An Industrial Food Processing Plant Automation using a Hybrid of PI and Fuzzy Logic Control

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Abstract-An industrial food processing plant consisting of nonlinear dynamics requires pressure and temperature controllers to be nonlinear. In this paper, nonlinear controllers are designed using fuzzy logic to augment the conventional pressure and temperature PI controllers for an industrial food processing plant. Simulation results are presented to show improvement in the plant response with the hybrid controllers.

I. INTRODUCTION

Like all other processing industries, the food industry is striving to economically and efficiently produce high quality products. Inherent nonlinear characteristics (such as dead-time and saturation nonlinearities) of real world systems contributes negatively towards the optimal performance of a conventional PID controller during transient conditions. The effects of these nonlinearities could result in increased oscillations and overshoots and long settling times. To reduce some of these negative effects, nonlinear control such as fuzzy logic control, has been known to positively enhance the control performance of the closed loop system.

Empirical evidence has shown that operator intervention is sometimes necessary in order to reduce any irregularities, such as large overshoots, which may occur during control actions during startup, dynamic and transient conditions. Many process control applications exploit the positive ability of fuzzy logic to transcribe human experience into a set of linguistically defined rules that are used to control the actions of the controller [1, 2]. Process control using fuzzy logic has been found to be more "forgiving" than conventional control using PID. The popularity of fuzzy logic controllers is increasing, especially in applications where they are known to augment conventional controllers [3, 4].

This paper describes the application of two fuzzy logic controllers to augment the conventional controllers on an industrial food processing plant. Temperature and pressure valve controls are carried out in order to have setpoint tracking capability and disturbance rejection ability more efficiently. The performance of the hybrid control system described is comparable to adaptive control systems.

II. FOOD PROCESSING PLANT

A typical industry food processing plant for making sweets is shown in Fig. 1 with back pressure and steam values. Typically losses range in order of 20% in these plants when manual control of the back pressure and steam valves is carried out.
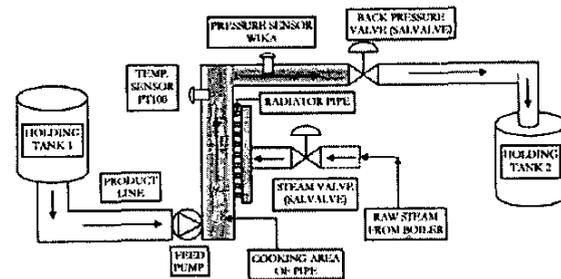

Fig. 1 Schematic diagram of an industrial food processor.

The desired cooking temperature is achieved by introducing *raw steam* into the product. *Raw steam* is steam that is fed directly into the product from the boiler. The product is a food mixture and consists predominately of glucose, water, starch, gelatin and sugar. The back pressure ensures that the product is exposed to the raw steam for a period of time sufficient enough for it to be cooked. A temperature sensor monitors the temperature. The back pressure is monitored via a pressure transducer. Uncooked product from Holding Tank 1 (HT1) is fed to Holding Tank 2 (HT2) via a pipe network. An expanded "radiator" type of pipe connects HT1 to HT2. The "radiator type" of pipe consists of a long vertical pipe feeding many smaller horizontal pipes, as seen in Fig. 1. The uncooked product coming out of HT1 is first exposed in the pipe to raw steam for cooking. The back pressure valve called the *salvalve* is situated between the steam inlet and the HT2. The temperature and pressure transducers are also situated in this section of the pipe work. The cooked product then fills into HT2 which then feeds the rest of the food plant. For a given product cooking, the temperature and back pressure are required to be constant and have certain setpoints. The typically problems identified for such plants are:

- Slow response time of the electric steam valve.
- Back pressure and temperature opposing one another i.e. back pressure decreases with an increase in temperature and vice-versa.
- Large temperature and pressure overshoots during imprecise and manual controls.

Therefore, an efficient control of the temperature and pressure becomes necessary to minimize raw materials wastage and ensure product quality.

A simulation model of a typical back pressure control valve (Wika type, 0 to 10 Bar) is shown in Fig. 2. The pressure valve transfer function is given by (1). K_1 and K_2 are pressure to current and current to pressure converter gains. K_3 is a gain that relates the output pressure to the valve stem length. The saturation element limits the output pressure to 10 Bars.
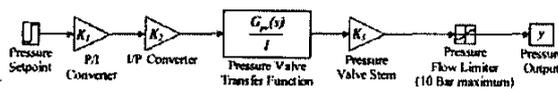
Fig. 2 Block diagram of the back pressure control valve.

$$G_{pv}(s) = 18.4502/(1+0.4s) \qquad (1)$$

A simulation model of a typical steam pressure control valve is shown in Fig. 3. The steam valve transfer function $G_{sv}(s)$ is identical to that given by (1). K_1 and K_2 are pressure to current and current to pressure converter gains. K_3 is a gain that relates the output temperature to the valve stem length. The steam tables are used for the temperature to pressure conversion and vice-versa.
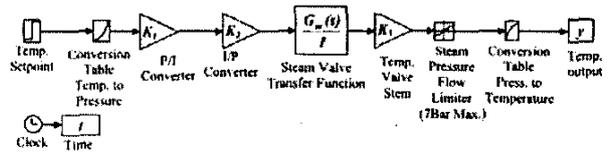
Fig. 3 Block diagram of the steam pressure control valve.

III. CONVENTIONAL CONTROL

The conventional PI controllers are designed for setpoint tracking and to handle disturbance rejection. Time response analysis is carried out to determine the gains and time constants of PI controller in both cases for the back pressure and steam pressure valves. A proportional controller for pressure control is used, given in (2) and a PI controller for the temperature control is used, given in (3) [5]. The block diagram with the P and PI control is shown in Fig. 4. The SIMULINK environment is used as the simulation platform [6]. The PID block represents P and PI control with the derivative term disabled. K_1, K_2 and K_3 are all equal to 1.6 and $K_4 = 2.285$.

$$U_{pressure}(t) = 2.5e(t) \qquad (2)$$

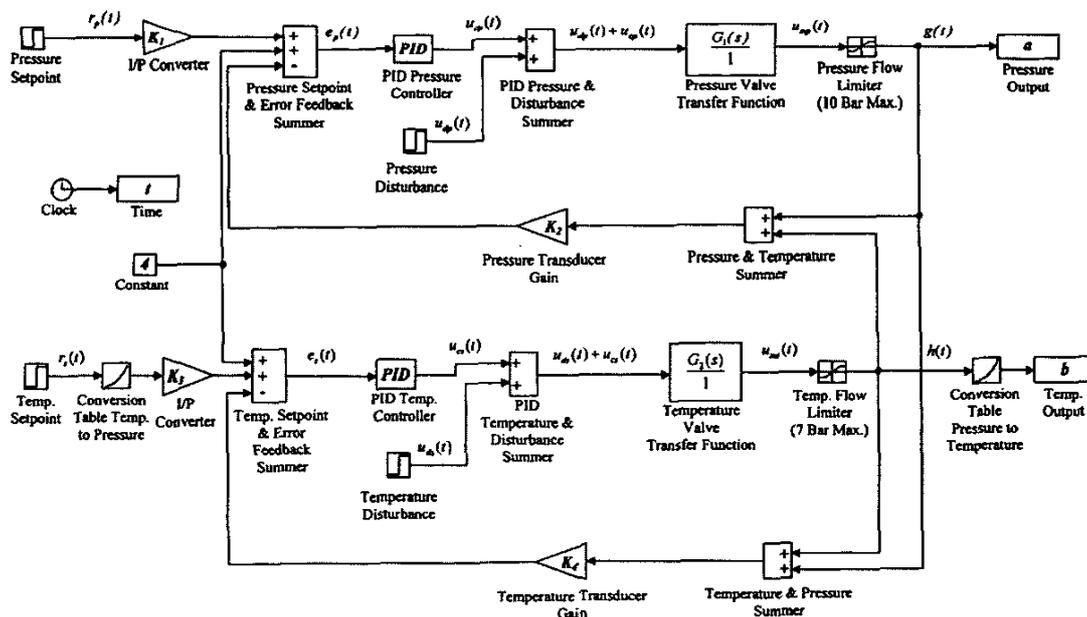$$U_{temp}(t) = 106e(t) + \frac{1}{7500}\int e(t)dt \qquad (3)$$

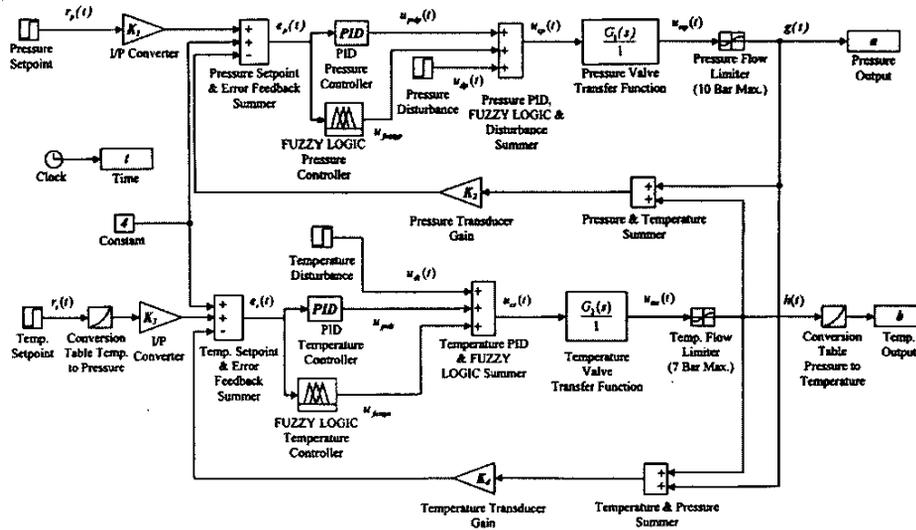Fig. 4 SIMULINK block diagram with the P and PI controllers.

Fig. 5 SIMULINK block diagram with the P, PI and fuzzy logic controllers.

IV. FUZZY LOGIC CONTROL

The fuzzy logic controller (FLC) is designed to augment the P (2) and PI (3) controller outputs for the pressure and temperature valve controls respectively as shown in Fig. 5. K_1, K_2 and K_3 are all equal to 1.6 and $K_4 = 2.285$. The combined control action for the PID and FLC can be expressed as:

$$U_c = U_{pid} + U_{fuzzy} \qquad (4)$$

where: U_{pid} = control action of the PID controller

U_{fuzzy} = control action of the FLC

For the pressure control system, the hybrid controller output is given by (5).

$$U_{pressure(p+f)} = 2.5e(t) + U_{fuzzyp} \qquad (5)$$

U_{fuzzyp} is determined by fuzzy rule base which consists of two simple rules:
1. *If (Pressure is Low) then (Pressure Valve is Closed)*
2. *If (Pressure is High) then (Pressure Valve is Opened).*

For the temperature control system, the hybrid controller output is given by (6).

$$U_{temp(p+f)} = 106e(t) + \frac{1}{7500}\int e(t)dt + U_{fuzzyt} \qquad (6)$$

U_{fuzzyt} is determined by fuzzy rule base which consists of two simple rules:

1. *If (Temperature is Low) then (Temperature Valve is Closed)*
2. *If (Temperature is High) then (Temperature Valve is Opened).*

V. SIMULATION RESULTS

A number of tests are carried out to evaluate the setpoint tracking and disturbance rejection performance of the hybrid controllers (PI+FLC) against that of the PI controller.

A change in the setpoint of the temperature was commanded as a step to 142 °C and the transient response of the two types of controller combination is shown in Fig. 6. The hybrid controller yields a faster rise time and settling time. The maximum overshoot is also reduced with the fuzzy logic controller augmenting the PI controller.

A similar test to the above is carried out now with a change in the setpoint of the pressure was commanded as a step to 2 Bars and the transient response of the two types of controller combination is shown in Fig. 7. Again, the hybrid controller has a faster rise time and a settling time compared to the conventional controller.

In order to evaluate the disturbance rejection capability of the fuzzy logic controller, a 10% disturbance in the pressure setpoint value is applied to the pressure value. The effect of this disturbance is noticeable in both the temperature and pressure plots (Figs. 8 and 9). It is clear that the hybrid controller system reacts faster and is able to minimize the disturbance effects more rapidly than the control using the P and PI control. A similar 10% disturbance in the temperature setpoint value was also applied to the temperature value. The responses are not shown in this paper but again the hybrid controller rejects the disturbance better than the P and PI control system. The performance of the hybrid control system

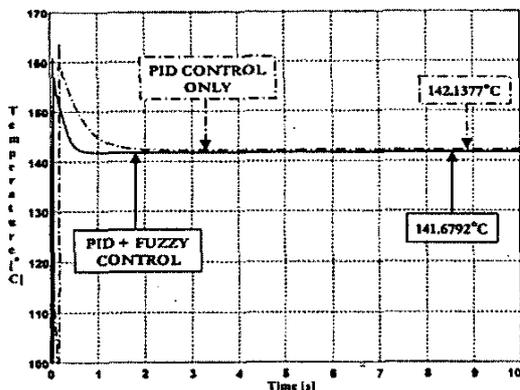(PI and fuzzy control) is comparable to conventional adaptive control.

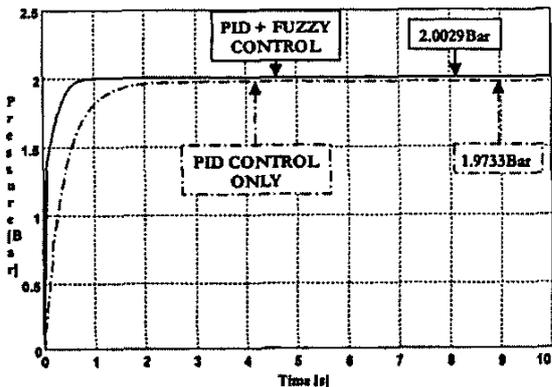Fig. 6 Step response test for a temperature of 142°C.

Fig. 7 Step response test for a pressure of 2 Bars.

VI. CONCLUSIONS

The paper has shown that the fuzzy logic controller augmenting the conventional P and PI controller does control more efficiently the industrial food processing plant with respect to setpoint tracking and disturbance rejection. The transient time is reduced, improvement in the rise and settling time are observed. All these are as a result of the fuzzy rule base. Though a simple rule base was used in this paper, an improvement in performance is clearly seen from the results. An increase in the number of rules will drastically improve the setpoint tracking and disturbance rejection performance. The use of an auxiliary fuzzy logic controller like the one described in this paper is one that can be implemented in hardware on basic microcontroller with an insignificant cost but with a tremendous cost saving for a food processing plant.

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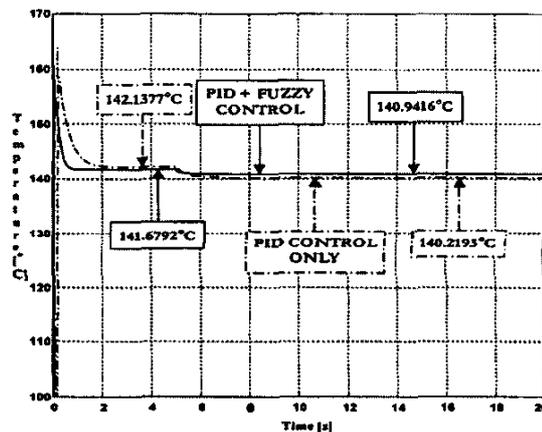
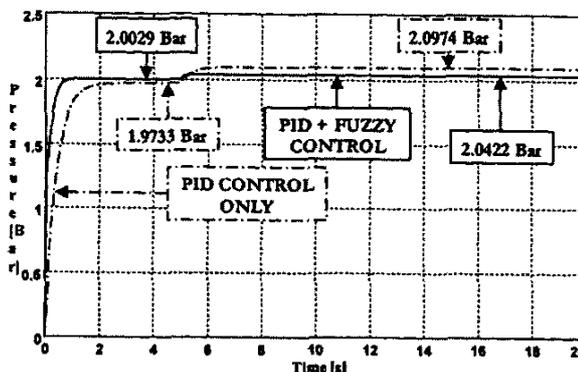Fig. 8 Effect of a pressure disturbance for a temperature setpoint of 142°C.

Fig. 9 Effect of a pressure disturbance for a pressure setpoint of 2 Bars.