Design and implementation of a level control at the bottom of the first column of a continuous binary distillation tower

M M Fitatá-Bojacá1 and O García-Bedoya1

1University of Bogotá Jorge Tadeo Lozano, Faculty of Natural Sciences and Engineering, Department of Engineering, Career 4 Nº 22-61, Bogotá D. C., Colombia.

monicam.fitatab@utadeo.edu.co

Abstract. The laboratory of the university has a continuous distillation tower where students carry out laboratory practice, require that student manipulate valve at high temperatures generating risk at operation. A control system was carried out on the plant to maintain the level of 0.18 meters in the bottom of the first column. For its identification, the inspection of the tower was carried out to identify the components of each distillation column. These tests allowed obtaining data from the point of operation during the start-up of the tower. With this information collected, a model was defined through the mass and energy balance. Additionally, the tower was simulated under the Aspen Hysys software to obtain the steady state and, over this point the dynamic system was analyzed through the linearized model to design the controller and test robustness. The control strategy implemented, with LabVIEW software, was ON-OFF with hysteresis due to limitations in the instrumentation. As a result, it was found that the time stabilization of the tower decreased from three hours to one hour to concerning the manual level control and, a better regulation was observed in the temperatures of the top of first column 96°C and second column 72°C.

1. Introduction
Distillation is one of the most important unit operations in the chemical industry, consisting of separating streams with two or more components [1]. The University Jorge Tadeo Lozano of Bogotá has a distillation tower located in the Centro de Investigación en Procesos de Ingeniería (C.I.P.I); which presents stabilization times of up to three hours, which reduces the operational experience of the students. At the same time, it generates an inadequate practice in the laboratory and insecurity in the functioning of the equipment; since it flooded in the bottoms [2].

The modeling and control of a binary distillation column for the separation of the ethanol-water mixture [3]. Its contribution is due to the dynamic model, and the assumptions and considerations adopted, with the nonlinear differential equations of each of the models are solved using fourth order Runge Kutta. The behavior of each of them is analyzed before variations in the parameters in order to determine the most appropriate model for the development of the control algorithm [3]. The thesis presents the dynamic analysis of the system of the binary distillation column by linearization around a point of equilibrium and
the study of bifurcations by varying the parameters of the system independently [3].

A thesis of Design and construction of a level control interface, temperature and water flow in a tank for use in laboratory practices is taken as reference. The contribution is to design and build the physical control interface, to model the system, to elaborate a computer program for the acquisition of data and control, was used the program Simulink for the numerical simulation [4].

The emulation of a continuous binary distillation column for purposes of training in control with educational purposes allows experimentation without having the real system. This article worked the emulation, the response of the composition of the product under disturbances in the feed is obtained using Matlab and Simulink [5].

For this reason, this work arises under the premise of giving continuity to the process previously performed in the distillation tower where was included the temperature control loop of the top of the second column of the continuous distillation tower [2].

This work consisted of designing and implementing a level control loop with the purpose of stabilizing the tower decreased from three hours to one hour to concerning the manual level control, keeping the controlled variable at a level of 0.18 meters, preventing the distillation tower from flooding due to excessive liquid inlet or on the contrary if the flow of liquid is low, the tower can be emptied. First, was done the identification of tower parameters is presented, following by the simulation of the system in Aspen Hysys to obtain the steady state of the system. The mathematical model of the system is presented to analyze the disturbances of the controller implemented with Simulink, the data acquisition consists of sensors, electro valve, data acquisition card and a PC with programmable software in LabVIEW.

2. Identification of tower parameters

The operation of the plant starts with the feed stream of an ethanol-water mixture, passes through a pump, and before entering the process passes directly through an exchanger to preheat, thus modifying the temperature a 55°C, to preheat the mixture is used as service fluid the thermal energy of the bottom of the first distillation column.

The tower has a control board with the signals of temperature indicators through thermocouples that allow the operator to read the temperature in each section of the tower. On the same board are the power buttons of the pumps. It also has pressure indicators type bourdon that allows the pressure to be measured and verify that the boiler supplies the proper steam to the tower. Because it contemplates regulation with a set of manual valves, it generates greater demands on the workforce of students. In this way, its operation must be carried out with a minimum of three people.

As shown in Figure 1, it is observed that the distillation tower consists of two columns:

Figure 1. Distillation tower of CIPI.
Column 1 is distillation (column on the left), consisting of three sections of plates [6] each with four plates per section and two sections of packaging in the upper part of the tower; this column has six temperature sensors. In the case of this plant, the input currents are the feed (A) that is given in the plate 13 (See Figure 2), and the injection of steam that comes into direct contact through a flute at the bottom of the column.

Column 2 is of Rectification (Column on the right) has four sections of the packed bed [6], has five temperature sensors, and an auxiliary steam supply that passes through a coil at the bottom of the column.

The tower was put into operation preparing approximately 200 L of a 15% by volume ethanol-water solution. The 200 L allow the operation of the column continuously, including the reflux system approximately six hours without implementing any control system.

Three tests were carried out (See Table 1). For the preparation, 30 L of 86% ethanol was used. Test one was performed without reflux, test two with low reflux and high distillation speed and test three with high reflux and low distillate speed, obtaining greater recovery of ethanol with high reflux at low distillation speed.

At the time of its manual operation, it was evidenced that the tower distills continuously when the temperature of the top of the first tower is maintained at 86 °C and the top of the second tower at 72 - 74 °C (see Figure 2), where the best distillate is obtained. In the Figure 2 was shows the inlet and outlet streams of the tower.

Figure 2 shows the input and output currents of the tower. Each stream was named as follows:

A: Food of the tower
D: Distillation of the tower
V: Steam coming from the boiler
F: Bottoms of the tower
F1: Bottoms of the first column
F2: Bottoms of the second tower
Table 1. Results of open loop tests.

| Parameter                                      | Test one | Test two | Test three |
|------------------------------------------------|---------|---------|-----------|
| Temperature at the top of the second column (°C) | 74.0    | 74.0    | 72.0      |
| Reflow (No. of turns)                          | 0.0     | 2.0     | 4.0       |
| Distillate obtained in practice (L/h)          | 4.0     | 1.8     | 2.0       |
| Ethanol recovery (%)                           | 77.0    | 84.0    | 85.0      |
| Practice time (h)                              | 5.0     | 6.0     | 6.0       |
| Prepared food (L)                              | 200.0   | 200.0   | 200.0     |

3. Simulation binary distillation tower in the steady state

The distillation tower was simulated in the steady state using the Aspen Hysys software [7], that is to say, the variables that define its behavior, with respect to time remain invariant, and corresponds to the initial conditions for the dynamic state [8].

For the estimation of thermodynamic properties, the model selected in the Aspen Hysys software was NTRL (Non-Random-Two-Liquid) that works non-ideal binary mixtures, based on the Gibbs energy equation with two or more binary parameters, that give reliable results, the model is not mathematically complex, it is of empirical and semi-analytic type [9].

The equipment used in the Aspen Hysys simulator was the distillation column as shown in Figure 3, simulated without reboiler and with 22 real stages that make up the equipment [2].

![Figure 3](image)

Table 3. Environment of the simulation in Aspen Hysys.

Table 2 shows the results obtained from the mass balance and in Table 3 shows the distillate composition. The letters correspond to the currents of Figure 2 and Figure 3.

Table 2. Mass balance according to simulation of the distillation tower in Aspen Hysys.

| Variable            | Reflux | Condenser | A   | D   | F   | V   |
|---------------------|--------|-----------|-----|-----|-----|-----|
| Vapor Fraction      | 0.00   | 1.00      | 0.00| 0.00| 0.00| 1.00|
| Temperature [°C]    | 76.76  | 76.77     | 55.00| 76.76| 92.32| 92.32|
| Pressure [kPa]      | 73.00  | 73.00     | 76.53| 73.00| 76.53| 76.53|
| Molar Flow [kg/mole/h] | 0.87  | 0.88      | 0.81| 0.03| 1.71| 0.89|
| Mass Flow [kg/h]    | 37.24  | 37.37     | 16.19| 0.13| 32.23| 16.17|
Table 3. Distillate composition in Aspen Hysys.

| Variable                  | Reflux | Condenser | A  | D  | F  | V  |
|---------------------------|--------|-----------|----|----|----|----|
| Comp Mole Frac (Ethanol)  | 0.87   | 0.87      | 0.15| 0.87| 0.03| 0.00|
| Comp Mole Frac (H₂O)      | 0.13   | 0.13      | 0.85| 0.13| 0.97| 1.00|

4. Assumptions and considerations
The mathematical model of the binary distillation column must represent the dynamic behavior of the real process. In order to obtain this model, the following assumptions and considerations were made:

- At the bottom of the column, the density, pressure, and temperature of the currents are constant.
- The temperature influences the energy, the problem is simplified assuming that the enthalpy specifies of the liquid can be expressed as a product of the temperature and its heat capacity (H = Cp T) [1].
- The reference temperature is T\(_\text{r}\) = 298.15 K
- The steam enthalpy of the section is constant and is expressed as (H = Cp T + λ), where λ is the heat of vaporization [1].
- The heat loss is considered negligible.
- The bottom of the tower is cylindrical V = hA\(_T\), where h: Level in the tank [m] and A\(_T\): Total area [m\(^2\)].

5. Balance and transfer equations
To make the model, Figure 4 represents a diagram concerning the balance of mass and the energy balance in the bottoms of the column [10]. Where the variables are defined:

- Variable to control (h): Level of the bottoms of the first column [m]
- Variable to manipulate \(q_{L_m}\): Volumetric flow of the liquid that leaves the section [m\(^3\)/h]
- Disturbance variables: \(q_{V_o}\) Volumetric flow of steam coming from the boiler [m\(^3\)/h] and \(q_{L_m}\) Volumetric flow of liquid entering the section [m\(^3\)/h].

The flows can be calculated through a total mass balance (1), a balance per component Water (2) and a balance by component Ethanol (2) around the contact stage can be written as follows [1].

\[
V_o + L_m = V_f + L_b \quad (1)
\]
\[
V_oZ + L_mX_i = V_fY_i + L_bX_i \quad (2)
\]

Where:
- \(V_o\): The mass flow of steam coming from the boiler [Kg/h]
- \(L_m\): The mass flow of liquid entering the section [Kg/h]
- \(V_f\): The mass flow of steam leaving the section [Kg/h]
- \(L_b\): The mass flow of the liquid that leaves the last section of the column by the gravity [Kg/h]
- \(Z\): Steam composition coming from the boiler [Kg water/Kg total]
- \(X_i\): Liquid composition of component \(i\) that can be water or ethanol [Kg del componente /Kg total]
- \(Y_i\): Steam composition of component \(i\) that can be water or ethanol [Kg del componente /Kg total]
Figure 4. Bottoms of the first column.

The energy balance contemplates the enthalpies of the vapor and liquid streams can be expressed as (3).

\[ V_o H_o - V_f H_f + L_m H_m - L_b H_b = \rho A_T C_p T \frac{dH}{dt} \]  

Where:
- \( H_o \): Mass enthalpy of steam coming from the boiler [J/kg]
- \( H_m \): Mass enthalpy of liquid entering the section [J/kg]
- \( H_b \): Enthalpy vapor mass leaving the section [J/kg]
- \( H_f \): Enthalpy mass of steam the bottoms of the column [J/kg]

Through (1) was eliminated \( V_f \) from (3) and was get the (4)

\[ V_o H_o - (V_o + L_m - L_b) H_f + L_m H_m - L_b H_b = \rho A_T C_p T \frac{dH}{dt} \]  

The model of the valve (5) is introduced into the system of equations. The rate of flow through the valve depends on the size, pressure drop, position and fluid properties [1]. The flow of the liquid through a valve is given by [11].

\[ q_{lb} = \alpha C_v (\nu p) \sqrt{\frac{\Delta P}{G}} \]  

Where:
- \( q_{lb} \): Flow of liquid that leaves the last section of the column due to gravity [m³/h]
- \( \alpha \): Coefficient of conversion to international system.
- \( C_v \): Valve coefficient [gpm/psf⁻¹/²]
- \( \Delta P \): Pressure drop through the valve [kPa]
- \( \nu p \): Opening of the valve; if its value is 0, the valve is closed; if the value is 1, the valve is open.
- \( G \): Specific gravity of the liquid flowing through the valve, without dimensions

For this process, the pressure drop (6) through the valve is given by [11].

\[ \Delta P(t) = P_1 + \rho gh - P_2 \]  

Where:
- \( P_1 \): Pressure on the liquid [kPa]
- \( \rho \): Density of the liquid [kg/m³]
- \( g \): Acceleration due to gravity [9.8 m/s²]
- \( P_2 \): Valve outlet pressure [kPa]
The equation (7) is obtained by replacing $q_{L_b}$ in (4) through (5) and (6).

$$\frac{dh}{dt} = \frac{Q_{V_0} \rho_{V_0} \left( C_{pV_0} (T_{V_0} - Tr) + \lambda_V \right)}{\rho A_T C p T} + \frac{q_{L_m} \rho_{L_m} C_{pLm} (T_{Lm} - Tr)}{\rho A_T C p T}$$

$$\left( q_{V_0} \rho_{V_0} + q_{L_m} \rho_{L_m} - \left( C_V (vp(t)) \sqrt{\frac{p_1 + \rho gh - p_2}{\rho}} \right) \rho_{Lb} \right) (Y_{et}(C_{pet}(T_{Vl} - Tr) + \lambda_{et}) + Y_{ag}(C_{pag}(T_{Vl} - Tr) + \lambda_{ag}))$$

$$= \frac{\left( C_V (vp(t)) \sqrt{\frac{p_1 + \rho gh - p_2}{\rho}} \right) \rho_{Lb} C_{pLb} (T_{Lb} - Tr)}{\rho A_T C p T}$$

(7)

Where:

$C_{pV_0}$: The heat capacity of ethanol in the vapor state as a pure component [J/kg °C]

$C_{pV_0}$: The heat capacity of water in the vapor state as a pure component [J/kg °C]

$T_{V_0}$: Temperature of the top of the bottom section of the first column [°C]

$\lambda_{et}$: Enthalpy of vaporization of water as a pure component to conditions of Bogota [J/kg]

$\lambda_{ag}$: Enthalpy of vaporization of ethanol as a pure component to conditions of Bogota [J/kg]

$T_{Vl}$: Temperature of the bottom section of the first column [°C]

$T$: Temperature of the section [°C]

For the linearization of (8) use the expansion of the Taylor series, with the point of operation presented in Table 2.

$$\frac{d\Delta h(t)}{dt} = \left( \frac{\partial f}{\partial \Delta h} \right)_{op} \Delta h(t) + \left( \frac{\partial f}{\partial \Delta V_0} \right)_{op} \Delta V_0(t) - \left( \frac{\partial f}{\partial \Delta V_1} \right)_{op} \Delta V_1(t)$$

(8)

The deviation variables are defined:

$$Q_{V_0}(t) = q_{V_0}(t) - q^{ref}_{V_0}, Q_{Lm}(t) = q_{Lm}(t) - q^{ref}_{Lm}, VP(t) = vp(t) - vp^s, \bar{h}(t) = h(t) - \bar{h}$$

The deviation variables are replaced in the linearized equation (9)

$$\frac{d\bar{h}(t)}{dt} = \alpha_1 Q_{V_0} + \alpha_2 Q_{Lm} - \alpha_3 \bar{h} - \alpha_4 \bar{h} - C_1 VP$$

(9)

Where the values of the constants are:

$$C_1 = C_V \sqrt{\frac{p_1 + \rho gh - p_2}{\rho}}$$

$$C_2 = C_V \rho gp v^2 \left( \sqrt{\frac{p_1 + \rho gh - p_2}{\rho}} \right)^{1/2}$$
The above allows to obtain the transfer functions (11) through the Laplace transforms of the first order (10), for the analysis of the dynamics of processes and the design of control systems [11].

\[
\dot{h}(S) = \frac{K_1}{s+1} V_o + \frac{K_2}{s+1} L_m + \frac{K_3}{s+1} VP
\]

Where,

\[
\tau = \frac{1}{\alpha_3 + \alpha_4}, \quad K_1 = \frac{\alpha_1}{\alpha_3 + \alpha_4}, \quad \frac{\alpha_2}{\alpha_3 + \alpha_4}, \quad \frac{\alpha_3}{\alpha_3 + \alpha_4}
\]

The transfer functions are represented in a block diagram [12] for the control system as shown in Figure 5.

Where the transfer function (\(G_{p}\)) (12) involves the transfer function of the bottom of the distillation column and the solenoid valve.

\[
G_p = \frac{K_1}{s+1} = \frac{2.86}{1.61s+1}
\]

The sensor transfer function (\(G_s\)) (13) defines the gain as the change in the output or response variable between the change in input or forcing function [11], the output is an electronic signal from 0 to 24 Volts, and the Inlet is the level of the liquid from 0 to 0.18 m.

\[
G_s = \frac{\text{Volts de salida}}{\text{Altura del liquido}} = \frac{24 - 0}{0.18 - 0} = 133.33
\]

Figure 5 also identifies the transfer functions of the disturbances for the level control loop in the bottoms, which for this system are those presented in (14).

\[
\frac{X(s)}{V_o(s)} = \frac{23.08}{1.61s+1}, \quad \frac{X(s)}{L_m(s)} = \frac{5.43}{1.61s+1}
\]
6. Disturbance analysis

To analyze the robustness and stability of the control system we performed simulations of the behavior of the system in different scenarios with the Simulink program. To do that the controller (Gc) was modeled with a Relay block, as shown in Figure 6, creating a hysteresis controller which allows the output to change between two specified values as implemented (see next section).

The first scenario was to make the stationary error zero in the operating conditions. Where the difference of the measurements of the reference point and the desired output is known as the error, which is converted into a value and conditioned to be used in the opening or closing of the final control element [13]. For the simulation to be close to reality a measurement noise was included; which is caused by the bubbles that form due to the phase change, modeled with a Band-Limited White Noise show in the Figure 7a. In its steady state, it is maintained around the desired level of 0.18 m with a noise of 0.02 m above and below the desired point as shown in Figure 7a. Figure 7b shows the control signal, in which it can be seen that although there is noise in the reading signal, the on and off frequency of the valve is not very high with a percentage of 54%.

The second scenario analyzed were the change in the operation of the variable considered as disturbance. In this case, the steam coming from the boiler has influence in the system to generate the formation of bubbles, and the increase of the temperature in the top of the column. As shown in Figure 7c, the set point is moved and does not maintain the desired level of 0.18 m. For other way, it was found that the controller is robust before changes of +/- 0.001.
Figure 6. Block diagram in Simulink.

Figure 7a. Level (m) vs Time (s) point of operation with the Simulink program.

Figure 7b. Control signal over point of operation with the Simulink program.
7. Level control strategy

Before implementing the assemblies, the instrumentation selection was carried out according to process conditions, instrumentation options that the university has in its robotic laboratory and permitting facility (Appendix A).

Two assemblies were carried out. The first was an ON-OFF control, as shown in Figure 8a under ISA-5.1-2009, where the capacitive proximity sensor, and the information generated by this measurement element is treated using a signal conditioner and converted to a digital format through NI USB-6009 [14] (Appendix A), where LabVIEW graphic programming language process the information. The controlled variable was a normally close ON-OFF valve activated electrically by LabVIEW [15]. Figure 8b show the implementation.

The control strategy consists of generating a delay in the opening of the solenoid valve according to a parameter established by the interface in seconds, through a time function. This did it because it was not feasible to install an analogous sensor due to the turbulence and vapors generated.

For assembly one, the control system has two fixed states, with no intermediate values. As shown in Figure 9 the valve remained 97% of the time open, which generated a little correction to the system, temperatures will increase, the tower will be destabilized, and the distillate will not be constant. Note, that this control signal is inverted with respect to the simulation because the valve is normally closed.
An improvement was made to the first assembly with an on-off control with hysteresis. This time two sensors were implemented as shown in Figure 10a and Figure 10b.

For its implementation (Appendix A), a source was needed to energize the solenoid valve and sensors, as the solenoid valve has a voltage of 24 VDC it is necessary to use an LM2596 converter that reduces the signal to 5 VDC to power the card, likewise for capacitive type sensors, relays were used that carry the signal to the card.

Within the LabVIEW environment (Figure 11a), the low sensor was called an LSL when it did not register anything, it sent the signal to the valve that had to close preventing the tower from emptying, at this point, it begins to fill until the sensor High LSH was lit. Only at the highest point did the valve open, allowing the tower to be emptied and not flooded.

As shown in Figure 11b, the program receives a low and a high signal, only until it receives the high signal, it decides to activate the valve so that it opens and does not allow the tower to flood this is done using a subroutine called RS flip-flop. The valve only closes if the low signal registers a value of zero. The waveform chart function was used to represent the behavior of the signal graphically.
However, the turbulence that appeared showed a constant record of one, with the valve remaining open at 64% during the 3 hours of operation as shown in Figure 12; unlike the first assembly, a better control to the system is generated.

Finally, to validate the behavior of the two assemblies, the 200 L solution of an ethanol-water solution at 15% by volume was again prepared. For the preparation, 30 L of commercial grade 74% ethanol are used; these results are recorded in table 4; the input of food is one liter per minute that according to the practices is where the meter takes a better record.

| Parameter                              | Assembly 1 | Assembly 2 |
|----------------------------------------|------------|------------|
| Average temperature at the top of the second tower (°C) | 74         | 72         |
| Reflow (No. of turns)                  | 4          | 4          |
| Quantity of distillate in practice (L/h) | 5          | 7          |
| Ethanol recovery (%)                   | 60         | 77         |
| Practical time (h)                     | 4          | 3          |
| Prepared food (L)                      | 200        | 200        |
When comparing the results of Table 4, assembly 1 took more time in practice and did not reach the recovery of ethanol from assembly 2, this was due to the fact that the first assembly was destabilized increasing the liquid intake, which meant that the temperature of the top would increase, the tower would be destabilized and the distillate will not be constant. For the second assembly another sensor was implemented in order to operate with hysteresis, having a high and low control, obtaining a stable recovery of ethanol and maintaining the temperatures at the top of each column.

8. Conclusions and recommendations

The design and implementation of a level control with hysteresis in the bottom of the first column was achieved, which reduces the labor of the students who manipulate the tower. Also, students reduce high-risk conditions by avoiding the manual valve management of the bottom that reaches temperatures above 90 °C with the replacement of the solenoid valve implemented.

With the control loop implemented, a chain reaction is generated, and indirectly it controls the temperature change, once it stabilizes, it is possible to decrease the stabilization time of the tower, going from 3 hours with practices without a control system to 1 hour with the implementation of the control system.

The capacitive sensors are low cost and easy to adapt as they work by proximity; however, the readings were influenced by the turbulence generating that the solenoid valve remained in 64% of the open time, which in the future generates that the valve coil can be reheated. In this way, it is proposed to improve the strategy of control with a mechanical adaptation at the tower, an external tube is connected to put a differential pressure transmitter and measure the pressure difference between of level lower and upper [16]. For money and time, its implementation was not possible.

References

[1] Luyben, W L 2014 Process Modeling, Simulation and Control for Chemical Engineers (Vol. Second Edition) McGraw Hill Education India Private Limited
[2] Cardenas Tovar, L N, & Rodríguez Rivera, N D 2016 Automatización De Una Torre De Destilación Para Operación Continua A Escala Laboratorio Caso De Estudio: Centro De Investigación En Procesos De Ingeniería (C.I.P.I.) (Bogotá, Colombia: Universidad Jorge Tadeo Lozano)
[3] Alzate Ibañez, A M 2010 Modelado y control de una columna de destilación (Manizales, Colombia: Universidad Nacional de Colombia - Sede Manizales)
[4] Richmond Salazar, E 2009 Diseño y construcción de una interfaz de control de nivel, temperatura y flujo de agua en un tanque para uso en prácticas de laboratorio (San Jose, Costa Rica: Universidad de Costa Rica)
[5] Franco Ocampo, D F, & Franco Mejía, E 2015 Emulación de una columna de destilación binaria continua para propósitos de formación en control UIS Ingenierías, 14(2), p 7-17
[6] Navas Herrera, S. J 2014 Control de Columnas de Destilación. Universidad de Sevilla. Retrieved from http://bibing.us.es/proyectos/abreproy/20374/fichero/Proyecto+completo.pdf
[7] AspenTech Inc 2005 Aspen Hysys: simulation basis Retrieved from http://www.aspentech.com
[8] Aceno Sánchez, J 2003 Control avanzado de procesos (Teoría y práctica) (España: Ediciones Díaz de Santos, S. A.)
[9] Poling, B. E, Prausnitz, J M, & O’Connell, J P 2004 The Properties of Gases and Liquids (Fifth Edition ed.) McGraw-Hill Companies
[10] Ogunnaike, B A, & Harmon Ray, W 1994 Process dynamics, modeling, and control (New York: Oxford University Press)
[11] A Smith, C, & B Corripio, A 2000 Control Automático de procesos. Teoría y práctica (México D.F: Editorial Limusa, S.A de C.V Grupo Noriega Editores)
[12] Peter Harriot, & Peter Harriott 1964 Process Control (United States of America: McGraw-Hill, Inc)
[13] Lázaro Castillo, I 2008 Ingeniería de Sistemas de Control Continuo (México: Universidad Michoacana De San Nicolás De Hidalgo) Retrieved from http://isidrolazaro.com/wpcontent/uploads/2013/01/Preview_Control_Continuo_1ed.pdf
[14] National Instruments 2014 Adquisición de datos Retrieved from http://www.ni.com/data-acquisition/what-is/esa/
[15] Villacruz Guijarro, G E 2011 Automatización y puesta en marcha de una columna de destilación continua de platos perforado tipo experimental para el sistema etanol-agua mediante PID y plataforma LabView denominada (UDCC) (Guayaquil, Ecuador: Universidad de Guayaquil)
[16] Creus Solé, A 2011 Instrumentación Industrial (Vol VIII) (México: Marcombo)

Acknowledgment
To Carlos Arturo Céspedes Zambrano in charge of laboratory of the CIPI for his support in the runs made with the tower, Andrés Felipe Ángulo Sánchez assistant of robotics laboratory for the loan of elements to assemble the control loop, this integration of careers allowed to carry out this work, obtaining the implementation of level control.
Appendix A

1. Solenoid valve.
The element final of control selected was a solenoid valve [16], are economical and only require an adequate energy source, where its purpose is to regulate the flow manipulated in the control system [11].

The flow capacity of a control valve is determined by its capacity factor or flow coefficient (Cv), introduced in 1944 by valve manufacturers Masoneilan International, Inc. [11], clearing from equation 5, where the bottoms in the first column are obtained at a rate of 0.269 gpm, considering that the valve is open \( \frac{v}{h} \) is equal to 1, its get that the value of Cv is 0.31 gpm/psi\(^{0.5} \) with this capacity factor and the characteristics shown in table A1, the solenoid valve was selected.

| Table A1. Characteristics of the solenoid valve. |
|-----------------------------------------------|
| Parameter       | Value                  |
| Medio           | Aggressive, Steam     |
| Internal material | Stainless steel      |
| Body            | Bronze brass          |
| Seals           | EPDM                  |
| Actuator action | NC                    |
| Connection      | 1/2''                 |
| Temperature     | 140 °C                |
| Voltage         | 24 V                  |

2. Capacitive Sensor.
Sensors of capacitive type [16] were used (See Table A2), responsible for manipulating the high, and low-level variable with the support of the dielectric constant of water. When feeling the presence of the fluid, the light diode (LED) lights up.

| Table A2. Characteristics of the sensor |
|----------------------------------------|
| Parameter                          | Value                      |
| Permissible operating voltage       | 12 – 48 V DC               |
| Switching output                    | PNP, normally open         |
| Material Front cover                | PTFE                       |
| Body material                       | Nickel-plated brass        |
| LED for the supply voltage          | Green                      |
| Switching element «ON» LED          | Yellow                     |

3. Materials and connection.
Figure A1 shows the materials that integrated the final assembly of the control system implemented by hysteresis. The materials were obtained by the robotics area of the University Jorge Tadeo Lozano.
Figure A1. Assembly of the electrical connection of the control system.

To give clarity, Figure A2 shows the electrical connection of the materials for assembly.

Figure A2. Schematic of electrical connection of the control system.