CONTROL THE OVERHEAD TEMPERATURE OF CRUDE OIL DISTILLATION COLUMN BY PID AND FUZZY PID CONTROLLERS

Huynh Van Tien*, Ha Kim Thanh Vy,
Van Tan Luong, Giang Ngoc Ha
Ho Chi Minh City University of Food Industry
*Email: *tienhv@hufi.edu.vn*

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ABSTRACT

Gasoline is mainly created by converting light and heavy naphtha from crude oil distillation column. Overhead temperature of main column is the most important parameter in quality control of gasoline. This protocol would offer two pathways to control the overhead temperature of crude oil distillation column in refinery. In this offer, temperature, flow parameters are cotrolled by proportional integral and derivative (PID) and fuzzy PID controllers. The feasibility and effectiveness of the proposed method are verified by the simulation results using Matlab/Simulink.

Keywords: PID, fuzzy PID, controller parameter, overhead temperature, crude oil, distillation.

1. INTRODUCTION

Temperature, pressure, flow and level are four main parametters in process control. In order to antomatic maintain the quality of product, the process must be in automatic. In refinery, Crude Oil Distillation Unit (CDU) is as the heart of plant. CDU provides primary separation of crude oil feedstocks: Crude oil is preheated against product and pumparound streams before being routed to a fire heater. The primary fractionation is carried out in the main crude column fractionator and associated side stream strippers. Overhead naphtha is further processed in the naphtha stabilizer column. Products are cooled and rundown to intermediate storage or further processing as appropriate. Light gas oil and heavy gas oil streams are vacuum dried prior to rundown.

In order to rearch the desire specification, a very complex and precise control process is required. In particular, the improvement of control methods brings very high efficiency in quickly achieving the specification, maintain the stability and rapid response to emergencies case to ensure the plant to be stable and safety.

Figure 1 describes that the top pumparound (P-01) circuit of the main fractionator provides reflux to the top section of column and maintains the temperature of column overhead vapour by controlling the amount of heat removed from the (P-01) circuit. Under normal operation, for a given unit throughput, the flow around the P-01 circuit remains constant and the heat duty is controlled by passing more or less flow around exchanger (E-01). The top temperature, TIC-01 resets the set point of duty controller UIC-01. Depending on the crude oil and product requirements, the setpoint for TIC-01 is from 120 °C to 150 °C [1].

Any increase in duty above the setpoint at UIC-01 will produce a decrease in the duty controller output B which will close valve UV-02 via calculation block FY-03 and hand controller HIC-02 and open valve UV-01 via calculation block FY-01 and controller HIC-01. The result will be to pass less liquid through the exchanger E-01 and more through bypass valve UV-01, i.e. duty is reduced.

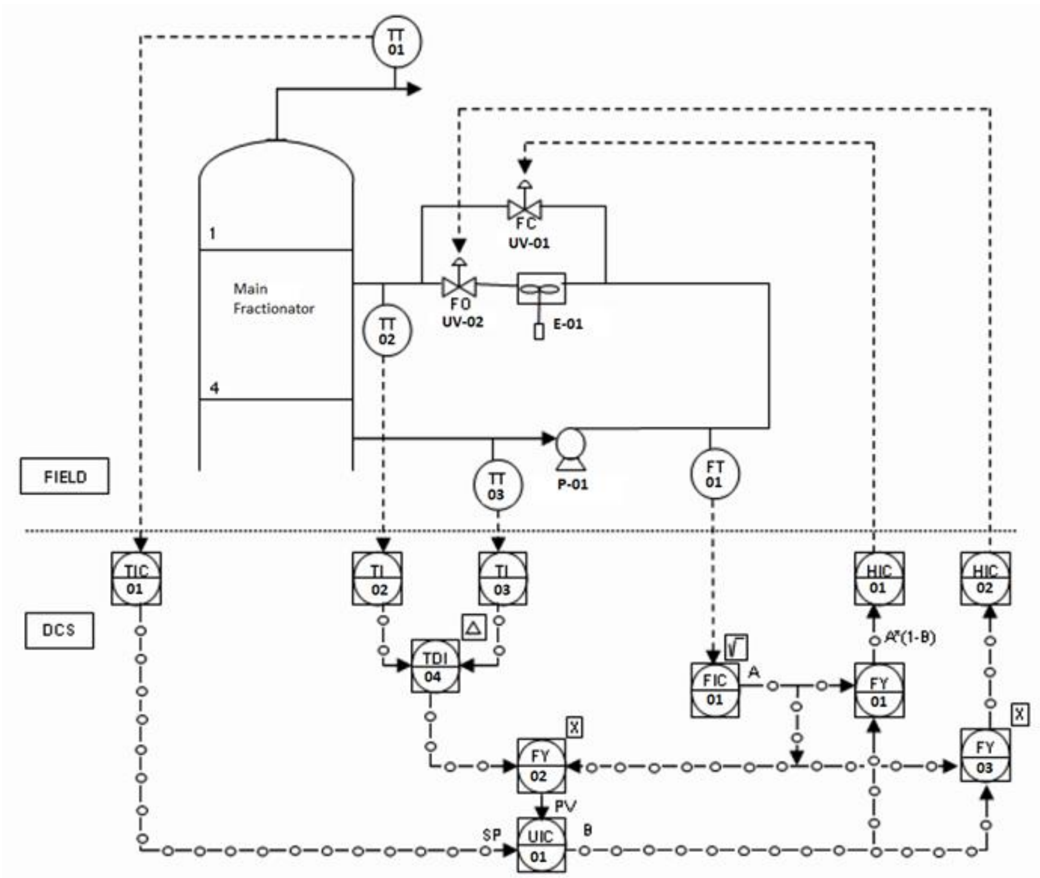

Figure 1. Functional description of overhead temperature control

Any increase in flow above the setpoint at controller FIC-01 will produce a decrease in flow controller output A, which will close both valve UV-01 and UV-02 by the same amount via their calculation blocks FY-01/FY-03 and hand controllers HIC-01/HIC-02, i.e. total flow is reduced. The flow controller FIC-01 must have priority above duty controller UIC-01 to prevent both valve close in temperature or duty failure case. In other hand, the flow controller has to be able to keep the flow in control otherwise duty controller failure for itself or for temperature indicator failure. UIC-01 output shall be limited to be from 10% to 90%.

Recently, many researches have fucused on automation control the crude oil distillation column [2-5]. Accordingly, proportional (P), proportional intergral (PI), proportional derivative (PD) and proportional intergral derivative (PID) methods were applied. Among them, PID method shows more superiority than other ones. However, compared to the fuzzy PID, the PID controller presents its limitations, which is that the original designed controller parameter is only suitable at a given operating time. At other operating times, the parameter is long convergence and fluctuating [6].

In this paper, we typically introduce the PID and fuzzy PID controllers to control the overhead temperature of crude oil distillation column (Main fractionator) and compare the effectiveness of these two control methods. The simulation results demonstrate that the fuzzy PID controller is better than the conventional PID controller.

2. EXPERIMENTAL

2.1. Rule adjustment of PID controller

The function of PID controller is

$$u(t) = K_p e(t) + K_I \int_0^t e(t)dt + K_D \frac{de(t)}{dt} \quad (1)$$

As shown in (1), the control parameters (K_P, K_I, K_D) are adjusted according to each controller separately based on the error e(t) and its derivative error. Many different methods have been applied to adjust the parameters of the PID such as: direct calibration method, method based on the minimum target function, calibration method according to Zhao, Tomizuka and Isaka ... [7-12]. The general principle of these methods is to start with K_P, K_I and K_D values according to Zeigler-Nichols. Then, based on the changing response of the output signal and the gradual change of K_P, K_I, K_D, their appropriate alignment direction is found.

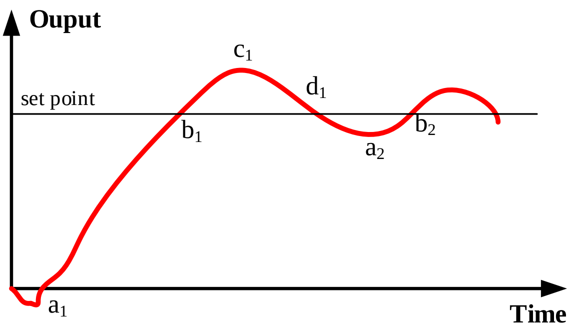

Figure 2. Rule adjustment of PID controller

The rule adjustment as shown in Figure 2 is done as follows:

- For the adjacent point a_1 we need strong control to shorten the time so we choose K_P and K_I large, K_D small
- For the adjacent point b_1 we avoid large overshoot, so choose K_P and K_I small, K_D large
- For the adjacent point c_1 and d_1 we perform the same as a_1 and b_1

2.2. PID controller simulation for crude oil distillation overhead temperature control system

The temperature of the top of the distillation tower is controlled via reflux. Depending on the quality of crude oil and product requirements, the temperature of the top of the column is set at a value from 120 °C to 160 °C. Both the reflux flow and the ovehead temperature normally are controlled by adjust the opening of reflux valve, the block diagram of the column overhead temperature control system is shown in the Figure 3.

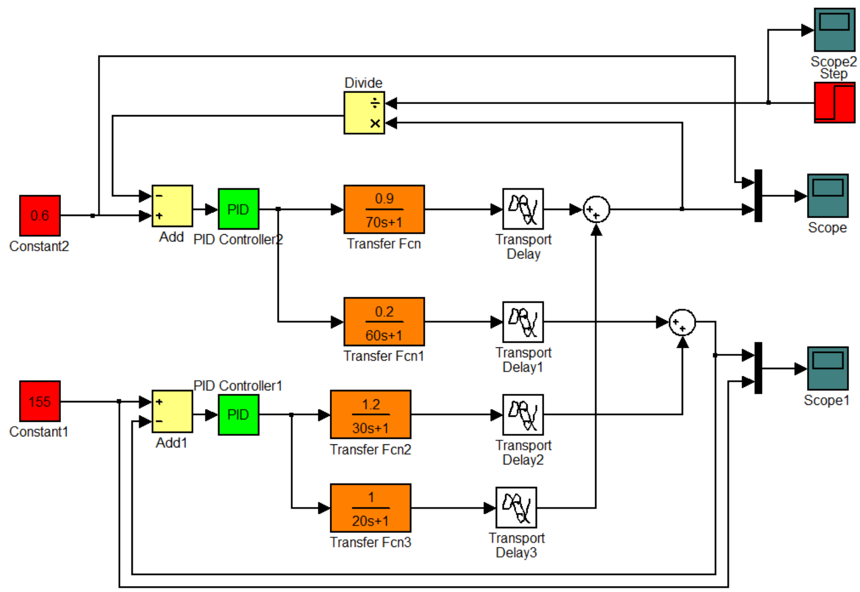

Figure 3. Block diagram of the column overhead temperature control system using the conventional PID controller

In Figure 2, the tranfer functions: $W_{11} = \frac{0.9e^{-2s}}{70s+1}$, $W_{12} = \frac{0.2e^{-2s}}{60s+1}$, $W_{21} = \frac{1.2e^{-1s}}{30s+1}$, $W_{22} = \frac{1.0}{20s+1}$ are created by Ziegler-Nichols method [6].

By enter expressions for proportional, intergral and dervivative terms in the functional block parameters on Matlab/Simulink simulation software, the result indicates that the overhead temperature of the column responds well, the settling time is about 400 seconds, the error is 0 and the overshoot is 13%. The convergence time to the setting value of the reflux flow controller is 500 seconds, the error is 0 and the overshoot is high.

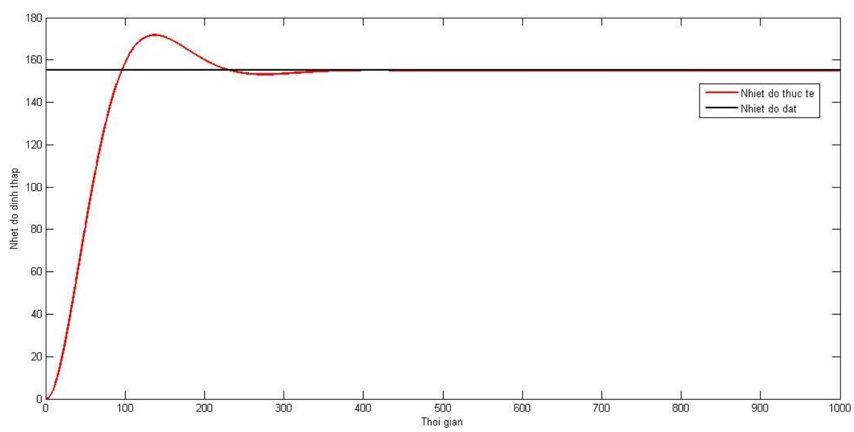

Figure 4. Responding of overhead temperature by PID controller

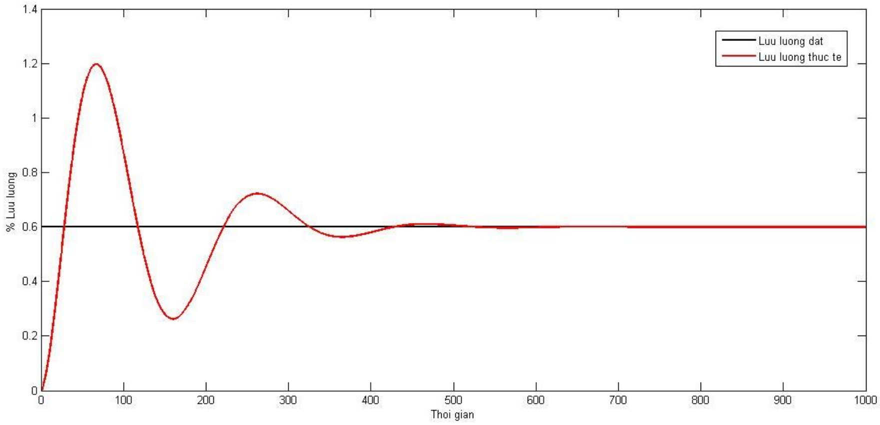

Figure 5. Responding of refux flow by PID controller

The PID controller responds well for this system but it has a relatively long setting time, high control overshoot so other control methods are needed to reduce these problems.

2.3. Simulate fuzzy PID controller for crude oil distillation overhead temperature control system

The parameters K_P, K_I, K_D or K_P, T_I, T_D of PID controller are adjusted base on the analysis of error e(t) and de(t)/dt derivative of the error. Many methods of adjusting parameters for PID controller have been implemented. However, in this paper, the fuzzy calibration methods of Zhao, Tomizuka and Isaka are studied with the following assumption: $K_P \in \left[K_P^{min}, K_P^{max}\right]$ and $K_D \in \left[K_D^{min}, K_D^{max}\right]$. In particular, K_P and K_D parameters have been standardized as follows: $K_P = \frac{K_P - K_P^{min}}{K_P^{max} - K_P^{min}}$ $K_D = \frac{K_D - K_D^{min}}{K_D^{max} - K_D^{min}}$. The fuzzy equalizer will have two inputs e(t), de(t)/dt and three outputs are K_P, K_D, α, in particular, $\alpha = T_I/T_D$ *or* $K_I = K_D^2/\alpha K_D$. Therefore, K_P, K_I, K_D can be considered as three fuzzy equalizers with two inputs ET, DET and three outputs K_P, K_D and K_I (see in Figure 6).

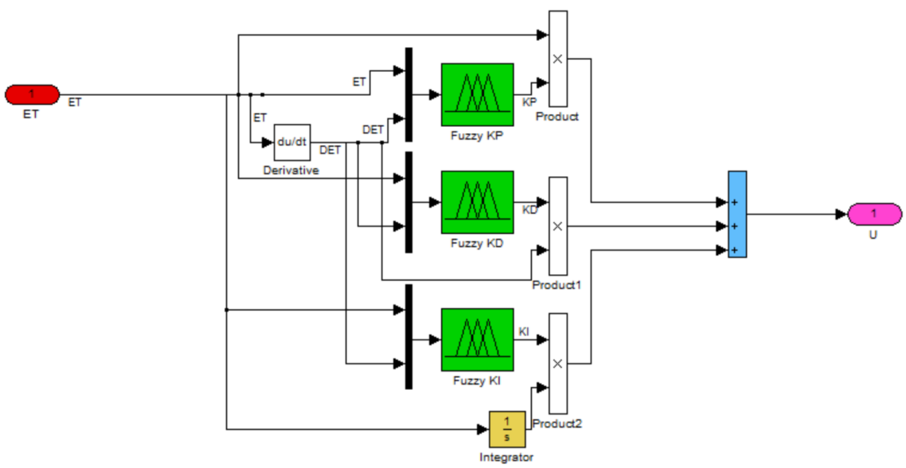

Figure 6. Structure of the fuzzy PID controller

In Figure 6, ET is the deviation between the set signal and the feedback signal, DET = $(ET_{i+1}-ET_i)/T$, where T is the signal receiving period. The output consists of three variables K_P, K_I, K_D which are factors of proportion, integral and derivative. Base on the structure of fuzzy PID controller the block diagram of the column overhead temperature control system use fuzzy PID controller were created.

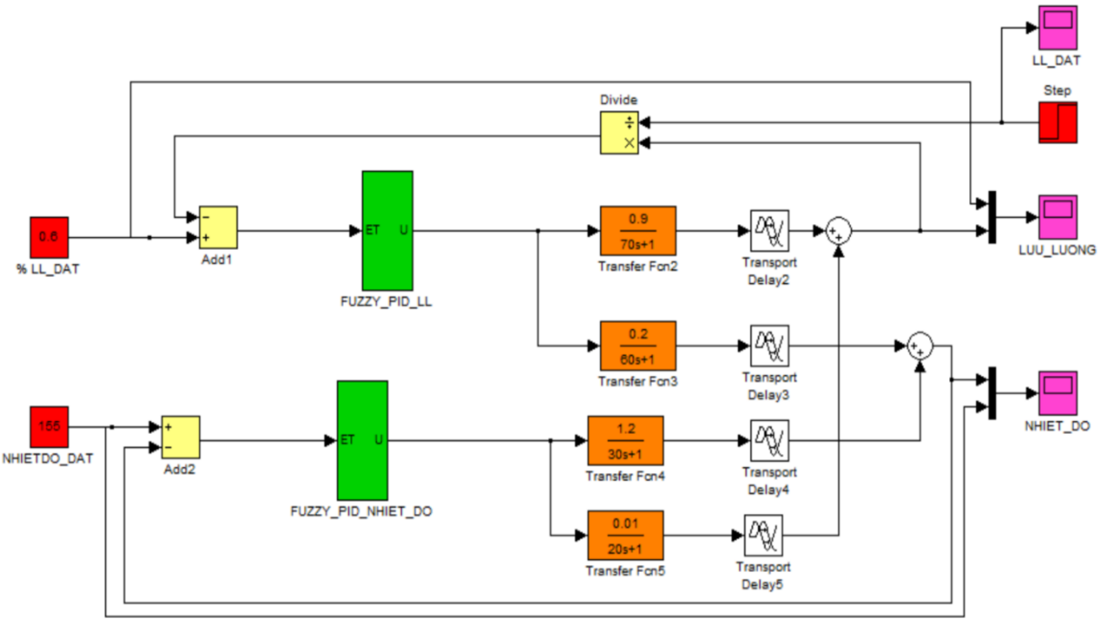

Figure 7. Block diagram of the column overhead temperature control system using the fuzzy PID controller

2.4. Control algorithms

For temperature controller, two input variables are ET (Error temperature) and DET (Derivative of the error temperature). ET = Setpoint – Feedback value; Derivative of the error temperature: DET = $\frac{ET(i+1)-E(i)}{T}$, T is the signal receiving period. The three output variables are K_P, K_I and K_D.

Variable definitions: ET = {large minus_AN, medium minus_AV, alittle minus_AI, zero_ZE, alittle positive _DI, medium positive_DV, large positive_DN; DET = {large minus_AN, medium minus_AV, alittle minus_AI, zero_ZE, alittle positive _DI, medium positive_DV, large positive_DN; K_P = { zero, small, medium, large, ultimate} (Z, S, M, L, U); K_I = {level 1, level 2, level 3, level 4, level 5} (L1, L2, L3, L4, L5); K_D = {zero, small, medium, large, ultimate} (Z, S, M, L, U).

For flowrate controller, two input variables are ET (Error flowrate) and DET (Derivative of the error flowrate). ET = Setpoint – Feedback value; Derivative of the error flowrate: DET = $\frac{ET(i+1)-E(i)}{T}$, T is the signal receiving period. The three output variables are K_P, K_I and K_D, any variable definitions are similar to temperature controller.

2.5. Rule adjustment of fuzzy PID controller

Table 1. K_P rule adjustment control reflux flowrate

K_P		DET						
		AN	AV	AI	ZE	DI	DV	DN
ET	AN	L	Z	Z	Z	Z	S	S
	AV	Z	Z	Z	Z	S	S	S
	AI	Z	Z	Z	Z	S	S	M
	ZE	S	S	S	Z	S	S	M
	DI	M	M	S	L	L	L	L
	DV	M	M	M	L	M	M	M
	DN	L	L	L	U	U	U	U

Table 2. K_I rule adjustment control reflux flowrate

K_I		DET						
		AN	AV	AI	ZE	DI	DV	DN
ET	AN	L4	L3	L3	L2	L2	L2	L1
	AV	L4	L4	L3	L3	L2	L2	L1
	AI	L5	L5	L4	L4	L3	L2	L2
	ZE	L5	L5	L4	L4	L3	L2	L2
	DI	L5	L4	L4	L3	L3	L2	L1
	DV	L5	L4	L3	L2	L2	L1	L1
	DN	L5	L4	L3	L2	L2	L1	L1

Table 3. K_D rule adjustment control reflux flowrate

K_D		DET						
		AN	AV	AI	ZE	DI	DV	DN
ET	AN	U	U	L	L	M	S	Z
	AV	U	U	L	L	M	Z	Z
	AI	U	U	L	M	S	Z	Z
	ZE	U	U	S	S	S	Z	Z
	DI	M	M	S	S	Z	Z	Z
	DV	L	M	M	S	Z	Z	Z
	DN	U	L	M	S	S	Z	Z

Table 4. K_P rule adjustment control overhead temperature

K_P		DET						
		AN	AV	AI	ZE	DI	DV	DN
ET	AN	L	Z	Z	Z	Z	S	S
	AV	Z	Z	Z	Z	S	S	S
	AI	Z	Z	Z	Z	S	S	M
	ZE	S	S	S	Z	S	S	M
	DI	M	M	S	L	L	L	L
	DV	M	M	M	L	M	M	M
	DN	L	L	L	U	U	U	U

Table 5. K_I rule adjustment control overhead temperature

K_I		DET						
		AN	AV	AI	ZE	DI	DV	DN
ET	AN	L4	L3	L3	L2	L2	L2	L1
	AV	L4	L4	L3	L3	L2	L2	L1
	AI	L5	L5	L4	L4	L3	L2	L2
	ZE	L5	L5	L4	L4	L3	L2	L2
	DI	L5	L4	L4	L3	L3	L2	L1
	DV	L5	L4	L3	L2	L2	L1	L1
	DN	L5	L4	L3	L2	L2	L1	L1

Table 6. K_D rule adjustment control overhead temperature

K_D		DET						
		AN	AV	AI	ZE	DI	DV	DN
ET	AN	U	U	L	L	M	S	Z
	AV	U	U	L	L	M	Z	Z
	AI	U	U	L	M	S	Z	Z
	ZE	U	U	S	S	S	Z	Z
	DI	M	M	S	S	Z	Z	Z
	DV	L	M	M	S	Z	Z	Z
	DN	U	L	M	S	S	Z	Z

By performing the rule adjusments in the fuzzy functional block parameters on Matlab/Simulink simulation software, the result indicates that the overhead temperature of the column responds well, the settling time is about 400 seconds, the error is 0 and the overshoot is 1.49%. The convergence time to the setting value of the reflux flow controller is 250 seconds, the error is 0 and the overshoot is 6.7%.

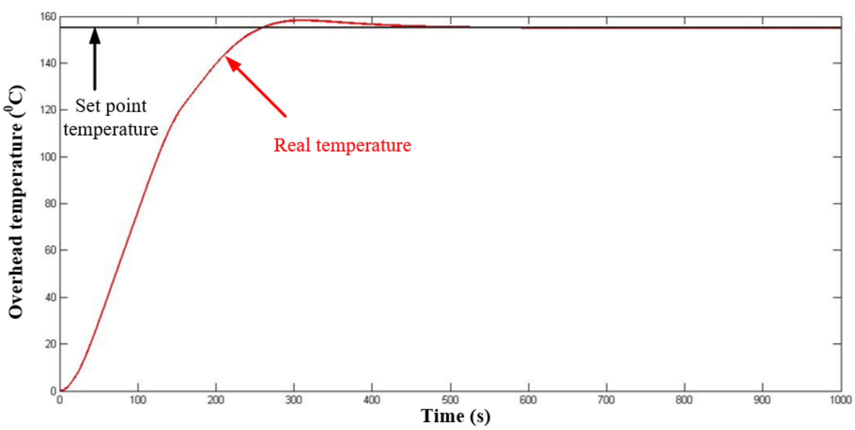

Figure 8. Responding of overhead temperature by fuzzy PID controller

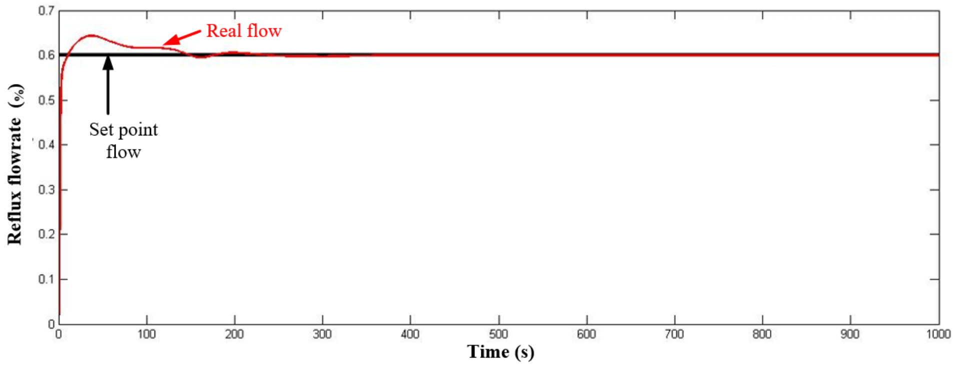

Figure 9. Responding of reflux flowrate by PID controller

By fuzzy PID controller, the overhead temperature and reflux flow are stabilized, quickly settling and negligible overshoot.

3. RESULTS AND DISCUSSION

3.1. Simulation results of overhead temperature and reflux flow

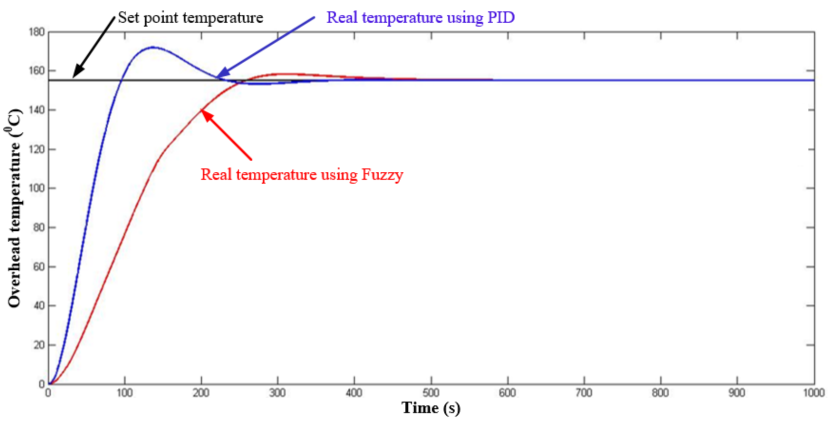

Figure 10. Simulation results of overhead temperature by PID and fuzzy PID controllers

Figure 10 shows that the results of simulating of overhead temperature using the fuzzy PID and PID controllers. As shown in Figure 10 and in Table 7, the overhead temperature was reached to the set value after 400 seconds for both controllers. However, the overshoot was only 1.94% in case of a fuzzy PID controller (compared to 13% of the conventional PID controller). Therefore, the use of fuzzy PID controller results in better operation, compared to the use of conventional PID controller.

Table 7. Overhead temperature responding comparing between conventional PID and fuzzy PID controller

	Conventional PID controller	Fuzzy PID controller
Settling time (s)	400	400
Overshoot (%)	13	1.94

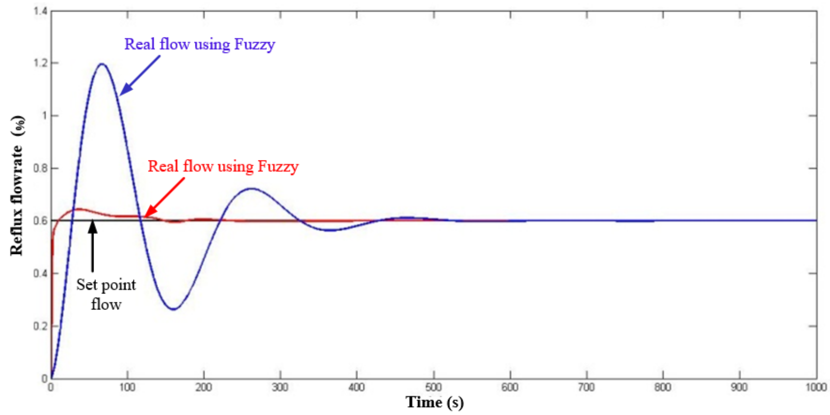

Figure 11. Simulation results of reflux flowrate by using conventional PID and fuzzy PID controllers

Figure 11 shows that the results of simulating of reflux flowrate using the fuzzy PID and PID controllers. As shown in Figure 10 and in Table 7, the reflux flowrate was reached to the setpoint after 250 seconds and the overshoot was only 0.63% in case of the fuzzy PID controller. Meanwhile, with the conventional PID controller, the set-up time needs to 500 seconds and overshoot is 1.2%. Therefore, the use of fuzzy PID controller results in better operation, compared to the use of conventional PID controller.

As mentioned before, the PID controllers only works properly at one specific operating point since the controller gains are seleted to be fixed. For this, to operate in a wide range, they should be changed. Thus, the combination of fuzzy controller to generate a signal to compensate for the PID controller.

Table 8. Reflux flowrate responding comparing between conventional PID and fuzzy PID controller

	Conventional PID controller	Fuzzy PID controller
Settling time (s)	500	250
Overshoot (%)	100	6.7

4. CONCLUSIONS

In summary, a strategy to control the crude oil distillation column using the fuzzy PID controller is proposed. The important control parametters such as overhead temperature and reflux flowrate were simulated by PID and fuzzy PID controllers. The simulation results on Matlab/Simulink have shown that the use of fuzzy PID controller is better than conventional PID.

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TÓM TẮT

ĐIỀU KHIỂN HỆ THỐNG CHƯNG CẤT DẦU THÔ DÙNG BỘ ĐIỀU KHIỂN PID MỜ

Huỳnh Văn Tiến*, Hà Kim Thanh Vy,
Văn Tấn Lượng, Giang Ngọc Hà
*Email: *tienhv@hufi.edu.vn*

Xăng chủ yếu được tạo ra bằng cách chuyển hóa naphtha nhẹ và naphtha nặng từ tháp chưng cất dầu thô. Nhiệt độ đỉnh tháp của cột chưng cất chính là thông số quan trọng nhất trong kiểm soát chất lượng xăng. Bài báo đề xuất 2 phương pháp để kiểm soát nhiệt độ đỉnh tháp chưng cất dầu thô trong nhà máy lọc dầu, trong đó các tham số nhiệt độ, lưu lượng được điều khiển bằng bộ điều khiển tỷ lệ tích phân và đạo hàm (PID) và bộ điều khiển mờ. Tính khả thi và hiệu quả của phương pháp đề xuất được xác minh bằng các kết quả mô phỏng sử dụng Matlab/Simulink.

Từ khóa: PID, PID mờ, thông số bộ điều khiển, nhiệt độ đỉnh tháp, dầu thô, chưng cất.