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MODELING OF DISTILLATION COLUMN AND INTELLIGENT CONTROL OF REFLUX DRUM

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ABSTRACT

A model based approach was chosen for such a complex MIMO system is due to the restrictions the system bear in terms of control variables. Though the process simply refers to separation of two or more liquid or vapor components, the process flow and the component fractions really has to be identified since that determines the quality of the distillate. A pure modeling concept for a sophisticated process like distillation column is demonstrated in this study. It's a complex task to model the distillation column and control the parameters since the process is a multiple input multiple output (MIMO) system. Hence only based on many assumptions about many of the control variables the response can be found. The work has been extended to modeling and control of various parts of column such as reflux drum and feed tray. Fuzzy Control of Reflux Drum was carried out where, the analysis of approximate data has done as a case study due to lack of industrial information.

Keywords: nonlinear processes, volatility, rectifying section, fuzzy control, modeling.

1. INTRODUCTION

The intelligent control is currently one of the most widely used advanced control methods in industrial research, for the process considered to be highly protective uncertain and complex.[8] In chemical Industry most of the processing units consists of the separation or distillation ranging from a distillery to a refinery. In the matter of economic barriers and safety, the process has to be highly controlled and coupled with other processes for better outcomes. The process of separating the mixture of various liquid or gaseous compounds in to two or more composition is termed as distillation. The separation is termed physically since it undergoes the differentiation of volatile components. A vertical column enhances the separation where the mixture inside depending on the volatility either gets escaped as vapor or flow down ward the column as liquid. The vapor stream raised from the reboiler is carried through the column in turn forcefully contacts with the liquid mixture flowing downward the column. The components with low boiling point (highly volatile) are made to be in correlation with vapor phase and the components with high boiling point (lightly volatile) are enriched in the liquid part sediment at the bottom. Thus the resultant product component stream collects the high volatile components at the top near the condenser and the stream from the bottom mainly liquid, contains less volatile or heavy components. There are many control structures and different control loop configurations. The distillate product composition and reflux drum level is the pair of control loop selected in this paper. The subsequent regulation of mole fractions at the drum level, reflux, distillate and reboiler are determined and adjusted by their flow rates respectively [4].

2. MATERIALS AND METHODS

2.1 Modeling and system description

Consider a binary mixture of saturated liquid comprising of two components to be separated in to two streams using conventional distillation.[8] The mixture is fed in the column as a saturated liquid F (lb-mol/h) on to the fraction of a component represented as z (0.5 mole fraction of A). Before entering the product stream, the high volatile component is passes through a condenser which results in liquid byproduct entering the reflux drum.[1] The condensed liquid from the overhead flows to reflux drum as V (lb-mol/h) and is stored and passed through the ratio valves. The schematic [8] of the same is shown in Figure-1.

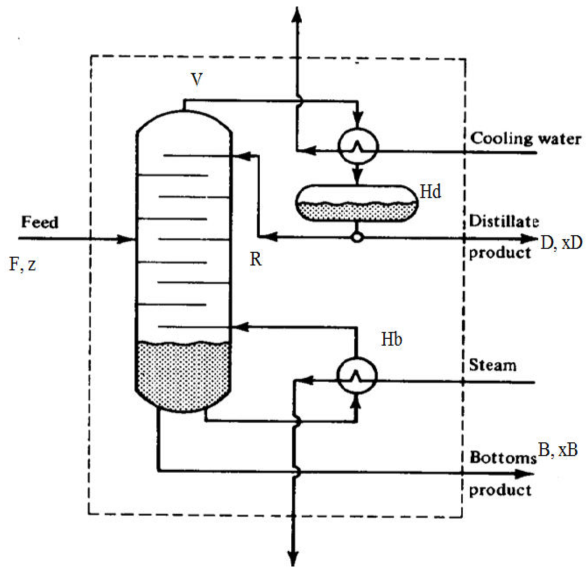

Figure-1. Schematic of a binary distillation column.

The condensation is enhanced with a stream of coolant (cooling water flow) where a heat exchange happens to draw down the temperature. The liquid from the reflux drum is partially allowed to the column through a side tray to distill further if any, and partially is taken out as a byproduct. The liquid molar flow rate flowing to the column from the drum is Reflux, R (lb-mol/hr) and the molar flow rate of the end product is Distillate, D (lb-mol/hr). The continuous removal of the liquid product is done at the bottom of the column that outputs the reboiler section, with a flow rate B (lb-mol/h) and a composition x_B (composition of bottom product).A provision for back flow of the liquid if not purely separated is also given which returns to the base of the column. The vapor hold up on the each N trays will be assumed negligible [6].

2.2 Mathematical modeling

2.2.1 Assumptions and simplifications

The column contains 20 trays numbered from bottom of the column to the top. Let H be the liquid hold up at the i^{th} tray. The vapor hold up on the each tray will be negligible. Several assumptions will be made in order not to complicate matters unnecessarily. Vapor hold up on the each tray will be neglected. It is assumed that the molar heats of component A and component B are equal. For 1 mol of liquid to vaporize it needs heat produced from 1 mol of condensing liquid. The losses in form of heatis not considered since they are too negligible and the relative volatility alpha is assumed to be constant throughout the column. The amount of vapor liberated from a tray is equal to the amount of liquid that flows downstream the column, hence the trays are assumed to have maximum efficiency, say 100%. From the above assumptions one can interpret that the energy balance in each tray is not necessary since the volumes are equal; $V= V_1=V_2=V_3=\ldots\ldots=V_N$. If the later assumptions are analysed closely, it is observed that a simple equilibrium relationship can be drawn between the liqud and gas mixture in the column, to relate the molar concentration of component A (vapor-y_i) and B (liquid-x_i) in the same tray.

$$Y_i = \frac{\alpha xi}{1+(\alpha-1)xi} \quad (1)$$

Where α is the relative volatility of the two components A and B. The final assumptions that we will make are the following:

- The dynamic behavior of condenser and the column is neglected.
- In regard with the Francis weir formula, the molar flow rate of liquid leaving the try is related to the liquid holdup of the tray and hence the momentum balance for the trays can be neglected.

$L_i= f(M_i)$, $i= 1,2,\ldots..f,\ldots,N$

Modeling equations

Reflux Drum:

$$dH_D/dt = V-R-D \quad (2)$$

$$dH_Dx_D/dt = Vy_{20}-Rx_D-Dx_D$$

Stage Above Feed (i):

$$H_sdx_i/dt = L(x_{i+1}-x_i)+V(y_{i-1}-y_i),\ \text{for } 13\le i\le 19 \quad (3)$$

Where, L=R

Feed Stage:

$$H_sdx_{12}/dt = Lx_{13}-L'x_{12}+V(y_{11}-y_{12})+Fz \quad (4)$$

L'=L+F

Stage Below Feed (j):

$$H_sdx_j/dt = L'(x_{j+1}-x_j)+V(y_{i-1}-y_i)\ \text{for} 1\le j\le 11 \quad (5)$$

Reboiler:

$$dH_B/dt = L'-V-B \quad (6)$$

$$dH_Bx_B/dt = L'x_1-Vx_B-Bx_B.$$

The distillate been with differential vapor pressures, a considerable change in overhead distillation is expected with respect to time. [3] The resulted end product or distillate may contain the higher volatile component with a higher rate. The control of the rectifying section is done in labview using conventional controllers. In the rectification part, the reflux drum level, feed flow rate and vapor flow rate are to be controlled. The latter is controlled using a valve. If the set point value of the level exceeds a limit say 200, the valve closes and if the set point value is lesser than the level of the drum, the valve opens in order to maintain the level at a certain value for the better working of the column. LABVIEW based model of the distillation column is shown in Figure-2.

The control of rectifying section is shown below. It is developed with conventional P and PI controllers. The vapor flow control together with the whole of rectifying section is implemented. The reflux drum itself has many economic as well as technical importance, [7] that part alone was considered to control. Initially the controlling was done using conventional P and PI controllers. The main disadvantage regarding these controllers is the level alone cannot be controlled since it is dependent on the other parameters as flow rates and ratio. So, a couple of conventional controllers are to be used for the proper control of the whole of reflux drum including the level. To overcome this fuzzy logic controller was implemented. The upcoming section deals with the controller implementation for the column parameters.

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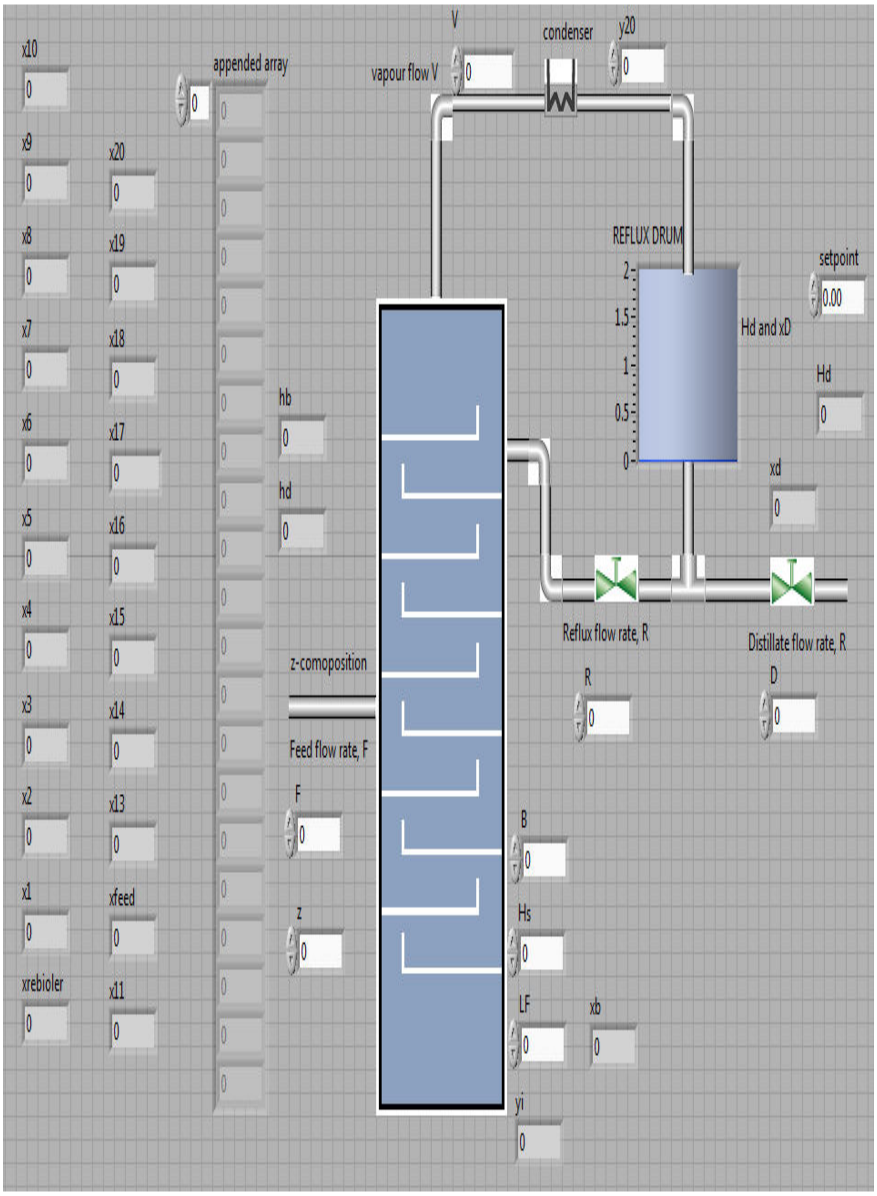

Figure-2. Distillation column modelling.

2.3 Fuzzy logic controller

The fuzzy logic controller is implemented and the membership functions for various variables are given below. In the system the level of the reflux drum are to be controlled due to many reasons.[9] If the liquid in the drum accumulates or decays beyond a limit, the whole distillation column is affected. The proposed controller is shown in Figure-3.

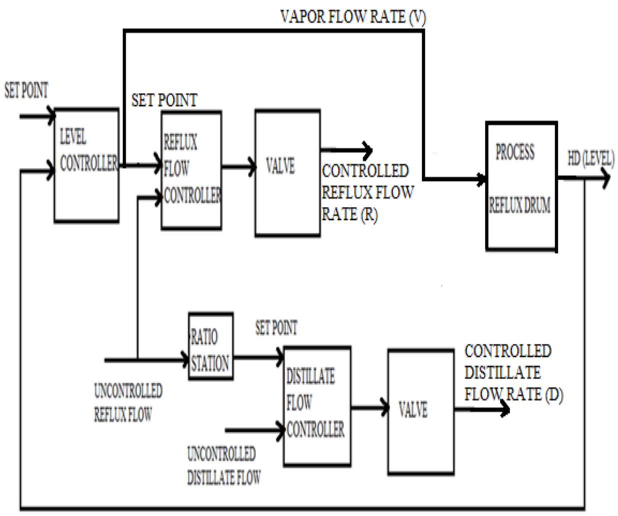

Figure-3. Block Diagram of the Proposed Controller.

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Since distillation is a continuous process, the constant removal of output product may result in many drastic changes in the column. Almost all the variables in the system are interdependent among each other. So, as explained above, a single control strategy cannot be used for control [5]. For reflux drum alone, the ratio as well as different flow rates is to be maintained to control the level. If the output flow rates of the process, say reflux flow rate and distillate flow rate are increased the input should be increased in order not to make the drum level to fall beyond a limit. In real time process these are made possible by adjusting a valve. Conversely, if the input flow is minimum then the reflux and distillate flow rates should be kept reduced or the valves should be closed to maintain the level. The principal is implemented for generating the rules for the fuzzy logic controller. A set of 81 rules is selected in such a way that when the vapor flow rate ranges between three variables as ZERO, PMIN (Positive Minimum) and PMAX (Positive Maximum). Figure-4 demostrates the overall cascade control used in the study. The fuzzy membership functions of reflex rate, vapor rate and distillate rate and the overall error and derrivative error is shown in Figures 5,6,7,8,9 respectively.

Example of the rules (IF-THEN) used for controlling level using vapor flow rate is illustrated below:

- If reflux is PMAX and distillate is PMIN and error is Positive and derivative error is Zero, then vapor is PMAX.

- If reflux is PMIN and distillate is PMAX and error is Positive and derrivative error is Negative, then vapor is PMAX

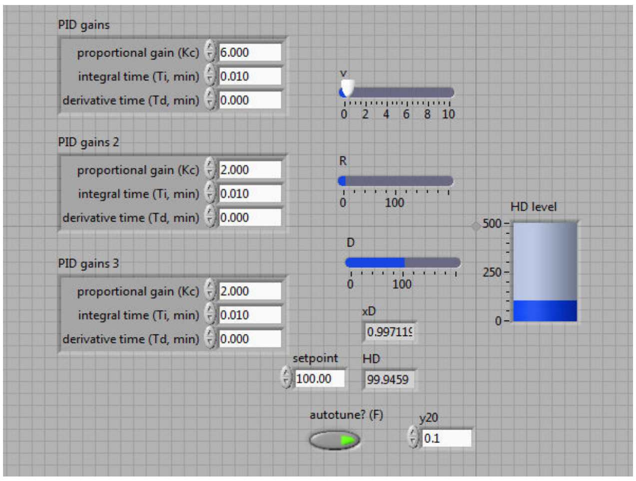

Figure-4. Cascade ratio control.

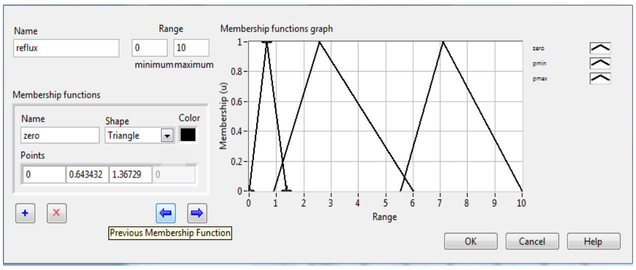

Figure-5. Membership functions for reflux flow rate.

Where reflux flow rate, distillate flow rate, error and derivative error has influence on the level of the drum.[4] The above rule implies that when reflux flow rate and distillate flow rate at the output is maximum, then the input, vapor flow rate should be maximum to maintain the level to the set point. If error and derivative error are considered, then also the input should be controlled to acquire desired output level for the reflux drum.The fuzzy rules set is described in Table-1.

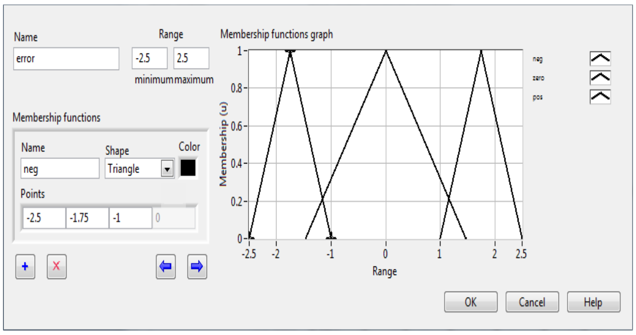

Figure-6. Membership functions for error.

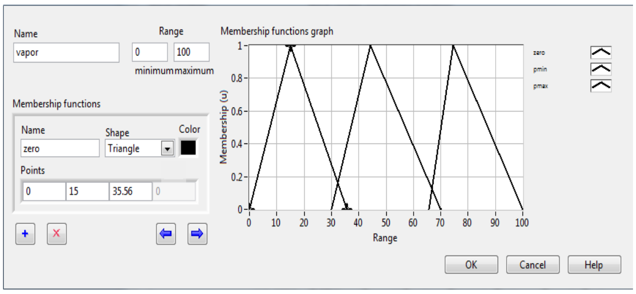

Figure-7. Membership functions for vapor flow rate.

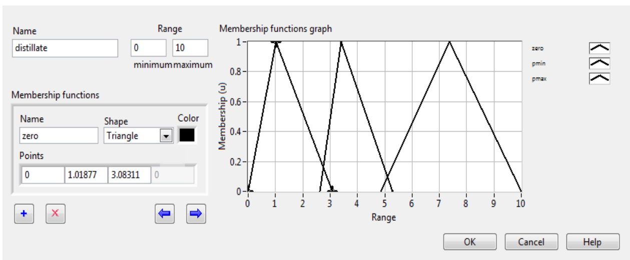

Figure-8. Membership functions for distillate flow rate.

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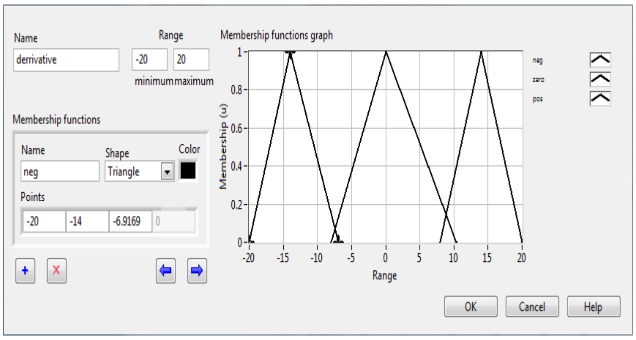

Figure-9. Membership functions for derivative error.

Table-1. Fuzzy rules with H_D as process output.

R	D	E	DE	V	HD
zero	zero	negative	Negative	Zero	sp
pmin	pmin	zero	zero	Pmin	sp
pmax	pmax	positive	positive	pmax	Sp

3. RESULTS AND DISCUSSIONS

The above observation implies that modelling of the distillation column itself is a complex task. The differential equations that describe the model of the system cannot be used to derive a transfer function since it consists of more than one dependent variable. The only way to establish such system is to model the system using the same set of differential equations, which is done in LabVIEW. Each tray is modeled separately including the reflux drum and reboiler section. The reflux drum itself has many economic as well as technical importance, that part alone was considered to control. The level of the drum serves as an important parameter to be controlled. The intelligent control of reflux drum is illustrated in Figure-10.

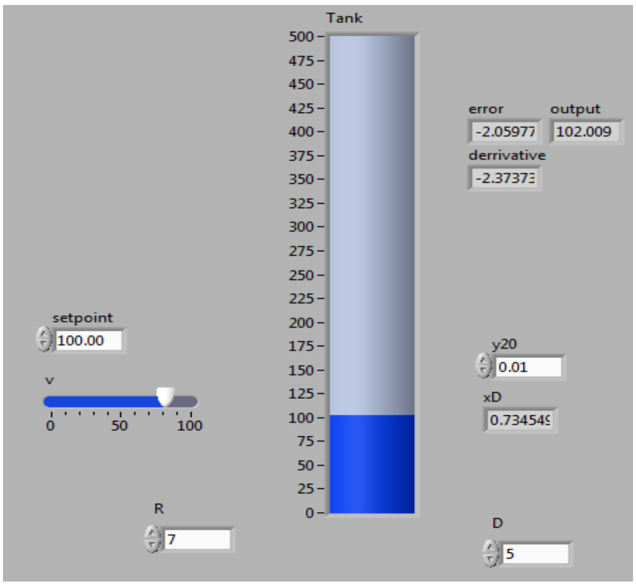

Figure-10. Fuzzy logic control of reflux drum.

Initially the controlling was done using conventional P and PI controllers. The main disadvantage regarding these controllers is the level alone cannot be controlled since it is dependent on the other parameters as flow rates and ratio. So, a couple of conventional controllers are to be used for the proper control of the whole of reflux drum including the level. To overcome this fuzzy logic controller was implemented. It replaces all conventional controllers with a single controller for level control. When comparing with the conventional controller the fuzzy logic controller didn't provide the set point tracking as accurate as conventional controller. But still the desired output is obtained to the most nearer value of the set point which is shown in Table-2.

Table-2. Performance Comparison.

CONTROLLER	SETTLING TIME
Cascade Ratio Control	98.54
Fuzzy Logic Control	100.94

The successful completion of the control of reflux drum alone was made. The other objective is to control the rectifying section of the column. It includes mainly the feed flow rate, the vapor flow control and the compositions of the upper ten trays of the column. The rectifying section consisting the feed flow rate and compositions where observed to be controlled. The vapor flow was controlled using a valve. The valve opens if the level of the drum falls beyond the output value and the valve closes when the level of the liquid in the drum exceeds beyond the set point. Thus the modeling of distillation column and control of rectifying section was made with a comparison of a conventional and intelligent controller for the control of the level of the reflux drum.

4. CONCLUSIONS

Practical values are not available for the verification of the modeling done. The steady state values of a binary distillation column are available for the study. Most of the industrial processes are multicomponent distillation columns. This finds difficult to be implemented in a binary distillation column. So the simulations are done on several assumptions on the column on various parameters as temperature, pressure, flow rates etc. For a complex process like distillation column prescribed in this project, there was no trained set of data which makes it difficult to use in intelligent controllers as networks as well as genetic algorithms. As a case study reflux drum was adopted and was control. The control objective can be expanded for full of distillation column and the stripping section, and even can be done for other types of distillation column.

The future scopes include the implementations of various adaptive and predictive controllers on reflux drum level control and comparison of its performances.

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