CYCTHERM

A Software Program for the Analysis of Complex Thermodynamic Cycles

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Presentation

CYCTHERM is a product of Idillium Technologies, a group of experts in thermodynamics and computer science.
For more information access the site **http://spazioinwind.libero.it/taw/indexeng.htm** or address your request to: idillium@inwind.it

THERPROP - a software for thermodynamic properties calculation - is also available from same authors.

Pisa, December 2002

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Introducing CYCTHERM

What is CYCTHERM ?

CYCTHERM is a software program for modelling thermodynamic systems structured in either simple or complex cycles.
CYCTHERM carries out the mass and energy balance and performs the second law analysis adopting the concept of exergy (available energy) in conjunction with the more advanced engineering methods of calculation.

Why the Exergetic Analysis ?

Exergetic or availability analysis is the examination of lost work or potential energy that is dissipated in a thermodynamic process. The process performance according to the exergetic analysis is measured by the rational efficiency. Adopting the rational efficiency as a criterion for process design, we may improve the utilisation of resources employed by the process.

How does it work ?

CYCTHERM recognises a set of elementary thermodynamic processes which each is implemented by a specific mechanical component. The program architecture allows, with major flexibility, the connection of the thermo-mechanical components that form the process. A Windows based graphic interface makes easy and fast the drawing of complex flow diagram. After having drawn the flow diagram and defined the process parameters, CYCTHERM solves the equations governing the mass and energy balance, then performs the exergetic analysis.

Which processes ?

CYCTHERM recognises different solids and fluids consisting of the most common fuels, ideal gases and mixtures, moist air, some real two-phase fluids i.e. water, refrigerants etc. and the binary two-phase mixture water-ammonia.
Such numerous fluids in addition to the structure of the program allow the simulation of many types of processes.
In the field of power generation you may not only deal with those based on steam and/or gas cycles, but also with those non conventional as the HAT cycle, the Kalina cycle and those peculiar of the geothermal industry.

Where does it help?

CYCTHERM is useful in the conceptual design phase of a steady state process and in improvement studies. It may also be used to assess the performance and the upgrading of an existing process.
CYCTHERM is not a plant simulator and does not deal with the off design analysis.

Which problems?

CYCTHERM solves direct and indirect (implicit of the type If..Then) problems and solves also scenario or sensitivity analysis.

CYCTHERM architecture

CYCTHERM features an open architecture that allows an easy extension of the program to deal with new components and new fluids.

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Working with CYCTHERM

This chapter illustrates the main characteristics of the program. It includes the following topics:

- Basic Information
- Building the Flow Diagram
- Defining the Operating Conditions
- Examining the Results

Basic Information

When you start CYCTHERM the window shown in Figure 2.1 is displayed in the screen of your computer.

The graphic area is the area where you draw the flow diagram of your process using the commands and the functions of the Menu-bar and of the Toolbar.

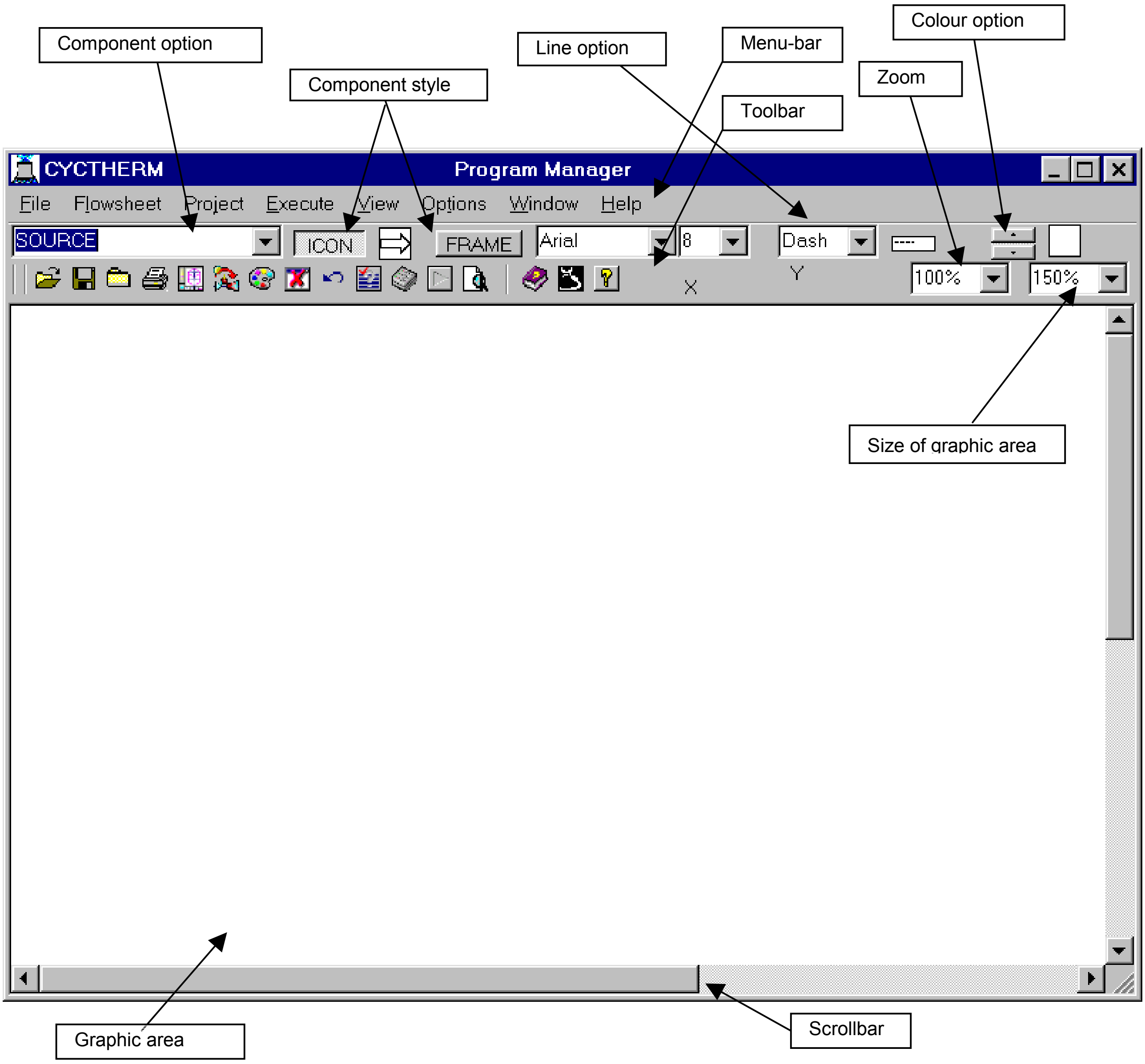


Figure 2.1. The main window of CYCTHERM. Pointing with the mouse an object in the toolbar, the description of the object is displayed.

For simulating a process you have to build the model of the process in the CYCTHERM environment. Building the model requires that you draw the process flow diagram in the graphic area followed by the definition of the operating conditions.

Building the Flow Diagram

CYCTHERM recognises a number of elementary thermodynamic processes like combustion, compression etc.. The list of available process components is displayed by clicking the arrow of the box labelled as *Component option* in Figure 2.1.

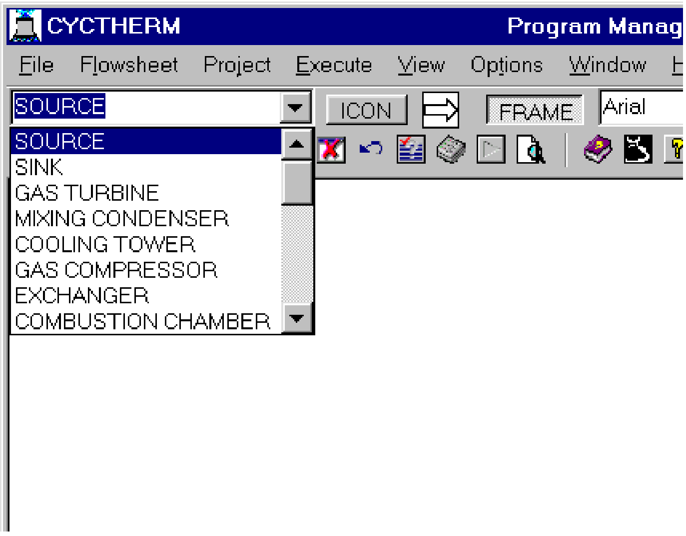
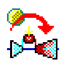


Figure 2.2. Pull-down list of components.

You may assess the performance of a single component or of a process. A process is made by a number of components connected together according the criteria required by the operating conditions.

Before you draw the process flow diagram in the graphic area you must recognise which are the components available for simulating the real process. You may eventually need to adapt your process to the capabilities of the program. To build the graphic model click on the **Component Style** button and choose one of two available styles**, ICON** or **FRAME**, for representing the components. Open the list of components and select that you need. Open menu **Flow-sheet** and click **Add New Component** or click the Add/New symbol in the toolbar illustrated as following:



The graphic symbol representing the component is displayed on the uppermost left corner of the graphic area.

Here below is reported the list of available components. For a complete description of their functions look at the help file ***Guide to the use of program.***

1- SOURCE	Fluid inlet
2- SINK	Fluid outlet
3- GAS TURBINE	Gas turbine
4- MIXING CONDENSER	Condenser (mixing type)
5- COOLING TOWER	Cooling tower
6- GAS COMPRESSOR	Gas compressor
7- EXCHANGER	Surface heat exchanger

COMPONENTS

8- COMBUSTION CHAMBER	Combustion chamber
9- SPLITTER	Fluid splitter
10- GENERIC EXCHANGER	Generic heat exchanger
11- HRSG	Heat recovery steam generator
12- CLOSED FEEDWATER	Closed feedwater heater w/w.out condensate recovery
13- OPEN FEEDWATER (Deaerator)	Open feedwater heater
14- PUMP	Pump for liquid
15- MIXER	Fluid mixer
16- SURFACE CONDENSER	Steam condenser (surface type)
17- STEAM TURBINE	Steam turbine
18- THROATTLING VALVE	Throattling valve
19- BOILER	Steam boiler with/out re heater
20- GEOTHERMAL TURBINE	Turbine for geothermal fluid
21- FLASHER	Flash tank
22- GAS SATURATOR	Gas saturator
23- FICTITIOUS SOURCE	Fictitious source
24- FLOW CONTROL	Flow control
25- NULL	Neutral component

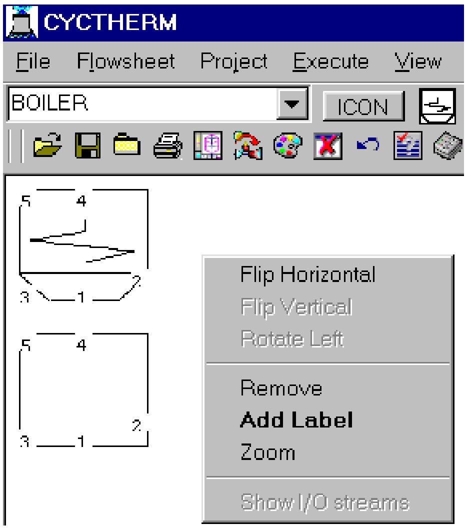


Figure 2.3. The representation of the component BOILER using the options ICON and FRAME and the popup menu of commands associated to BOILER.

For manipulating a component open the popup menu of commands and for moving drag the component in a proper location of the graphic area.

On the contour line of the symbol numbers are displayed distinguishing the gates through which the fluid/solid streams enter or exit the component.

Pointing the gates with the mouse the function description of the gate is displayed. You may bring the numbers of the gates forward or backward the symbol just clicking the component.

To connect a component to another, recognise the component gates to be connected. Consider first the upstream component. Point the gate to be connected and click. The graphic image of the gate changes to a black dot.

Consider then the downstream component. Point the gate to be connected to the upstream component and click. The gate image changes and a dotted line, made by three segments connecting the two clicked gates, are displayed.

You may customise the style of the connection line by clicking the arrow on the box labelled as *Line option* or *Colour option* in Figure 2.1. Commands for changing style are also available in the **Flow sheet** pull- down menu. To cancel the line use the commands **Delete** and **Undelete** in the toolbar. The editing will take place when the command is clicked before the interception of the line.

Modifying the layout of the line is a very simple matter: you may translate horizontally the vertical segment and translate vertically the horizontal. To translate a segment, drag it with the left button of the mouse.

The Figure 2.4 shows how a flow diagram of a simple process is displayed in the graphic area of CYCTHERM.

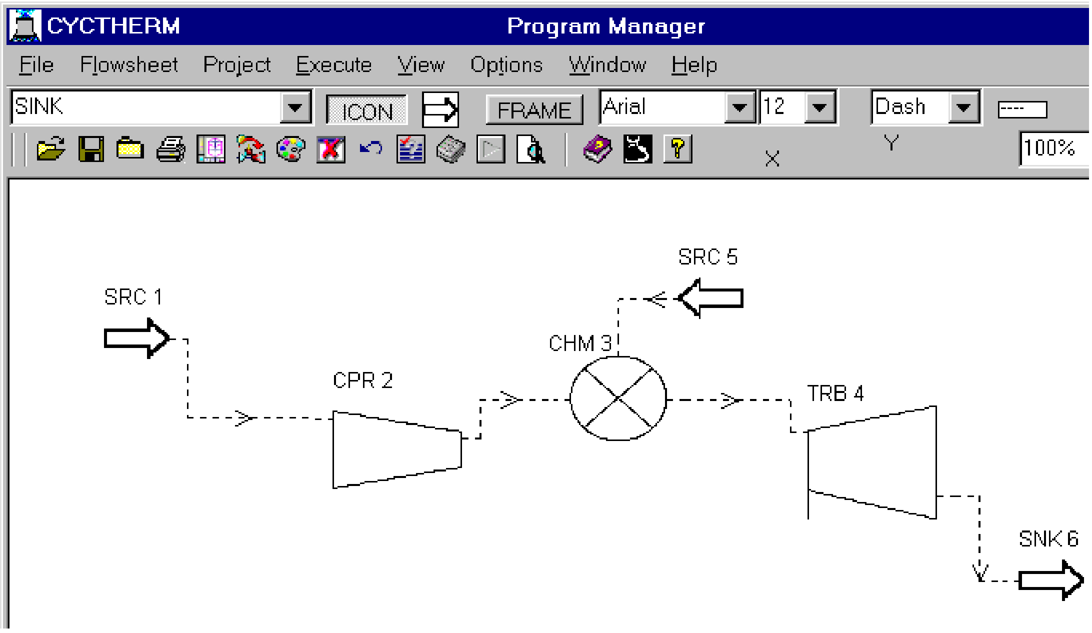


Figure 2.4. The flow diagram of the Brayton gas cycle built in the graphic area of the program.

Fixing the Operating Conditions

The operating conditions of the process are defined fixing the process parameters that determine the performance of the components. Furthermore you have to fix the control parameters that specify how the calculation is carried out.
Open the pull-down menu **Project** in the menu-bar to access the commands for fixing the process and control parameters. If you choose the **Process Parameter** button a screen similar to the following figures appears. The Figures 2.5 and 2.6 show the screens that allow the input of the process parameters for the components SOURCE and TURBINE respectively.

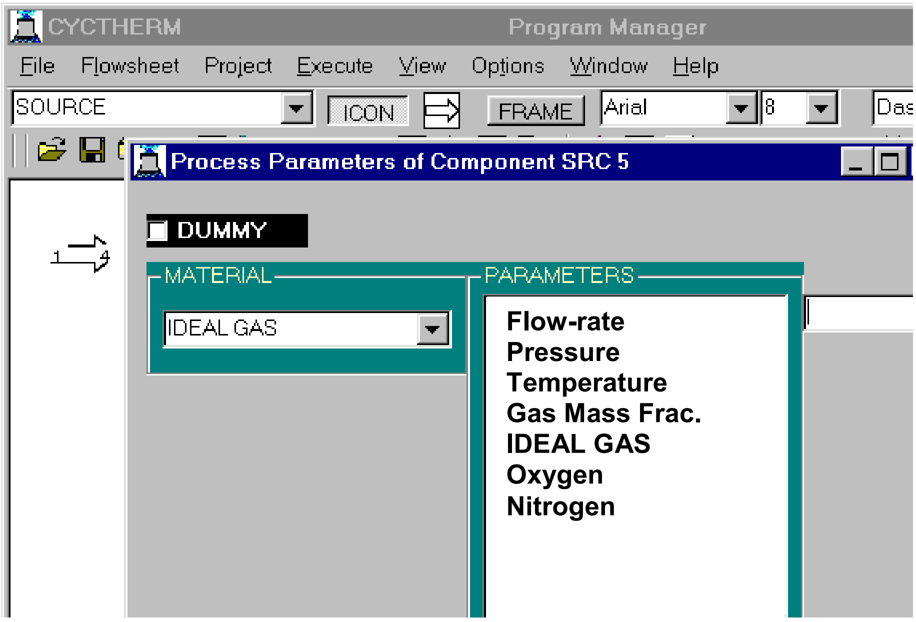


Figure 2.5. The window used to enter the parameters of the component SOURCE where a mixture of the ideal gases Nitrogen and Oxygen is selected.

The options of solids/fluids identified as MATERIAL considered by CYCTHERM are:

MATERIALS

- Fuels (Solid, liquid and gas). More common liquid and gaseous fuels.
- Moist air
- Ideal gases
- Real two phase fluids: Water, Refrigerants R134a, R22, Carbon dioxide, Ammonia, Methane
- Binary fluid Water-Ammonia
- Mixtures of Ideal gas and Water

The wide MATERIAL choice allows simulation of processes of various typologies. In the field of power generation you may not only deal with those based on steam and/or gas cycles, but also with those non conventional as the HAT cycle, the Kalina cycle and those peculiar of the geothermal industry.

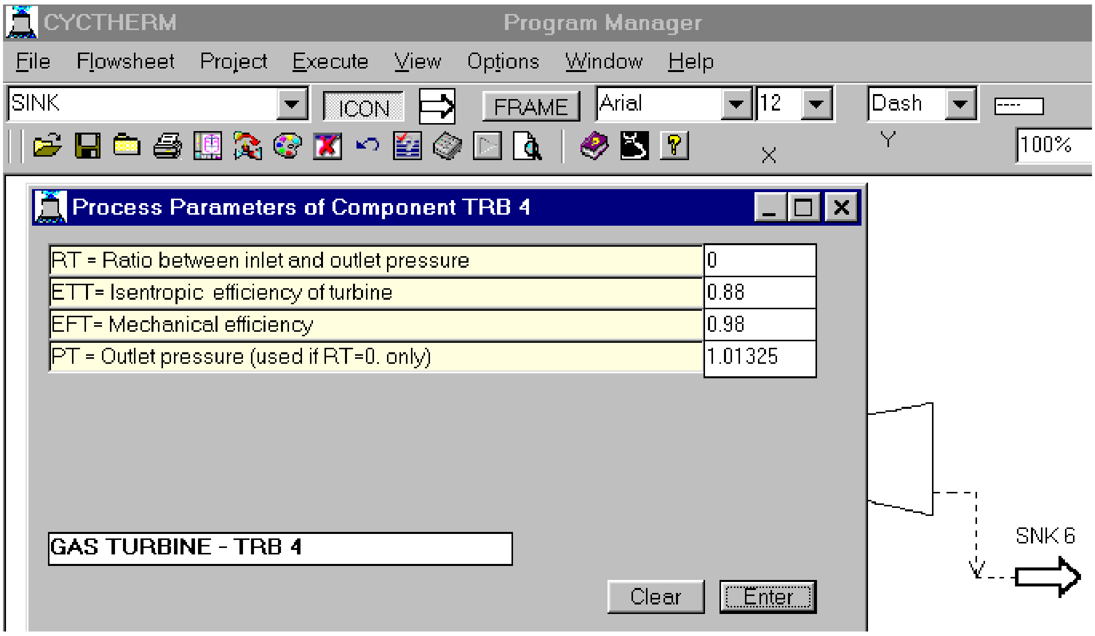


Figure 2.6. The window used to enter the parameters of the component TURBINE.

The control parameters are used to:

- Fix the environmental conditions.
- Fix the calculation options.

The environmental conditions are those specifying the pressure and the temperature of the environment as well the composition of the ambient air. CYCTHERM adopts, as default, the conditions of the standard ambient air according to ASHRAE.

The calculation options are selected when you want to solve an implicit problem, a problem of type “If..then” or to analyse a scenario.

An example of an implicit problem is: “How much is the fuel consumption of the Brayton cycle if the temperature at the turbine entry is kept fixed at 1100 º C?”
You are dealing with a scenario when you want to analyse the performance of the Brayton cycle while varying the outlet pressure of the air compressor.

These commands are enabled by setting IMPLICIT=YES/NO or CYCLE=YES/NO in the cells that appear in the window of control parameters.

Examining the Results

The execution of the simulation is activated clicking the command **Execute**.
The results generated are stored in the ASCII files *projectname.out* or *projectname.cyc* depending of which calculation option is selected.
The Figure 2.7 shows how the results are reported in the output file *projectname.out*.

```
FLUID PROPERTIES AT THE GATES OF COMPONENTS


     Component code   2
                     CPR 2
               NINP1        NOUT1
                   1            2
 FLOW-RATE   0.421000D+02 0.421000D+02
 PRESSURE    0.101325D+01 0.140000D+02
 ENTHALPY    0.292824D+03 0.659208D+03
 QUALITY     0.100000D+01 0.000000D+00
 FLUID         IDEAL GAS    IDEAL GAS
 TEMPERATURE 0.150000D+02 0.371993D+03
 ENTROPY     0.682508D+01 0.689552D+01
 LHV         0.000000D+00 0.000000D+00
 X(GAS;NH3)  0.100000D+01 0.100000D+01
 EXERGY      0.267283D+02 0.145673D+05
 REL. HUM.   0.000000D+00 0.000000D+00
 O2/O        0.231870D+00 0.231870D+00
 N2/N        0.754610D+00 0.754610D+00
 AR          0.135100D-01 0.135100D-01

                    Performance assessment
  Power required      (kW)     = 0.157396D+05
  Thermodynamic efficiency     = 0.880000D+00
  Mechanical losses   (kW)     = 0.314792D+03
  Enthalpy balance    (kW)     = 0.000000D+00
```

Figure 2.7. Fluid properties at the gates of component CPR 2. The label CPR stays for COMPRESSOR and the labels NINP1, NOUT1 indicate the inlet and the outlet gates.

You may open and explore the results using the **View** command in the **Menu-bar**. Then click **Results of Simulation** and choose the **Mode STANDARD**[1] or **Mode CYCLE**[2] according to the control parameters settled for executing the simulation. The results are selected according the categories *Component, Connection, Global, Exergy accounting.*
For example *s*electing *Connection* (see figure 2.8) you may look at the properties of the "material" streams related to one of the connections of the flow diagram or selecting *Component* you access the properties of the streams at the inlet/outlet gates of the component.

While selecting *Connection* or *Component* in the window of results, the selected object is marked in the flow diagram. Furthermore, you may print, save or graph the results displayed.

[1] The **Mode STANDARD** is used when the parameter **IMPLICIT=YES** is imposed as calculation option and the results are stored in the file *projectname.out.*
[2]If Use **Mode CYCLE** if you have set the control parameter **CYCLE=YES;** the results are stored in the file *projectname.cyc*.

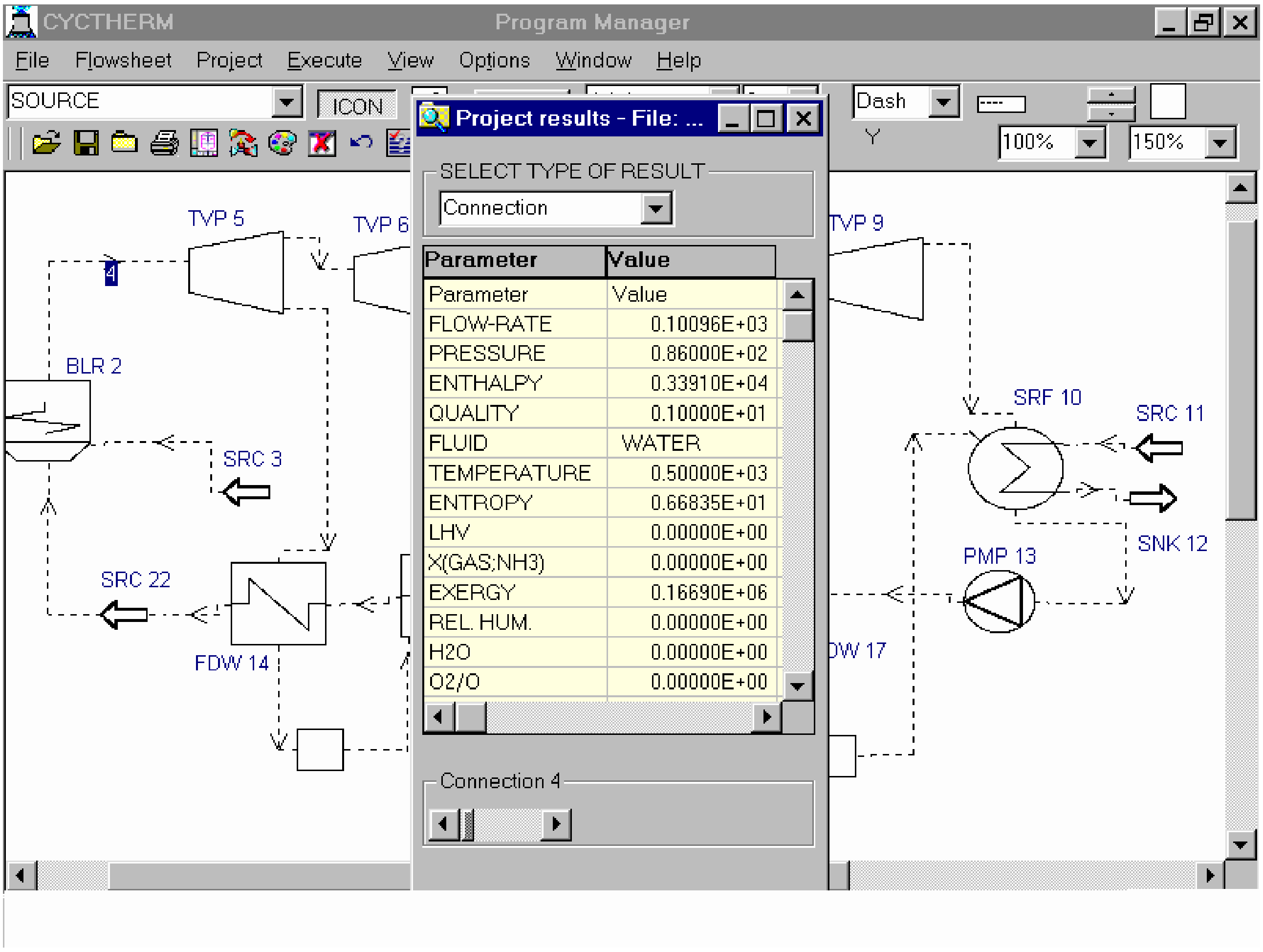


Figure 2.8 .The fluid properties in connection 4. The selected connection is labelled with its number in the flow diagram.

You may display an appropriate thermodynamic diagram of a specific fluid related to one or various connections by opening the pop-up menu linked to the window of “Project results”. Two options are available; Temperature-Entropy or Enthalpy-Pressure diagrams. The figure 2.9 shows the TS diagram for an ideal Rankine cycle.

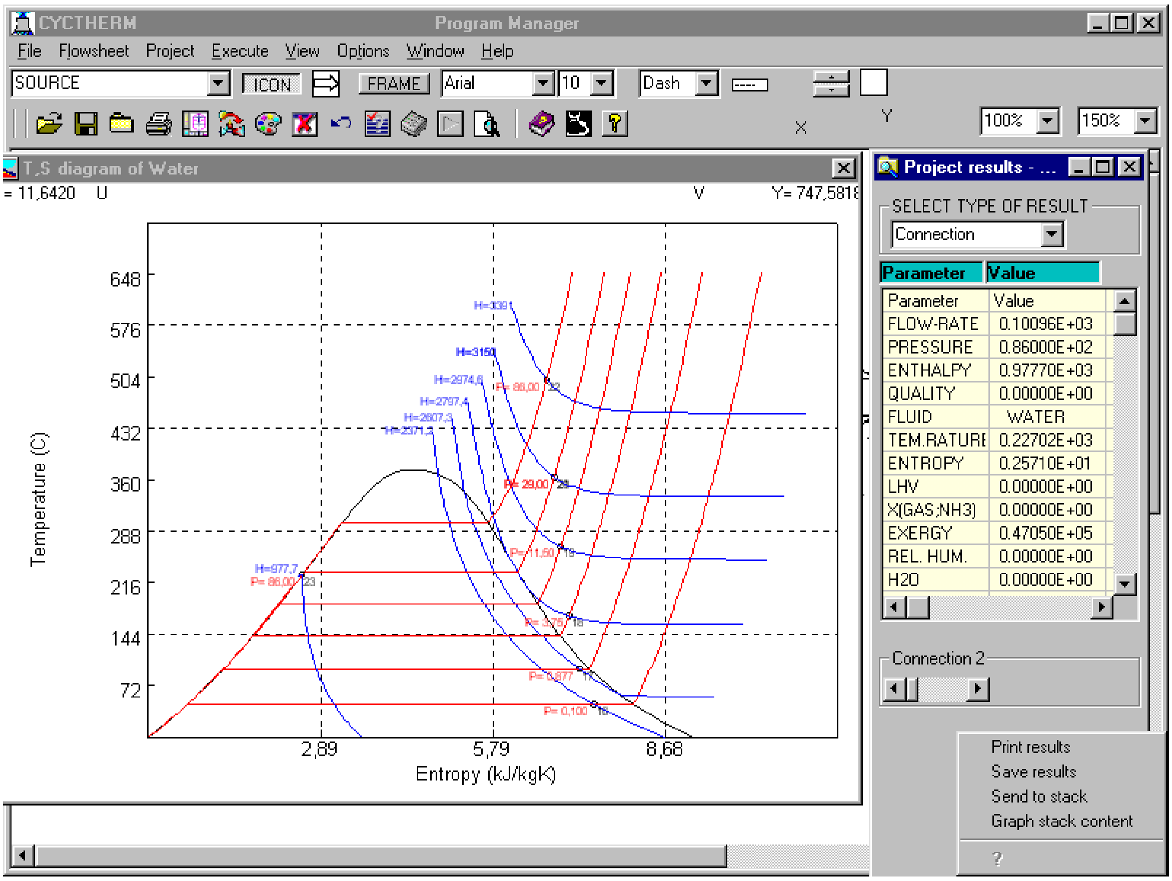


Figure 2.9. The physical states of water, from the boiler to the condenser of an ideal Rankine steam cycle, reported on the T-S diagram.

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Examples of application

This chapter shows a few of thermodynamic systems modelled with CYCTHERM that are listed below.

- ALTOF - Regenerative gas cycle
- GEOTER - Geothermal power plant
- FLASH - Multiple flash process of mixture of water and non condensable gas
- PLANT - Thermal power plant with steam cycle fuelled by lignite
- KALINA - The Kalina cycle
- COMPLEX - Thermal cycle of a supercritical steam power plant
- COMBINE - Gas-steam combined cycle with two pressure levels

ALTOF

The figure below represents a gas cycle fired by a low rank fuel gas produced in a blast furnace. The fuel and the air before entering the combustion chamber are preheated with the flue gas exiting the turbine. This model is built-up with the aim of calculating the optimum pressure at the inlet of the gas turbine. The fuel flow rate is kept constant while no constraints are posed to the temperature at the turbine inlet.

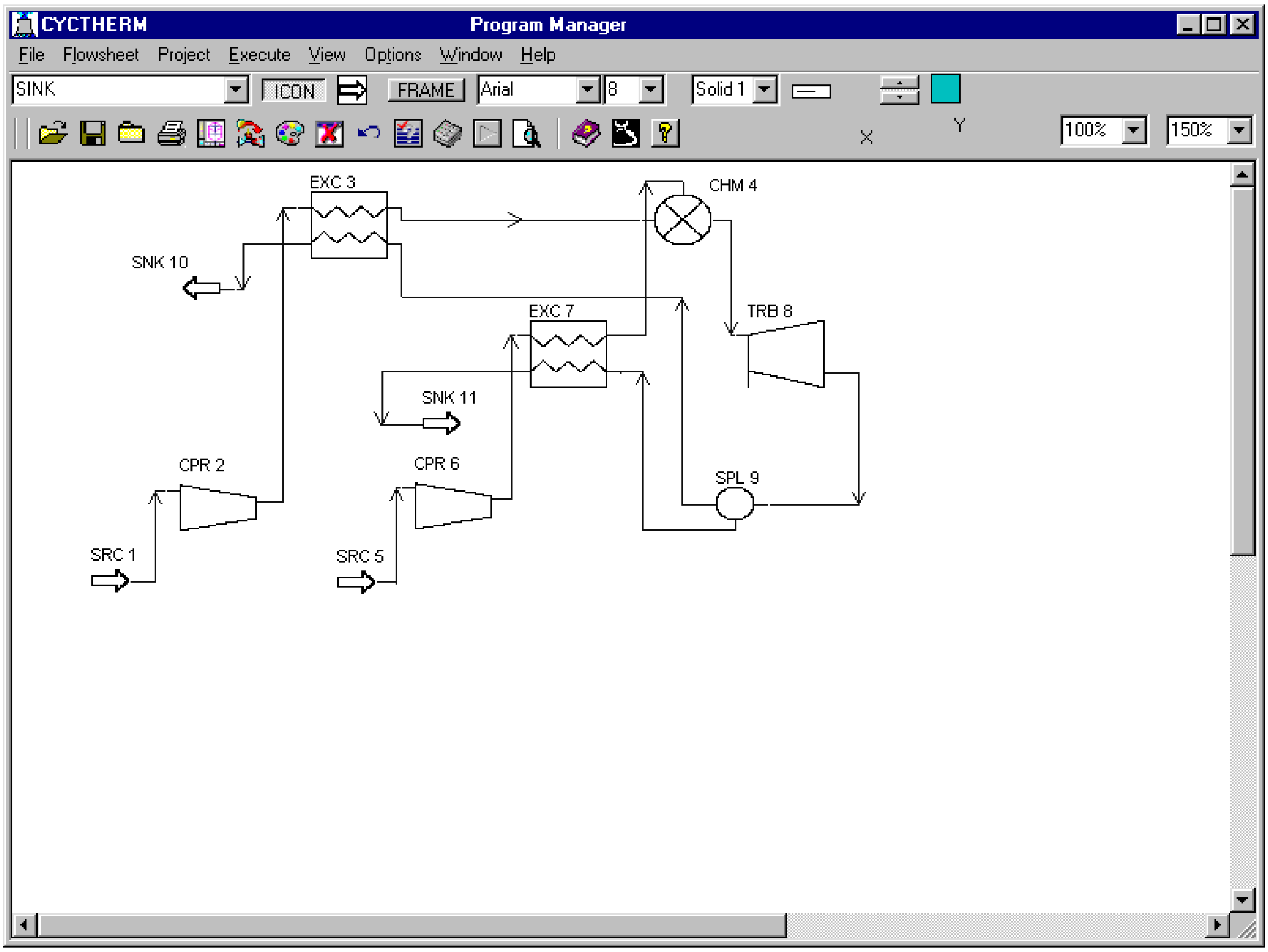

Figure 3.1
Flow diagram of the regenerative gas cycle.

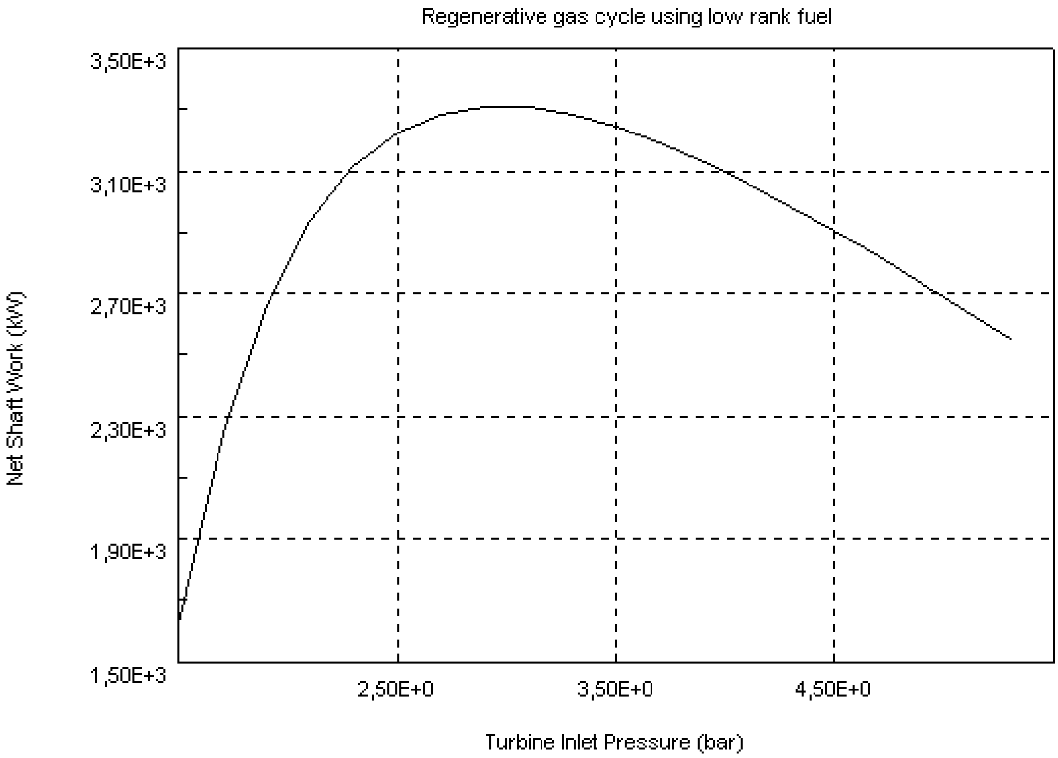

Figure 3.2
Net shaft work of the regenerative cycle of Figure 3.1 as function of the pressure in the combustion chamber.

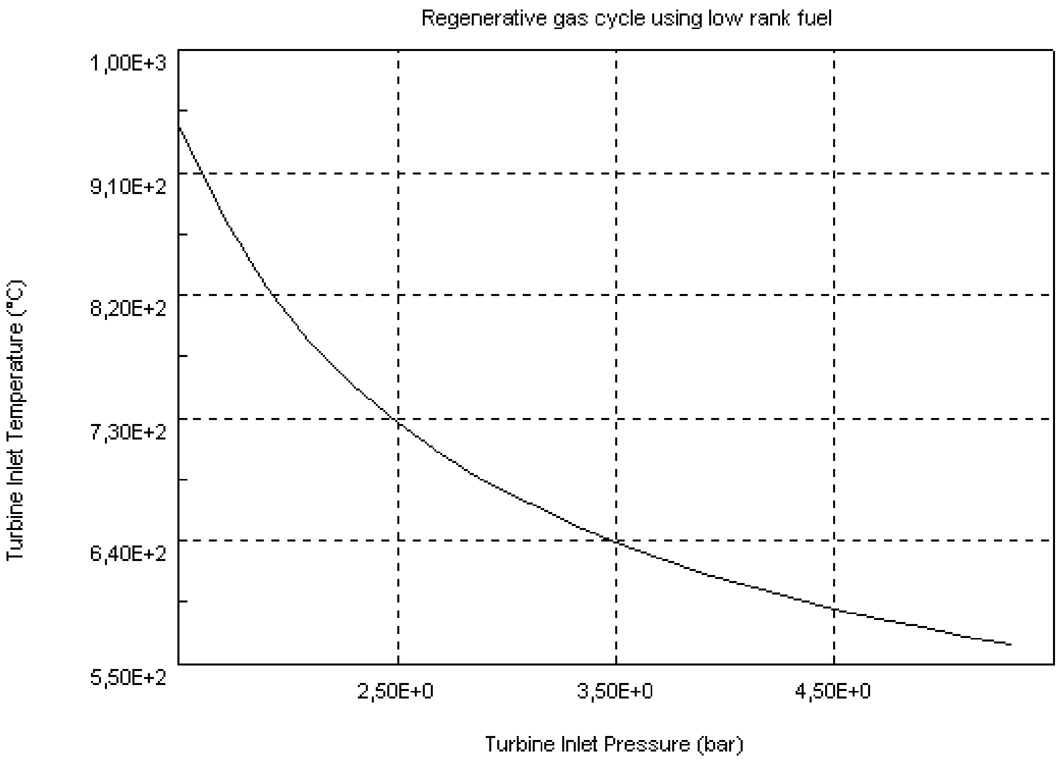

Figure 3.3
Gas temperature at the turbine entry of the regenerative cycle of Figure 3.1 as function of the pressure in the combustion chamber.

GEOTER

A flow diagram of the condensing geothermal power plant is shown in the following figure.
A mixture of steam, carbon dioxide and liquid water at pressure of 18 bars and at temperature of about 205 °C expands through a condensing steam turbine after separation of liquid water. The condenser is of direct contact type; non-condensable gases are extracted by means of a three stage compressor with inter cooling between first and second stage. An induced draft-cooling tower cools the water from the condenser. Water from cooling tower is partly discharged before returning to the condenser because the process generates liquid water. The components VLV have been introduced for modelling concentrated pressure drops.

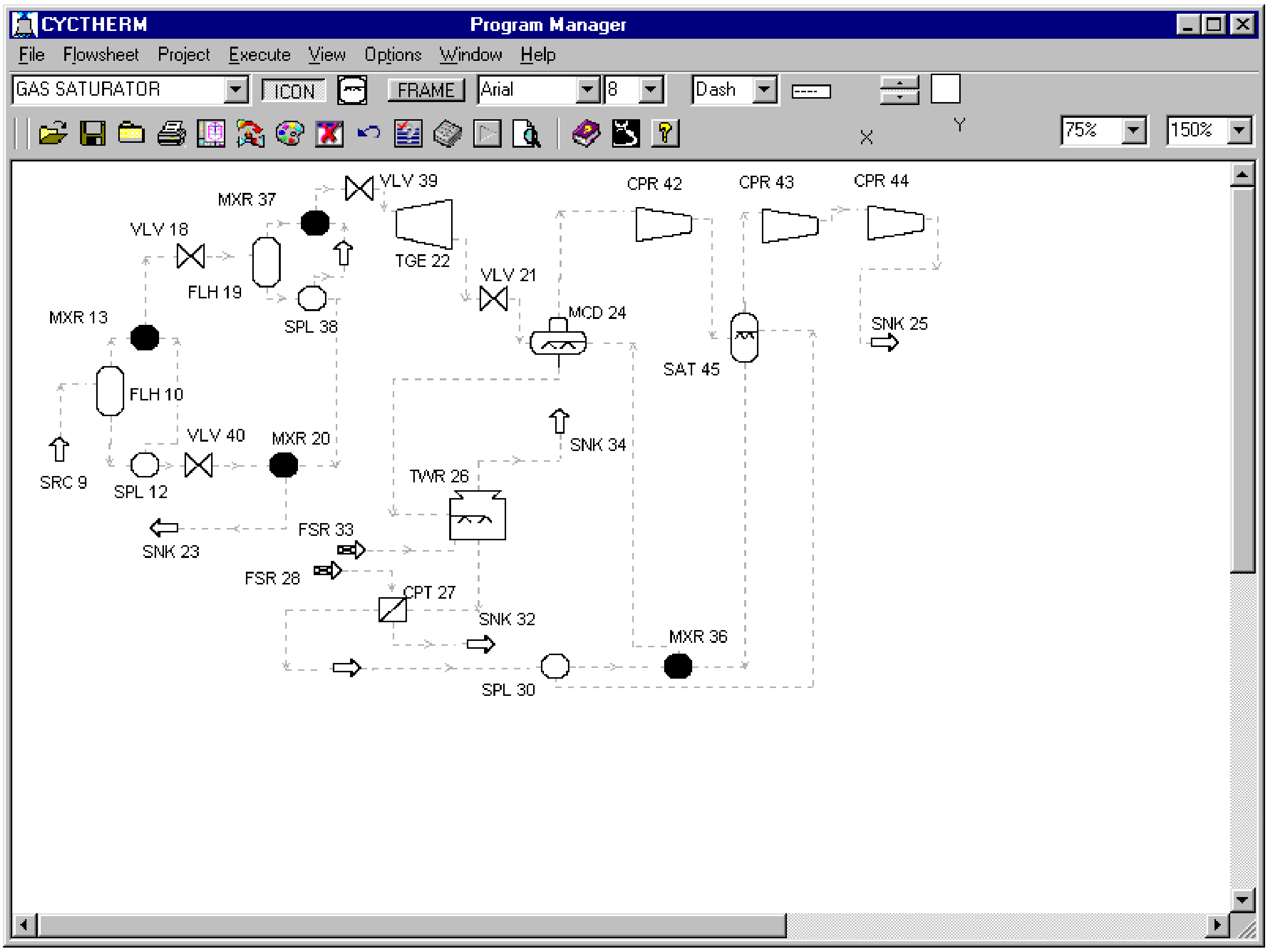

Figure 3.4
Flow diagram of a geothermal power plant fed by a mixture of water, steam and non condensable gas.

FLASH

The double flash process (see figure below) is utilised for almost pure steam generation from mixtures of water and non-condensable gases at temperatures lower than the dew point. The component MCD 3 simulates a *condenser-reboiler* and operates at a pressure of approximately 11 bar. The component SCR 1 feeds the process with a water solution (30 % of Carbon dioxide) at 180 °C and 24 bar.

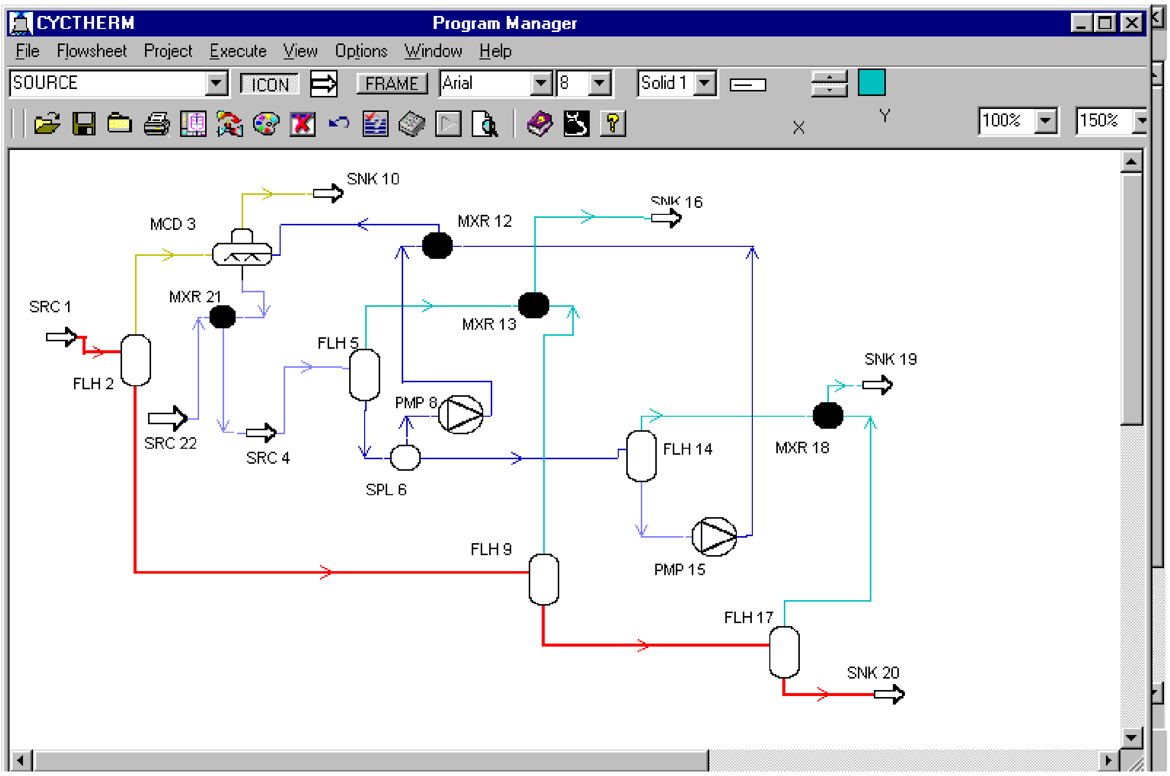

Figure 3.5
Double flash process of a low temperature water-gas mixture.

PLANT

The process Plant, shown in following figure, refers to an electric power generating unit and adopts a sub-critical thermal cycle with re-heating and regenerative cycle with seven heaters. The steam, generated at 170 bar and 538 C, expands through three different turbines in cascade with multiple bleedings. The component TVP is used to model the steam expansion across one or more stages. The gross shaft power is about 580 MW.

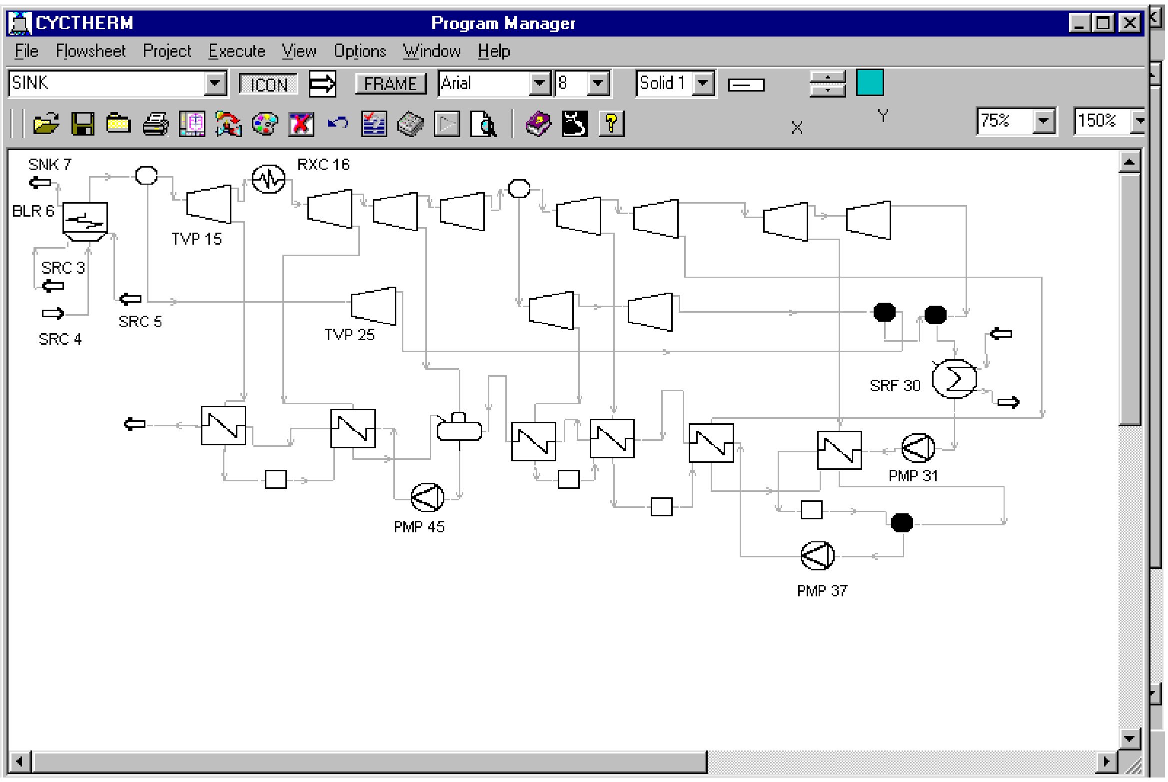

Figure 3.6
Flow diagram of a thermal power plant fuelled by lignite.

KALINA

The figure shows a process that adopts a mixture of water and ammonia to recover the heat content of the flue gas of a stroke engine. The water-ammonia vapours produced in a heat recovery boiler expand through a turbine down to a pressure slightly lower than the atmospheric and generate useful work. A complex condensing system at the turbine exit generates the water-ammonia mixture with same composition existing at the inlet of the cycle.

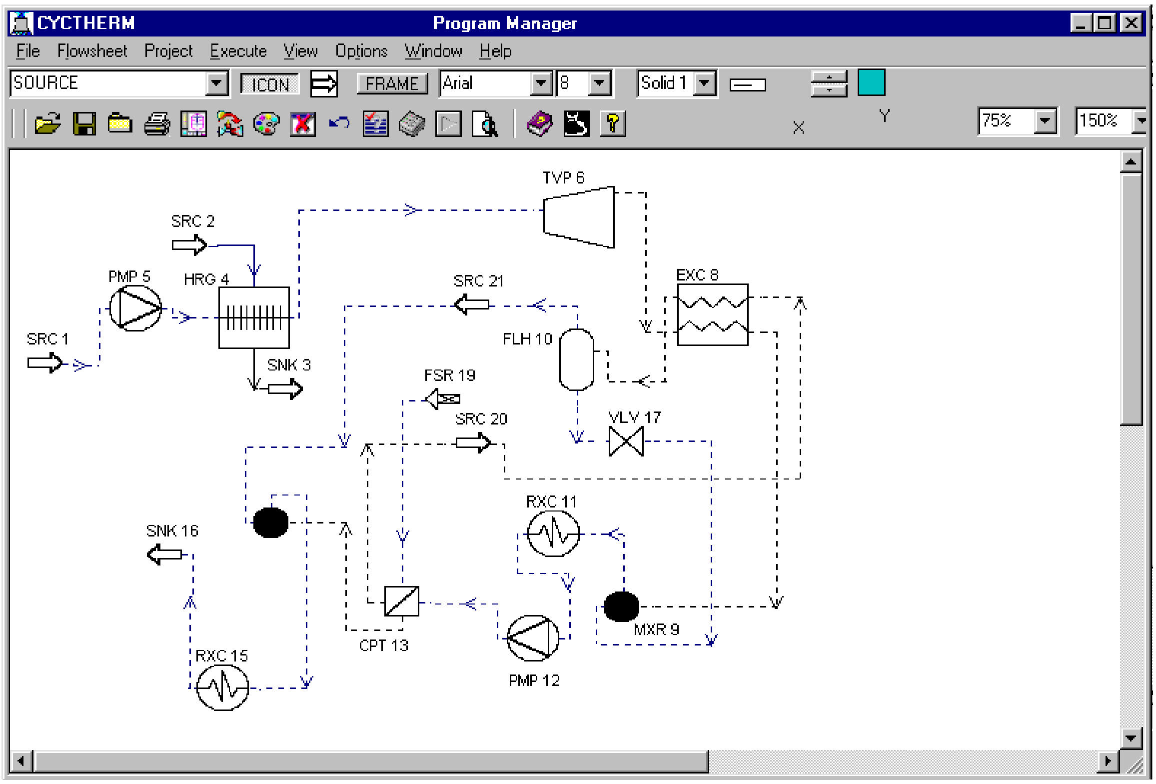

Figure 3.7
Process flow diagram of the Kalina cycle.

COMPLEX

The following figure shows the flow diagram of the thermal cycle of a supercritical steam-generating unit of 660 Mwe. The cycle features a single re-heater stage and a regenerative circuit equipped with ten closed feed-water heaters

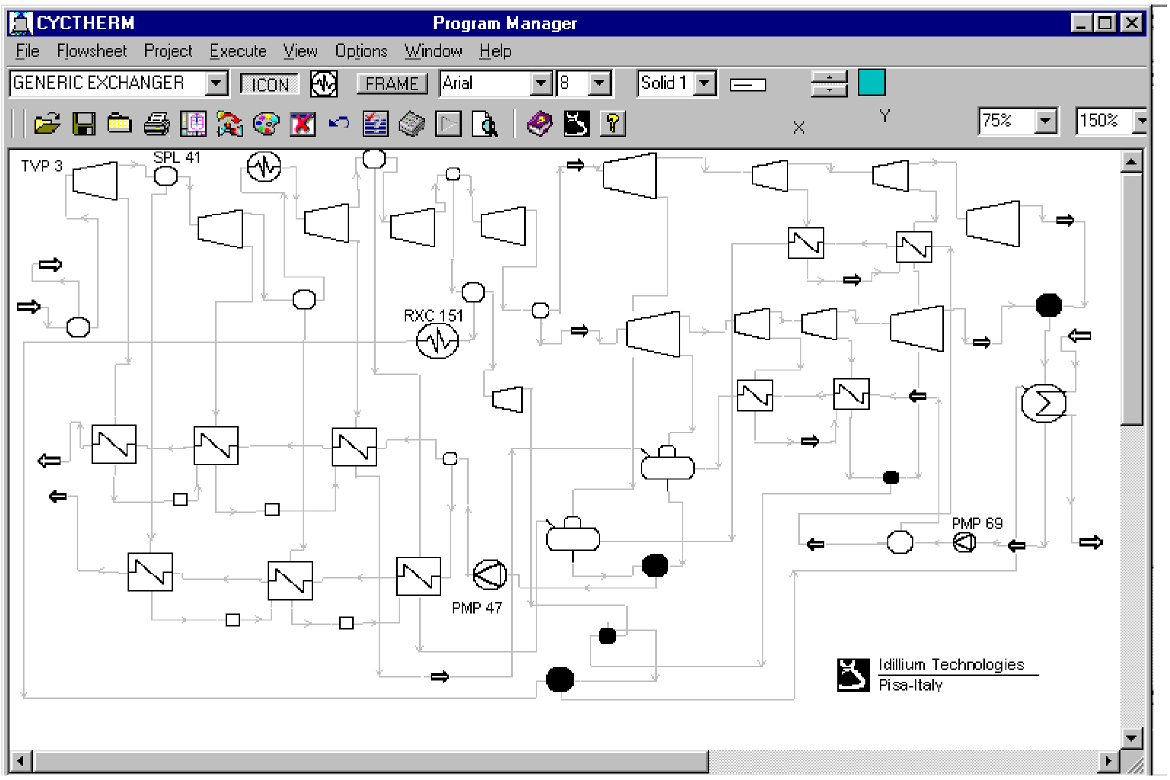

Figure 3.8
Thermal cycle of a supercritical steam electric power generating unit.

COMBINE

The figure below shows the scheme of a gas-steam combined cycle fuelled by natural gas. The steam cycle features two pressure levels.

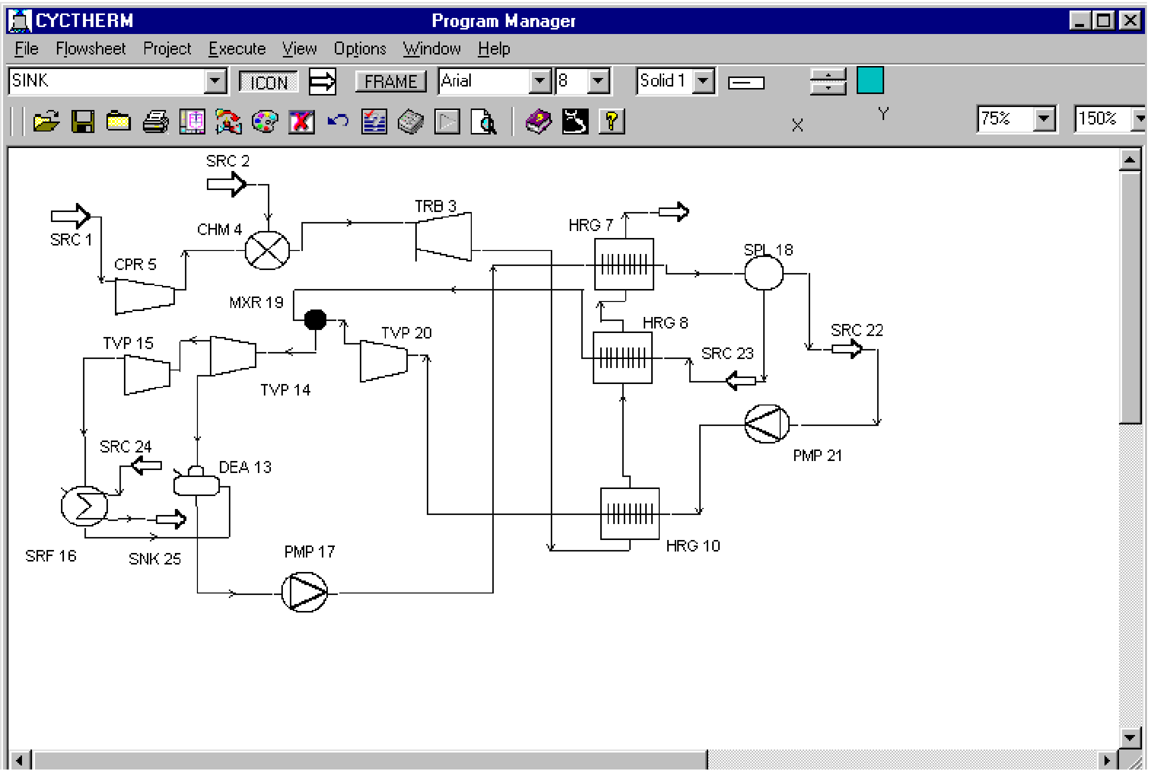

Figure 3.9
Flow diagram of a two pressure levels combined cycle.