ASIMPTOTE Advanced SIMulation Programs for TOTal Energy systems

Reference Guide

A program for thermodynamic modeling
and optimization of energy conversion systems

Table of contents

Chapter 1

Introduction

This part is meant as a reference guide for setting-up a process scheme and for specifying input data. It merely contains brief information on the components and parameters which are needed to define a system.
The intention has been to limit the extent of this part of the manual. The necessary explanations are as brief as possible. A description of the output of the program is given also.

The reference guide has the following contents:

- ***Input***

Chapter 2: apparatuses
Chapter 3: connections
Chapter 4: medium data
Chapter 5: system data
Chapter 6: calculation settings

- ***Output***

Chapter 7: text output
Chapter 8: tables

Each paragraph, with exception of the general apparatus data and the introductions, can be read independently from other parts.

In paragraph 2.1 the general apparatus data are described. They apply to almost all apparatus types. This paragraph also contains an overview of the available apparatus types. The general input data for apparatuses should be known before specifying input data for the specific apparatus types.

Chapter 2

Apparatus

2.1 General apparatus data

Table 2-1 gives a summary of the apparatus types available in Cycle-Tempo together with the default names and the number of system equations added to the system matrix by the apparatus type.

The general parameters for the apparatuses are:

No. = identification number of the apparatus (apparatus number).
The apparatus number must be equal to, or greater than 1, but less than 32767. Apparatus numbers are automatically assigned, but may be changed if desired.

Name = apparatus name to be entered by the user (for default values see Table 2-1). The name may not be longer than 12 characters. The names specified are used in tables with calculation results or diagrams.

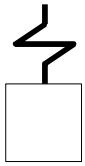
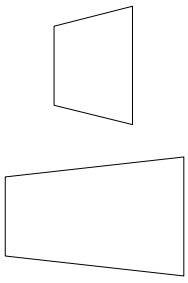
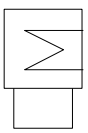
For almost all apparatus the following thermodynamic data can be specified:

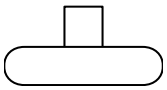
PIN	=	inlet pressure	(bar)
POUT	=	outlet pressure	(bar)
DELP	=	pressure loss in the apparatus	(bar)
TIN	=	inlet temperature	(°C)
TOUT	=	outlet temperature	(°C)
DELT	=	temperature *rise* in the apparatus	(°C)

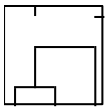
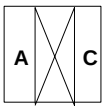
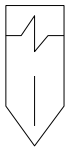
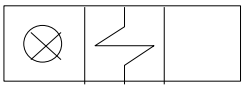
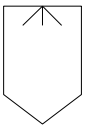
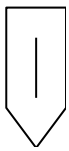
For the heat exchanging apparatus the variables PIN, POUT, DELP, TIN, TOUT and DELT are post fixed with a 1 for the primary medium (heated medium) and with a 2 for the secondary medium (cooled medium) (e.g. PIN1, TOUT2, etc.).
The other data are described and explained for each apparatus type. The default values of the thermodynamic data are, unless otherwise indicated, fixed at UNKNOWN, represented by the numeric value -8888.8.

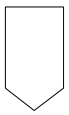
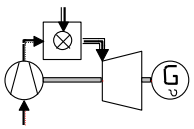
Table 2-1: summary of available apparatus types

Explanation: M = mass equation, E = energy equation, P = production function
/ = exclusive choice, + = mandatory combination

Type	Default name	System equations	Symbol
1	Boiler	1M	
2	Reheater	1M	
3	Turbine	1M	
4	Condenser	2M / (EEQCOD = 2; type 6) 2M + 1E (EEQCOD = 1; type 12)	
5	Flash.Heater	2M + 1E	

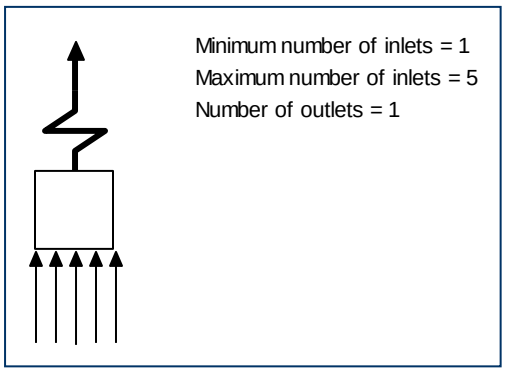
Type	Default name	System equations	Symbol
6,12	Heat Exchgr.	2M / (EEQCOD = 2; type 6) 2M + 1P (EEQCOD = 1; type 12)	
7	Deaerator	1M + 1E	
8	Pump	1M	
9,11	Node	1M / (EEQCOD = 2; type 9) 1M + 1E (EEQCOD = 1; type 11)	
10	Sink/Source	1M (in case of only 1 pipe connected then 1M only if DELM, DELV or DELVN is specified)	
10	Heat Sink	1M (in case of only 1 pipe connected then 1M only if DELM, DELV or DELVN is specified)	
10	Stack	1M (only if DELM, DELV or DELVN is specified)	
13	Combustor	1M / (EEQCOD = 2) 2M (EEQCOD = 1, or EEQCOD = 2 if LAMBDA specified) (ash pipe connected → +1M)	
14	Valve	2M	
15	Drum	1M + 1E	

Type	Default name	System equations	Symbol
20	Reformer	2M / (EEQCOD = 2) 2M + 1E (EEQCOD = 1) (SFRATI specified → +1M)	
21	Fuel Cell	2M / (EEQCOD = 2) 2M + 1E (EEQCOD = 1) (cooled LTFC → +1M) (UOX specified → +1M) (POWER specified → +1M)	
22	Moist. Sepr.	2M / (EEQCOD = 2) 2M + 1E (EEQCOD = 1) (if mass flow of separated moisture is calculated: +1M)	
23	Gasifier	2 M / (EEQCOD = 2) 2 M + 1E (EEQCOD = 1) (ash pipe connected → +1M) (OFRATI or ESTOFR specified → +1M) (SFRATI specified → +1M)	
25	Scrubber	2M	
26	Separator	2M	
27	Reactor	1M	

Type	Default name	System equations	Symbol
28	Saturator	2M	
29	Compressor	1M	
30	Gas turbine	1M if a bottoming cycle is present	
G	Generator	-	
M	Electromotor	-	

Boiler

2.2 Type = 1 Boiler



Applications

This apparatus type is intended for use as a boiler in closed cycles, where the boiler is only modeled as an apparatus in which heat is added to the cycle and where details of the flue gas system are not taken into account. The boiler comprises only the economizer, evaporator and superheater; any reheater present must be modeled separately (see type = 2, reheater).

Input parameters

PIN, POUT, DELP, TIN, TOUT and DELT are standard.

DELE = energy flow released from the boiler (kW) (default = UNKNOWN). Radiation losses cannot be specified separately, but may be rediscounted in the thermal efficiency. Specification is only allowed for boilers with 1 inlet and 1 outlet pipe. The value should differ by at least EPS from -8888.8. If DELE is specified, ESTMAS should be specified also.

ESTMAS = estimated mass flow rate (kg/s) (default = UNKNOWN).
ESTMAS must be specified if DELE has been prescribed, in order to obtain a realistic specific enthalpy change over the boiler in the first main iteration.

ETHAB[1)] = thermal efficiency of the boiler (-) (default = 1.0).
ETHAB is only useful for the efficiency calculation.

LHV[1)] = lower heating value of the fuel (kJ/kg) (default = UNKNOWN).
Specification of LHV is only important for the exergy calculation.

EXFUEL[1)] = exergy of the fuel (kJ/kg) (default = UNKNOWN).

1) If LHV, EXFUEL and ETHAB are specified, an exergy input and an exergy efficiency of the system will be calculated. An exergy efficiency of the boiler will be calculated also.

Number of equations for system matrix

This apparatus type adds 1 mass equation to the system matrix.

Calculation rules

1. $p_{out} = p_{in}$ - DELP
2. $T_{in} = T_{out}$ - DELT
3. $h_{in} = h_{out}$ - DELE/Φ_m Φ_m = mass flow (kg/s)

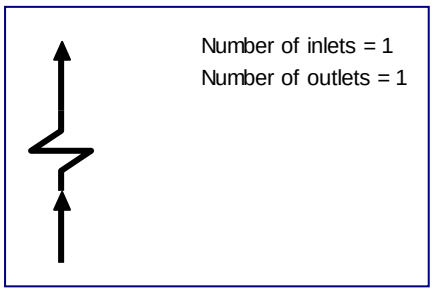
Capitalized data is taken from apparatus input, the other variables written with subscripts are either apparatus input data or the data of connected apparatus or pipes.

Off-design calculations

For performing off-design calculations no extra calculation rules are available.

Reheater

2.3 Type = 2 Reheater



Applications

This apparatus type, like the boiler (type = 1), is intended for modeling in closed cycles, where details of the flue gas system are not taken into account.

Input parameters

PIN, POUT, DELP, TIN, TOUT and DELT are standard.

DELE	=	energy flow released from the reheater (kW) (default = UNKNOWN). Radiation losses cannot be specified separately, but may be rediscounted in the thermal efficiency. Specification is only allowed for reheaters with 1 inlet and 1 outlet pipe. The value should differ by at least EPS from -8888.8. If DELE is specified, ESTMAS should be specified also.
ESTMAS	=	estimated mass flow rate (kg/s) (default = UNKNOWN). ESTMAS must be specified if DELE has been prescribed, in order to obtain a realistic specific enthalpy change over the reheater in the first main iteration.
ETHAB[1)]	=	thermal efficiency of the reheater (-) (default = 1.0). ETHAB is only useful for the efficiency calculation.
LHV[1)]	=	lower heating value of the fuel (kJ/kg) (default = UNKNOWN). Specification of LHV is only important for the exergy calculation.
EXFUEL[1)]	=	exergy of the fuel (kJ/kg) (default = UNKNOWN).

1) If LHV, EXFUEL and ETHAB are specified, an exergy input and an exergy efficiency of the system will be calculated. An exergy efficiency of the reheater will be calculated also.

Number of equations for system matrix

This apparatus type adds 1 mass equation to the system matrix.

Calculation rules

1. $p_{out} = p_{in}$ - DELP
2. $T_{in} = T_{out}$ - DELT
3. $h_{in} = h_{out}$ - DELE/Φ_m Φ_m = mass flow (kg/s)

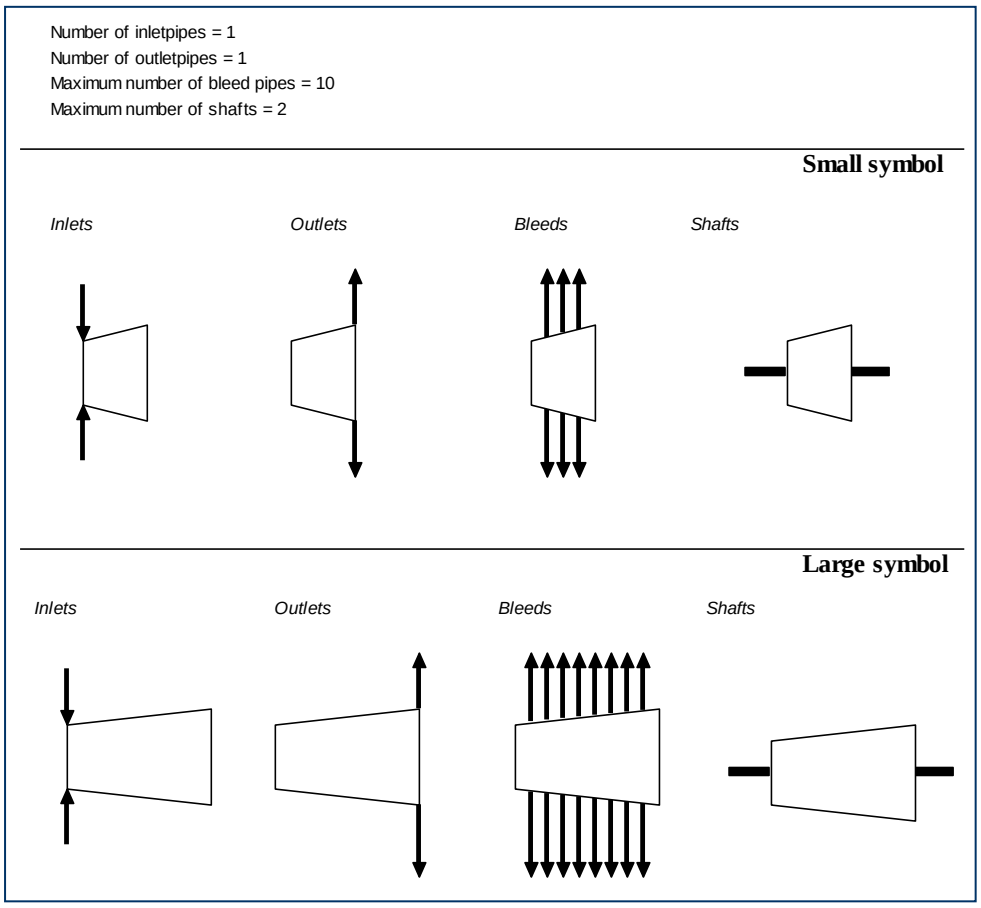
Capitalized data is taken from apparatus input, the other variables written with subscripts are either apparatus input data or the data of connected apparatus or pipes.

Off-design calculations

For performing off-design calculations no extra calculation rules are available.

Turbine

2.4 Type = 3 Turbine



Applications

The apparatus type turbine is intended for modeling different types of turbines. In addition to an inlet and an outlet a turbine may have a maximum of 8 extraction points. The addition of an extra mass flow in the expansion section between the turbine inlet and outlet is not possible; in this case the turbine can be modeled as two turbines in series.

The general type (TUCODE = 0) can be used as an expansion turbine in cycles with various media, e.g. as steam turbine, gas turbine etc. For this type no routines are available for determining the internal efficiencies; these must be specified directly or indirectly. No exhaust losses are calculated for this type either.

Several types are available for modeling steam turbines. Large steam turbines usually consist of a number of sections. By using the types indicated in Table 2-2 (TUCODE starting with digits 1 to 9) a turbine of virtually any size can be modeled. For all these types there are procedures for determining the internal efficiencies; these do not then have to be specified. For the condensation sections the exhaust losses are also determined; these are rediscounted in the internal efficiency.
It should be noted that the method for calculating the efficiencies dates from 1974 and that with present-day steam turbines greater efficiencies can be obtained. However, for tendency calculations the method is very useful. In addition it is possible for the turbines with TUCODE beginning with digits 2 to 9 to revise the basic value of ETHAID as required.
These models for steam turbines do not generally give valid results for media other than WATERSTM (see chapter 4 Medium Data).
Off-design calculations are possible for all types. Traupel's formulae are used for this (a refinement of Stodola's cone law).

Input parameters

PIN, TIN, TOUT and DELT are standard.
(N.B. it is not possible to specify POUT and DELP).

TUCODE = five digit turbine code, $t_1\ t_2\ t_3\ t_4\ t_5$. The digit furthest on the left, (t_1) indicates the turbine type (default = 0).

GDCODE = code which indicates the presence (GDCODE = 2) or absence (GDCODE = 1) of a governing stage (default = UNKNOWN).

ETHAI = isentropic efficiency (default = UNKNOWN for TUCODE = 0).

ETHAM = mechanical efficiency (default = 1).

Depending on the type of turbine, indicated by t_1 of TUCODE, a few geometric data have to be specified. A summary of the input variables is given in Table 2-2. For a detailed description see part “Technical Notes” of the manual.

Number of equations for system matrix

This apparatus type adds 1 mass equation to the system matrix.

Pressure calculation

1. Design load: No relations are available to calculate pressures: the outlet pressure and the pressures at the extraction points have to be specified with data for apparatus downstream of the turbine (or with the help of extra conditions for pipes).
   The turbine inlet pressure can be specified for the turbine or for apparatus upstream of the turbine.

2. Off-design: The pressures at extraction points are calculated using Traupel's formula, provided the pressure of the outlet is known, and the design extraction point pressures are specified in the input.
   The calculation of the turbine inlet pressure using Traupel's formula is only output when the relevant turbine section does not have a governing stage (GDCODE = 1).

Temperature, specific enthalpy and vapor fraction
(for design load and off-design calculation)

3. $T_{out} = T_{in} + DELT$
4. $h_{out} = f(h_{in}, ETHAI)$
   a straight or curved expansion line is assumed and pressures have to be known.
5. Thermodynamic variables at extraction points are computable from turbine inlet and outlet conditions and the pressure of the extraction point. The isentropic efficiency (η_i) can be specified in the input (as $t_1 = 0$), or is computable from user defined turbine data, using polynomials suggested by General Electric (t_1 = 1 to 5, 8 and 9) or VMF Stork (nowadays NEM Hengelo, the Netherlands) (t_1 = 6 and 7). In addition the enthalpy at the extraction points is also influenced by the shape of the expansion line. In the h,s-diagram this is a straight line for $t_5 = 0$. For turbine sections with t_1 = 5, 8 or 9 a curved expansion line may be chosen with $t_5 = 1$.

Table 2-2: Input data for the turbine types

Turbine type	TUCODE	GDCODE	ETHAID [1]	Required data	Optional data
General turbine	0	1 or 2	not applicable	-	ETHAI
Intermediate pressure section [2] (with double reheating)	10000	1	not applicable	-	-
High pressure section with 1-row governing stage	2f00v	2	0.870	DIAIN	POUTDS, DESMAS [3]
High pressure section with 2-row governing stage	3f00v	2	0.840	-	POUTDS, DESMAS [3]
Turbine without reheater with 2-row governing stage	4f000	2	0.8948	-	POUTRT, DESMAS [3]
Condensing section MP + LP, 3000 rpm [4]	5mdLe	1	0.9193	SLENG, DIAOUT	-
Back pressure turbine (pressure controlled)	60c00	2	0.800	DESMAS, DELH	-
Back pressure turbine (mass flow controlled)	70c00	2	0.800	DESMAS, DELH	-
Condensing section 3000/1500 rpm [4]	8mdLe	1	0.9193	SLENG, DIAOUT	PINCND
Condensing section 1500 rpm [4]	9mdLe	1	0.9295	SLENG, DIAOUT	-

1) The values are default values; the user is free to specify other values.

2) The validity range for the pressure ratio is: $p_{in} / p_{out} \geq 2$ (extrapolated to $p_{in} / p_{out} \geq 1.33$).

3) Only for off-design calculations.

4) For 60 Hz installations 3600 and 1800 rpm respectively.

Explanation to Table 2-2:

TUCODE	=	f:	number of parallel flows (**f**lows)	t_2
		m:	number of parallel flows in the **m**edium pressure part of the condensing section	t_2
		L:	number of parallel flows in the **l**ow pressure part of the condensing section	t_4
		v:	number of inlet valves (**v**alves)	t_5
		c:	**c**orrection for the isentropic enthalpy drop	t_3
		d:	outlet direction of the condensing section (**d**irection):	t_3
			d = 1: downward, at 3000 and 3600 rpm (t_1= 5)	
			d = 2: downward, at 1500 and 1800 rpm (t_1= 8 of 9)	
			d = 3: axial, at 1500 and 1800 rpm (t_1= 8 of 9), (structurally only possible for one outlet)	
		e:	shape of the **e**xpansion line for condensing sections	t_5
			e = 0: straight expansion line in h,s-diagram	
			e = 1: curved expansion line	

ETHAID	=	basic value for the isentropic efficiency; default values: see Table 2-2 (-)
DIAIN	=	pitch diameter [1] of the governing stage (m)
DIAOUT	=	pitch diameter [4] of the last row of blades (m)[2]
SLENG	=	blade length of the last row of blades (m)[5]
DESMAS	=	design inlet mass flow rate (kg/s)
PINCND	=	pressure between medium and low pressure section; for part load calculations the design value must be specified here (bar)
POUTDS	=	design value of the outlet pressure; for part load calculations the default value is the first value of the array ‘Pressure’ (see the next heading), which is the outlet pressure (bar)
POUTRT	=	pressure just downstream of the governing stage; (default = 0.625*PIN) (bar)
DELH	=	isentropic enthalpy drop at design conditions (kJ/kg)

1) Pitch diameter means: the diameter at half blade height. The default values are 0.965 m and 1.158 m for 3600 and 3000 rpm, respectively.

2) The limits for DIAOUT and for SLENG are:

$1.33 \le DIAOUT \le 2.30$ $0.36 \le SLENG \le 0.85$ for 3000 and 3600 rpm

$2.79 \le DIAOUT \le 3.858$ $0.88 \le SLENG \le 1.32$ for 1500 and 1800 rpm

Input parameters for off-design calculations

The results of the design calculation are written to the file with design data for off-design calculations. These data can be copied to the required input parameters for off-design calculations using the Paste-button.

For turbines the following variables can be specified:

DESVOL	=	inlet volume flow (m3/s)
HOUTRT[1)]	=	specific enthalpy after the governing stage (kJ/kg)

The following 4 arrays of figures in order of increasing pressure (the variable for the outlet with the lowest pressure is the first element):

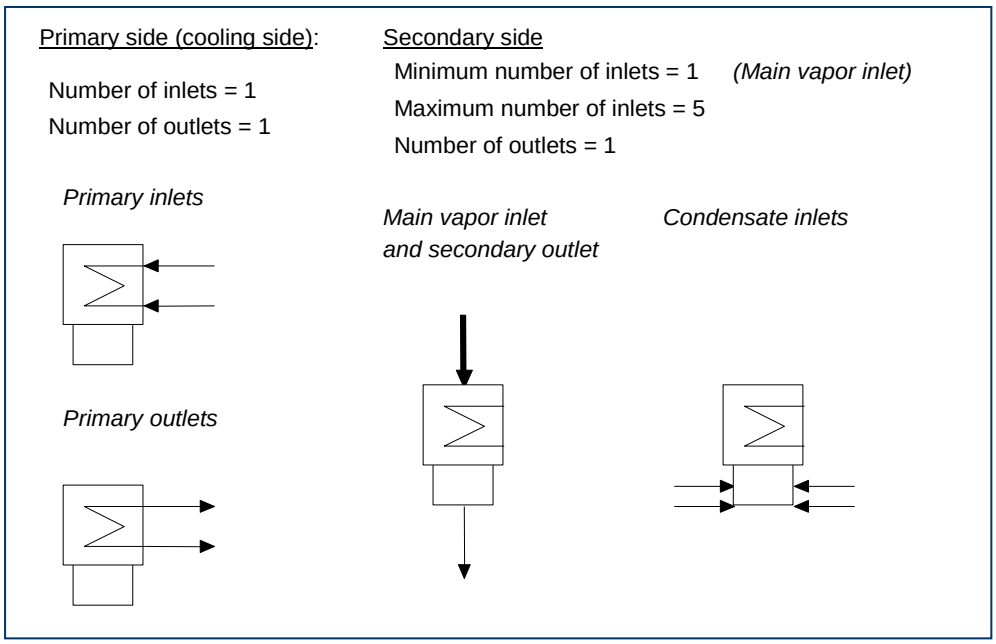
Bleed pipe no.[2)]	=	column with pipe numbers (connected to the turbine)
Pressure	=	column with pressures in the pipes connected (bar)
Mass flow	=	column with mass flows in the turbine sections (kg/s)
Specific volume	=	column with specific volumes at the extraction points (m^3/kg)

1) This input is optional and may be omitted (calculated from the design data).

2) Bleed pipe no. = 0 to prescribe conditions just after the governing stage.

Condenser

2.5 Type = 4 Condenser



Applications

The condenser model is designed for the calculation of condensers in steam turbine cycles. The heat of condensation is then removed via the cooling water. If the model is used for design calculations, then the use of other media is also permitted (where data are present they are in the material library). In that case the heat transfer relations are not used.
With regard to description of the off-design behavior it is assumed that the steam to be condensed is not superheated and that the condensate is not subcooled.
In calculations with the condenser model the energy equation (energy balance) over the condenser is available to calculate an unknown variable (mass flow or enthalpy). The

variable, which is solved from the energy equation, depends on the value of the **E**nergy **EQ**uation **COD**e (EEQCOD):

- **EEQCOD = 1:** the energy equation of the apparatus is used to calculate a mass flow. The energy equation will be added to the system matrix.

- **EEQCOD = 2:** the energy equation of the apparatus is used to calculate an enthalpy in one of the inlets or outlets. The energy equation will not be added to the system matrix.

If the EEQCOD is not specified the default value 1 is used.

When an off-design calculation is carried out, an extra equation is available, namely the heat transfer equation. From this equation an unknown temperature can be solved.
The possible calculation options are summarized in the diagram below:

	Design		**Design with U-value**		**Off-design**	
EEQCOD	1	2	1	2	1	2
Calculate	Φ_m	T	Φ_m	T	Φ_m	T
					T	T
Geometry data	-	-	specify	specify	specify	specify
Data from design calculation	-	-	-	-	specify	specify

The design calculation

In the design calculation an unknown mass flow or enthalpy can be solved from the energy equation. In this calculation option all media are permitted in the condenser. In addition it is permitted for the secondary medium to flow into the condenser superheated and to leave it again subcooled, see Figure 2-1.

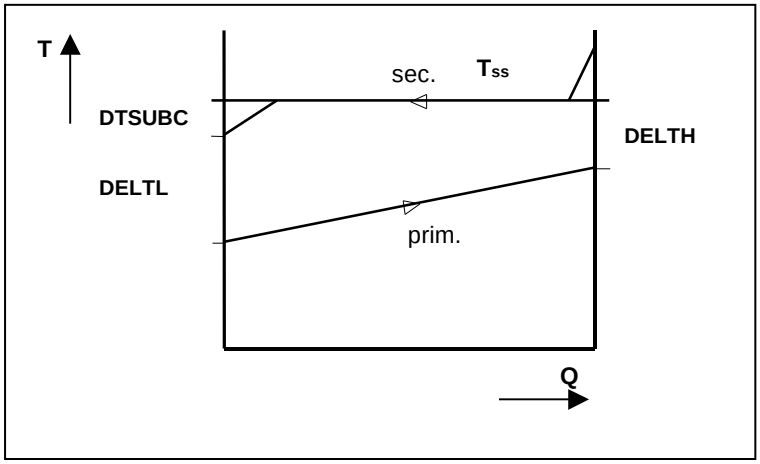


Figure 2-1: Q, T diagram of the condenser

The design calculation with U-value calculation

In this case the calculation options are the same as those for a normal design calculation. In addition the overall heat transfer coefficient U ($kW/m^2 K$) for the heat transfer is calculated and the necessary size of the heat exchanging area A (m^2). These data from the design calculation are necessary as an input for carrying out an off-design calculation.

The calculation method for the U-value is only available for a condenser with:

- cooling water as primary medium;
- steam as secondary medium;
- wet or saturated steam at inlet, saturated condensate at outlet;
- flow of the secondary medium through the condenser without pressure drop.

To calculate the U-value extra input data relating to the geometry must be specified.

The extra result of this calculation (the size of the heat exchanging area A) is written to the file with design data for off-design calculations. Using the Paste-button this datum can be copied to the required input parameter for off-design calculations. See also below.

The off-design calculation

For performing off-design calculations the size of the heat exchanging area must be specified. When the value of A is not known, this can be calculated in the extended design calculation, see above.

In order to calculate the U-value, data relating to the bundle geometry must be specified. This is done by means of the geometry input parameter.

When performing the off-design calculation the energy equation can be used to calculate an unknown mass flow or enthalpy. The heat transfer equation is available for computing an unknown temperature. In the diagram below the possible combinations are summarized:

EEQCOD	To be calculated			
	$\Phi_{m,p}$	$\Phi_{m,s}$	T_{ss}/p_{ss}	$T_{out,p}$
1	X		X	
	X			X
		X	X	
		X		X
2			X	X

The overall heat transfer coefficient (U-value) must be specified for the off-design calculation from the geometry data, the thermodynamic data and the mass flows. The restrictions also apply for the off-design calculations, which are given for the extended design calculation for the U-value calculation method.

Input parameters

For the apparatus data the following can be specified:

PIN1, POUT1, DELP1, TIN1, TOUT1, DELT1 are standard
PIN2, POUT2, DELP2, TIN2, TOUT2, DELT2[1)] are standard

EEQCOD = code which indicates whether the energy balance is used to calculate a mass flow (EEQCOD=1) or a temperature (EEQCOD=2) (default=1)

SATCOD[2)] = saturation code (default = UNKNOWN), specify 0.0 to indicate that secondary (condensate) outlet is saturated.

RPSM = initial estimate of the ratio between the primary and secondary mass flow (default = 65). This value is only used where the EEQCOD is 2.

DELTH = difference between the saturation temperature of the secondary medium and the outlet temperature of the primary medium (°C), $T_{ss} - T_{out,p}$ (default = UNKNOWN).
This value may not be specified in an off-design calculation.

DELTL[2)] = difference between the outlet temperature of the secondary medium and the inlet temperature of the primary medium (°C), $T_{out,s} - T_{in,p}$ (default = UNKNOWN).
This value may not be specified in the case of an off-design calculation.

DTSUBC[2)] = difference between the saturation temperature of the condensate of the secondary medium and the outlet temperature of the secondary medium (°C), $T_{ss} - T_{out,s}$ (default = UNKNOWN).
This value may not be specified in the case of an off-design calculation.

DELE = energy flow to the environment (e.g. radiation loss) (kW) (default = 0.0).
If DELE > 0 energy is given off to the environment.

1) *DELT2 is defined as temperature rise, this value hence normally has a negative value for the secondary medium.*

2) *If SATCOD=0.0 is specified DTSUBC, TOUT2 and DELTL may not be specified. If TOUT2 or DTSUBC is specified then this value is ignored. If SATCOD is not specified TOUT2, DTSUBC or DELTL must be specified.*

Number of equations for system matrix

This apparatus type adds 2 mass equations to the system matrix. If EEQCOD = 1 the energy equation is added also.

Summarizing:
EEQCOD = 1: 2 mass equations + 1 energy equation = 3 equations
EEQCOD = 2: 2 mass equations

Calculation rules

For the primary medium

1.	p_{out}	=	p_{in}	-	Δp_1	Δp_1 = pressure loss on primary side.
2.	p_{in}	=	p_{out}	+	Δp_1	
3.	T_{out}	=	T_{in}	+	ΔT_1	ΔT_1 = temperature rise on primary side.
4.	T_{in}	=	T_{out}	-	ΔT_1	
5.	T_{ss}	=	$f_{sat}(p_{in,s})$			

	$T_{out,p}$	=	T_{ss}	-	DELTH	
6.	$T_{in,p}$	=	$T_{out,s}$	-	DELTL	

For the secondary medium

7.	p_{out}	=	p_{in}	-	Δp_2	Δp_2 = pressure loss on secondary side
8.	T_{out}	=	T_{in}	+	ΔT_2	ΔT_2 = temperature rise on secondary side

Rules 7 and 8 can only be used when only 1 inlet pipe is connected to the secondary side (main pipe).

9.	T_{ss}	=	$T_{out,p}$	+	DELTH	
	$p_{out,s}$	=	$f_{sat}(T_{ss})$			
10.	$T_{out,s}$	=	$T_{in,p}$	+	DELTL	
11.	$T_{out,s}$	=	$f_{sat}(p_{out,s})$			applies when SATCOD=0
12.	T_{ss}	=	$f_{sat}(p_{out,s})$			
	$T_{out,s}$	=	T_{ss}	-	DTSUBC	

Input parameters for geometry

For the condenser the following geometry data can be specified:

DIAIN	=	the inside diameter (m) of the pipes in the condenser (default = 0.018)
DIAOUT	=	the outside diameter (m) of the pipes in the condenser (default = 0.020)

PITCH	=	the pitch, the distance between centers of the pipes (m), the standard assumption is a staggered layout (default = 0.030)
NPIPES	=	the total number of pipes in the bundle (default = 35500)
NEDGE	=	the number of pipes on the edge of the bundle, the number of mantle pipes (default = 3550)
PRISEC	=	code, which indicates whether the energy equation is used to determine the primary or the secondary mass flow. PRISEC must be specified if EEQCOD = 1 and an off-design calculation is carried out (default = UNKNOWN). PRISEC = 1 : the primary mass flow is calculated PRISEC = 2 : the secondary mass flow is calculated
LAMBDW	=	the thermal conductivity coefficient of the wall (kW/m K) (default = 0.085)
RFOUL	=	heat resistance to fouling on the cooling water side (m^2 K/kW) (default = 0.045)
AIRFAC	=	correction factor for air influence, the heat resistance on the steam side is increased by the factor AIRFAC (default = 1.4)

A few hints for the choice of the geometry data:

- Choose the combination of the inside diameter and the total number of pipes so that the speed of the cooling water in the pipes in the design situation is between 1 and 2 m/s.

$$v = \frac{4 \times \phi_m}{\rho \times \pi \times DIAIN^2 \times NPIPES}$$

- The inside and outside diameter much be chosen such that the wall thickness is given an acceptable value.

- The ratio of the total number of pipes to the number of pipes on the edge is for most bundles around 10.

- The pitch diameter ratio (outside) of the bundle is around 1.5.

- The value of the thermal conductivity coefficient depends on the pipe material. A very common value is 0.085 kW/m K (copper alloy).

Input parameters for off-design calculations

For a condenser the following data must be specified for off-design situations:

A = heat exchanging area (m^2)

At the end of the extended design calculation the logarithmic temperature difference over the condenser and the heat transfer coefficient are calculated. With these data and the quantity of heat transferred the size of the heat exchanging area is calculated.
The result of this calculation is written to the file with design data for off-design calculations. Using the Paste-button this datum can be copied to the required input parameter for off-design calculations.

In the design calculation the logarithmic temperature difference over the condenser and, with the help of the geometry data, the heat transfer coefficient, are calculated. With these data and the transferred heat the size of the heat exchanging area is calculated. Using this the length of the bundle is then established, where:

$$A = NPIPES \times \pi \times DIAOUT \times l$$

Feed water heater

2.6 Type = 5 Feed water heater

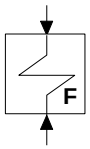
Primary side (feedwater):

Number of inletpipes = 1
Number of outletpipes = 1

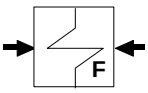
Secondary side

Minimum number of inletpipes = 1 *(bleed steam inletpipe)*
Maximum number of inletpipes = 5
Number of outletpipes = 1

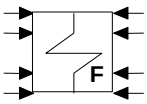
Primary inlets



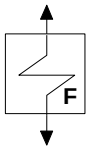
Bleed steam inlets



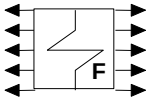
Other secondary inlets



Primary outlets



Secondary outlets



Applications

A flashed heater normally uses extraction steam from the turbine. The energy balance is employed for mass flow rate calculations and is automatically added to the system matrix. The secondary inlet refers to an extraction line from the turbine.
The calculation rules assume a condensing medium for the secondary side.

Input parameters

PIN1, POUT1, DELP1, TIN1, TOUT1, DELT1 are standard
PIN2, POUT2, DELP2, TIN2, TOUT2, DELT2[1)] are standard

SATCOD[2)] = saturation code (default = UNKNOWN), enter 0.0 to indicate saturation of the secondary (condensate) outlet.

DELTH = temperature difference between the primary outlet temperature and the saturation temperature of the extraction steam (°C) (default = UNKNOWN)

DELTL = temperature difference between primary inlet temperature and secondary outlet temperature (°C) (default = UNKNOWN)

DELE[3)] = energy flow to the environment (kW) (default = 0.0) (e.g. radiation loss)

1) *DELT2 is defined as temperature rise, so this value is normally a negative value for the secondary medium.*

2) *If SATCOD = 0.0 is specified, neither TOUT2 nor DELTL may be given.*

3) *This value may not be altered in a user subroutine.*

Number of equations for system matrix

This apparatus type adds 3 equations to the system matrix: 2 mass equations + 1 energy equation.

Calculation rules for pressure

Primary medium

1.	$p_{out,p}$	=	$p_{in,p}$	-	DELP1	

Secondary medium

2.	$p_{out,s}$	=	$p_{in,s}$	-	DELP2	
3.	T_{ss}	=	$T_{out,p}$	+	DELTH	only for one secondary inlet
	$p_{in,s}$	=	$f_{sat}(T_{ss})$			saturation conditions

$T_{out,s}$ may be specified for the input (TOUT2), calculated in an apparatus upstream, or calculated with one of the following calculation rules:

Calculation rules for temperature, specific enthalpy, steam quality

(for design and off-design calculations)

Primary medium

4.	$T_{out,p}$	=	$T_{in,p}$	+	DELT1	
5.	T_{ss}	=	$f_{sat}(p_{in,s})$			only for one secondary inlet saturation conditions
	$T_{out,p}$	=	T_{ss}	-	DELTH	
6.	$T_{in,p}$	=	TOUT2	-	DELTL	

Secondary medium

7.	$T_{out,s}$	=	$T_{in,s}$	+	DELT2	only for one secondary inlet.
8.	$T_{out,s}$	=	$T_{in,p}$	+	DELTL	
9.	$T_{out,s}$	=	$f_{sat} (p_{out,s})$			saturation conditions, SATCOD = 0.0

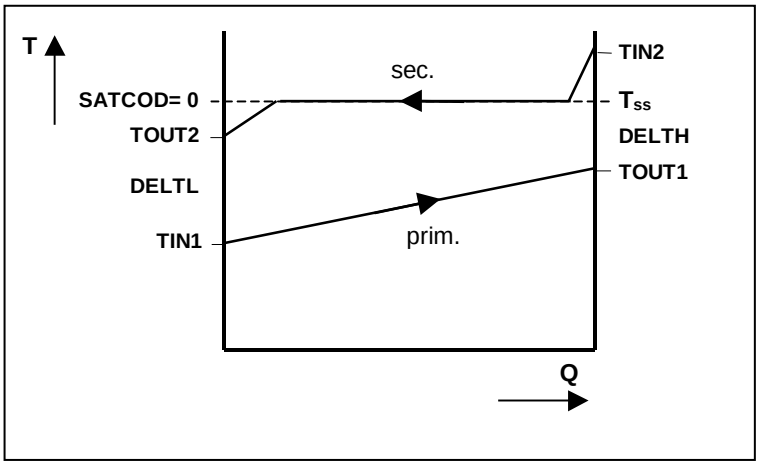


Figure 2-2: Temperature determination flashed heater

Off-design calculations

The values specified for DELTH and/or DELTL are adapted if either DSMAS1 for the primary or DSMAS2 for the secondary medium is given as input for off-design calculations. DELTH and/or DELTL will be adapted according to the curves shown in Figure 2-3. This method is appropriate since the UA-value cannot be established in a reliable way for heat exchange between media showing phase changes.

Input parameters for off-design calculations

DSMAS1	=	design mass flow primary side	(kg/s)
DSMAS2	=	design mass flow secondary side	(kg/s)

Either DSMAS1 or DSMAS2 should be given, not both.

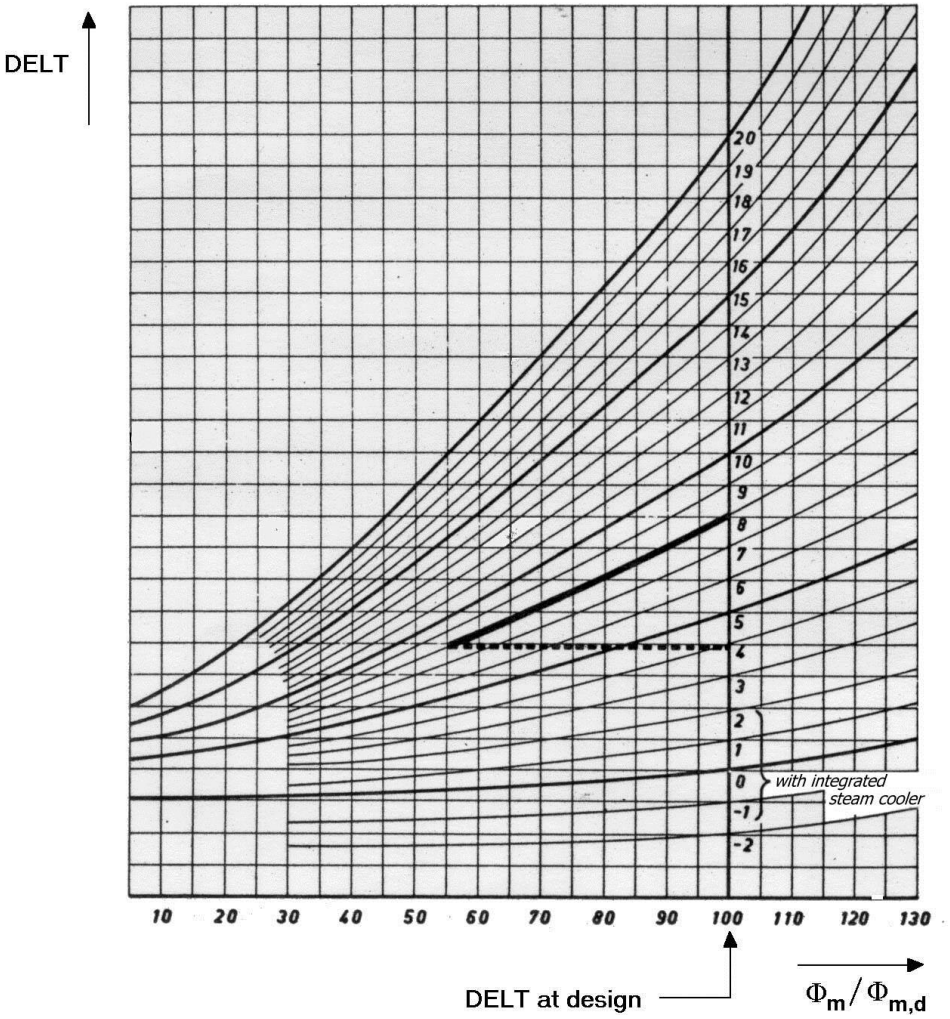
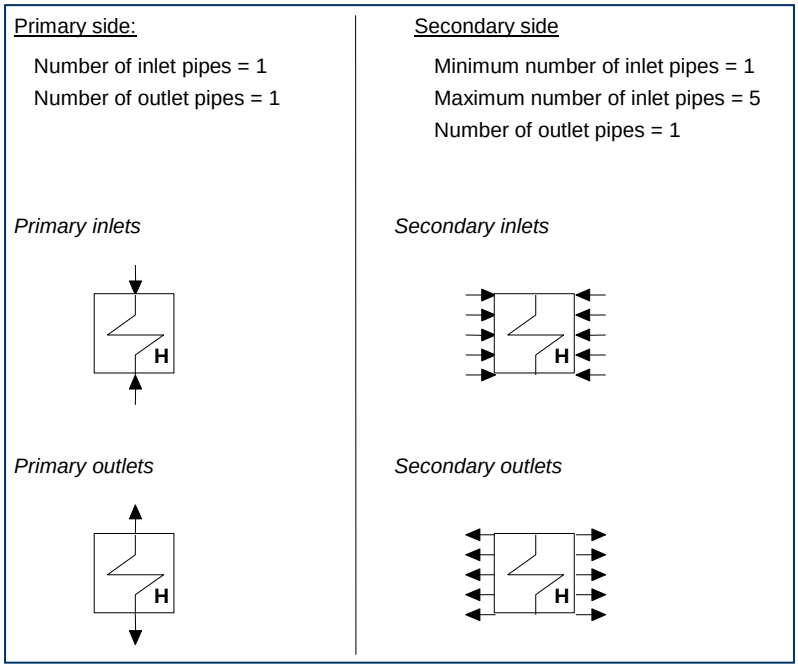


Figure 2-3: Adapting DELTH/DELTL at off-design

Surface heat exchanger

2.7 Type = 6, 12 Heat exchanger



Applications

This apparatus is used as a general heat exchanger, evaporator or furnace. The former two are represented by the subtype “General”, the latter by subtype “Furnace”.

For the furnace, the radiation constant is calculated at design using, among other, the furnace outlet temperature. This temperature is calculated at off-design using the Ter Linden method. For furnaces EEQCOD = 1 should be chosen. Additional input for furnaces is described at the end of this paragraph.

The energy equation code (EEQCOD) determines the usage of the energy equation:

- **EEQCOD = 1:** the energy equation of the apparatus is used to calculate a mass flow. An energy equation, defined by the user (possibly in combination with other apparatuses), can be specified as a production function. If this is not the case, the program will automatically define the production function. The value of this function represents the energy release to the environment, i.e. a thermal loss. The energy equation will be added to the system matrix.

- **EEQCOD = 2:** the energy equation of the apparatus is used to calculate an enthalpy in one of the inlets or outlets. The energy equation will not be added to the system matrix.

If the EEQCOD is not specified the default value 2 is used.

For off-design calculations the heat transfer equation is used. For this the heat transfer capacity rate (UA-value) must be specified in the input. The primary and secondary medium may in that case only have 1 inlet and 1 outlet.

Input parameters

PIN1, POUT1, DELP1, TIN1, TOUT1, DELT1 are standard
PIN2, POUT2, DELP2, TIN2, TOUT2, DELT2[1)] are standard

EEQCOD	=	code which indicates whether the energy balance is used to calculate a mass flow (EEQCOD=1) or a temperature (EEQCOD=2) (default=2)
DELTH	=	high terminal temperature difference (°C) see Figure 2-4. (default = UNKNOWN)
DELTL	=	low terminal temperature difference (°C) see Figure 2-4. (default = UNKNOWN)
RPSM	=	initial estimate for the ratio of the primary/secondary mass flow

1) DELT2 is defined as temperature rise, so this value normally has a negative value for the secondary medium.

for EEQCOD = 2. A negative value indicates a parallel flow heat exchanger and a positive value gives a counter current heat exchanger (default = 1.0).
Specification of RPSM is recommended if it is anticipated that the mass flow ratio between primary and secondary medium will differ appreciably from 1. This can prevent fluctuations in the mass flows during the first iteration steps. For EEQCOD = 1 only the sign of RPSM is used to determine the flow directions.

DELE = energy flow to the environment (kW) for EEQCOD = 2 (default = 0.0). DELE > 0 is energy flow to the environment, for example radiation loss. This value, which is used in a local energy balance, can be altered in a user subroutine (APSUB).
DELE should differ by at least EPS from -8888.8

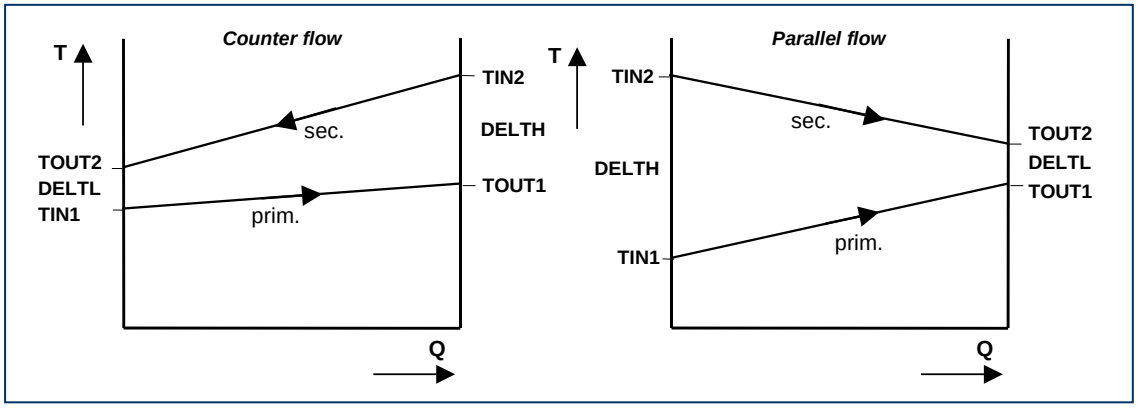


Figure 2-4: temperature determination heat exchanger

Number of equations for system matrix

This apparatus type adds 2 mass equations to the system matrix. If EEQCOD = 1 an energy equations is added also, in the form of a production function. The program will automatically generate a production function if it detects that the apparatus has not been defined in another production function.

Summarizing:

EEQCOD = 1: 2 mass equations + 1 production function = 3 equations

EEQCOD = 2: 2 mass equations

Calculation rules

For both media

1.	p_{out}	=	p_{in}	-	Δp	Δp = pressure drop on primary or secondary side
	p_{in}	=	p_{out}	+	Δp	
2.	T_{in}	=	T_{out}	-	ΔT	ΔT = temperature rise on primary or secondary
	T_{out}	=	T_{in}	+	ΔT	side

These are only used when the medium has 1 inlet and 1 outlet.

Counter current

Primary medium

3.	$T_{out,p}$	=	$T_{in,s}$	-	DELTH only for one secondary inlet.
4.	$T_{in,p}$	=	$T_{out,s}$	-	DELTL

Secondary medium

5.	$T_{out,s}$	=	$T_{in,p}$	+	DELTL
6.	$T_{in,s}$	=	$T_{out,p}$	+	DELTH only for one secondary inlet.

Co current

Primary medium

3.	$T_{out,p}$	=	$T_{in,s}$	-	DELTL only for one secondary inlet.
4.	$T_{in,p}$	=	$T_{in,s}$	-	DELTH

Secondary medium

5.	$T_{out,s}$	=	$T_{out,p}$	+	DELTL
6.	$T_{in,s}$	=	$T_{in,p}$	+	DELTH only for one secondary inlet.

Off-design calculations

The values of DELTH and DELTL can be adapted using the actual mass flow if DSMAS1 or DSMAS2 is specified as input data for off-design calculations; see the procedure mentioned in paragraph 2.6. However, this is not recommended. The following method is preferred.

If only 4 pipes are connected to the heat exchanger, the heat transfer capacity rate U*A is given, all inlet and outlet pressures are known, and:

- **EEQCOD = 1:** three enthalpies are known, then the unknown enthalpy is calculated using the heat transfer equation. The ratio primary mass flow/secondary mass flow is calculated from the system matrix solving procedure.

- **EEQCOD = 2:** two enthalpies are known, then the two unknown enthalpies are calculated using the energy equation and the heat transfer equation.

Input parameters for off-design calculations

DSMAS1	=	design mass flow primary side	(kg/s)
DSMAS2	=	design mass flow secondary side	(kg/s)
UA	=	heat transfer capacity rate of a surface heat exchanger (kW/K). The value of UA can be adapted to the mass flow with: If DSMAS1 is specified: $UA' = UA * (\Phi_m / DSMAS1)^{ETHA}$ If DSMAS2 is specified: $UA' = UA * (\Phi_m / DSMAS2)^{ETHA}$	

This formulae should not be used for discontinuous temperature profiles (see Figure 2-5)

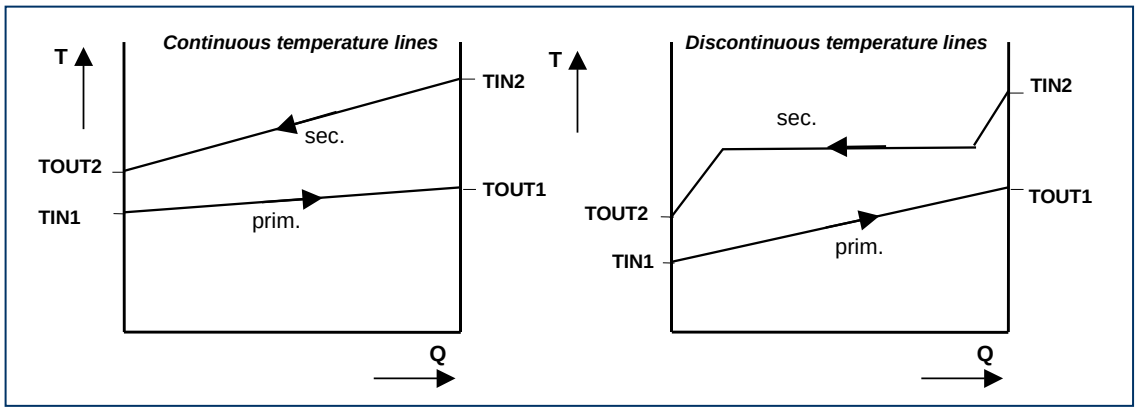


Figure 2-5: temperature lines heat exchangers

Either DSMAS1 or DSMAS2 should be specified, not both.

It is recommended to specify DSMAS for the medium, which influences the overall heat transfer coefficient most.

For example, heat transfer between flue gas and water is dominated by the flue gas side. In that case one specifies DSMAS2 (flue gas is the cooled medium, therefore the secondary side).

If UA is not specified, DSMAS is used to adapt the temperature differences DELTL or DELTH, according to the curves shown in Figure 2-3 (paragraph 2.6).

Furnace heat exchanger

The furnace heat exchanger can be used to calculate the furnace outlet temperature at off-design according to the method of Ter Linden. For a furnace heat exchanger **EEQCOD = 1** should be chosen. Additional input data can be specified in the input window behind the "Furnace data" button if type "Furnace" has been chosen. The input contains only one parameter:

TP = mean pipe wall temperature (°C) (default = see below)

The mean pipe wall temperature is used to calculate the radiation constant of the furnace at design. This constant is used at off-design to calculate the furnace outlet temperature. If the mean pipe wall temperature is not specified, it will be calculated from the inlet and outlet temperatures of the primary medium.

The output can be found on the last page of the "Text output" among the other design data for off-design calculations, and consists of the apparatus number of the furnace heat exchanger, the mean pipe wall temperature , the furnace outlet temperature and the radiation constant. This constant (CRAD) is also written to the file with design data for off-design calculations. Using the Paste-button the value of the constant can be copied in the appropriate field as input for off-design calculations.

Off-design calculations for a furnace heat exchanger

For an off-design calculation the following input parameters are available:

CRAD = radiation constant (kW/K^4)

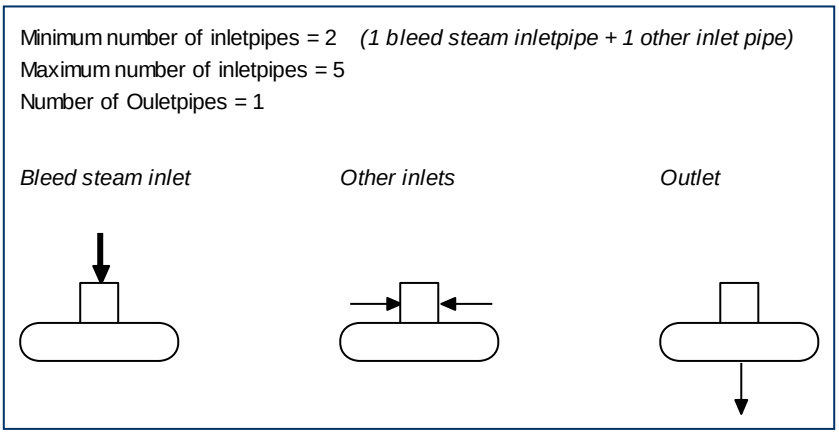
TP = mean pipe wall temperature (°C)

ESTTFU = estimation of furnace outlet temperature (°C)

In a design calculation, the radiation constant is a calculation result, which will be used at off-design. At off-design, the mean pipe wall temperature can either be specified or calculated. In the latter case it will be calculated from the inlet and outlet temperatures of the primary medium. Therefore an estimation of the furnace outlet temperature is needed in order to start the iteration process.
The radiation constant and the mean pipe wall temperature are used in the method of Ter Linden to calculate the furnace outlet temperature at off-design.

Deaerator

2.8 Type = 7 Deaerator



Applications

This apparatus is used as a general contact heater assuming saturated liquid at the outlet. Normally this type is used to model a deaerator.

The energy balance of this apparatus is used to calculate an unknown mass flow and is automatically added to the system matrix with DELE as right-hand side.
This value cannot be altered by means of a call from the user subroutine APSUB.
The calculation rules assume saturation conditions at the outlet.

Input parameters

PIN, POUT, DELP, TIN and TOUT are standard

DELE = energy loss (kW) (default = 0)
DELE cannot be adjusted in a user subroutine

Number of equations for system matrix

This apparatus type adds 2 equations to the system matrix: 1 mass equation + 1 energy equation.

Calculation rules

1.	p_{out}	=	f_{sat}(TOUT)			saturation conditions assumed
2.	p_{in}	=	p_{out}	+	DELP	for all inlet pipes
3.	p_{out}	=	p'	-	DELP	p' = pressure of main heat supplying inlet flow (normally the extraction steam pipe)
4.	T_{out}	=	$f_{sat}(p_{out})$			saturation conditions assumed

N.B. At least two inlet pipes must be connected

Pump

2.9 Type = 8 Pump

Number of inlet pipes = 1
Number of outlet pipes = 1
Maximum number of shafts = 2

Inlet and outlet *Shafts*

Input parameters

PIN, POUT, DELP[1)], TIN, TOUT and DELT are standard.

ETHAI = isentropic efficiency (-) (default = UNKNOWN)

ETHAM[2)] = mechanical efficiency (-) (default = see Figure 2-6)

ETHAE[3)] = electric efficiency (-) (default = see Figure 2-6)

1) DELP is defined as pressure drop, this value should be negative for pumps.

2) ETHAM is used in the calculation of the system efficiency and in the conversion of shaft power and pump power and vice versa.

3) ETHAE is used in the calculation of the system efficiency and in the exergy calculation.

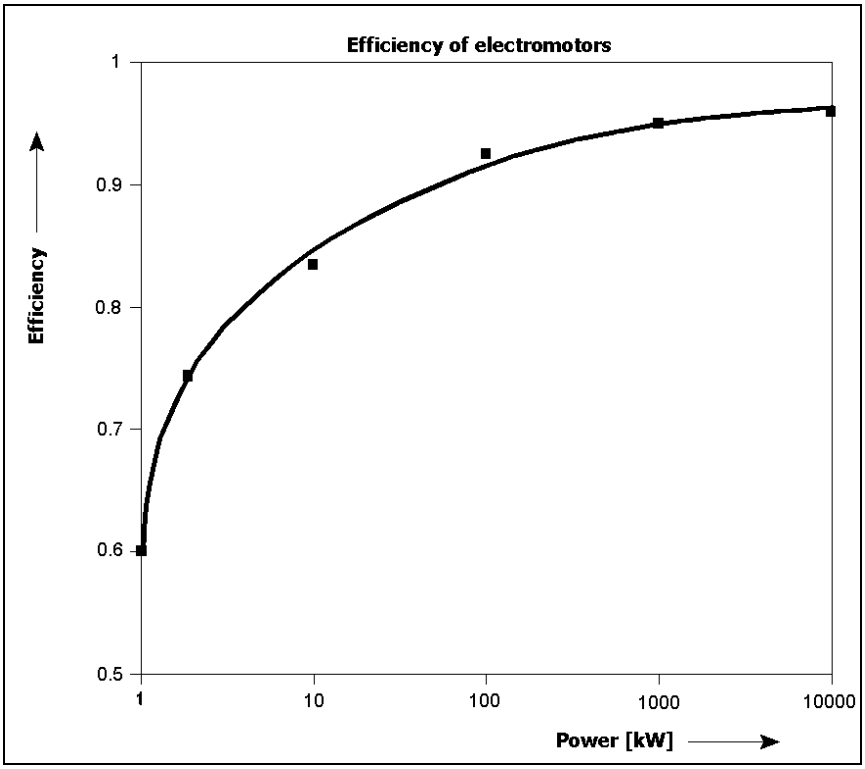


Figure 2-6: The efficiency of electromotors including the mechanical efficiency of the motor and pump as a function of the power on the shaft of the pump

If one of the efficiencies, ETHAM or ETHAE, is not specified then the efficiency which is not specified is taken as equal to 1. If neither of the two efficiencies is given then the total efficiency is calculated by interpolation from Figure 2-6.

Number of equations for system matrix

This apparatus type adds 1 mass equation to the system matrix.

Calculation rules

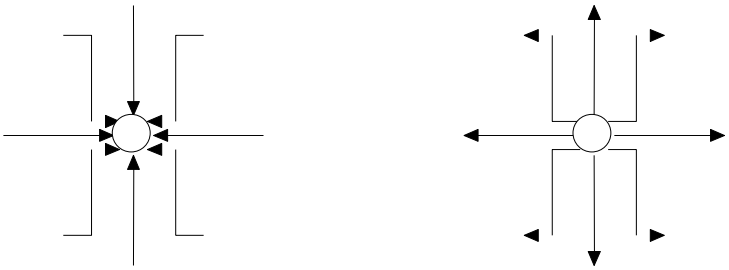
1.	p_{out}	=	p_{in} - DELP	4.	T_{out}	=	T_{in} + DELT
2.	p_{in}	=	p_{out} + DELP	5.	h_{in}	=	f (h_{out}, ETHAI)
3.	T_{in}	=	T_{out} - DELT	6.	h_{out}	=	f (h_{in}, ETHAI)

Node (mixer, splitter)

2.10 Type = 9, 11 Node

Splitter -->	Number of inletpipes = 1 Minimum number of outletpipes = 1 Maximum number of outletpipes = 5	*(There are 8 connecting possibilities for pipes of which only 6 may be used)*
Mixer -->	Minimum number of inletpipes = 1 Maximum number of inletpipes = 5 Number of outletpipes = 1	*(There are 8 connecting possibilities for pipes of which only 6 may be used)*

Inlets *Outlets*



Applications

This apparatus is used to mix or to split process flows. Depending on the value of the energy equation code (EEQCOD) there are two possibilities to use the energy equation:

- **EEQCOD = 1 (type = 11)**: the energy equation is used to calculate a mass flow ratio, and is automatically added to the system matrix. One of the useful applications as a mixer is to use this apparatus type to model a steam cooler. With EEQCOD = 1 this apparatus type can also be used as a splitter, but only if the specific enthalpies in the outlet pipes are specified (or calculated at other apparatus downstream) and are not

equal to each other. An often-used example is a vapor/liquid separator to split a two-phase mixture in its vapor and liquid substreams.

- **EEQCOD = 2 (type = 9):** the energy equation is used to calculate an unknown specific enthalpy. At default, EEQCOD = 2 is assumed.

Input parameters

DELP	=	pressure loss over the node (bar) (default = UNKNOWN). If DELP is not specified, either the outlet pressures (for a splitter) or the inlet pressures (for a mixer) may differ. If DELP is specified, either all inlets (for a mixer) or all outlets (for a splitter) will have the same pressure.

EEQCOD = 1 (type = 11):

DELE	=	energy loss (kW) (default = 0.0). DELE cannot be adjusted in a user subroutine.

EEQCOD = 2 (type = 9) (default)**:**

Specification of RMASS 1 etc. is only useful for a mixer, and ***NOT*** for a splitter.

RMASS1 to RMASS6	=	initial estimates for all mass flows, expressed as fractions of the outlet flow. The supplied values will only be used in the very first iteration. The sum of the values should equal 2.0 (the outlet mass flow is also included). At default, the contributions of the inlet mass flows to the outlet mass flow are assumed to be equal.

RMASS is an array of numbers, indicating for a mixer the expected ratios of the mass flows in the inlet and outlet pipes. The order in the array is that of increasing pipe number.

Specification is recommended if the expected mass flows differ appreciably. These variables can prevent large undesired fluctuations in the mass flows and compositions. These fluctuations can cause problems in the calculation such as negative arguments for the root or the logarithmic function, which then result in breaking off the calculation.

Example

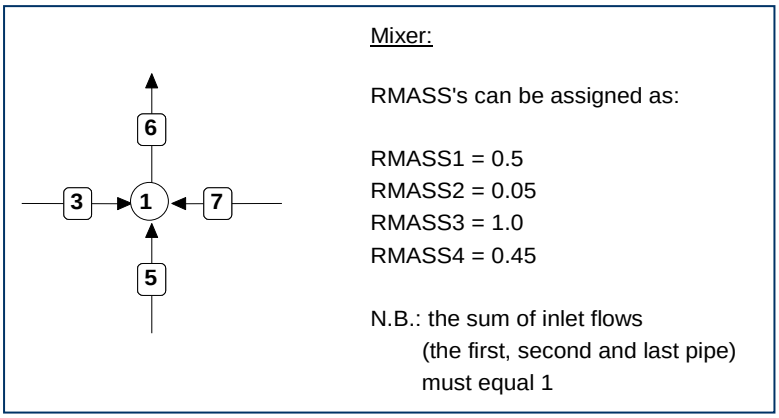


Figure 2-7: example of a mixer (EEQCOD = 2, type =9)

Number of equations for system matrix

This apparatus type adds 1 mass equation to the system matrix. In case of EEQCOD = 1, the energy equation is added also.

Summarizing:

EEQCOD = 1: 1 mass equation + 1 energy equation = 2 equations

EEQCOD = 2: 1 mass equation (default)

Calculation rules for pressures

For a node DELP is defined in a somewhat different way compared to the other apparatus types. Below the calculation rules are mentioned, assuming *i* to be one of the *n* inlet (for a mixer) or outlet (for a splitter) pipes.

The following is valid if DELP has not been specified:

Splitter:

1. $p_{in} = \max \{p_{out}(i)\}$ (either all inlet pressures or the outlet pressure must be known)

2. $p_{out}(i) = p_{in}$ (if p_{in} is known)

Mixer:

3. $p_{out} = \min \{p_{in}(i)\}$ (either the outlet pressure or all inlet pressures must be known)

4. $p_{in}(i) = p_{out}$ (if p_{out} is known)

The following is valid if DELP has been specified:

Splitter:

5. $p_{out}(i) = p_{in} - DELP$ (i = 1.....n)

6. $p_{in} = p_{out}(k) + DELP$ (k: pipe with known pressure)

This means that of all pipes connected (inlets and outlets) just one pressure must be known.

Mixer:

7. $p_{out} = p_{in}(k) - DELP$ (k: pipe with known pressure)

8. $p_{in}(i) = p_{out} + DELP$ (i = 1.....n)

This means that of all pipes connected (inlets and outlets) just one pressure must be known.

Remaining calculation rules

Mixer with EEQCOD = 2 (type 9):

9. $$h_{out} = \frac{\sum_{i=1} \left(h_{in}(i) \times \Phi_{m,in}(i) \right)}{\Phi_{m,out}}$$ if all $h_{in}(i)$ are known

10. $$h_{in}(k) = \frac{h_{out} \times \Phi_{m,out} - \sum_{i \neq k} \left(h_{in}(i) \times \Phi_{m,in}(i) \right)}{\Phi_{m,in}(k)}$$ if h_{out} and $h_{in}(i)$ are known for all $i \neq k$

Splitter with EEQCOD = 2 (type 9):

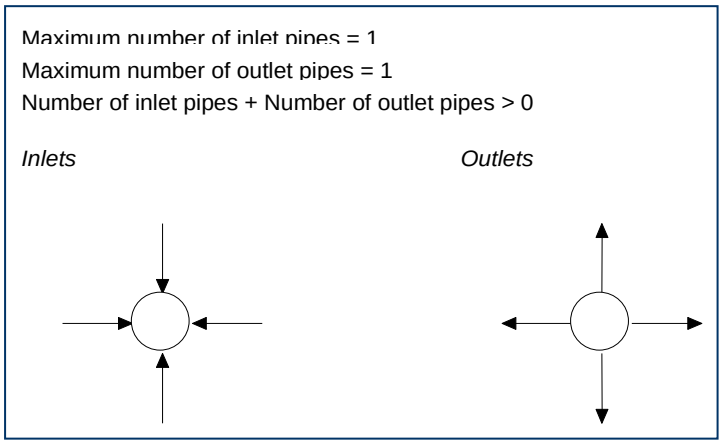
11. $$h_{out}(i) = h_{in}$$

12. $$h_{out}(k) = \frac{h_{in} \times \Phi_{m,in} - \sum_{i \neq k} \left(h_{out}(i) \times \Phi_{m,out}(i) \right)}{\Phi_{m,out}(k)}$$ if h_{in} and $h_{out}(i)$ are known for all $i \neq k$

Calculation rule 12 will only be applied if the conditions of the outlet pipes $i \neq k$ have been specified. In other situations rule 11 will be applied.

Sink, source, expansion valve

2.11 Type = 10 Sink/Source



Applications

This model can be used for modeling:

- a mass flow source or sink;
- an energy source or sink;
- a pressure reducer (expansion valve);
- a change in composition or medium type;
- a temperature estimation.

In the first case the apparatus may only be connected with 1 pipe. If the mass flow is specified directly with DELM, or indirectly with DELV or DELVN, then this gives 1 mass equation for the system matrix. In the other cases 1 inlet and 1 outlet pipe is required, whereby DELE must be specified for the energy source or sink and DELH = 0.0 for the pressure reducer.

Input parameters

PIN, POUT, DELP, TIN, TOUT and DELT are standard.

HIN = specific inlet enthalpy (kJ/kg) (default = UNKNOWN)

HOUT = specific outlet enthalpy (kJ/kg) (default = UNKNOWN)

DELH = specific enthalpy difference between inlet and outlet (kJ/kg)
(default = UNKNOWN)
The convention is: DELH = HOUT - HIN.
Consequently: DELH > 0 for a specific enthalpy rise.
DELH < 0 for a specific enthalpy drop.
For a pressure reducer DELH = 0.0 should be specified.

XIN = vapor fraction at the inlet (-) (default = UNKNOWN)
XIN cannot be specified for non-condensing medium types.

XOUT = vapor fraction at the outlet (-) (default = UNKNOWN)
XOUT cannot be specified for non-condensing medium types.

DELM = mass flow from or to the system (kg/s) or (-)
(default = UNKNOWN)

DELV = volume flow from or to the system (m^3/s) or (-)
(default = UNKNOWN)

DELVN = volume flow at normal conditions (1.01325 bar, 0 °C) from or to the system (m_n^3/s) or (-) (default = UNKNOWN)

- *Either DELM, DELV or DELVN may be specified, provided only 1 pipe is connected to the apparatus.*
- *If DELM, DELV or DELVN is specified then an extra mass equation will be added to the system matrix.*
- *The value of DELM, DELV or DELVN must differ by at least EPS from -8888.8, and may only be altered in a user subroutine if this is specified relative to PIPE.*

PIPE = pipe number, if given then DELM, DELV or DELVN is considered to be relative to the pipe mentioned.

DELE = energy supply or discharge (kW) (default = UNKNOWN)
DELE < 0 energy from environment to the system.
DELE > 0 energy from the system to the environment.
If DELE is specified, ESTMAS should be specified also.
If DELE is specified the value which is used in a local energy equation, can be altered in a user subroutine (APSUB). The value must differ by at least EPS from -8888.8.

ESTMAS = estimate for the mass flow (kg/s) (default = UNKNOWN)
ESTMAS must be specified if DELE has been prescribed to obtain a reasonable specific enthalpy change in the first iteration step.

LHV = lower heating value of the fuel entering the system (kJ/kg) (default = UNKNOWN)
The lower heating value will be used to determine the incoming energy flow of the system on behalf of the calculation of the system efficiency. The lower heating value of flows with medium type GASMIX will be calculated by Cycle-Tempo. The lower heating value for flows with medium type FUEL must be specified by the user. This means that LHV should only be specified at apparatus type 10 if one wishes to use another value than Cycle-Tempo will calculate.

DTSUBC = degree of subcooling: difference between the temperature of saturated liquid and the actual temperature (K) (default = UNKNOWN)
DTSUBC cannot be specified for non-condensing medium types.

DTSUPH = degree of superheating: difference between the actual temperature and the temperature of saturated vapor (K) (default = UNKNOWN)
DTSUPH cannot be specified for non-condensing medium types.

SUBTYP = code to specify type of sink/source (default = UNKNOWN):
= 0: general type
= 1: heat sink
= 2: fuel source

The following input data only apply to the situation that Cycle-Tempo needs an initial value for a certain temperature.

ESTTIN = estimate for the inlet temperature (°C) (default = UNKNOWN)

ESTTOU = estimate for the outlet temperature (°C) (default = UNKNOWN)

WFOT = (weight factor of old temperature) weight factor for the temperature calculated in the previous iteration (default = 0.0). The temperatures calculated in the actual and previous iterations are used to estimate the temperature for the next iteration. The temperature calculated in the previous iteration is weighted according to:

$$T_{new} = \frac{T_{calc} + WFOT \times T_{old}}{1 + WFOT}$$

Description of subtypes

If SUBTYP is not given, Cycle-Tempo sets it to SUBTYP = 2 if an incoming fuel flow is detected or LHV is given.

SUBTYP = 0: The apparatus will be ignored when the efficiency of the system is calculated, even if an incoming fuel flow is detected or LHV is given.

SUBTYP = 1: The energy to or from the environment is considered as useful heat. This will result in the calculation of a heat efficiency and a total efficiency. In case of a heat source with one (outgoing) pipe the thermo-mechanical energy of the flow will be used. In case of two connected pipes DELE or DELH will be used. If specified LHV will be ignored.

SUBTYP = 2: Incoming fuel flows will be used to calculate the system efficiency. Cycle-Tempo itself determines whether a source is of subtype 2, namely if the heating value is greater than zero and if there is just one outgoing pipe. Therefore specification of subtype = 2 is not necessary.

Designation of subtypes

At default, Cycle-Tempo will designate the subtypes as follows:

subtype 0:	-	'PRES.REDUCER'	if DELH = 0.0
	-	'SINK/SOURCE'	if 2 pipes are connected
	-	'SINK'	if the single connected pipe is incoming
	-	'SOURCE'	if the single connected pipe is outgoing
subtype 1:	-	'HEAT-INPUT'	heat flow to system
	-	'HEAT-OUTPUT'	heat flow to environment
subtype 2:	-	'FUEL-INPUT'	fuel input

Number of equations for system matrix

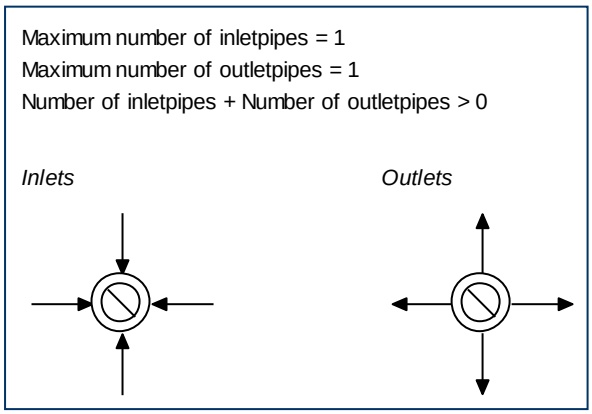
If two pipes are connected to the apparatus, 1 mass equation is added to the system matrix. If just one pipe is connected, a mass equation is added to the system matrix only if DELM, DELV or DELVN is specified.

Calculation rules

1.	p_{in}	=	p_{out}	+	DELP	
2.	p_{out}	=	p_{in}	–	DELP	
3.	T_{in}	=	T_{out}	–	DELT	
4.	T_{out}	=	T_{in}	+	DELT	
5.	h_{in}	=	h_{out}	–	DELH	
6.	h_{out}	=	h_{in}	+	DELH	
7.	h_{out}	=	h_{in}	–	DELE / Φ_m	Φ_m =mass flow from the previous iteration. (starting value: Φ_m = ESTMAS)
8.	p_{in}	=	$p_{sat}(T_{in}$, XIN)			
9.	p_{in}	=	$p_{sat}(T_{in}$+ DTSUBC, x=0)			
10.	p_{in}	=	$p_{sat}(T_{in}$ - DTSUPH, x=1)			
11.	p_{out}	=	$p_{sat}(T_{out}$, XOUT)			
12.	p_{out}	=	$p_{sat}(T_{out}$+ DTSUBC, x=0)			
13.	p_{out}	=	$p_{sat}(T_{out}$ – DTSUPH, x=1)			
14.	T_{in}	=	$T_{sat}(p_{in}$, XIN)			
15.	T_{in}	=	$T_{sat}(p_{in}$, x = 0)	–	DTSUBC	
16.	T_{in}	=	$T_{sat}(p_{in}$, x = 1)	+	DTSUPH	
17.	T_{out}	=	$T_{sat}(p_{out}$, XOUT)			
18.	T_{out}	=	$T_{sat}(p_{out}$, x = 0)	–	DTSUBC	
19.	T_{out}	=	$T_{sat}(p_{out}$, x = 1)	+	DTSUPH	

Heat source, heat sink

2.12 Type = 10 Heat Sink



Applications

This apparatus type can be used to model a heat source or a heat sink. The amount of energy exchanged with the environment is regarded as useful heat, and will therefore be used in the calculation of the system efficiencies to determine a heat efficiency and a total efficiency.
A heat source is regarded as a heat sink with a negative heat flow. In case of only one pipe connected the thermo-mechanical energy of the process stream is used.

Input parameters

PIN, POUT, DELP, TIN, TOUT and DELT are standard.

HIN = specific inlet enthalpy (kJ/kg) (default = UNKNOWN)

HOUT = specific outlet enthalpy (kJ/kg) (default = UNKNOWN)

DELH = specific enthalpy difference between inlet and outlet (kJ/kg)
(default = UNKNOWN)
The convention is: DELH = HOUT - HIN.
Consequently: DELH > 0 for a specific enthalpy rise.
DELH < 0 for a specific enthalpy drop.

XIN = vapor fraction at the inlet (-) (default = UNKNOWN)
XIN cannot be specified for non-condensing medium types.

XOUT = vapor fraction at the outlet (-) (default = UNKNOWN)
XOUT cannot be specified for non-condensing medium types.

DELM = mass flow from or to the system (kg/s) or (-)
(default = UNKNOWN)

DELV = volume flow from or to the system (m^3/s) or (-)
(default = UNKNOWN)

DELVN = volume flow at normal conditions (1.01325 bar, 0 °C) from or to the system (m_n^3/s) or (-) (default = UNKNOWN)

- *Either DELM, DELV or DELVN may be specified, provided only 1 pipe is connected to the apparatus.*
- *If DELM, DELV or DELVN is specified then an extra mass equation will be added to the system matrix.*
- *The value of DELM, DELV or DELVN must differ by at least EPS from -8888.8, and may only be altered in a user subroutine if this is specified relative to PIPE.*

PIPE = pipe number, if given then DELM, DELV or DELVN is considered to be relative to the pipe mentioned.

DELE = energy supply or discharge (kW)
(default = UNKNOWN)
DELE < 0 energy from environment to the system.
DELE > 0 energy from the system to the environment.
If DELE is specified, ESTMAS should be specified also.

If DELE is specified the value which is used in a local energy equation, can be altered in a user subroutine (APSUB). The value must differ by at least EPS from -8888.8.

ESTMAS = estimate for the mass flow (kg/s)
(default = UNKNOWN)
ESTMAS must be specified if DELE has been prescribed to obtain a reasonable specific enthalpy change in the first iteration step.

DTSUBC = degree of subcooling: difference between the temperature of saturated liquid and the actual temperature (K) (default = UNKNOWN)
DTSUBC cannot be specified for non-condensing medium types.

DTSUPH = degree of superheating: difference between the actual temperature and the temperature of saturated vapor (K) (default = UNKNOWN)
DTSUPH cannot be specified for non-condensing medium types.

Number of equations for system matrix

If two pipes are connected to the apparatus, 1 mass equation is added to the system matrix. If just one pipe is connected, a mass equation is added to the system matrix only if DELM, DELV or DELVN is specified.

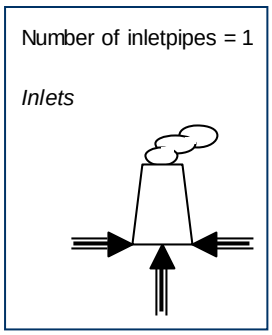
Calculation rules

1.	p_{in}	=	p_{out}	+	DELP
2.	p_{out}	=	p_{in}	–	DELP
3.	T_{in}	=	T_{out}	–	DELT
4.	T_{out}	=	T_{in}	+	DELT
5.	h_{in}	=	h_{out}	–	DELH
6.	h_{out}	=	h_{in}	+	DELH

7.	h_{out}	=	h_{in}	–	DELE / Φ_m	Φ_m =mass flow from the previous iteration. (starting value: Φ_m = ESTMAS)
8.	p_{in}	=	$p_{sat}(T_{in}$, XIN)			
9.	p_{in}	=	$p_{sat}(T_{in}$+ DTSUBC, x=0)			
10.	p_{in}	=	$p_{sat}(T_{in}$ - DTSUPH, x=1)			
11.	p_{out}	=	$p_{sat}(T_{out}$, XOUT)			
12.	p_{out}	=	$p_{sat}(T_{out}$+ DTSUBC, x=0)			
13.	p_{out}	=	$p_{sat}(T_{out}$ – DTSUPH, x=1)			
14.	T_{in}	=	$T_{sat}(p_{in}$, XIN)			
15.	T_{in}	=	$T_{sat}(p_{in}$, x = 0)	–	DTSUBC	
16.	T_{in}	=	$T_{sat}(p_{in}$, x = 1)	+	DTSUPH	
17.	T_{out}	=	$T_{sat}(p_{out}$, XOUT)			
18.	T_{out}	=	$T_{sat}(p_{out}$, x = 0)	–	DTSUBC	
19.	T_{out}	=	$T_{sat}(p_{out}$, x = 1)	+	DTSUPH	

Stack

2.13 Type = 10 Stack



Applications

The stack is used as a sink for flue gases.

The cooling curve can be presented in Q,T- and value diagrams, and starts with the conditions at the outlet of the pipe connected to the stack. The end point of the cooling curve is determined by the pressure and temperature of the environment. If not specified by the user (see 5.2), Cycle-Tempo will assume 1.013 bars and 15°C, respectively.

Input parameters

PIN and TIN are standard.

HIN = specific inlet enthalpy (kJ/kg) (default = UNKNOWN)

DELM = mass flow from the system (kg/s) or (-)
(default = UNKNOWN)

DELV = volume flow from the system (m^3/s) or (-)
(default = UNKNOWN)

DELVN = volume flow at normal conditions (1.01325 bar, 0 °C) from the system (m_n^3/s) or (-) (default = UNKNOWN)

- *Either DELM, DELV or DELVN may be specified.*
- *If DELM, DELV or DELVN is specified then an extra mass equation will be added to the system matrix.*
- *The value of DELM, DELV or DELVN must differ by at least EPS from -8888.8, and may only be altered in a user subroutine if this is specified relative to PIPE.*

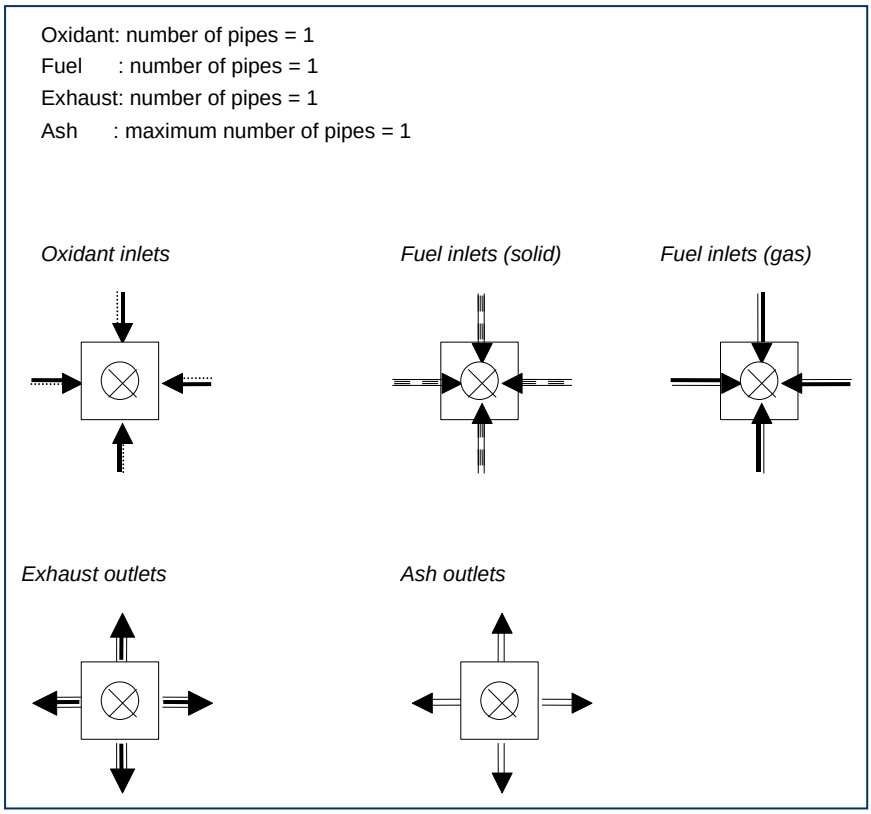
PIPE = pipe number, if given then DELM, DELV or DELVN is considered to be relative to the pipe mentioned.

Number of equations for system matrix

Only if DELM, DELV or DELVN is specified, 1 mass equation will be added to the system matrix.

Combustor

2.14 Type = 13 Combustor



Applications

In the combustor an oxidant and a fuel flow react. The composition of the product gas is determined by the chemical equilibrium at the specified or calculated conditions, which may deviate from the prevailing conditions, if so specified by the user. In the combustor no heat transferring area is modeled; the heat, which is released, is used to increase the temperature of the product gas and ash. The reaction enthalpy is calculated and used in the energy

balance. Depending on the energy equation code (EEQCOD) there are two possible ways of using the energy balance:

- **EEQCOD = 1**: The energy balance can be used to define a mass flow. In this model there are 3 unknown mass flows (the mass flow in the ash pipe is defined separately). Two mass flows are defined by adding equations to the system matrix (energy balance and total mass balance). The mass flow missing must be specified or calculated elsewhere.

- **EEQCOD = 2 (default)**: The energy balance can be used to determine the temperature of the outgoing product gas. In this case only the total mass balance is added to the system matrix for calculating one of the unknown mass flows. The two missing mass flows can be determined in 2 ways:
  - both mass flows can be specified or calculated elsewhere;
  - the air factor (LAMBDA) can be specified in combination with the specification or calculation elsewhere of a mass flow.

Where an ash pipe is specified, composition and mass flow are defined by:

- Automatic discharge of a number of solid or liquid components to the ash pipe. These components are $Al_2O_3(s)$, $Al_2O_3(l)$, $Fe_2O_3(s)$, $SiO_2(s)$, $SiO_2(l)$.
- Specification of a mass or molar percentage per component with respect to the mass or mole flow in the fuel pipe (see input of **Reaction data** in paragraph 4.2 of part "Cycle-Tempo Operation").

The composition in the incoming lines (fuel and oxidant) must always be specified, or calculated in the apparatuses upstream. The composition in the product gas pipe is calculated according to chemical equilibrium. It is however possible to keep parts of the reactants outside the reaction (see input of **Reaction data** in paragraph 4.2 of part "Cycle-Tempo Operation").

The temperature at which chemical equilibrium is calculated (TREACT) can be specified. Where this is not specified, the outlet temperature is used as equilibrium temperature. It is then however possible to specify a temperature difference (DTREAC) between equilibrium temperature and outlet temperature (TREACT=TOUT + DTREAC).
The equilibrium pressure can also be specified (PREACT). If this is not specified the

pressure at the outlet is used. If the pressure difference (DPREAC) is specified the equilibrium pressure becomes PREACT=POUT + DPREAC.

Symbols for connections and medium types

Symbol flue gas pipe : "Flue gas"
Symbol ash pipe : "Ash"
The symbols for the remaining pipes connected may be chosen freely.

The medium type of all pipes connected should be GASMIX. The only exception is the fuel pipe, which may also be of type FUEL.

Input parameters

The following apparatus data can be specified:

PIN, POUT, DELP, TIN and TOUT are standard

EEQCOD	=	code which indicates whether the energy balance is used to calculate a mass flow (EEQCOD = 1) or a temperature (EEQCOD = 2) (default = 2)
LAMBDA	=	air factor (actual oxidant-fuel ratio/stoichiometric oxidant-fuel ratio) (-) (default = UNKNOWN)
ESTOFR	=	estimate of the oxidant-fuel ratio for the first iteration where LAMBDA= UNKNOWN (kg/kg) (default = 15)
DELE	=	energy flow to the environment (kW) (default=0)
PREACT	=	pressure at which equilibrium is calculated (bar) (default = POUT + DPREAC)

DPREAC	=	difference between equilibrium pressure and outlet pressure (only to be specified if PREACT is not specified (bar) (default = 0)
TREACT	=	temperature at which the chemical equilibrium is calculated (°C) (default = TOUT + DTREAC)
DTREAC	=	difference between equilibrium temperature and outlet temperature (only to be specified if TREACT is not specified (°C) (default = 0)
ESTPOU	=	estimate for the outlet pressure if PREACT and POUT are not specified (bar) (default = 4)
PASH	=	pressure in ash pipe (bar) (default = PREACT-DPASH)
DPASH	=	difference between equilibrium pressure and pressure in ash pipe, only to be specified if PASH is not specified (bar) (default = 0)
TASH	=	temperature of the ash discharged (°C) (default = TREACT-DTASH)
DTASH	=	difference between equilibrium temperature and temperature in ash pipe, only to be specified if TASH is not specified (default = 0).

Number of equations for system matrix

As default (EEQCOD = 2), 1 mass equation is added to the system matrix. If either EEQCOD = 1 is specified, or EEQCOD = 2 together with parameter LAMBDA, an extra equation is added. If an ash pipe is connected, again an extra mass equation is added to the system matrix.

Summarizing:

Without ash pipe:

EEQCOD = 1:	1 mass equation + 1 energy equation
EEQCOD = 2:	1 mass equation
EEQCOD = 2 + LAMBDA specified:	2 mass equations

With ash pipe:

EEQCOD = 1:	2 mass equations + 1 energy equation
EEQCOD = 2:	2 mass equations
EEQCOD = 2 + LAMBDA specified:	3 mass equations

Calculation rules

1.	p_{out}	=	p_{in}	−	DELP
2.	p_{in}	=	p_{out}	+	DELP
3.	p_{react}	=	p_{out}	+	Δp_{react}
4.	T_{react}	=	T_{out}	+	ΔT_{react}
5.	y_{out}	=	$f_1(y_{cec}, y_{noncec})$		
	y_{cec}	=	chemical equilibrium composition		
	y_{noncec}	=	composition non-reacting part		
6.	y_{cec}	=	$f_2(p_{react}, T_{react}, y_{reactants})$		
	$y_{reactants}$	=	composition reactants		
7.	h_{react}	=	$f_3(p_{react}, T_{react}, y_{reactants})$		

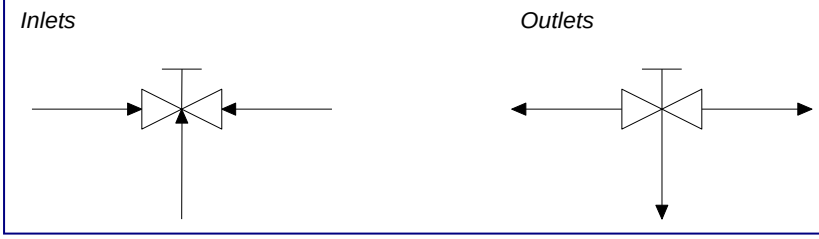
Valve

2.15 Type = 14 Valve

Splitter --> Number of inletpipes = 1
Minimum number of outletpipes = 1
Maximum number of outletpipes = 4

(To connect pipes you can use an inlet or outlet more than once)

Mixer --> Minimum number of inletpipes = 1
Maximum number of inletpipes = 4
Number of outletpipes = 1



Applications

The apparatus may be used as a splitter or a mixer:

- Splitter: 1 inlet and 1 to a maximum of 4 outlets.
- Mixer: 1 outlet and 1 to a maximum of 4 inlets.

This apparatus type is used to specify a mass or volume flow in one of the pipes connected. In case of a splitter, one of the outlet flows can be specified. In case of a mixer, one of the inlet flows can be specified. Specification of one of the mass or volume flows can be done in an absolute way, or relative to the flow in one of the other pipes in the system.

Input parameters

Specification of a flow and a pressure loss are possible. The flow specification is mandatory, the pressure loss specification is optional.

The following input data fields are available:

Pipe to specify flow for:	If there is only 1 inlet pipe, then here the number of one of the outlet pipes should be specified. If there are more than 1 inlet pipes, then here the number of one of the inlet pipes should be specified.
Flow:	Value of the flow. The units are displayed next to the field, and depend on which flow type the user has specified (see below)
Pressure loss:	Pressure loss over the valve.

Furthermore the user can choose whether the value of the flow is an absolute value, or relative to one of the other pipes in the system. If the latter option is chosen, another input data field becomes accessible in which the user should specify the number of that pipe.

Finally the user must choose the type of flow for which a value has been specified. At default the mass flow is chosen, but actual volume flow (i.e., volume flow at the actual pressure and temperature of the flow) and standard volume flow (i.e., volume flow at 1.01325 bar and 0°C) can be chosen alternatively.

Note

The apparatus can also be used with 1 input and 1 output. This is useful if one wishes to prescribe a mass or volume flow in a pipe or a cycle.

Number of equations for system matrix

This apparatus type adds two mass equations to the system matrix.

Calculation rules

Splitter

1. $p_{out}(i) = p_{in}$ (for all i = 1.....n)

2. $p_{in} = p_{out}(k)$ k = number of the pipe for which the pressure is known[1)]

3. $h_{out}(i) = h_{in}$ (for all i = 1.....n)

1) *This means that the pressure in not more than 1 outlet pipe should be specified or calculated downstream.*

Mixer

4. $p_{out} = \min_{i=1}^{n}\{p_{in}(i)\}$

5. $p_{in}(i) = p_{out}$ (for all i = 1.....n)

6. $$h_{out} = \frac{\sum_{i=1}^{n}\left(h_{in}(i) * \Phi_{m,in}(i)\right)}{\Phi_{m,out}}$$ if all h_{in} (i) are known

7. $$h_{in}(k) = \frac{h_{out} * \Phi_{m,out} - \sum_{i \neq k}\left(h_{in}(i) * \Phi_{m,in}(i)\right)}{\Phi_{m,in}(k)}$$ if h_{out} and $h_{in}(i)$ are known for all $i \neq k$

Additional information for user subroutines

The input data specified by the user are assigned to input parameters which are available for usage or alteration in user subroutines (array DATA in APSUB, and array DATAP in EPILOG; see part "User Subroutines " of the manual for more details). Only in such cases the following information is relevant.
If there is just 1 inlet pipe, then the RMASS, RVOL and RVOLN parameters refer to the outlet pipe(s). If there are more than 1 inlet pipes, then the RMASS, RVOL and RVOLN parameters refer to the inlet pipes.

RMASS1	=	mass flow (absolute or relative) in the pipe with the lowest pipe number ((kg/s) or (-)).
RMASS2	=	mass flow (absolute or relative) in the pipe with the lowest but one pipe number ((kg/s) or (-)).
RMASS3	=	mass flow (absolute or relative) in the pipe with the lowest but two pipe number ((kg/s) or (-)).
RMASS4	=	mass flow (absolute or relative) in the pipe with the lowest but three pipe number ((kg/s) or (-)).
RVOL1	=	volume flow (absolute or relative) in the pipe with the lowest pipe number ((m^3/s) or (-)).
RVOL2	=	volume flow (absolute or relative) in the pipe with the lowest but one pipe number ((m^3/s) or (-)).
RVOL3	=	volume flow (absolute or relative) in the pipe with the lowest but two pipe number ((m^3/s) or (-)).
RVOL4	=	volume flow (absolute or relative) in the pipe with the lowest but three pipe number ((m^3/s) or (-)).
RVOLN1	=	volume flow at normal conditions[1] (absolute or relative) in the pipe with the lowest pipe number ((m_n^3/s) or (-)).
RVOLN2	=	volume flow at normal conditions[1] (absolute or relative) in the pipe with the lowest but one pipe number ((m_n^3/s) or (-)).
RVOLN3	=	volume flow at normal conditions[1] (absolute or relative) in the pipe with the lowest but two pipe number ((m_n^3/s) or (-)).

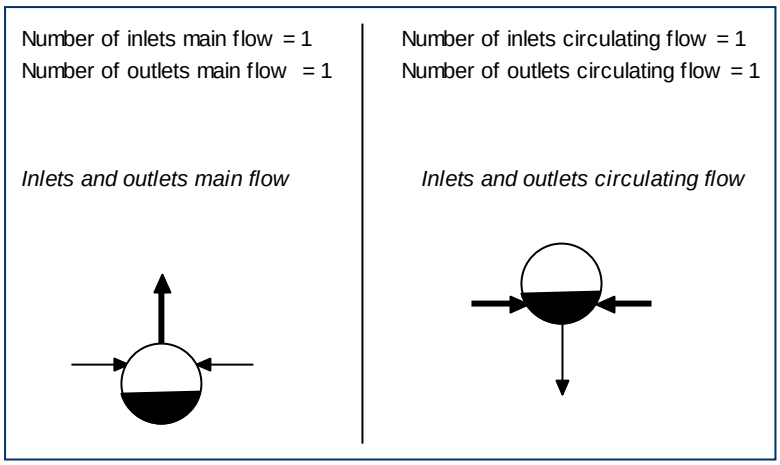
[1)] Defined at 1.01325 bar and 0 °C

RVOLN4 = volume flow at normal conditions[1] (absolute or relative) in the pipe with the lowest but three pipe number ((m_n^3/s) or (-)).

PIPE = Number of the pipe in relation to which the mass or volume flow is specified.

Drum

2.16 Type = 15 Drum



Applications

This apparatus type can be used to mix a liquid and a vapor stream, and to separate the resulting 2-phase mixture in its vapor and liquid substreams. Normally this type is used to model a drum in a steam system, but other applications are also possible; e.g., a flash vessel with two inlet streams or even a tray in a distillation column (e.g., for medium type NH3-H2O).

For the outgoing vapor pipe saturated vapor is assumed (x = 1.0).
The down pipe is assumed to contain saturated liquid (x = 0.0). The vapor fractions of the outgoing vapor pipe and the outgoing down pipe may be specified by XINL or XOUTL via extra conditions for pipes. In that case the vapor fractions for both pipes have to be specified!

Example:	down pipe	XINL = 0.02 (via extra conditions for this pipe)
	vapor pipe	XINL = 0.98 (via extra conditions for this pipe)

The vapor fraction of the incoming pipe (from the evaporator) can be specified with XINL or XOUTL for the relevant pipe; instead of this a value may also be specified for the circulation ratio CRATIO.

Input parameters

Only the following input data may be specified:

PIN = inlet pressure (bar) (default = UNKNOWN)

POUT = outlet pressure (bar) (default = UNKNOWN)

DELE = energy flow to the system (kW) (default = 0.0)

CRATIO = circulation ratio (-) (default = UNKNOWN)
CRATIO is, roughly, the ratio between the mass flow in the evaporator circuit and the main mass flow. The reciprocal value of CRATIO is equal to the quality of the vapor leaving the evaporator.

Number of equations for system matrix

This apparatus type adds 1 mass equation and 1 energy equation to the system matrix.

Calculation rules

1. $p_{out} = p_{in}$

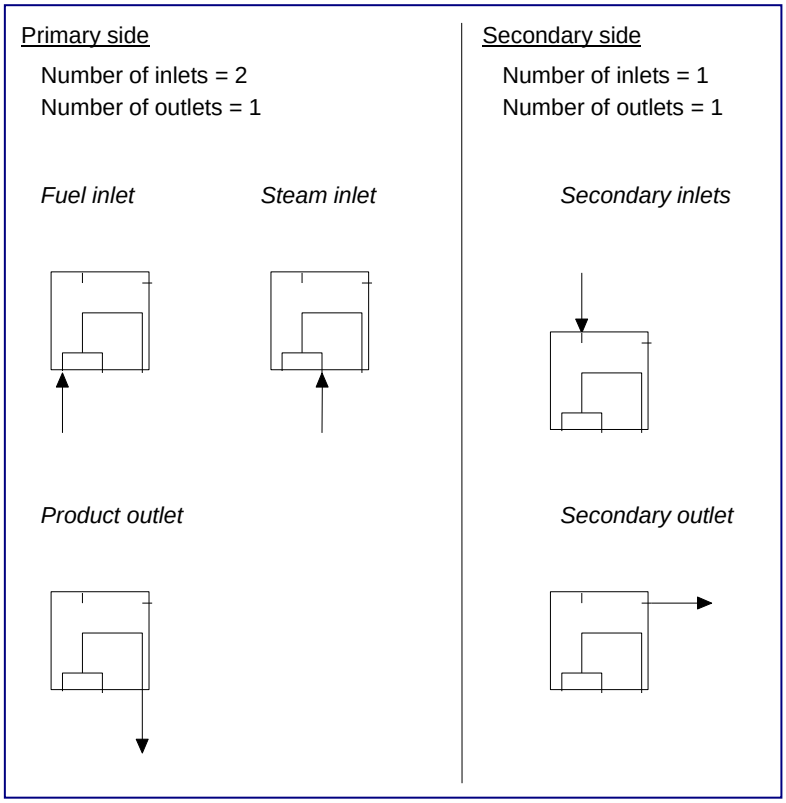
2. $p_{in} = p_{out}$

3. $T_{out,h} = f_{sat}(p_{out})$

4.	$T_{out,c}$	=	$f_{sat}(p_{out})$	
5.	$x_{out,h}$	=	1.0	(main flow)
	$x_{out,c}$	=	0.0	(circulation flow)
	$x_{in,c}$	=	1.0/CRATIO	unless otherwise specified with XINL or XOUTL via extra conditions for pipes

Reformer

2.17 Type = 20 Reformer



Applications

A reformer is used in fuel cell systems to convert methane and higher hydrocarbons in a gas into a hydrogen rich gas using steam. The required heat is extracted from a secondary medium, e.g. process gas or flue gas.

The energy balance can be used to calculate an unknown inlet or outlet enthalpy.
The reformer is used to calculate the chemical equilibrium composition at a given condition. Furthermore, the heat needed for the chemical reaction is calculated. The composition of the in-going flows can be chosen freely.

Input parameters

PIN1, POUT1, DELP1, TIN1, TOUT1, DELT1 are standard
PIN2, POUT2, DELP2, TIN2, TOUT2, DELT2 are standard

EEQCOD = code which indicates whether the energy equation is used to calculate a mass flow (EEQCOD = 1) or a temperature (EEQCOD = 2) (default = 2)

RPSM = initial estimation for the ratio between primary and secondary mass flow (default = 1.0)
Stating RPSM is recommended, as it can be expected that the mass flow ratio between primary and secondary medium will differ considerably from 1. Thus fluctuations in the mass flows during the first iteration steps can be prevented.

DELE = energy flow to the environment (kW) (default = 0.0)
DELE > 0 is the energy flow to the environment, e.g. radiation loss. This value that is used in a local energy balance can be modified in a user subroutine (APSUB). DELE should differ at least EPS from -8888.8.

PREACT = pressure at which chemical equilibrium is calculated (bar) (default = UNKNOWN)
This pressure can be specified independently from the inlet and outlet conditions.

TREACT = temperature at which chemical equilibrium is calculated (°C) (default = UNKNOWN)

This temperature can be specified independently from the inlet and outlet conditions.

SFRATI = steam/fuel ratio (kg/kg) (default = UNKNOWN)
SFRATI gives the relation between in-going steam and the fuel flow. The composition of the fuel *and* of the steam can be given independently. If no mass is supplied via the steam pipe, SFRATI=0.0 should be stated. The value of SFRATI *cannot* be modified in a user subroutine.

Number of equations for system matrix

This apparatus type adds 2 mass equations to the system matrix. If EEQCOD = 1 the energy equation is added also. If SFRATI is specified, an extra mass equation is added to the system matrix.

Summarizing:

SFRATI not specified:
EEQCOD = 1: 2 mass equations + 1 energy equation = 3 equations
EEQCOD = 2: 2 mass equations

SFRATI specified:
EEQCOD = 1: 3 mass equations + 1 energy equation = 4 equations
EEQCOD = 2: 3 mass equations

Calculation rules

For both media

1. $p_{out} = p_{in} -$ DELP
DELP = pressure loss at primary (DELP1) or secondary side (DELP2)

Primary medium

2. $T_{out,p} = T_{in,p} + DELT1$

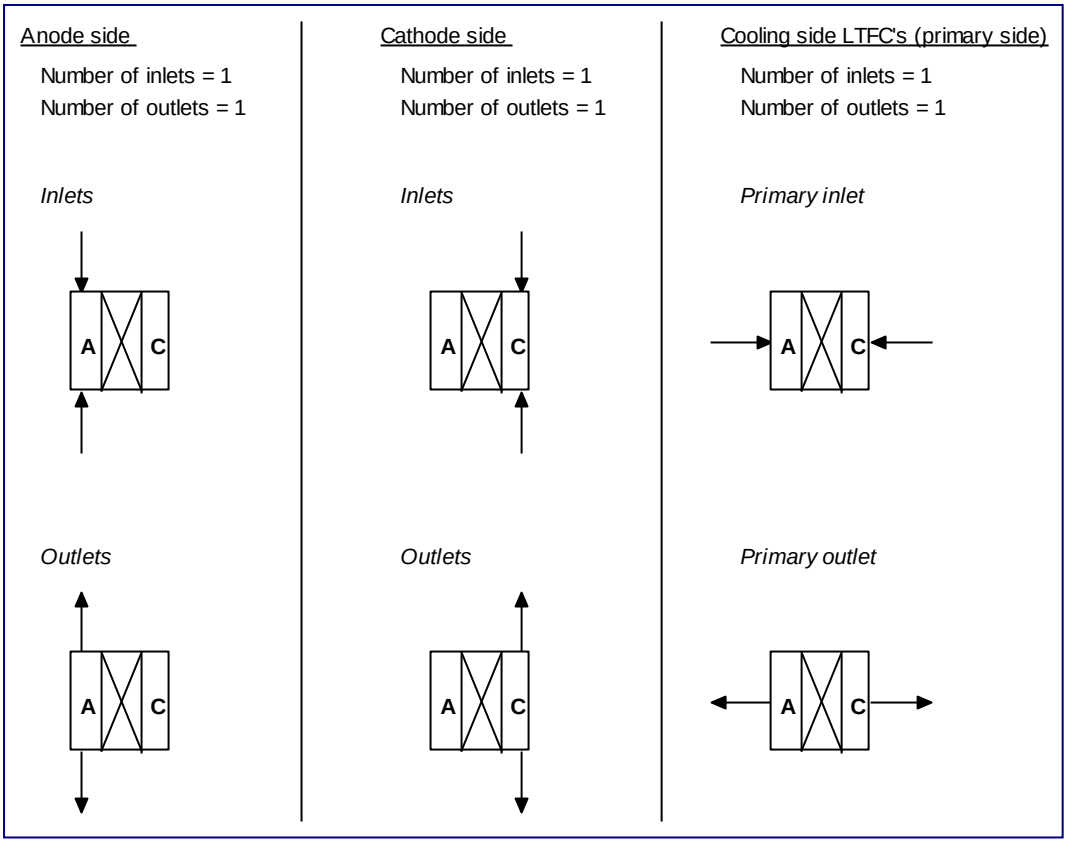
3. $T_{in,p} = T_{out,p} - DELT1$

Off-design calculations

No extra calculation rules are available for off-design calculations.

Fuel cell

2.18 Type = 21 Fuel Cell



In Cycle-Tempo, models are available for five types of fuel cells:

- solid oxide fuel cell (SOFC);
- molten carbonate fuel cell (MCFC);
- phosphoric acid fuel cell (PAFC);
- solid polymer fuel cell (SPFC) or polymer electrolyte fuel cell (PEFC);
- alkaline fuel cell (AFC).

General characteristics of the models are:

- A number of options regarding the design of the modeled fuel cell can be specified:
  - fuel cell type: MCFC, SOFC, PAFC, SPFC or AFC
  - reforming: external reforming (all fuel cell types) or internal reforming (only MCFC and SOFC), the latter to be distinguished in direct and indirect internal reforming
  - flow type: co-flow or counter flow
- The model can be used for modeling stacks of both tubular and flat plate cells.
- The model is **isothermal:** the calculated chemical balances on the active cell area and the current density are based on the average cell temperature.
- A fuel cell stack consists of a number of (electrical) cells connected in series, with identical performance.
- In off-design calculations (only MCFC and SOFC), the distribution of the current density is calculated on the basis of a constant cell resistance.

A. Design calculations

The user should indicate what type of fuel cell is modeled and whether the reforming is done internally or externally. The default value for the flow type (co-flow, counter flow or cross flow) is co-flow. Part “Technical Notes” of the manual deals with the modeling of the different options.
Furthermore, for each type of calculation (design and off-design), all conditions at the inlet (pressure, temperature and composition) of both the anode and the cathode sides should be specified, or should be calculated in the preceding apparatuses.
In design calculations, cell voltage, current density and utilisation are specified by the user. On the basis of this data, the program calculates the corresponding cell resistance and cell area. If the user has not specified the effective power of the fuel cell, this is calculated on the basis of the fuel mass flow to the anode.

In fuel cell models it is assumed that only H_2 is directly converted in the electro-chemical reaction. Other components in the fuel, such as CO, CH_4 and higher hydrocarbons can be converted through chemical reactions.

With high-temperature fuel cells (MCFC and SOFC) CO is converted into H_2 in the shift reaction. It is assumed that the shift reaction in the fuel cell will always result in an equilibrium at cell pressure and temperature (PFCELL and TFCELL). For fuel cells with direct internal reforming (SOFC-DIR and MCFC-DIR) it is also assumed that the CH_4-reforming reaction is in equilibrium.
With stacks of high-temperature fuel cells, with the exception of those in the fuel cell itself, reforming can also take place in the reformers that are built in the stacks: indirect internal reforming. For modeling this type of fuel cells (SOFC-IIR and MCFC-IIR) it is assumed that the fuel will reach an equilibrium in the integrated reformer given a specified temperature (TREACT) before it can be transmitted to the anode (see part “Technical Notes” of the manual).

Regarding low-temperature fuel cells (PAFC, SPFC and AFC) it is assumed by default that only H_2 present in the fuel is converted and that the shift reaction does not take place. However, the user can specify by means of variable XSHIFT (0,1) how much CO is converted in the shift reaction compared to conversion to equilibrium. The equilibrium composition is calculated on the basis of temperature and pressure at the outlet of the anode. The calculation options are summarized in Table 2-3.

Table 2-3: chemical reaction in stacks of fuel cells

	In the fuel cell	**In integrated reformer**
LTFC	conversion CO determined by XSHIFT	not applicable
MCFC-ER / SOFC- ER	CO conversion to equilibrium at TFCELL	not applicable
MCFC-IIR / SOFC-IIR	CO conversion to equilibrium at TFCELL	conversion CO, CH_4 and higher hydrocarbons to equilibrium at TREACT.
MCFC-DIR / SOFC-DIR	conversion CO, CH_4 and higher hydrocarbons to equilibrium at TFCELL	not applicable

With the SPFC water of the anode is transported through the membrane to the cathode as a result of electro-osmotic effects. According to Kinishita et al.[1)] for every transported ion H+ 3.5 to 4 molecules H_2O are transported from the anode to the cathode at a temperature of 100 °C. A connection between this ratio and the temperature is not yet available. The ratio can be specified with parameter TH2OOS (default=3.75).
Because this ratio is that large, the fuel has to contain a large amount of water. If there is not enough water present in the fuel, a warning will be given and all water available will be sent to the cathode. Then the program will go on with the calculation.

For low-temperature fuel cells (PAFC, SPFC and AFC) there is a possibility to model an external cooling side. This can be done by connecting an additional inlet and outlet pipe to the fuel cell.

1) Kinoshita, K., F.R. McLarnon and E.J. Cairns
Fuel cells, a Handbook
Lawrence Berkeley, California
DOE/METC-88/6096 (1988)

Mass balances

It is possible to determine a minimum of 2 and a maximum of 6 unknown mass flows with the fuel cell model. The two equations that are always added to the system matrix are the total mass balance for the system and the mass balance for the anode of which the mass transport of cathode to anode (or vice versa) is a part. Beside this extra equations can be added, which depends on the input specified by the user.

- The mass flow fuel can be calculated out of the power given off by the fuel cell. The user can specify this or, as is the case with off-design calculations, it can be determined out of the specified cell voltage and current density.
- Regarding high-temperature fuel cells and low-temperature fuel cells without cooling cycle, the oxidant flow at the cathode side is not only used for the supply of O_2 and CO_2 to the fuel cell, but also for the dissipation of heat that is released from the processes in the fuel cell. The size of this flow is determined by the permissible heating in the cell (i.e. the difference in temperature between incoming and outgoing oxidant flows). The user has two possibilities to determine the size of the oxidant flow in the fuel cell. If the temperature at the outlet of the fuel cell is specified (it is assumed that the temperatures at anode and cathode outlet are the same) the corresponding mass flow oxidant is calculated out of the energy balance. It is also possible to specify the percentage oxygen that is being absorbed from the cathode flow (oxidant utilisation) which results in the calculation of the heating of the oxidant flow by the program. In this case the program calculates the oxidant utilisation as well as the heating of the oxidant flow.
- If the user has modeled a cooling cycle 1 or 2 additional mass flows are determined. The mass flow from the outgoing cooling medium is determined out of the mass balance on the cooling flow. If the incoming mass flow is not determined in another apparatus, it can be determined out of the energy balance on the cooling flow. In this case the conditions (p, T and x) of the cooling medium at the inlet and outlet of the fuel cell have to be specified or calculated elsewhere. In this case the energy balance cannot be used for the calculation of the mass flow oxidant: this has to be determined in another apparatus or by means of specifying the oxidant utilisation.

Specifying fuel utilisation UFL

Fuel utilisation UFL has to be specified for every type of calculation. However, there are a number of ways how to do this.

The maximum current supplied by the fuel cell occurs when all combustible components in the fuel (H_2, CO, CH_4, C_2H_6, etc.) are being converted through shift and reforming reactions into H_2 (and CO), which can be converted in the electrochemical reaction. The maximum amount of H_2 (mole/mole fuel) that can result, is called mole H_2-equivalent. The fuel utilisation is defined in Cycle-Tempo as the ratio between the number of mole H_2 (and CO) in the fuel cell and the number of mole H_2-equivalent in the fuel.
It is also possible to apply a more specific definition of the utilisation. For a fuel cell, in which e.g. only the present H_2 and CO can be converted (example: external reforming molten carbonate fuel cells) it can be useful to define the utilisation as the fraction of H_2 and CO present in the fuel. The user can adjust the definition of the utilisation by means of the input parameter ICCUFL. The possibilities are summarized in Table 2-4:

Table 2-4: users' definitions for fuel utilisation

ICCUFL	utilisation based on
Default	all combustible components
1	H_2 present in fuel
2	H_2 and CO present in fuel
3	H_2, CO and CH_4 present in fuel

The utilisation that has been specified, is the utilisation per passage. If a part of the anode or the cathode gas is recycled, the overall utilisation (related to the supplied fuel or oxidant in the system) differs from the utilisation per passage (related to the anode inlet). In a number of cases (see part "Technical Notes" of the manual) the overall utilisation can be specified. The pipe compared to which this overall utilisation has been defined has to be specified with IPUFL and IPUOX respectively. In this case the fuel model calculates the utilisation per passage (see "Text output").

This option can only be used if:

- the fuel and the oxidant flow respectively between the specified pipe and the mixing point with the recycled flow is not mixed with other process flows and is not being separated;
- the fuel and the oxidant flow respectively between the mixing point with the recycled current and the inlet of the fuel cell is not mixed with other process flows and is not being separated;

- the recycle flow between the separation after the fuel cell and the mixing point with the recycled flow is not mixed with other process flows;
- the composition of the recycle flow is equal to the composition of the fuel cell outlet.

Summary of the input for design calculations

▪ fuel cell type:	FCTYPE
▪ conditions anode, cathode [1]:	PINAN / POUTAN / DELPAN, TINAN PINCA / POUTCA / DELPCA, TINCA
▪ fuel utilisation:	UFL
▪ electric parameters:	VCELL, CDENS (geometric parameters)
▪ point of operation:	either POWER or $\Phi_{m,fuel}$ [2]
▪ calculation of mass flow oxidant:	either UOX or TOUTPS [3] or $\Phi_{m,ox}$ [3]

1) Data either specified or calculated at another apparatus.

2) Mass flow is determined at another apparatus.

3) Anode and cathode outlet temperatures are assumed to be identical within the model.

B. Off-design calculations (only MCFC and SOFC)

In off-design calculations, the design of the apparatus is completely determined. The values of parameters that determine the electrochemical processes (cell resistance and cell area) are fixed (e.g. by executing a design calculation). In order to fix the point of operational conditions, one of the following data should be fixed: cell voltage, current density, generated power, or the fuel mass flow. The remaining data are determined by the program. Besides this, the input does not differ from a design calculation.

Summary of the input for off-design calculations

- fuel cell type: FCTYPE
- conditions anode, cathode [2)]: PINAN / POUTAN / DELPAN, TINAN, PINCA / POUTCA / DELPCA, TINCA
- fuel utilisation: UFL
- electric parameters: ACELL, RCELL (geometric parameters)
- point of operation: either POWER or $\Phi_{m,fuel}$ [3)] or VCELL or CDENS (both geometric parameters)
- calculation of mass flow oxidant: either UOX or TOUTPS [4)] or $\Phi_{m,ox}$ [3)]

Input parameters

EEQCOD = code which indicates whether the energy balance is used to calculate a mass flow (EEQCOD = 1) or a temperature (EEQCOD = 2)
(default = 1 if TOUTPS is specified
2 if TOUTPS = UNKNOWN)
If a cooling side is specified (only possible for PAFC, SPFC and AFC), EEQCOD = 1 means that the mass flow of the cooling fluid will be calculated. In all other cases with EEQCOD=1 the mass flow at the anode or cathode will be calculated. If a cooling side is specified (only possible for PAFC, SPFC and AFC), EEQCOD = 2 means that the outlet temperature of the cooling fluid will be calculated. In all other cases with EEQCOD=2 the outlet temperature at the anode/cathode will be calculated.

PINAN	=	inlet pressure anode (bar) (default = UNKNOWN)
POUTAN	=	outlet pressure anode (bar) (default = UNKNOWN)
DELPAN	=	pressure drop anode (bar) (default = UNKNOWN)
PINCA	=	inlet pressure cathode (bar) (default = UNKNOWN)
POUTCA	=	outlet pressure cathode (bar) (default = UNKNOWN)
DELPCA	=	pressure drop cathode (bar) (default = UNKNOWN)
TINAN	=	inlet temperature anode (°C) (default = UNKNOWN)
TINCA	=	inlet temperature cathode (°C) (default = UNKNOWN)
TOUTPS	=	outlet temperature anode and cathode (°C) (default = UNKNOWN)
POWER	=	electric (AC) power generated in the stack (MW) (default = UNKNOWN)
DCAC	=	efficiency of DC/AC conversion (-) (default = 1)
DELE	=	energy loss to the environment (kW) (default = 0)
DELEP	=	relative heat losses to the environment (-) (default = 0) Heat loss = generated (DC) power x DELEP (MW)
PFCELL	=	pressure at which electrochemical processes occur (bar)
TFCELL	=	temperature at which electrochemical processes occur (°C) (MANDATORY)
PREACT	=	reaction pressure for pre-reforming (bar)

(default = NO PREREFORMING)

TREACT = reaction temperature for pre-reforming (°C)
(default = NO PREREFORMING)

UFL = fuel utilisation (-) (MANDATORY)

UOX = oxidant utilisation (-) (default = UNKNOWN)

IPUFL[1)] = number of pipe in relation to which the fuel utilisation is specified (default = anode inlet)

IPUOX[5)] = number of pipe in relation to which the oxidant utilisation is specified (default = cathode inlet)

ICCUFL = code to indicate the definition of fuel utilisation

ICCUFL =	1	Fuel utilisation related to H_2
	2	Fuel utilisation related to H_2 and CO
	3	Fuel utilisation related to H_2, CO and CH_4

(at default the fuel utilisation is related to all combustible components)

ESTUFL[2)] = estimation of fuel utilisation (default = UNKNOWN)

ESTUOX[6)] = estimation of oxidant utilisation (default = UNKNOWN)

ESTMFL[6)] = estimation of fuel mass flow (kg/s) (default = UNKNOWN)

ESTMOX[3] = estimation of oxidant mass flow (kg/s) (default = UNKNOWN)

---

1) The fuel and/or oxidant utilisation can be specified in relation to an arbitrary pipe in the system. This option can be used for systems with recirculation of anode and/or cathode gas. The utilisation per passage (inlet to outlet) is presented in the output of the calculation.

2) Estimations are used in the first iteration to calculate the compositions and the oxidant utilisation.
3) Estimations are used in the first iteration to calculate the compositions and the oxidant utilisation.

The following input parameters are only possible for low-temperature fuel cell types (PAFC, SPFC and AFC):

PIN1	=	inlet pressure cooling fluid (bar) (default = UNKNOWN)
POUT1	=	outlet pressure cooling fluid (bar) (default = UNKNOWN)
DELP1	=	pressure drop cooling fluid (bar) (default = UNKNOWN)
TIN1	=	inlet temperature cooling fluid (°C) (default = UNKNOWN)
TOUT1	=	outlet temperature cooling fluid (°C) (default = UNKNOWN)
DELT1	=	temperature rise cooling fluid (°C) (default = UNKNOWN)
XSHIFT	=	ratio between the actual extent into which CO is converted via CO-shift reaction and the extent into which CO is converted according to chemical equilibrium (-). XSHIFT must have a value between 0 and 1 (default = 0)
TH2OOS	=	ratio between the amount of transported H_2O- molecules (from anode to cathode) and the amount of transported H^+-ions. This parameter is only possible for type SPFC. (default = 3.75)

Input parameters for geometry

FLOW	=	flow type (default = 1 (co-flow)) FLOW = 0: co-flow type FLOW = 1: counter flow type FLOW = 2: cross flow type
CDENS	=	mean current density (A/m^2) (default = UNKNOWN)
ACELL	=	cell area (m^2) (default = UNKNOWN)
VCELL	=	cell voltage (V) (default = UNKNOWN)
RCELL	=	cell resistance (ohm m^2) (default = UNKNOWN)
NCELL	=	number of cells (default = 1) NCELL is used to calculate stack voltage and stack current.
NITER	=	number of design iterations (default = 0) In the first iterations large fluctuations in the calculated mass flows may occur. In order to prevent possible problems at off-design calculations like negative mass flows, cell voltage cross-over and reversible voltage cross-over, it is possible to specify the cell voltage and current density for the first iterations. In this way one may control these fluctuations before the actual off-design procedure is started.
ESTVLT	=	estimation of cell voltage (V) (default = UNKNOWN)
ESTCDN	=	estimation of current density (A/m^2) (default = UNKNOWN)

Number of equations for system matrix

This apparatus type at least adds 2 mass equations to the system matrix. If EEQCOD = 1 the energy equations is also added. In the following cases an extra mass equation is added:

- usage of low-temperature fuel cell types with cooling media
- specification of UOX
- specification of POWER

Summarizing:

EEQCOD = 1: 2 mass equations + 1 energy equation = 3 equations

EEQCOD = 2: 2 mass equations

Low-temperature fuel cell types with cooling medium:

EEQCOD = 1: 3 mass equations + 1 energy equation = 4 equations

EEQCOD = 2: 3 mass equations

UOX specified:

EEQCOD = 1: 3 mass equations + 1 energy equation = 4 equations

EEQCOD = 2: 3 mass equations

POWER specified:

EEQCOD = 1: 3 mass equations + 1 energy equation = 4 equations

EEQCOD = 2: 3 mass equations

Low-temperature fuel cell types with cooling medium + UOX specified:

EEQCOD = 1: 4 mass equations + 1 energy equation = 5 equations

EEQCOD = 2: 4 mass equations

Low-temperature fuel cell types with cooling medium + POWER specified:

EEQCOD = 1: 4 mass equations + 1 energy equation = 5 equations

EEQCOD = 2: 4 mass equations

UOX specified+ POWER specified:

EEQCOD = 1: 4 mass equations + 1 energy equation = 5 equations

EEQCOD = 2: 4 mass equations

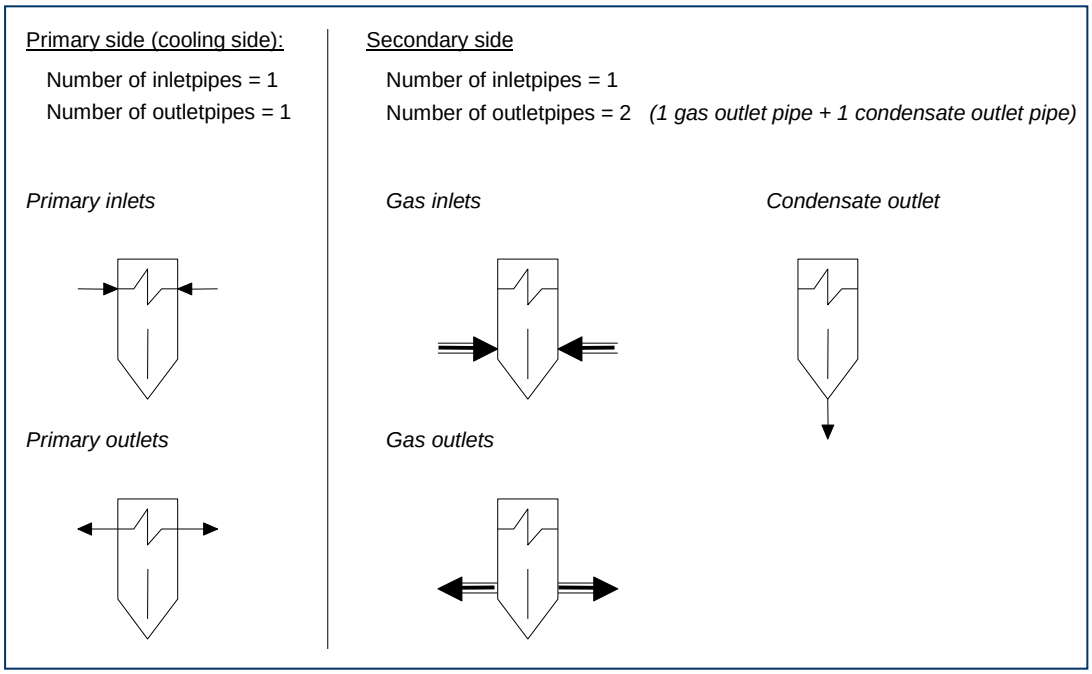
Low-temperature fuel cell types with cooling medium + UOX specified + POWER specified:

EEQCOD = 1: 5 mass equations + 1 energy equation = 6 equations

EEQCOD = 2: 5 mass equations

Moisture separator

2.19 Type = 22 Moisture Separator



Applications

In a moisture separator a gas flow is cooled, whereby condensation occurs. The condensed moisture is separated via a separate pipe. Counter current between the heat exchanging media is assumed.

Calculation options

The quantity of moisture, which is separated, can be determined in two ways.

1. The mass flow of moisture to be separated is determined outside the apparatus (e.g. with a valve or a sink).
   In this case an estimate *must* be given for the ratio condensate/inlet mass flow gas (CGRATI).
   The gas outlet temperature must be unknown, this or an estimate for it must *not* be given.

   The energy balance may be used to
   - **EEQCOD = 1:** calculate the mass flow of cooling water
   - **EEQCOD = 2:** calculate the outlet temperature of the cooling water (the outlet temperature of the gas cannot be calculated from the energy balance, where this is tried then an error message follows 'TOO MUCH DATA AVAILABLE')

2. The mass flow of moisture to be separated is calculated from the outlet pressure and temperature of the gas. The pressure may be specified or calculated. The temperature may be specified, calculated from data elsewhere in the system, or calculated from the energy balance.
   In this case the gas outlet temperature *must* be given, or an estimate for it, where the temperature is calculated elsewhere in the system or from the energy balance.
   No estimate may be specified for the ratio condensate/inlet mass flow gas.

   The energy balance may be used to
   - **EEQCOD = 1:** calculate the mass flow of cooling water
   - **EEQCOD = 2:** to calculate a temperature, mostly the outlet temperature of the cooling water (where the gas outlet temperature is calculated from the energy balance, then the condensate temperature is also calculated from this, see calculation rule 9)

Input parameters

PIN1,POUT1,DELP1,TIN1,TOUT1,DELT1 are standard
PIN2,POUT2,DELP2,TIN2,TOUT2,DELT2 are standard (N.B. see calculation rules 6 and 9)

EEQCOD	=	code which indicates whether the energy balance is used to calculate a mass flow (EEQCOD = 1) or a temperature (EEQCOD = 2) (default = 1)
DELE	=	energy loss to the environment (kW) (default = UNKNOWN)
DELTL	=	temperature difference between primary inlet and secondary outlet (°C) (default = UNKNOWN)
DELTH	=	temperature difference between primary outlet and secondary inlet (°C) (default = UNKNOWN)
ESTPGS	=	estimate of the gas outlet pressure in the 0th iteration if POUT2 is not specified (bar) (default = UNKNOWN) N.B. either POUT2 or ESTPGS must be specified; otherwise an error message is given.
ESTTGS	=	estimate of the gas outlet temperature in the 0th iteration if TOUT2 is not specified and the quantity of moisture to be separated must be calculated from the outlet conditions of the gas (°C) (default = UNKNOWN)
CGRATI	=	estimate of the ratio condensate/inlet mass flow gas in the 0^{th} iteration where the outlet temperature of the gas must be calculated from this (-) (default = UNKNOWN)
RPSM	=	estimate of the ratio mass flow cooling medium/inlet mass flow gas for the 0th iteration, where EEQCOD = 2 (default = 1.0)

All input parameters apart from DELE can be modified in a user subroutine.

Number of equations for system matrix

As standard the total mass balance and the primary mass equation (over the cooling pipes) are added to the matrix. Where the quantity of moisture to be separated has to be calculated from the gas outlet conditions, an extra mass equation is added, which determines how much moisture (kg/s) is separated.
Where the parameter EEQCOD is given the value 1, then the energy balance is also added to the system matrix.

Summarizing:

EEQCOD = 1: 2 mass equations + 1 energy equation = 3 equations
EEQCOD = 2: 2 mass equations

If the amount of moisture is to be calculated:
EEQCOD = 1: 3 mass equations + 1 energy equation = 4 equations
EEQCOD = 2: 3 mass equations

Media

The composition of the ingoing mass flow can be chosen freely, but the medium type must be GASMIX. The medium type of the primary (cooling) flows can be chosen freely.

Calculation rules

Primary medium

1.	$p_{out,p}$	=	$p_{in,p}$	-	DELP1
2.	$p_{in,p}$	=	$p_{out,p}$	+	DELP1
3.	$T_{out,p}$	=	$T_{in,p}$	+	DELT1
4.	$T_{in,p}$	=	$T_{out,p}$	-	DELT1

Secondary medium

5.	$p_{out,gas}$	=	$p_{in,gas}$	-	DELP2
6.	p_{cond}	=	$p_{out,gas}$		
7.	$p_{in,gas}$	=	$p_{out,gas}$	+	DELP2
8.	$T_{out,gas}$	=	$T_{in,gas}$	+	DELT2
9.	T_{cond}	=	$T_{out,gas}$		
10.	$T_{in,gas}$	=	$T_{out,gas}$	-	DELT2

11. If the gas outlet temperature must be calculated from the quantity of moisture to be separated, then the following applies:

$T_{out,gas} = T_{sat}(\partial p_{out,gas,H2O})$ (ideal mixture)

In words: the gas outlet temperature is equal to the saturation temperature of water at a pressure which is equal to the partial pressure of the residual water vapor in the gas.

Temperature differences

12. $T_{out,p} = T_{in,gas} -$ DELTH

13. $T_{in,gas} = T_{out,p} +$ DELTH

14. $T_{in,p} = T_{out,gas} -$ DELTL

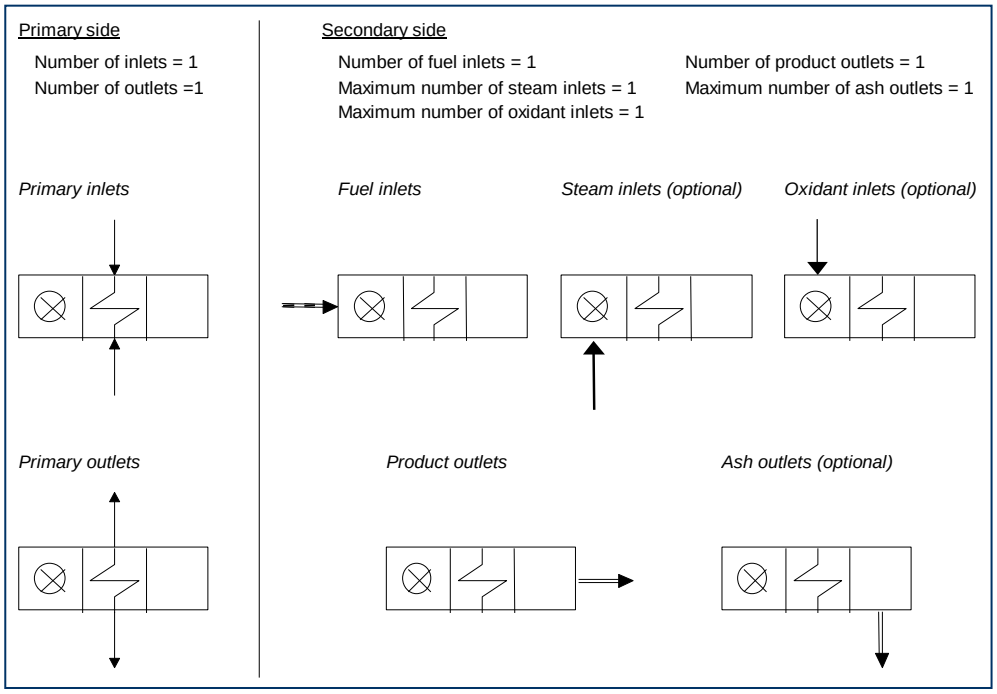
15. $T_{out,gas} = T_{in,p} +$ DELTL

Off-design calculations

For off-design calculations no extra calculation rules are available.

Gasifier

2.20 Type = 23 Gasifier



Applications

The gasifier is used for the calculation of the chemical equilibrium composition of the outgoing gas in case of specified or calculated conditions, as model for a reactor in which, for example, coal reacts with steam and an oxidant or with one of both. Furthermore, the heat is calculated that is needed for or that is released in the chemical reaction. The compositions of the incoming flows of coal, steam and oxidant are free to be chosen. Components that do not take part in the chemical reaction, can be specified (see **Reaction data** in paragraph 4.2 of part “Cycle-Tempo Operation” of the manual).

Options for calculation

The options for calculation are characterized by the way in which the chemical equilibriums, the reaction temperature (TREACT) and the ratio oxidant/fuel (OFRATI) are being determined, and the way in which the energy balance is being used.

1. The conditions and the mass flow ratios at the inlets are known, the heat absorbed by the cooling system is known and TREACT is specified.
   a. the outlet temperature of the gas is calculated (EEQCOD = 2).
   b. the mass flow of the cooling medium is calculated (EEQCOD = 1).

2. The conditions and the mass flow ratios at the inlets are known, TREACT is unknown. The gas and ash outlet temperature result from the chemical equilibrium reactions as is the case for TREACT; however, they can be influenced, see calculation rules 7 and 8.
   a. the outlet temperature of the cooling medium is calculated (EEQCOD = 2).
   b. the mass flow of the cooling medium is calculated (EEQCOD = 1).

   The conditions at the inlets and outlets are known, the heat absorbed by the cooling medium is known and TREACT is specified as well as the mass flow ratio steam/fuel (SFRATI).
   The mass flow ratio oxidant/fuel (OFRATI) can then be calculated out of the energy balance (EEQCOD = 2).

In all cases the reaction pressure (PREACT) can be specified. If PREACT is not specified, calculation rule 5b will be applied. In all cases the pressure and/or the temperature of the ash can be specified. If they are not specified, calculation rules 6 and 7 will be applied, respectively.

Input parameters

PIN1, POUT1, DELP1, TIN1, TOUT1, DELT1 are standard.
PIN2, TIN2 (if specified they apply to *all* connected secondary inlet pipes), POUT2, TOUT2 are standard

EEQCOD	=	code that indicates if the energy balance is used to calculate a mass flow (EEQCOD = 1) or a temperature (EEQCOD = 2) (default = 1)
DELE	=	energy flow to the environment (kW) (default = 0.0)
PREACT	=	pressure at which the chemical equilibrium is calculated (bar) (default = POUT2 + DPREAC)
DPREAC	=	difference between equilibrium pressure and outlet pressure, only to be specified if PREACT is not specified (bar) (default = 0)
TREACT	=	temperature at which the chemical equilibrium is calculated (°C) (default = TOUT2 + DTREAC)
DTREAC	=	difference between equilibrium temperature and outlet temperature, only to be specified if TREACT is not specified (°C) (default = 0)
ESTPOU	=	estimation for the outlet pressure if PREACT and POUT2 are not specified (bar) (default = UNKNOWN)
SFRATI	=	(steam/fuel ratio) mass flow ratio steam/fuel (kg/kg) (default = UNKNOWN)
OFRATI	=	(oxidant/fuel ratio) mass flow ratio oxidant/fuel (kg/kg) (default = UNKNOWN)
ESTOFR	=	estimation for OFRATI if this has to be calculated (kg/kg) (default = UNKNOWN)

AFRATI	=	(ash/fuel ratio) mass flow ratio ash/fuel (kg/kg) Can only be specified if the compositions at the ash and gas outlet are specified (default = UNKNOWN)
PASH	=	pressure in the ash pipe (bar) (default = PREACT-DPASH)
DPASH	=	difference between equilibrium pressure and pressure in ash pipe, only to be specified if PASH is not specified (bar) (default = 0)
TASH	=	temperature in the ash pipe (°C) (default = TREACT-DTASH)
DTASH	=	difference between equilibrium temperature and temperature in ash pipe, only to be specified if TASH is not specified (°C) (default = 0)

All input parameters, except for DELE, can be adjusted in a user subroutine.

Number of equations for system matrix

It is standard to add the mass balance and the secondary mass equation (on the incoming and outgoing cooling pipes) to the system matrix. If a steam, oxidant or ash pipe is connected, then an additional mass equation is added to the matrix for each of them separately. The total number of mass equations can therefore vary from 2 to 5, dependent on the number of connected pipes.
If the energy equation code (EEQCOD) receives value 1, the energy balance is also added to the system matrix.

Summarizing:

EEQCOD = 1: 2 mass equations + 1 energy equation = 3 equations
EEQCOD = 2: 2 mass equations

With ash pipe:
EEQCOD = 1: 3 mass equations + 1 energy equation = 4 equations
EEQCOD = 2: 3 mass equations

Either OFRATI, or ESTOFR specified:
EEQCOD = 1: 3 mass equations + 1 energy equation = 4 equations
EEQCOD = 2: 3 mass equations

SFRATI specified:
EEQCOD = 1: 3 mass equations + 1 energy equation = 4 equations
EEQCOD = 2: 3 mass equations

With ash pipe either OFRATI, or ESTOFR specified:
EEQCOD = 1: 4 mass equations + 1 energy equation = 5 equations
EEQCOD = 2: 4 mass equations

With ash pipe + SFRATI specified:
EEQCOD = 1: 4 mass equations + 1 energy equation = 5 equations
EEQCOD = 2: 4 mass equations

Either OFRATI, or ESTOFR specified + SFRATI specified:

EEQCOD = 1: 4 mass equations + 1 energy equation = 5 equations

EEQCOD = 2: 4 mass equations

With ash pipe + either OFRATI, or ESTOFR specified + SFRATI specified:

EEQCOD = 1: 5 mass equations + 1 energy equation = 6 equations

EEQCOD = 2: 5 mass equations

Media

The medium in the cooling pipes is free to be chosen. The medium in the steam and oxidant pipes has to be GASMIX, the medium in the fuel pipe can be GASMIX as well as FUEL.

Calculations rules

For the primary medium (cooling medium)

1.	$p_{out,p}$	=	$p_{in,p}$	–	DELP1	
2.	$p_{in,p}$	=	$p_{out,p}$	+	DELP1	
3.	$T_{out,p}$	=	$T_{in,p}$	+	DELT1	
4.	$T_{in,p}$	=	$T_{out,p}$	–	DELT1	

For the secondary medium (coal/gas)

5.a	p_{react}	=	PREACT			if PREACT is specified
5.b	p_{react}	=	$p_{out,gas}$	+	DPREAC	if PREACT is not specified
6.	p_{ash}	=	p_{react}	–	DPASH	
7.	T_{ash}	=	T_{react}	–	DTASH	

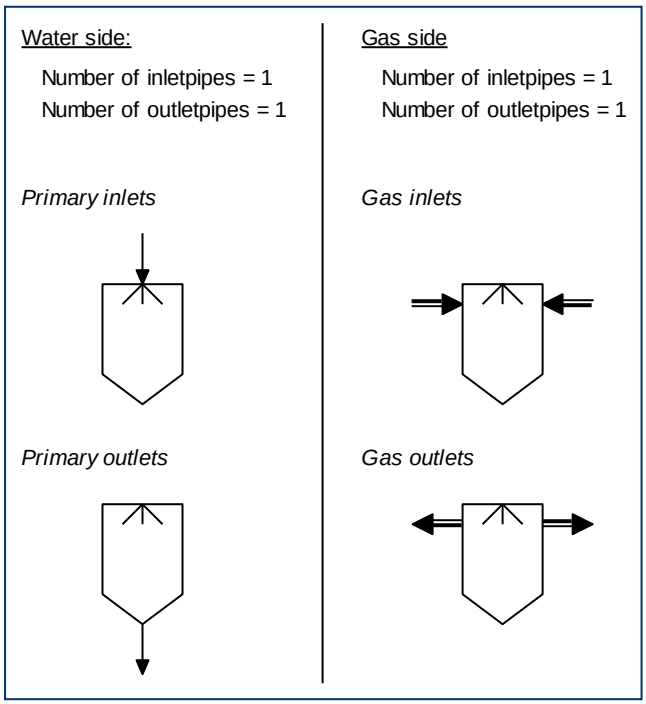
8.a	T_{react}	=	TREACT		if TREACT is specified
8.b	T_{react}	=	$T_{out,gas}$ +	DTREAC	if TREACT is not specified N.B. $T_{out,gas}$ is calculated

Off-design calculations

For off-design calculation no extra calculation rules are available.

Scrubber

2.21 Type = 25 Scrubber



Applications

In a scrubber gas is saturated with water. It functions as a parallel flow saturator, which means that the same pressures and temperatures dominate in the gas and water outlet pipes. In a scrubber no gas components can be separated, this has to be done in a pre or post-connected separator type 26.
Also see part “Technical Notes” of the manual.

Calculation options

The temperatures in both outlet pipes have to be calculated. Among other things the energy balance is used for this. It is possible to have all supplied water evaporated or to use the scrubber as an injection cooler. However, it is obligatory to connect a water outlet pipe. In the situation in which the ratio between mass flows in the gas and water outlet is becoming very large (among other things if not all the water evaporates) convergence problems can occur.

Input parameters

PING, PINW, DELPG, DELPW, TING and TINW are standard; the parameters with a 'G' at the end apply for the gas side and those with a 'W' at the end for the water side.

POUT	=	pressure in gas and water outlet pipes (default = UNKNOWN)
DELE	=	loss of energy to the environment (default = 0.0)
RELHUM	=	relative humidity in the gas outlet (default = 0.99)
ESTPGS	=	estimation of the outlet pressure for the first iteration (default = POUT)
ESTTEM	=	estimation of the outlet temperature for the first iteration (default = UNKNOWN)
ESTMLF	=	estimation of the molar fraction water in the gas outlet for the first iteration (default = UNKNOWN)
MAXIT	=	maximum number of iterations with the calculation of outlet temperatures (default = 25)
DSPLIT	=	reproduction of the iteration progress with the calculation of outlet temperatures (default = 0): 0 = no reproduction 1 = reproduction

Number of equations for system matrix

It is standard to add the general mass balance and an additional mass equation to the matrix. The latter determines how much water the gas absorbs.

Media

The medium in the connected pipes has to be GASMIX, which therefore also applies to pipes with water.

Calculation rules

For the first iteration

1. $molar\ fraction\ H_2O_{gas,out} = RELHUM \times \frac{p_{sat}(ESTTEM)}{ESTPGS}$

2. $T_{out} = T_{sat}\left(ESTPGS \times \frac{ESTMLF}{RELHUM} \right)$

No more and no less than two of the three possible starting estimations have to be known.

Other calculation rules

3. $p_{out,water} = p_{out,gas}$

4. $p_{out,gas} = p_{in,gas} -$ DELPG

5. $p_{in,gas} = p_{out,gas} +$ DELPG

6. $p_{out,water} = p_{in,water} -$ DELPW

7. $p_{in,water} = p_{out,water} +$ DELPW

8. $T_{out,water} = T_{out,gas}$ (break-off criterion)

9. The final result meets the relation:

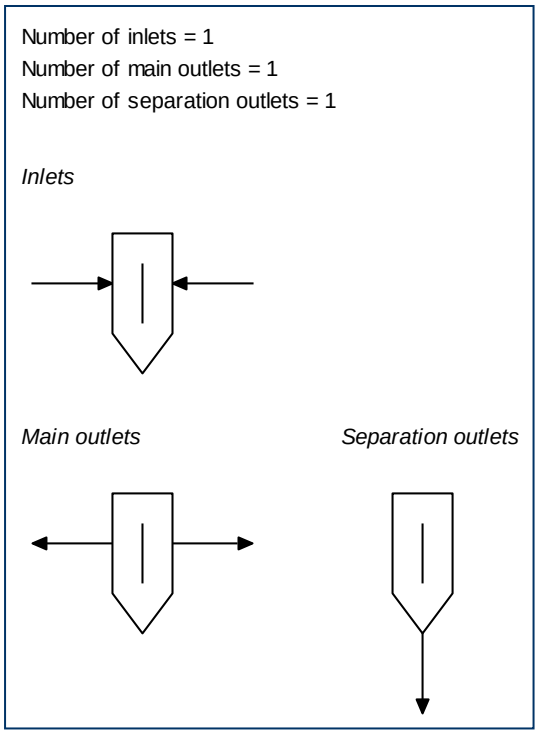
$$mole\,fraction\ H_2O_{gas,out} = RELHUM \times \frac{p_{sat}(T_{out,gas})}{p_{out,gas}}$$

Off-design calculations

For off-design calculations no extra calculation rules are available.

General separator

2.22 Type = 26 General separator



Applications

By means of this apparatus definable components in also definable amounts can be separated from a medium. The apparatus supplies the system matrix with two mass equations. The energy equation can be used as follows: if the loss of energy to the environment has been defined in a production function, a mass flow is calculated out of the energy balance. If this is not the case and also DELE is not specified, the energy exchange with the environment is calculated. If DELE is specified, one or two temperatures are calculated out of the energy balance.

Input parameters

PIN, POUT5, POUT6, DELP5, DELP6 are standard
TIN, TOUT5, TOUT6, DELT5, DELT6 are standard

Outlet conditions with a 5 apply to the main outlet, those with a 6 apply to the separation outlet. Differences in conditions with a 5 apply between the inlet and the main outlet, those with a 6 between the inlet and the separation outlet

DELE	=	energy loss to the environment (kW) (default = UNKNOWN)
TEMDIF	=	difference in temperature between the main and the separation outlet pipe (default = UNKNOWN)

Number of equations for system matrix

This apparatus type adds two mass equation to the system matrix.

Media

The separation outlet always contains GASMIX. All other pipes must have the same medium type: GASMIX or FUEL.

Identification of components to be separated

The components to be separated will have to be specified via input for **Reaction data** (see paragraph 4.2 of part "Cycle-Tempo Operation").
It is possible to specify the complete composition of the main outlet. It is automatically calculated what will be separated then, in which at least one component is completely passed to the main outlet. However, specifications at "Separate components" have priority in the calculations.
For example, specification of a mole percentage of 80% for CO_2 at "Separate components" has as result, that 2.4 mole/s of CO_2 goes out through the separation outlet if 3 moles/s of CO_2 comes in through the inlet. Specification of a mole percentage of 20% for CO_2 at "Bypass components" has as result, that the concentration of CO_2 in the main outlet pipe will be 0.2 mole/mole if that is possible. When the supply of CO_2 is not sufficient, all CO_2 is discharged through the main outlet. The sum of the concentrations specified at "Separate components" and "Bypass components" is not allowed to be larger than 100%.

Calculation rules

1.	$p_{out,5}$	=	p_{in}	–	DELP5
2.	$p_{out,6}$	=	p_{in}	–	DELP6
3.	$T_{out,5}$	=	T_{in}	+	DELT5
4.	$T_{out,6}$	=	T_{in}	+	DELT6

Above relations are also used for the calculation of the mentioned inlet conditions. When inconsistencies occur between relations 1 and 2 or between 3 and 4, relations 1 and 3 have priority. If the situation occurs that of all temperatures only the inlet temperature is known, relation:

5.	$T_{out,5}$	=	$T_{out,6}$	+	TEMDIF

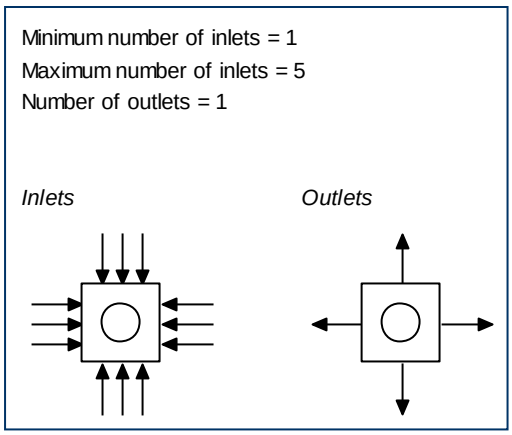
comes into action if TEMDIF is specified. Both temperatures can then be calculated out of the energy balance if DELE is specified.

Off-design calculations

For off-design calculations no extra calculation rules are available.

Chemical reactor

2.23 Type = 27 Chemical reactor



Applications

In the chemical reactor a new equilibrium can be calculated for a chemical reaction on the basis of an equilibrium temperature. For this purpose equilibrium constants are used. Also various reactions can be brought to equilibrium simultaneously, at various equilibrium temperatures.

The available reactions are:

- water gas shift reaction: $CO + H_2O \leftrightarrow CO_2 + H_2$
- CH_4-reforming reaction: $CH_4 + H_2O \leftrightarrow CO + 3\ H_2$
- reactions programmed by the user via user subroutine USREAC

The equilibrium constants only depend on the equilibrium temperatures. If no equilibrium temperature is specified for a reaction, it is assumed, that the reaction does not take place.

Input parameters

PIN, POUT, DELP, TIN, TOUT are standard
N.B: if PIN is specified, it applies to all inlet pipes.

DELE	=	loss of energy to the environment (kW) (default = 0.0)
PREACT	=	reaction pressure, independent of the pressures at inlet or outlet; if PREACT is not specified, the lowest inlet pressure is taken as reaction pressure (default = UNKNOWN)
ESTPGS	=	estimation of the pressure at the inlet for the first iteration; not to be specified if PREACT is specified (default = UNKNOWN)
ESTMAS	=	estimation of the mass flow for the first iteration; if ESTMAS is specified DELE will not be zero during the first iteration (default = UNKNOWN)
RMASS	=	array with estimations of the ratios between mass flows in the inlet pipes, the sum of RMASS has to be 1.0 (default = UNKNOWN)
TWGS	=	reaction temperature for water gas shift reaction (default = UNKNOWN)
TCH4R	=	reaction temperature for the CH_4-reforming reaction (default = UNKNOWN)
TRUSER	=	reaction temperature for a reaction programmed by the user (default = UNKNOWN)
MAXIT	=	maximum number of iterations during the calculation of the latest equilibrium of all reactions together (only applicable if more reactions are brought to equilibrium at the same time) (default = 25)

Number of equations for system matrix

Only the total mass balance is added to the system matrix. The energy equation is used to calculate an unknown temperature, which will often be the outlet temperature.

Media

The connected pipes have to have the medium GASMIX.

Calculation rules

1. $p_{out} = \min_{i=1}^{n}\{p_{in}(i)\} - DELP$ (n = number of inlet pipes)

2. $p_{in}(i) = p_{out} + DELP$ (for all i = 1 number of inlet pipes)

3. Out of the energy balance an unknown temperature is calculated. The outlet as well as an inlet temperature can be calculated.
   N.B.: If all temperatures are already known, the outlet temperature is calculated and this value overwrites the value that was already present.

Off-design calculations

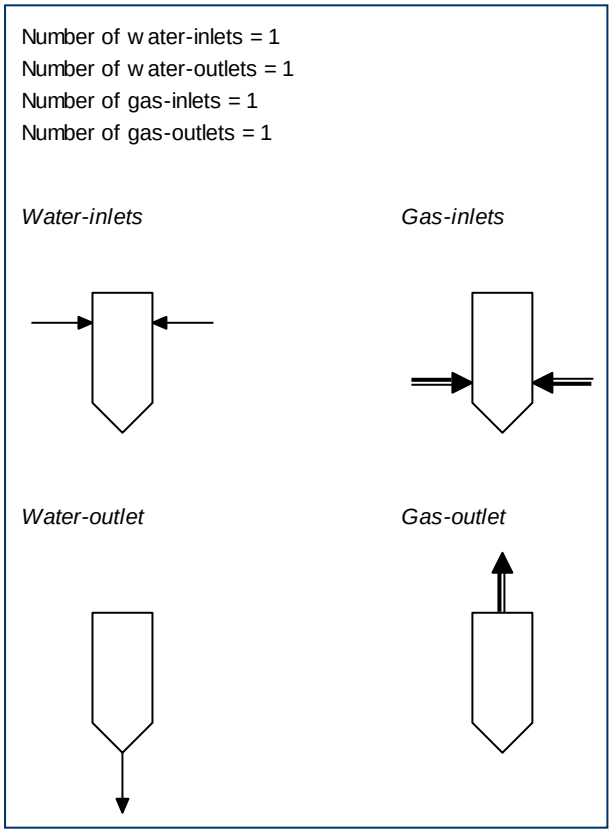
For off-design calculations no extra calculation rules are available.

Reactions programmed by the user

User-defined reactions can be programmed in user subroutine USREAC. This routine will be called if TRUSER is specified. For more information about USREAC see part “User Subroutines” of the manual.

Saturator

2.24 Type = 28 Saturator



Applications

The saturator is meant to moisturize a gas with water vapor. This apparatus adds two mass equations to the system matrix. The energy balance can be used to calculate a temperature or a mass flow or the energy exchange with the environment. If a temperature has to be calculated out of the energy balance DELE and ESTTEM have to be specified. Cycle-Tempo

will then find out which temperature is the unknown temperature. If a mass flow has to be calculated out of the energy balance the energy exchange with the environment has to be specified in a production function. If the energy exchange with the environment is not specified for the apparatus or via a production function, it will be calculated from the energy balance.

Media

Four pipes are connected to the apparatus:
– inlet gas pipe
– inlet water pipe
– outlet gas pipe
– outlet water pipe

The medium of all connected pipes has to be GASMIX.

Input parameters

Standard input:

PING, POUTG[1) (see below)], DELPG, TING, TOUTG[1) (see below)], DELTG (for gas)
PINW, POUTW, DELPW, TINW, TOUTW, DELTW (for water)

EEQCOD	=	code that indicates if the energy balance is used to calculate a mass flow (EEQCOD = 1) or a temperature (EEQCOD = 2) (default = 2)
DELE	=	energy flow (loss) to the environment (kW) (default = UNKNOWN)
ESTTEM	=	estimation of the temperature to be calculated; if DELE is specified also ESTTEM must be specified (default = UNKNOWN)
RELHUM	=	relative humidity of the gas at the outlet: 0.0 is dry, 1.0 is saturated (default = 0.99)

If RELHUM is given value 1.0, the risk exists that condensation occurs in the gas outlet pipe or pipes further downstream. This can have unpleasant results for the convergence of the calculation.

DELTL = difference in temperature between incoming water and outgoing gas (default = UNKNOWN)

DELTH = difference in temperature between outgoing water and incoming gas (default = UNKNOWN)

ESTMLF = estimation of the molar fraction water in the outlet gas pipe for the first iteration (default = UNKNOWN)
If ESTMLF is not specified, it is looked at whether or not POUTG or TOUTG are specified in order to calculate with them the molar fraction for the first iteration. If they are not specified as well, the structure of the gas in the outlet gas pipe is considered to be equal to that of the gas in the inlet gas pipe in the first iteration.
ESTMLF has absolute priority in the first iteration, even over MLFH2O.

MLFH2O = molar fraction water vapor in gas outlet pipe[1)2)]
(default = UNKNOWN)

DELMW = amount of water to evaporate (kg/s)[1)2)] (default = UNKNOWN)

PIPE = if PIPE is specified, DELMW is relative compared to the mass

1) The molar fraction water vapor in the gas outlet pipe can be calculated in three ways:
- specified with MLFH2O
- calculated out of DELMW
- calculated out of pressure and temperature in gas outlet pipe

If MLFH2O or DELMW are specified POUTG and TOUTG cannot be specified both. If this does happen, TOUTG will be ignored and at best be used as an estimation during the first iteration, if ESTMLF is not specified.

2) If MLFH2O or DELMW are specified, the pressure or the temperature in the gas outlet pipe is calculated. Default the temperature is calculated. However, if TOUTG is specified, the pressure is calculated.

flow in the pipe, the number of which is mentioned in PIPE (default = UNKNOWN)

WFOTEB = (weight factor of old temperature from energy balance) weight factor of the temperature calculated in the previous iteration out of the energy balance. This can be averaged with the new temperature that is calculated in order to make a new estimation of the temperature (default = 0.0)

If a temperature has to be calculated out of the energy balance it is possible to average the calculated temperature with the calculated temperature from that pipe in the previous iteration in order to prevent large fluctuations. The new estimation of the temperature to be calculated is then determined as:

$$T_{new} = \frac{T_{calc} + WFOTEB \times T_{old}}{1 + WFOTEB}$$

This is especially important if the temperature to be calculated out of the energy balance is the one of the outlet gas pipe. This because the structure of the gas is dependent on that temperature. However, such a situation is not recommended. WFOTEB is therefore the weight factor of the temperature of the previous iteration in the averaging.
If the default value of WFOTEB is held, the new estimation is equal to the calculated temperature and the averaging is cancelled.

Calculation rules

1. $p_{out,g} = p_{in,g} - DELPG$

2. $p_{out,w} = p_{in,w} - DELPW$

3. $p_{out,w} = p_{out,g}$ if $p_{out,w}$ is not specified or calculated according to rule 2

4. $T_{out,g} = T_{in,g} + DELTG$

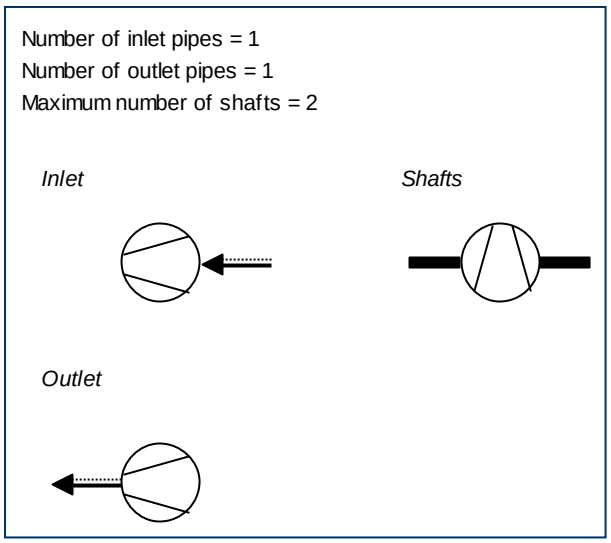
5. $T_{out,w} = T_{in,w} + DELTW$

6. $T_{out,g} = T_{in,w} - DELTH$

7. $T_{out,w} = T_{in,g} + DELTL$

Compressor

2.25 Type = 29 Compressor



Applications

Three compressor type are currently available:

1. General : general compressor (default)
2. SULZR-A : Sulzer axial compressor
3. SULZR-AV : as SULZR-A, but with adjustable vanes

For a design calculation there is no difference between the compressor types, except that for the Sulzer compressors the isentropic efficiency can be calculated as a function of the volume flow.
For an off-design calculation only relations for the Sulzer compressors are available. For more information, see part “Technical Notes” of the manual.

Input parameters

PIN, POUT, DELP[1)], TOUT, TIN and DELT are standard.

PRATI = pressure ratio (-) (default = UNKNOWN)
PRATI is defined as POUT/PIN.

ETHAI[2)] = isentropic efficiency (-) (default = UNKNOWN)

ETHAM[3)] = mechanical efficiency of drive train (-) (default = see Figure 2-6)

ETHAE[4)] = electric efficiency (-) (default = see Figure 2-6)

1) DELP is defined as pressure drop. Therefore, DELP is normally negative regarded to compressors.

2) For compressors of the type SULZR the isentropic efficiency can be calculated as function of the volume flow and pressure ratio.

3) ETHAM is used for the calculation of the system efficiency and for the conversion of axis and compressor power vice versa.

4) ETHAE is used for the calculation of the system efficiency and for exergy calculations.

Electricity and turbine driven compressors

If one of the efficiencies, ETHAM or ETHAE is not specified, the efficiency that is not specified is considered to be equal to 1. If none of the outputs are specified the total efficiency is calculated by means of interpolation out of Figure 2-8.
For turbine driven compressors ETHAE is not used.

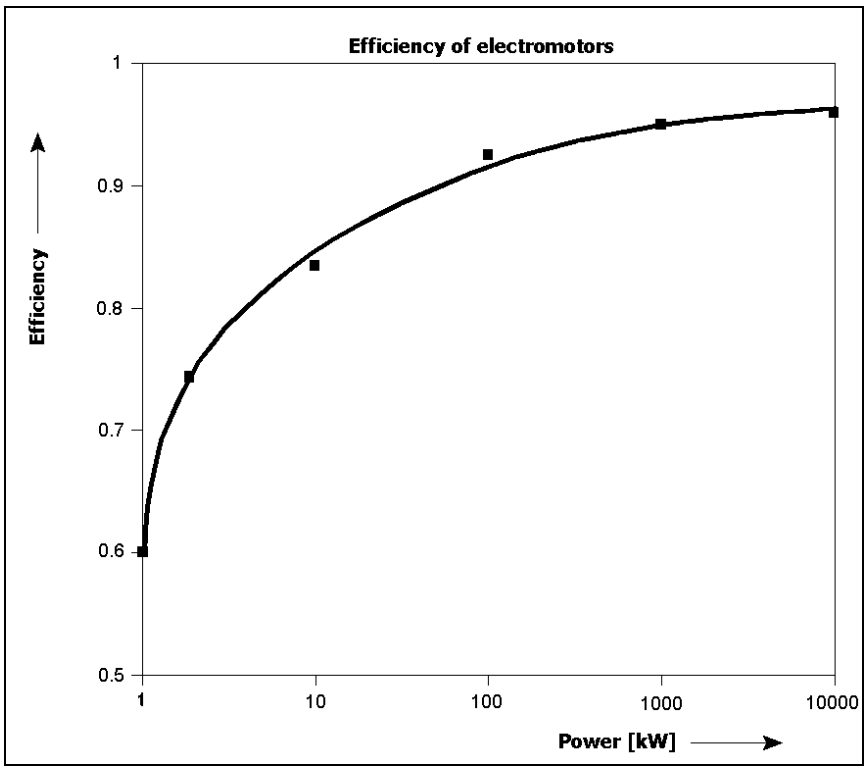


Figure 2-8: the efficiency of electromotors including the mechanical efficiency of the motor and compressor as a function of the power on the shaft of the compressor

Number of equations for system matrix

This apparatus type adds 1 mass equation to the system matrix..

Calculation rules

1.	p_{out}	=	p_{in}	-	DELP
2.	p_{out}	=	p_{in}	x	PRATI
3.	p_{in}	=	p_{out}	+	DELP
4.	T_{in}	=	T_{out}	-	DELT
5.	T_{out}	=	T_{in}	+	DELT
6.	h_{in}	=	f (h_{out}, ETHAI)		
7.	h_{out}	=	f (h_{in}, ETHAI)		

Input parameters for off-design calculations

If the design data for volume flow, pressure ratio and isentropic efficiency are specified in the input fields for design data for off-design calculations, the isentropic efficiency with an off-design calculation can be determined for compressors of the type SULZR-A and SULZR-AV.
For the compressor types SULZR-A and SULZR-AV the following parameters may be specified:

DESVOL = design inlet volume flow (m^3/s)
(default = UNKNOWN, specification MANDATORY)

ETHAID = design isentropic efficiency
(default = UNKNOWN, specification MANDATORY)

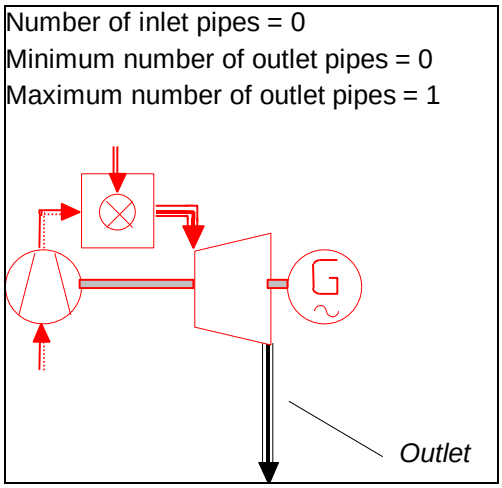
PRATID = design pressure ratio
(default = UNKNOWN, specification MANDATORY for compressor type SULZR-AV)

PCTRPM = rotational speed as a percentage of the rotational speed at design

For compressor type SULZR-AV it is required to specify either PRATID or PCTRPM, not both.

Gas turbine

2.26 Type = 30 Gas turbine



Applications

The gas turbine has been developed for quick-scans. A large number of standard gas turbines can be compared, especially with respect to the performance of bottoming cycles. The gas turbine can be used with as well as without a bottoming cycle. Without a bottoming cycle, there is no need to connect the outlet to a stack or a sink. Furthermore, air and fuel sources cannot be connected; those are part of the gas turbine model itself, input data for air and fuel has been fixed by the selected model in the input window. The air and fuel pipe in the figure above have an illustrative purpose and are used for displaying calculation results in the diagram.

Input window

At the right side of the input window there is a list of available gas turbines with their relevant performance data (see figure 2- 10 below). You can use the vertical scroll bar to browse through the library. With the horizontal scroll bar other data, like inlet temperature, peak rate and speed, can be made visible.

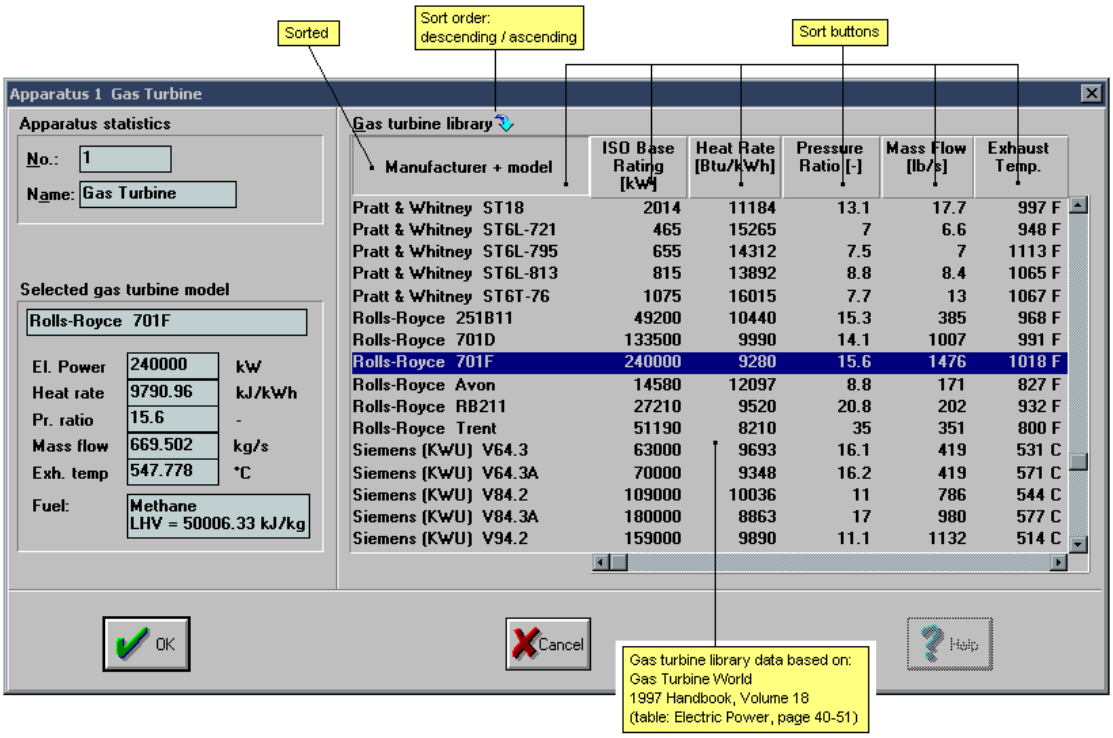


Figure 2-9: input window gas turbine

You can select a gas turbine model by clicking on the corresponding row in the library. Data of the selected model are displayed in metric units at the left side of the window.
You can sort the library by clicking on one of the sort buttons above the columns. Default the library is sorted alphabetically by "Manufacturer + model". By clicking on a sort button once again, the list will be sorted in reversed order. This is visualized by the arrow at the top of the window.

Input parameters and fixed data

There are no input parameters for the gas turbine.

Fixed data in the gas turbine are:

- Combustion air: temperature 15 °C
  sea level ISO conditions: 1.0 1325 bar
  composition: Standard Air (see paragraph 4.5, page 4-4)

- Fuel: temperature 15 °C
  pressure: 1,2 x pressure ratio [bar]
  composition: depending on selected model:

  - Natural gas fuel (methane):

    Composition:

Component	Mole %
CH_4	100

    The lower heating value is 50006.33 kJ/kg

  - Fuel oil [medium] :

    Composition:

Element	Mass %
C	85.3
H	11.6
0	0.3
N	0.3
S	2.5

    The lower heating value is 40770 kJ/kg

Number of equations for system matrix

This apparatus type is composed of different other basic apparatus types. Net it adds one mass equation to the system matrix if a bottoming cycle has been connected (the flue gas mass flow will be calculated by the gas turbine model). Without bottoming cycle, there is no need to worry about the number of equations, because the gas turbine itself is a complete system.

Off-design calculations

Because the input of the gas turbine is fixed by the selected model and therefore there aren't any input parameters that can be changed, off-design calculations cannot be applied for this apparatus type.

Calculation rules

The next properties are available at the outlet of the gas turbine:

- Exhaust temperature and enthalpy
- Mass flow
- Flue gas composition

The outlet pressure will be set by the bottoming cycle, if applied. In case of pressure losses in the bottoming cycle, correction of the net electrical power and the exhaust temperature will not be applied.

Displaying calculation results in the diagram

As with other apparatus models, calculation results and input data can be displayed in the diagram by double-clicking on the apparatus. In addition, the next calculation results can be displayed:

- air properties
- fuel properties

- exhaust properties

Figure 2-11 shows where the user should click to display the additional properties listed above.

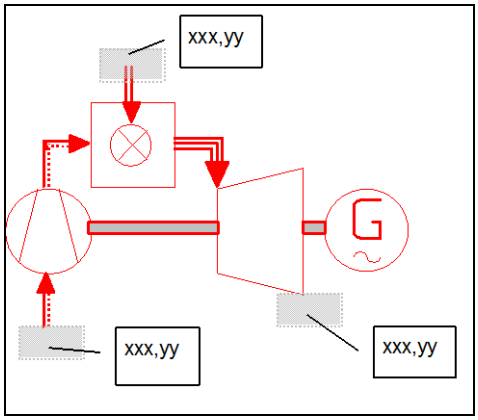


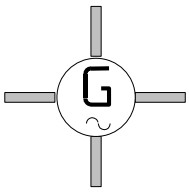
Figure 2-10:positions to click on for displaying additional calculation results

Generator

2.27 Type = G Generator

Minimum number of shafts = 1
Maximum number of shafts = 2

Shafts connection points



Applications

This apparatus type is meant to model a generator for the conversion of mechanical power into electric power. The generator must be connected to at least one turbine, or to a drive train containing at least one turbine.

Input parameters

ETAGEN	=	Generator efficiency (default = UNKNOWN). If ETAGEN is specified, COSPHI, GENMVA, KTURB, KGEN and CPRATI cannot be specified. See also Figure 2-9.
COSPHI	=	Cosine ϕ of the generator (default = UNKNOWN)
GENMVA	=	Generator capacity (MVA) (default = UNKNOWN)

KTURB = Turbine code (default = UNKNOWN):

– for single casing or tandem compound double flow turbines:

1 if 22 < GENMVA < 110 (MVA)

2 if 110 < GENMVA < 500 (MVA)

3 if GENMVA > 500 (MVA)

– for all other turbines:

4 if GENMVA < 500 (MVA)

5 if GENMVA > 500 (MVA)

KGEN = Generator code (default = UNKNOWN):

– for conventionally cooled generator:

1 for 3600 or 3000 RPM

2 for 1800 or 1500 RPM

– for conductor cooled generators:

3 for 3600 or 3000 RPM

4 for 1800 or 1500 RPM

CPRATI = Capacity-power ratio (default = UNKNOWN). Must be specified if the power to be supplied by the turbine is not specified and only in combination with COSPHI, GENMVA, KTURB and KGEN. See also Figure 2-9.

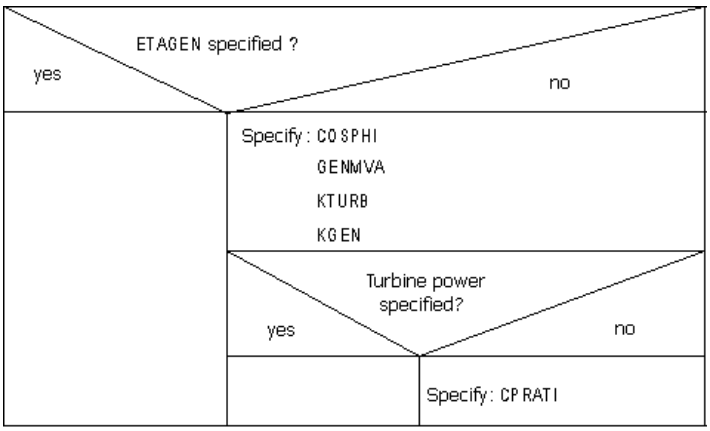


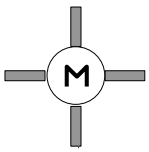
Figure 2-11: decision scheme input data generator

Electromotor

2.28 Type = M Electromotor

Minimum number of shafts = 1
Maximum number of shafts = 2

Shafts connection points



Applications

This apparatus type only has an illustrative purpose to indicate that a pump or compressor is driven by an electromotor.

Input parameters

This apparatus type doesn't have input parameters. The combined mechanical and electric efficiency of the motor can be specified for the pump or the compressor via parameter ETHAE.

Chapter 3

Connections

3.1 Pipes

Extra conditions

It is possible to prescribe the pressure, temperature, specific enthalpy or vapor quality in a pipe. In addition a mass flow can be specified. Then an estimate must be specified for a thermodynamic or typical apparatus variable, which is adapted during the calculation to meet the prescribed mass flow.
It is however recommended to prescribe mass flows which have to be prescribed using a valve, type 14.

Input parameters

PINL	=	pressure at the inlet of the pipe	(bar)
POUTL	=	pressure at the outlet of the pipe	(bar)
DELP	=	absolute pressure drop in a pipe, $p_i - p_o$	(bar)
DELPR[1)2)]	=	pressure drop in a pipe, $(p_i - p_o)/p_i$	(-)
DELGH[2)]	=	difference in height between inlet and outlet of a pipe (default = 0)	(m)
DELPF[2)]	=	pressure loss by flow resistance in a pipe (default = 0)	(bar)
HINL	=	enthalpy at the inlet of a pipe	(kJ/kg)
HOUTL	=	enthalpy at the outlet of a pipe	(kJ/kg)
DELH[3)]	=	enthalpy drop in a pipe, $h_i - h_o$	(kJ/kg)
TINL	=	temperature at the inlet of a pipe	(°C)
TOUTL	=	temperature at the outlet of a pipe	(°C)
XINL[4)]	=	vapor fraction at the inlet of a pipe	(-)

XOUTL[4)]	=	vapor fraction at the outlet of a pipe	(-)
MASFLO[5)]	=	prescribed mass flow	(kg/s)
APNO	=	apparatus number for which the estimate of a thermodynamic or an apparatus-typical variable is specified.	
VAR[6)]	=	the name of the variable used for the prescribed mass flow. This name must also be specified as input for the apparatus with number APNO.	

1) It is possible to create a barrier for the pressure calculation by specifying -8888.8 < DELPR < -999. Then it is not assumed that the outlet pressure can be calculated from the inlet pressure and vice versa.
2) See also the calculation rules mentioned below.
3) Not available for turbine outlet pipes with condensing section (TUCODE=5....,8.... or 9....), as the exhaust losses are stored here.
4) XINL and XOUTL is not possible for non-condensing medium types.
5) Specification of MASFLO is not permitted for pipes which are directly connected to a boiler.
6) Parameter RMASS may not be used for the VAR parameter! Parameter DELM of type 10 can only be used for VAR if DELM is specified in combination with parameter PIPE.

Calculation rules

DELP(R) is determined by the pressures at the inlet (p_{in}) and the outlet (p_{out}) of the pipe. If a pressure at the inlet or the outlet of the pipe is not known, it is calculated by DELP(R). The default value of DELP(R) is 0.

1. DELP and DELPR are specified: DELPR will be ignored

2. $p_{out} = p_{in}$ - DELP, or
   $P_{out} = p_{in}$ x (1 - DELPR)

3. $p_{in} = p_{out}$ + DELP, or
   $p_{in} = p_{out}/(1 - DELPR)$

4. -8888.8 < DELPR < -999 is specified:
   DELP $= p_{in} - p_{out}$
   DELPR $= (p_{in} - p_{out})/p_{in}$

5. DELGH and DELPF are specified: DELP(R) = f(DELGH, DELPF)

6. DELGH, DELPF and DELP(R) are specified:
   DELGH and DELPF will be ignored and warning 1.66 will be produced

7. DELGH and DELP(R) are specified:
   DELP(R) will be used in the calculation and DELGH will be ignored. The value of DELPF = f(DELP(R), DELGH) will be printed in the table “Losses in Pipes”.

8. DELPF and DELP(R) are specified:
   DELP(R) will be used in the calculation and DELPF will be ignored. The values of DELGH = f(DELP(R), DELPF) and the height difference $\Delta h = f(DELGH)$ will be printed in the table “Losses in Pipes”.

9. $h_{out} = h_{in} - DELH$

10. $h_{in} = h_{out} + DELH$

11. $x_{in} = x_{out}$

Off-design calculations

Pressure differences in pipes at off-design conditions can be calculated using design data.

The design data are produced by a design calculation and are stored in the file with design data for off-design calculations. At design, DELGH or DELPF must be specified. At off-design, specification of DELGH should remain, and specification of DELPF will be ignored (see calculation rules 2 and 3, respectively).
If DELP(R) is specified as an extra condition, this will be ignored and an error message is produced. The pressure difference in the pipe will not be adjusted according to the off-design model.

Input parameters for off-design calculations

DESMAS	=	mass flow in PIPE at design (kg/s) (default = UNKNOWN)
DESSV	=	average specific volume in PIPE at design (m3/kg) (default = UNKNOWN)
DESDPF	=	pressure loss by flow resistance in PIPE at design (bar) (default = UNKNOWN)

All above-mentioned parameters must be specified. Otherwise the data specified will be ignored and an error message will be produced (see calculation rule 4).

Calculation rules for off-design calculations

1. DELPF = f (DESMAS, DESSV, DESDPF)
   DELP = f (DELGH, DELPF)
2. DELGH is not specified as an extra condition: DELGH = 0 (default value)
3. DELPF is specified as an extra condition: DELPF will be ignored
4. DESMAS, DESSV, or DESDPF are not specified:
   Input for off-design calculations will be ignored; pressure difference in the pipe will not be adjusted for the off-design situation.

3.2 Shafts

Applications

Shafts are used to indicate that pumps, compressors and/or generators are driven by one or more turbines, or that pumps or compressors are driven by electromotors. A shaft must contain at least one power supplying device (turbine, electromotor).

Where the surplus power of the turbine-pump or turbine-compressor combination is specified, then an energy equation is automatically added to the system matrix to calculate an unknown mass flow. If the surplus power is not specified, then the data are only used in the efficiency calculation.

A shaft connected to an electromotor is only illustrative.

Input parameters

Only the following input parameter can be specified:

Surplus Power	=	surplus of energy from the turbines (MW) (default = UNKNOWN)

Remarks

- The efficiency of the transmission must be specified by specifying ETHAM for the turbines, pumps and compressors.
- Where the turbine does not only drive a pump or compressor but also a generator, the power of the generator must be specified (MW).

Chapter 4

Medium data

4.1 Specifying medium data

The medium data to be specified, are:

- medium type
- a number of additional data, depending on the medium data

The medium type indicates the medium library which will be used to calculate the thermodynamic properties.

Medium data are specified for pipes. This does not have to be done for each pipe as the program has a procedure which determines the medium type in the other pipes. For each cycle the medium type in at least one pipe should be specified.

For closed systems the medium type needs to be specified for just one (arbitrary) pipe. All other pipes automatically will have the same medium type.
For open systems the medium type should be specified for all incoming pipes (the pipes connected to all apparatuses of type 10 with only one connected pipe which is outgoing). The medium types of all other pipes will be determined by Cycle-Tempo.

With a sink/source, type 10, a switch to another medium type can be made. It is not a switch in composition, but a switch to another medium library. An example is shown in Figure 4-1, where for a water flow a switch is made from medium type WATERSTM to medium type GASMIX.

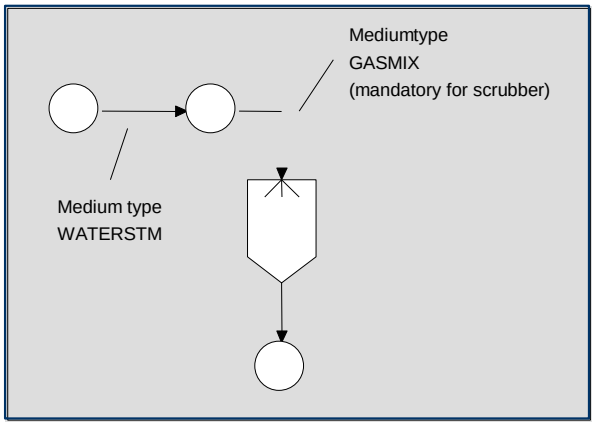


Figure 4-1: switching to another medium type

4.2 Available medium types

The following medium types are available:

- WATERSTM : water/steam
- POTASIUM[1] : potassium
- GASMIX : ideal gas mixtures
- FUEL : solid and liquid fuels
- NH3-H2O[1] : ammonia/water mixtures
- Refrigerants[1] : Single refrigerants and refrigerant mixtures
- Liquids[1] : Liquid secondary refrigerants

[1] Available at extra costs.

4.3 Medium type WATERSTM

Two sets of relations are available to the user:

1) Water and steam based on the Industrial Formulations 1997 (IF97) from the IAPWS[1].
   Validity range:
   For pressures between 0.00611657 and 1000 bars the temperature may vary between 0.01 and 800 °C

   For pressures between 0.00611657 and 100 bars the temperature may vary between 0.01 and 2000 °C

2) Water and steam based on the I.F.C.-equations (1967).
   Validity range:
   For pressures between 0.00611657 and 1000 bars the temperature may vary between 0.01 and 800 °C

At default the IF97 relations are used. For WATERSTM no additional data need to be specified.

4.4 Medium type POTASIUM[2]

Data for liquid and vapor potassium are extracted from the Sodium Nak Engineering Handbook. The validity range runs from 0 to 900°C and for several properties to 1300°C.

For POTASIUM no additional data need to be specified.

[1] Wagner, W. and A. Kruse, *The Industrial Standard IAPWS-IF97 for the Thermodynamic Properties and Supplementary Equations for Other Properties*, Springer-Verlag Berlin-Heidelberg-New York, 1998.

[2] Available at extra costs.

4.5 Medium type GASMIX

Ideal mixtures of real gases[1].

Validity range: 25 – 3000 °C

The enthalpy of a gas equals the enthalpy of formation at standard conditions (25°C and 1.013 bar (1 atm)). At 0 K the entropy is 0.

Available components (species) are:

Al_2O_3 *(s)*	Al_2O_3 *(l)*	Ar	BCl_3	BF_3	Br_2	C *(s)*
CCl_4	CO	COS	CO_2	CS_2	CH_4	C_2H_4
C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}	C_6H_{14}	Cl_2	F_2
Fe_2O_3 *(s)*	HCl	HCN	HF	H	H_2	H_2O
N_2O_3	H_2S	He	Ne	NH_3	NO	NO_2
NOCl	N_2	N_2O	O	O_2	OH	S
S *(s)*	S *(l)*	SF_6	SiF_4	SiH_4	SiO_2	SiO_2 *(s)*
SiO_2 *(l)*	SO_2	SO_3				

There are three pre-defined compositions of gas mixtures available:

1. Standard Air

Relative humidity 60% at: p = 1.01325 bar
T = 15 °C

Composition:	Component	Mole %
	N_2	77.29
	O_2	20.75
	H_2O	1.01
	Ar	0.92
	CO_2	0.03

2. Standard Natural Gas

[1] Gordon, S. and B.J. McBride, *Computer Program for Calculation of Complex Chemical Equilibrium Compositions*, Lewis Research Center, NASA SP-273, 1971.

Slochteren natural gas

Composition:	Component	Mole %
	CH_4	81.29
	C_2H_6	2.87
	C_3H_8	0.38
	C_4H_10	0.15
	C_5H_{12}	0.04
	C_6H_{14}	0.05
	N_2	14.32
	O_2	0.01
	CO_2	0.89

3. Standard Flue gas

Composition:	Component	Mole %
	N_2	70.49
	H_2O	19.19
	CO_2	9.50
	Ar	0.82

This composition is obtained when Standard Natural Gas is burnt stoichiometrically with Standard Air.

Remarks:

- If the sum of the mole percentages is greater than 100% a warning is produced. It is however allowed to proceed; Cycle-Tempo will automatically scale down the mole percentages.

- The parameter “Is estimation” indicates that the specified composition must be regarded as an initial estimate. It may sometimes be necessary to work with an estimate for the composition, for example, when a recycle flow is included in a cycle. The composition specified is then only used in the first main iteration. In further iterations the composition calculated from the previous iteration is used. If “Is estimation” is not activated (which is the default value), then the composition is regarded as fixed.

4.6 Medium type FUEL

Fuel (mostly coal or oil), according to an atomic composition and with a lower heating value, both to be specified by the user. Determination of the heat of formation of the fuel is based on the lower heating value. Only in combustors (apparatus type 13), gasifiers (apparatus type 23) and reactors (apparatus type 27) FUEL can be mixed with GASMIX on behalf of chemical reactions.

For the available components see medium type GASMIX.

There is one pre-defined composition of a solid fuel available:

1. Standard Coal

Composition:	Component	Mole %	Mass %
	C(S)	60.63	59.90
	H_2	25.46	5.34
	O_2	3.07	16.95
	N_2	0.50	1.15
	S	0.51	1.35
	Cl_2	0.05	0.30
	F_2	0.01	0.02
	SiO_2	3.03	15.00

The lower heating value is 24610 kJ/kg.
The calculated enthalpy for this coal at 25 °C and 1.013 bar is:
h = -3825.36 kJ/kg

Remarks:

- It is usual to give the atomic composition of coal in mass fractions. To limit the number of components in a calculation, a choice is made in the output of the program to give an indication in compounds (H_2, O_2, etc.), instead of in elements (H, O, etc.). This makes no difference for the mass fractions, but does for the molar fractions. The enthalpy of the coal is however not calculated from the constituent components, but using the net heating value specified, so that the result does not affect the calculated enthalpy.

- For the parameter “Is estimation” see medium type GASMIX.

- Gaseous fuel of which the composition in species is known, should be specified as GASMIX.

4.7 Refrigerants[1]

For refrigerants Cycle-Tempo contains two libraries:

- REFPROP
- DUPONT

4.7.1 REFPROP

This database (REFrigerant PROPerties) concerns Version 4.0 of the Standard Reference Database 23 of NIST (National Institute of Standards and Technology) from the U.S.A. The database contains 38 different refrigerants (see the table on the next page).

For all refrigerants, except for ammonia, a simple as well as a more complex thermodynamic model is available.

The simple model is the equation of state according to Carnahan-Starling-DeSantis (CSD). This equation represents the properties of refrigerants quite well between certain limits. The model can easily be extended to mixtures of refrigerants. However, the model is not suited to calculate properties over wide ranges of pressure and temperature.

There are two different thermodynamic models available, which are more complex and can predict the properties of refrigerants more accurately over wide ranges of pressure and temperature. The MBWR-model (Modified Bennedict-Webb-Rubin) for the calculation of thermodynamic properties is available for 11 refrigerants. These refrigerants are marked with an asterisk *) in the table shown below. For the remaining refrigerants the ECS-model (Extended Corresponding States) is available.

The properties of ammonia can be calculated with the high-accuracy equation of state developed by Haar en Gallagher (see: *J. Phys. Chem. Ref. Data* **7**, 635-792 (1978)).

The transport properties of refrigerants are always calculated with the ECS-model.

[1] Available at extra costs.

Table 4-1: pure refrigerants

		Critical point		
Nr.	**Type**	**p_c (bar)**	**T_c (°C)**	**v_c (m^3/kg)**
1	R11	44.7	198.1	179.81E-05
2	R12	41.8	111.8	179.47E-05
3	R13	38.7	28.9	173.27E-05
4	R13B1	40.2	67.1	134.31E-05
5	R14	38.0	-45.6	160.23E-05
6	R21	51.7	178.5	191.59E-05
7	R22	50.5	96.2	195.44E-05
8	R23	49.0	26.0	189.97E-05
9*)	R32	57.9	78.2	231.43E-05
10	R113	34.6	214.4	175.58E-05
11	R114	32.5	145.7	179.62E-05
12	R115	31.5	79.9	163.14E-05
13*)	R123	36.7	183.8	181.78E-05
14	R123a	37.4	188.0	183.87E-05
15*)	R124	36.4	122.5	178.65E-05
16*)	R125	36.3	66.2	174.84E-05
17	R134	45.6	119.0	185.24E-05
18*)	R134a	40.7	101.2	195.04E-05
19	R141b	41.2	204.2	185.57E-05
20	R142b	41.2	137.2	229.87E-05
21	R143	45.2	156.8	226.08E-05
22	R143a	38.1	73.1	230.37E-05
23	R152a	44.9	113.6	274.03E-05
24	R218	26.8	72.0	159.23E-05
25*)	R290 (propane)	42.5	96.7	498.90E-05
26	RC270 (cyclopropane)	55.8	125.2	461.03E-05
27	RC318	27.8	115.2	162.36E-05
28	R227ea	29.5	101.9	168.78E-05
29	R236ea	35.3	139.3	175.14E-05
30	R245cb	31.4	106.9	203.79E-05
31*)	R600 (n-butane)	38.0	152.0	438.72E-05
32*)	R600a (i-butane)	36.3	134.7	440.44E-05
33*)	n-C5 (n-pentane)	33.6	196.4	408.32E-05
34*)	i-C5 (i-pentane)	33.7	187.4	424.12E-05
35*)	CO2 (R744)	73.8	30.9	217.45E-05
36	E134	42.3	147.1	189.78E-05
37	E245	34.2	170.9	199.94E-05
38	NH3 (R717)	113.3	132.3	425.72E-05

Table 4-2: refrigerant mixtures

Mixture	Components	Composition (mass %)
R401A	R22/R152a/R124	53/13/34
R401B	R22/R152a/R124	61/11/28
R401C	R22/R152a/R124	33/15/52
R402A	R22/R290/R125	38/2/60
R402B	R22/R290/R125	60/2/38
R403A	R22/R218/R290	75/20/5
R403B	R22/R218/R290	56/39/5
R404A	R125/R134a/R143a	44/4/52
R405A	R22/R152a/R142b/RC318	45/7/5.5/42.5
R406A	R22/R142b/R600a	55/41/4
R407A	R32/R125/R134a	20/40/40
R407B	R32/R125/R134a	10/70/20
R407C	R32/R125/R134a	23/25/52
R407D	R32/R125/R134a	15/15/70
R408A	R22/R125/R143a	47/7/46
R409A	R22/R124/R142b	60/25/15
R409B	R22/R124/R142b	65/25/10
R410A	R32/R125	50/50
R410B	R32/R125	45/55
R412A	R22/R218/R142b	70/5/25
R413A	R218/R134a/R600a	9/88/3
AM DI36	R22/R124/R600	50/47/3
AM DI44	R22/R125/R143a/R290	50/42/6/2
Daikin	R32/R134a	30/70
EA FX40	R32/R125/R143a	10/45/45
EA FX220	R23/R32/R134a	4.5/21.5/74
Hoec HX4	R32/R125/R134a/R143a	10/33/21/36
HOTSHOT	R22/R124/R600a/R142b	50/39/1.5/9.5
NARM 22	R23/R22/R152a	5/80/15
NARM 502	R23/R22/R152a	5/90/5
OZ 12	R290/R600a	50/50
Isceon59	R125/R134a/R600a	46/50/4
Isceon89	R125/R290/R218	86/5/9
R500	R12/R152a	73.8/26.2
R501	R22/R12	75/25
R502	R22/R115	48.8/51.2
R503	R23/R13	40.1/59.9
R504	R32/R115	48.2/51.8
R507	R125/R143a	50/50
R509A	R22/R218	44/56

Besides the pure refrigerants listed in Table 4-1 a large number of commercially available refrigerant mixtures is available. Table 4-2 lists the mixtures presently available in Cycle-Tempo and their corresponding compositions. The thermodynamic properties are calculated with the CSD-model, and the transport properties with the ECS-model.

With regard to the validity range of the models the following can be said:

CSD-model

- $0.6 * T_c < T < T_c$ (T in K) for pressures up to the saturation pressure, thus not for compressed liquid.

- $T > T_c$ (T in K) for densities (ρ) below the critical value (the critical density ρ_c is the reciprocal value of the critical volume v_c, as mentioned in the third column of the table).

It is wise to avoid situations with $0.95 * T_c < T < 1.1 * T_c$ (T in K) for $0.5 * \rho_c < \rho < 2 * \rho_c$.

MBWR-model

Temperatures from triple point up to $1.2 * T_c$ (T in K) for pressures up to $2.2 * p_c$. Situations near the critical point should best be avoided.

ECS-model

$0.35 * T_c < T < 1.2 * T_c$ (T in K) for pressures up to $2.2 * p_c$. Situations near the critical point should best be avoided.

Input parameters

For medium type REFPROP the following input parameters can be specified:

1. Reference state for enthalpy and entropy.

   There are 3 possibilities:

   - Liquid at normal boiling point (1 atm) (default value)
   - Liquid at -40°C (ASHRAE-convention)
   - h = 200 kJ/kg and s = 1 kJ/kgK for saturated liquid at 0°C (IIR-convention)

2. Thermodynamic model to be used to calculate thermodynamic and transport properties.

   There are 3 possibilities:

   - CSD-equation of state
   - If possible MBWR-equation of state, otherwise ECS-model
   - Special equation of state for ammonia

4.7.2 DUPONT

Besides the REFPROP-database another database is available with 8 refrigerants, of which some are out-dated. The relations used for the calculation of thermodynamic and transport properties originate from Du Pont[1].
The database contains the following refrigerants:

TYPE	Validity range				Critical point	
	p_{min} (bar)	p_{max} (bar)	T_{min} (°C)	T_{max} (°C)	p_c (bar)	T_c (°C)
R502	0.033	40.0	-100.0	82.5	40.8	82.2
R22	0.02	49.0	-100.0	96.0	49.8	96.0
R114	0.015	37.0	-73.0	145.0	32.7	145.7
R113	0.115	30.3	-5.0	270.0	34.13	214.0
R13	0.107	31.7	-115.0	130.0	38.6	28.8
R12	0.03	23.0	-55.0	190.0	41.15	112.0
R11	0.121	39.3	-25.0	290.0	44.0	198.0
R23	0.145	47.27	-110.0	47.2	47.5	25.6

[1] Downing, R.C., *Refrigerant equations*, No. 2313, The Du Pont Company, undated.
Downing, R.C. and B.W. Knight, *Computer Program for Calculating Properties of the "Freon" Refrigerants*, The Du Pont Company, 1971.

4.8 Medium type NH3-H2O[1]

Mixtures of ammonia and water according to Ziegler and Trepp[2].

Validity range:

pressure	0.1 – 50 bar
temperature	-40 – 230 °C

For the pipes for which medium type NH3-H2O is specified, the ammonia mass fraction must be specified also.

The parameter “Is estimation” indicates that the specified composition must be regarded as an initial estimate. It may sometimes be necessary to work with an estimate for the composition, for example, when a recycle flow is included in a cycle. The composition specified is then only used in the first main iteration. In further iterations the composition calculated from the previous iteration is used. If “Is estimation” is not activated (which is the default value), then the composition is regarded as fixed.

4.9 Medium type LIQUIDS[1]

This medium type is meant for liquids, for which only simple relations (polynomials in the temperature) for the density and specific heat are available.

A number of liquids have been implemented in the program. At the moment 13 secondary refrigerants have been implemented: glycols and salt solutions. These are listed in the table below, together with their application range. The concentrations mentioned in the table apply to the first-mentioned component, i.e. ***not*** to the water.

[1] Available at extra costs.

[2] Ziegler, B. and Ch. Trepp, Equations of State for Ammonia-Water Mixtures, *Revue Internationale du Froid*, Vol. 7, Nr. 2, 1984.

Secondary refrigerant	C_{min}	C_{max}	T_{max}
	(% refr.)	(% refr.)	(°C)
Ethylene glycol / Water	0	56.1	40
Propylene glycol / Water	15	57	40
Ethyl alcohol / Water	11	60.1	20
Methyl alcohol / Water	7.8	47.4	20
Glycerol / Water	19.5	63	40
Ammonia / Water	7.8	23.6	20
Potassium carbonate / Water	0	39	30
Calcium chloride / Water	9	29.4	30
Magnesium chloride / Water	0	20.5	30
Sodium chloride / Water	0	23	30
Potassium acetate / Water	11	41	30
Pekasol 50 / Water	43	100	60
Freezium / Water	19	50	40

The data for the refrigerants all come from an IIR publication[1], except for Pekasol 50 and Freezium, of which the data are supplied by the manufacturers (pro KÜHLSOLE GmbH from Germany, and Kemira from Finland, respectively). The method which is used to transform these data into thermodynamic functions to calculate state properties (enthalpy and entropy values), has been described elsewhere[2].

The user has to make sure that all occurring conditions of the liquids apply to the liquid state, as the thermodynamic relations are only meant for the liquid state within the application range as mentioned in the table. Other states than the liquid state will not be

[1] Melinder, A., *Thermodynamic Properties of Liquid Secondary Refrigerants*, IIF/IIR, Paris, 1997.

[2] Verschoor, M.J.E. and R.J.M. van Gerwen, Modeling Refrigeration and Heat Pump Systems with Software for Power Cycles, *Proc. Sydney Conf.*, IIF/IIR, 1999.

recognized. If for a given concentration the temperature appears to be below the freezing point, an error message will indicate that.

Chapter 5

System data

5.1 Production functions

A production function is a user defined energy equation, of which the right-hand side represents the amount of energy which is exchanged with the environment. For a turbine, this will be the generated power; for a heat exchanger the energy loss as a result of imperfect isolation. This namelist is specified for apparatuses for which the energy equation is used for the mass flow calculation.

It is not permitted to specify a production function for apparatuses for which automatically an energy equation is added to the system matrix. These apparatuses can be found in Table 2-1, where in the column “system equations” the letter E is specified.

The amount of energy exchange with the environment can be specified for an apparatus or group of apparatuses (e.g. HP turbine, MP turbine and LP turbine which drive a generator). An energy flow from the system to the environment must have a *positive* sign; an energy flow from the environment to the system must have a *negative* sign.

Input parameters

Apparatus	=	number of the apparatus, or the numbers of a group of apparatuses, separated by commas.
Power	=	amount of electricity or heat generated by the apparatus(es) (MW) (default = 0)

A user defined energy equation must be prescribed for each apparatus type = 12, alone or in combination with other apparatus types.

An energy equation to be defined by the user (a production function), should not be specified for apparatuses for which the energy equation is already added automatically to the system matrix (types 5, 7, 11, 15 always, types 4, 13 and above 15 if EEQCOD = 1), nor for apparatuses for which the energy equation is used to calculate an enthalpy (= temperature) (types 6, 9, 14 always and types 1, 2, 4, 10, 13 and above 15 if DELE is specified or if EEQCOD = 2). Summarized: do not specify a production function for apparatus type

- 5, 6, 7, 9, 11, 14, 15;
- 4, 13, >15 if EEQCOD = 1;
- 1, 2, 4, 10, 13, >15 if DELE is specified or if EEQCOD = 2.

However, it is allowed to include these apparatuses in production functions for apparatuses not mentioned.

Sources and sinks with only one connected pipe should not be included in a production function. The program will issue an error warning.

In order to prevent convergence problems in the main iteration, it is recommended that no production functions be written with the specific enthalpy as coefficients which are calculated from other energy equations. For apparatus types 6, 9, and 13 a specific enthalpy is calculated from an energy equation. For apparatus types 1, 2 and 10 an energy balance is used to calculate specific enthalpy when the energy exchange with the environment (DELE) is specified. For the apparatus types 4, 13, 22, 23, 25 and 28 the energy balance is used to calculate a specific enthalpy if EEQCOD = 2. By taking a combination of apparatuses the problems mentioned can be prevented.

5.2 Definition of environment

The definition of the environment (pressure, temperature and chemical composition) is used to calculate exergy values. The pressure and temperature of the environment are used to calculate heating values.

Summary of input options

The following input parameters are needed for exergy calculations. The pressure and temperature are enough for calculating the heating values.

Pressure	=	pressure of the environment (bar) (default = UNKNOWN)
Temperature	=	temperature of the environment (°C) (default = UNKNOWN)
Composition	=	list with components and their concentrations (mole %)

For exergy calculations + calculation of heating values:

- Define a complete environment: pressure, temperature and composition
- Heating value at standard conditions: choose “Conditions: 1 atm, 25°C”
- Heating value at environment conditions: choose “Environment conditions”

Remark

An exergy calculation can be de-activated temporarily by activating the option “No exergy calculation”. In that case the definition of the environment is still there.

Just calculation of heating values:

- Heating value at standard conditions: choose “Conditions: 1 atm, 25°C”. This is the default value.
- Heating value at environment conditions: choose “Environment conditions”, and specify the required values for pressure and temperature.

Pre-defined definitions of environment

The following pre-defined definitions of environment are available:

1. ***Definition of the environment as proposed by Baehr[1]***

Pressure	= 1.01325 bar	
Temperature	= 25 °C	
Composition:	Component	Mole %
	Ar	0.9
	CO_2	0.03
	H_2O	3.12
	N_2	75.65
	O_2	20.30

2. ***Like 1, but at 15°C***

Pressure	= 1.01325 bar	
Temperature	= 15 °C	
Composition:	Component	Mole %
	Ar	0.91
	CO_2	0.03
	H_2O	1.68
	N_2	76.78
	O_2	20.60

Exergy calculation

It is possible to calculate the exergy by determination of the amount of work that is needed or generated when a fluid comes into equilibrium with the environment. This calculation can be carried out for the following types of media:

- WATERSTM
- GASMIX
- FUEL

For other media only the thermo-mechanical exergy will be calculated.

1 Baehr, H.D., Thermodynamik, Springer Verlag Berlin, 4th edition (1978)

In order to perform exergy calculations the environment must be defined. Such a definition is complete if pressure, temperature and chemical composition are known. The environment must be in equilibrium with itself. This means that liquid water must be in equilibrium with water vapor: the gaseous environment is saturated with water vapor. Furthermore should each component of the defined environment fix just one element.

If a definition of the environment is specified, the exergy calculation is carried out. The calculated exergy of all process streams (kJ/kg) are presented in the table “Data for all pipes”. The exergy flows (kW) in the pipes, split-up into chemical and thermo-mechanical exergy, are given in a separate table.
Exergy losses and exergy efficiencies of all apparatuses in the system are calculated and presented in a separate table.

Calculation of heating values

The ambient pressure and temperature specified can be used to calculate the heating value at other pressure and temperature than the standard of 25°C and 1 atm. The user can indicate this by choosing “Environment conditions” under “Calculation heating values”. By choosing “No exergy calculation” the definition of the environment is only used to calculate heating values.

For all pipes with medium type GASMIX the lower heating value (LHV) and higher heating value (HHV) are determined. These values (kJ/mole) are given in the table with the gas compositions. In a separate table these values are given in MJ/kg. In case the gas contains water vapor, the heating values are also given per kg dry gas.
For pipes with medium type FUEL the LHV must be given by means of “Lower heating value”. The HHV will be calculated. Both values are given in the table.
The LHV is used to calculate the energy content of incoming fuel flows (at sources, apparatus type 10) on behalf of the calculation of the system efficiency. If at this source LHV is given also, Cycle-Tempo will use this value in stead of the calculated value.

5.3 Additional power consumers

Applications

Power consumers not modeled can be specified with their electricity consumption, on behalf of the calculation of system efficiencies.

Input parameters

System name = Name of the system or the apparatus which consumes electric power. This name may not be longer than 16 characters.

Power = The electric power which the system or apparatus consumes (kW) (default = 0).

Chapter 6

Calculation settings

6.1 General calculation settings

Calculation settings concern the control of the calculation process.

The following parameters are available:

General parameters:

Off-design factor	=	The off-design factor is only used in off-design calculations for initial estimates during the first iteration. The off-design factor should be regarded as the ratio between the mass flows during off-design and design (default = 100%)
Net frequency	=	frequency of the electricity grid (Hz) (default = 50 Hz)

Parameters for iteration procedure

Relative accuracy	=	relative accuracy required for convergence (default = 0.0001) It is recommended that EPS $\leq 2.0 \cdot 10^{-3}$ be chosen as the program uses the value EPS as a break-off criterion for the internal iteration loops.
Minimum number of main iterations	=	minimum number of main iterations (default = 0)

This option is useful when parameters are calculated for the first time after a number of main iterations, e.g. calculations of pressures or temperatures at off-design or calculations within user subroutines.

Maximum number of main iterations	=	maximum number of main iterations (default = 25)
Number of extra main iterations	=	number of extra main iterations (default = 0) This option is meant to perform a number of main iterations after convergence has been reached. This is useful for parameters for which a convergence criterion does not exist, e.g. calculations of pressures or temperatures at off-design.
Number of iterations with under relaxation	=	number of main iterations with mass stream under-relaxation (default = maximum number of main iterations) Normally (after the first two main iteration steps) as a new estimate for a mass flow the average is taken of the last and last but one mass flow calculated. The under-relaxation obtained from this has a stabilizing effect where the iterations are alternated. In situations where convergence is guaranteed, the calculation time can be reduced by limiting the number of iterations for which under-relaxation is applied (e.g. when it is known that the solution is being approached from one side). It is recommended that a value only be specified when the calculation process can be properly looked through.

6.2 Control of output extent

The following parameters are available to control the extent of "Text output":

- General output control parameter
- Output control parameter for testing purposes

General output control parameter

The following options are available to control the output:

1. Maximum output.
2. Idem, without matrices being printed.
3. Reduced output (suitable for reports).
4. Short output (default).

Output control parameter for testing purposes

With this code additional output can be obtained, which may be important in the analysis of the calculation process for new cases which are not yet running properly. In addition to the normal output described above intermediate results are also given. For this code the following options may be selected:

1. No additional output (default).
2. After each main iteration for all the apparatus the state of the calculation is indicated in the form of a code (see paragraph 7.3) and the calculated values are given for the flows in the pipes.
3. The same data as for 2 after each time all the apparatus subroutines have been called once. Apparatus subroutines are in fact called several times per main iteration.
4. The same data as for 2 after each time an apparatus subroutine has been called.

N.B. Values 3 and 4 should, where at all possible, not be used as this will result in a great deal of output. In that case it can be recommended to limit the number of main iterations to 1 or 2.

6.3 Parameter optimization

Cycle-Tempo offers the possibility to optimize input parameters specified by the user for one or more apparatuses in the system.

To activate the optimization procedure, the apparatus number(s), the name(s) of the input parameter(s) to be optimized, and the starting value(s) for the input parameter(s) should be specified. At default the system efficiency will be optimized, but the user can define another function to be optimized.

Up to 10 input parameters can be optimized at the same time.

Input parameters

App. no.	=	apparatus number indicating to which apparatus the input parameter to be optimized belongs (MANDATORY)
Input parameter	=	name of the input parameter to be optimized. Only names available in the input parameter list are valid (MANDATORY)
Starting value	=	starting value for the input parameter to be optimized (MANDATORY)
Use user defined optimization function	=	indicates that the objective function of which the optimum has to be found, is defined by the user in subroutine FUNCOP. See part “User Subroutines” of the manual.
Rounding precision	=	number of decimals to which the calculated objective function has to be rounded-off (default = 14)

Chapter 7

Text output

7.1 Introduction

The “Text output” of Cycle-Tempo can be divided into three groups:

1. Output directly related to the input.
2. Output to monitor the iteration process for the compositions and mass flows.
3. Output of the calculated results.

This output can be controlled by two parameters described in paragraph 6.2.

7.2 Output directly related to the input

The following components are printed out:

a. A summary relating to the size of the problem, such as number of apparatuses, number of pipes, number of cycles etc.
In addition the necessary computer storage, necessary for storing all the important data, is calculated and printed out. The size calculated is compared with the size indicated. Where necessary a bigger storage must be specified (see part “User Subroutines” of the manual).

b. Thermodynamic and typical apparatus data are classified. The pipe input is checked for permitted connections to apparatuses and the prevention of double pipe numbers. In addition a table is printed out with the pipe number specified, the external numbers of the apparatuses at the pipe's inlet and outlet, the pipe code, the number of the cycle of which the pipe is part, and finally the internal pipe number

allocated (pipe identification number), which is used in the program. Finally a summary of the input data of the pipes.

c. A summary of the medium compositions input, if the medium type is GASMIX or FUEL.

d. A matrix with all the available mass and energy balances. This matrix wilt count more equations than the number of pipes as one or more further mass balances must be eliminated to obtain an independent system of equations.

e. For off-design calculations a summary is given of the design data specified for the surface heat exchangers and turbines.

f. Classified summary of data on generators, turbine driven pumps/compressors and production functions.

g. A summary of how the number of system equations is built up.

The influence of the general output control parameter on the above components is:

1. Maximum output : a-g
2. Idem, without matrices being printed : a-c, e, g
3. Reduced output : a, c, e, g
4. Short output : idem

7.3 Output showing the course of the iteration process

To calculate the gas compositions and media types in the pipes the procedure described in part “Technical notes” is carried out. If all the medium types and gas compositions have been calculated, all the calculated gas compositions are printed out if the output control parameter for testing purposes (see paragraph 6.2) has the right value.
In addition the number of lines which do *not* meet the break-off criterion for the composition of the main iteration is printed out. Also the maximum absolute change in the concentration with regard to the previous main iteration is printed out indicating the relevant pipe number.

For calling an apparatus subroutine the apparatus number is printed out together with a code which indicates the state of the calculation for that specific apparatus.
For this code the following convention applies:

Code	=	9	initial call of the apparatus subroutine.
	=	8	the apparatus subroutine has been called previously, but has not yet calculated all the inlet and outlet pressures.
	=	7	all inlet and outlet pressures of the apparatus have been calculated.
	=	6	all thermodynamic variables from the outlet pipe have been calculated.
	=	0	all thermodynamic variables to the inlet and outlet pipes have been calculated.

For the apparatus with two media (for example: type 5, 6 and 12) the code consists of two digits. The first digit refers to the secondary flow, the second digit to the primary flow. If the total of all the codes is equal to zero, then all the thermodynamic variables are known and the coefficients of the system matrix can be substituted. In the first main iteration the system of equations obtained is printed out just before it is solved and the mass flows are calculated. The complete output of the thermodynamic variables and mass flows for all the pipes can be obtained by giving the output control parameter for testing purposes (see paragraph 6.2) the right value.

Furthermore the number of lines which do *not* meet the break-off criterion of the main iteration is printed out. In addition the maximum mass flow change, absolute and relative, with respect to the previous main iteration is printed out indicating the relevant pipe number. This information indicates whether the calculation process converges and if so, how quickly the process converges (in the following iteration steps).

7.4 Output of the calculated results

If the break-off criterion for both the compositions and the mass flows is met, the calculated results are printed out. The output consists of the following parts:

a. At the very first iteration (iteration 0) a summary is given of the content of the system matrix, including the vector with the right-hand sides of the relevant mass and energy equations.
b. A summary of the main iteration process.
c. As a, for the last iteration.
d. A standard calculation of the efficiency of the system in question.
e. A table with the energy exchange with the environment per apparatus and in addition for apparatus with separate flows the heat transferred in the apparatus.
f. Should the system contain medium type GASMIX or FUEL, a table with the calculated compositions per pipe, together with lower and higher heating values (LHV and HHV), and the relative and absolute humidity of the flow in the pipe.
g. A table with for each pipe: medium type, mass flow, molar flow, volumetric flow, pressure, temperature, enthalpy, entropy, exergy (if applicable), vapor quality and mass fraction (if applicable).
h. A table with for each pipe: pressure drop, temperature drop, enthalpy difference, entropy difference and exergy difference (if applicable). Only for pipes where changes in pressure and/or temperature occur.
i. When an exergy calculation is performed: a table with exergy flows (kW), split up into thermo-mechanical and chemical exergy. The energy flows are printed also.
j. When an exergy calculation is performed: a table with an exergy balance, exergy losses and exergy efficiencies of the apparatuses.
k. A summary of the input data of the apparatuses including any calculated apparatus data.
l. An output of the isentropic efficiencies of turbines, pumps and compressors, calculated data for fuel cells and the temperature differences for surface heat exchangers (type = 4, 5, 6, 12, 21, 22 and 23).
m. For design calculations an output of all the relevant data for turbines and surface heat exchangers for an off-design calculation.

The influence of the general output control parameter on the items mentioned above is:

1. Maximum output : a-m
2. Idem, without matrices being printed : b-m
3. Reduced output : b, d-m
4. Short output . : b, d-j, l-m

The tables from “Text output” correspond with the separate tables available within the user interface, as described in the next chapter.

Chapter 8

Tables

8.1 Introduction

The summary below indicates which tables are automatically generated and under which conditions.

Table 8-1: automatically generated tables

Table name	Generated under following conditions
System efficiencies	Energy input, energy output, energy consumption > 0
Energy balance	Always
Compositions of fluids	Number of pipes with medium types GASMIX or FUEL > 0
Heating values	Number of pipes with medium types GASMIX or FUEL > 0
Data for all pipes	Always
Losses in pipes	Number of pipes with losses > 0
Energy and exergy flows	Definition of environment specified
Exergy values in the system	Definition of environment specified
Rotating equipment	Number of turbines (type 3), pumps (type 8) or compressors (type 29) > 0
Motors and generators	Number of generators or electricity driven pumps or compressors > 0
Heat exchanging equipment	Number of condensers (type 4), feed water heaters (type 5), heat exchangers (type 6,12) or moisture separators (type 22) > 0

In the following paragraphs an example is given of each table. The data presented in the table, and the conditions under which the table is generated, are explained. The figures correspond to the simple STAG-unit shown in Figure 8-1.

A simple STAG unit

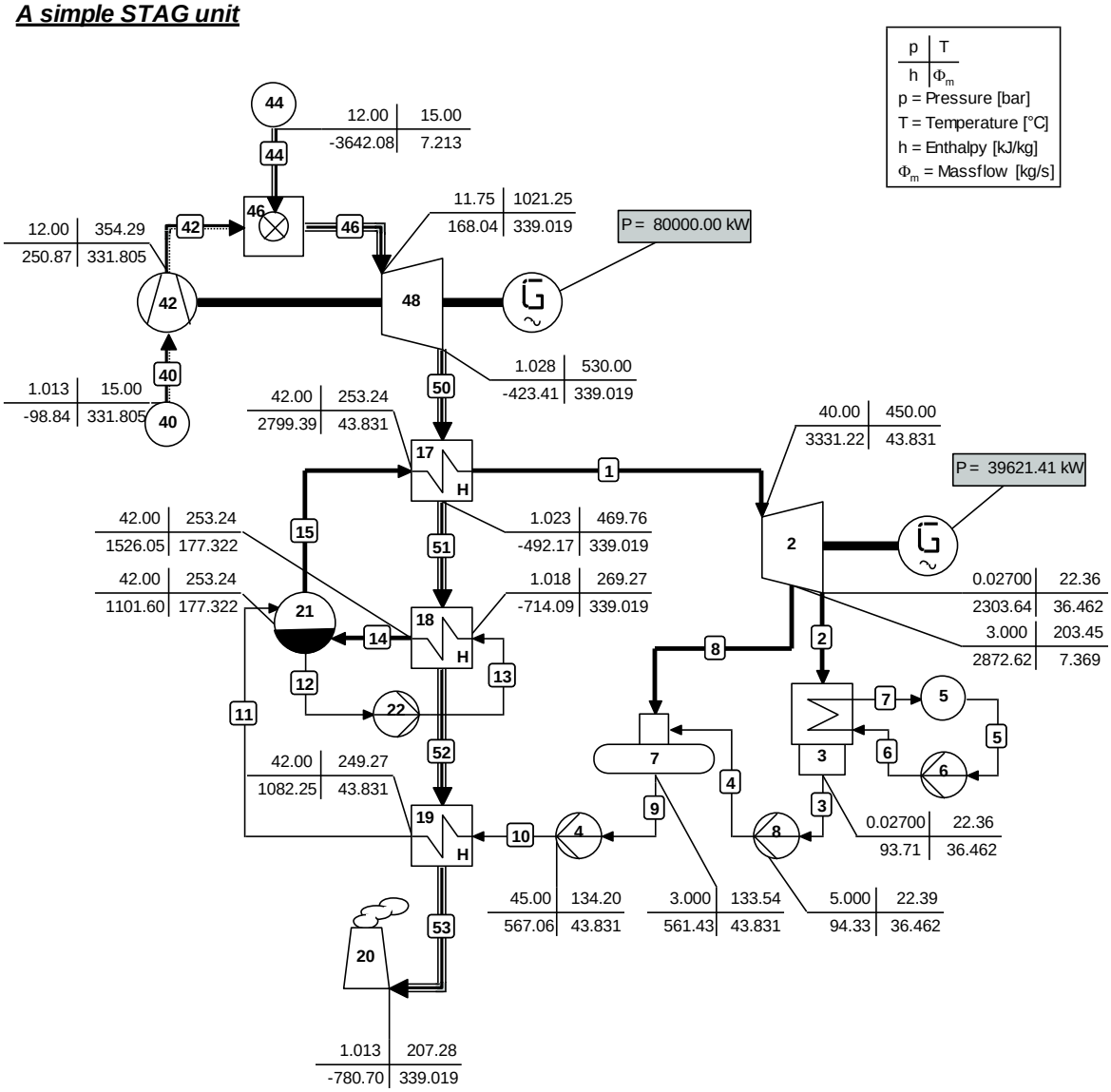


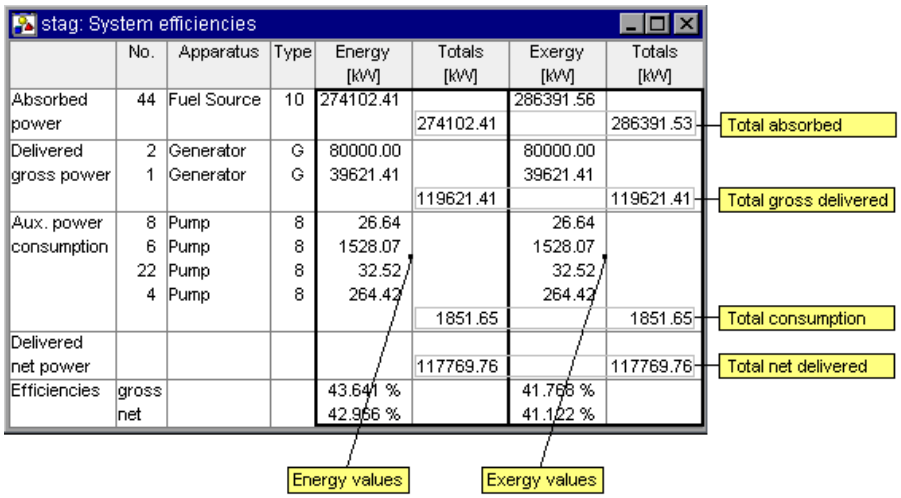
Figure 8-1: scheme of a simple STAG-unit

8.2 System efficiencies

The table “System efficiencies” contains gross and net energy and exergy efficiencies, and energy and exergy figures regarding:

- input energy
- energy consumption
- power production
- heat production

The table is generated if one of these items is present.



Exergy figures

The table contains exergy figures if an exergy analysis is performed, i.e. if a definition of the environment is given and the option “No exergy calculation” is not activated.

Absorbed power

The table contains the part “Absorbed power” if the system contains one or more boilers (type = 1), reheaters (type = 2) or fuel sources (type = 10 with 1 out-going pipe containing GASMIX or FUEL with a calculated or specified LHV > 0).
The exergy of the fuel includes the thermo-mechanical exergy. The energy of the fuel (heating value) includes the thermo-mechanical energy.

Delivered power

The table contains the part “Delivered gross power” and “Delivered net power” if the system generates electricity (generators or fuel cells) or mechanical power (turbines not connected to a generator).

Auxiliary power consumption

The table contains the part “Auxiliary power consumption” if the system contains electricity driven pumps or compressors, or if additional electricity consumption is specified by the user (via General Data | Auxiliary Power Consumption).

Delivered heat

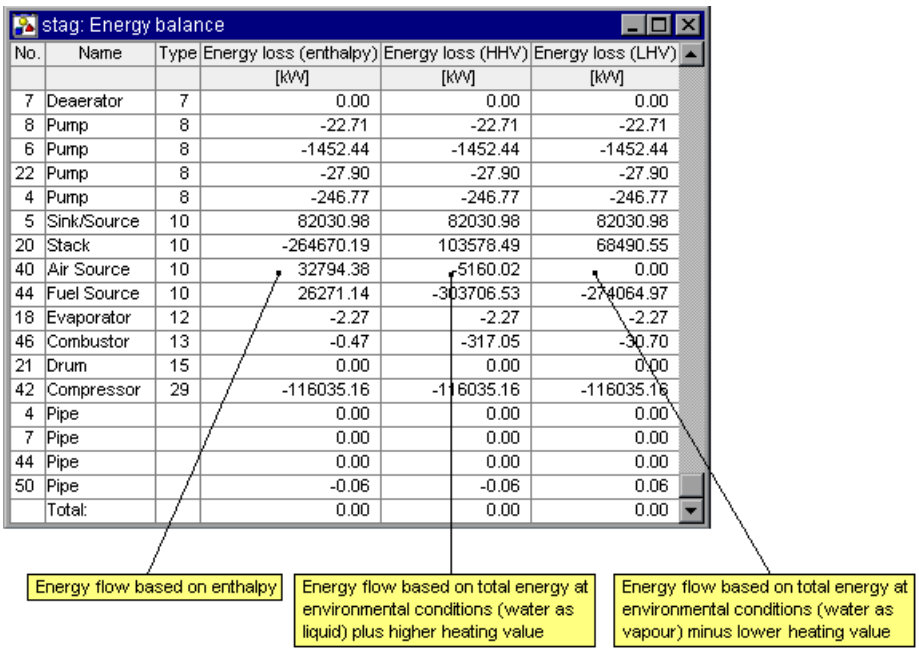
If the system contains a “Heat Sink” the item “Delivered Heat” is presented in the table. In addition, a heat efficiency and a total efficiency are presented also.

Efficiencies

Gross and net efficiencies are presented if absorbed power and delivered power (or delivered heat) can both be determined.

8.3 Energy balance

In the energy balance the amount of energy exchanged with the environment is presented for all apparatuses. Pipes in which the medium undergoes changes in pressure and/or temperature are included also.
The energy balance is always generated after a successful run.



No.	Name	Type	Energy loss (enthalpy)	Energy loss (HHV)	Energy loss (LHV)
			[kW]	[kW]	[kW]
7	Deaerator	7	0.00	0.00	0.00
8	Pump	8	-22.71	-22.71	-22.71
6	Pump	8	-1452.44	-1452.44	-1452.44
22	Pump	8	-27.90	-27.90	-27.90
4	Pump	8	-246.77	-246.77	-246.77
5	Sink/Source	10	82030.98	82030.98	82030.98
20	Stack	10	-264670.19	103578.49	68490.55
40	Air Source	10	32794.38	-5160.02	0.00
44	Fuel Source	10	26271.14	-303706.53	-274064.97
18	Evaporator	12	-2.27	-2.27	-2.27
46	Combustor	13	-0.47	-317.05	-30.70
21	Drum	15	0.00	0.00	0.00
42	Compressor	29	-116035.16	-116035.16	-116035.16
4	Pipe		0.00	0.00	0.00
7	Pipe		0.00	0.00	0.00
44	Pipe		0.00	0.00	0.00
50	Pipe		-0.06	-0.06	0.06
	Total:		0.00	0.00	0.00

A value greater than 0 represents an energy flow from the system to the environment, a value less than 0 an energy flow from the environment to the system.

The energy exchange is based on process flows. This means that mechanical and electric losses are not included.

Besides an energy balance based on enthalpy an energy balance based on total energy is presented.

The total energy equals the thermo-mechanical energy augmented with the chemical energy. The thermo-mechanical energy is the energy which is released when the fluid expands and cools down to ambient pressure and temperature, respectively. Two definitions are possible. In the first definition water (in medium types WATERSTM, GASMIX and FUEL) condenses totally. In the second definition water evaporates totally:

Definition 1:	GASMIX:	$H - H_{amb.,H2O(l)} + HHV$
	WATERSTM:	$H - H_{amb.,H2O(l)}$
	FUEL:	$H - H_{amb.,H2O(l)} + HHV$
Definition 2:	GASMIX:	$H - H_{amb.,H2O(g)} + LHV$
	WATERSTM:	$H - H_{amb.,H2O(g)}$
	FUEL:	$H - H_{amb.,H2O(g)} + LHV$

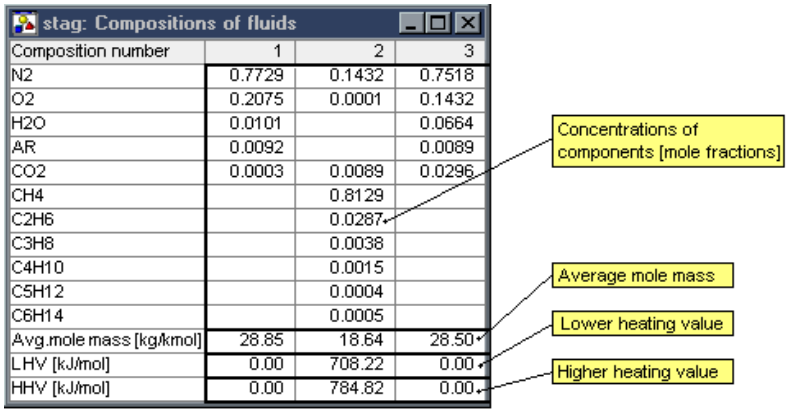
With medium type FUEL the evaporation heat of the water in the fuel is embedded in the heating value.

The columns in the table are explained as follows:

- Column “Energy loss (enthalpy)” : energy balance based on enthalpy
- Column “Energy loss (HHV)” : energy balance based on total energy according to definition 1
- Column “Energy loss (LHV)” : energy balance based on total energy according to definition 2

8.4 Composition of fluids

In the first column of the table “Composition of fluids” all the components present in the system are listed. The next columns contain all different compositions for medium types GASMIX or FUEL the program has found. The table will only be generated if GASMIX or FUEL is present in the system.



Composition number	1	2	3
N2	0.7729	0.1432	0.7518
O2	0.2075	0.0001	0.1432
H2O	0.0101		0.0664
AR	0.0092		0.0089
CO2	0.0003	0.0089	0.0296
CH4		0.8129	
C2H6		0.0287	
C3H8		0.0038	
C4H10		0.0015	
C5H12		0.0004	
C6H14		0.0005	
Avg.mole mass [kg/kmol]	28.85	18.64	28.50
LHV [kJ/mol]	0.00	708.22	0.00
HHV [kJ/mol]	0.00	784.82	0.00

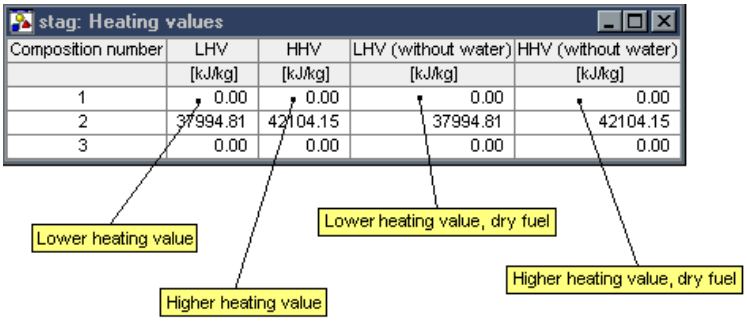
The numbers in column “Medium” of table “Data for all pipes” (see paragraph 8.6) refer to the composition number mentioned in table “Compositions of fluids”.
For example: “GASMIX 3” in table “Data for all pipes” refers to composition number 3 in table “Compositions of fluids”.
The compositions are given as mole fractions. If a mole fraction appears to be 0.0000 in the table, then this means that the component is present, but with a mole fraction less than 0.00005.
The last three rows in the table contain the average mole mass, the lower heating value and the higher heating value respectively. The heating values are also presented in table “Heating values”, but there in kJ/kg (see paragraph 8.5).

Note:
In addition to these values the corresponding table in the output file (via View | Text output) shows the relative and absolute humidity of *each* gas flow. The absolute humidity is expressed in grams of water per kg DRY gas. For gas mixtures of 100% water the *absolute* humidity is not defined. In the table this is denoted by a number of asterisks. For a gas mixture with a temperature above the critical temperature of water the *relative* humidity is not defined. This is also denoted by a number of asterisks.

8.5 Heating values

Table “Heating values” contains the lower and higher heating values of media in the system. The first column refers to the composition numbers mentioned in table “Composition of fluids” (see paragraph 8.4).

The table will only be generated if GASMIX or FUEL is present in the system.



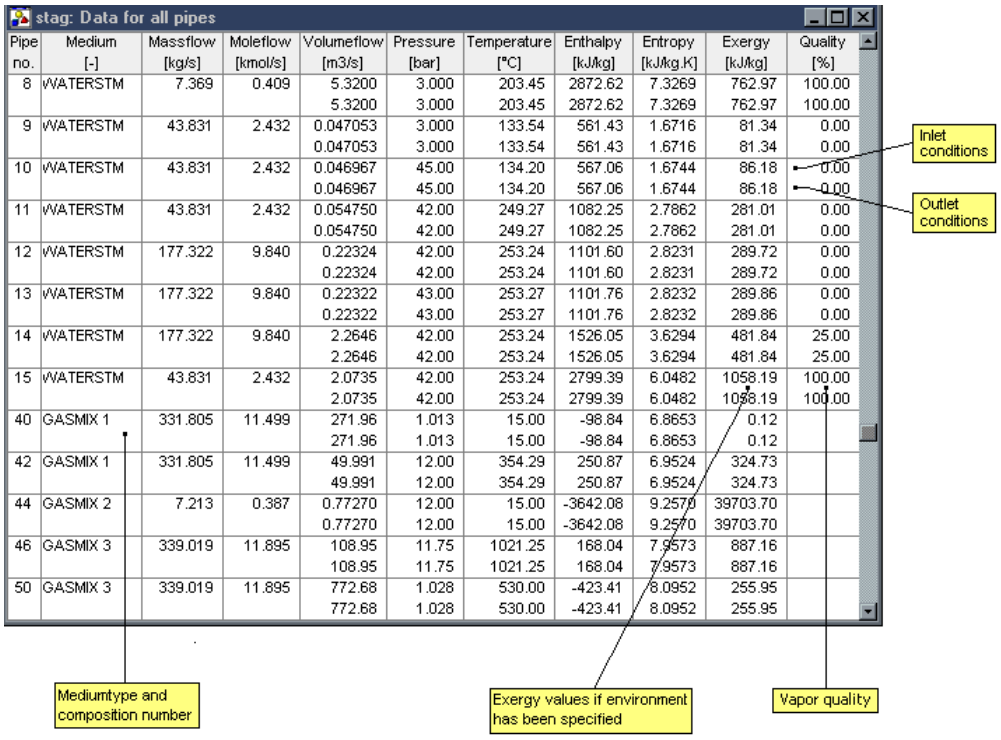
In the other columns the following figures are given:

- LHV : lower heating value (kJ/kg)
- HHV : higher heating value (kJ/kg)
- LHV (without water) : lower heating value of dry fuel (kJ/kg)
- HHV (without water) : higher heating value of dry fuel (kJ/kg)

The figures for LHV and HHV are also given in table “Composition of fluids”, but there in kJ/mole (see paragraph 8.4).

8.6 Data for all pipes

Table “Data for all pipes” contains the thermodynamic data for the process streams in the system. The table is always generated after a successful run.



Pipe no.	Medium [-]	Massflow [kg/s]	Moleflow [kmol/s]	Volumeflow [m3/s]	Pressure [bar]	Temperature [°C]	Enthalpy [kJ/kg]	Entropy [kJ/kg.K]	Exergy [kJ/kg]	Quality [%]
8	WATERSTM	7.369	0.409	5.3200	3.000	203.45	2872.62	7.3269	762.97	100.00
				5.3200	3.000	203.45	2872.62	7.3269	762.97	100.00
9	WATERSTM	43.831	2.432	0.047053	3.000	133.54	561.43	1.6716	81.34	0.00
				0.047053	3.000	133.54	561.43	1.6716	81.34	0.00
10	WATERSTM	43.831	2.432	0.046967	45.00	134.20	567.06	1.6744	86.18	0.00
				0.046967	45.00	134.20	567.06	1.6744	86.18	0.00
11	WATERSTM	43.831	2.432	0.054750	42.00	249.27	1082.25	2.7862	281.01	0.00
				0.054750	42.00	249.27	1082.25	2.7862	281.01	0.00
12	WATERSTM	177.322	9.840	0.22324	42.00	253.24	1101.60	2.8231	289.72	0.00
				0.22324	42.00	253.24	1101.60	2.8231	289.72	0.00
13	WATERSTM	177.322	9.840	0.22322	43.00	253.27	1101.76	2.8232	289.86	0.00
				0.22322	43.00	253.27	1101.76	2.8232	289.86	0.00
14	WATERSTM	177.322	9.840	2.2646	42.00	253.24	1526.05	3.6294	481.84	25.00
				2.2646	42.00	253.24	1526.05	3.6294	481.84	25.00
15	WATERSTM	43.831	2.432	2.0735	42.00	253.24	2799.39	6.0482	1058.19	100.00
				2.0735	42.00	253.24	2799.39	6.0482	1058.19	100.00
40	GASMIX 1	331.805	11.499	271.96	1.013	15.00	-98.84	6.8653	0.12	
				271.96	1.013	15.00	-98.84	6.8653	0.12	
42	GASMIX 1	331.805	11.499	49.991	12.00	354.29	250.87	6.9524	324.73	
				49.991	12.00	354.29	250.87	6.9524	324.73	
44	GASMIX 2	7.213	0.387	0.77270	12.00	15.00	-3642.08	9.2570	39703.70	
				0.77270	12.00	15.00	-3642.08	9.2570	39703.70	
46	GASMIX 3	339.019	11.895	108.95	11.75	1021.25	168.04	7.9573	887.16	
				108.95	11.75	1021.25	168.04	7.9573	887.16	
50	GASMIX 3	339.019	11.895	772.68	1.028	530.00	-423.41	8.0952	255.95	
				772.68	1.028	530.00	-423.41	8.0952	255.95	

If the medium type is GASMIX or FUEL, then a number is added representing the composition number mentioned in table “Composition of fluids”.

For each pipe in the system the table shows two rows, one for the pipe inlet, and one for the pipe outlet.

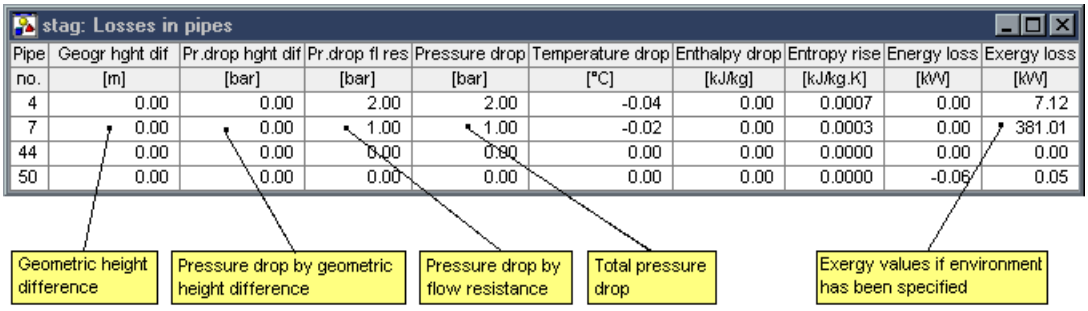
If an exergy calculation is performed, a column with exergy values is added.

If the system contains medium types for which two-phase conditions are allowed, a column named “Quality” is added. A value 0.00 represents saturated or subcooled liquid, a value 100.00 represents saturated or superheated vapor.

If the system contains binary mixtures (such as NH3-H2O), a column named “Mass fractions” is added. The values represent the mass fraction of one of the two component in the mixture. For medium type NH3-H2O this is the ammonia mass fraction.

8.7 Losses in pipes

In table “Losses in pipes” the differences between inlet and outlet conditions in pipes are presented, but only if the differences in pressure or temperature exceed the value 0.0001.

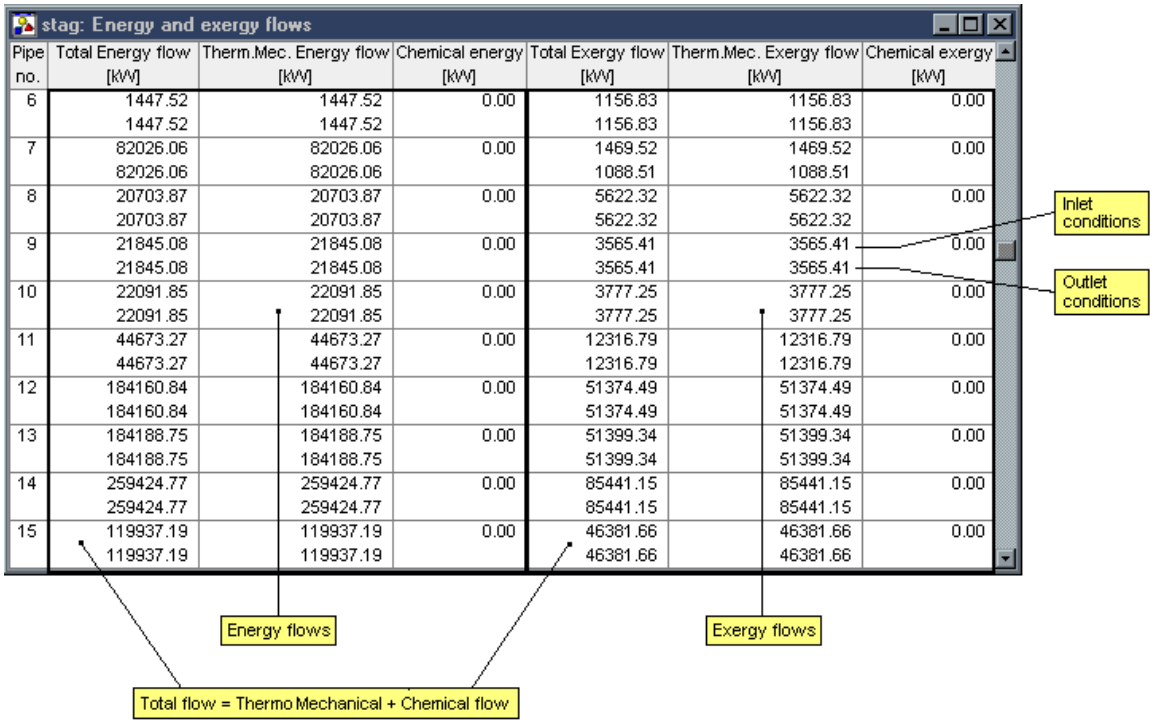


The pressure loss is the sum of the pressure loss by height and the pressure loss by flow resistance. If the difference in height equals 0 m (default value), the pressure loss by flow resistance is set to the value of the total pressure loss.

If an exergy calculation is performed, a column with exergy losses is added.

8.8 Energy and exergy flows

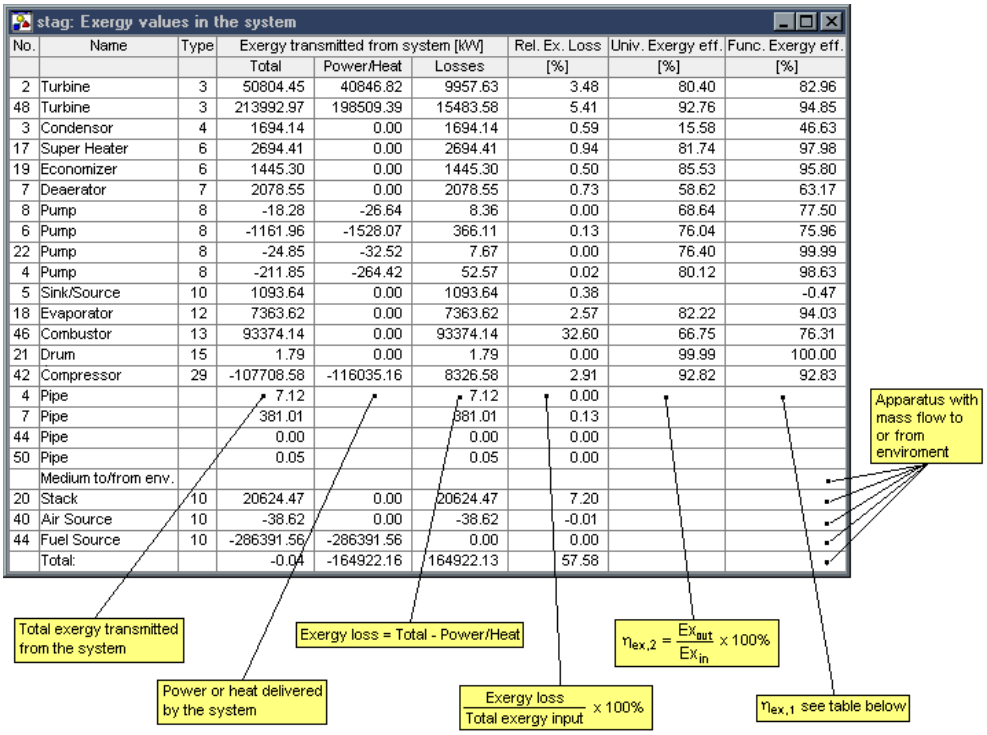
Table “Energy and exergy flows” contains the energy and exergy flows in the pipes. The table will only be generated if an exergy calculation is performed.



The left part of the table presents energy figures, and the right part exergy figures. Both types of figures are split into a thermo-mechanical and a chemical part, both given separately for the inlet and for the outlet of a pipe.

8.9 Exergy values in the system

Table “Exergy values in the system” presents exergy losses in apparatuses and pipes, and exergy efficiencies of apparatuses. The table will only be generated if an exergy calculation is performed.



No.	Name	Type	Exergy transmitted from system [kW]			Rel. Ex. Loss	Univ. Exergy eff.	Func. Exergy eff.
			Total	Power/Heat	Losses	[%]	[%]	[%]
2	Turbine	3	50804.45	40846.82	9957.63	3.48	80.40	82.96
48	Turbine	3	213992.97	198509.39	15483.58	5.41	92.76	94.85
3	Condensor	4	1694.14	0.00	1694.14	0.59	15.58	46.63
17	Super Heater	6	2694.41	0.00	2694.41	0.94	81.74	97.98
19	Economizer	6	1445.30	0.00	1445.30	0.50	85.53	95.80
7	Deaerator	7	2078.55	0.00	2078.55	0.73	58.62	63.17
8	Pump	8	-18.28	-26.64	8.36	0.00	68.64	77.50
6	Pump	8	-1161.96	-1528.07	366.11	0.13	76.04	75.96
22	Pump	8	-24.85	-32.52	7.67	0.00	76.40	99.99
4	Pump	8	-211.85	-264.42	52.57	0.02	80.12	98.63
5	Sink/Source	10	1093.64	0.00	1093.64	0.38		-0.47
18	Evaporator	12	7363.62	0.00	7363.62	2.57	82.22	94.03
46	Combustor	13	93374.14	0.00	93374.14	32.60	66.75	76.31
21	Drum	15	1.79	0.00	1.79	0.00	99.99	100.00
42	Compressor	29	-107708.58	-116035.16	8326.58	2.91	92.82	92.83
4	Pipe		7.12		7.12	0.00		
7	Pipe		381.01		381.01	0.13		
44	Pipe		0.00		0.00	0.00		
50	Pipe		0.05		0.05	0.00		
	Medium to/from env.							
20	Stack	10	20624.47	0.00	20624.47	7.20		
40	Air Source	10	-38.62	0.00	-38.62	-0.01		
44	Fuel Source	10	-286391.56	-286391.56	0.00	0.00		
	Total:		-0.04	-164922.16	164922.13	57.58		

The table contains the following data:

- Exergy exchange with the environment, split-up into
  - Exergy exchange with environment (“Total”)
  - Supplied power or heat (“Power/Heat”)
  - Exergy loss (“Losses” = “Total”- “Power/Heat”)
- Relative exergy loss (“Rel. Ex. Loss”)
- Universal exergy efficiency (“Univ. Exergy eff.”)
- Functional exergy efficiency (“Func. Exergy eff.”)

Supplied power or heat

“Power” represents:

- mechanical power of turbines
- mechanical power of non-electricity driven pumps or compressors
- electric power of electricity driven pumps or compressors
- electric power of fuel cells

The exergy losses include mechanical and electric losses. Losses in generates are not included.

“Heat” applies to “Heat Sink” (type = 10, subtype = 1).

Exergy efficiencies

See also part “Technical notes” (chapter 5) of the manual for a detailed description of the definitions of exergy efficiencies.

The table contains columns for the functional efficiency $\eta_{ex,1}$, and the universal efficiency $\eta_{ex,2}$

$\eta_{ex,1}$: gives the ratio between useful outgoing exergy and the incoming exergy flows;

$\eta_{ex,2}$: gives the ratio between the outgoing exergy and the incoming exergy:

$$\eta_{ex,2} = \frac{Ex_{out}}{Ex_{in}}$$

Generally $\eta_{ex,1}$ is used. If it is not defined, $\eta_{ex,2}$ can be used. Table 8-2 gives $\eta_{ex,1}$ for all apparatuses for with this efficiency can be defined.

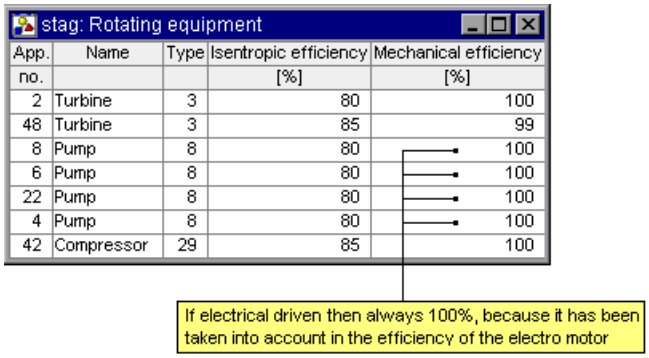
Table 8-2: exergy efficiencies of apparatuses

Type	Name	$\eta_{ex,1}$
1 2	Boiler Reheater	$\frac{Ex_{out} - Ex_{in}}{Ex^{ch}_{fuel}}$
3	Turbine	$\frac{P_{mech.}}{Ex_{in} - Ex_{out}}$
4 5 6,12 22	Condenser Flashed heater General heat exchanger Evaporator, heat exchanger	$\frac{Ex_{p,out} - Ex_{p,in}}{Ex_{s,in} - Ex_{s,out}}$
7	Deaerator[1)]	$\frac{\Phi_{m,p} \times ex_{out} - Ex_{p,in}}{Ex_{s,in} - \Phi_{m,s} \times ex_{s,out}}$
15	Drum	$\frac{Ex_{out,main\,flow} - Ex_{in,main\,flow}}{Ex_{in,circ} - Ex_{out,circ}}$
8 29	Pump Compressor	$\frac{Ex_{out} - Ex_{in}}{P_{mech./el.}}$
13	Combustor, burner	$\frac{Ex^{tm}_{fluegas} + Ex^{tm}_{ash} - Ex^{tm}_{fuel} - Ex^{tm}_{oxid.}}{Ex^{ch}_{fuel} + Ex^{ch}_{oxid.} - Ex^{ch}_{ash} - Ex^{ch}_{fluegas}}$
20	Reformer	$\frac{Ex^{ch}_{prod.} - Ex^{ch}_{stm} - Ex^{ch}_{gas}}{\left(Ex_{in} - Ex_{out.}\right)_{fluegas} - \left(Ex^{tm}_{prod.} - Ex^{tm}_{stm} - Ex^{tm}_{gas}\right)}$
21	Fuel cell	$\frac{P_{el.}}{\left(Ex_{in} - Ex_{out.}\right)_{fuel} - \left(Ex_{in} - Ex_{out}\right)_{oxid.}}$
23	Gasifier	$\frac{Ex_{prod} + Ex^{tm}_{ash} + \left(Ex_{out} - Ex_{in}\right)_{cooling}\left(Ex^{tm}_{fuel} + Ex^{tm}_{stm} + Ex^{tm}_{oxid.}\right)}{Ex^{ch}_{fuel} + Ex^{ch}_{stm} + Ex^{ch}_{oxid} - Ex^{ch}_{ash}}$

1) For the deaerator $\eta_{ex,1}$ equals the exergy increase of the feed water (and condensate flows, if any) divided by the exergy decrease of the extraction steam (and condensate flows, if any). $\Phi_{m,p}$ is the sum of all inlet flows which undergo an exergy increase, and $\Phi_{m,s}$ all inlet flows which undergo an exergy decrease.

8.10 Rotating equipment

Table “Rotating equipment” shows the efficiencies of rotating machines. The table will only be generated if the system contains one or more turbines (type = 3), pumps (type = 8) or compressors (type = 29).



App. no.	Name	Type	Isentropic efficiency [%]	Mechanical efficiency [%]
2	Turbine	3	80	100
48	Turbine	3	85	99
8	Pump	8	80	100
6	Pump	8	80	100
22	Pump	8	80	100
4	Pump	8	80	100
42	Compressor	29	85	100

The mechanical efficiency of an electricity driven pump or compressor is fixed at 100% in the table, since it is part of the total efficiency of the pump/compressor including drive train (see paragraph 8.11).

8.11 Motors and generators

Table “Motors and generators” contains efficiencies for electromotors and generators. The table will only be generated if the system contains one or more generators, electricity driven pumps (type = 8) or electricity driven compressors (type = 29).

If the efficiency of the generator has been specified, only the total efficiency is shown. If this efficiency has been calculated, the mechanical and electric efficiencies are shown.

stag: Motors and generators

No.	Name	Type	Mechanical efficiency	Electrical efficiency	Mechanical*Electrical eff.
			[%]	[%]	[%]
2	Generator	G	99.52	98.51	98.03
1	Generator	G			97
8	Pump	8	95	90	85.5
6	Pump	8			95.05
22	Pump	8			85.83
4	Pump	8	98	95	93.1

Displayed if efficiency is calculated

Calculated according figure 2-8

Displayed if assigned at input

If no efficiency has been specified for the pump or compressor, only the total efficiency is shown. This efficiency is calculated according to the curve shown in Figure 2-6 and 2-8.
If both the mechanical and electric efficiency have been specified, these values are shown.
If only one efficiency has been specified, the other efficiency is taken as 100%.

8.12 Heat exchanging equipment

Table “Heat exchanging equipment” contains data for heat exchanges. The table will only be generated if the system contains one or more condensers (type = 4), feed water heaters (type = 5), heat exchangers (type = 6, 12), or moisture separators (type = 22).

stag: Heat exchanging equipment

App. no.	Name	Type	Lower end temperature diff. [K]	Higher end temperature diff. [K]	Transmitted heat flow [kW]
3	Condensor	4	7.33	2.33	80578.54
17	Super Heater	6	216.52	80.00	23310.53
19	Economizer	6	73.07	20.00	22581.42
18	Evaporator	12	16.00	216.52	75236.02