Design of a Fuzzy Supervisory Control System for a Binary Distillation Column

N.Sangster, T.Lalla, S.Mohammed

***Abstract*—** In a distillation column, slight changes in the flow rate of the feedstock have an effect on the operational efficiency and product quality of the column, unless some operating parameters, such as reflux rate or vapour boil up rate, are modified. Most plants have operators that monitor these variables and make the necessary adjustments to maintain the desired product quality. Most of the time then, product quality depends on the operator's experience or his/her response time to the disturbance variable. This work looked at developing a fuzzy supervisory controller which included a feed-forward and two feedback controllers for the purpose of improving the dual product quality control of an existing pilot binary distillation column. The fuzzy system rule bases were designed using data collected from experimentation and interviews with operators. The membership functions were based on the temperature error and its rate of change. The controller actions were then simulated using the fuzzyTECH software. These outputs were compared to the experience based control values from the operators and the controllers were fine tuned to achieve a less than ten percent percentage error. Positive results were achieved as the majority of the simulated controller outputs were within 10% of the actual values.

Keywords— Fuzzy, binary distillation column, feed forward control, feedback control.

I. INTRODUCTION

According to Riggs (2006), "approximately 40,000 distillation columns are operated in the U.S. chemical process industries and they comprise 95% of the separation processes for these industries. Distillation control is a challenging problem because of the following factors; process nonlinearity, multivariable coupling, severe disturbances and non-stationary behavior."

The main challenge with binary distillation control is that conventional controllers require an accurate linear mathematical model of the process to give the best control performance. The distillation process, however, is very nonlinear and dynamic; therefore the linear mathematical models developed are only approximate. The result is a reduction in the performance of these conventional controllers when applied to distillation control.

In day-to-day-operations, normally an operator is constantly monitoring the column and making adjustments to utility stream set points when there are disturbances to the column's steady state operation. Experience is critical when making these adjustments and not all operators are able to quickly correct the problem. The challenge then, is to design a system that will provide quick and accurate automatic control of a binary distillation column when there are less experienced operators at hand.

Distillation is no doubt a major separation process and control issues have direct effects on product quality, resource and utility consumption. Fuzzy control offers the opportunity to develop a control system which does not rely on accurate mathematical models of the system being available. It instead uses the knowledge of experienced operators and engineers in order to develop the control actions.

II. METHOD AND SYSTEM DESIGN

Firstly, experimentation was done for a period of two (2) months using the pilot binary distillation column. The data collected included the time variation of key process parameters due to implemented changes. In addition to this interviews were conducted with technical staff that had experience with operating distillation columns. Secondly, the fuzzy controller was designed, tested and tuned using commercial software – fuzzyTECH.

A. Binary Distillation Column

The pilot binary distillation column used separates a methanol and water mixture. The condenser uses water as the coolant to generate reflux and the re-boiler has an electric coil to provide heat input to generate the vapor boil up. There are ten trays in the column and the feed tray can be varied. The DeltaV software is used for the column so the operator can easily make changes to various set points. There are thermocouples on each tray so the temperature profile across the column can be viewed. The process flow diagram for the specific column is shown in Fig. 1 and Fig. 2 shows where the fuzzy supervisor would be placed.

N. Sangster is with The University of Trinidad and Tobago, O'Meara Campus, ARIMA, Trinidad and Tobago, Phone: 868-497-5608; e-mail: nadine.sangster@utt.edu.tt

T.Lalla is with The University of the West Indies, St Augustine Campus, Trinidad and Tobago, e-mail: terrence.lalla@sta.uwi.edu

S.Mohammed is with the ASCO Group, Trinidad and Tobago

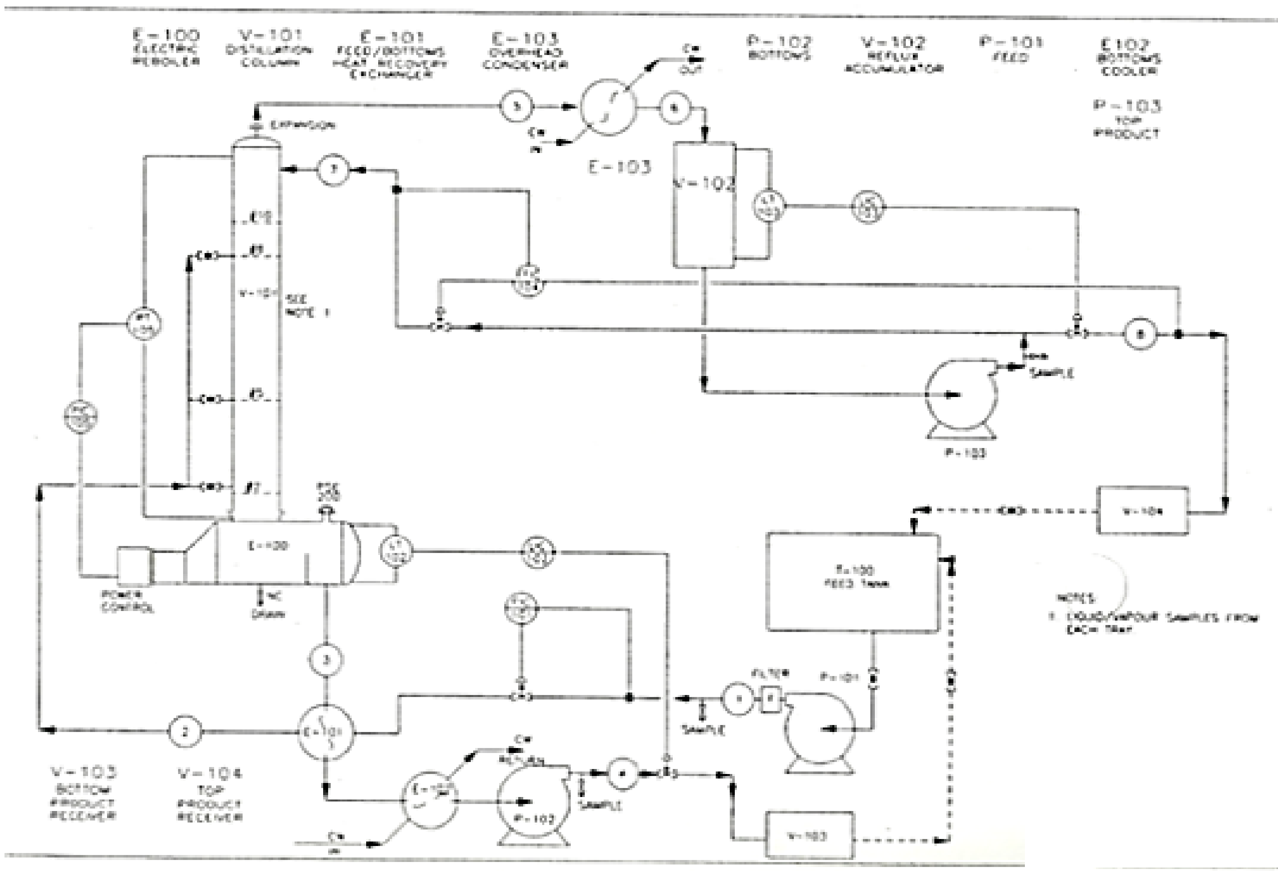

Fig. 1 Schematic of the binary distillation column

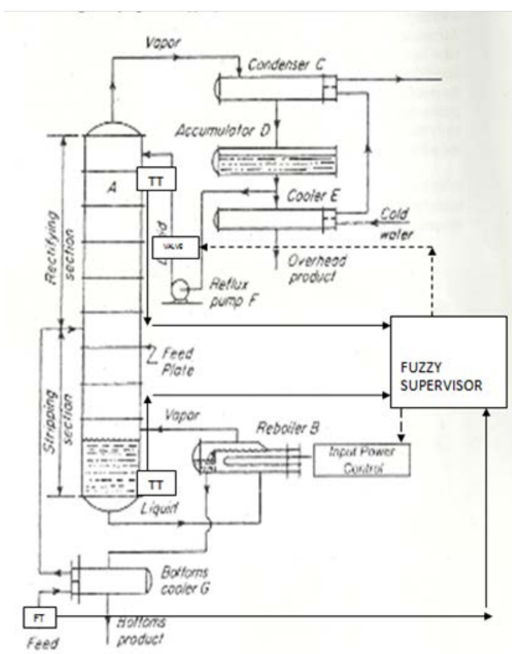

Fig. 2 Shows where the fuzzy supervisor would be placed

During the experimentation stage, the process was set up at a steady state condition. All experiments were conducted for the feed flow range of 60 kg per hour to 80 kg per hour with the initial steady state feed flow being 70 kg per hour. The power was set to 83 percent and the reflux was set to 10.5 kg per hour and the column pressure was essentially constant. The range used for the experiments meant that the control system would only be able to handle a plus or minus ten kg per hour maximum disturbance from the steady state condition.

B. Fuzzy Design

The proposed design entailed a feed-forward controller which monitored the feed flow to the distillation column and thus adjusted both the reflux and power input set points. There were also two feedback controllers that started after the first minute of a detected feed change. Mamdani type fuzzy controllers were utilized in the design.

The feed forward controller

The feed forward controller consisted one input and two outputs as shown below in fig. 3.

INPUT: FeedFlow (reflects the change in feed flow rate)
OUTPUTS: PowerSetpoint, RefluxSetpoint (adjusts power and thus temperature and reflux flow rate)

Spreadsheet Rule Editor - FEED_FORWARD_CONTRO...

#	IF	THEN		THEN	
	FeedFlow	DoS	PowerSetpoint	DoS	RefluxSetpoint
1	very_low	1.00	very_low	1.00	very_low
2	low	1.00	low	1.00	low
3	NORMAL	1.00	medium	1.00	medium
4	high	1.00	high	1.00	high
5	very_high	1.00	very_high	1.00	very_high

Fig. 3 Shows the rule table for the feed forward controller.

Feedback Controller 1: Top (tray) temperature

The top feedback controller was designed to correct temperature errors on the first tray of the distillation column. The inputs are Temperature Error (top) and the Rate of change of the temperature error while the output is Change in the reflux rate set point that was required to correct the error. Fig.4 shows the rule table for feedback controller 1.

Spreadsheet Rule Editor - TopFeedbackController

#	IF		THEN	
	DeltaTopError	Top_temp_error	DoS	DELTAREFLUX
1	NB	NB	1.00	NB
2	NM	NB	1.00	NM
3	Z	NB	0.80	NM
4	PM	NB	1.00	NM
5	PB	NB	0.40	NS
6	PB	NM	0.30	NSS
7	PM	NM	0.40	NS
8	Z	NM	0.90	NS
9	NM	NM	1.00	NS
10	NB	NM	0.60	NM
11	PM	Z	0.10	PS
12	PB	Z	1.00	PM
13	Z	Z	0.30	Z
14	NM	Z	0.70	NSS
15	NB	Z	0.60	NS
16	PB	PB	0.40	PB
17	PM	PB	0.40	PM
18	Z	PB	0.60	PS
19	NM	PB	0.20	PSS
20	NB	PB	0.70	NSS

Fig. 4. Shows Rule Table for Feedback controller 1 (top temperature)

Spreadsheet Rule Editor - bottom_feedback_controlle

#	IF		THEN	
	BtempErate	BTEMPERROR	DoS	DELTAP
1	NB	NB	0.50	PB
2	Z	NB	1.00	PB
3	PB	NB	0.50	NS
4	NB	Z	1.00	PM
5	Z	Z	0.50	Z
6	PB	Z	0.50	NM
7	NB	PB	1.00	PS
8	Z	PB	0.50	NB
9	PB	PB	1.00	NB

Fig. 5 Shows Rule table for feedback controller 2 (bottom temperature)

The bottom feedback controller was designed to correct temperature errors in the re-boiler of the distillation column since this is where the bottoms product is drawn off. The inputs are Temperature Error (bottom) and the Rate of change of the temperature error while the output is Change in the power set point that is required to correct the error. Fig. 5 shows the rule table for feedback controller 2.

III. RESULTS AND DISCUSSION

The proposed fuzzy supervisory control system design sought to reduce the error, sometimes created in the correcting control actions introduced by the operator (when disturbances in the feed flow to a binary distillation column arose). It would not require the attention of an operator once the disturbance was in the acceptable range for the controllers. Outside this tolerable range, an experienced operator would need to put the system in manual mode and make the necessary adjustments.

The proposed supervisory system is unique to all those that have been reviewed in a few ways. Firstly, most of the designs found in research papers used a typical step response for a process to develop the if-then rule bases for the controllers whereas this design used experience based information to generate the rule bases. By using the experienced based information the system had the advantage of being specifically tailored for the actual column. This in turn reduced the amount of fine tuning required after the implementation and testing had been conducted.

Another way in which this design differed is in the supervisory system's controller outputs. All fuzzy binary distillation control systems in the past have sought to alter the gains of conventional controllers, usually PID, which in turn throttles the valves to manipulate the flow rates of the utility streams. This will then either raise or lower the tray temperatures accordingly. These previous systems were developed in research laboratories and applied to small pilot columns but has not been applied to any great extent on industrial columns. This is due to the fact that the equipment required for these designs are complex and is not standard on most industrial columns. In industrial practice, special personnel are used whenever a PID gain is changed on a controller and therefore this type of design is not suitable for industrial columns.

Some industrial columns have automatic cascade controllers to control product quality. The first controller monitors the temperature on a specific tray and then outputs the required set point of the corresponding utility stream. This set point value is the input to the second controller which throttles the utility stream valve accordingly. Most binary columns have two similar independent control loops when dual product quality is a concern, one at the top and one at the bottom. This type of decentralized system does not take into consideration the strong effect of coupling between the top and bottom loop as any change in the bottom utility set point will usually have a drastic effect in the top temperature. The response time of this control scheme can be improved as each controller will contribute to the overall lag time. The system's performance would be improved significantly if the required utility set point changes can be determined ahead of time. This was the requirement that encouraged the design of a fuzzy supervisory control system.

The design proposed in this work sought to build on the features described previously. The fuzzy supervisor replaces the first controller in the cascade system and consists three controllers. To predict the required set point changes, the system accepts the temperature error and the rate of change of this error. These set point changes will then be the inputs to the PID controllers that already exist on industrial columns. Using the equipment that is already there makes the proposed system much easier to implement and test.

The results are shown in Figs 6, 7 and 8. The proposed fuzzy control system showed positive results when compared to the experienced based values gathered. These experience based values were obtained from distillation column operators. Test results showed that most of the controller outputs had a less than ten percent error between the values and thus fuzzy control is feasible for this design. Transitions between negative to positive output changes were not as smooth and need to be investigated further. It may be the case that separate rule bases need to be created to deal with these sign changes.

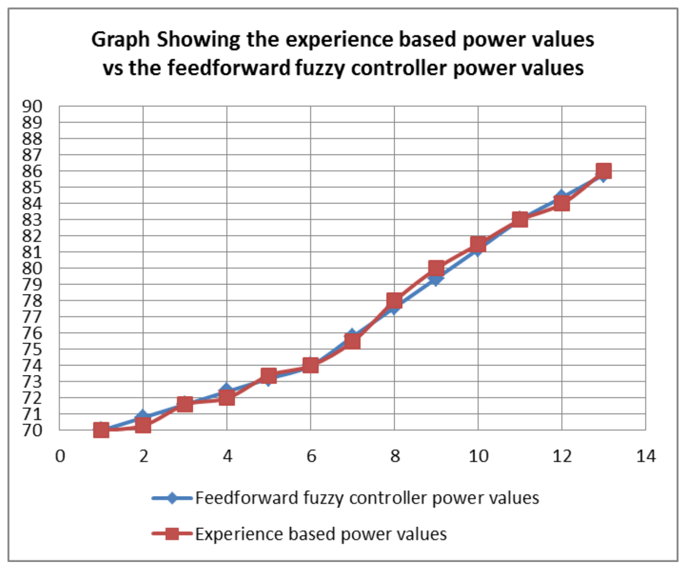

Fig. 6 Graph showing the fuzzy feed forward controller power values versus the experience based power values

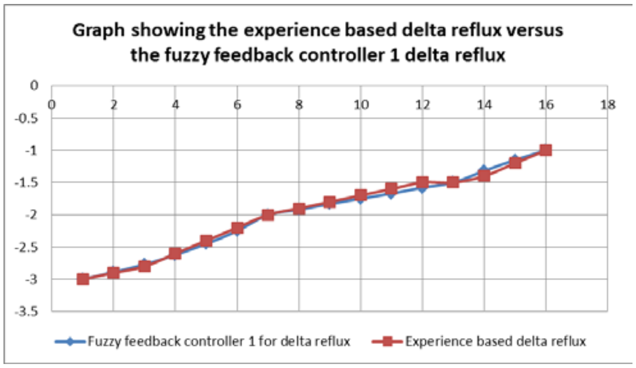

Fig. 7 Graph showing the experience based delta reflux versus the fuzzy feedback controller 1 delta reflux

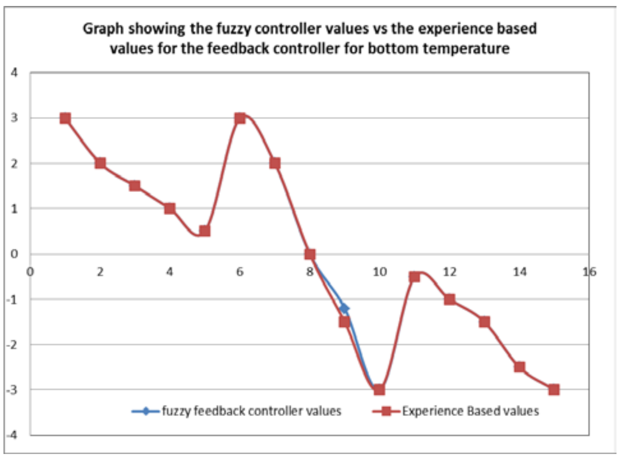

Fig. 8 Graph showing the fuzzy controller values vs the experience based values for feedback controller 2

IV. CONCLUSION

The results shown provide a basis for further work in using a fuzzy supervisory controller for binary distillation column control.

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