FUZZY MODELLING ON CONTROL OF HEAT EXCHANGERS

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ABSTRACT

Heat exchangers are an indispensable part of many chemical processes. These are the systems that allow the transfer of heat between two or more fluids. The dynamics of heat exchangers are highly nonlinear; thus, many methods have been used to control these systems. Feedback, feedforward and cascade control loops can be presented as traditional methods. The type of controller used in these systems is also crucial, and controllers such as P, PI, PID are widely used in industry. Because of the complexity of the control, intelligent controllers like fuzzy logic controllers (FLCs) are also considered to provide an alternative to existing controllers, since FLCs provide ability to implement human knowledge and experience. In this study, control of a heat exchanger with process gain Kp = 50 and process time constant τ = 30 was investigated by using a fuzzy controller with feedback control loop. By comparing the conventional membership function for the fuzzy variables with proposed membership function, the response of the heat exchanger system to a step change of 10 units applied to the setpoint was interpreted.

***K*eywords** Control · Heat Exchanger · Fuzzy Control

1 Introduction

A heat exchanger is a system that is used to transfer heat between two or more fluids. It is used in almost all production lines, since temperature control is critical in most chemical or physical processes. Heat exchangers can be designed to tolerate wide range of pressure and temperature; thus, they are widely used in industry [1]. Applications range from power production, petroleum refining and chemicals, paper and pharmaceutical production, to aviation and transportation industries. A large percentage of world market for heat exchangers is served by the industry workhorse, the shell-and-tube heat exchanger. Recent developments in other exchanger geometries, such as plate-type and jacketed heat exchangers, have penetrated in various industry applications; however, the shell-and-tube exchanger by far remains the industry choice where maintainability and reliability are vital. [2].

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Control of these heat exchangers are essential in the chemical processes since they are widely used and slight shifts in the temperature may affect many critical parameters, such as viscosity, pressure, reaction rates in reactors, concentration, vapor pressure etc. Thus, the control of these systems has been studied rigorously by researches all around the world. Several methods have been developed to achieve this goal, most important ones being feedback, feedforward and cascade control systems [3]. The advantages and disadvantages of these systems over each other are thoroughly analyzed in literature and beyond the scope of this study. The main objectives of these control systems are to track reference trajectories when a disturbance occur, and to maintain the controlled variable close to the setpoints [4].

In this study, an approach for fuzzy feedback control of heat exchanger is proposed by using Mamdani interface system built in MATLAB. Then, the definations of the fuzzy variables for the control are variated in order to see in what manner the response of the system will change.

2 Preliminaries

2.1 Feedback Control System

A feedback control system is a system whose output is controlled using its measurement as a feedback signal. This feedback signal is compared with a reference signal to generate an error signal which is filtered by a controller to produce the system's control input. Feedback control is needed to counteract disturbance signals affecting the output, to improve the system performance in the presence of model uncertinty and to stabilize an unstable output [4]. The control scheme of a feedback control is given in Figure 1.

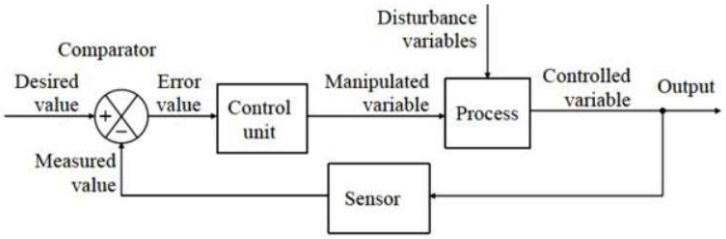

Figure 1: General control scheme of a feedback control system.

2.2 Obtainment of Process Transfer Function

In order to control a process, the process should be accurately modeled first. Thus, to model the heat exchanger, a simple energy balance is conducted for the fluid whose temperature is to be controled, as shown in the following equations (1) and (2).

$$EnergyAccumilation = EnergyIn - EnergyOut \tag{1}$$

$$V\rho c_p dT/dt = F\rho c_p T_0 + M\Delta H_b - F\rho c_p T \tag{2}$$

where V is the volume of heat exchanger, ρ is the density, c_p is the heat capacity, T is the temperature and F is the flow rate of the main process fluid. M is the flow rate and ΔH_b is the enthalpy change of the fluid which is heating or cooling the main process fluid. The fluids are assumed incompressible and the changes in the physical properties of the fluids with changing temperature are neglected for simplicity, which is a common application in modelling of the heat exchangers.

In order to control this system, we need to obtain the transfer function of the process. Thus, by taking the Laplace transform of equation (2), equation (3) is obtained. When this equation is reorganized as in equation (4), we obtain the process and disturbance transfer functions as the coefficients of M(s) and T_0(s); respectively.

$$V\rho c_p sT(s) = F\rho c_p T_0(s) + M(s)\Delta H_b - F\rho c_p T(s) \tag{3}$$

$$T(s) = 1/(\tau s + 1)T_0(s) + (\Delta H_b/(F\rho c_p))/(\tau s + 1)M(s) \tag{4}$$

where τ is the residance time, which is defined as τ = V/F.

In this study, we are not investigating the changes in the disturbance, namely T_0, thus, T_0(s)=0. This results the equation (5), where the coefficient of M(s) is known as process transfer function, denoted by G_p(s).

$$T(s) = (\Delta H_b/(F\rho c_p))/(\tau s + 1)M(s) \tag{5}$$

$$G_p(s) = K_p/(\tau s + 1) \tag{6}$$

where K_p is the process gain, defined as K_p=ΔH_b/(F ρ c_p).

For both simulations conducted in this study, K_p=50 and τ=30 will be taken since they are variables that depend on the system, and the investigated system will be assumed the same.

3 Proposed Aproach for Fuzzy Feedback Control of Heat Exchanger

Fuzzy control has several advantages over conventional controllers such as simplicity, flexibility, ability to handle problems with imprecise data etc. In order to construct a fuzzy feedback control, a fuzzy controller is needed. In this study, Mamdani interface system (built in MATLAB) was used for construction of the fuzzy controller, and the error between the set point and the controlled variable (e), derivative of the error (de) and the output (Δu) variables are defined with the fuzzy numbers NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small) and PB (Positive Big) whose membership functions are illustrated in Figures 2 and 3.

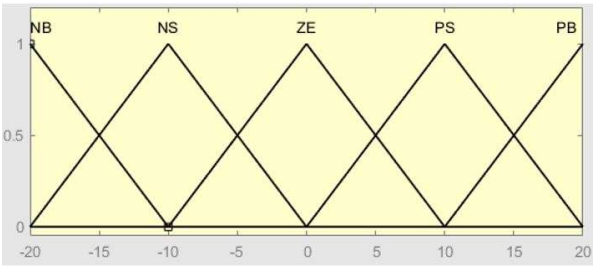

Figure 2: Membership function of input variables error (e) and difference in error (de).

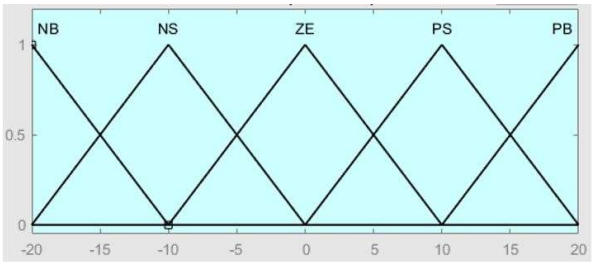

Figure 3: Membership function of fuzzy output variable Δu.

The rule table for the control was designed as presented in table 1. The non-linear control surface generated by these rules is illustrated in Figure 4. Then, feedback control system with the fuzzy controller was implemented, resulting the flow diagram given in Figure 5, which is similar to other works in the literature [5, 6].

Table 1: Rule table for the fuzzy controller.

Processes	**$\dot{m}$(kg/s)**	**T_i (°C)**	**T_o (°C)**	**ρ (kg/m^3)**	**c_p (kj/kg K)**	**μ (Pa s)**	**k (W/m K)**	**R_f (m^2 K/W)**
Process 1								
Shellside: Methanol	27.8	95	40	750	2.84	0.00034	0.19	0.00033
Tubeside: Sea Water	68.9	25	40	995	4.2	0.00080	0.59	0.00020
Process 2								
Shellside: Kerosene	5.52	199	93.3	850	2.47	0.00040	0.13	0.00061
Tubeside: Crude Oil	18.8	37.8	76.7	995	2.05	0.00358	0.13	0.00061
Process 3								
Shellside: Distilled Water	22.07	33.9	29.4	995	4.18	0.00080	0.62	0.00017
Tubeside: Raw Water	35.31	23.9	26.7	999	4.18	0.00092	0.62	0.00017

10 units of step change is applied to the set point at t=1 in order to observe the reaction of the system. The response of the heat exchanger can be seen in the Figure 6. Note that there occurs an off-set, which is uncharacteristic for a PID-like controller, which tries to minimize the absolute value of error whenever possible. However, the occurrence of such off-set is actually resulted from nature of the fuzzy numbers, since when the temperature value adjusted 9.5 units, the controller was able to deduce that there is no big difference between 9.5 and 10, thus stopped resulting any output. In order to decrease this off-set, the definition of fuzzy variables may be altered accordingly. As an example, if the fuzzy variables e, de and Δu are defined as in Figure 7, with the same rule table, the offset may be decreased, resulting a response of the system as seen in Figure 8.

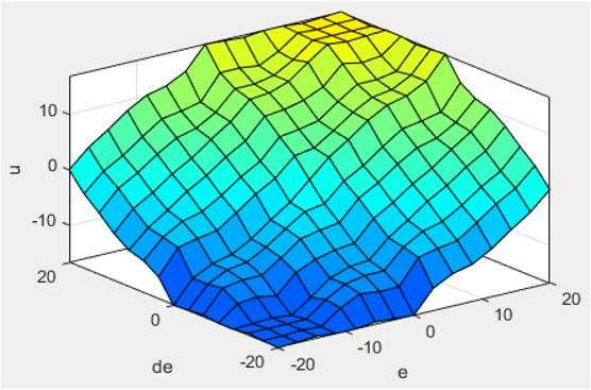

Figure 4: Control surface for non-linear control system.

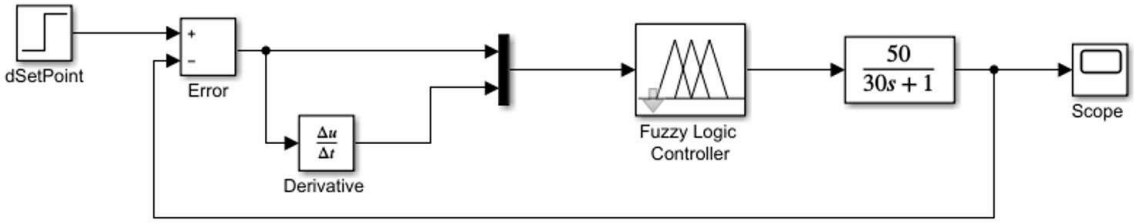

Figure 5: Flow diagram of feedback control with fuzzy controller.

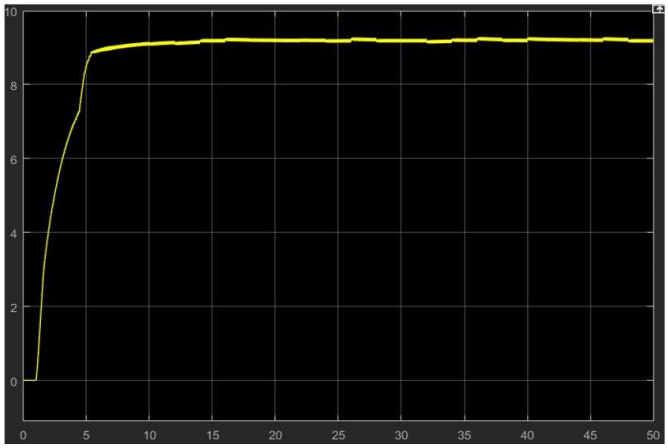

Figure 6: System response after a 10 units of step change in the setpoint with the controller variables defined as in Figures 2 and 3.

4 Conclusion

In this study, we have presented an aproach for the fuzzy control of a simple heat exchanger system. The response of the system was quick to react, but an off-set was observed which is quite contrary to the nature of PID controllers. This contradiction stems from the nature of the fuzzy numbers. Because the "stop condition" was defined with the fuzzy number ZE, the controller was able to deduce that 0.5 is within the bounds of ZE and it does not increase the temperature more than necessary, which is a significant thing to be understood by a controller. We have also shown

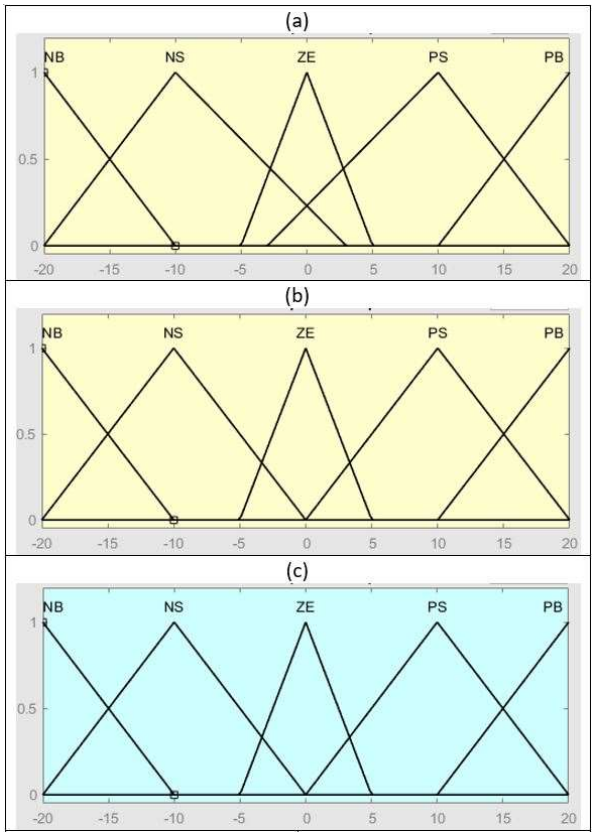

Figure 7: New definitions for variables e (a), de (b) and Δu (c).

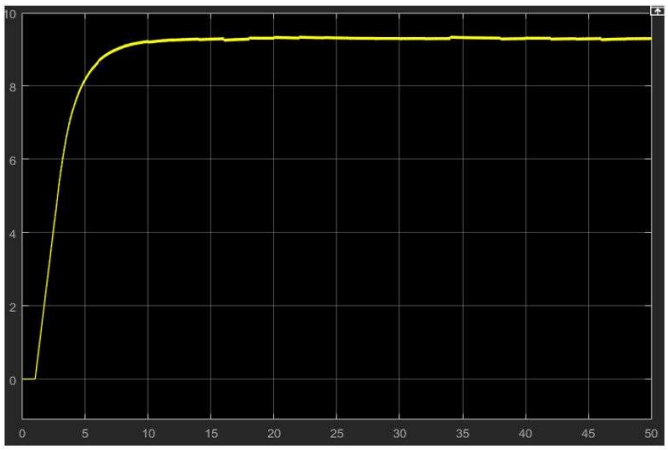

Figure 8: System response after a 10 units of step change in the setpoint with the controller variables defined as in Figure 7.

that when the definations of the fuzzy variables are variated, different responses of the system are obtained. As a future direction, this topic should be investigated more rigorously to obtain a relation between the response and the definitions of the fuzzy variables.

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