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*Modelado, Simulación y Control de un Evaporador de Doble Efecto como Herramienta Didáctica para el Control de Procesos*

*Modeling, Simulation and Control of a Double Effect Evaporator as a Didactic Tool for Process Control*

*Modelação, Simulação e Controlo de um Evaporador de Duplo Efeito como Ferramenta Docente para Controlo de Processos*

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## Resumen

El presente trabajo de investigación modela, simula y controla un evaporador de doble efecto como herramienta didáctica para la cátedra de control de procesos mediante software. El modelado matemático del comportamiento del evaporador de doble efecto se realizó mediante balances de masa y energía para el primer y segundo efecto, obteniendo las respectivas ecuaciones diferenciales, las cuales se introducen en un modelo en Simulink. Además, para cumplir con los objetivos de control establecidos, fue necesario controlar las variables concentración del producto ( $X_p$ ), acumulación en el primer efecto y segundo efecto ( $M_1 - M_2$ ) para que se mantengan por debajo o en el punto de consigna. La creación de la interfaz didáctica se desarrolló a partir de los componentes básicos de la aplicación de Matlab "App Designer", incluyendo comandos dentro de las líneas de código para que haya interacción entre el modelo de Simulink y la interfaz creada. Este comando es procesado por el Compilador de Simulink y fue empaquetado como una aplicación independiente gracias al Compilador de Matlab. Como resultado, se obtuvo una interfaz gráfica que opera de forma independiente, donde se pueden definir los diferentes valores de ajuste (SET-POINTS). El modelo matemático utilizado para la simulación fue validado con el artículo "Simulación y control de un evaporador comercial de doble efecto: Tomato Juice" presentado por Yadav & Jana (2010) cuyos resultados muestran valores de consigna de: 0,2609 kg de soluto / kg de solución para la concentración de producto y 2268 kg de acumulación en el primer efecto. Comparando estos resultados con el presente trabajo, se obtuvieron los siguientes datos: 0,26067 kg soluto / kg, y 2268,07 kg respectivamente, mostrando un error porcentual relativo de 0,088% y -0,003% respectivamente, siendo valores de error aceptables.

**Palabras clave:** modelado simulación; didáctica; procesos.

## Abstract

The present research work models, simulates and controls a double effect evaporator as a didactic tool for the chair of process control through software. The mathematical modeling of the behavior of the double effect evaporator was carried out by means of mass and energy balances for the first and second effect, obtaining the respective differential equations, which are entered in a model in Simulink. In addition, to meet the set control objectives, it was necessary to control the variables concentration of the product ( $X_p$ ), accumulation in the first effect and second effect ( $M_1 - M_2$ ) so that they remain below or at the set point. The creation of the didactic interface was developed from

the basic components of the Matlab application "App Designer", including commands within the code lines so that there is interaction between the Simulink model and the interface created. This command is processed by the Simulink Compiler and was packaged as a separate application thanks to Matlab Compiler. As a result, a graphical interface that operates independently was obtained, where the different adjustment values (SET-POINTS) can be defined. The mathematical model used for the simulation was validated with the article "Simulation and Control of a Commercial Double Effect Evaporator: Tomato Juice" presented by Yadav & Jana (2010) whose results show setpoint values of: 0.2609 kg solute / kg solution for the product concentration and 2268 kg for accumulation in the first effect. Comparing these results with the present work, the following data were obtained: 0.26067 kg solute / kg, and 2268.07 kg respectively, showing a relative percentage error of 0.088% and -0.003% respectively, being acceptable error values.

**Keywords:** modeling; simulation; didactics; processes.

## Resumo

O presente trabalho de investigação modela, simula e controla um evaporador de duplo efeito como uma ferramenta didáctica para a cadeira de controlo de processos através de software. A modelação matemática do comportamento do evaporador de duplo efeito foi realizada por meio de balanços de massa e energia para o primeiro e segundo efeito, obtendo as respectivas equações diferenciais, que são introduzidas num modelo em Simulink. Além disso, para cumprir os objectivos de controlo estabelecidos, foi necessário controlar a concentração das variáveis do produto ( $X_p$ ), acumulação no primeiro efeito e segundo efeito ( $M_1 - M_2$ ) para que permanecessem abaixo ou no ponto estabelecido. A criação da interface didáctica foi desenvolvida a partir dos componentes básicos da aplicação Matlab "App Designer", incluindo comandos dentro das linhas de código, para que haja interacção entre o modelo Simulink e a interface criada. Este comando é processado pelo Simulink Compiler e foi empacotado como uma aplicação separada graças ao Matlab Compiler. Como resultado, foi obtida uma interface gráfica que funciona independentemente, onde os diferentes valores de ajuste (SET-POINTS) podem ser definidos. O modelo matemático utilizado para a simulação foi validado com o artigo "Simulação e Controlo de um Evaporador Comercial de Duplo Efeito": Sumo de tomate" apresentado por Yadav & Jana (2010) cujos resultados mostram valores de setpoint de: 0,2609 kg soluto / kg solução para a concentração do produto e 2268 kg para a acumulação no primeiro efeito. Comparando estes resultados com o presente trabalho, foram obtidos os seguintes dados: 0,26067 kg

de soluto / kg, e 2268,07 kg respectivamente, mostrando um erro percentual relativo de 0,088% e - 0,003% respectivamente, sendo os valores de erro aceitáveis.

**Palavras-chave:** modelação; simulação; didáctica; procesos.

## Introduction

“The study of process dynamics and control is an essential component of any chemical engineering study program” (Moodley, 2020).

At the height of World War II control was a tool used for electrical systems, process control, telecommunications, and ship management. However, the golden age of control began in 1960 when it was established as a discipline whose theoretical basis was servomechanism and analog data processing was used both for control implementation and as a simulation tool. In addition, the study of dynamic simulation of various processes was deepened. (Åström & Kumar, 2014).

Nowadays, dynamic simulation enables the understanding of the operation of various simulators used in industry for the design, control, training and support of process operations using platforms such as Matlab/Simulink. These platforms can be used to design simple dynamic simulation models such as distillation columns, chemical reactors, pH processes, and others that are widely used in research and education (Komulainen et al., 2012). In short, dynamic simulation is a very useful teaching tool in areas of chemical engineering because simulation software enables the demonstration and testing of different types of processes and equipment, control algorithms, and safety procedures.

Evaporation is an important process within the chemical industry, its objective is to achieve concentration by evaporating a solvent (usually water) to get the output product to contain the right parameters in terms of solids. When several effects are connected in series, the steam generated in a higher temperature vessel upstream is used to generate steam to the next lower temperature vessel downstream (Luyben, 2018). The double effect evaporator has been widely employed in research so it has diversified in the research analyses in the field of chemical engineering.

The use of a virtual control tool of a double effect evaporator will allow to develop more distinguished laboratory practices through the use of a graphical interface software (GUI) achieving that what is taught by the teacher is understood by students clearly, and that the student can observe the actual operation of control systems. The objective of this teaching-learning tool is to be easily accessible and help to deepen process control issues, to be didactic and serve as a complement to learning in the process control signature.

## **Theoretical Framework**

### **Dynamic simulation of multiple effect evaporators**

Multi-stage evaporators (also known as multi-effect evaporators) are the most energy consuming unit and require a solid understanding of steady state and non-steady state behavior to ensure energy savings, to improve system dynamics of product concentration variation and steam temperature variation in the feed stream. It is also necessary to implement a strong control strategy.

A good option to regulate the product concentration would be to use a proportional, integral and derivative controller (PID), since it allows to regulate different variables of a process in general (Verma et al., 2017).

Understanding the dynamic performance of the multiple stage evaporator (MSE) through detailed dynamic modeling has proven to be quite useful to efficiently track and easily control product concentrations through the implementation of a Cascade - PID strategy (Verma et al., 2018).

### **Evaporation and Multi-Effect Evaporators**

Evaporation is a unit operation whose purpose is to concentrate a solution composed of a non-volatile solute and a volatile solvent, generally using water as the solvent in most evaporative processes. "Evaporation is performed by vaporizing a portion of the solvent to produce a concentrated solution" (McCabe et al., 1991).

Evaporators may consist of one or more effects. In a multiple-effect evaporator, steam from one body heats a second body to a lower boiling temperature. The first effect is heated directly with steam, and the additional bodies are arranged in order of descending boiling temperature (or pressure) (Hackett, 2018). "The coupling of evaporator bodies or effects in a multiple-effect system is a matter of interconnecting piping and not the structure of the individual units" (McCabe et al., 1991).

There are four methods of feeding in multiple effect evaporators: direct feeding, countercurrent, mixed and parallel feeding.

### **Automatic process control**

The automatic process control is responsible for maintaining the process variables (temperature, pressure, flow, composition, etc.) at the required operating values. It should be emphasized that processes are generally dynamic in nature, changes occur spontaneously and if adequate measures are not taken to respond, significant process variables (variables related to safety, productivity and product quality) will not meet the required conditions (Smith & Corripio, 2014).

The most common types of control systems are: control systems in open loop and closed loop.

In the same way it should be mentioned to the most used control strategies within control systems, which are: feedback and feedforward control.

### **Controllers tuning**

The tuning of controllers is conceptualized as the determination of the control parameters according to some specifications also called tuning criteria. Tuning is necessary in two cases, the first lies in the commissioning of a control system and the second case is when the user observes a deterioration of the behavior of the control system (García Morilla, 2006).

There are three methods of controller tuning: trial-and-error methods, experience-based methods, model-based analytical methods and automatic tuning methods.

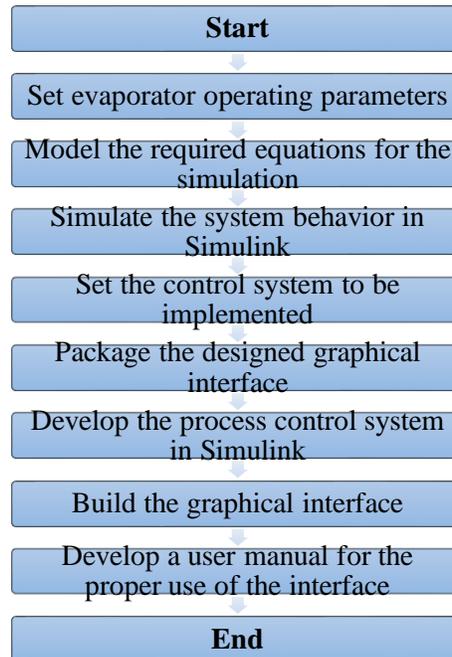
### **Used Software**

The Matlab program (MATrix LABoratory) was used to create the application for the control system of a double effect evaporator. It is characterized as a mathematical and graphical software with numerical, graphical and programming capabilities. It has built in functions to perform many operations, and there are toolboxes that can be added to enhance these functions. In addition, Matlab integrated tools such as Simulink, Simulink Compiler, Matlab Compiler and App Designer were used, which have several interactive controls that allow not only to create a comprehensive design of any application from a graphical interface but also to program its behavior from the creation of a code (Dunn et al., 2006).

### **Methodology**

The stages for the construction of the graphic interface are shown in diagram 1, which is detailed below:

**Diagram 1.** Proposed methodology for the degree thesis



**Elaborated by:** Mena, Jerry. 2021.

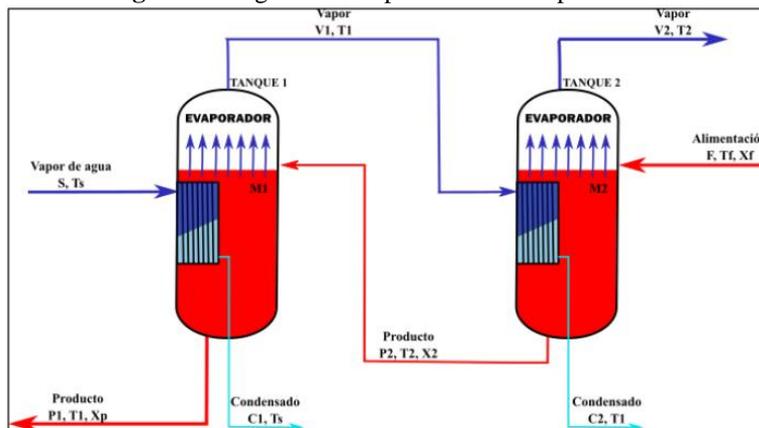
The aim of this proposal is to implement a graphical interface that covers basic knowledge of controllers and for users to understand how a control system influences the development of the process.

### **Establish operating parameters of the process**

This process is carried out with a double-effect evaporator with backward feed arrangement. The feed with flow rate  $F$ , composition  $X_f$  and temperature  $T_f$  enters tank 2 and the steam with flow rate  $S$  and temperature  $T_S$  enters tank 1. The mass accumulations in both tanks are defined by  $M_1$  and  $M_2$ . The steam flow rates  $V_1$  and  $V_2$  from the top of both tanks with temperature  $T_1$  and  $T_2$ . While  $P_1$  and  $P_2$  are the product flow rates of the two effects with composition  $X_p$  and  $X_2$  and temperature  $T_1$  and  $T_2$  respectively, as shown in Figure 1:

Modeling, Simulation and Control of a Double Effect Evaporator as a Didactic Tool for Process Control

**Figure 1.** Diagram of the process to be implemented



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The following numerical values for use in the process have been taken from a commercial scale tomato paste evaporator study, Table 1 specifies the values to be used:

**Table 1:** Numerical values used in the process

Variable	Abbreviation (Unit)	Value	Value in seconds
Mass accumulation in tank 1	M1 (Kg)	2268	2268
Mass accumulation in tank 2	M2 (Kg)	2268	2268
Inlet feed flow	F0 (Kg/h)	26103	7,25
Inlet steam flow	S0 (Kg/h)	11023	3,06
Liquid product flow rate in tank 1	P1 (Kg/h)	5006	1,39
liquid product flow rate in tank 2	P2 (Kg/h)	14887	4,14
Steam flow in tank 1	V1 (Kg/h)	9932	2,76
Steam flow in tank 1	V2 (Kg/h)	11165	3,10
Feed composition	Xf (Kg/Kg)	0,05	0,05
Composition in tank 1	Xp (Kg/Kg)	0,2607	0,2607
Composition in tank 2	X2 (Kg/Kg)	0,0874	0,0874
Steam temperature	Ts (°C)	115,7	115,7
Feed temperature	Tf (°C)	85	85
Temperature in tank 1	T1 (°C)	74,7	74,7
Temperature in tank 2	T2 (°C)	52	52
Heat transfer area in tank 1	A1 (m <sup>2</sup> )	102	102
Heat transfer area in tank 2	A2 (m <sup>2</sup> )	412	412
Overall heat transfer coefficient for tank 1	U1 (KJ/h.m <sup>2</sup> .°C)	5826	1,62
Overall heat transfer coefficient for tank 2	U2 (KJ/h.m <sup>2</sup> .°C)	2453	0,68

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When considering a binary solution of water and inert soluble solids in tomato juice (Miranda & Simpson, 2005, p. 205), the following empirical correlations are established:

- Product enthalpy (Runyon et al., 1991, p. 189)

$$h(T, X) = (4.177 - 2506X)T \quad (Ec.1)$$

- Polynomial regression equation of steam table values (Runyon et al., 1991, p.189)

$$H(T) = (2495 + 1.958T - 0.002128T^2)T \quad (Ec.2)$$

- Liquid enthalpy of pure solvent for condensate streams (Runyon et al., 1991, p. 189)

$$h(T) = 4.177T \quad (Ec.3)$$

- Latent heat of vaporization is given by the following equation (Runyon et al., 1991, p. 189)

$$\lambda(T) = H(T) - h(T) = 2495 + 1.958T - 0.002128T^2 \quad (Ec.4)$$

### Required equations for the simulation

Using the mass and energy balances, the equations necessary to carry out the simulation are obtained.

*Equations obtained from mass balances*

- A. Mass balance in the first effect

$$A = E - S \quad (Ec.5)$$

$$\frac{dM_1}{dt} = P_2 - P_1 - V_1 \quad (Ec.6)$$

Where:

**E:** input; **S:** output and **A:** accumulation

- B. Equation obtained from the balance of components (solute) in the first effect:

$$\frac{dX_P}{dt} = \frac{P_2(X_2 - X_P) + X_P V_1}{M_1} \quad (Ec.7)$$

- C. Equation obtained from the mass balance of the second effect

$$\frac{dM_2}{dt} = F - P_2 - V_2 \quad (Ec.8)$$

- D. Equation obtained from the balance of components (solute) in the second effect:

$$\frac{dX_2}{dt} = \frac{F(X_f - X_2) + X_2 V_2}{M_2} \quad (Ec.9)$$

*Equations obtained from energy balances*

- A. Equation obtained from the energy balance in the first effect expressing the constants as a=4.177 y b=2.506

(Ec.10)

$$\frac{dT_1}{dt} = \frac{1}{(4.177 - 2.506X_p)} \left\{ \left[ \frac{1}{M_1} \left( P_2 h_{2(T_2, X_2)} + S \lambda_{(T_s)} - P_1 h_{(T_1, X_p)} - V_1 H_{1(T_1)} - h_{(T_1, X_p)} \frac{dM_1}{dt} \right) \right] + bT_1 \frac{dX_p}{dt} \right\}$$

- B. Equation obtained from the energy balance in the second effect expressing the constants as a=4.177 y b=2.506

(Ec.11)

$$\frac{dT_2}{dt} = \frac{1}{(4.177 - 2.506X_2)} \left\{ \left[ \frac{1}{M_2} \left( F h_{f(T_f, X_f)} + V_1 \lambda_{2(T_1)} - P_2 h_{2(T_2, X_2)} - V_2 H_{2(T_2)} - h_{2(T_2, X_2)} \frac{dM_2}{dt} \right) \right] + bT_2 \frac{dX_2}{dt} \right\}$$

- C. Equation of the vapor rate for the first effect

$$V_1 = \frac{Q_{v1}}{H_{1(T_1)}} \quad (Ec.12)$$

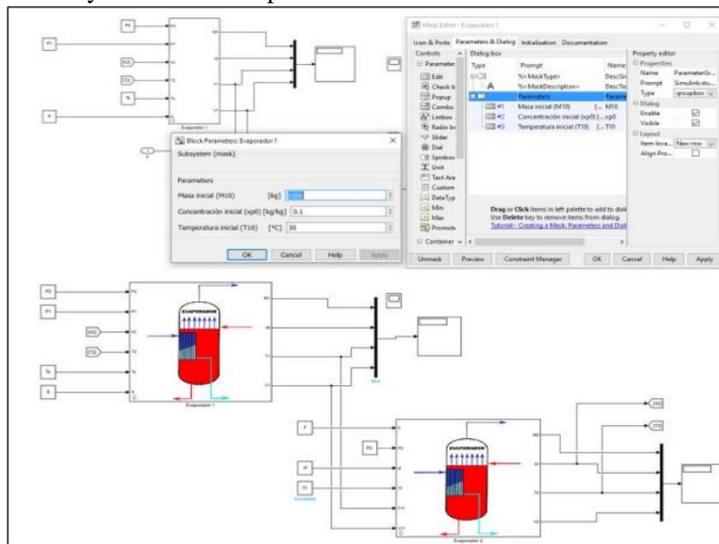
- D. Equation of the vapor rate for the second effect

$$V_2 = \frac{Q_{v2}}{H_{2(T_2)}} \quad (Ec.13)$$

### Simulate the dynamic system behavior in Simulink

After obtaining the differential equations, the simulation is performed by entering the equations obtained for each evaporator separately, then the equations of the two evaporators are entered into subsystems to facilitate the form of interconnection of an evaporator with the other. Considering that for the data input a mask is created in each subsystem, Inkscape software is also used to add an image to the subsystem masks. Figure 2 shows the subsystem masks for the processes that were created within the Simulink environment.

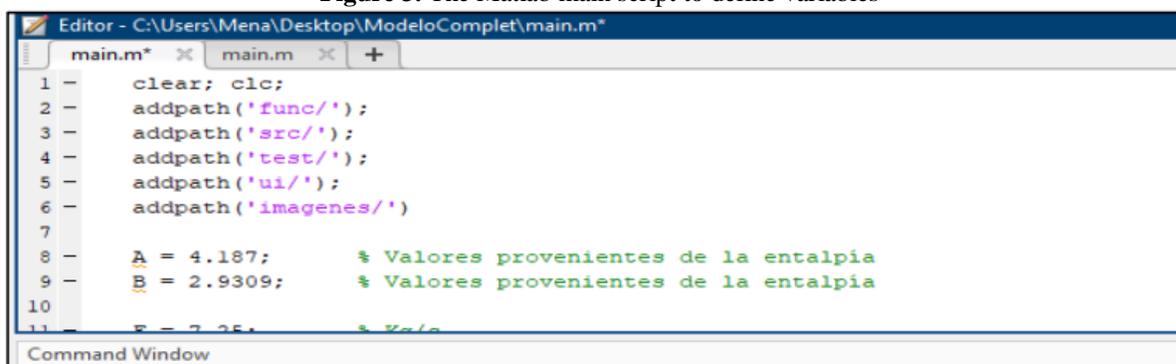
**Figure 2.** Subsystem masks for processes created within the Simulink environment



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In Matlab a script is created in which the variables are entered and at the same time the folders to be used within the path to add images in the subsystem masks are introduced. Figure 3 shows the main script of Matlab to define variables.

**Figure 3.** The Matlab main script to define variables



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### Design the control system to be implemented

In order to keep the process flowing correctly, the solids concentration of the output product must be maintained at the desired value and the retention of liquid mass must be controlled, thus avoiding the drying of the evaporator tubes. Table 2 below shows the control pairs selected in the process.

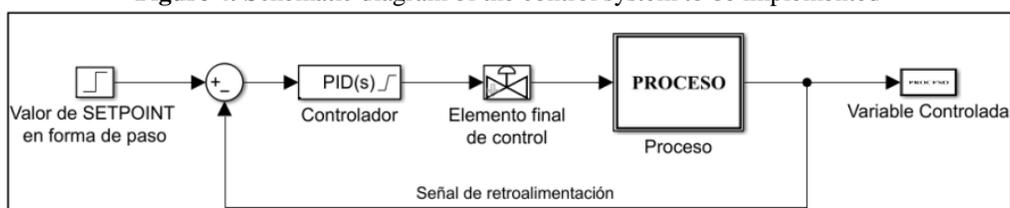
Controlled variable	Manipulated variable
Xp	S
M1	P1
M2	P2

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### Schematic diagram of the control system to be implemented

This control scheme consists of a reference value at the input called set point, together there is a summation symbol that generates a difference value between the Set point value entered and the feedback signal from the output. The resulting signal feeds the controller and the output signal goes directly to the final element. This signal regulates the flow rate that will pass through the valve to the process, at the end you get a controlled variable that yields accurate values. In Figure 4 is the scheme of the control system.

Figure 4. Schematic diagram of the control system to be implemented

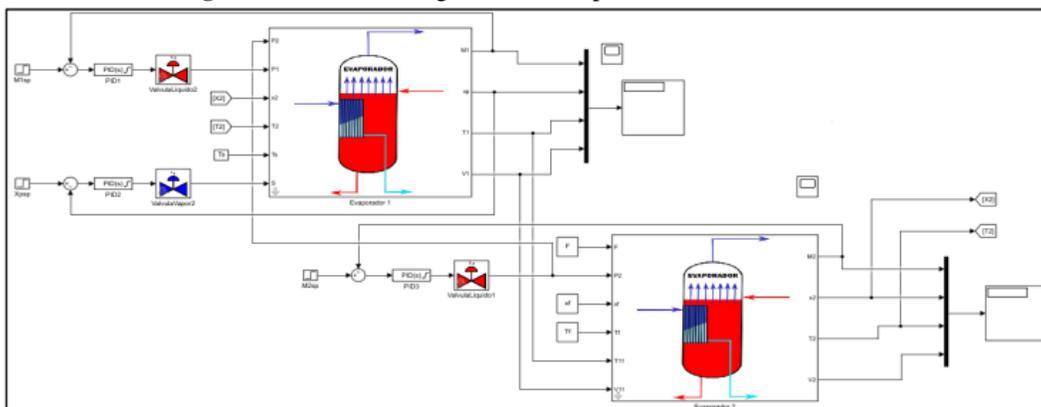


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### Schematic diagram of the implemented Simulink model

To start, the desired value of the variable to be controlled is entered, the sum block is placed and the signs are adjusted, consequently, the PID Controller block is placed, the given signal will connect to the valve, and the resulting signal serves as an indicator of the manipulated variable. Figure 5 shows the schematic diagram of the implemented Simulink model.

**Figure 5.** Schematic diagram of the implemented Simulink model



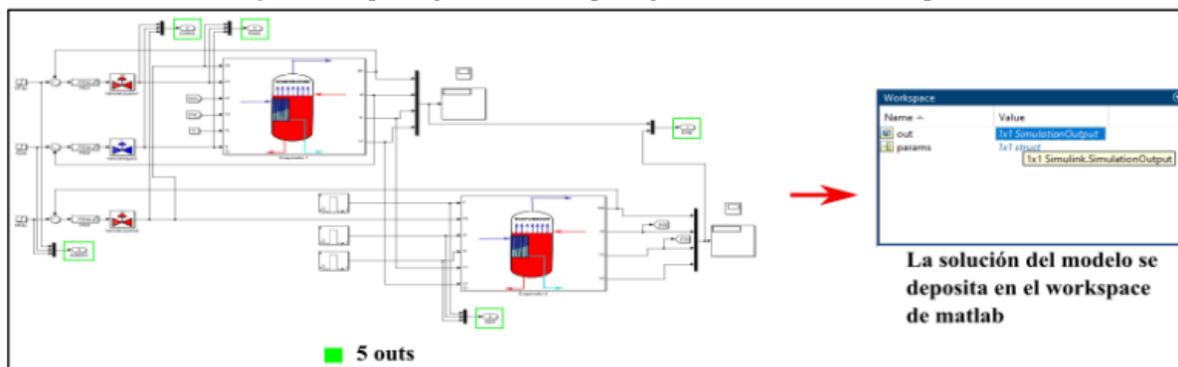
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### Build the graphical interface

Using the workspace in Matlab, inputs can be entered as a single element and specific methods can be defined for each model, in which elements can be nested to be read by the Simulink model.

To determine the signals to be obtained, the out block is added and a mux is placed to avoid unnecessary connections. The output of this mux will be connected to the out block in this way, the results obtained will be stored in an out structure, and these values will be used by the application to create different graphs, as shown in figure 6.

**Figure 6.** Exporting results as output signals to the Matlab workspace

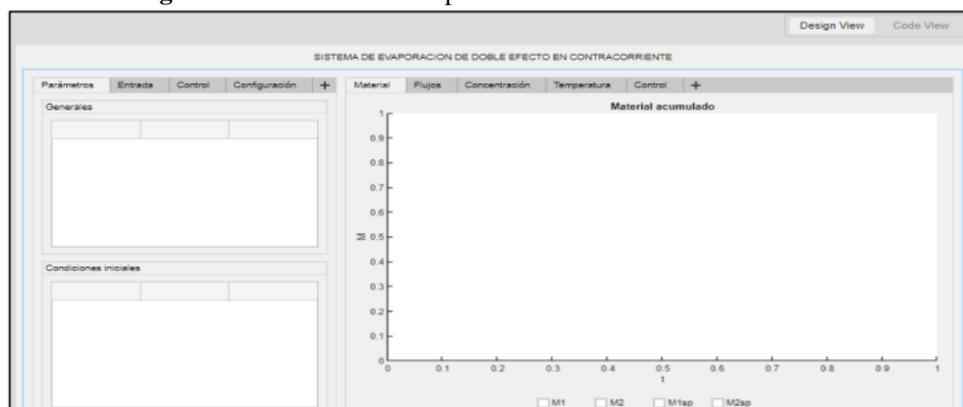


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## User interface: Main

In this section we cover the results of the Simulink model by creating a blank app designer template. For the design the uicontrols are inserted and the order is maintained using tab group. The window is divided into 3 parts: in the first part is the title of the theme, and in the third part are the buttons like simulate, restart and exit. The second part contains the contents of the application, which in turn is divided into two parts: in the first subdivision there are 4 tabs where the parameters, inputs, control and configuration are located, and in the second subdivision there are 6 tabs that cover the material, flows, concentration, temperature, control and information. Within each tab there is a graph showing the results of the application. The view of the divided window is shown in Figure 7.

**Figure 7.** Preview of the template interface and the uicontrols used



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All the properties involved in the interface will be displayed, if there is a case of defect or modification the params property will store the information in a safe way. If you want to modify the case, the data will be saved for the execution of a new simulation. Figure 8 below shows the code used to define the properties.

**Figure 8.** Code to be executed after component creation

```
properties (Access = private)
    params % Description
    results
    simulation
    cfg
    flags
end
```

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After defining the properties, the interface will display the case and copy the data from the script (main) then proceed to create the AppFillTables function to fill the tables with the information. Figure 9 shows the code that helps to store the information.

**Figure 9.** Code that stores the information to be loaded by default

```
methods (Access = private)

function defaultCase(app)
    % Overall params
    app.params.Ts = 115.7;    % °C
    app.params.Tb = 100;    % °C
    app.params.A = 4.187;
    app.params.B = 2.9309;

    % Evaporator's parameters
    app.params.Evap1.M0 = 1000; % kg
    app.params.Evap1.C0 = 0.1; % kg solut/kg sol.
    app.params.Evap1.T0 = 30; % °C

    app.params.Evap2.M0 = 1000; % kg
    app.params.Evap2.C0 = 0.1; % kg solut/kg sol.
    app.params.Evap2.T0 = 30; % °C

    app.fillTables;
end
```

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Subsequently, a callback is implemented which will refill the components within the interface with the values that were set for the case. See figure 10.

**Figure 10.** Code lines inserted for default values to be displayed

```
% Callbacks that handle component events
methods (Access = private)

% Code that executes after component creation
function startupFcn(app)
    % Cargar datos caso por defecto
    app.defaultCase;
end
end
```

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In addition, the function (getData) will be introduced which allows the input parameters to change according to the user needs. See figure 11.

**Figure 11.** Code lines for configuring input parameters

```
function getData(app)
    % Función para capturar datos desde los campos.

    data = app.UITable.Data.Valor;
    app.params.Ts = data(1);
    app.params.Tb = data(2);
    app.params.A = data(3);
    app.params.B = data(4);
    app.params.dcl = data(5);
    app.params.dcg = data(6);
    app.params.gs = data(7);

    data = app.UITable2.Data.Valor;
    app.params.Evap1.M0 = data(1);
```

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For the simulation to be carried out, a communication function is executed between the Simulink model and the input parameters. See figure 12.

**Figure 12.** Code lines for configuring the simInp input parameters for interface deployment

```
function configSimulation(app)

    simInp = simulink.SimulationInput('DoubleEffectEvaporator');

    simInp = simInp.setVariable('params', app.params);

    simInp = simInp.setModelParameter('startTime', num2str(app.config.startTime));
    simInp = simInp.setModelParameter('stopTime', num2str(app.config.stopTime));
    simInp = simInp.setModelParameter('FixedStep', num2str(app.config.stepTime));

    simInp = simulink.compiler.configureForDeployment(simInp);

    app.simulation = simInp;

end
```

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The function run simulation will call all functions step by step to execute and display the results. See figure 13.

**Figure 13.** Code lines to run the Simulink model inside the interface

```
function runSimulation(app)
    % 1. Configurar la simulación
    app.getData;
    app.configSimulation;

    % 2. Correr la simulación
    app.toggleSimButton('off', 'Simulando...');
    simOut = sim(app.simulation);
    app.toggleSimButton('on', 'simular');

    % 3. Guardar los resultados
    app.results.time = simOut.tout;
    app.results.evap = simOut.yout.signals(1).values;
    app.results.control = simOut.yout.signals(2).values;
    app.results.flows = simOut.yout.signals(3).values;
    app.results.setpoint = simOut.yout.signals(4).values;
    app.results.input = simOut.yout.signals(5).values;

    %
    disp(app.results);

    % 5. Dibujar las gráficas
    app.drawResults;
end

function toggleSimButton(app, state, label)
    app.ResolverButton.Enable = state;
    app.ResolverButton.Text = label;
end
```

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To plot the values, the states are stored inside flags, followed by a code to clean the plots and a code to draw more than one line, as well as a code to add a legend, and to draw the lines the conditional "if" is used to establish if the checkbox is activated. The same procedure is followed for flows, concentrations, accumulated mass and temperature. See the code in figure 14.

**Figure 14.** Code lines for plotting set point values

```
function drawMassAccumulated(app)
    % Flags from checkbox
    app.flags.hflags = [app.M1CheckBox.Value, ...
        app.M2CheckBox.Value, ...
        app.m1spCheckBox.Value, ...
        app.m2spCheckBox.Value];

    % Clean axes
    cla(app.UIAxes4);

    % Hold on
    hold(app.UIAxes4, 'on');

    % Legend names' vector
    legname = {};

    % Draw Lines
    if app.flags.hflags(1) == 1 % M1
        plot(app.UIAxes4, app.results.time, app.results.evap(:,1));
        legname[end+1] = 'M1';
    end
    if app.flags.hflags(2) == 1 % M2
        plot(app.UIAxes4, app.results.time, app.results.evap(:,5));
        legname[end+1] = 'M2';
    end
    if app.flags.hflags(3) == 1 % m1sp
        plot(app.UIAxes4, app.results.time, app.results.setpoint(:,1), '--', 'Color', [0.6350 0.0780 0.1840]);
        legname[end+1] = 'm1sp';
    end
    if app.flags.hflags(4) == 1 % m2sp
        plot(app.UIAxes4, app.results.time, app.results.setpoint(:,3), '--', 'Color', [0.6350 0.0780 0.50]);
        legname[end+1] = 'm2sp';
    end

    % Add legend
    legend(app.UIAxes4, legname);

    ylabel(app.UIAxes4, 'M [kg]');
```

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Modeling, Simulation and Control of a Double Effect Evaporator as a Didactic Tool for Process Control

To complete the functionalities of the interface, callbacks are used for the buttons and checkboxes that must have direct communication with the functions. Finally, to display the information in the interface, a callback is created for the InfoButton and the following is entered: (See figure 15).

Figure 15. Code lines for displaying the information contained in the user interface

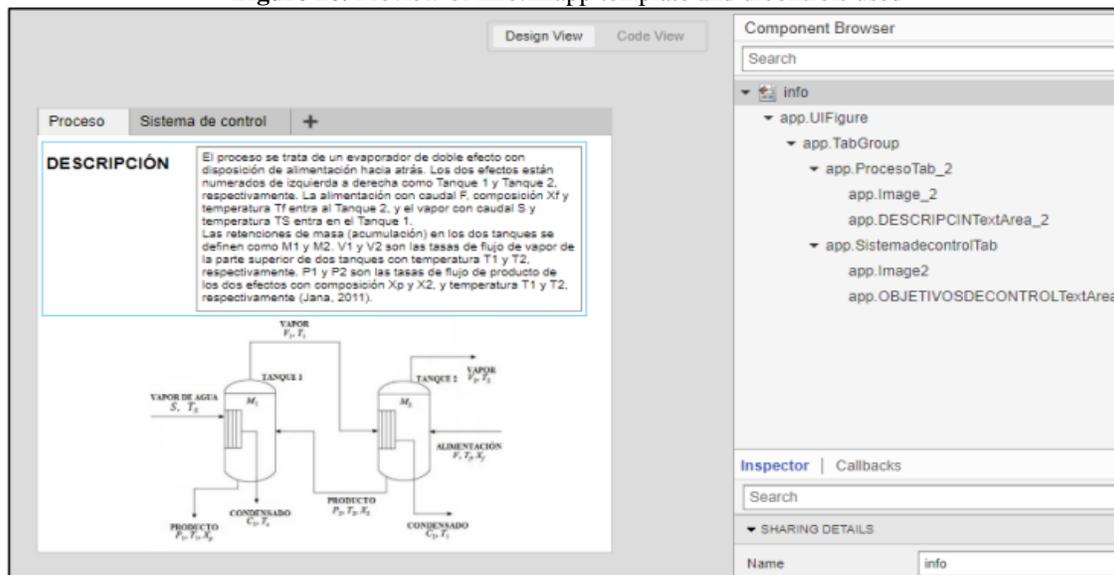
```
% Button pushed function: InfoButton  
function InfoButtonPushed(app, event)  
    info  
end
```

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### User interface: info

A blank app designer template is created and the uicontrols are placed according to the design to be displayed. Figure 16 shows a preview of the template.

Figure 16. Preview of info.mlab template and uicontrols used

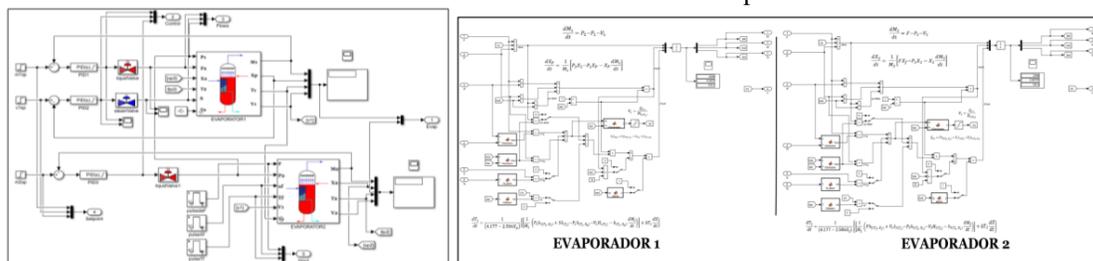


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## Results

### Simulation results report

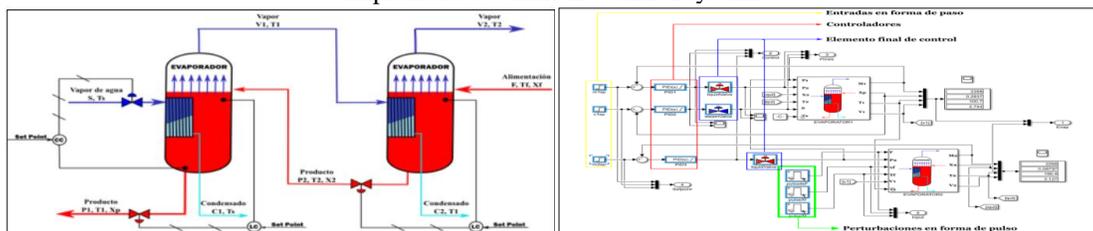
**Figure 17.** Schematic diagram of the complete simulation of the double effect evaporator, and schematic diagram of the detailed simulation of the double effect evaporator.



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The figure (Figure 17) includes the schematic diagram of the double effect evaporator that shows the result of the variables  $M1$ ,  $Xp$ ,  $T1$ ,  $V1$ ,  $M2$ ,  $X2$ ,  $T2$ ,  $V2$ ,  $P1$ ,  $S$  and  $P2$ , these values are useful to implement the control system. For the solution of the differential equations that were directly entered into the Simulink model, an iterative approximation method to the ODE solution was used, so the fixed-step solver configuration of type ode4 (Runge-Kutta) with a step size of 0.1 was used. On the other hand, Figure 18 shows the scheme of the control system and the resources to be implemented.

**Figure 18.** Schematic diagram of the control system to be implemented, and schematic diagram of the resources implemented within the control system.



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### Report on the results of the application generated

The application consists of three windows. The initial window is displayed when running the application and contains author information, project name and a button that when it is pressed leads to the main window. The main window establishes communication with the simulated part coming

from the simulated model in Simulink, it also allows to show the results when pressing the solve button. The third window is executed by pressing the information button (known as information window), this window consists of four tabs that provide information related to the process, information about the control system, perturbations immersed in the system and general details about the Simulink model. See Figure 19 for the three windows described above.

Figure 19. Final application structure (.exe)



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### Validation of programmed modeling

A clear way to determine how exact the programmed modeling was is by validating the simulated model with available parameters in the literature, so it is necessary to find studies that have the same characteristics as those of the equipment used in the research. For this research, the article published in the Chemical Product and Process Modeling magazine titled as "Simulation and Control of a Commercial Double Effect Evaporator: Tomato Juice" was taken as a reference, developed by (Yadav & Jana, 2010).

The input values taken from (Yadav & Jana, 2010) were entered into the simulation and had to make some conversions in the input values in the terms of the simulation. As the simulation was run, a difference between the actual values and the set point values was observed because different differential equations were used in the modeling to define the amount of vapor at the inlet of each of

the effects. The most relevant results were the product concentration ( $X_p$ ) and the accumulation in the first effect (M1), therefore these were taken as a value to find the percentage error.

As a result of the error calculation, it was determined that there is a percentage error in the product concentration of 0.08% and in the accumulation in the first effect an error of -0.0029%. Therefore, the simulation and the results obtained by the developed interface are accepted, since the percentage error is less than the permissible error.

## Conclusion

- The behavior of the double effect evaporator was mathematically modeled by means of mass, energy and component balances for the first and second effect, respectively. Thanks to the versatility of the software used, it was possible to directly enter the differential equations of mass and energy balance, such resolutions were possible due to the solver included in the software.
- Through the use of Simulink software, the simulation for the double effect evaporator was programmed, including physical parameters. In addition, the control system was programmed in accordance with the objectives of the simulation, so that in order to maintain the solids concentration of the product at the desired value, the variable  $X_p$  must be controlled and to avoid overflowing or drying of the evaporator tubes it was necessary to control the level of the accumulation M1 and M2.
- The programmed simulation was validated with the article "Simulation and Control of a Commercial Double Effect Evaporator: Tomato Juice" presented by Yadav & Jana (2010) whose results show set point values of: 0.2609 kg solute/kg solution for product concentration and 2268 kg for accumulation in the first effect. Comparing these results, 0.26067 kg solute/kg and 2268.067 kg were obtained, showing a relative percentage error of 0.088% and -0.0029% respectively, being acceptable error values.

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