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DISTILLATE COMPOSITION CONTROL OF BINARY DISTILLATION COLUMN

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ABSTRACT

Distillation is a continuous process in the petroleum and the chemical industries. A high amount of energy used in the chemical and petrochemical industries is consumed in the distillation process, since large amount of heat transfer takes place between the trays of distillation column. Thus, there is a need of energy efficient process to be designed and controlled, in order to make the final product of the distillation process of desired quality and the whole process being more economic.

In this paper, graphical programming of LabVIEW software has been utilized to develop model for distillation column and also to control the product stream composition. Use of virtual instrumentation for the modeling of systems and controlling the process variables improves the performance and reliability of the whole plant. Virtual instrumentation saves the extra cost, time and energy that are incurred while setting up traditional instrumentation systems. It is a latest form of modern measurement or monitoring technology where all types of measurements are done on front panels created on PC screen. This paper explores the very capability of Virtual instrumentation to monitor and control the process variables, which is composition of the top product stream of the distillation process, and the use of LabVIEW in the field of Process control. In this work, the mathematical modeling is made in the frame of LabVIEW and control properties of distillation column are investigated using PID control structure.

Keywords: Composition control, Distillation column, LabVIEW, Modeling, PID controller

1. INTRODUCTION

Distillation columns are widely used in chemical process, such as crude oil refinery. Therefore, improved distillation control can have a significant impact on reducing energy consumption, improving product quality and protecting environmental resources. However, both distillation modeling and control are difficult task because the plant behavior is usually nonlinear, non stationary, interactive and is subjected to constraints and disturbances. The control of the overhead and bottom compositions in a binary distillation column using reflux and bottom flow rates has been shown to be a particularly difficult problem, due to the significant time delay nonlinear inherent interaction in the process.

In this paper, the mathematical modeling is made in the frame of LabVIEW and control properties of distillation column are investigated using PID control structure. PID controllers have the advantage of a short development time, and small development effort. LabVIEW is a widely used graphical code developing environment which allows system-level developers to perform rapid prototyping and testing. The aim of this paper is to show the integration of distillation column dynamics with the LabVIEW environment used for its monitoring and control. This has been employed to the control of a binary distillation column modeled in the LabVIEW.

2. MATHEMATICAL MODELLING OF DISTILLATION COLUMN

The following assumptions have been adopted to develop the mathematical process model.

- Equimolar over flow.
- Constant relative volatilities.
- Liquid holdup is constant on each tray.
- The liquid is perfectly mixed on each stage.
- The heat loss from the column to the surrounding is negligible.
- Reflux drum holdup is constant.
- The molar heats of vapourization of both components are about the same
- Each tray is assumed to be ideal.

The assumptions above stated, including vapour holdup, mean that the vapour rate through all trays of the column is the same, dynamically as well as at steady state.

$$V = V_1 = V_2 = V_3 = \dots = V_{NT} \quad (1)$$

A simple Francis Weir formula relationship has been used to relate the liquid holdup on the tray (M_n) to the liquid flow rate leaving the tray (L_n).

$$F_L = 3.33 L_W (h_{ow})^{1.5} \quad (2)$$

Where,

F_L = liquid flow rate over weir
 L_W = length of weir
 H_{ow} = height of liquid over weir.

Figure 1: Material balance diagram of distillation column

Consider a binary distillation column; the condenser removes all the latent heat from the overhead vapour. The reflux and distillate are therefore at the bubble point and $Y_{NT} = X_D$. The trays are numbered from bottom to top. The feed is a mixture of binary components, is introduced to the feed tray. The overhead vapour is condensed in the condenser and is withdrawn from the reflux drum. A fraction of condensed liquid is recycled back to the column as reflux stream and some of the liquid is removed as distillate. At the base of the column bottom product is cooled as a liquid stream. The component Y_n of vapour from the n^{th} tray is in equilibrium with the liquid composition X_n leaving the same tray and is expressed as

$$Y_n = \frac{\alpha X_n}{1 + (\alpha - 1) X_n} \quad (3)$$

Where,

Y_n = vapour composition on the n^{th} tray.

X_n = liquid composition on the n^{th} tray.

α = relative volatility.

The equations which describe the system can be stated as,

Consider the enriching section total material balance around a general tray n is given as

$$\frac{dM_n X_n}{dt} = L_{n+1} X_{n+1} - L_n X_n + VY_{n-1} - VY_n \quad (4)$$

For the condenser and reflux drum;

$$\frac{dM_D X_D}{dt} = VY_{NT} - LX_D - DX_D \quad (5)$$

For the top tray;

$$\frac{dM_{NT} X_{NT}}{dt} = LX_D - L_{NT} X_{NT} + VY_{NT-1} - VY_{NT} \quad (6)$$

For the feed tray;

$$\frac{d(M_{NF} X_{NF})}{dt} = L_{NF+1} X_{NF+1} - L_{NF} X_{NF} + VY_{NF-1} - VY_{NF} + FX_F \quad (7)$$

For stripping section;

$$\frac{dM_m X_m}{dt} = L_{m+1} X_{m+1} - L_m X_m + VY_{m-1} - VY_m \quad (8)$$

For first tray;

$$\frac{dM_1 X_1}{dt} = L_2 X_2 - L_1 X_1 + VY_B - VY_1 \quad (9)$$

For reboiler and column base;

$$\frac{dM_B X_B}{dt} = L_1 X_1 - VY_B - BX_B \quad (10)$$

The heat balance equation establishing the vapour rate is;

$$\frac{d(McT)}{dt} = q - VH \quad (11)$$

Where,

M_c = molar heat capacity

H = vapour enthalpy.

2.1 Mathematical modeling using LabVIEW

The model for the distillation column has different trays and each tray has same differential equation, except feed tray, top tray and bottom tray, with different values of the input and output. The general tray equation can be programmed as:

Figure 2: Block diagram for n^{th} tray

3. EXPERIMENTAL SETUP

The experimental system consists of Laboratory Sieve tray Distillation column. The equipment consists of a vertical shell with a number of equally spaced trays mounted inside of the column. Liquid flows through gravity from each tray to other tray below. It has a reboiler which is a part of distillation column, provides the necessary vaporization for the distillation process. The condenser is used to cool and condense the vapor leaving the column from top of the column. The Reflux drums to hold the condenser vapor from the top of column so that liquid (reflux) can be recycled back to the column. The vertical shell together with the condenser and reboiler consist a distillation column.

Figure 3. Laboratory Sieve Tray Distillation Column

3.1 Distillation column control

The control scheme for controlling the composition of the products is then has been decided on the basis of these equations. The feed rate F and the composition Z are given and are taken as the disturbances for the plant. Because distillation requires a desired product concentration or flow rate, constraint control is used to ensure the desired operation conditions by having set points designated for the requirements of the system. The constraint is usually a concentration and the control of this concentration can vary depending on the application. When designing the composition controls for a distillation column, the composition to be controlled must be one that is affected to a significant degree by the controls. The controls primarily influence two compositions: The heavy key in the distillate product, for the methanol-

water system this would be the methanol in the top product. And the light key in the bottoms product, it would be water in the bottom product.

The composition can be controlled by PID controller strategy; because it is a controller widely used in industry and has been universally accepted in industrial control. And the popularity of PID controllers can be attributed partly to their robust performance in a wide range of operating conditions and partly to their functional simplicity.

3.2 Control Programming

The control program is developed by taking the readings of reflux flow rate, vapour boilup and top and bottom compositions on each time, and by find out the relation between the reflux flow rate and distillate composition, such that how the reflux flow rate will affect the distillate composition and also the relation between vapour boilup and bottom product composition, such that how will the vapour boilup affect the bottom composition. These relations can be finding out from the transfer function regarding each pair of data. The transfer function can be built in the model from the model equation. Then the parameters of the controlling action can be finding from the controller tuning methods, for the best controlling action. In this case we use PID controllers for both distillate and bottom composition controlling. The parameters of the PID controller can be found out from the auto tuning method. The control program is developing in LabVIEW software. The values of the model parameters are used for controller program are as follows,

Table 1: Distillation Column Model Parameters

Parameter	Value
Number of trays	7
Feed tray	5
Relative volatility	1.5
Feed composition, (mole fraction)	0.9
Feed flow rate,(litres/h)	5.5
Distillate composition,(mole fraction)	0.995
Distillate flow rate,(litres/h)	5
Bottom product composition, (mole fraction)	0.005
Bottom flow rate,(litres/h)	0.5
Reflux rate, (litres/h)	10
Vapour boilup	1600

The PID controller parameters are:

Proportional gain $K_c = 68.23$

Integral time $T_i = 6.595$

Derivative time $T_d = 1$

The block diagram and front panel of the control program is

Figure 4: Front panel of control programming

4. RESULT AND DISCUSSION

The model for binary distillation column is developed. And a step change of magnitude in the feed flow has been fed to the system and the variation in the composition of the top and the bottom product has been analyzed. An impulse mode change in feed to the system and the variation in the composition of the top and the bottom product have also been analyzed. And change in reflux flow rate is analyzed.

4.1 Step change in feed flow rate

When a step change in feed flow rate occur in the system, there is a change occurred in the desired output, i.e., decrease in distillate composition occurred from its desired level. The composition on a plate starts to change when the flow of the stream to the plate changes, and the changes in liquid flow travel down the column faster than the changes in liquid composition.

Figure 5: Response of the Distillate composition for a step change in feed flow

4.2 Impulse change in feed flow

When an impulse change in feed flow rate occurs in the system, there is a small change occurred in the desired output. An oscillation is occurred in the composition value, and finally came to the desired point. After a sudden change in feed flow, plates near the feed tray started to change the liquid and vapour flow almost immediately, and trying to return to the initial condition.

Figure 6: Response of the Distillate composition for impulse change in feed flow.

4.3 Step change in reflux flow

The change in reflux flow made a longer response on the distillate composition, because changing the reflux requires a longer response to its effect on the temperature. When a change in reflux flow occur, a change in temperature occur in the top tray which affect the composition and it took more time to come to the desired level.

Figure 7: Response of the Distillate composition for a step change in reflux flow

5. CONCLUSION

Binary distillation column has been modeled and using dynamic modeling of the binary distillation column behavior during different operational disturbances, the effect of such disturbances is characterized. The process is a multivariable one, with two outputs and four main inputs, two controlled variables (the reflux and bottom product flows) and two disturbances (the feed flow and feed composition). The obtained process model is a nonlinear one, but represented as linear models. The presented results are the outcomes of a simulated distillation process,

The controlled outputs obtained were within the desired range and expected product composition also attained. The result of the work indicates that the chemical process such as a binary distillation column operation establishes a clear nonlinear behavior and can be modeled, dynamically simulated to observe different process variations, using LabVIEW software. PID control strategies were used to control the product compositions. The PID control action gave a better response and easily come to the desired composition values (set point). The responses of the system for different disturbances are also obtained.

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