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Review

# Optimal temperature control in a batch polymerization reactor using fuzzy-relational models-dynamics matrix control

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**Abstract**

In this work, fuzzy-relational models-dynamics matrix control (Fuzzy-DMC) was applied to the free radical solution polymerization of styrene in a jacketted batch reactor and its performance was examined to reach the required monomer conversion, molecular weight and chain length in a minimum time. The reactor temperature was controlled by manipulating the heat-input to the reactor. The performance of the Fuzzy-DMC controller was compared with that of the nonlinear generalized predictive control (NLGPC).


*Keywords:* Dynamic matrix control; Fuzzy-relational models; Polymerization

**Contents**



## 1. Introduction

Optimization and control of polymerization reactors have an importance for process applicability and economics. Recently, researches have focussed mainly on the cost reduction of polymer production satisfying product quality. The molecular structure of polymer is sensitive to reactor operating conditions. Polymerization temperature of the reactor has remarkable importance in obtaining critical molecular properties, such as molecular weight distribution (MWD), chain length, conversion of monomer, etc. Polymerization reactions are very complex and generates a large amount of heat, which must be removed from the reactor. Control of polymerization reactors in chemical industries is a difficult problem, due to their nonlinear nature.

PID control method, which is known as one of the convensional control method has been used in many industrial processes (Fisher, 1991). But, it was observed that the control method was not closer to the requirements for high quality polymer production depending on the application areas. Therefore, new control methods were designed and examined.

There are many applications of dynamic matrix control (DMC) for nonlinear processes. A linear algorithm of DMC was developed and employed for chemical processes (Peterson, Hernández, Arkun, & Schark, 1989a), while new nonlinear model-predictive control method was advanced and applied to a semibatch polymerization reactor. The proposed control

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**Nomenclature**

| | |
|---|---|
| $a_I$ | parameters of $A$ polynomial |
| $A(z^{-1})$ | the polynomial that shows the poles of the discrete-time system in $z$ domain |
| $b_I$ | parameters of $A$ polynomial |
| $B(z^{-1})$ | polynomial in $z$-domain representing the zeros of the discrete-time |
| $C(z^{-1})$ | the polynom that shows the zeros of the process noises in $z$-domain |
| $d$ | offset |
| $e_t$ | total error |
| $I$, $I_0$ | initiator concentration, initial initiator concentration (mol l$^{-1}$) |
| $m_c$ | flow rate of the cooling water (kg s$^{-1}$) |
| $m^*$ | desired monomer conversion (%) |
| $M$, $M_0$ | monomer concentration, initial monomer concentration (mol l$^{-1}$) |
| $Q$ | weighting polynomial acting on control input |
| $Q_w$ | heat power (W) |
| $R$ | fuzzy-relational matrix |
| $R(z^{-1})$ | weighting polynomial acting on set-point |
| $t$ | time (s) |
| $t_f$ | reaction time (min) |
| $T$ | temperature (°C) |
| $u$ | input variable at time $t$ |
| $V$ | volume of the mixture (m$^3$) |
| $V_c$ | volume of the cooling water jacket (m$^3$) |
| $X_n$, $X_n^*$ | number of average chain length, desired number of average chain length, respectively |
| $y(t)$ | output variable at time $t$ |
| $y_{sp}$ | setpoint at time $t$ |

algorithm used an explicit nonlinear process model and the basic elements of the classical dynamic matrix control (DMC) (Peterson, Hernández, Arkun, & Schark, 1989b). DMC of a batch solution polymerization reactor was investigated experimentally and theoretically to achieve a specific constant number average chain length and conversion in a minimum time (Erdoğan, Yüce, Karagöz, Hapoğlu, & Alpbaz, 2001).

The type of fuzzy model in the related work (Demircan, Çamurdan, & Postlethwaite, 1989) is not amenable to updating the relational model array using a recursive least squares algorithm. Edgar and Postlethwaite (2000) have used a fuzzy-relational model (FRM). They applied FRM in the whole operating region and incorporated this model within an internal model control (IMC) structure.

DMC was performed to neutralize a continuous process stream in a stirred tank (Draeger & Engell, 1985). It is noted that the controller performance deteriorated in the presence of large disturbances. An adaptive DMC was successful in overcoming process model mismatch.

An adaptive control of input–output linearizable system was used by Wang, Carriou, and Pla (1994). They applied an extended Kalman filter for a simulated batch polymerization reactor to perform the output tracking in the presence of model parameter uncertainties. It was noted that this technique was robust and the output follows the setpoint.

An adaptive control strategy for linearizable system was developed by Sastry and Isidori (1989). The exact cancellation of nonlinear terms was robustified by a parameter adaptation technique was used to robustify. They applied this method to a simulated batch polymerization reactor so that the monomer conversion followed a reference trajectory. Globally obtained variable FRMs were conducted in their work. The recursive least squares (RLS) algorithm was also elucidated to update the relational array so as to provide on-line learning. They noted that the FRMs identified in a local region performed satisfactorily as well as those were identified in the whole operating region, and that the variable model performance of the system was poor.

In this work, the optimal temperature trajectory control of a batch jacketed free radical polymerization reactor with Fuzzy-DMC system has been investigated. Fuzzy-DMC system was applied to keep the reactor temperature at a time varying optimal temperature trajectory for the polymer reactor. The change of reactor temperature and heating rate during polymerization was monitored to see the control performance. The optimization techniques were applied to find the variable temperature profiles to obtain previously determined monomer conversion, chain length number and average molecular weight in the shortest time in the minimum amount of initial initiator concentration (Chen & Huang, 1981). The polymerization reactor temperature was controlled by heat-input to the system which was chosen as a manipulated variable. The used linear and fuzzy models for DMC and the change of heating rate during polymerization was monitored to see the control performance. Monomer conversion, chain length, average viscosity molecular weight and control performance were observed.

The results of the Fuzzy-DMC experiments were compared with theoretical results that were obtained by applying the Hamiltonian principle method to the mathematical modeling of this reactor system. The comparison of the performances of Fuzzy-DMC controller and NLGPC controller is an interesting contribution, it was found that the desired final monomer conversion, molecular weight and chain length in the Fuzzy-DMC were better than in NLGPC controllers.

## 2. Fuzzy-DMC algorithm

Fuzzy-DMC algorithm is shown in Fig. 1. In this work, Fuzzy-DMC algorithm was applied to a styrene polymerization reactor using combination of feed forward and feedback control scheme. Control action was calculated at every sampling time by the DMC algorithm using the approximate linear and fuzzy models. The objective function is given below for this control objective (Cutler & Ramaker, 1980):

$$\min_{\Delta u} \sum_{i=1}^{P} \gamma^2 [y_{sp}(k+i) - \hat{y}(k+i)]^2 + \sum_{j=1}^{M} \lambda^2 [\Delta u(k+j-1)]^2 \tag{1}$$

where $y_{sp}$, $\hat{y}$, $u$ represent the set-point sequences, the predicted future output and future control moves respectively. $\gamma$ and $\lambda$ are