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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols

c_1 and c_2	-	Acceleration constants
A	-	Area of the packed column
p_{id}	-	Best value of individual particle
ε	-	Cell-face void fraction
P(s)	-	Characteristic polynomial of the closed-loop system
α_i	-	Characteristic ratio
a_i	-	Coefficient of characteristic polynomial
l_i, $k_{i,}$ k_1 and k_0	-	Coefficients of CDM controller polynomials
C_{SO2}	-	Concentration of SO_2 in liquid
C_{H2O2}	-	Concentration of SO_2 in the liquid
C_{AI}	-	Concentration of solute A at the interface
C_{AL}	-	Concentration of solute A in the liquid
α	-	Conservation of mass in each phase (gas and liquid)
K_c	-	Controller gain
u	-	Controller signal
N	-	Degree of polynomial
D(s)	-	Denominator polynomials of the plant transfer function
ρ_α	-	Density of phase α
K_d	-	Derivative gain
T_d	-	Derivative time constant
S_α	-	Different source terms (drag or body forces)
$\Gamma Y_{\alpha A}$	-	Diffusion coefficient
S_k	-	Droplet mass source

τ	-	Equivalent time constant
y	-	Error in the frequency domain
$\frac{1}{\Gamma(\alpha)}$	-	Euler's Gamma function
D	-	External disturbance signal
$C_f(s)$	-	Feed forward controller transfer function
B(s)	-	Feedback numerator polynomial of CDM controller Transfer function
K_f	-	Feedback proportional gain
K_4	-	Flooding factor
A(s)	-	Forward denominator polynomial of CDM controller Transfer function
λ	-	Fractional differentiation order
μ	-	Fractional integral order
ω_u	-	Gain cross over frequency
ρ_g	-	Gas density
G_m	-	Gas mass flow rate
V_w^*	-	gas mass flow rate / column cross sectional area
p_{gd}	-	Global best value
H_{OG}	-	Height of transfer units
m	-	Henry's constant
p_{best}	-	Individual best value
w	-	Inertia factor
N_D	-	Integer order of differentiator
N_I	-	Integer order of integrator
K_i	-	Integral gain
T_i	-	Integral time constant
g_i	-	i^{th} component of the gravity vector
ρ_L	-	Liquid density

L_m	-	Liquid mass flow rate
μ_L	-	Liquid viscosity
ω_L		Lower band of crossover frequency
C(s)	-	Main controller transfer function
$Y_{\alpha A}$	-	Mass fraction
K_{H2O2}	-	Mass transfer coefficient in liquid phase
k_g	-	Mass-transfer coefficient for gas film
k_l	-	Mass-transfer coefficient for liquid film
$\dot{m}_{\beta\alpha}$	-	Mass-transfer rate from phase β into phase α
ω_{max}	-	Maximum frequency of approximation
$iter_{max}$	-	Maximum number of iterations
$w_{max,}$	-	Maximum value for inertia factor
x^{max}		Maximum value of the particle
w_{min}		Minimum value for inertia factor
x^{min}		Minimum value of the particle
X_2	-	Mole fraction of aqueous H_2SO_4 entering the column
X_1	-	Mole fraction of aqueous H_2SO_4 leaving the column
Y_1	-	Mole fraction of SO_2 in gas stream entering the column
Y_2	-	Mole fraction of SO_2 in gas stream leaving the column
Y	-	Mole fraction of SO_2 in the gas phase
X	-	Mole fraction of SO_2 in the liquid phase
N_{OG}	-	Number of transfer unit
N(s)	-	Numerator polynomials of the plant transfer function
F(k)	-	Objective function for the FOPID (or) fitness function
g_{best}	-	Overall best solution
Z	-	Packed Height
F_P	-	Packing factor
P_{SO2}	-	Partial pressure of SO_2 in gas

P_{AI}	-	Partial pressure of solute A at the interface
P_{AG}	-	Partial pressure of solute A in the gas
$\Gamma\alpha$	-	Phase-diffusion coefficient
P_i	-	Poles of the rational transfer function
x_{id}	-	Position of the particle
$G_f(s)$	-	Pre-filter element transfer function
F_{LV}	-	Pressure drop in the packed column
θ	-	Process delay
K_p	-	Process gain
τ_p	-	Process time constant
K_c	-	Proportional gain
N_{SO2}	-	Rate of mass transfer of SO_2
N_A	-	Rate of transfer of component A
R	-	Reference input
F(s)	-	Reference numerator polynomial of CDM controller Transfer function
t_s	-	Settling time
ρ_v	-	SO_2 gas density
K_{SO2}	-	SO_2 gas mass transfer coefficient
M_{SO2}	-	SO_2 molecular weight
$S_{\alpha A}$	-	Source term for chemical reaction in the column
γ_i	-	Stability index
γ_1 and γ_2	-	Stability indices
γ_i*	-	Stability limits
Y	-	System output
$P_{target}(s)$	-	Target characteristic polynomial
P_{TOT}	-	Total pressure in the packed column
$G_P(s)$	-	Transfer function model of the P controller
$G_{PI}(s)$	-	Transfer function model of the PI controller

G(s)	-	Transfer function model of the plant
$\vec{v}_{\alpha}$	-	Velocity vector
r_{α}	-	Volume fraction of the phase
Z_i	-	Zeros of the rational transfer function

Abbreviations

AC	-	Alternating Current
NH_3	-	Ammonia
ADC	-	Analog to Digital Converter
ANN	-	Artificial Neural Networks
AVR	-	Automatic Voltage Regulator
CO_2	-	Carbon Dioxide
CO	-	Carbon monoxide
CAS	-	Chaotic Ant Swarm
CAS-FOPID	-	Chaotic Ant Swarm - Fractional Order Proportional Integral Derivative
CFC	-	Chlorofluorocarbon
CD	-	Coefficient Diagram
CDM	-	Coefficient Diagram Method
CDM-PI	-	Coefficient Diagram Method- Proportional Integral
CDM-PID	-	Coefficient Diagram Method -Proportional Integral Derivative
CDM-PI-P	-	Coefficient Diagram Method -Proportional Integral-Proportional
CDM-PI-PD	-	Coefficient Diagram Method -Proportional Integral-Proportional Derivative
CC	-	Cohen Coon
CRONE	-	Comman de Robuste de Ordre Non Entier
CFD	-	Computational Fluid Dynamics

DAQ	-	Data Acquisition
DAC	-	Digital to Analog Converter
DC	-	Direct Current
EE	-	Electrically Erasable
FOPDT	-	First Order Plus Dead Time
FGCS	-	Flue Gas Cleaning Systems
FGD	-	Flue Gas Desulphurization
FO	-	Fractional Order
FOCDM-$PI^{\lambda}D^{\mu}$	-	Fractional Order based Coefficient Diagram Method -PID Controller
FOCP	-	Fractional Order Characteristic Polynomial
FO-PI	-	Fractional Order -Proportional Integral
FOPID	-	Fractional Order Proportional Integral Derivative
FTDP	-	Frequency Time Domain performance
GM	-	Gain Margin
GUI	-	Graphical User Interface
HC	-	Hydro Carbon
HCl	-	Hydro Choric acid
pH	-	Hydrogen ion concentration
H_2O_2	-	Hydrogen peroxide
IO	-	Integer Order
IOPID	-	Integer Order Proportional Integral Derivative
IAE	-	Integral Absolute Error
ISE	-	Integral Squared Error
ITAE	-	Integral Time Absolute Error
I-PDA	-	Integral-Proportional Derivative Acceleration
$CaCO_3$	-	Lime
LQR	-	Linear Quadratic Regulator
MCU	-	Microcontroller Unit

MOEF	-	Ministry of Environmental and Forest
HNO_3	-	Nitric acid
NO_2	-	Nitrogen dioxide
NO_X	-	Nitrogen oxides
PA	-	Pade Approximation
PSO	-	Particle Swarm Optimisation
PSO-FOPID	-	Particle Swarm Optimisation- Fractional Order Proportional Integral Derivative
PC	-	Personal Computer
PM	-	Phase Margin
PCB		Pollution Control Board
P	-	Proportional
PI	-	Proportional Integral
PID	-	Proportional Integral Derivative
PIDA	-	Proportional Integral Derivative Acceleration
PID-P	-	Proportional Integral Derivative-Proportional
PI-PD	-	Proportional Integral-Proportional Derivative
PRBS	-	Pseudo-Random Binary Sequence
PWM	-	Pulse Width Modulation
RGA	-	Relative Gain Analysis
RL	-	Riemann- Liouvelle
SOPDT	-	Second Order Plus Dead Time
SIMO	-	Single Input Multi Output
SISO	-	Single Input Single Output
NaOH	-	Sodium Hydroxide
SO_2	-	Sulphur di oxide
SO_X	-	Sulphur oxides
H_2SO_4	-	Sulphuric acid
SPM	-	Suspended Particulate Matters

2DOF	-	Two Degree of Freedom
UART	-	Universal Asynchronous Receiver Transmitter
UFOPTD	-	Unstable First Order Plus Time Delay
VFD	-	Variable Frequency Drive
VSI	-	Voltage Source Inverter
WFGD	-	Wet Flue Gas Desulphurization
WHO	-	World Health Organisation
ZN	-	Ziegler Nichols
ZN-PID	-	Ziegler Nichols- Proportional Integral Derivative
ZN-PI	-	Ziegler Nichols-Proportional Integral