PID Controller for Batch Process using MATLAB-Simulink-Real-Time-Windows Target

S.A. Zulkeflee[1], S. Abd Sata[2], N. Aziz[3*]

[1,2,3]School of Chemical Engineering, Engineering Campus, Universiti Sains Malaysia, Seri Ampangan, 14300 Nibong Tebal, Seberang Perai Selatan, Penang, Malaysia

*Corresponding authors: chnaziz@eng.usm.my

Abstract: *The difficulties in implementing a controller in the real process leads to the practice of a real-time user-friendly simulator programming. This paper presents the application of the Simulink model as a Graphical User Interface (GUI) for signal visualization and parameter tuning in the real-time implementations. This can be achieved by the integration between MATLAB Simulink external mode and Real-Time Windows target software (MATLAB-Simulink-Real-Time-Windows Target). The application of this integration is demonstrated through the real-time implementation of the PID controller in controlling the reaction temperature in batch process. From the results achieved, it can be concluded that the proposed embedded design architecture is able to deliver the desired outcome.*

Keywords: MATLAB-Simulink, Real-Times-Windows Target, Temperature Control, Batch Reactor, Esterification Process

1.   INTRODUCTION

Implementation of controller in real-time is a time consuming in any industry controller design process. Due to this reason, the practice of rapid control prototyping which helps to reduce project completion time, has gained good acceptance. Nowadays, the computational and graphical power of modern computers lead to more flexible control systems including higher-level functions and advanced algorithms where it can be implemented successfully in real systems. With the widespread use of a MATLAB Simulink graphical programming environment, modelling and simulation of various plants and controllers can be accomplished quite easily without extensive training in digital control and numerical methods[1].

Real-Time Windows Target (RTWT) software is a PC solution for prototyping and testing real-system. Integration with Simulink was the feasible way to create, simulate and analyze complex dynamic systems by simply connecting functional blocks, mostly available from various preconfigured libraries, within a friendly graphical user interface (GUI). The primary advantage of its usage lies in the familiar mathematical notation used to express the problem at hand[2]. Furthermore, integration between Simulink external mode and Real-Time Windows target software allows Simulink model to be used as a GUI for signal visualization

and parameter tuning. By using this tool, the user can concentrate on modelling and control issues, as opposed to programming issues.

In this work, the simulation and experimental studies for lipase-catalyzed esterification batch process using MATLAB-Simulink Real-Time-Windows Target is presented. Experimental data and a physically based model is used to design the controller for batch esterification reactor. A system transfer function is estimated from an open loop response experiment. Then a controller design is conducted using PID controller design techniques. Finally, the performances of the PID controller are evaluated based on its set-point tracking, set-point change and load change.

2. CASE STUDY: TEMPERATURE CONTROL FOR BATCH ESTERIFICATION PROCESS

Ester has been continuously developed and gained an important role in our daily life. They can be found not only as a more robust alternative to organic flavor and fragrances in the food and pharmaceuticals industry but also as emulsifiers in the food, cosmetic and chemical industries. The understandings of factors influencing the lipase activity are crucial for the control and manipulation of products of lipase-catalyzed reactions. The rate and equilibrium yield as well as the stability of enzymes can be influenced by many factors and the most critical are temperature. Temperature has a strong influence on the enzymatic esterification process[3]. The temperature should preferably be above the melting points of the substrates and the product, but not too high, as the enzyme's activity and stability decreases at elevated temperatures. Therefore, temperature control is important in the esterification process in order to achieve maximum ester production. In this work, the reactor's temperature is controlled by manipulating the flowrate of cooling water into the reactor jacket. The esterification processes were conducted in 1.5L jacketed batch reactor. The reaction mixture in iso-octane of Citronellol, Lauric acid and immobilized lipase was stirred at 200rpm. Computer control and the instrumentations for the experimental apparatus are shown in Fig. 1.
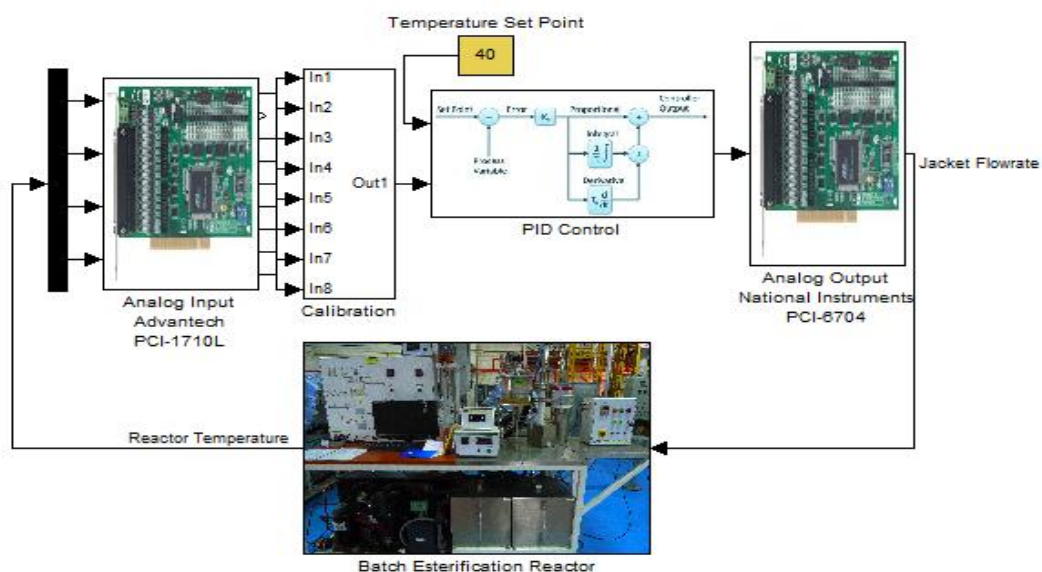

Fig. 1: Schematic Diagram of the Batch Esterification Reactor with RTWT Interface for Temperature Control Systems

2.1   Hardware and Software

The current signal, after appropriate signal conditioning, is converted to a digital signal by a 12-bit A/D converter (Advantech PCI-1710). The I/O card is getting the signal from all sensors such as thermocouples, flow sensors, pressure sensor, humidity sensor, conductivity sensor, and pH sensor. The computer used in the experiment is an IBM PC/XT having an Intel 80286 16-bit CPU with a 20 Mhz clock speed. The real time control and interface routines are written using Real-Time Windows Target in MATLAB software. The digital outputs are given to Advantech PCI-1710 to control solenoid valves and converted into an analog electrical signal by a 12-bit D/A converter (National Instruments, PCI-6704) which controls the proportional valve, stirrer and dosing pump. The developed controller computations are carried out in the PC whereas the actual control is implemented through the hardware controller with sampling time of 10s.

In the temperature control loops, one pneumatic control valves, one flow meter, two solenoid valves are installed. At the inlets and outlets of the jacket, two thermocouples are located (-18-538°C Platinum+10% rhodium+platinum); accuracy ±0.1 to 0.3^{o}C). The reactor temperature is measured by the thermocouple of the same type (accuracy ±0.1^{o}C). The volumetric flow rates inside the jacket are measured by flow transmitter which output a 4-20mA signal proportional to the flow rate. The measured temperature of the reactor was compared with the set-point and the cooling water flow into the jacket was manipulated via a proportional valve.

2.2   Simulink Environment

The experiment also illustrates the use of the MATLAB-Simulink RTWT environment. The RTWT module performs classical control experiments using hardware-in-loop simulations. Using RTWT, the sampling time was reduced by an order of magnitude to 5ms. The corresponding Simulink model was developed in order to send and receive signals to/from the real batch esterification system, as depicted in Fig. 2. Some configuration of the simulation parameters need to be done. The guides and details of these configurations can be found in[4].
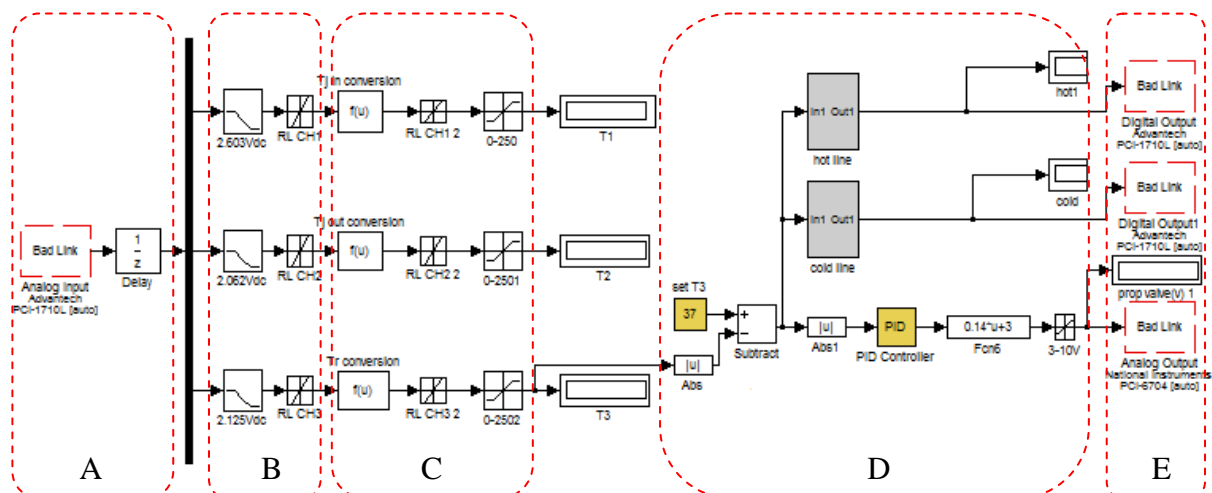
Fig. 2: Simulink model for the RTWT application for batch esterification reactor

where:

A: Integration to input/output card Advantech PCI-1710L

B: Filter and rate limiter to stabilize the input signal from sensor instruments.

C: Calibration equation to convert analog input into the actual readings

D: PID controller to control proportional valve of jacket flow rate

E: Output signal to input/output card National Instruments PCI-6704

3.   RESULTS AND DISCUSSION

In the time domain, specifications for a control system design involve certain requirements associated with the time response of the system. The requirements are often expressed in terms of the standard quantities on the rise time, settling time, overshoot, peak time, and steady state error of a step response. In the time domain, the PID controller is assumed to be of the form:

$$u(t) = K_p \left[e(t) + \frac{1}{T_i} \int_0^t e(\tau)d\tau + T_d \frac{de(t)}{dt} \right]$$

where K_p, T_i and T_d are the PID parameters, $e(t) = r(t) - y(t)$ is the difference between the set point input $r(t)$ and the real process input $y(t)$ and $u(t)$ is the control input.

Since the esterification reaction is an exothermic process, the heat energy is released in the form of heat. A cooling system is required to bring the temperature back to a set point and also to ensure that the temperature does not rapidly increase, or runaway. The PID tuning parameters design for First-Order plus Time delay (FOPTD) process shown in Appendix A has resulted in a PID control law. This tuning was based on the relationship of the IMC and the PID controller which has been proposed by[5]. The final tuning of PID parameters is given in Table 1. Details of this work can be found in[6].

Table 1- Parameters for PID controller

Controller	K_p	T_i	T_d
PID	0.00016	13.17	0.328

Real-time responses of the PID controller system in tracking the constant set-point at 37 °C and disturbance rejection are shown in Fig. 3. As can be seen in Fig 5, the real-time response for PID controller drives the process output to desired set-point with slow response time and no overshoot. However there are some oscillatory responses in tracking the set-point. For disturbance rejection, the initial jacket temperature was considered as the process disturbance. A step change of the initial jacket temperature from 25 °C to 27 °C was implemented into the system. From the results, it was observed that the PID controller was able to reject the effect of disturbances with some oscillation responses. Thus it proves the feasibility of MATLAB-Simulink Real-Time-Windows Target algorithm implementation in controlling the batch esterification reactor.
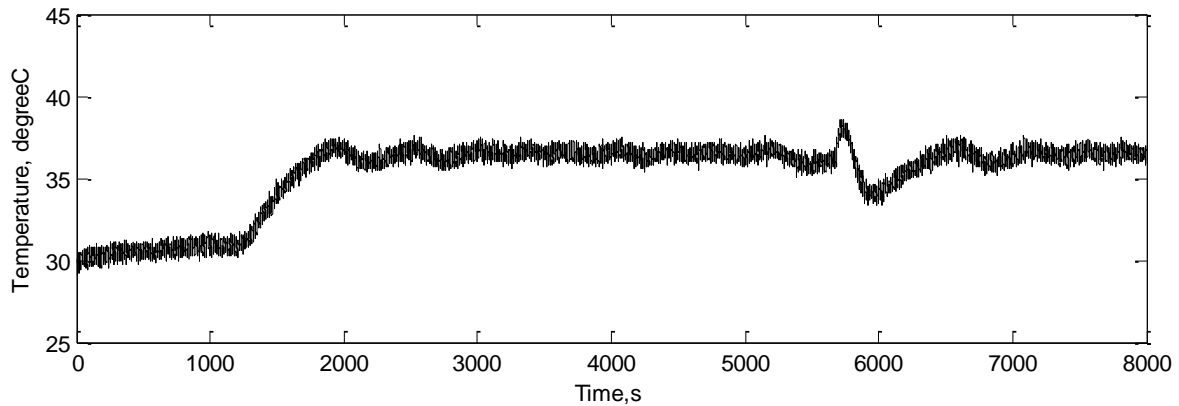
Fig. 3: Reactor temperature response of real-time PID controller for set point tracking and load change.

4. CONCLUSIONS

In this work an interactive and effective tool to design control loops in real-time for batch esterification reactor using MATLAB-Simulink Real-Time-Windows Target has been presented. The relevance of real-time implementation has been exposed by implementing the PID controller in controlling the temperature of batch esterification reactor. The results from this work show that the proposed embedded design architecture based on Matlab is capable of delivering the desired outcome.

5. ACKNOWLEDGMENT

6. REFERENCES

1. Enikov, E.T. (2012). Mechatronic Aeropendulum: Demonstration of Linear and Nonlinear Feedback Control Principles with MATLAB/Simulink Real-Time Windows Target, *IEEE Transactions on Education*, 55(4), 538-545.
2. Hernandez, A., Chavarro, A and Keyser, R.D. (2011). A Matlab® Approach for Implementing Control Algorithms in Real-Time: RTWT, *Engineering Education and Research Using MATLAB* (pp. 55-70). InTech, Available from: http://www.intechopen.com/books/engineering-education-and-research-using-matlab/a-matlab-approach-for-implementing-control-algorithms-in-real-time-rtwt
3. Zulkeflee, S.A. and Aziz, N. (2010) Model Identification for Batch Esterification to Produce Citronellyl Laurate. *The IASTED International Conference on Modeling, identification and Control (AsiaMIC 2010)*. Phuket, Thailand. Nov 24-26

4. "Real-Time Windows Target User's Guide", The MathWorks Inc. Available from: http://www.mathworks.com/products/rtwt/,1999

5. Rivera, D.E., Morari, M. and Skogestad, S. Internal model control: PID controller design. *Industrial & Engineering Chemistry Process Design and Development*, **25** (1), 252-265, 1986.

6. Zulkeflee, S.A. and Aziz, N (2010) Online implementation of IMC based PID controller for Batch Esterification Reactor. The 5th International Symposium on Design, Operation and Control of Chemical Processes (PSE Asia 2010). Singapore. July 25-28.

Appendix

In this work, the process model is considered as FOPTD:

$$g = \frac{K}{1 + Ts} e^{-\theta s} \tag{A.1}$$

where K= 15540; Ts=11.1 and θ = 6.573

Use a first-order Padé approximation for deadtime

$$e^{-Ls} \approx \frac{-0.5\theta s + 1}{0.5\theta s + 1} \tag{A.2}$$

$$\breve{g} = \frac{K(-0.5\theta s + 1)}{1 + Ts(0.5\theta s + 1)} \tag{A.3}$$

Factor out the non-invertible elements, where $\breve{g}_-$ is transfer function of minimum phase part and $\breve{g}_+$ is non-minimum phase part containing time delay.

$$\breve{g}_- = \frac{K}{1 + Ts(0.5\theta s + 1)} \tag{A.4}$$

$$\breve{g}_+ = -0.5\theta s + 1 \tag{A.5}$$

Form the idealized controller

$$g_c = \frac{1 + Ts(0.5\theta s + 1)}{K} \tag{A.6}$$

The filter is added to make the numerator of g_c to be one order higher than the denominator.

$$g_c^* = \frac{1 + Ts(0.5\theta s + 1)}{K} \frac{1}{\lambda s + 1} \tag{A.7}$$

Now, find the PID equivalent. Recall that

$$g_c = \frac{g_c^*}{1 - \breve{g}g_c^*} \tag{A.8}$$

$$g_c = \left(\frac{1}{K}\right) \frac{1 + T(0.5\theta s + 1)}{(\lambda + 0.5\theta)s} \tag{A.9}$$

We can expand the numerator term to find

$$g_c = \left(\frac{1}{K}\right) \frac{0.5T\theta s^2 + (T + 0.5\theta)s + 1}{(\lambda + 0.5\theta)s} \tag{A.10}$$

We can multiply Eq. A.10 by $(T + 0.5\theta/T + 0.5\theta)$ to find the PID parameters as shown in Table 1.