equal to the conditions of the incoming cooling water, i.e. T= 12° and p= 4 bar. Table 8 shows the exergy values in the system and Table 9 shows the energy and exergy flows.

Table 8 Exergy values in the system

No.	Name	Type	Exergy transmitted from system [kW]			Rel. Ex. Loss [%]	Univ. Exergy eff. [%]	Func. Exergy eff. [%]
			Total	Power/Heat	Losses			
1	Condenser	4	5965.10	0.00	5965.10	66.11	33.41	33.89
2	Sink/Source	10	0.00	0.00	0.00	0.00		
3	Sink/Source	10	2993.35	0.00	2993.35	33.17		
4	Sink/Source	10	-9023.16	0.00	-9023.16	-100.00		
5	Sink/Source	10	64.71	0.00	64.71	0.72		
	Total:		0.00	0.00	0.00	0.00		

Table 9 Energy and exergy flows

<i>Pipe no.</i>	<i>Total Energy flow</i>	<i>Total Exergy flow [kW]</i>
1	225042.06	9023.16
2	5023.99	64.71
3	0.00	0.00
4	220018.06	2993.35

For an explanation of the exergy definitions, the user is referred to paragraph 1.1.4, or to the Cycle-Tempo manual.

1.2.10 Input for the off-design calculation of an unknown temperature

In this example the off-design calculation will be discussed. The condenser will be used to condense a steam flow with a mass-flow which is 60% of the original mass-flow of 100 kg/s. The input temperature and the mass-flow of the cooling water are held constant and Cycle-Tempo has to calculate the new cooling water outlet temperature. Table 10 shows the input parameters.

Table 10 Input data for the off-design calculation of an unknown temperature

Input parameters	
Condenser (apparatus Nr.1)	
<i>EEQCOD</i>	2
<i>DELP1</i>	2
<i>PIN2</i>	0.03
<i>DELP2</i>	0
<i>SATCOD</i>	0
Geometry input data	
<i>DIAIN</i>	0.018
<i>DIAOUT</i>	0.020
<i>PITCH</i>	0.030
<i>NPIPES</i>	35500
<i>NEDGE</i>	3550
<i>LAMBDW</i>	0.085
<i>RFOUL</i>	0.045
<i>AIRFAC</i>	1.4
Off-design input data	
<i>A</i>	pasted from design situation
Sink/Source (apparatus Nr.2)	
<i>POUT</i>	4
<i>TOUT</i>	12
<i>DELM</i>	-5000
Sink/Source (apparatus Nr.3)	
	-
Sink/Source (apparatus Nr.4)	
<i>DELM</i>	-60
<i>XOUT</i>	0.9
Sink/Source (apparatus Nr.5)	
	-

Cycle-Tempo can now calculate the outlet cooling water temperature.

1.2.11 Results of the off-design calculation of an unknown temperature

Figure 9 shows the results for the off-design calculation.

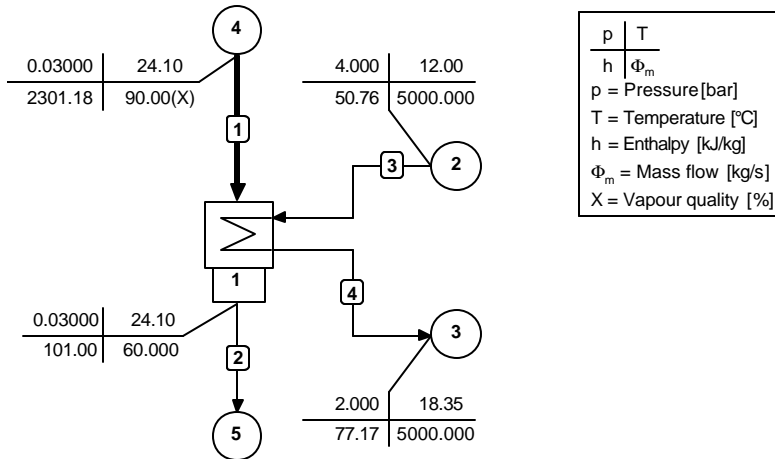


Figure 9 Results of the off-design calculation of an unknown temperature

1.3 Condensate inlets

In Cycle-Tempo there is a possibility of modelling multiple condensate inlets into the condenser. Up to four extra inlets can be modelled. The next paragraph will give an example of a condenser with a condensate inlet.

1.3.1 Condenser with a condensate inlet

In this example the same configuration and input data are used as for the example in paragraph 1.2.2, except for an extra inlet of a condensate flow into the condenser, see Figure 10.

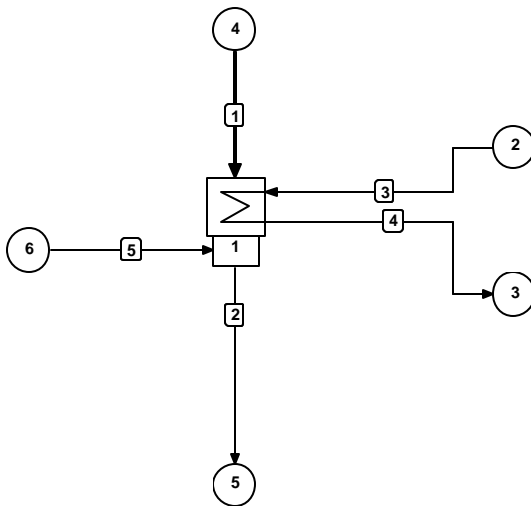


Figure 10 Scheme condenser with condensate inlet

1.3.2 Input for a condenser with a condensate inlet

The input data for this problem are the same as the input data for the example of paragraph 1.2.2. The only difference is the sink (Nr.6) that is added and connected to the condenser with a water pipe (Nr.5). It is assumed that a condensate flow of 10 kg/s with a temperature of 15° Celsius and with a pressure, which is equal to the condenser pressure, is added to the condenser. The input parameters for the sink are shown in Table 11.

Table 11 Input parameters for the added sink/source

Sink/Source (apparatus Nr.6)	
TOUT	15
DELM	-10

1.3.3 Results for a condenser with a condensate inlet

Figure 11 shows the results for a condenser with a condensate inlet.

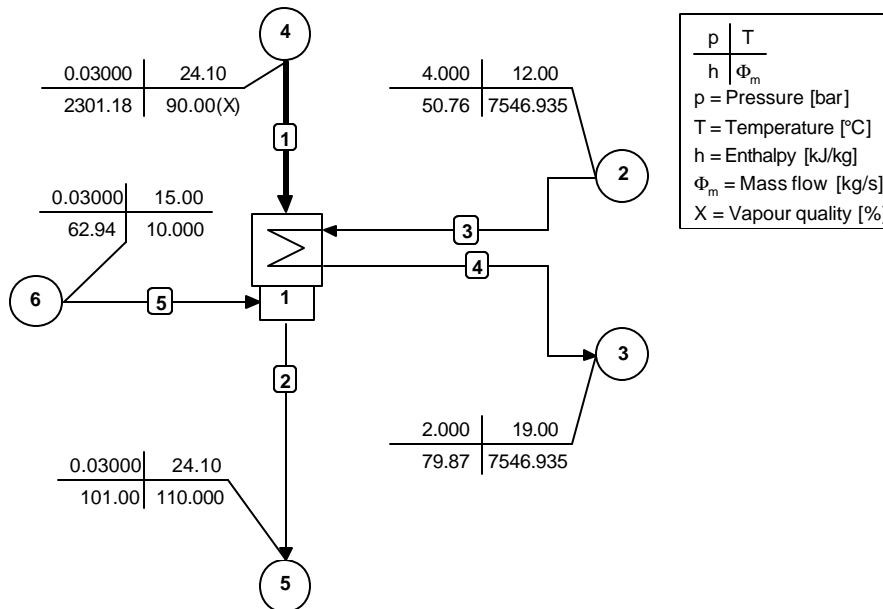


Figure 11 Results for a condenser with a condensate inlet

The user should notice that in comparison with the results in paragraph 1.2.3, Cycle-Tempo calculated a lower cooling water mass-flow. This is due to the extra condensate flow with a lower temperature than the condenser temperature. In other words, extra cooling capacity is added by the extra condensate flow.