Investigation of PID and Self-Tuning Fuzzy PID Controller Achievements for Level and Temperature Control of the Mixing Tank

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***Abstract*— Liquid level and temperature control is the most important part of the system layout in many industrial plants. Failure to make the optimum control of liquid level and temperature can lead to moral and material damages for these plants in some cases. Fuzzy logic based control and traditional control methods are used in many applications. Self-Tuning Fuzzy-PID controller means that the three parameters K_p, K_i, and K_d of PID controller are tuned using fuzzy tuner. In this study, water tank, which is a nonlinear multi input multi output system, is simulated by MATLAB/Simulink using PID and Self-Tuning Fuzzy PID Controller.**

Keywords*-- *Mixing Tank, PID, Self-Tuning Fuzzy-PID Controller.

I. INTRODUCTION

Level and temperature control of the fluid mix tanks is very important for food industry, agricultural spraying, textile, wastewater treatment, milk production, nuclear power generation, petrochemical, chemical processes and pharmaceutical industry [1]. Industrial liquid mixing processes composed two or more liquid mixtures has been checked with control and automation systems [2]. Classical controller performance in the control of nonlinear system is low. Based on fuzzy logic controllers is more successful the control of this type system control [3]. In this study, a water tank having 2 inputs and two outputs is modelled in MATLAB/Simulink simulation program with PID controller and self-tuning fuzzy-PID controller. Dynamic performance of the controllers is tested for level and temperature control.

II. MIXING TANK SYSTEM

Rectangular prism water tank was used in this study. Through pumps working with 0,25 m^3/s flow, hot and cold water is given to the water tank. Flow rate of the hot and cold water entering the bank is performed by adjusting control valves according to invented water level and water temperature. The setting of the drain valve used for water outlet from the bank is made by the users. General structure of the water mixture tank is showed in figure 1. The temperature of water entering water mixture tank T_1 and cold water temperature T_2 are accepted constant. Hot water flow to the tank is $Q_{hot}= Q_{max}*C_{hot}$. Cold water flow to the tank is $Q_{cold}= Q_{max}*C_{cold}$. Where Q_{max} is pump capacity, C_{hot} ve C_{cold} are aspect ratio of control valves in the range (0-1). The total amount of the water flowing into the tank is $Q_{input}=Q_1+Q_2$, mixture water temperature is T and flow rate is Q_{output}. To control water level and temperature of the tank mathematical model and differential equations with state variables of the system are given in equations 1, 2 and 3 [4,5-9].

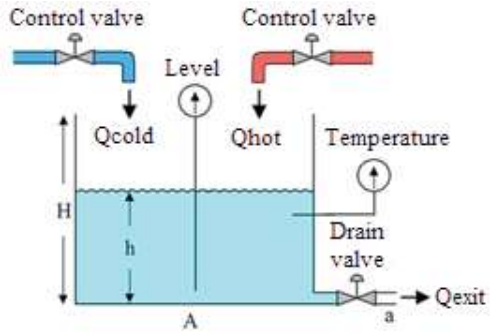


Fig. 1. Water mixture tank

$$Q_{out} = a\sqrt{2gh} \tag{1}$$

$$\frac{dh}{dt} = \frac{1}{A}\left(Q_{hot} + Q_{cold} - Q_{out}\right) \tag{2}$$

$$\frac{dT}{dt} = \frac{1}{Ah}\left(Q_{hot}(T_1 - T) + Q_{cold}(T_2 - T)\right) \tag{3}$$

Where h and A are respectively shown the water height in the tank and footprint of the tank. The values related to the structure of the mixed water tank used in this study are given

TABLE I
UNITS FOR MAGNETIC PROPERTIES

Explanation	Symbol	Value
Footprint	A	1 m^2
Outlet port section	a	0,0025 m^2
Height	h	2 m
Gravitational acceleration	g	9,82 m/s^2
Beginner level	h_0	0,1 m
Pump capacity	Q_{max}	0,25 m^3/s
Hot water temperature	T_1	70 °C
Cold water temperature	T_2	5°C
Beginner temperature	T_3	5°C

in table 1.

III. MATLAB/SIMULINK MODEL OF THE SYSTEM

In this study the water mixture tank model is obtained by creating all system component models with MATLAB/Simulink simulation program. Simulink model used for the flow control valve to control the flow rate of water entering the bank is shown in figure 2 [10-11].

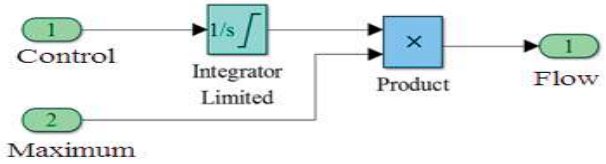


Fig. 2. Flow control valve Simulink model

Simulink model of the mixture tank is given in figure 3.

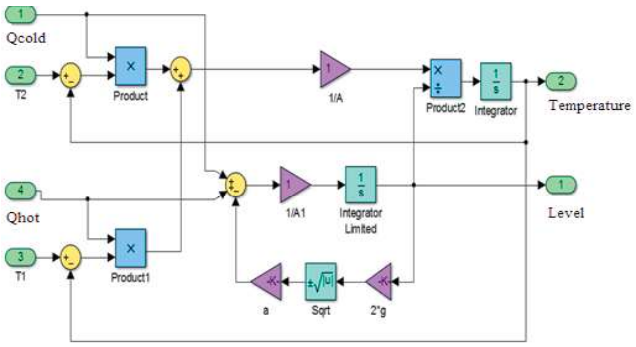


Fig. 3. Mixture tank Simulink model

IV. PID CONTROLLER

Due to robust performance and simple structures, PID controllers are the most frequently used controllers in control systems. PID controllers consist of proportional (P), integral (I), derivative (D) gains. PID controller is a controller that combines the advantages of these three basic earnings in a single unit. Each of the gain for the systems to be monitored take different values and the PID controller gain values have a different impact on the system. The block diagram of the internal structure of the PID controller is shown in figure 4. The output of the PID controller can be expressed in equation 4.

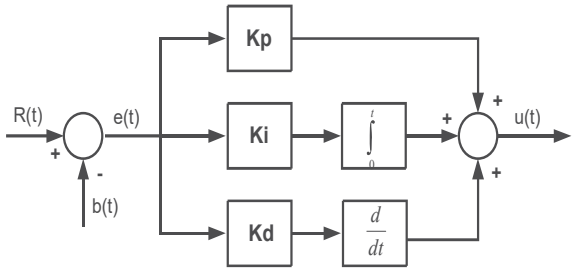


Fig. 4. PID controller block diagram

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{d}{dt} e(t) \quad (4)$$

As a conventional methods Z-N method is frequently used in calculating PID controller parameters. In this method response of the system is achieved to enter the oscillation by increasing proportional (P) gain value. Gain value at the time of entry of system oscillation is expressed as oscillation gain

TABLE II
CALCULATION OF P, I AND D PARAMETERS FOR Z-N METHOD

Controller	Kp	Ki	Kd
P	Ku/2	-	-
PI	Ku/2,2	Pu/1,2	-
PID	Ku/1,7	Pu/2	Pu/8

(K_u) and by using oscillation period (P_u) necessary PID gains can be determined using formulas in table 2 [12].

V. SELF-TUNING FUZZY-PID CONTROLLER

Fuzzy logic was first put forward in 1965 by Lotfi A. Zadeh. Since then the importance of extant increasingly fuzzy logic, expression of uncertainty and established to work with uncertainty can define as a solid mathematical order. Because it has the logic classical logic is a component element of a cluster or not modelling and control of complex systems is difficult with classical logic method. Because data must be complete and clear [13-14]. There is no certainty in fuzzy logic and there are more qualitative definition. The most interesting of fuzzy logic side of the experts of the information embedded into the controller system is monitored. So the system does not need any mathematical model. FLC, with general structure, makes up of four basic components as fuzzification, fuzzy inference, flushing and knowledge base. General structure of FLC is given in figure 5.

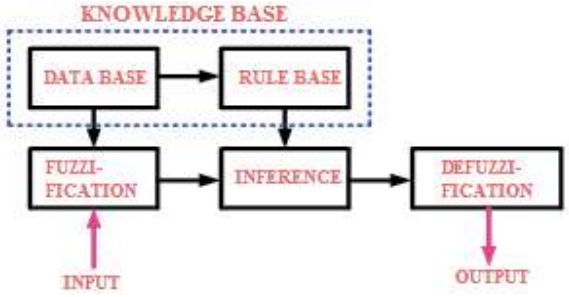


Fig. 5. FLC general structure

The aim of the Self-Tuning Fuzzy-PID controller is to find out by forming with fuzzy logic controller gain parameters suitable for the system PID gain values. Because PID gain parameters are constant with time, it cannot give successful results for nonlinear and time-varying systems. PID controller's adverse conditions take away by automatically adjusting Self-Tuning Fuzzy-PID and PID gain values [15]. In Self-Tuning Fuzzy-PID for Kp, Ki, Kd gain parameters are respectively selected minimum and maximum range values [Kpmin, Kpmax], [Kimin, Kimax], [Kdmin, Kdmax]. When selecting this range, Kp, Ki, Kd gain parameters found for the PID controller has taken reference. The mixture tank level and temperature control Kp, Ki, Kd values for the selected range

of gains and mathematical equations are given in equation 7.

Kp € [5-15], Ki € [0.00001-0.00004], Kd € [2.5-7.5].

$$K_p' = \frac{K_p - K_{p\min}}{K_{p\max} - K_{p\min}}$$
$$K_i' = \frac{K_i - K_{i\min}}{K_{i\max} - K_{i\min}} \quad (7)$$
$$K_p' = \frac{K_d - K_{d\min}}{K_{d\max} - K_{d\min}}$$

Self-tuning Fuzzy-PID controller block diagram is given in figure 6.

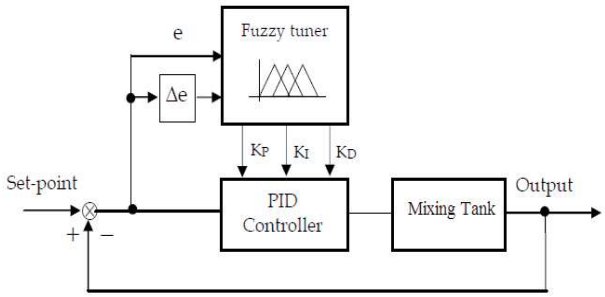


Fig. 6. Self-Tuning Fuzzy-PID controller block diagram

Input and output variables in FLC (Fuzzy Logic Controller) blur process is converted into a symbolic expression. Linguistic variables used in the designed controller including NL(Negative Large), N (Negative), Z (Zero), P (Positive), PL (Positive Large) five variables were used. The choice of membership functions for each input supplied to the system is completely arbitrary. There can be triangle, trapezoid, sinusoid, cauchy, bell, sigmoid, gaussian types. Fuzzy logic system with 2 inputs and 3 outputs are shown in figure 4. These can be defined error (e) and error change (de). The outputs are created for Kp, Ki and Kd. Error (e) and error change (de) used in the level and temperature control triangle membership functions formed for Kp, Ki and Kd are given in figures 8-9-10-11-12 [16].

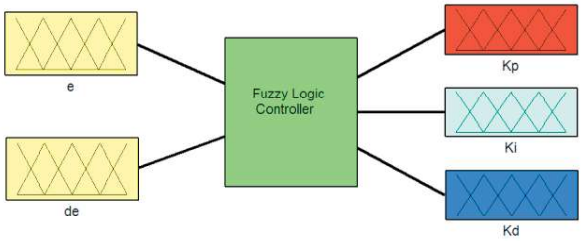


Fig. 7. Fuzzy Logic Control System

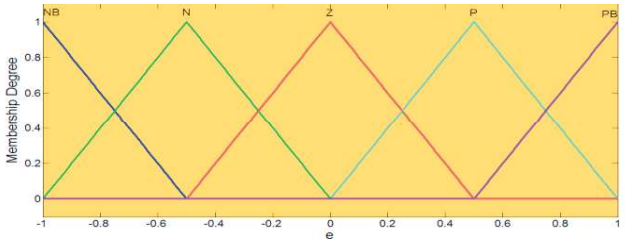


Fig. 8. The error membership functions created for level and temperature control

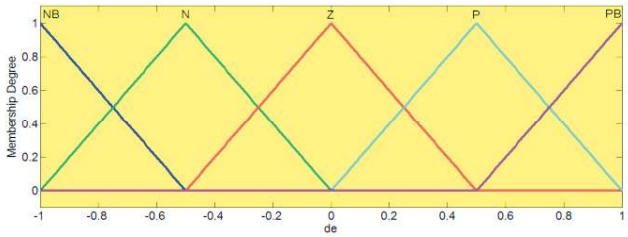


Fig. 9. The error exchange membership functions created for level and temperature control

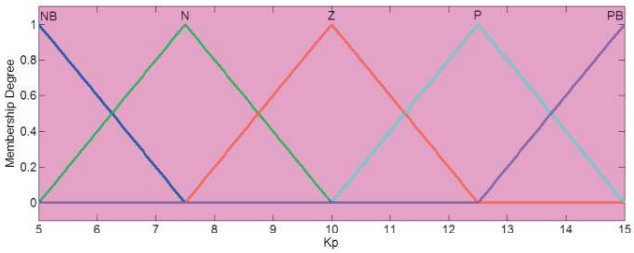


Fig. 10. The membership functions created for Kp in level and temperature control

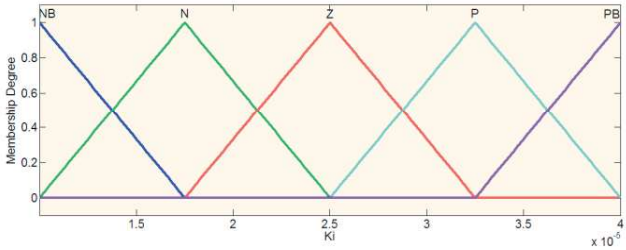


Fig. 11. The membership functions created for Ki in level and temperature control

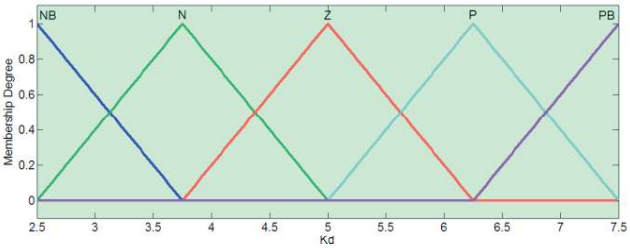


Fig. 12. The membership functions created for Kd in level and temperature control

Rule base created for the outputs of Kp, Ki and Kd is given in table 3-5.

TABLE III
TABLE RULES FOR Kp

Kp		de				
		NB	N	Z	P	PB
e	NB	NB	NB	NB	N	Z
	N	NB	N	N	N	Z
	Z	NB	N	Z	P	PB
	P	Z	P	P	P	PB
	PB	Z	P	PB	PB	PB

TABLE IV
TABLE RULES FOR Ki

Kİ		de				
		NB	N	Z	P	PB
e	NB	PB	PB	PB	N	NB
	N	PB	P	P	Z	NB
	Z	P	P	Z	N	NB
	P	Z	P	N	N	NB
	PB	Z	N	NB	NB	NB

TABLE V
TABLE RULES FOR Kd

Kd		de				
		NB	N	Z	P	PB
e	NB	NB	NB	NB	P	PB
	N	NB	N	N	Z	PB
	Z	Z	N	Z	P	PB
	P	Z	N	P	P	PB
	PB	Z	P	PB	PB	PB

VI. SIMULATION RESULTS

In water mixture tank in beginning, there is water having 0.1 m high, 5°C temperature. 70^0C hat water and 5^0C cold water is given by the pumps to the mixture tank. Level and temperature control mechanism created with respectively in MATLAB/Simulink Self-Tuning Fuzzy-PID and PID controllers have been given in the figure 13 and 14.

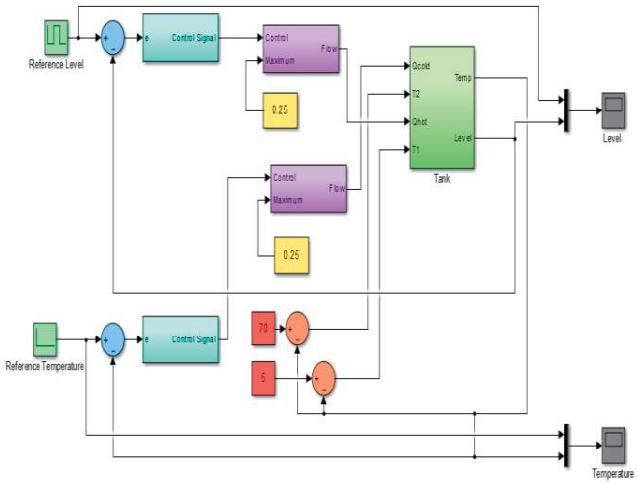


Fig. 13. Self-Tuning Fuzzy-PID control mechanism

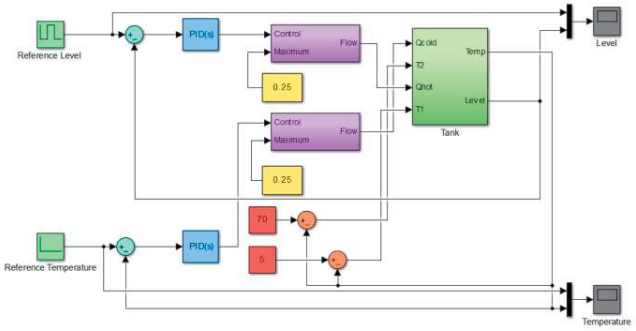


Fig. 14. PID control mechanism

Variable reference level, constant reference temperature has been given to the system. With applying to the system self-tuning fuzzy PID controller and PID controllers, the obtained level-time chart has been given in figure 15, temperature-time chart has been given in figure 16.

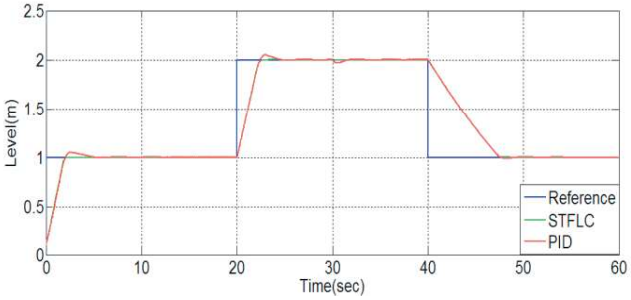


Fig. 15. Level-time chart

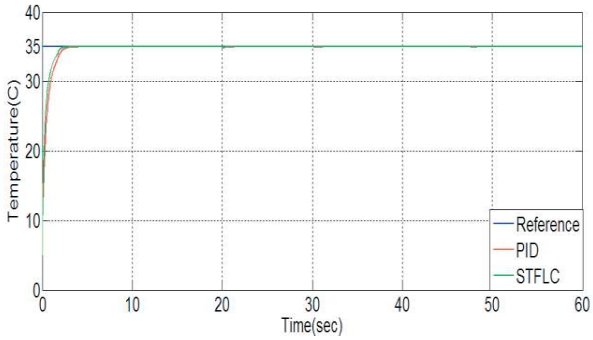


Fig. 16. Temperature-time chart

VII. CONCLUSION

The control of mixture tank system 2 independent Self-Tuning fuzzy PID controller and 2 independent PID controller was used. Classical control systems cannot show desired performance characteristics in changing status conditions. By modeling these systems to change state conditions a suitable control system design is quite difficult. The most important feature of the fuzzy logic is to gain the ability to think like a human. For the level and temperature control of the multi-input and multi-output mixture tank system, 2 input and 2 output self-tuning fuzzy PID controller gave the best response rate with minimal error. Self-tuning fuzzy-PID controller created by the addition of fuzzy logic for the nonlinear multi-input multi-output systems was found to be more suitable than PID controllers.

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