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HEAT BALANCE STUDIES AND OPERATION OPTIMISATION WITH ECOSIMPRO

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Abstract

Within the environment of EcosimPro, the THERMAL_BALANCE library has been developed to carry out thermal analyses. It includes typical equipment components which usually form part of Thermal, Nuclear and Combined Cycle Power Plants. At the present time the library contains components which only work in stationary operating conditions, but there are plans to include dynamic components for analysing transient operating conditions.

Key words: Heat Balance, BOP

1. INTRODUCTION

For more than 15 years, our heat balance calculation program HBAL has been of great assistance in studies aimed at improving the performance and predicting the behaviour of thermal cycles in Power Plants. It has been applied to a large part of our nuclear and fossil-fired park, not to mention a number of foreign power plants.

Especially prepared to perform heat balance analyses with EcosimPro, the THERMAL_BALANCE components library has been based on the formulation of the old HBAL components. Where necessary, it has been corrected so that, taking advantage of the power of the algorithms of the differential algebraic systems of equations incorporated into EcosimPro, the library would be capable of transient state analyses. The advantages of one of the most modern and effective simulation packages on the current market have been combined with the experience of HBAL, giving rise to a product which is both easy to use and of wide scope so that models can be built and executed in truly reduced times in a user-friendly environment.

The library admits three systems of units, namely, the International System of Units, metric and imperial.

2 LIBRARY COMPONENTS

The library (see Figure 1) currently contains the following components:

Abstract Components

COMPONENT	FUNCTION
Channel	Component with a *water* IN port and OUT port
AdiabaticChannel	Channel with equal inlet – outlet enthalpies
Burner	Gas component in which combustion takes place

Operating Components

COMPONENT	FUNCTION
AirInlet	Air supply
Alternator	Alternator
Aux_turbine	Auxiliary turbine
Boiler	Boiler
Chamber	Combustion chamber
Compressor	Compressor
Conden_SPE	Seal steam condenser
Condenser	Main condenser
Deaerator	Deaerator
Dereheat	Dereheat
Divider	Water divider
DrainCooler	Drain cooler
Drum	Boiler drum
Economiser	Economiser
Evaporator	Evaporator
FeedWaterHeater	Feedwater heater
Flash_Tank	Flash tank
Gas_inlet	Gas inlet
Gas_Turbox	Gas turbine
Gpipe_nat	Gas pipe
Heater	Heat exchanger
Mixer	Mixer
MoistSeparator	Moisture separator
Motor	Internal combustion engine

COMPONENT	FUNCTION
Pipe	Pipe
Pump	Pump
Split	Gas split
Reheater	Reheater (with steam)
Superheater	Superheater
Tower	Cooling tower
Turbine	Steam turbine stage
Valve	Valve

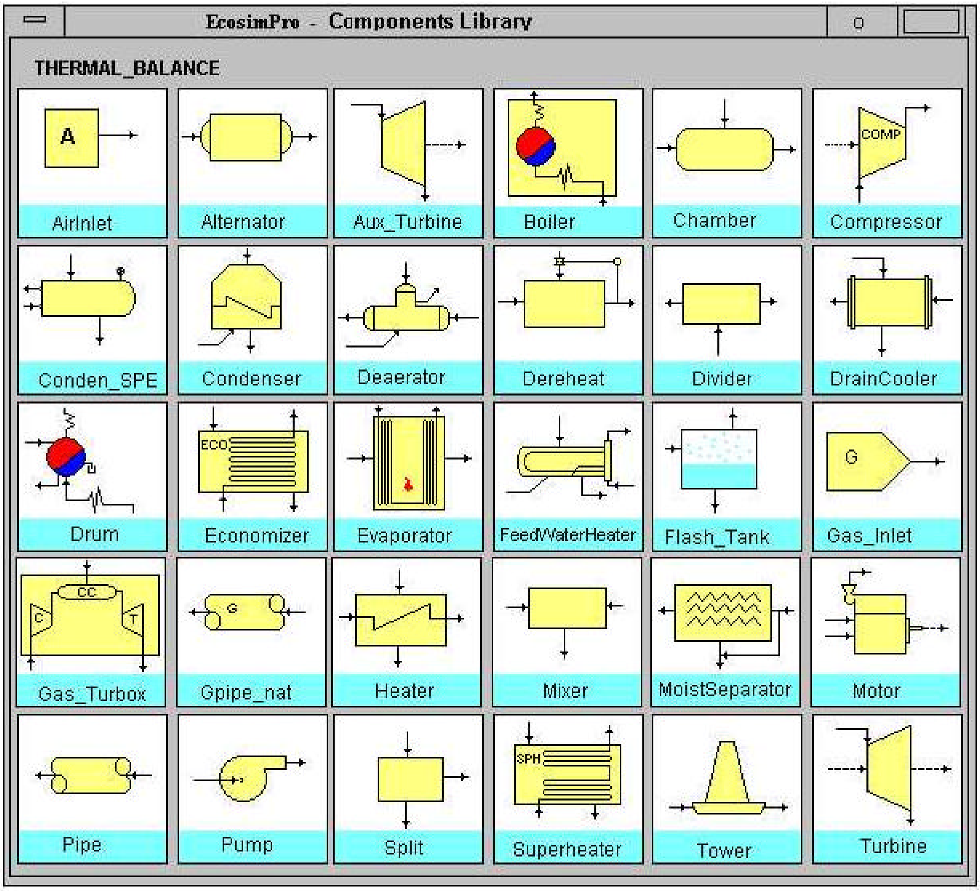

Figure 1: Thermal_Balance
Library Components

3 PORTS USED BY THE LIBRARY

The library uses two types of ports, ie,: "**water**" and "**gas**", for the working fluids which are water-steam and gases, respectively.

The ports calculate all the thermodynamic and transfer variables necessary as a function of pressure and enthalpy —both in the case of water/steam and in the case of gas flows— using the ASME functions embedded in an external object (developed in Visual Fortran). The object includes the functions for water/steam, as well as those for gases admitted as working fluids, these being: air, H_2,O_2, N_2, CO_2, CO, He, Ar, CH_4, C_2H_6, C_3H_8, C_4H_{10}, SO_2 and H_2O.

4 EXAMPLE OF A PLANT MODEL BUILT WITH ECOSIMPRO

4.1 MODEL OF AN 800 MW COMBINED CYCLE POWER PLANT

Figure 2 is a functional diagram of a model built of a combined cycle power plant and Figure 3 shows the block diagram of the model created with EcosimPro.

Simulation was oriented to the analysis of plant behaviour operating with different loads under stationary conditions, the consequences of different types of failures and the study, *a priori*, of a set of procedures which facilitates the obtainment of maximum performance and minimises the consequences of breakdown, component replacement, etc.

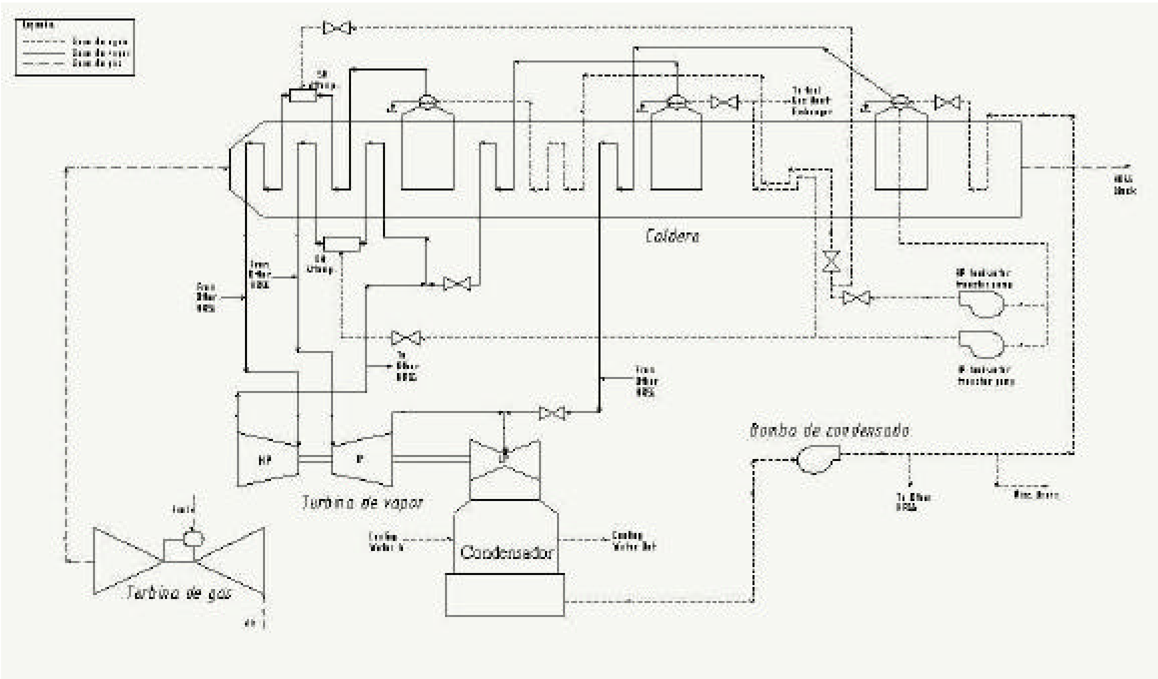

Figure 2

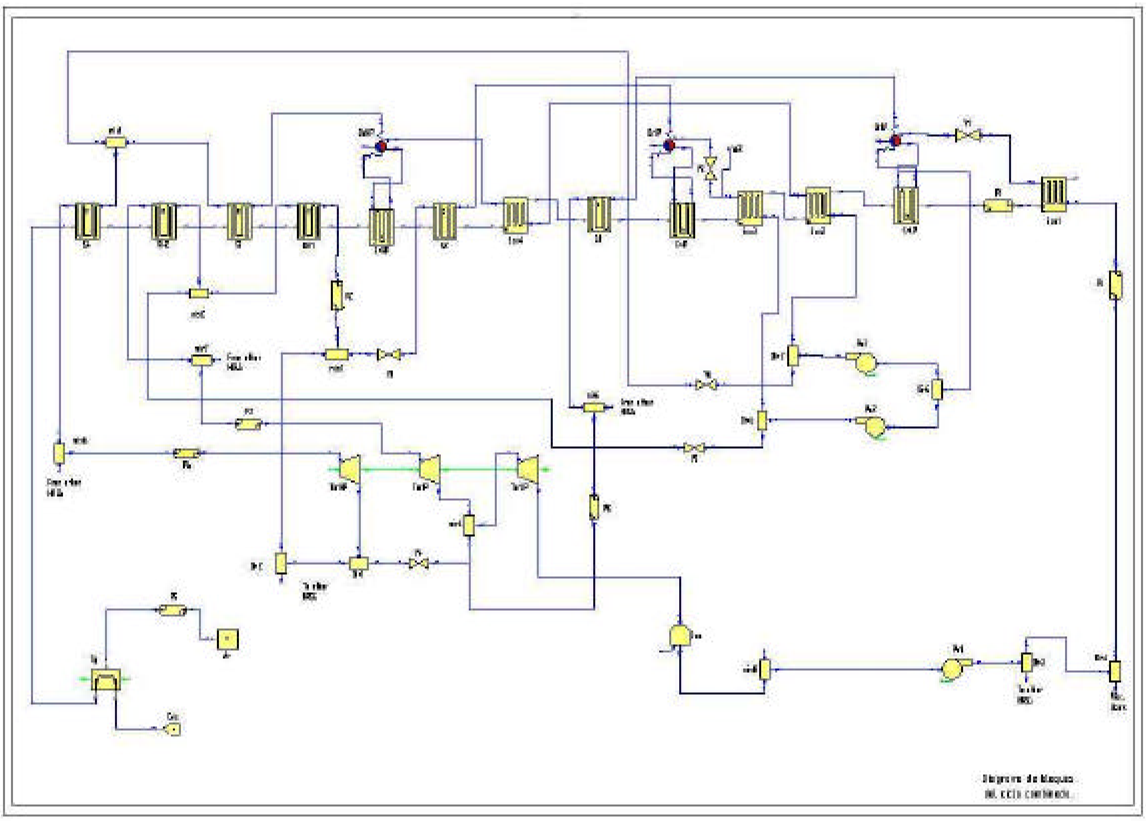

Figure 3

4.2 MODEL OF A SPENT FUEL STORAGE POOL AND ITS ASSOCIATED COOLING SYSTEM

The Heat Balance components library was used to build this model (Figure 4) and advantage was taken of the possibility offered by EcosimPro to reuse components, which meant that we only had to build a couple which were specific to the study of this problem:

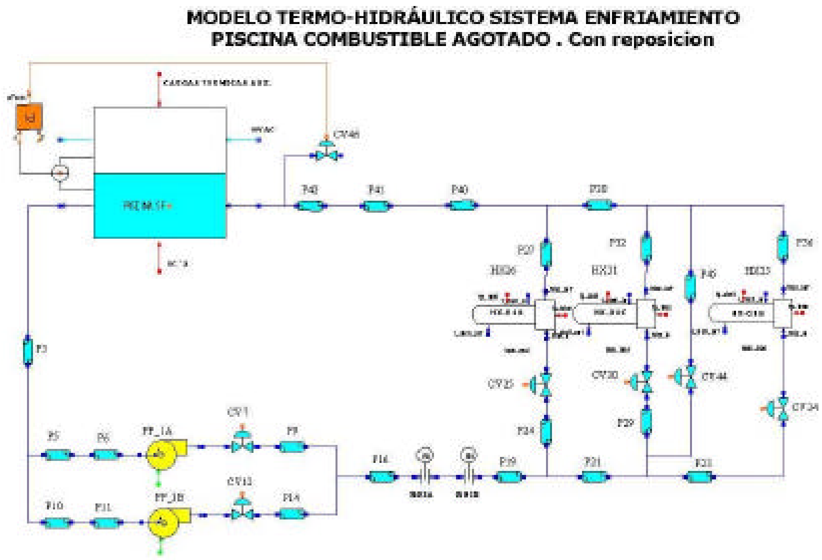

Figure 4

The first component is a heat exchanger which is capable of reproducing, with the required degree of detail, the behaviour of those installed in the power plant. To this effect we took one of the heat exchanger models included in the ECLSS library and adapted it to our requirements.

The second component constitutes the enclosure that houses the spent fuel pool. It includes the fuel pool itself and its atmosphere, so that it has four connection ports, ie an atmospheric air inlet and outlet and a water inlet and outlet. Two thermal ports allow the addition to the enclosure of heat from the fuel elements and environmental heat produced by equipment located inside the enclosure.

In this component we model all the phenomena of the exchange of mass and energy between the free surface of the pool and the ambient atmosphere (conduction, convection, radiation and evaporation or condensation).

With the model we can assess the behaviour of the system on the basis of both the thermal load and the cooling conditions. The model has also been used to solve the problem of determining —for a series of pool temperature measurements and certain cooling water inlet environmental conditions— the heat contribution owing to spent fuel. Given that the pool temperature is one of the dynamic variables, this case gives rise to a high index problem to which EcosimPro’s response can be summarised into the following steps:

1. It detects that there is a high index problem.
2. It symbolically differentiates the analytical function of temperature adjustment using variable coefficients of measured temperature for each time interval.
3. It solves the overall problem.

Examples of outputs for this case are shown in Figure 5.

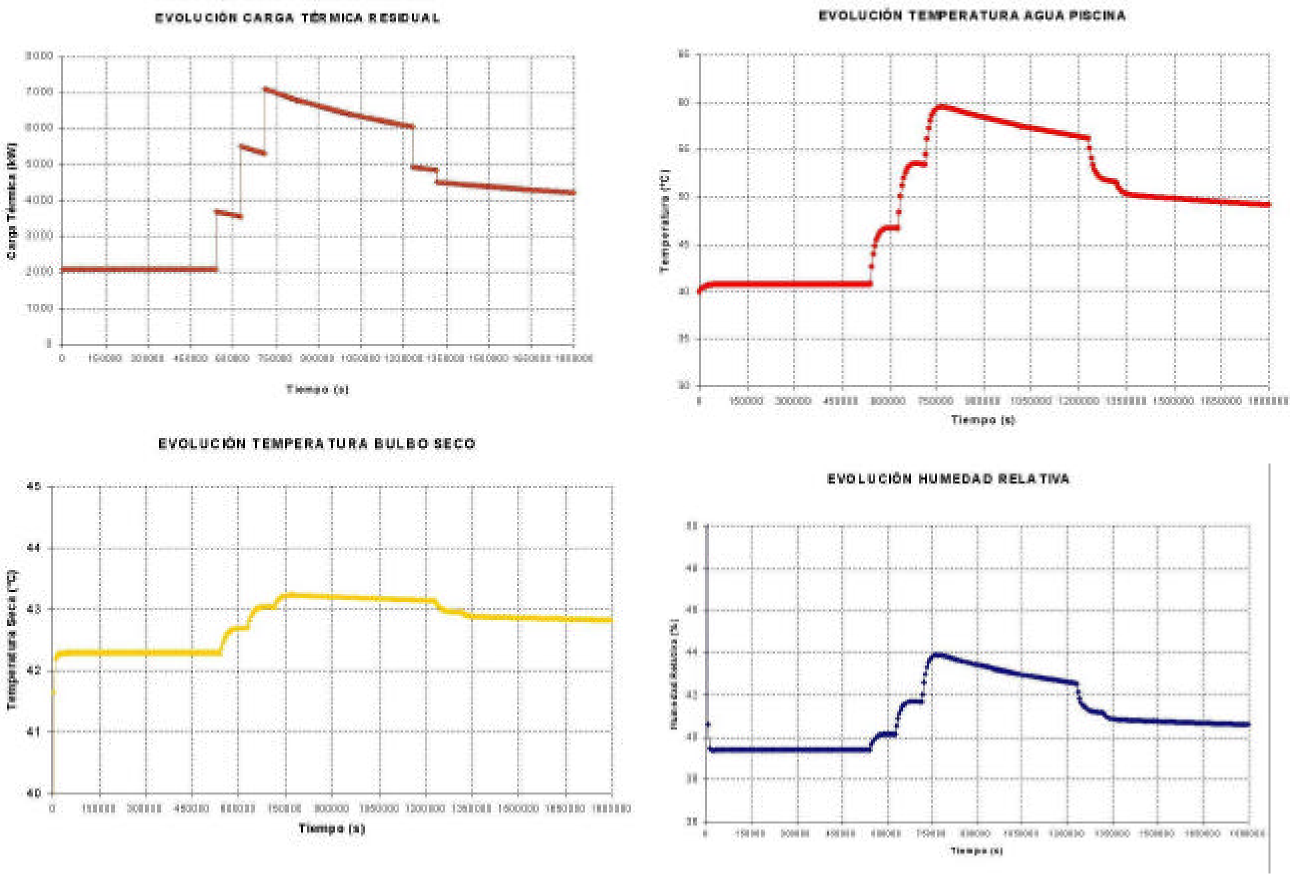

Figure 5.

5. CONCLUSIONS

EcosimPro has proved to be of great help in building behaviour models of power plants both in stationary and transient operating conditions. They have been easy to build and adapted to the needs of each moment.

A library of components which are suitable for studies of conventional systems and BOP is now a reality and it will grow with the addition of other components which are oriented to more specific studies of power plant systems.

6. ATTACHMENT: EXAMPLES OF MODELLING WITH EL (EcosimPro Language)

"Water" port

as described in section 3

```
PORT Water
        SUM REAL  W = 1 "Mass flow (kg/s, Tn/h, or Lb/h)"
        EQUAL REAL P = 10 "Pressure(bar, kg/cm2, or PSI"
        EQUAL OUT REAL H = 200 "Enthalpy (Kj/Kg, Kcal/Kg, or Btu/lb)"
        SUM IN REAL WH "Energy flow (kW)"
        REAL T  = 150 "Temperature (ºC,ºC,ºF)"
        REAL X = 0 "Quality"
        REAL rho = 1000. "Density (kg/m3,Kg/m3,lñb/ft3)"
        REAL S = 1.3 "Entropy(kj,kg/C,kcal/kg/c,Btu/lb/F)"
CONTINUOUS
        WH = W*H*CONV_Q[UNI]
        INVERSE(H) div_safe(WH,W*CONV_Q[UNI],1.e-6,H)
        H2_STATE_PH (P,H,T,rho,s,X,IU())
END PORT
```

"MoistSeparator" component

It represents a moisture separator with the possibility of also separating dry steam of extraction to a heater
It includes a SteamTrap parameter, the objective of which is as follows:
If SteamTrap is TRUE, the moisture separator sets the flow through w_moist port without allowing "dry" flow through the outlet line
If it is FALSE, the outlet flow through the w_moist port is left undetermined and a component (normally a heater) located downstream will request power, so that a "dry" flow is also removed from the moisture separator outlet line via the w_moist port until the balance is closed.
It has two DATA, eff (moisture separator efficiency) and
wfrac is the fraction of water carried.

```
COMPONENT MoistSeparator (BOOLEAN SteamTrap = TRUE )
PORT
        IN Water w_in
        OUT Water w_out
        OUT Water w_moist
DATA
        REAL eff = 0.9 "Efficiency"
        Real wfrac = 0. "fraction of water carried"
DECLS
        REAL hf
        REAL w_H2O_sep
        REAL wfrac_w
        REAL w_extr
DISCRETE
        ASSERT (w_moist_w > w_H2O_sep+wfrac_w) ERROR "Total flow less than necessary"

CONTINUOUS

  w_in.W = w_out.W + w_moist.W
  w_extr = w_moist.W - w_H2O_sep

  w_out.P = w_in.P
  w_moist.P = w_in.P

  w_H2O_sep = w_in.W * eff * (1 - w_in.X)
  wfrac_w = w_in.W * wfrac
  EXPAND (SteamTrap == TRUE)
      w_moist.W = w_H2O_sep + wfrac_w
  hf = H2O_H_vs_PX (w_in.P, 0.,IU())
  w_out.H = (w_in.H - eff * (1.-w_in.X) * hf)/\
     (1 - eff * (1 - w_in.X))
  w_in.WH = w_out.WH + w_moist.WH

END COMPONENT
```

FIGURE 2

KEY
water line
steam line
gas line

a. Boiler
b. Gas turbine
c. Steam turbine
d. Condenser
e. Condensate pump

FIGURE 3

Combined cycle block diagram

FIGURE 4

THERMO-HYDRAULIC MODEL OF THE SPENT FUEL POOL COOLING SYSTEM. With replacement

a. Aux. Thermal Loads

FIGURE 5

a. EVOLUTION OF RESIDUAL HEAT LOAD
b. Thermal Load (kW)
c. Time (s)

d. EVOLUTION OF SPENT FUEL POOL WATER TEMPERATURE
e. Temperature (°C)
f. Time (s)

g. EVOLUTION OF DRY BULB TEMPERATURE
h. Temperature (°C)
i. Time (s)

j. EVOLUTION OF RELATIVE HUMIDITY
k. Relative Humidity (%)
l. Time (s)