IChemE
www.icheme.org/cherd
doi: 10.1205/cherd06027

0263–8762/06/$30.00+0.00

Trans IChemE, Part A, November 2006
Chemical Engineering Research and Design, 84(A11): 1012–1018

APPLICATION OF FUZZY CONTROL METHOD WITH GENETIC ALGORITHM TO A POLYMERIZATION REACTOR AT CONSTANT SET POINT

A. ALTINTEN[1]*, S. ERDOGAN[1], H. HAPOGLU[2], F. ALIEV[3] and M. ALPBAZ[2]

[1]*Gazi University, Faculty of Engineering and Architecture, Department of Chemical Engineering, Ankara, Turkey*
[2]*Ankara University, Faculty of Engineering, Department of Chemical Engineering, Ankara, Turkey*
[3]*Ankara University, Faculty of Science, Department of Statistics, Ankara, Turkey*

In this work, the fuzzy control was designed using genetic algorithm (GA) to control the temperature of a jacketed batch reactor in which styrene polymerization takes place under isothermal conditions. The fitness function for GA is chosen as the integral of the absolute value of the error (IAE). By using fuzzy parameters specified at constant temperatures, the efficiency of the fuzzy controller with GA was examined by simulation and experimentally. It was seen that GA is able to tune the fuzzy controller efficiently for different situations and therefore to control the temperature of the polymerization reactor.

Keywords: polymerization reactor; genetic algorithms; fuzzy control; membership functions.

INTRODUCTION

In recent years, fuzzy control has successfully been used for controlling a number of physical systems. Fuzzy controllers model the human decision making process with a collection of rules. A fuzzy controller mainly depends on the selection of the membership function that produces maximum performance as a subjective decision. The trial-and-error method is usually used to find fuzzy control rules and membership functions. However, with the development of optimization methods, some different techniques are used to find fuzzy control rules. The approach chosen in this work is based on genetic algorithm (GA). This algorithm has recently been used to find the optimal-tuning values of the controllers. In this work, GA is used to select optimal membership functions of fuzzy values. Considerable literature can be found on the fuzzy control of chemical reactors. However, application of control algorithms is mostly by simulation alone. There have been a few reports on the application of fuzzy controllers to real experimental systems and real industrial processes.

The first genetic algorithm (GA) was developed by Holland (1975). It uses Darwinian survival-of-the-fittest strategy to eliminate unfit characteristics. The searching process is the same as the natural evaluation of living things. The fittest among a group of creatures can survive and form a new generation randomly and by gene exchange. It allows reproduction from the best one which adapts to a changing environment to survive. Actually, current research shows that a good GA does not only follow Darwinian Principle, but it also finds a feasible solution to an optimization problem if the initial condition is suitably selected. For the genetic algorithms, the parameters are binary coded into one string. Each string of 0s and 1s is the encoded version of a solution to the optimization problem. GAs have three fundamental operators: reproduction, crossover and mutation. Using these operators the algorithm creates the subsequent generation from the strings of the current population. The generational cycle is repeated until a desired termination criterion is reached. Wang *et al.* (1996), Wang and Kwok (1994) and Lee *et al.* (1997) applied GA methods to many different problems and the best control parameters of controllers were obtained. Krishnakumar and Goldberg (1992) applied the GA to aerospace control system. Karr *et al.* (1990), Ng and Li (1994), Chin and Qi (1998) applied GA to the design of fuzzy controllers for searching the poorly understood, irregular and complex membership function space with improved performance. Gurocak (1999) used GA for tuning fuzzy logic controllers. Zhou and Lai (2000), Wu and Liu (2000) showed that fuzzy controller based on GA can achieve good performance.

Polymers constitute a large fraction of the total production of the chemical industry. Polymerization reactors have nonlinear natures and they show time varying behaviour. Their dynamic nature and the wide variations in operating conditions during batch cycles can make the reactor control difficult and important. Temperature variations greatly affect the kinetics of polymerization process and

**Correspondence to*: Assistant Professor Dr A. Altinten, Gazi University, Faculty of Engineering and Architecture, Department of Chemical Engineering, 06570, Maltepe, Ankara, Turkey.
E-mail: altinten@gazi.edu.tr

change the physical properties and quality characteristics of the produced polymer (Ni *et al.*, 1997). As a result, to keep the product quality constant, the temperature of the reactor should be efficiently controlled. In the present paper, fuzzy controller with GA was used to accomplish the temperature control of a batch jacketed polymerization reactor in which styrene free radical solution polymerization takes place. There exist many researches in literature on the control of the batch polymerization reactors by PID algorithms, dynamic matrix (Altinten and Erdogan, 2000; Yuce *et al.*, 1999), adaptive (Wang *et al.*, 1994; Clarke-Pringle and MacGregor, 1997), predictive (Rho *et al.*, 1998) and generalized minimum variance (Karagoz *et al.*, 2000) controllers. In this paper, we present the fuzzy control of the polymerization reactor. The objective of the control problem is to achieve the desired number average chain length and a desired conversion in a minimum time by adjusting the temperature and initial initiator concentration. To determine the optimal temperature and optimal initiator initiation concentration, Lagrange's Multiplier method (Chen and Jeng, 1978) was used. The membership functions and controller relation matrix of fuzzy controllers are obtained by GA. The performance of fuzzy controller was examined by simulation and then experimentally. These optimal values are implemented in the experimental reactor system and fuzzy control system was applied in order to control the reactor temperature. Here, genetic algorithm is used off-line.

MATHEMATICAL MODEL OF THE REACTOR

Considering the standard free radical polymerization and assuming constant density, no chain transfer and no gel effects, and applying the pseudo steady-state approximation for the radical concentrations and making long chain approximation, the equations for monomer conversion, initiator conversion and the dimensionless zeroth moment of the molecular weight distribution (MWD) can be written as (Chen and Jeng, 1978);

$$\frac{dX}{dt} = k_1(1-c)^{0.5}\frac{(1-X)}{g} \tag{1}$$

$$\frac{dc}{dt} = k_d(1-c) \tag{2}$$

$$\frac{dq_o}{dt} = (2-v)\alpha k_d(1-c) \tag{3}$$

with the initial conditions, $X(0) = c(0) = q_o(0) = 0$ where

$$k_1 = k_p(2fk_dI_o/k_t)^{1/2} = I_o^{1/2}A_1\exp(-E_1y);$$
$$X = 1-\frac{M}{M_o};\ c = 1-\frac{I}{I_o};\ g = 1;$$
$$\alpha = \frac{fI_o}{M_o};\ v = k_{tc}/k_{td} = 1 \tag{4}$$
$$E_1 = E_p + E_d/2 - E_t/2$$
$$A_1 = (2f)^{1/2}A_pA_d^{1/2}A_t^{-1/2} \tag{5}$$

The number average chain length can be given as

$$L_n = \frac{X}{q_o} \tag{6}$$

For the isothermal batch jacketed reactor, the control variables are taken as reaction temperature and initial initiator concentration. To find the optimal values of these variables, the method of Lagrange's Multiplier is used (Chen and Jeng, 1978) and the equations for optimal I_o and T are found as

$$\frac{E_d}{2(E_d-E_1)}\ln\left(1-\frac{M_oX_d}{fI_oL_{nd}}\right) + \frac{M_oX_d}{fI_oL_{nd}(1-M_oX_d/(fI_oL_{nd}))^{0.5}} = 0 \tag{7}$$

$$T = \frac{(E_d-E_1)}{R\ln[-\ln(1-X)/((A_1(fA_d))I_o^{0.5}(1-(1-M_oX_d/(fI_oL_{nd}))^{0.5}))]} \tag{8}$$

The kinetic constants used in this work are given in the notation section.

Assuming perfect mixing, constant reacting heat capacity and density, the reactor dynamic can be expressed by energy balances for the reactor and jacket as follows (Altınten and Erdogan, 2000):

$$\frac{dT}{dt} = \frac{Q}{V\rho C_p} + \frac{(-\Delta H)r_M}{\rho C_p} - \frac{UA(T-\bar{T}_c)}{V\rho C_p} \tag{9}$$

$$\frac{dT_{co}}{dt} = \frac{\dot{m}_c(T_{ci}-T_{co})}{V_c\rho_c} + \frac{UA(T-\bar{T}_c)}{V_c\rho_cC_{pc}} \tag{10}$$

where

$$r_M = \frac{dM}{dt} = -k_p\left(\frac{2fk_d}{k_t}\right)^{1/2}I^{1/2}M \tag{11}$$

The overall heat transfer coefficient for the batch jacketed polymerization reactor was modelled as a function of the viscosity of the reacting mixture as

$$U = \frac{1}{\mu_r^{0.33}S+F} \tag{12}$$

where S and F are constants which depend on the reactor size and physical properties, μ_r is the viscosity of the reacting mixture.

DESIGN OF FUZZY MODEL BASED CONTROLLER USING GENETIC ALGORITHM

The performance of a fuzzy controller depends on a number of parameters such as membership functions (Newell and Lee, 1989). The tuning of the fuzzy membership functions is an important task in the design of fuzzy controllers. But there are some difficulties of choosing rules and high-performance membership functions for a given system. The present approaches in choosing the membership functions are mainly based on trial and