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MODELLING AND SIMULATION OF AN INDUSTRIAL STEAM BOILER WITH ECOSIMPRO

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Abstract

A steam boiler is a complex system comprised of numerous components. With EcosimPro, each component has been modelled individually in such a way that when they are fitted together, the complete boiler can be simulated. A real industrial boiler was taken as a reference to build the model.

Key words: Simulation, EcosimPro, object-oriented modelling, steam boilers, control systems.

1   INTRODUCTION

A steam boiler is a process unit of great importance in all types of industries. An industry's need for steam can generally be summarised into:
- steam as a means of direct or indirect heating
- steam as a raw material
- steam as a means of generating electrical power

The effective control of a boiler's operating conditions is an obvious necessity if we take into account that the high working pressures and temperatures are the main hazard problems because of the risk of explosion. Nor should we forget the financial aspect, considering not only the costs of construction, but also the high costs of operation (the great amounts of fuel burnt) and the cost of maintenance related with the above-mentioned operating conditions.

The search for these optimum operating conditions and a way to control them is not an easy task, because a steam boiler is a very complex system in which all the variables are interrelated. And what is more, it is very difficult to carry out tests directly on a boiler, both from the technical point of view (because of the dangers derived from manipulating the operating conditions), and the economic point of view (the time and money necessary). Taking this into consideration, we have to look for an alternative method of analysis: simulation.

Simulation is the representation of the behaviour of a real process through the resolution of a mathematical model. The advantages of using mathematical models can be summarised as follows:
  - A process can be analysed in depth, determining which variables or parameters are critical and have a decisive effect on overall system behaviour.
  - They are of great help in the search for optimum operating conditions.
  - Limit or extreme conditions, far away from the normal operating conditions, can be studied safely to analyse their consequences.
  - They can be used for teaching purposes: operator training.

2   OBJECTIVES

The objectives that were established when this work was undertaken can be summarised into:
- Study of the process unit and the elements of which it is comprised.
- Development of a dynamic mathematical model and simulating it with EcosimPro.
- Estimation of parameters and model´s validation by means of comparison with real operating data.
- Design of the complete control system.

This work forms part of a project, the ultimate objective of which is to develop a complete simulator of a sugar production plant to be used for training operators.

3   OPERATION OF A STEAM BOILER

The principle of boiler operation is simple: the aim is to evaporate water and superheat the steam obtained using the energy which is released in a combustion reaction. Specifically, the steam boiler which was chosen as the basis for the model operates in the following way: (see Figure 1)
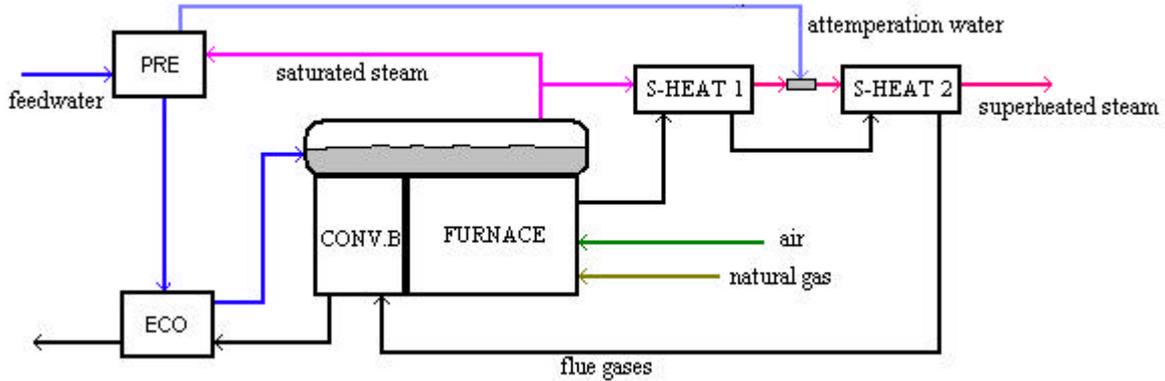
Figure 1. Sketch of the Operation of an Industrial Steam Boiler

Before the feedwater enters into the actual steam generator system, it passes through a heat exchanger where it is preheated before it enters the economizer. Saturated steam taken from the boiler is used as the heating medium.

Using the flue gases generated in the actual boiler as the heating medium, the water continues to be heated in the economiser but it does not turn into vapour.

From the economizer, the water goes to the steam drum and from there it passes through the downcomers into the water drum. It is then distributed through the different steam generation circuits associated with the combustion chamber and the convection bank.

As the water rises through the tubes (by natural circulation) part of it turns into vapour, so that it forms a mix of vapour and water when it returns to the steam drum. The steam generated in the drum must be separated from the water, and for this purpose a cyclonic separator system has been installed.

The dry steam leaving the steam drum goes to the superheating section which is formed by two superheaters separated by a attemperator. When it leaves the secondary superheater, the steam goes to process.

This boiler, which has been chosen as a basis for the model, produces superheated steam at 40 bar and 380°C from water at 120°C. As fuel it uses natural gas with a lower calorific power equal to 9100 kcal/m³N.

4 PHYSICAL-MATHEMATICAL MODEL

To build the model of the steam boiler, it has been divided into the different elements of which it is comprised, modelling each one separately so that when they are fitted together, we can simulate the overall behaviour of the boiler.

The following are the main elements considered:
- Combustion furnace
- Convection bank
- Primary and secondary superheater
- Attemperator
- Economizer
- Water preheater
- Steam drum and water drum
- Ducts and pipes
- Chimney
- Fan

Each unit is modelled based on the laws of conservation of mass, energy and momentum, aiming always for the correct balance between a reliable representation of the real process and the mathematical complexity derived therefrom. It is an undertaking that can be translated into the consideration of certain suppositions and the calculation of certain parameters.

Generally speaking, the laws of conservation can be translated mathematically as:
Balance of mass:

$$\frac{dM}{dt} = W_{entrada} - W_{salida} + W_{generación} - W_{consumo} \qquad (1)$$

Balance of energy

$$\frac{d(M \cdot H)}{dt} = W \cdot H_{entrada} - W \cdot H_{salida} + Q_{absorbido} - Q_{cedido} \quad (2)$$

Transmission of heat

$$Q = U \cdot S \cdot (\Delta Tm) \quad (3)$$

Balance of momentum (Bernoulli Equation)

$$\frac{P_1}{r \cdot g} + z_1 + \frac{u_1^2}{2 \cdot g} = \frac{P_2}{r \cdot g} + z_2 + \frac{u_2^2}{2 \cdot g} + hf \quad (4)$$

where: ΔTm (average temperature difference), H (specific enthalpy), hf (pressure drop), P (pressure), Q (heat flow), S (effective heat exchange surface), U (overall coefficient of heat transmission), W (mass flow rate), z (height), ρ (density).

These equations are used to model all the units that comprise the boiler, adjusting them to each specific case. The most complex units from the point of view of modelling are the combustion furnace and the steam drum and, for this reason, it was considered necessary to describe them in more detail.
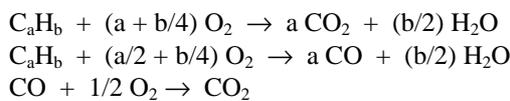
4.1 COMBUSTION FURNACE

The combustion furnace is one of the most important parts in a steam boiler. It is where the combustion reaction of the selected fuel takes place (in this case, natural gas) with the combustion agent (air). These reactions are highly exothermic and they provoke the appearance of a flame. The existence of this flame and the high temperatures reached as a result of the combustion means that the greater part of the heat which goes towards the tubes where the water evaporates is transmitted by radiation.

The following is a brief description of the equations used to model this unit, as well as of the suppositions that have been considered.

4.1.1 Combustion Reaction

Combustion has been considered as instantaneous and incomplete. The reactions that take place can be described as follows:

$C_aH_b + (a + b/4) O_2 \rightarrow a CO_2 + (b/2) H_2O$
$C_aH_b + (a/2 + b/4) O_2 \rightarrow a CO + (b/2) H_2O$
$CO + 1/2 O_2 \rightarrow CO_2$

Taking into account these reactions, the composition of combustion gases is expressed as:

$$0 = Wi_{entrada} - Wi_{salida} + Wi_{generado} - Wi_{consumido} \quad (5)$$

where W_i is the mass flow rate of the 'i' species present in the gases. The sum of all the output flows will give us the total amount of flue gas produced.

4.1.2 Heat Flow Exchange

In order to construct the combustion furnace model correctly, each and every single exchange of energy between the elements that comprise it must be analysed. In this regard, we have to consider:
Flows of radiation [1] between surfaces and flames:

$$Q_{LL \to S} = A_S \cdot s \cdot \frac{e_s + 1}{2} \cdot e_{LL} \cdot \left[T_{LLAMA}^4 - T_S^4 \right] \quad (6)$$

Flows of radiation between surfaces and combustion gases [1]:

$$Q_{G \to S} = A_S \cdot s \cdot \frac{e_s + 1}{2} \cdot \left[e_G T_G^4 - a_G T_S^4 \right] \quad (7)$$

The furnace floor is lined with a layer of firebrick (to prevent direct contact of the tubes with the gases). The flow of radiation exchanged between this wall and the tubes can be expressed by [1]:

$$Q_3 = s \cdot A \cdot \frac{1}{\left(1/e_{Pared} + 1/e_{Tubo} - 1 \right)} \cdot \left(T_{Pared}^4 - T_{Tubo}^4 \right) \quad (8)$$

In these equations: A (surface of heat exchange), Q (flow of heat), T (temperature), σ (Stefan-Boltzmann constant), ε (emissivity), a (absorptance).

To calculate the flow of heat exchanged by radiation and convection between the combustion gases and the tubes through which the water circulates, the Lobo-Evans method has been used [3]:

$$Q = 0.173 \cdot F \cdot \left[\left(\frac{T_G}{100} \right)^4 - \left(\frac{T_T}{100} \right)^4 \right] \cdot a \cdot A_{cp} + \\ + h_c \cdot A \cdot \left(T_{Gas} - T_{Tubo} \right) \quad (9)$$

where A (total surface of the tubes), A_{cp} (equivalent plane surface of the tubes), F (overall exchange factor), h_C (convection coefficient), Q (flow of heat), T (temperature), α (absorption efficient factor).

The heat transmitted from the tubes to the water circulating through them can be calculated with the equation [2]:

$$Q_W = h_i \cdot S_{iTUBO} \cdot \left(T_t - T_{W \; HOG} \right) \quad (10)$$

where: h_i (coefficient of heat transmission), S_{TUBO} (averaged total interior surface of the tubes), T (temperature).

4.1.3 Balances of Mass and Energy: Temperature Calculations

When it comes to calculating the balances of mass and energy of the combustion furnace, each of the elements that comprise it will again have to be considered separately: flame, walls, gases, tubes, water.

4.1.3.1 Flame Temperature

To calculate the temperature reached by the flame, the flame's energy balance must be determined taking into consideration that all the heat given off in the combustion of natural gas with air is transmitted to the walls and the tubes that form the combustion chamber and to the gases generated in the reaction.

$$W_{comb} \cdot H_{comb} + W_{air} \cdot H_{aire} + H_{reac}^{\circ} = W_{Humo} \cdot H_{Humo} + Q_{LL} \quad (11)$$

4.1.3.2 Furnace Walls

The firebrick walls have been considered as grey surfaces with high emissivity. They have the capacity to absorb and emit energy [1].

$$M_{Pared} \cdot Cp_P \cdot \frac{dT_{Pared}}{dt} = Q_{absorbido} - \left(s \cdot A_P \cdot e_P \cdot T_{Pared}^4 \right) \quad (12)$$

The heat absorbed is the sum of the heat radiated by the flame and the heat radiated by the gases.

4.1.3.3 Combustion Gases

As the combustion gases pass through the furnace, they get involved in different heat exchange processes which modify their outlet temperature from the combustion chamber.

$$\frac{d(M_H \cdot H_H)}{dt} = W_H \cdot H_{H\ llama} - W_H \cdot H_{H\ out} + Q_{Humos} \quad (13)$$

The term Q_{humos} represents the *net heat flow*; the heat the gases exchange with the other elements. It includes: heat from the flame which is absorbed by the gases, heat exchanged with the firebrick walls, heat transmitted by the gases to the tubes of the radiant section via a combined mechanism of radiation and convection.

4.1.3.4 Radiant Section Tubes

The tubes that form the boiler furnace are exposed to very high temperatures and are in the presence of dry gases that could be corrosive. The control of tube temperature is an important point to be studied to prevent breaks that might occur if the thermal resistance of the material is exceeded. This temperature can be analysed by applying an energy balance to the tubes:

$$M_T \cdot Cp_T \frac{dT_T}{dt} = Q_{TUBOS} - Q_W \quad (14)$$

The total heat (Q_{TUBOS}) absorbed by the tubes includes: heat radiated by the flame, convection and ratiation heat from the gases, heat given off by a layer of firebrick covering the furnace floor, heat losses through the insulation.

4.1.3.5 Water that Evaporates

Due to the heat transmitted through the walls of the tubes, a part of the water that rises from de water drum to de steam drum turns into vapor.

To simplify the model, the temperature and pressure profile throughout the length of the water risers has not been modelled.

$$\frac{d(M_W \cdot H_W)}{dt} = W_{W\ in} \cdot h_{W\ in} - W_{W\ out} \cdot H_{W\ out} - W_{V\ out} \cdot H_{V\ out} + Q_W \quad (15)$$

$$W_{W\ in} = W_{W\ out} + W_{V\ sal} \quad (16)$$

In all these equations: Cp (specific heat), M (mass), h_W (specific enthalpy of the water), H (specific enthalpy), H_V (specific enthalpy of the steam), H°_{reac} (flow of heat emitted in the combustion reaction), Q (heat flow), T (temperature), W (mass flow).

4.2 STEAM DRUM

From the point of view of modelling, the objective is to represent the shrink and swell phenomenon: increases or decreases in the demand for boiler steam bring out a variation in level quite the contrary to that which we would intuitively expect.

If there is a sudden increase in the demand for steam, instead of a level decreasing with the extraction of more steam, it temporarily increases due to a momentary drop in steam pressure brought about by the increase in consumption. This initial drop in pressure brings about greater evaporation and an increase in the size of the steam bubbles (*swell phenomenon*) which causes the level in the drum to rise until the flow of heat can increase enough to restore the pressure value.

On the other hand, if there is a sudden decrease in the demand for steam, there will be a temporary decrease in the drum level (*shrink phenomenon*). A similar

phenomenon takes place with the change of feedwater.

To model these phenomena, it has been assumed that three distinguishable phases coexist at all times inside the drum - water, steam and bubbles - which must be studied separately. (See Figure 2.)
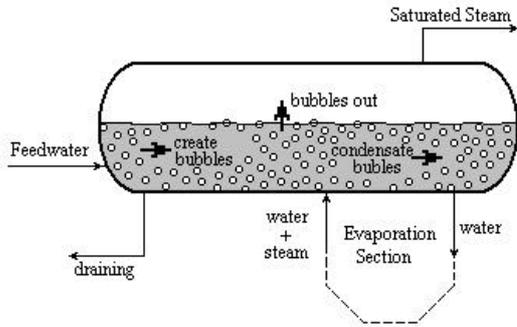

Figure 2. Sketch of Currents in the Steam Drum

4.2.1 Mass Balances

$$\frac{dMw}{dt} = Ww_{feed} - Ww_{purga} - Ww_{in\ c.evap} + Ww_{out\ c.evap} + \quad (17)$$
$$+ \quad Wb_{cond} - Wb_{crean}$$

$$\frac{dMv}{dt} = Wb_{salen} - Wv_{out} \quad (18)$$

$$\frac{d\ Mb}{dt} = Wv_{in\ c.evap} - Wb_{cond} + Wb_{crean} - Wb_{salen} \quad (19)$$

The terms for the bubbles that condense, that are created and that pass through the liquid to the steam phase were considered proportional to the mass of bubbles or mass of liquid and to the difference in pressure of the phases. The proportionality constants are system parameters which must be calculated on the basis of experimental data.

The flow of water which circulates through the evaporation circuit (steam drum, downcomers, water drum and evaporation tubes or risers) can be calculated based on the principle which governs natural circulation: "the algebraic sum of all the pressures around a closed path of a system in equilibrium must equal zero" or, in other words, "the weight flow in the downcomers must be equal to the weight flow in the risers".

4.2.2 Energy Balances

$$\frac{d(Mw \cdot hw)}{dt} = Ww_{feed} \cdot hw_{feed} - Ww_{purga} \cdot hw -$$
$$- Ww_{in\ c.evap} \cdot hw + Ww_{out\ c.evap} \cdot hw_{out\ c.evap} + \quad (20)$$
$$+ Wb_{cond} \cdot Hb - Wb_{crean} \cdot Hb_{crean}$$

$$\frac{d(Mv \cdot Hv)}{dt} = Wb_{salen} \cdot Hb_{salen} - Wv_{out} \cdot Hv \quad (21)$$

$$\frac{d(Mb \cdot Hb)}{dt} = Wv_{in\ c.evap} \cdot Hv_{in\ c.evap} - Wb_{cond} \cdot Hb + \quad (22)$$
$$+ Wb_{crean} \cdot Hb_{crean} - Wb_{salen} \cdot Hb_{salen}$$

In these equations: M (mass), W (mass flow), H (specific enthalpy) and the subscripts w (water), v (steam), b (bubbles)

5 BUILDING THE MODEL WITH ECOSIMPRO

Once the mathematical model has been built, it has to be transferred to EcosimPro. To do this, a series of simple components have to be created which will represent each of the process units that comprise the boiler so that they can subsequently be fitted together to simulate the behaviour of the complete boiler.

In addition to the components that represent the process units that make up the boiler, a series of general libraries have to be built, including:
- a library of chemical components and their physical and chemical properties
- a library of ports (gas, steam, fluid, etc)
- a library of flow elements: pipes (compressible and incompressible fluid), pumps, valves, etc
- a control library: regulators, gauges, etc

In principle, the individual components associated with the boiler will not be reusable because they are created with a lot of detail. This is because the objective of this work is to create a unique boiler component (although it would later become general) which will form part of a general library of elements of a sugar factory. These components are too big to reproduce them in this document so, as an example, it includes some of the other general components which has also been created.

The following code presents the components associated with a gas port, a gas valve, and a control system cascaded for the boiler level:

```
------------------------------------------------------------------------
-- Gas port
------------------------------------------------------------------------
PORT gas (SET_OF(Chemical)Mix)
```

```
SUM    REAL W  RANGE 0.,Inf  "mass flow (Kg/s)"
SUM IN REAL  Wi[Mix]  RANGE 0.,Inf
                 "component's mass flow (Kg/s)"
EQUAL  OUT  REAL  C[Mix]  RANGE 0.,1.
              "Concentrations (%1 en weigh)"
REAL  x[Mix]  RANGE 0.,1.
              "Concentrations (molar fraction)"
EQUAL  REAL  P  RANGE 0.,Inf  "Pressure (bar)"
EQUAL  OUT  REAL  T  RANGE -273.,Inf  "Temperat.(ºC)"
REAL  H   "especific enthalpy (KJ/Kg)"
SUM IN    REAL  f_energ   "energy flow (KJ/s)"
REAL  Rho_g  RANGE 0.,Inf  "Density (Kg/m^3)"
REAL  F   RANGE 0.,Inf   "volumetric flow"

CONTINUOUS

1 = SUM (j IN Mix; C[j])
EXPAND(j IN Mix EXCEPT setofElem(Mix,1)) Wi[j]=C[j]*W
W = SUM(j IN Mix;Wi[j])
H = entalp_gas (Mix, T, x)
f_energ = W * H
Rho_g = dens_gas (Mix, T, P, x)
F = W/Rho_g
-- relationship between C[j] and x[j]
EXPAND (j IN Mix) x[j] = (C[j]/Mmolec[j]) \
       / SUM (i IN Mix; (C[i]/Mmolec[i]) )

END PORT

---------------------------------------------------------
-- component name: Valvula_gas
-- Description: LINEAL valve for gases
-- Data: flow coefficent (Kv),laminar flow coefficent (dplam)
-- Author: Susana Pelayo Díaz
---------------------------------------------------------
COMPONENT Valvula_gas (SET_OF(Chemical)gas_mix)

PORTS
 IN    gas (Mix = gas_mix) f_in
 OUT gas (Mix = gas_mix) f_out
 IN    analog_signal    Ap    -- valve opening (%)

DATA
 REAL Kv            "flow coefficent"

DECLS
 REAL coef          "coefficent for internal calculations"
 REAL caidaP        "pressure drop (bar)"

INIT
 IF(f_in.W == 0)THEN
        f_out.T = 0.
        f_out.Rho_g = 0.
        f_out.H = 0.
 END IF

CONTINUOUS
 f_out.W = f_in.W
 EXPAND (j IN gas_mix) f_out.C[j] = f_in.C[j]
 f_in.T = f_out.T
 f_out.P = f_in.P - caidaP
 <eqn3> coef = Kv * Ap.signal/100.
 0.05*f_in.W' = (coef*sqrt(max(1.e-8,(f_in.P**2 \
         - f_out.P**2)))) - f_in.W

END COMPONENT
-------------------------------------------------------------
---- LEVEL CONTROL SISTEM IN STEAM DRUM-------
-------------------------------------------------------------
-- component name: control_nivel
-- Description: structure for liquid level in steam drum control
-- Data need: none
-- Author: Susana Pelayo Díaz.
-------------------------------------------------------------
COMPONENT control_nivel
```

```
PORTS
 IN    analog_signal  nivel  -- liquid level in steam drum
 IN    liquido (agua)  agua_in
 OUT liquido (agua)  agua_out

TOPOLOGY
 Medidor_W_liquido (fluido_mix=agua)  m_W_agua
 Valvula_liq(fluido_mix=agua) v_AGUA (Kv=293.2048)
 Cntrl_pi reg_L_cv(k=10.,Ti=100.,Tr=0.007,u_min=0.001, \
              u_max=40.,man=17.5333192)
 Cntrl_pi  reg_W_feed (k=15,Ti=10.,Tr=0.007,u_min=0.001, \
              u_max=100.,man=50.)

 CONNECT agua_in  TO  m_W_agua.f_in
 CONNECT reg_L_cv.s_out  TO  reg_W_feed.s_set
 CONNECT m_W_agua.flujo TO  reg_W_feed.s_var
 CONNECT reg_W_feed.s_out  TO  v_AGUA.Ap
 CONNECT m_W_agua.f_out  TO  v_AGUA.f_in
 CONNECT v_AGUA.f_out   TO  agua_out

CONTINUOUS
 nivel.signal = reg_L_cv.s_var.signal
 v_AGUA.f_in.P - v_AGUA.f_out.P = 0.00132

END COMPONENT
```

6   BOILER COMPONENT

The final component 'BOILER', which is obtained by fitting together the different simple components that have been created, contains all the information of these components. They have been connected in such a way that the final user does not need to have in-depth knowledge about the mathematical model that lies beneath. In addition, and to facilitate its use, the only boundary variables that are still visible are those which are most important from the point of view of studying system behaviour.

In order to ensure that the operation of the overall boiler component is correct, a minimum control system had to be introduced to keep the critical process variables within reasonable limits. The introduction of this control system can be justified if we bear in mind the great interaction that exists between all the process variables.

The control system includes:
1. Control of pressure in the steam collector, by means of the fuel inlet flow to the furnace.
2. Control of the liquid level in the steam boiler, by means of the feedwater flow to the boiler.
3. Control of the superheated steam temperature, by means of the inlet water flow to the attemperator.

The parameters that the user should introduce into this overall component as DATA are those associated with the fuel, air and feedwater sources (pressure, temperature and composition of the current), the parameters of the regulators (gain, integral time, value of the control signal in manual operation, etc), and the dimensions of the steam outlet pipe (length and internal diameter). The majority of these data have already been assigned a default value in the

individual components so that, in principle, the user does not have to worry about assigning them a value.

The regulator set-points and the steam demand are the only variables that should be fixed as BOUNDARY CONDITIONS.

To summarise the foregoing, an appendix is included at the end of this article which lists all the components that have been developed.

Once the complete BOILER component had been built, the following tasks were carried out:
- Design of a complete control system which would be suitable for the system.
- Study and design of different load distribution policies of different boilers connected in parallel based on the total steam demand.
- Connection of this component with the other models built for other sugar processing units.

As an example, we include a component which represents the parallel connection of two boilers with a single steam collector, a single chimney and a uniform load distribution.

```
-------------------------------------------------------------
----------- PARALLEL CONNECTION OF TWO BOILERS ------
-------------------------------------------------------------
COMPONENT C2_paralelo

TOPOLOGY
  fuente_gas(gas_mix=aire) f_aire(T=30.,P=1.01325, \
                   C={0.233, 0.767, 0.00})
  fuente_gas(gas_mix=gas_natural) f_comb(T=30.,P=1.001325, \
                   C={0.815, 0.16, 0.016, 0.009})
  fuente_liq(fluido_mix=agua) f_agua(T=120.,P=45.72,C={1.})

  c1_nueva            C1
  c1_nueva            C2
  Tubo_vapor          tuberia1(D=0.20272,L=14.6)
  Tubo_vapor          tuberia1(D=0.20272,L=14.6)
  colector_vapor      colector
  chimenea            chim
  Cntrl_pi  reg_P_col (k=0.05,Ti=100.,Tr=0.007,u_min=0.001, \
                   u_max=7.,man=1.00508557)
  Medidor_P_vapor  m_P_col




  CONNECT f_aire.f_out      TO  C1.aire_in, C2.aire_in
  CONNECT f_comb.f_out      TO  C1.comb_in, C2.comb_in
  CONNECT f_agua.f_out      TO  C1.agua_in, C2.agua_in
  CONNECT C1.vapor_out   TO  tuberia1.f_in
  CONNECT C2.vapor_out   TO  tuberia2.f_in
  CONNECT tuberia1.f_out,tuberia2.f_out TO colector.f_in
  CONNECT colector.f_out      TO  m_P_col.f_in
  CONNECT m_P_col.presion  TO  reg_P_col.s_var
  CONNECT reg_P_col.s_out    TO  C1.s_regP,C2.s_regP
  CONNECT C1.humos_out, C2.humos_out  TO  chim.f_in

END COMPONENT
```

7 RESULTS

As an example of the results obtained from the simulation, Figures 3 and 4 show the typical behaviour of a boiler due to variations in the demand for steam (shrink and swell phenomenon).
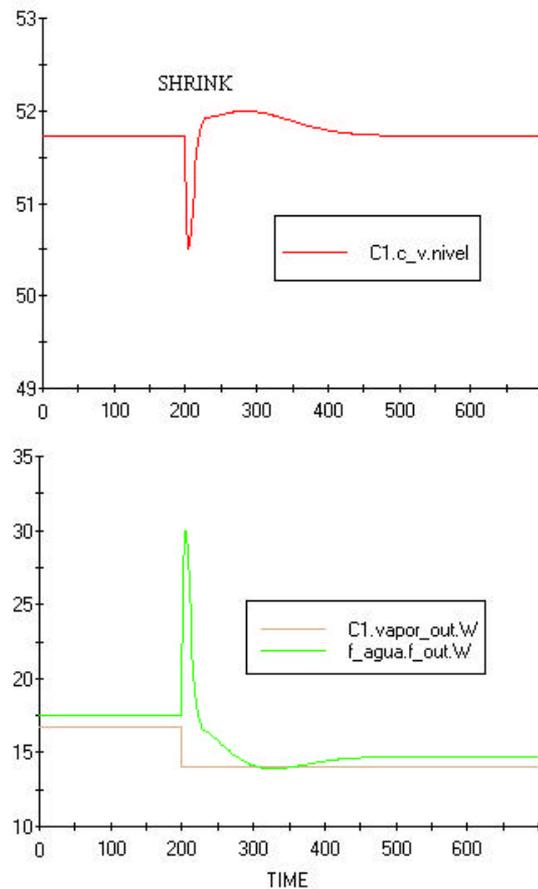

Figure 3. Shrink or Contraction in the steam drum liquid level as the demand for steam decreases
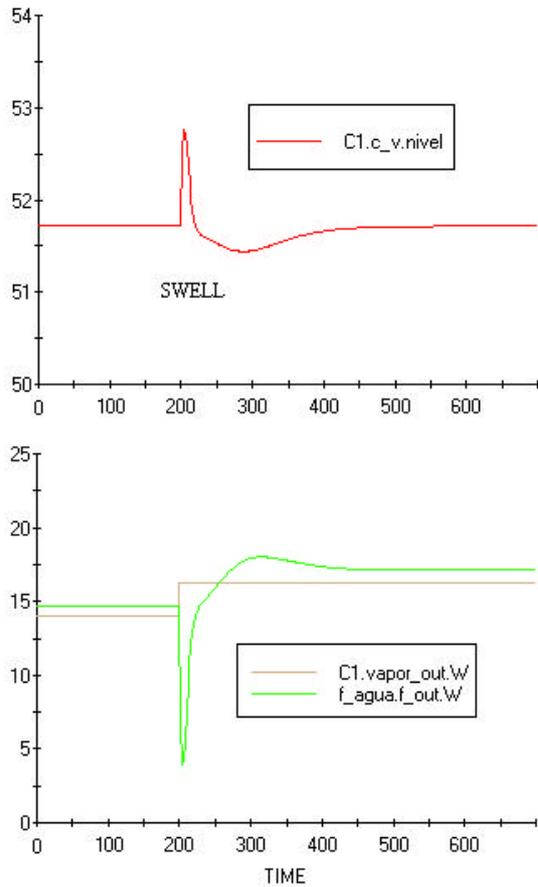
Figure 4. Swell or Expansion in the steam drum
liquid level as the demand for steam increases

The graphics in Figure 5 show the results that would be obtained if there was an increase in the amount of air that enters the furnace. As we can see from the graphs, an increase in the amount of air will bring about a decrease in the flame temperature and, therefore, less evaporation, and this would cause a momentary drop in steam pressure in the drum until the system regains its steady state, increasing the flow of fuel. The final consequence is a decrease in boiler perfomance.

8   CONCLUSIONS

The model built fulfils the established requirements and correctly represents the real behaviour of the system.

The simulation tool used, EcosimPro, has facilitated modelling by very simple elements, and their connection allows us to simulate a complex system.

The end component obtained can be reused, as long as some minimum requirements fixed by the actual creation of the model are fulfilled.

The use of these models in operator training is made even easier because no knowledge is required of the code with which they have been developed.

Appendix

BOILER Library	
Component	*Description*
Atemperador	Attemperator
Bajante	Downcomers to the water drum
BDC	Convection bank
calderin_agua	Water drum
Chimenea	Chimney
colector_vapor	Superheated steam collector
cond_aire	Air inlet duct
cond_ce	Boiler to economiser duct
cond_ec	Economiser to chimney duct
control_atemperacion	Attemperation control system
control_combustion	Air-fuel ratio control and safety system
control_nivel	Steam drum liquid level control system
CV_sub	Steam drum with subcooled section
Economizador	Economizer
Hogar	Combustion furnace
Precalentador	Feedwater preheater
Sobrecalent1	Primary superheater
sobrecalent2	Secondary superheater
Ventilador	Air inlet fan
C1_nueva	Boiler shell
C1_nueva_demo	Complete boiler component
C2_paralelo	Connection of two boilers in parallel

Other library components that have been used

PORTS Library	
Component	*Description*
Gas	Port for gases or mixtures
Liquido	Port for liquids or mixtures
vapor	Steam port

CONTROL Library	
Component	*Description*
analog_signal	Analogic signal port
Cntrl_pi	PI controller
Medidor_Ci_gas	Gas composition gauge
Medidor_P_vapor	Steam pressure gauge
Medidor_T_vapor	Steam temperature gauge
Medidor_W_gas	Gas mass flow gauge
Medidor_W_liquido	Liquid mass flow gauge

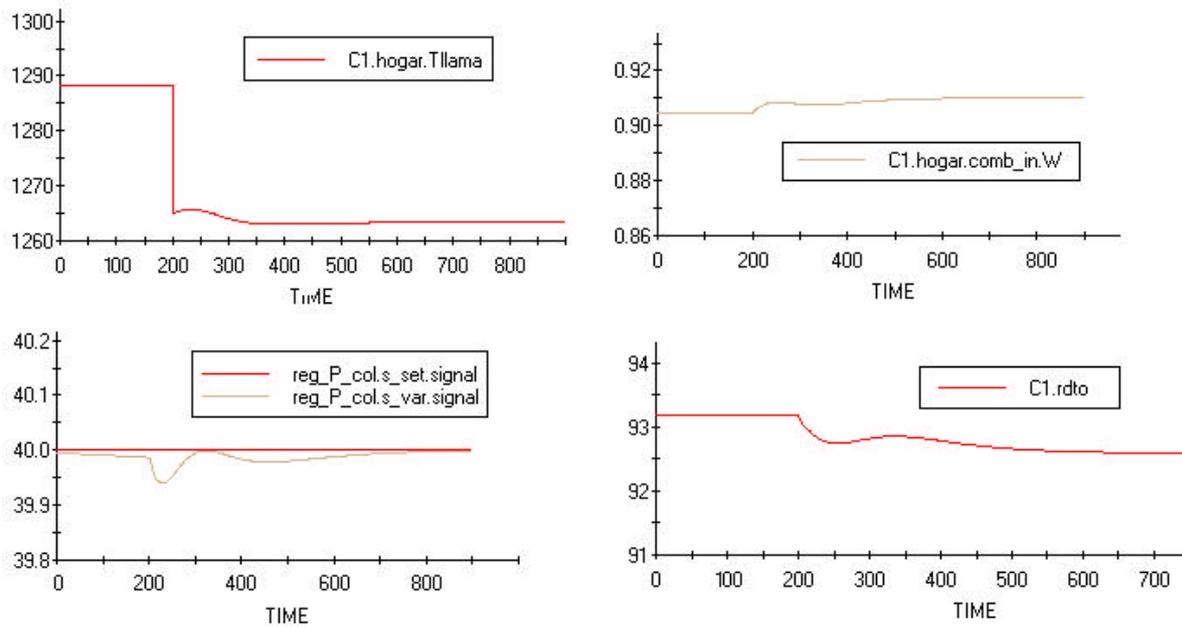| FLOW ELEMENTS Library	
Component	*Description*
fuente_gas	Source of gases or mixtures
fuente_liq	Source of liquids or mixtures
fuente_vapor	Source of steam
Tubo_gas	Gas pipe
Tubo_liq	Liquid pipe
Tubo_vapor	Steam pipe
Valvula_gas	Linear valve for gases
Valvula_gas_mariposa	Butterfly valve for gases
Valvula_liq	Linear valve for liquids

Figure 5. Results of the Simulation in the light of an increase in the flow of air entering the furnace

Acknowledgements

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