List of Symbols and Abbreviations

List of Symbols

A_1, A_2	Exponential factors in Arrhenius equation
A_T	Heat transfer area
$C^*_{O_2,0}$	Equilibrium concentration of oxygen in distilled water
C_{O_2}	Oxygen concentration in the liquid phase
$C^*_{O_2}$	Equilibrium concentration of oxygen in the liquid phase
$C_{heat,j}$	Heat capacity of cooling agent
$C_{heat,r}$	Heat capacity of the fermentation medium
CE_i	Control effort for valve i
C_P	Ethanol concentration
$C_{S,in}$	Glucose concentration in the feed stream
C_S	Glucose concentration
C_x	Biomass concentration
E_{a1}, E_{a2}	Activation energy
F_h	Hot utility flow
F_e	Bioreactor downstream flow
F_i	Inlet flow rate of CSTR
F_{in}	Bioreactor feed flow
F_o	Outlet flow rate of CSTR
G_c	Feedback controller transfer function
G_m	Process model
G_{m-}	Invertible part of model
G_{m+}	Non invertible part of model
$G_p(s)$	Process transfer function
K_{O_2}	Constant for oxygen consumption
$K_L a$	Product of the mass-transfer coefficient for oxygen and gas-phase specific area

K_P	Constant of growth inhibition by ethanol
K_{P1}	Constant of fermentation inhibition by ethanol
K_S	Constant in the substrate term for growth
K_{S1}	Constant in the substrate term for ethanol production
K_T	Heat transfer coefficient
$\tilde{Q}$	IMC Controller
R_{SP}	Ratio of ethanol produced per glucose consumed for fermentation
R_{SX}	Ratio of cell produced per glucose consumed for growth
T_{in}	Temperature of the substrate flow entering to the bioreactor
T_j	Jacket temperature
T_r	Temperature in the bioreactor
V_j	Volume of the jacket
Y_{O_2}	The amount of oxygen consumed per unit biomass produced
Y_{sp}	Setpoint
k_c	Proportional Controller gain
r_{O_2}	Oxygen uptake rate mg
$u_{k,i}$	Control signal to valve i at moment
μ_{O_2}	Maximum specific oxygen consumption rate
μ_P	Maximum specific fermentation rate
μ_x	Maximum specific growth rate
ρ_j	Density of jacket liquid
ρ_r	Density of the fermentation medium
τ_D	Derivative Time Constant
τ_I	Integral Time Constant
τ_c	Tuning parameter
τ_f	Derivative filter
ΔH_r	Reaction heat of fermentation
Δu_i	Normalized control signal variation
b	Setpoint weighting parameter
C_A	Outlet concentration of component A

C_{Ain}	Inlet concentration of component A
c_p	Specific heat
e	Controlled variable error
E	Activation energy for the reaction
F	Total volumetric flow rate
H	Specific ionic constant
I	Ionic strength
k	Pre-exponential constant
k	Process gain
Ku	Ultimate controller gain
m	Quantity of inorganic salt
M	Molecular/atomic mass
Ms	Maximum sensitivity
Pu	Period of oscillations
Q	Heat supplied to the reactor
R	Universal gas constant
S(s)	Sensitivity function
T	Time
T(s)	Complementary sensitivity
V	Reactor volume
ΔH	Heat of reaction (exothermic)
θ	Time delay
λ	Tuning parameter
ρ	Density
τ	Time constant
$C(s)$	Controller transfer function
V	Volume of the bioreactor
$f(s)$	IMC filter

List of Abbreviations

ADALINE	Adaptive linear neural network
ANN	Artificial Neural Network
C-C	Cohen-Coon
CSA	Cuckoo search algorithm
CSTR	Continuous stirred tank reactor
DIPTD	Double integrating plus time delay
DMC	Dynamics Matrix Control
DO	Dissolved Oxygen
DS	Direct Synthesis
DS-d	Direct Synthesis for disturbance rejection
FBR	Fluidized bed bioreactor
FOIMC	Fractional order Internal Model Control
FOPDT	First order plus dead time
FOPI	Fractional order proportional integral
GA	Genetics Algorithms
GM	Gain Margin
GPC	Generalized Predictive Controller
IAE	Integrating absolute error
IFOPTD	Integrating first order plus time delay
IMC	Internal Model Control
INN	Inverse Neural Network
ISE	Integral square error
ITAE	Integral of time weighted absolute error
LMPC	Linear Model predictive control
MAC	Model Adaptive Control
MFOIMC	Modified fractional order Internal Model Control
MIMO	Multiple Input Multiple Output
MPC	Model predictive control
MPC-NPL	Model predictive control with nonlinear prediction

MRAC	Model Reference Adaptive Control
NARMA	Nonlinear autoregressive moving average
NNMPC	Neural Network Model Predictive Control
NSGA	Nondominated sorted genetic algorithm
OS	Overshoot
P	Proportional
PI	Proportional Integral
PID	Proportional Integral Derivative
PIPTD	Pure integrating plus time delay
PM	Phase Margin
RHP	Right hand pole
SIMC	Simple Internal Model Control
SISO	Single Input Single Output
SOIR	Second order inverse response
SOM	Setpoint overshoot method
SOPDT	Second order plus dead time
TL	Tyreus-Luyben
T-S	Takagi-Sugeno
TV	Total Variation
USOPDT	Unstable Second order plus dead time
Z-N	Ziegler-Nichols