Model Predictive Control with Single Heat Transfer Fluid for Batch Reactor Temperature Control

Yoshikazu Noguchi & Masanori Kobari

1 JGC Corporation (Nikki K. K.), Information Technology Department

2-3-1, Minato Mirai, Nishi-ku, yokohama, 220-6001, Japan

noguchi.yoshikazu@jgc.co.jp, kobari.masanori@jgc.co.jp

Abstract: JGC proposes a practical solution to the temperature control issues for batch process reactors by combining model predictive controller and silicone oil based single heat transfer fluid. By combination of model predictive controller and Single Silicone oil based heating / cooling media, it is possible to realize the good temperature control performance for wide temperature range, i.e. minus 50degC to 150degC. By using the new controller design environment with A&D's controller, it is possible to reduce the installation time of the designed controller on the MATLAB / Simulink to the target machine (A&D's controller) dramatically, less than 1/3.

Keywords: Model predictive control, Batch Reactor, Single Heat Transfer Fluid

1. Introduction

In the batch process, temperature control performance of the fluid inside the batch reactor using heating or cooling media is the most important factor to determine the product quality or to minimize the by-product generation.

Recently, one common batch reactor is used to produce wider range of product recipes or wider range of operation ranges. In order to obtain good quality of the product or to minimize the by-product generation, the temperature control loop performance shall not be degraded during batch operation even if the product recipe or operation condition is changed.

Generally speaking, the volume, physical properties, such as density and specific heat, of the fluid inside the batch reactor are changed during the batch process or time and process dynamics such as process gain or time constant are changed. Therefore, a PID controller with a set of tuning parameter doesn't show good control performance over the wide operating condition during batch operation.

Model Predictive Control (MPC) has been widely used especially in Oil Refining & Petrochemical industry over the past 20 years and its superior controllability compared with the performance of the conventional PID controller has already been recognized by the MPC users. However, there are a few reports for the MPC applications for batch process. This is because the conventional MPC with a set of tuning parameter doesn't also show good control performance over the wide operating condition during batch operation.

In addition to these conventional controllers, to use a batch reactor to produce wide variety of products, we have to use several conventional heating or cooling media by switching the media during the batch for wide temperature range, such as minus 50degC to 150degC. During the media switching, it is not possible to keep the temperature controller mode as AUTO, because we have to empty the jackets or coil of the reactor during media switching.

JGC propose the practical solution to these temperature control issues for batch reactors called "Flexthermo" , i.e., combination of model predictive controller for batch reactors and silicone oil based single heat transfer fluid.

2. Flexthermo

Flexthermo uses a Single Transfer Fluid, Silicone Oil. By using a Single transfer fluid, we can keep the control mode of the temperature controller in AUTO for all temperature range as shown in Fig.1 and we can simplify the piping configuration dramatically as shown in Fig. 2.

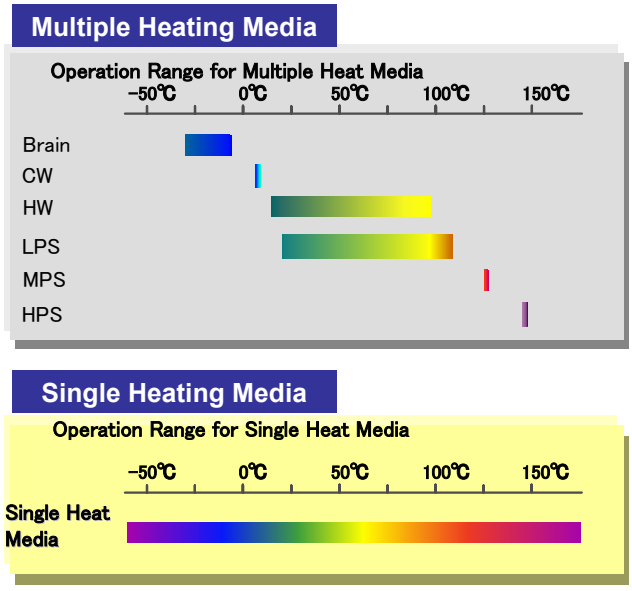


Fig. 1. Operation Range for Heating Media

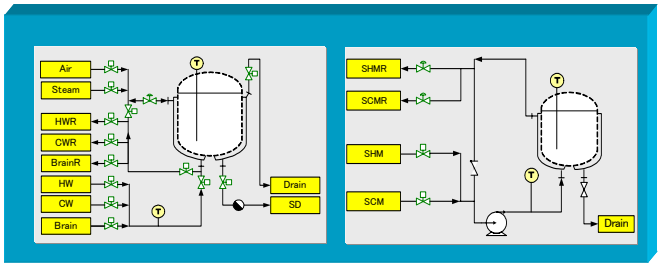


Fig. 2. Comparison of Multiple & Single Heat/ Cool Media

There are following advantage to apply the Single Heat/Cooling media against the multiple media:

(1) It is possible to expect higher productivity and higher quality control performance, because it is possible keep control mode of the temperature controller in AUTO for all temperature range as shown in Fig.1.

(2) It is possible to reduce mis-operation of the valves, because the piping configuration will be significantly simplified as shown in Fig.2.

(3) It is possible to avoid the mixture or loss of the different media.

(4) It is possible to avoid leak of heating media to the sewer, because it is not necessary to switch the media.

(5) It is possible to reduce the piping corrosion.

JGC can currently provide the two types of heating and cooling media, JS120 & JS60. JS120 can be used between minus 100degC and 200degC. JS60 can be used between minus 50degC and 200degC. Food grade level safety is certified.

3. Model Predictive Controller

JGC introduced a model predictive controller license for batch reactor (PCR) from Sherpa Engineering. PCR is an internal model based controller which is designed for batch reactor temperature control. PCR model parameters, such as process gain & time constant can be easily scheduled based on the rigorous physical model parameters such as liquid level, specific heat, liquid density and heat transfer coefficient. By this scheduling, PCR can keep good temperature control performance for batch process with wide temperature operation range. Fig.3 shows a typical batch reactor temperature control example. Fig.4 shows the typical trend graph using PID controllers and Fig.5 shows the typical trend graph using PCR controllers.

As you can see from these figures, PCR can reduce the standard deviation of temperature inside the reactor (RIT) and usage of heating or cooling duty and improve temperature control performance.

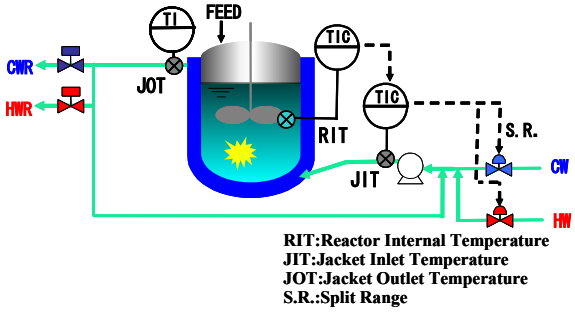


Fig. 3. Temperature Control Loop (PID)

JGC recently installed Flexthermo system to the batch reactors for Japanese Pharmaceutical plant and it was successfully commissioned. Refer to Fig. 6 for the dynamic simulation results of temperature control comparison for crystallization process between PID and PCR.

As you can see from these figures, PCR can reduce the standard deviation of RIT and reduce the usage of heating and cooling media.

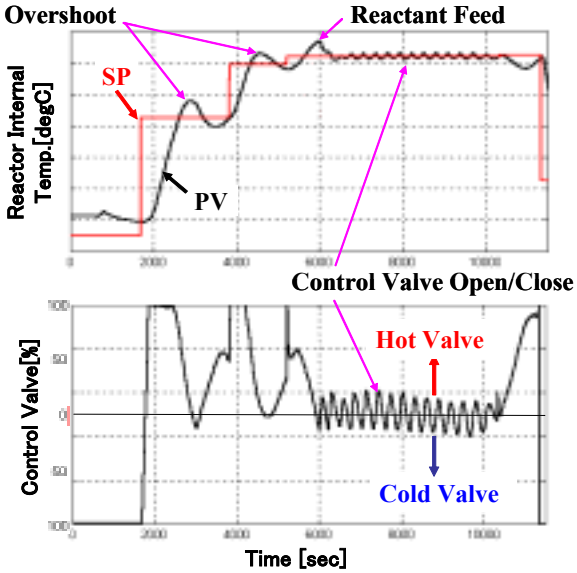


Fig.4. Trend Graph (PID)

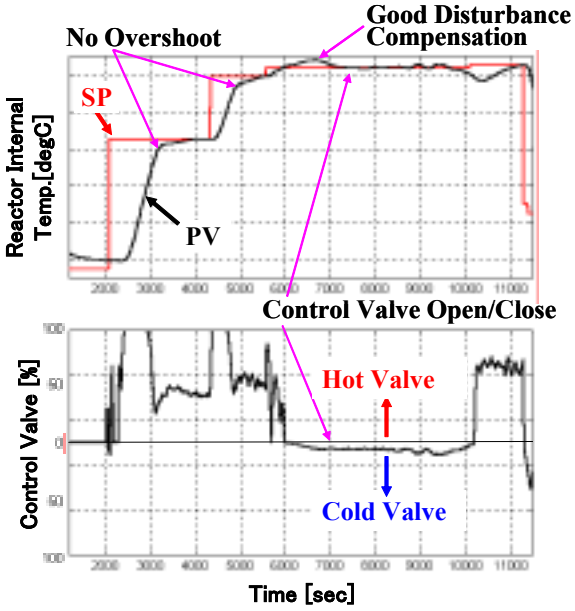
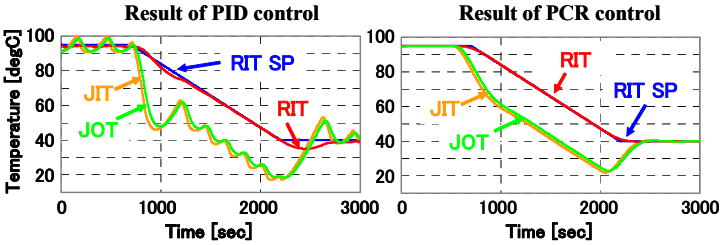


Fig.5. Trend Graph (MPC)



Consumption ratio of heat and cool source :
PID_heat / PCR_heat = 5.9 [-]
PID_cool / PCR_cool = 8.1 [-]

Standard deviation from RIT SP :
PID : 1.5 [degC]
PCR : 0.4 [degC]

Maximum deviation from RIT SP :
PID : 4.9 [degC]
PCR : 2.1 [degC]

Fig.6. Temperature Control for Crystallization (PID vs PCR)

It is also known that most significant disturbance to the batch reactor temperature control is heat of reaction. By using the disturbance compensation module, it is possible to reduce the effect of heat of reactions as shown in the Fig.7. This disturbance compensation module estimates the degree of disturbance from the difference between actual reactor internal temperature and predicted temperature based on the internal model of PCR.

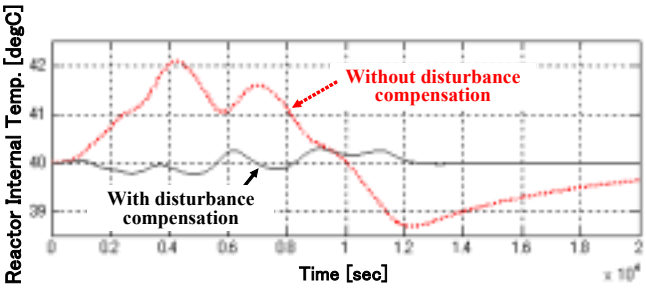


Fig.7. Disturbance Comparison of PCR

4. PCR Implementation

PCR is the simplified linear model based model predictive controller and the control calculation doesn't include any iteration calculation and the program is supplied by C. Therefore, it is possible to install the PCR in any computers which runs C, such as process computer, PC, DCS & PLC.

For the engineering environment for PCR, MATLAB / Simulink supplied by MathWoks is employed. PCR function blocks are defined as S-function of MATLAB / Simulink. By using the GUI of Simulink, it is quite easy to define the PCR controllers and batch process reactors and simulate the closed loop performance of PCR.

For actual PCR application for process plant, we selected PLC as a platform of PCR as shown in Fig.8. This is because, it is reliable than PC and reasonable cost than DCS.

Fig. 9 shows the typical PCR implementation steps for PLC.

From "Model Identification" to "Closed Loop Simulation", we can execute these steps efficiently by using GUI of Simulink on a PC. However, through the PCR implementation project, we have learned that it takes quite long time to install and debug the controller on a PLC compared with the time for controller design itself on a PC.

This is because, it is not able to export and install the designed PCR controller from PC to PLC easily. To install the designed controller into PLC, we have to use PLC engineering environment and it sometimes not easy to use. It requires a lot of efforts to develop the application, debug and maintain the application in PLC especially memory handling. This is because we have to handle the data via memory address but not tag and use several languages such as C and ladder. The PLC's engineering environments are different from modules of PLC and we may have to use several PLC modules for actual PCR applications.

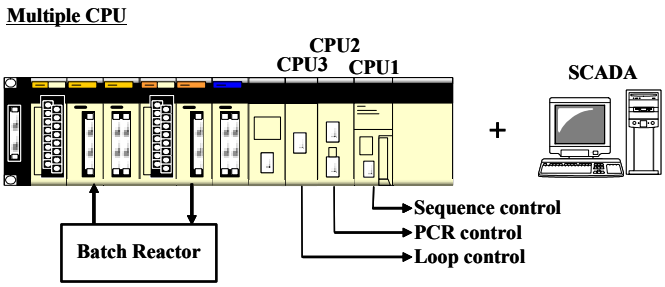


Fig.8. Conventional PCR Platform: PLC

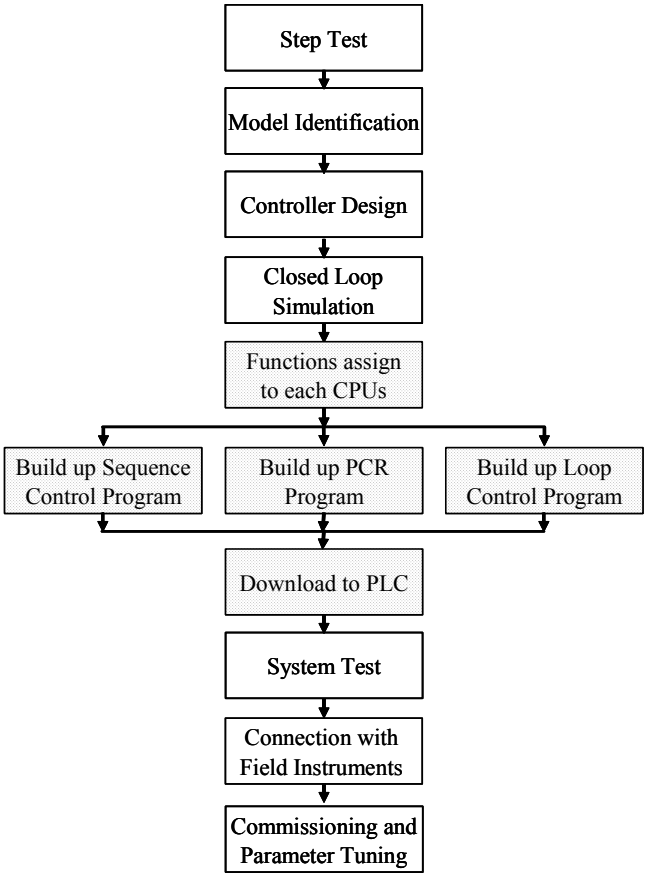


Fig.9. Typical PCR Implementation Steps to PLC

JGC has started developing PCR engineering environment with A&D so that we can export and install MATLAB / Simulink model easily and efficiently from PC to Target controller, i.e. A&D's controller(AD-4820).

After the completion of the development, your designed controller in MATLAB / Simulink, such as modified PID, fuzzy controller or rigorous model based controller will be able to install AD-4820 via much simpler steps.

You don't have to bother with controller installation into PLC and you can concentrate on controller design using MATLAB / Simulink.

Fig.10 shows the single CPU based controller(AD-4820) supplied by A&D. Though it is still under development by JGC & A&D, after the completion of development, we can export and install MATLAB / Simulink model such as PCR controller or your designed controllers easily and efficiently from PC to AD-4820.

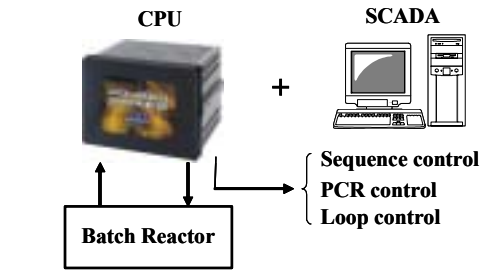


Fig. 10. PCR Platform: A&D controller

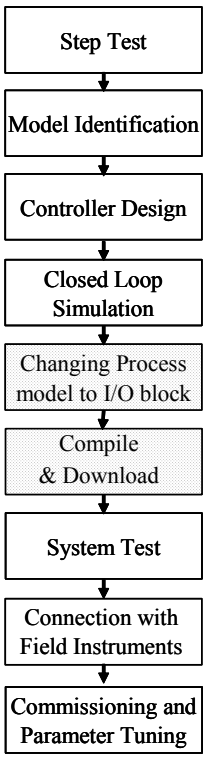


Fig.11. PCR Implementation Steps to A&D controller

After completion of closed loop simulation on Simulink, you should replace the process dynamic model by I/O blocks defined by S-function in Simulink dedicated for AD-4820 such as AI, AO, DI & DO blocks and press cross compile button on Simulink to compile the Simulink model automatically generate to the executables which will run on the AD-4820. By using this engineering environment with AD-4820, it is possible to reduce the designed controller to installation time dramatically, less than 1/3.

5. Conclusions

By combination of model predictive controller (PCR) and Single Silicone oil based heating / cooling media, it is possible to realize the good temperature control performance for wide temperature range, i.e. minus 50degC to 150degC.

By using the new controller design environment with A&D's controller (AD-4820), it is possible to reduce the installation time of the designed controller to the AD-4820 dramatically, less than 1/3.

References

[1] Jacque, Richalet, "Model Predictive controller goes to work in chemical plant", Control engineering Europe, pp 34-36, October 2000

[2] Eguchi, Noguchi, Kozaki & Ito, "Recent & future technical trend for batch process", Mechanical Material Manufacturing & Electronics Equipment Engineering, pp 254-258, April 2003.

[3] Tsuneki Harada and Masanori Kobari, "Proposal on the Temperature Predictive Control System with Single Heat Transfer Fluid for Bulk Pharmaceutial Chemicals Facilities", PHARM TECH JAPAN, pp 61-67, Vol.21 No.5(2005)

Notes:

(1) "MATLAB" and "Simulink" are the software package distributed by Mathworks.

(2) "PCR" is the model predictive controller software developed by ADERSA and supplied by Sherpa Engineering.

(3) "JS60" and "JS120" are the Silicone Oil based heating & cooling media supplied by JGC.

(4) "Flexthermo" is the name of the batch reactor system combined with model predictive controller based temperature controller with Silicone Oil based heating & cooling media supplied by JGC.