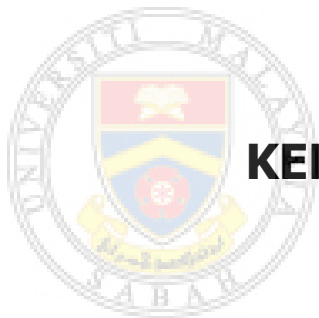


**ADAPTABLE ALGORITHMS FOR  
PERFORMANCE OPTIMIZATION OF  
DYNAMIC BATCH MANUFACTURING  
PROCESSES**



**KENNETH TEO TZE KIN**

**UMS**  
UNIVERSITI MALAYSIA SABAH

**FACULTY OF ENGINEERING  
UNIVERSITI MALAYSIA SABAH  
2018**

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**KENNETH TEO TZE KIN**



**UMS**

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DOCTOR OF PHILOSOPHY**

**FACULTY OF ENGINEERING  
UNIVERSITI MALAYSIA SABAH  
2018**

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## DECLARATION

I hereby declare that the material in this thesis is my own except for quotations, equations, summaries and references, which have been duly acknowledged.

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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PERFORMANCE OPTIMIZATION OF DYNAMIC BATCH  
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DEGREE : **DOCTOR OF PHILOSOPHY  
(ELECTRICAL AND ELECTRONIC ENGINEERING)**

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### **SUPERVISOR**

Prof. Dr. Yeo Kiam Beng @ Abdul Noor

---

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30 August 2017

Kenneth Teo Tze Kin

## ABSTRACT

This study aims to explore the potential of implementing a multi-objective dynamic optimizer to acquire regular optimization on nonlinear characteristic of batch manufacturing process. The idea is proposed in an effort of accessing the functionality and practicability of the dynamic optimizer for the purpose of precision optimization. As such, yield productivity of maximizing the desired product while minimizing the undesired by-product could be improved. Traditionally, a fixed temperature profile has been identified and assumed as 'nominal optimized' for manufacturers to follow. Whether the process is fully optimized under inconsistent internal heat liberation, external environmental variations, model mismatches and process uncertainties remains as a challenging topic. In practice, the commercial batch process plant are often utilized to handle numerous production with different varieties of specific products and thus it is rarely being classified as dynamically optimized. This thesis investigates different approaches of integrating hybrid adaptable intelligent algorithms to accommodate the concept of precision optimization via simulated models of industry-scale and pilot-scale. The dynamic changes causing the need of dynamic modelling for a better dynamic optimization will be catered via a specifically formulated fitness function. With nowadays high end computation ability, revolutionary changes of implementing precision measurement is expectable and applicable to obtain expensive products. Central to precision manufacturing is artificial intelligence as this thesis presents the performance characteristics of tuning-based, rule-based, learning-based and evolutionary-based algorithms. Performance analyses are presented to validate how significant of the dynamic optimization based on the product molarity surpasses the existing conventional prescribed temperature approach. Various algorithms are designed, formulated and computed in MATLAB and then embedded to a real-time programmable microcontroller. The results indicate that the proposed algorithm is able to improve the percentage of yield by at least 10-15% under physical properties variation which could be a vital tool in the future era of precision manufacturing industries.

## **ABSTRAK**

### **ALGORITMA KECERDASAN ADAPTIF UNTUK OPTIMASI PRESTASI BAGI DYNAMIK PROSES PEMBUATAN BERKELOMPOK**

*Kajian ini bertujuan untuk meneroka potensi pelaksanaan pengoptimuman dinamik pelbagai objektif untuk memperolehi pengoptimuman kerap ke atas ciri-ciri proses tidak linear dalam pembuatan kimia secara kelompok. Idea ini dicadangkan sebagai usaha mengakses kebolegunaan pengoptimuman dinamik bagi tujuan pengoptimuman tepat. Dengan itu, kecekapan untuk memperolehi maksimum hasil produk diinginkan dengan minimum produk sampingan tidak diinginkan boleh ditambahbaik. Secara tradisinya, profil suhu sasaran telah dikenalpasti dan diambil sebagai pendekatan 'pengoptimuman nominal' untuk dipatuhi. Samada proses dioptimumkan sepenuhnya di bawah pembebasan tenaga haba tidak konsisten, perubahan persekitaran luaran, ketidakpadanan model dan ketidaktentuan proses kekal sebagai satu topik yang mencabar. Dalam praktikal, loji proses kelompok komersial sering digunakan untuk mengendalikan pelbagai jenis produk di mana ia jarang diklasifikasikan sebagai proses dinamik yang telah dioptimumkan. Tesis ini mengkaji pendekatan yang berbeza mengintegrasikan hibrid algoritma pintar penyesuaian diri untuk menampung konsep pengoptimuman ketepatan melalui simulasi model bagi reaktor kelompok pelbagai skala. Perubahan dinamik memerlukan pemodelan dinamik untuk pengoptimuman dinamik lebih baik boleh diperolehi melalui rumusan fungsi kecerdasan secara khusus. Dengan keupayaan pemrosesan yang cekap pada masa kini, revolusi untuk pengukuran tepat dapat dijangka dan digunakan bagi penghasilan produk mahal. Keutamaan dalam pengeluaran tepat adalah kecerdasan buatan di mana tesis ini menyiasat ciri-ciri prestasi penentuan, peraturan asas, pembelajaran dan evolusi algoritma. Analisis prestasi dibentangkan bagi pengesahan kepentingan pengoptimuman dinamik berdasarkan kepekatan produk melebihi cara konvensional mematuhi profil tetap. Algoritma direka, dirumus dan dikira melalui MATLAB serta terbenam pada pengawal dalam talian secara praktikal. Keputusan menunjukkan algoritma yang dicadang mampu meningkatkan peratusan hasil 10-15% melalui variasi fizikal akan menjadi alat penting bagi industri pembuatan ketepatan dalam era masa depan.*



# TABLE OF CONTENTS

	Page
<b>TITLE</b>	i
<b>DECLARATION</b>	ii
<b>CERTIFICATION</b>	iii
<b>ACKNOWLEDGEMENT</b>	iv
<b>ABSTRACT</b>	v
<b><i>ABSTRAK</i></b>	vi
<b>TABLE OF CONTENTS</b>	vii
<b>LIST OF TABLES</b>	xii
<b>LIST OF FIGURES</b>	xiv
<b>LIST OF ABBREVIATIONS</b>	xix
<b>LIST OF NOMENCLATURES</b>	xx
<b>GLOSSARY</b>	xxv

	Page
<b>CHAPTER 1: INTRODUCTION</b>	<b>1</b>
1.1 Research Background	2
1.2 Control Strategy in Batch Process Optimization	3
1.2.1 Background of Batch Reactor Process	3
1.2.2 Background of Computer Control	5
1.3 Research Motivation	7
1.3.1 Problem Statement	8
1.3.2 Challenges	9
1.4 Research Aim	10
1.4.1 Objectives	10
1.4.2 Scope of Work	12
1.5 Thesis Outline	12
<b>CHAPTER 2: REVIEW OF BATCH PROCESS OPTIMIZATION</b>	<b>15</b>
2.1 Process Optimization	16
2.2 Review of Process Plant	18
2.2.1 Thermal Process System	20
2.2.2 Plant Disaster Incident	21
2.3 Review of Conventional Control	23
2.3.1 Tuning-Based Algorithm	23
2.3.2 Rule-Based Algorithm	26
2.3.3 Model-Based Algorithm	28
2.4 Review of Computational Intelligence	33
2.4.1 Learning-Based Algorithm	34
2.4.2 Evolutionary-Based Algorithm	38
2.4.3 Hybrid of Computational Algorithm	42
2.5 Summary for Process Optimization	45

	Page
<b>CHAPTER 3: METHODOLOGY OF BATCH PROCESS OPTIMIZATION</b>	48
3.1 Research Framework	49
3.2 Benchmark of Batch Process Plant Model	55
3.2.1 Industry-Scale Plant	59
3.2.2 Pilot-Scale Plant	60
3.3 Dynamic Modelling with Dynamic Programming	62
3.3.1 Modelling Algorithm	67
3.3.2 Extracted Dynamic Model	70
3.4 Dynamic Optimizing with Evolutionary Computing	71
3.4.1 Optimizing Algorithm	75
3.4.2 Dynamic Fitness Function	81
3.5 Summary for Research Framework	83
<b>CHAPTER 4: MODELLING OF BATCH REACTOR PLANT</b>	85
4.1 Plant Modelling	86
4.2 Mathematical Modelling of Process Plant	88
4.2.1 Industry-Scale Model	95
4.2.2 Pilot-Scale Model	98
4.3 Dynamical Modelling of Simulated Plant	101
4.3.1 Parameter Variation	103
4.3.2 Modelling Error	106
4.4 Control Characteristic of Simulated Plant	108
4.4.1 Nominal Condition	111
4.4.2 Properties Variation	114
4.5 Summary for Plant Modelling	119

	Page
<b>CHAPTER 5: COMPUTATION OF ADAPTABLE ALGORITHMS</b>	121
5.1 Computational Algorithm	122
5.2 Non-Evolutionary Fixed-Profile Algorithm	124
5.2.1 Tuning-Based (FLPID <sub>TC</sub> )	125
5.2.2 Rule-Based (FL <sub>TC</sub> )	130
5.2.3 Non-Evolutionary Temperature Controller	135
5.3 Evolutionary Fixed-Profile Algorithm	138
5.3.1 Profile-Based Genetic Algorithm (GA <sub>TC</sub> )	139
5.3.2 Profile-Based Swarm Algorithm (SA <sub>TC</sub> )	144
5.3.3 Evolutionary Temperature Controller	149
5.4 Evolutionary Unfixed-Profile Algorithm	152
5.4.1 Molarity-Based Genetic Algorithm (GA <sub>MO</sub> )	153
5.4.2 Molarity-Based Swarm Algorithm (SA <sub>MO</sub> )	158
5.4.3 Evolutionary Molarity Optimizer	163
5.5 Summary for Computational Algorithm	166
<b>CHAPTER 6: ANALYSIS OF PERFORMANCE OPTIMIZATION</b>	168
6.1 Performance Analysis	169
6.2 Feasibility of Optimized Fixed-Profile	171
6.2.1 Multi-Stage Optimized Controller (EA <sub>OC</sub> )	172
6.2.2 Performance Evaluation in Multi-Stage	180
6.3 Functionality of Artificial Intelligent Optimizer	182
6.3.1 Multi-Mode Switchable Optimizer (EA <sub>TO-MO</sub> )	183
6.3.2 Performance Evaluation in Multi-Mode	191
6.4 Practicability of Artificial Intelligent Optimizer	193
6.4.1 Real-time Programmable Optimizer (EA <sub>OC-MO</sub> )	194
6.4.2 Performance Evaluation in Real-Time	202
6.5 Summary for Performance Analysis	204

	Page
<b>CHAPTER 7: CONCLUSION</b>	206
7.1 Summary	207
7.2 Research Finding	208
7.2.1 Utilizing Modelling in Optimization	209
7.2.2 Exploring Molarity as Fitness	209
7.3 Research Contribution	210
7.3.1 Evolutionary Optimized Controller	211
7.3.2 Evolutionary Switchable Optimizer	211
7.4 Recommendation	212
7.4.1 Future Research Development	213
7.4.2 Potential Industrial Application	213
7.5 Concluding Remarks	214



## LIST OF TABLES

	page
Table 2.1: Plant Review of Batch and Continuous Process	19
Table 2.2: Incident Review of Historical Industrial Disaster	22
Table 2.3: Algorithm Review of Conventional Tuning-Based Method	25
Table 2.4: Algorithm Review of Conventional Rule-Based Method	27
Table 2.5: Algorithm Review of Conventional Model-Based Method	31
Table 2.6: Algorithm Review of Computational Learning-Based Method	37
Table 2.7: Algorithm Review of Computational Evolutionary-Based Method	41
Table 2.8: Algorithm Review of Hybrid Computational Method	44
Table 2.9: Summary of Algorithm Review	47
Table 3.1: Processing Specification of Workstation Computation	53
Table 3.2: Processing Specification of Microcontroller Computation	54
Table 3.3: Terminology of Dynamic Programming	69
Table 3.4: Terminology of Evolutionary Algorithm	80
Table 3.5: Summary of Research Methodology	83
Table 4.1: Modelling Parameters of Industry-Scale Plant	96
Table 4.2: Modelling Parameters of Pilot-Scale Plant	99
Table 4.3: Pseudo-Code of Plant Modelling ( $DP_{ME}$ )	101
Table 4.4: Pseudo-Code of Temperature Controller ( $DM_{TC}$ )	108

Table 4.5:	Performance Measurement of Temperature Controller ( $DM_{TC}$ )	110
Table 4.6:	Summary of Plant Modelling	119
Table 5.1:	Pseudo-Code of Temperature Controller ( $FLPID_{TC}$ )	125
Table 5.2:	Pseudo-Code of Temperature Controller ( $FL_{TC}$ )	130
Table 5.3:	Performance Measurement of Temperature Controller ( $FLPID_{TC}$ )	135
Table 5.4:	Performance Measurement of Temperature Controller ( $FL_{TC}$ )	136
Table 5.5:	Simulation Parameters of Evolutionary Fixed-Profile Algorithm	138
Table 5.6:	Pseudo-Code of Temperature Controller ( $GA_{TC}$ )	139
Table 5.7:	Pseudo-Code of Temperature Controller ( $SA_{TC}$ )	144
Table 5.8:	Performance Measurement of Temperature Controller ( $GA_{TC}$ )	149
Table 5.9:	Performance Measurement of Temperature Controller ( $SA_{TC}$ )	150
Table 5.10:	Simulation Parameters of Evolutionary Unfixed-Profile Algorithm	152
Table 5.11:	Pseudo-Code of Molar Optimizer ( $GA_{MO}$ )	153
Table 5.12:	Pseudo-Code of Molar Optimizer ( $SA_{MO}$ )	158
Table 5.13:	Performance Measurement of Molarity Optimizer ( $GA_{MO}$ )	163
Table 5.14:	Performance Measurement of Molarity Optimizer ( $SA_{MO}$ )	164
Table 5.15:	Summary of Computational Algorithm	166
Table 6.1:	Performance Measurement of Multi-Stage Controller ( $EA_{OC}$ )	180
Table 6.2:	Performance Measurement of Multi-Mode Optimizer ( $EA_{TO-MO}$ )	191
Table 6.3:	Performance Measurement of Real-Time Optimizer ( $EA_{OC-MO}$ )	202
Table 6.4:	Summary of Performance Analysis	204

## LIST OF FIGURES

	page
Figure 2.1: Energy Release Curve of Exothermic Reaction	21
Figure 3.1: Flowchart of Research Methodology	50
Figure 3.2: Schematic Diagram of Batch Reactor	55
Figure 3.3: Schematic Diagram of Industry-Scale Batch Reactor	59
Figure 3.4: Picture of Pilot-Scale Batch Reactor	60
Figure 3.5: Schematic Diagram of Pilot-Scale Batch Reactor	61
Figure 3.6: Input-Output Model of Process System	63
Figure 3.7: Schematic Diagram of Dynamic Modelling in Batch Process	66
Figure 3.8: Flowchart of Dynamic Programming	68
Figure 3.9: Schematic Diagram of Dynamic Optimization in Batch Process	74
Figure 3.10: Flowchart of Genetic Algorithm	76
Figure 3.11: Flowchart of Swarm Algorithm	77
Figure 4.1: Benchmark Model of Batch Reactor	89
Figure 4.2: Reaction Curve of Industry-Scale (Plant 1)	97
Figure 4.3: Reaction Curve of Pilot-Scale (Plant 2)	100
Figure 4.4: Schematic Diagram of Model Estimator ( $DP_{ME}$ )	101
Figure 4.5: Variations of Physical Properties in Industry-Scale (Plant 1)	103



Figure 4.6: Variations of Reaction Properties in Industry-Scale (Plant 1)	104
Figure 4.7: Variations of Physical Properties in Pilot-Scale (Plant 2)	105
Figure 4.8: Variations of Reaction Properties in Pilot-Scale (Plant 2)	105
Figure 4.9: Comparison of Modelling Errors in Industry-Scale (Plant 1)	106
Figure 4.10: Comparison of Modelling Errors in Pilot-Scale (Plant 2)	107
Figure 4.11: Schematic Diagram of Temperature Controller ( $DM_{TC}$ )	108
Figure 4.12: Control Setting of Dual-Mode Temperature Controller	109
Figure 4.13: Performance Profile of $DM_{TC}$ in Plant 1 (Nominal Condition)	111
Figure 4.14: Performance Profile of $DM_{TC}$ in Plant 2 (Nominal Condition)	112
Figure 4.15: Performance Profile of $DM_{TC}$ in Plant 1 (Capacity Variation)	114
Figure 4.16: Performance Profile of $DM_{TC}$ in Plant 1 (Reaction Variation)	115
Figure 4.17: Performance Profile of $DM_{TC}$ in Plant 2 (Capacity Variation)	116
Figure 4.18: Performance Profile of $DM_{TC}$ in Plant 2 (Reaction Variation)	117
Figure 5.1: Schematic Diagram of Temperature Controller ( $FLPID_{TC}$ )	125
Figure 5.2: Performance Profile of $FLPID_{TC}$ in Plant 1 (Nominal Condition)	126
Figure 5.3: Performance Profile of $FLPID_{TC}$ in Plant 1 (Properties Variation)	127
Figure 5.4: Performance Profile of $FLPID_{TC}$ in Plant 2 (Nominal Condition)	128
Figure 5.5: Performance Profile of $FLPID_{TC}$ in Plant 2 (Properties Variation)	129
Figure 5.6: Schematic Diagram of Temperature Controller ( $FL_{TC}$ )	130
Figure 5.7: Performance Profile of $FL_{TC}$ in Plant 1 (Nominal Condition)	131

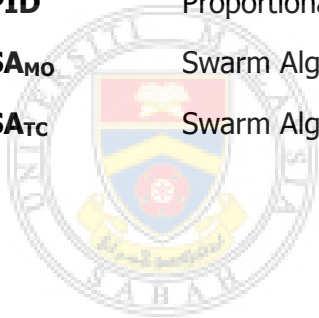
Figure 5.8: Performance Profile of $FL_{TC}$ in Plant 1 (Properties Variation)	132
Figure 5.9: Performance Profile of $FL_{TC}$ in Plant 2 (Nominal Condition)	133
Figure 5.10: Performance Profile of $FL_{TC}$ in Plant 2 (Properties Variation)	134
Figure 5.11: Performance Analysis of Non-Evolutionary Temperature Controller	137
Figure 5.12: Schematic Diagram of Temperature Controller ( $GA_{TC}$ )	139
Figure 5.13: Performance Profile of $GA_{TC}$ in Plant 1 (Nominal Condition)	140
Figure 5.14: Performance Profile of $GA_{TC}$ in Plant 1 (Properties Variation)	141
Figure 5.15: Performance Profile of $GA_{TC}$ in Plant 2 (Nominal Condition)	142
Figure 5.16: Performance Profile of $GA_{TC}$ in Plant 2 (Properties Variation)	143
Figure 5.17: Schematic Diagram of Temperature Controller ( $SA_{TC}$ )	144
Figure 5.18: Performance Profile of $SA_{TC}$ in Plant 1 (Nominal Condition)	145
Figure 5.19: Performance Profile of $SA_{TC}$ in Plant 1 (Properties Variation)	146
Figure 5.20: Performance Profile of $SA_{TC}$ in Plant 2 (Nominal Condition)	147
Figure 5.21: Performance Profile of $SA_{TC}$ in Plant 2 (Properties Variation)	148
Figure 5.22: Performance Analysis of Evolutionary Temperature Controller	151
Figure 5.23: Schematic Diagram of Molar Optimizer ( $GA_{MO}$ )	153
Figure 5.24: Performance Profile of $GA_{MO}$ in Plant 1 (Nominal Condition)	154
Figure 5.25: Performance Profile of $GA_{MO}$ in Plant 1 (Properties Variation)	155
Figure 5.26: Performance Profile of $GA_{MO}$ in Plant 2 (Nominal Condition)	156
Figure 5.27: Performance Profile of $GA_{MO}$ in Plant 2 (Properties Variation)	157

Figure 5.28: Schematic Diagram of Molar Optimizer ( $SA_{MO}$ )	158
Figure 5.29: Performance Profile of $SA_{MO}$ in Plant 1 (Nominal Condition)	159
Figure 5.30: Performance Profile of $SA_{MO}$ in Plant 1 (Properties Variation)	160
Figure 5.31: Performance Profile of $SA_{MO}$ in Plant 2 (Nominal Condition)	161
Figure 5.32: Performance Profile of $SA_{MO}$ in Plant 2 (Properties Variation)	162
Figure 5.33: Performance Analysis of Evolutionary Molarity Optimizer	165
Figure 6.1: Performance Profile of $EA_{OC}$ in Plant 1 (Nominal Condition)	172
Figure 6.2: Performance Profile of $EA_{OC}$ in Plant 1 (Properties Variation)	173
Figure 6.3: Performance Profile of $EA_{OC}$ in Plant 1 (Charging Deviation)	174
Figure 6.4: Performance Profile of $EA_{OC}$ in Plant 1 (Control Fault)	175
Figure 6.5: Performance Profile of $EA_{OC}$ in Plant 2 (Nominal Condition)	176
Figure 6.6: Performance Profile of $EA_{OC}$ in Plant 2 (Properties Variation)	177
Figure 6.7: Performance Profile of $EA_{OC}$ in Plant 2 (Charging Deviation)	178
Figure 6.8: Performance Profile of $EA_{OC}$ in Plant 2 (Control Fault)	179
Figure 6.9: Performance Analysis of Multi-Stage Controller ( $EA_{OC}$ )	181
Figure 6.10: Performance Profile of $EA_{TO-MO}$ in Plant 1 (Nominal Condition)	183
Figure 6.11: Performance Profile of $EA_{TO-MO}$ in Plant 1 (Properties Variation)	184
Figure 6.12: Performance Profile of $EA_{TO-MO}$ in Plant 1 (Charging Deviation)	185
Figure 6.13: Performance Profile of $EA_{TO-MO}$ in Plant 1 (Control Fault)	186
Figure 6.14: Performance Profile of $EA_{TO-MO}$ in Plant 2 (Nominal Condition)	187

Figure 6.15: Performance Profile of EA <sub>TO-MO</sub> in Plant 2 (Properties Variation)	188
Figure 6.16: Performance Profile of EA <sub>TO-MO</sub> in Plant 2 (Charging Deviation)	189
Figure 6.17: Performance Profile of EA <sub>TO-MO</sub> in Plant 2 (Control Fault)	190
Figure 6.18: Performance Analysis of Multi-Mode Optimizer (EA <sub>TO-MO</sub> )	192
Figure 6.19: Picture of Microcontroller ATmega328	193
Figure 6.20: Performance Profile of EA <sub>OC-MO</sub> in Plant 1 (Nominal Condition)	194
Figure 6.21: Performance Profile of EA <sub>OC-MO</sub> in Plant 1 (Properties Variation)	195
Figure 6.22: Performance Profile of EA <sub>OC-MO</sub> in Plant 1 (Charging Deviation)	196
Figure 6.23: Performance Profile of EA <sub>OC-MO</sub> in Plant 1 (Control Fault)	197
Figure 6.24: Performance Profile of EA <sub>OC-MO</sub> in Plant 2 (Nominal Condition)	198
Figure 6.25: Performance Profile of EA <sub>OC-MO</sub> in Plant 2 (Properties Variation)	199
Figure 6.26: Performance Profile of EA <sub>OC-MO</sub> in Plant 2 (Charging Deviation)	200
Figure 6.27: Performance Profile of EA <sub>OC-MO</sub> in Plant 2 (Control Fault)	201
Figure 6.28: Performance Analysis of Real-Time Optimizer (EA <sub>OC-MO</sub> )	203

## LIST OF ABBREVIATIONS

<b>DM<sub>TC</sub></b>	Dual-Mode temperature controller
<b>DP<sub>ME</sub></b>	Dynamic Programming as a model estimator
<b>EA<sub>OC</sub></b>	Evolutionary algorithm optimized controller
<b>EA<sub>OC-MO</sub></b>	Evolutionary algorithm optimized controller and molarity optimizer
<b>EA<sub>TO-MO</sub></b>	Evolutionary algorithm multi-mode optimizer
<b>FL<sub>TC</sub></b>	Fuzzy Logic temperature controller
<b>FLPID<sub>TC</sub></b>	Fuzzy Logic PID temperature controller
<b>GA<sub>MO</sub></b>	Genetic Algorithm molarity optimizer
<b>GA<sub>TC</sub></b>	Genetic Algorithm temperature controller
<b>PID</b>	Proportional-Integral-Derivative
<b>SA<sub>MO</sub></b>	Swarm Algorithm molarity optimizer
<b>SA<sub>TC</sub></b>	Swarm Algorithm temperature controller



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## LIST OF SYMBOLS

$\alpha_{AB}$	Estimated reaction-rate coefficient
$\alpha_{AC}$	Estimated reaction-rate coefficient
$\alpha_j$	Estimated model coefficient
$\alpha_r$	Estimated model coefficient
$a_k$	Arbitrary constants of model output
$A_s$	Conducting surface area of reactor substances
$\beta_{AB}$	Estimated reaction-rate coefficient
$\beta_{AC}$	Estimated reaction-rate coefficient
$\beta_j$	Estimated model coefficient
$\beta_r$	Estimated model coefficient
$b_k$	Arbitrary constants of model output
$c$	Molar concentration of substance
$c_i$	Molar concentration of substance in $i$ th inlet stream
$c_j$	Molar concentration of substance in $j$ th outlet stream
$ce$	Change in error
$C_A$	Molar heat-capacity of substance $A$
$C_B$	Molar heat-capacity of substance $B$
$C_C$	Molar heat-capacity of substance $C$
$C_D$	Molar heat-capacity of substance $D$
$C_f$	Heat capacity of fluid
$C_i$	Molar heat-capacity of substance $i$
$C_s$	Total molar heat-capacity of reactor substances
$d_l$	Process disturbance
$\epsilon_n$	Error of variation between model and measured outputs
$e$	Error

$E_{cj}$	Sum of heat energy transferred from fluid to jacket
$E_i$	Activation energy of reaction $i$
$E_j$	Sum of heat energy stored in jacket
$E_{jr}$	Sum of heat energy transferred from jacket to reactor
$E_r$	Sum of heat energy stored in reactor
$E_{rj}$	Sum of energy transferred from reactor to jacket
$E_R$	Sum of heat energy released due to reaction
$f_C$	Fitness function of control system
$f_{MO}$	Fitness function of molarity optimizer
$f_O$	Fitness function of optimization system
$f_{TC}$	Fitness function of temperature controller
$f_{TO}$	Fitness function of temperature optimizer
$F_c$	Manipulated fluid flow rate
$F_i$	Volumetric flow rate of the $i$ th inlet stream
$F_j$	Volumetric flow rate of the $j$ th outlet stream
$h_i$	Specific enthalpy of the material in the $i$ th inlet stream
$h_j$	Specific enthalpy of the material in the $j$ th outlet stream
$h_s$	Conducting height of reactor substances
$\Delta H_{AB}$	Enthalpy change of Reactions $AB$
$\Delta H_{AC}$	Enthalpy change of Reactions $AC$
$k$	Reaction-rate constant
$k_B$	Boltzmann constant
$k_i$	Reaction rate constant of reaction $i$
$k'_{AB}$	Rate constant of Reactions $AB$
$k'_{AC}$	Rate constant of Reactions $AC$
$k'_i$	Frequency factor of reaction $i$
$K$	Kinetic energy of the reactor system
$K_d$	Derivative parameter

$K_i$	Integral parameter
$K_p$	Proportional parameter
$m_k$	Process input
$\tilde{m}_{n-k}$	Previous measured input
$M_A$	Number of moles to substance $A$
$M_B$	Number of moles to substance $B$
$M_C$	Number of moles to substance $C$
$M_D$	Number of moles to substance $D$
$M_i$	Number of moles to substance $i$
$M_s$	Total moles for reactor substances
$M'_A$	Molar mass of substance $A$
$M'_B$	Molar mass of substance $B$
$M'_C$	Molar mass of substance $C$
$M'_D$	Molar mass of substance $D$
$M'_i$	Molar mass of substance $i$
$M_e^2$	Squared modelling error
$\int M_e^2 dt$	Integral squared modelling error
$\rho$	Density of the material in the reactor system
$\rho_f$	Fluid density
$\rho_i$	Density of the material in the $i$ th inlet stream
$\rho_j$	Density of the material in the $j$ th outlet stream
$\rho_s$	Overall density of the reactor substances
$P$	Potential energy of the reactor system
$P_i$	Process parameters
$Q_{cj}$	Heat transferred from the fluid to jacket
$Q_j$	Heat exchanged in the jacket
$Q_{jr}$	Heat transferred from jacket to reactor
$Q_r$	Heat exchanged in the batch reactor