1st National Colloquium on Process Control 2013
1st October 2013

Review on Advanced Control Technique in Batch Polymerization Reactor of Styrene

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Abstract: *Polymerization process have a nonlinear nature since it exhibits a dynamic behavior throughout the process. Therefore, accurate modeling and control technique for the nonlinear process needs to be obtained. In this paper, the main objective is to review on advanced control technique that was utilized in batch reactor polymerization of styrene in the previous literature study. Its performance was examined to reach required monomer conversion and average chain length in minimum time at optimal temperature trajectory. Moreover advanced control techniques also have the potential to improve performance.*

Keywords: Polymerization, advanced control technique, batch reactor, monomer conversion, average chain length **(**NACL)

1. INTRODUCTION

For decades, batch reactors are widely used in the polymer industry, especially for multi-purpose processes where different types of polymers are produced on demand[1]. One of the many advantages of batch processes is ability to allow for the change of operating conditions, both at start up and along the reaction, in order to conduct them to desired products and material properties. Besides, residence time in batch reactor is more uniform thus better yields may be obtained. Other than batch reactor, semi-batch and continuous reactor also can be used in polymerization process. Polymerization is a chemical process that combines several monomers to form a polymer compound which reaction is extremely exothermic. There are two types of polymerization those are addition and condensation polymerization. In polymerization system, styrene will undergo addition polymerization which also known as chain growth polymerization. Control of temperature in batch polymerization of styrene is one of the most important aspects in order to obtained quality final polymer properties. Proper control technique and mathematical models needs to be applied to control the reactor temperature. Furthermore, better yield in product tends to possess a higher desirable polymer characteristic such as tensile and compressive strength. Higher impact strength also achieved if higher molecular weight yield in the process[2].

However, the chemical process industries encounters many problems in controlling and monitoring polymerization reactors due to the complex process dynamics, strong nonlinearities and interaction between variables. Conventional PID controller also failed in achieving desired polymer product when applied to the polymerization reactor. Thus, it is a difficult task to develop mathematical models for polymerization processes. A lot of works have been conducted to solve these issues. Researchers have been work very hard by continuously searching a better solution to control and monitoring the polymerization reactors in order to achieve quality polymeric products. Nowadays, varieties of modeling and advanced control algorithm are widely implemented in the chemical industry. However, the application towards polymerization engineering is still very limited[3]. The main advantage of the advanced control technique is simplicity that suits control engineers since wide range of industrial processes can be controlled by the proposed method[4].

The main objective of this paper is to review the application of modeling and advanced control techniques in polymerization reactors. The attention is focus more on the papers published in the last ten years in order to observe the recent trends in the field. The next section will discuss about all the advanced control techniques applied in the simulation and also experimental mostly in batch reactor polymerization of styrene. Most of the studies are compared with conventional PID and also with another advanced control technique from previous literature study to see the controller performance. From the studies, the temperature was controlled at the optimum value in order to get higher yield in polymer product.

2. LITERATURE STUDIES

Table 1 shows the recently paper published and research effort done to control batch polymerization reactors using advanced control technique. Furthermore, the review of several advanced control technique applied in the previous study of batch reactor polymerization of styrene was explained in this chapter. The control techniques show great performance and improve the control action in terms of robustness and accuracy.

Table 1 : Application of advanced control technique

	Journal	Authors	Control technique	Reactor	Controlled Variable	Manipulated Variable	Disturbance
1	Application of Model Predictive Control to Batch Polymerization Reactor	N.M. Ghasem et al, 2006	MPC	Batch	- Reaction T - Initial initiator concentration	-Heat given to the reactor	-Increasing reactor T
2	Application of Fuzzy Control Method with Genetic Algorithm to a Polymerization Reactor at Constant Set Point	A. Altinten et al, 2006	Fuzzy Control method with GA	Batch	-Reaction T -Initial initiator concentration	- Heat given to the reactor	none
3	Generalized delta rule (GDR) algorithm with generalized predictive control (GPC) for optimum temperature tracking of batch polymerization	Z. Zeybek et al, 2006	GDR algorithm with GPC	Batch	-Reaction T	-Heat input	-Heat released during reaction
4	Temperature Control of a Bench-Scale Batch Polymerization Reactor for Polystyrene Production	Nayef Mohamed Ghasem et al, 2007	-fuzzy logic and GMC	Batch	-Reaction T	- Heat given to reactor	-Increasing T of the cooling medium,T_{jo}
5	Control of polystyrene batch reactors using neural network based model predictive control (NNMPC)	Mohammad Anwar Hosen et al, 2011	-NN based MPC	Batch	-Reaction T	- Heat given to reactor -Output reactor T	-Increasing coolant flow rate -Increasing coolant inlet T
6	Optimal temperature control in a batch polymerization reactor using fuzzy-relational models-dynamics matrix control	Sevil Cetinkaya et al, 2006	Fuzzy-DMC	Batch	- Reaction T	-Heat given to the reactor	none

2.1 Journal 1

Model predictive control is widely used to deal with large multivariable constrained control issues in industry. The main aim is to minimize a performance criterion in the future that would possibly be subject to constraints on the manipulated inputs and outputs, where the future behavior is computed according to a model of the plant. In this study, model predictive control (MPC) was applied to the batch polymerization reactor of styrene. The controller performance was tested for nominal, sinusoidal, step change in reactor temperature set point and optimum temperature profile to achieve desired monomer conversion and number average chain length (NACL). The objective is to control reactor temperature at its optimum set point with minimal temperature overshoot. At nominal condition, the concentration of initiator and monomer, and jacket temperature are dropping with time and make heat input to reactor increase. However, the controller managed to sustain the reactor temperature set point as the reaction proceed with time. The robustness and performance of the proposed controller was also tested when the reaction temperature set point is in sinusoidal form. The result shows that the MPC controller can detect the disturbance occurred and make action to keep the reactor temperature to its set point profile. For step change in reactor temperature set point, the result shows that at first 5000 s, the reactor temperature can detect the temperature set point under MPC controller action. After 5000 s, there exist reactor temperature deviations from the set point due to the depletion initiator concentration in the system. However the overshoot only took a few second before its going back to the trajectory point. To obtain desired polymer product properties, the optimal reactor temperature needed to be controlled. For this MPC controller was used to track the optimal reactor temperature successfully. As a conclusion, the simulation results show that MPC controller technique give good performance and can act as reliable controller in polymerization reactor.

2.2 Journal 2

In this work, genetic algorithm (GA) is applied into the fuzzy controller to accomplish the temperature control of a batch jacketed polymerization reactor of styrene. GA is used off-line and then tested on the experimental system to see the performance of the fuzzy controller. In order to achieve the desired number average chain length and a desired conversion in a minimum time, temperature and initial initiator concentration was adjusted at two different values. The results show that an overshoot is observed at the beginning but then the controller brings the reactor temperature back to the set point. Besides, the performance of the controller also was observed by manipulating the heat given to the reactor at these two different values. The heat was manipulated between 100 W and 200 W. The results show that at 200 W, the graph is more oscillatory because of the high temperature set point. Moreover, the desired conversion and NACL were also in a good agreement with the predicted result using these operation conditions. As a conclusion, the fuzzy controller shows good performance throughout the study since the desired conversion is obtained in a minimum time. The fuzzy controller performance also is better than the other controllers used in previous study in the same system.

Abdul Halim and Abdul Sata, 2013

2.3 Journal 3

Although there are a lot of number of advanced control technique in controlling polymerization reactor such as model predictive control and fuzzy logic, these controllers also possess some technical problem which associates with the computational and selection model structure. In this study, generalized delta rule (GDR) with generalized predictive control (GPC) was introduced to counter the problem. It requires a dataset of the desired output for many inputs, making up the training set. The objective of this paper is to compare the GDR with GPC controller with conventional GPC controller in term of controlling the optimal temperature trajectory in order to get desired polymer properties. The optimal temperature in this study was determined by using Hamiltonian Maximum Principle. As for this study, the optimum reactor temperature obtained in minimum time was determined at two different values of initial initiator concentrations. Therefore the results discussed were based on the optimal reactor temperature at these two values of initial initiator concentrations. Based on the graph, GDR-GPC showed that the reactor temperature followed the optimal temperature trajectory closely and as soon as the reaction started the optimum trajectory was captured. Meanwhile when the disturbance is introduced to the system, GDR-GPC can detect the optimal temperature trajectory very well. Molecular weight, experimental conversion and average chain length obtained at the optimal temperature trajectory also agreed well with the prediction values. As a conclusion, the GDR-GPC can acts smoothly as a controller in a nonlinear polymerization process of styrene. Moreover, the controller was easy to utilize as it capabilities does not require the use of historical input-output data set which means it can adapt to new conditions itself.

2.4 Journal 4

For this paper, the first objective is to investigate the optimal temperature trajectory of a batch free radical styrene polymerization with two advanced control techniques those are fuzzy logic and generic model control (GMC). There were two tests performed for tracking the temperature profile, one under optimal conditions and another one with disturbance. Other objective is to obtained the desired end-use properties when the optimal temperature at given initial initiator and monomer concentration is determined. This study also applied the maximum principle to solve the optimal temperature policy in order to minimize the reaction time required to achieve final conversion and number-average chain length of the polymer. Lastly both controllers were compared to the conventional PID controller to see which act as the best controller. Due to the nonlinear behavior exist in the polymerization system, conventional linear controllers often fail to control polymerization reactors. Other than that, direct measurement of polymer quality is rarely achievable, which make the online control of the reactor difficult. Therefore advanced control strategy, the GMC and fuzzy logic were introduced in this work. These control techniques are widely used in other study regarding polymerization reactors. The idea was to incorporate a nonlinear process model directly into the controller. As a conclusion, the proposed advanced controller can track the set point profile very well as compared to the PID controller. The conversion and NACL also give a good result as the target is to produce polystyrene with 50% conversion and 500 NACL.

2.5 Journal 5

The polymer engineers need to maintain the low cost and produce the quality of polymer product. So the aim here is to upgrade the control system in order to reduce energy consumption as well as to minimize production cost. Besides, there are many advanced control techniques was implemented in the polymerization of batch reactor. In parallel with that, the controller neural network based model predictive control (NN-MPC) was introduced in this study. NNMPC was developed to control the temperature of polystyrene batch reactor. The controller set-point tracking and load rejection performance also was investigated and compared with conventional PID for the performance result. After running the experiment, results show that the temperature performed well in tracking the temperature set-point profile despite the highly nonlinear exothermic reaction happened in the reactor. As compare with the PID controller, the result shows that PID controller took longer time than NN-MPC to reach stable set-point tracking. In industrial practice, there always some disturbances occurred. To encounter this problem, disturbances were introduced. It shows that NN-MPC controller rejects the disturbance and speedily tracks back the temperature set-point profile but for PID controller, it caused the temperature to drop below the set-point with permanent offset of oscillation. Other than that, monomer conversion and number of average chain length also investigated in this study. The results show that NN-MPC gave results closer to the desired conversion of monomer and number average chain length as compared to PID controller. As a conclusion, the performance of NN-MPC controller is better than conventional PID controller due to the positive result given throughout the study.

2.6 Journal 6

Control of temperature in polymerization reactor of styrene is very important in producing a satisfying product quality. Over century, conventional PID controller was utilized in the polymerization process. However, the requirement for the product polymer quality always cannot be achieved when using the conventional controller. In this study, the fuzzy-relational models-dynamic matrix control (FDMC) was proposed and applied to the batch polymerization reactor and the temperature was controlled at its optimum point in order to obtained higher monomer conversion, average viscosity molecular weight and chain length in a minimum time. The performance of the FDMC was compared to the nonlinear generalized predictive control (NLGPC) controller in this experiment. For all control works, the amount of heat produced by the immersed heater was taken as the manipulated variable. From the study, the optimum temperature profiles were obtained at two different values of initial initiator concentration. As FDMC was compared to NLGPC controller, the result shows that FDMC controller is better than NLGPC. This is because FDMC can follow the optimal temperature trajectory closely and traced the optimum trajectory very quickly as the reaction started. Furthermore, by using FDMC, the desired yield of monomer conversion, molecular weight and average chain length were higher than those using NLGPC controller. As a conclusion, FDMC controller is decided to be a better controller in controlling the optimal reactor temperature when compared to NLGPC since the required product yield in higher values.

3. CONCLUSION

As a conclusion, the development of advanced control techniques really useful in the polymerization process industry. Measurement of the molecular properties such as molecular weight and average chain length also achieved at its desired value with the utilizing of advanced control technique. Furthermore, the good performance showed by the advanced control technique also makes them as a reliable controller to be used in the polymerization process.

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