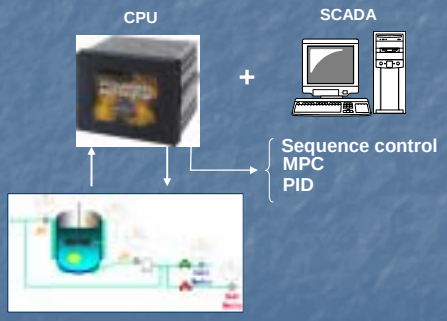
Model Predictive Control with Single Heat Transfer Fluid for Batch Reactor Temperature Control



Session MA2-17

[OS28]: Activities of SICE Instrument and Control Engineers

JGC Corporation
Y.Noguchi

Are you really satisfied with your controller Performance & its design environment?

Temperature controller performance:

- ➔ **Most Dominant factor to determine Product quality!!**
- ➔ **We need a High performance Temp controller which runs on a reliable platform such as PLC.**

However,
It is not easy to have a good controllability for:

- wide temperature range, e.g., - 50 to +150 Deg.C
- wide variety of products

It is not easy to design & Implement controller to PLC?

Are you really satisfied with your controller Performance & its design environment?

Why is it not easy to have a good co

- wide temperature range, e.g., - 50 to +150 Deg.C
- wide variety of products

JGC Solution

Single Heat Media

This is because, Process Dynamics is changed by:

- Temperature range (No Control during Heat Media Change)
- Time
- Products

$$Time\ Const = \frac{\rho_m Cp_m V_m}{UA}$$

(Physical property & volume of the fluid inside the reactor change ➔ Process Dynamics change.)

MPC

Why is it not easy to design & Implement control

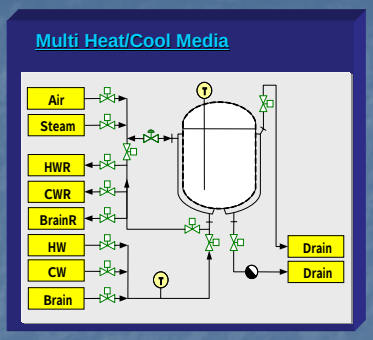
Reliable Controller

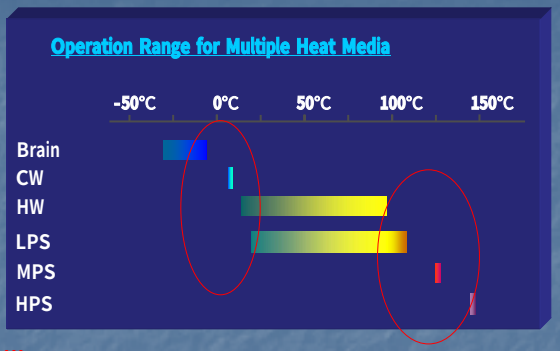
- There is no user friendly controller design & implementation tool.

User Friendly Design Environment

Multiple Heat Transfer Media vs Single Heat Transfer Media

Typical Batch Reactor Configuration





Bad Temp. Controllability!

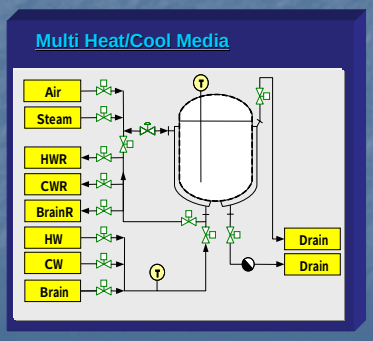
Why?: No temperature control during heating & cooling media change.

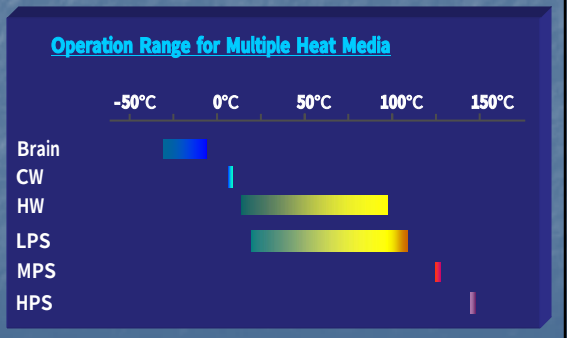
It is almost impossible to realize a good temperature controllability for batch reactor for wide temperature range during heating & cooling media change!!

Issues for Multiple Heat transfer Media

Other Issues:

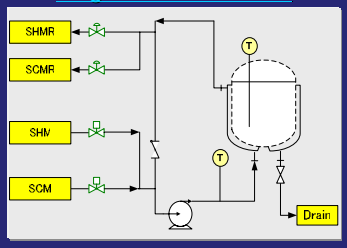
1. Mix or loss of multiple heating and cooling media
2. Leak of multiple media to sewer (Environmental issue)
3. High probability of mis-operation cased by many valves





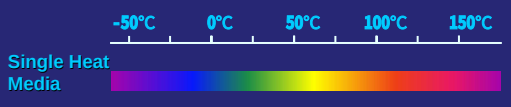
Single Heat Transfer Media System

Single Heat/Cool Media



Silicon Oil based
Heat Transfer Media

Operation Range for Single Heat Media



Good Temp. Controllability!

Why?:

No heat transfer media change is required!

We can keep temperature controller mode in AUTO during batch operation continuously!

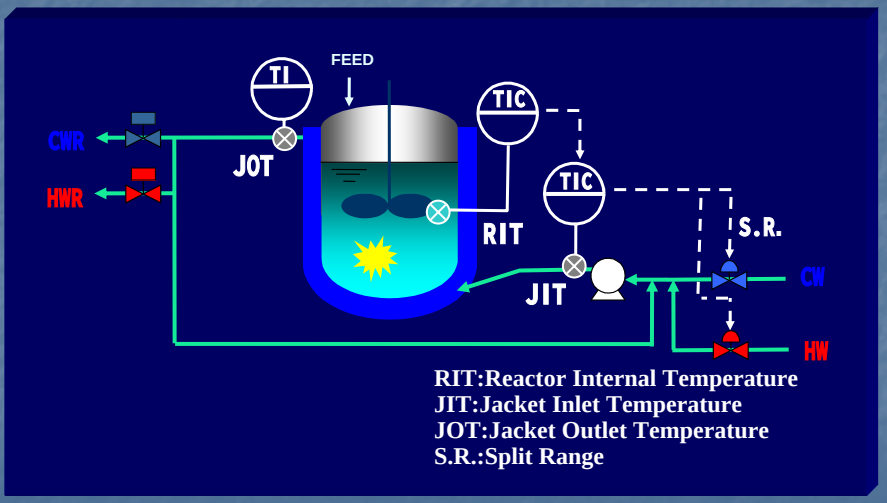
Other Advantages:

1. No Mix or loss of heating and cooling media
2. Less Leak of multiple media to sewer (Environmental Friendly)
3. Low probability of mis-operation by simple piping layout

PID Controller
vs
Model Predictive Controller (PCR)

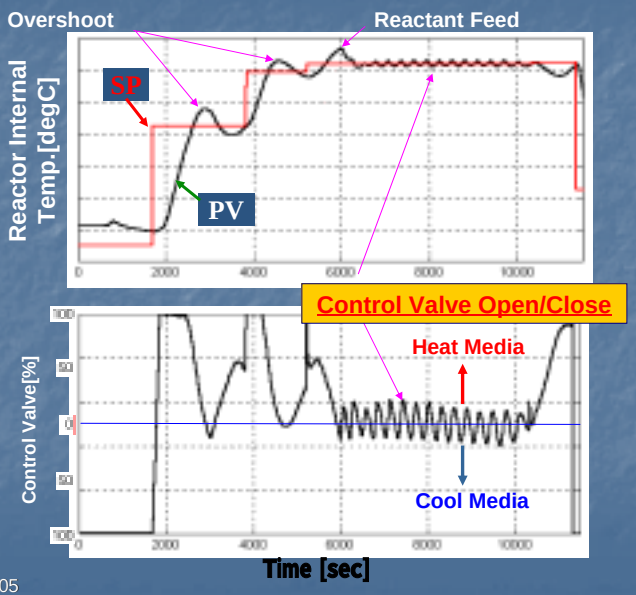
JGC's solution: FlexThermo:
MPC + Single Heat Transfer Media

Typical Temperature Control Loop with PID controllers

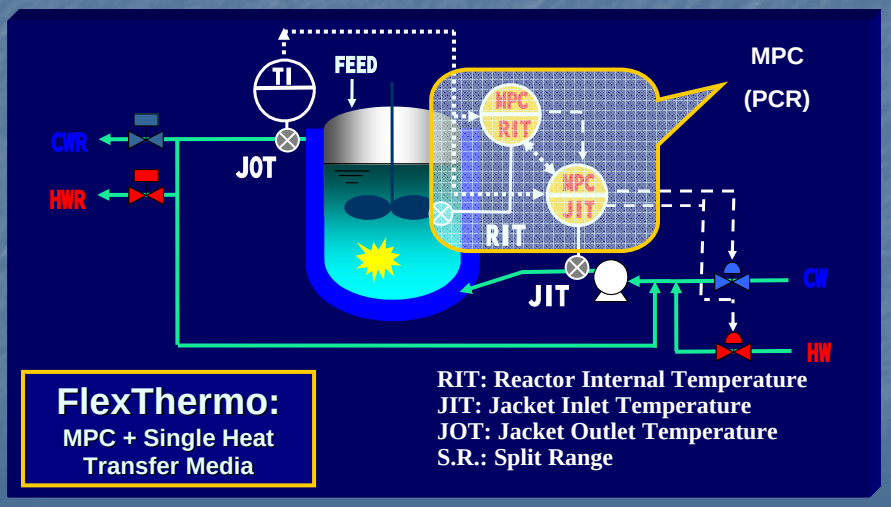


RIT:Reactor Internal Temperature
JIT:Jacket Inlet Temperature
JOT:Jacket Outlet Temperature
S.R.:Split Range

Trend Graph (PID)



Typical Temperature Control Loop with MPC



FlexThermo:
MPC + Single Heat Transfer Media

RIT: Reactor Internal Temperature
JIT: Jacket Inlet Temperature
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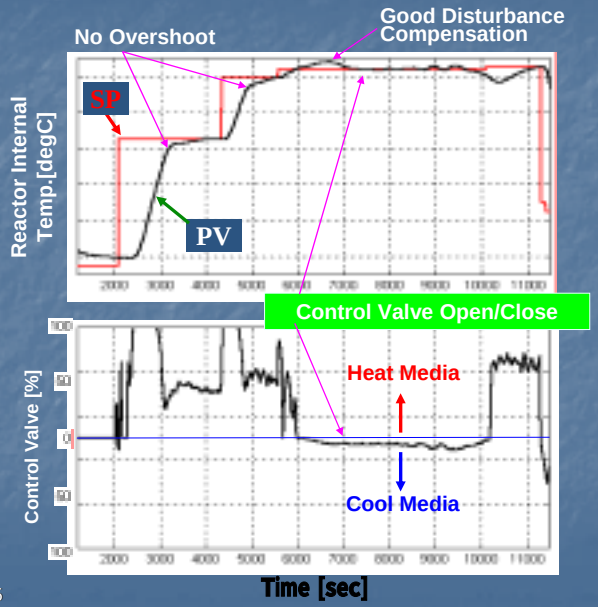
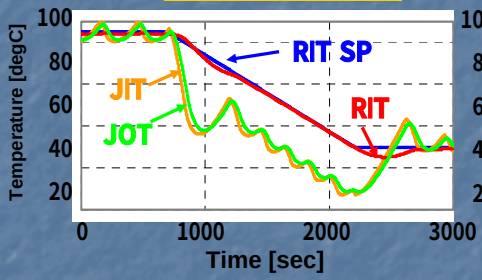
S.R.: Split Range

Trend Graph (MPC)

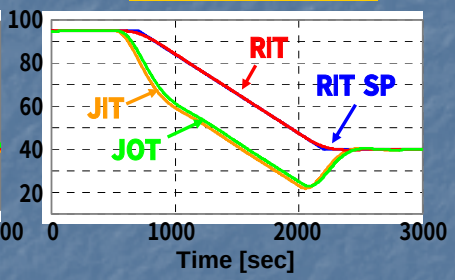


Temperature Control for Crystallization (PID vs MPC)

Result of PID control



Result of PCR control



Consumption ratio of hot and cold utility :

PID_hot / PCR_hot = 5.9 [-]

PID_cold / PCR_cold = 8.1 [-]

Standard Deviation :

PID: 1.5 [degC]

PCR: 0.4 [degC]

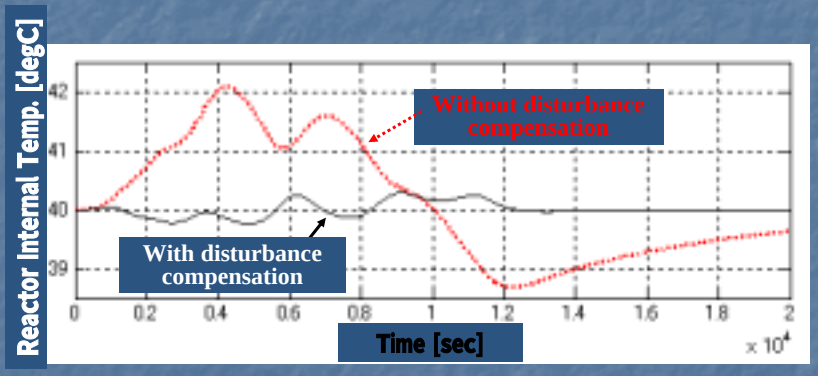
Maximum deviation from RIT SP :

PID: 4.9 [degC]

PCR: 2.1 [degC]

83 – 88% Reduction of Utility Consumption with excellent controllability by MPC.

Result of the simulation with disturbance compensation



Why does MPC shows good controllability?

Why PID shows bad controllability?

This is caused by Process Dynamics change.

- Temperature range (No Control during Heat Media Change)
- Time
- Products

(Physical property & volume of the fluid inside the reactor change ➔ Process Dynamics change.)

MPC (PCR introduced from Sherpa Engineering) shows good Controllability:

MPC Internal model parameter such as Time constant, Process gain can be updated based on:

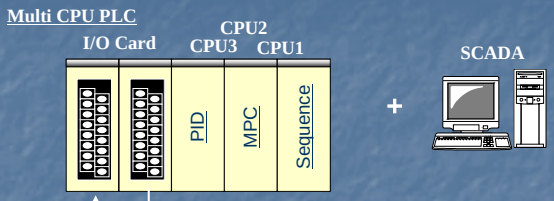
- Temperature range (No Control during Heat Media Change)
- Time
- Products

$$\text{MPC Internal Model Parameter Scheduling: } Time\,Const = \frac{\rho_m Cp_m V_m}{UA}$$

Multiple CPU Type Controller (PLC)
vs
Single CPU Type Controller

AD4820

Multiple CPU type Controller (PLC) Advantage & Disadvantage



Batch Reactor

Advantage of Multi-CPU PLC:

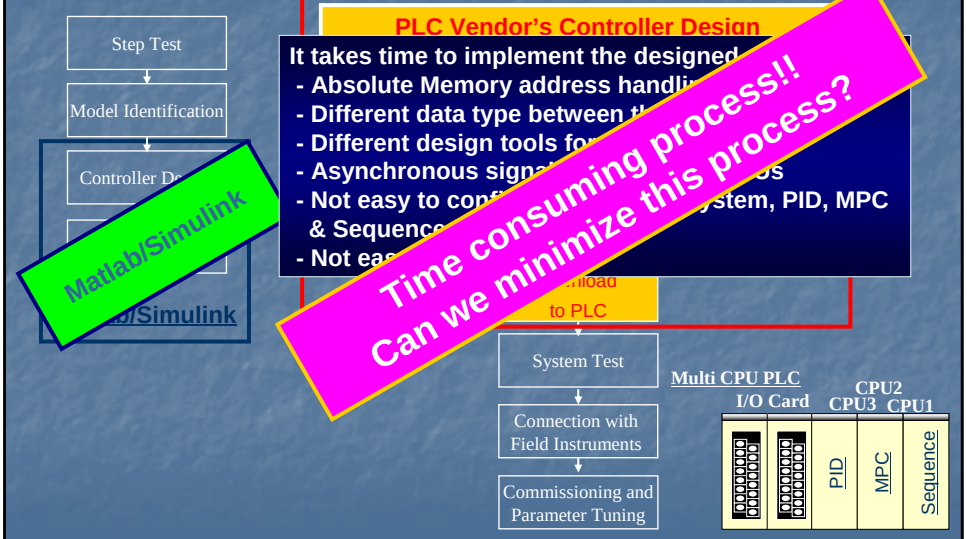
- Easy to expand the system capacity by adding required modules
- We can add required modules only.

Disadvantage of Multi-CPU PLC:

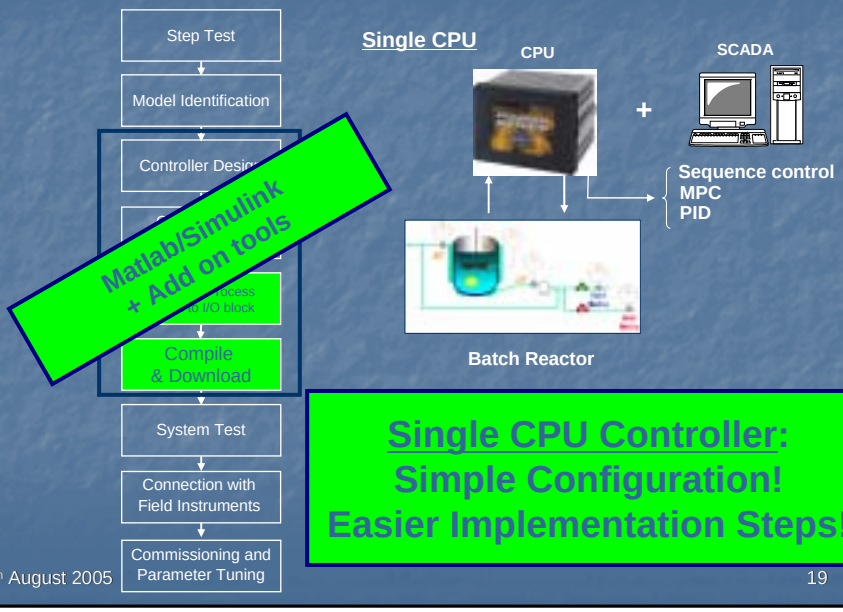
It takes time to implement the designed controller.

- Absolute Memory address handling
- Different data type between the CPUs
- Different design tools for each CPU
- Asynchronous signals between the CPU
- Not easy to configure integrated system, PID, MPC & Sequence controller
- Not easy to debug integrated system

Typical Implementation Steps to PLC

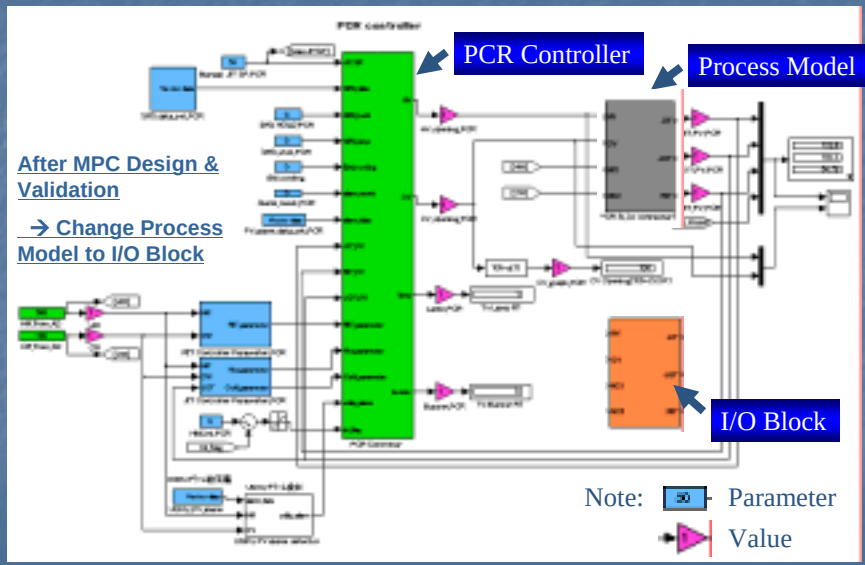


Implementation Steps to Single CPU Controller



Single CPU Controller:
Simple Configuration!
Easier Implementation Steps!

MPC Design by Matlab/Simulink



After MPC Design & Validation

→ Change Process Model to I/O Block

MPC Design by Matlab/Simulink

Controller Design

Simulation

Process Model

→ I/O Block

C Code Generation

RTW, State Flow coder

Cross Compile

Down Load to AD4820

Simulink + Add on

Control engineer can concentrate on controller design by using Matlab/Simulink design environment not only design and simulation but also for controller implementation on target computer, i.e., AD4820!

JGC & A&D's solution for Batch Process Control

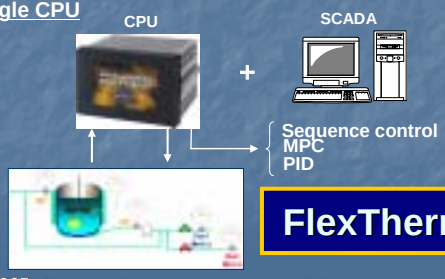
Solution:

Combination of:

1. **Silicone Oil Based Single Heat Transfer Media**
2. **MPC (PCR introduced from Sherpa Engineering)**
3. **Reliable A&D's Controller (ADX) with User friendly Simulink based Design Environment**

Designer can concentrate on Controller design!

Single CPU



FlexThermo **AD4820**

Demonstration System Configuration

PC

SCADA (iFIX)

IP:172.16.202.10

AD4820-1

PCR & PID controller

IP:172.16.202.12

AD4820-2

Process Model (Batch Reactor)

IP:172.16.202.13

Sequence control
PCR control
Loop control

Ethernet HUB

Any Questions?

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Email: noguchi.yoshikazu@jgc.co.jp

PCR ?

バッチリアクター温度制御向けに開発されたモデル予測制御パッケージ

- 開発元/販売元：Sherpa Engineering (France)
- 制御対象：バッチ反応器、熱交換器の温度制御
- プラットフォーム：PLC・DCS・PC・プロコン等
- 制御アルゴリズム：モデル予測制御
- モデル：一次遅れ+無駄時間モデル

PCRの特徴(1)内部モデル

- 内部モデル：1次遅れ＋無駄時間モデル

$$Gp(s) = K\frac{e^{-Ds}}{1+Ts}$$

K:ゲイン[-]
T:時定数[sec]
D:無駄時間[sec]

- 制御アルゴリズムに収束計算がなく、C言語で記述
  - ➔PLC,PC,DCS,プロコンで動作可能
- 物理的なパラメータと内部モデルとの関連付けが容易
  - ➔レシピに応じた内部モデルのパラメータ設定

$$T = \frac{\rho_m Cp_m V_m}{UA}$$

ρm:密度[kg/m3]
Cpm:定圧比熱 [J/kg/℃]
Vm:反応器内容積[m3]
U:総括熱伝達係数[J/sec/m2/℃]
A:伝熱面積[m2]