A simple water/steam cycle

Table of Contents

1.1   Introduction

To introduce the Cycle-Tempo program, using a simple water/steam cycle an example of program input and output is given. The same example is used in the 'Technical Notes' to explain the basic principles of the program. A diagram of the water/steam cycle is shown in Figure 1-1. Only the most important results of the output of the calculation are shown.
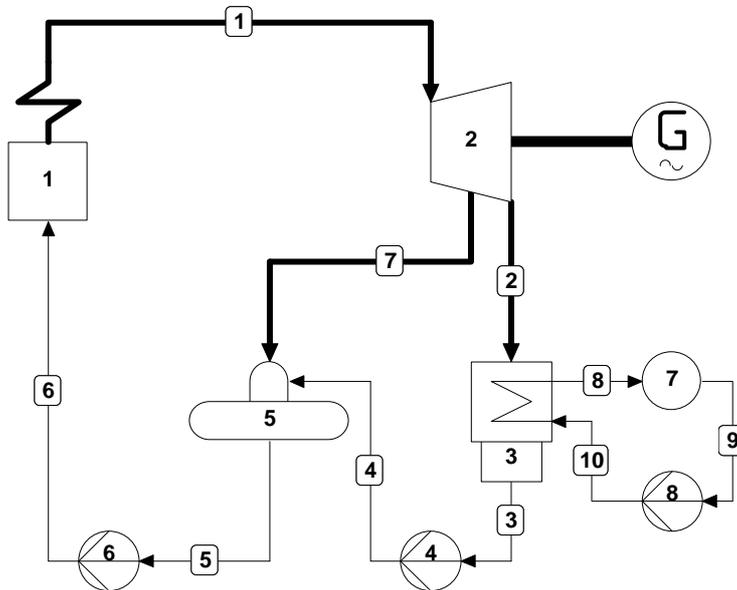
*Figure **Error! No text of specified style in document.**-1: a simple water/steam cycle*

1.2 Base calculation

1.2.1 System description

In boiler 1 superheated steam is generated. This steam expands in steam turbine 2, which drives a generator. The steam in then condensed into water in condenser 3. The cooling water circuit is modelled by sink 7 and cooling water pump 8. The condensate from the condenser is pumped by condensate pump 4 to the deaerator 5, where it is vented from the turbine using extraction steam. Then the feedwater is pumped by feedwater pump 6 to the boiler.

1.2.2 Starting points for the calculation

In the system the following starting points are specified:

Apparatuses

Boiler 1:	outlet pressure	70 bars
	outlet temperature	400 °C
Turbine 2:	η_i (ETHAI)	0.8
Condensor 3:	outlet pressure condensate	0.027 bars
	pressure drop steam side	0 bar
	pressure drop cooling water	1 bar
	temperature rise cooling water	5 K
Pump 4:	η_i (ETHAI)	0.75
Deaerator 5:	outlet pressure	3 bars
	pressure drop	0 bar
Pump 6:	outlet pressure	80 bars
	η_i (ETHAI)	0.75
Source/sink 7:	outlet temperature cooling water	15 °C
	outlet pressure cooling water	1 bar
Pump 8:	outlet pressure	4 bars
	η_i (ETHAI)	0.75

Pipes

pipe 1:	pressure drop	3 bars
pipe 4:	pressure drop	2 bars

For the pipes these data are specified as extra conditions.

Pipe 7 is connected to the top of the deaerator, as the pipe contains extraction steam for the deaerator (see also the input description of the deaerator in part "Reference Guide" of the manual).

As production function it is specified that the generator must supply 100 MW$_e$.
For the efficiency of the generator $\eta_{gen.}$= 0.97 (ETAGEN) is specified.

1.2.3 Results of the calculation

In the table "System efficiencies" a summary is given of the system efficiency, the primary energy absorbed by the boiler, the power produced by the generator, the electricity consumption of the pumps and the net supplied power. It should be mentioned that the pump efficiencies shown at "Aux. power consumption" are default values assigned by the program (for input data for pumps, see part "Reference Guide" of the manual).

The table "Energy balance" shows the amounts of energy exchanged with the environment for apparatuses and pipes. The power supplied by the steam in the turbine is presented here (POWER divided by ETAGEN).

The table "Data for all pipes" contains a.o. mass flows, pressures, temperatures and enthalpies of all pipes in the system. Many starting points can be seen here, such as the temperature of the steam from the boiler (inlet of pipe 1), and the outlet pressure of pump 6 (inlet of pipe 6). The cooling water pressure drop in the condenser is the difference between the pressure at the outlet of pipe 10 and the pressure at the inlet of pipe 8.

Losses in pipes are given in table "Losses in pipes". The pressure loss defined for pipe 1 (specified as an extra condition) can be found here also.

The energy and exergy flows in the pipes are presented in table "Energy and exergy flows". Each energy or exergy flow is split-up into its thermo-mechanical and chemical parts. Exergy losses and exergy efficiencies for apparatuses in the system can be found in table "Exergy values in the system".

Calculated and specified efficiencies of devices connected to a shaft (turbines, pumps, compressors, motors and generators) are given in the tables "Rotating equipment" and "Motors and generators". Data for heat exchangers can be found in table "Heat exchanging equipment". In this case, only a condenser is present.

All input and output data are also written in the output file, which may be viewed via the "Text Output" option. At the end of the output file design data for turbines, compressors and heat exchangers are presented, which are also written in the file EX1.PLD.

1.3 Calculation with user subroutine

1.3.1 Introduction

In this example for turbine 2 in the user subroutine APSUB a new value for the isentropic efficiency is calculated, which is dependent on the mass flow. For this the number of the turbine is specified via Calculation | User Subroutines. The user-defined subroutine APSUB, which is linked to the user executable, will be called for this apparatus (see also Figure 1-2).
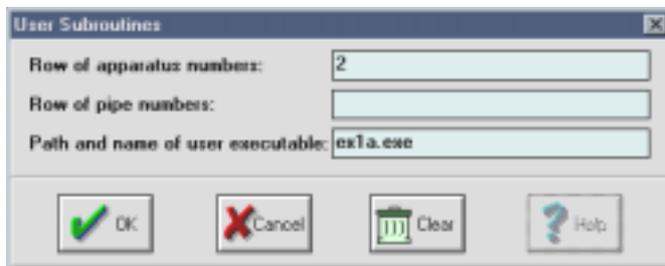
*Figure **Error! No text of specified style in document.**-2: input dialog for data of user subroutines*

The input remains the same. The example is stored in EX1A.GUI. The user-defined version of subroutine APSUB, of which the content is shown in the next paragraph, is stored in file EX1_APSU.FOR.

1.3.2 Source text of the user subroutine

```
*-----------------------------------------------------------------------*
*     User subroutine APSUB, meant for example ex1a                     *
*                                                                       *
*     For the turbine with NO=2 the mass flow dependent isentropic      *
*     efficiency is calculated.                                         *
*-----------------------------------------------------------------------*

      SUBROUTINE APSUB( NLIN,ILIN,IAP,ITYP,ITM,DATA,NP,IPIPE,FM,H,
     *                  P,T,X,C,RESULT,COMP,CONC,AVERG,IDX,NCOMP,APNAME,
     *                  NUMGEN,RDATGE)

      IMPLICIT DOUBLE PRECISION (A-H,O-Z)

      DOUBLE PRECISION  DATA(50),FM(NP),H(NP,3),P(NP,3),T(NP,2),
     *                  X(NP,2),C(NP),CONC(NLIN+7,NCOMP),AVERG(NLIN+7),
     *                  RDATGE(NUMGEN,6)
      INTEGER           IPIPE(NP),ILIN(NLIN),IDX(NCOMP)
      CHARACTER         COMP(NCOMP)*8,APNAME*12

      PARAMETER ( A = 0.0001 )
      SAVE ETHAIB

      IF (IAP.EQ.2) THEN

*         Save basic efficiency
          IF (ITM.EQ.0) ETHAIB = DATA(7)

*         Write basic efficiency to standard outputfile (UNIT = 7)
          WRITE (7,1) DATA(7)

*         Calculate isentropic efficiency depending on massflow
          FLOW   = FM(IPIPE(1))
          RESULT = ETHAIB + A*FLOW

*         Write the results of each iteration to standard outputfile
          WRITE (7,2) FLOW, RESULT

      ENDIF

  1   FORMAT (/' Ethai(old) = ', F8.5)
  2   FORMAT (/' Massflow = ', F8.3, '     Ethai = ', F8.5)
      END
```

1.4 Optimization

1.4.1 Introduction

This example concerns the same system, but extended with the use of the optimization procedure of Cycle-Tempo. This example is stored in file EX1B.GUI. The bleeder pressure of turbine 2 (specified by POUT of apparatus 5) will be adjusted by the procedure in such a way that the system efficiency will be maximized. When the optimum value of the bleeder pressure is found, a standard Cycle-Tempo calculation is performed with this value.
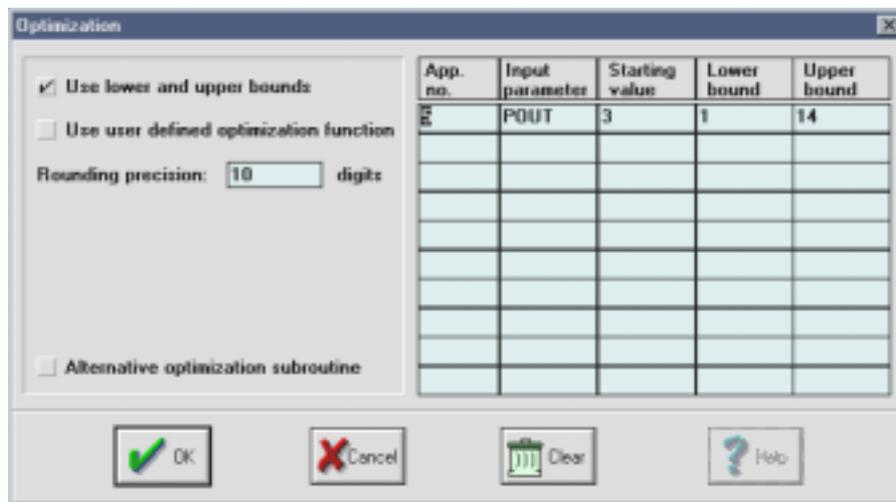
Figure **Error! No text of specified style in document.**-3: *input dialog for optimization data*

1.4.2 Changes in the input

To activate the optimization procedure a correct set of optimization data should be specified via Calculation | Optimization. The following data are given (see also Figure 1-3):

1.   the apparatus number of which the variable has to be optimized: App. No. : 5;
2.   the name of the variable to be optimized: POUT;
3.   starting value from which the optimization procedure starts: Starting value = 3 (bars);

5.   the lower and upper bound of the variable to be optimized: Lower bound = 1 (bar)
        and Upper bound = 10 (bar), respectively;

6.   the number of digits to which the system efficiency is to be rounded in the
        optimization procedure: Rounding precision = 10.

1.4.3 Results of the calculation

In the output file (viewed via View | Text Output) the progress of the optimization procedure
is presented. After 19 optimization iterations the value of the bleeder pressure is found at
which the system efficiency reaches a maximum. The corresponding values of the bleeder
pressure and the system efficiency are given:

1.   bleeder pressure: VARIABLE(1):   3.8534375 (bars);
2.   system efficiency: OPTIM. FUNCTIONVALUE: 0.3062971649

The optimization progress shows that the system efficiency has rised from 0.3062137331 at
a bleeder pressure of 3 bars, to 0. 3062971649 at a bleeder pressure of 3.8534375 bars. The
gain in efficiency is therefore 0.0000834.

With the new value of the bleeder pressure the normal calculation is performed. The results
are stored in the tables as usual.