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Design of PLS based software sensor for a CSTR process

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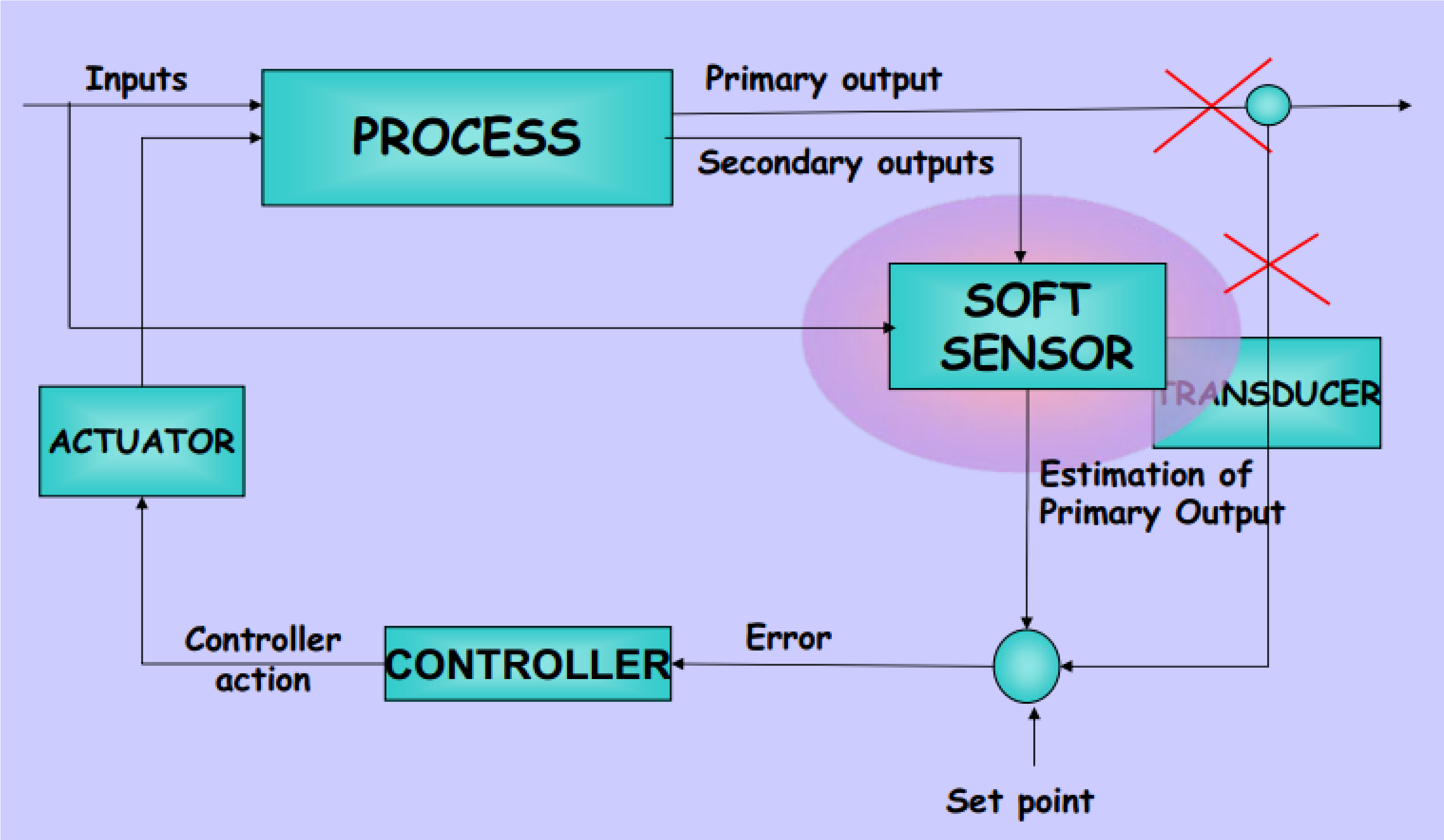


Fig : Schematic Representation of a Control Loop using Soft Sensor

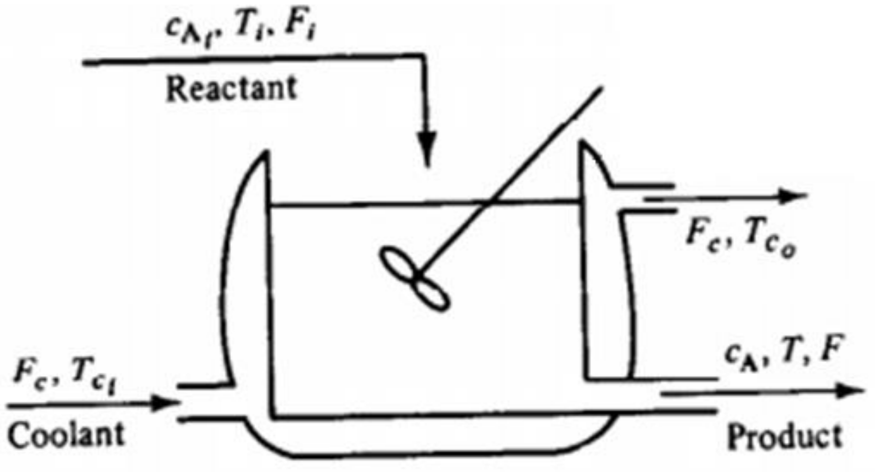


Fig : Diagrammatic representation of a CSTR

In the above figure :

Manipulated inputs : F_i , F_c
Measured Output : T, c_A
Disturbances : T_i , c_{Ai} , T_{ci}

Governing Equations of a CSTR:

$$\frac{dCa}{dt} = \frac{F_i}{V}(c_{Ai} - c_A) - k_o \exp\left(-\frac{E}{RT}\right) C_A$$

$$\frac{dT}{dt} = \frac{F_i}{V}(T_i - T) - \left(-\frac{H_r}{\rho C_p}\right) k_o \exp\left(-\frac{E}{RT}\right) C_A - Q/V\rho \quad C_p$$

$$Q = \frac{aF_c^{b+1}}{(F_C + (\frac{aF_c^b}{2\rho C_{pc}})}(T - T_{ci})$$

V = Volume of CSTR
k_o = First order reaction rate constant
H_r = Heat of Reaction
ρ = Density of Reactant
ρ_c = Density of coolant

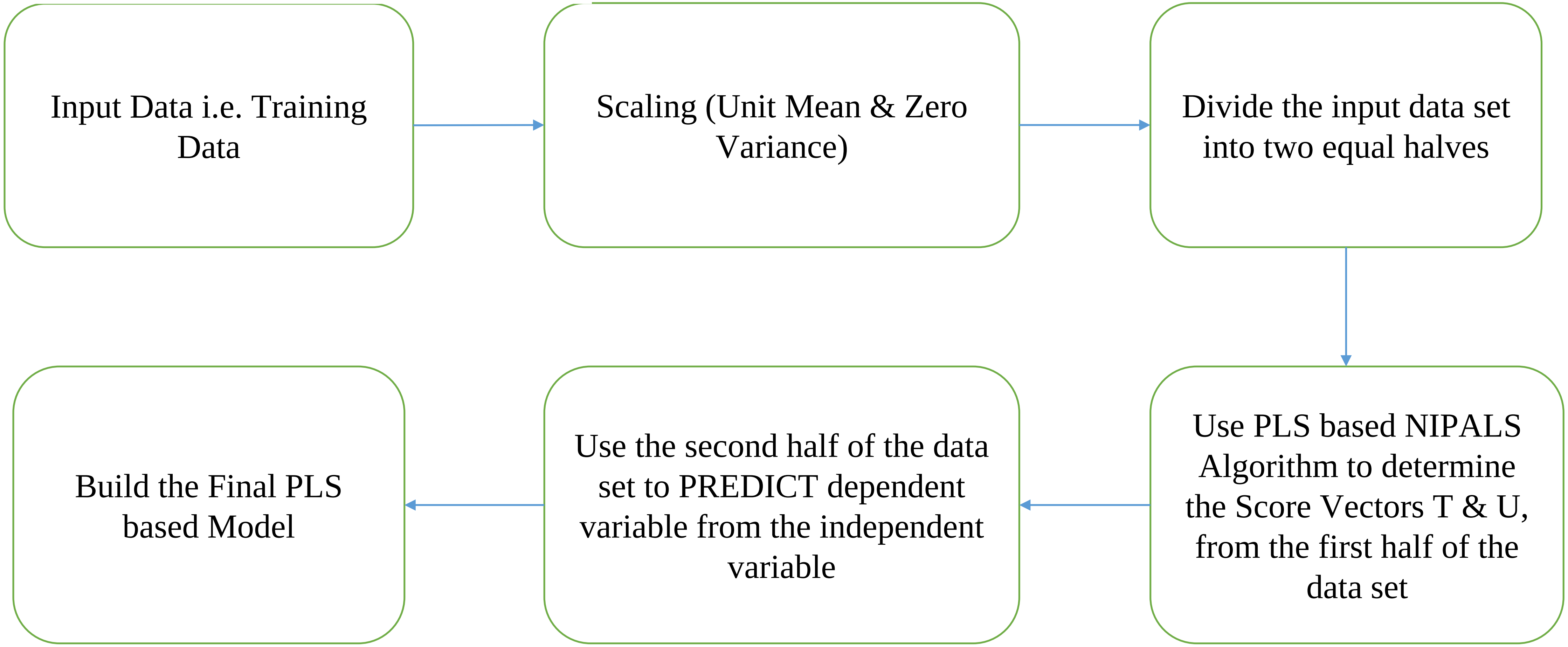


Fig : Flowchart for determining a PLS Based Model

NIPALS based PLS Algorithm:

A PLS Algorithm Consists of 2 relations:

1.) Outer Relation :

$$X = X' + J = \sum_{k=1}^{l} t_k p_k^T + J = TP^T + J$$

$$Y = Y' + H = \sum_{k=1}^{l} u_k q_k^T + H = UQ^T + H$$

Where,

X = Input Matrix
Y = Output Matrix
X' = Estimated Input Matrix
Y' = Estimated Output Matrix
T = Input Latent Variables
U = Output Latent Variables
P = Input Loading Vectors
Q = Output Loading Vectors
J = Residual Input Matrix
H = Residual Output Matrix

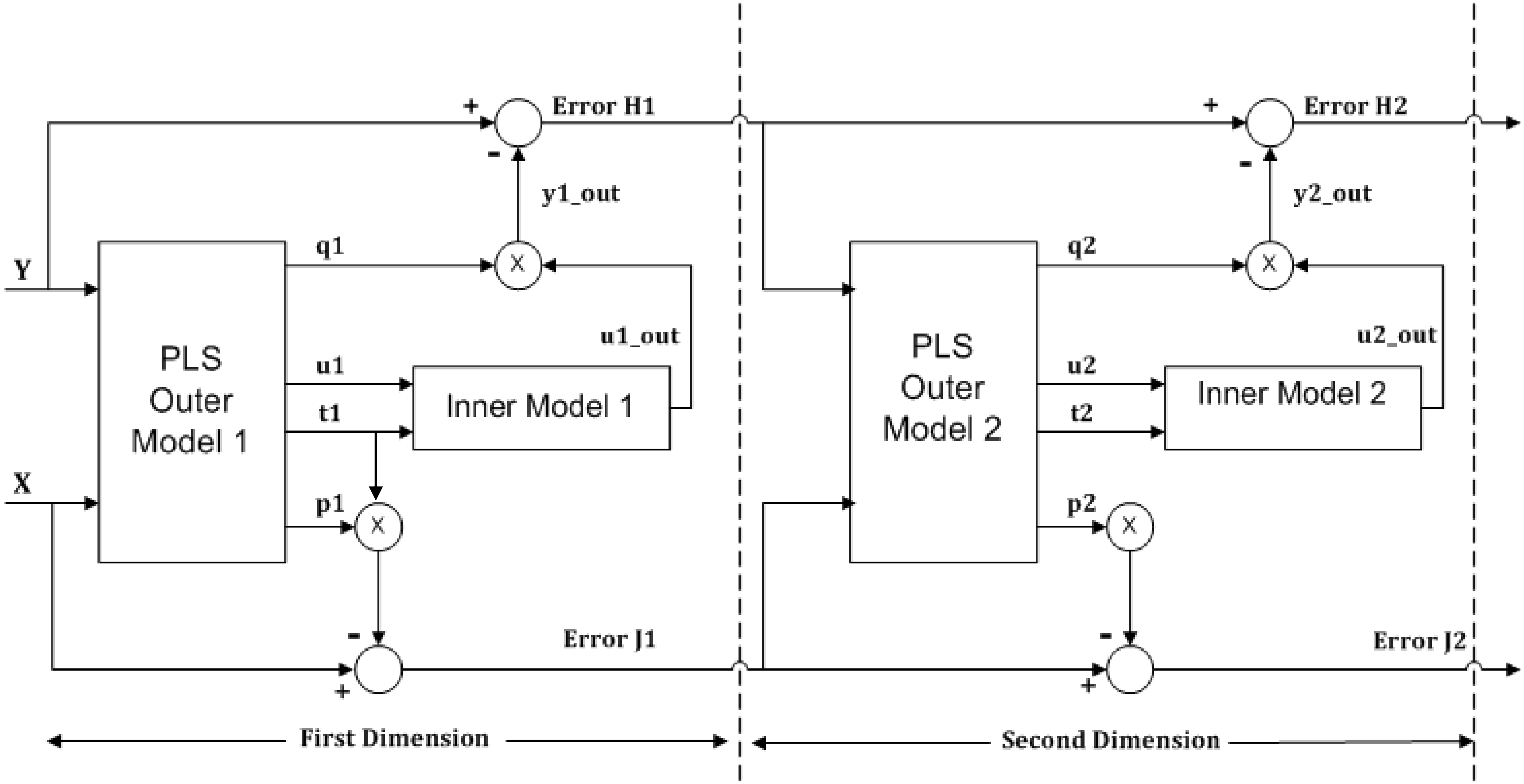
2.) Inner Relation:

$$U = TB + L$$

Where,

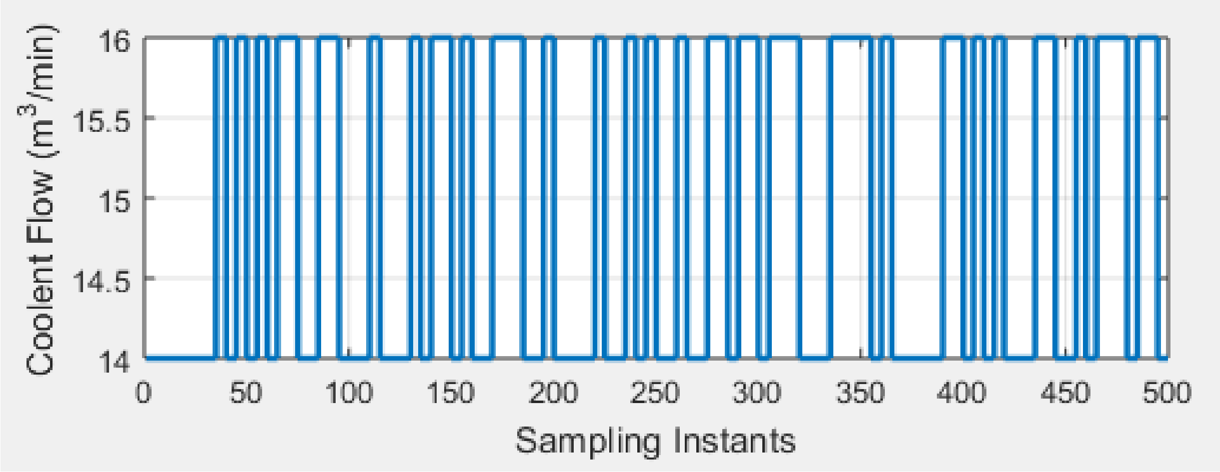
B = Regression Matrix
L = Residual Matrix

Diagrammatic representation of NIPALS based PLS Algorithm:



Where,

Error $J1 = X - (t1 \times p1)$ & Error $H1 = Y - (t1 \times b1 \times q1)$



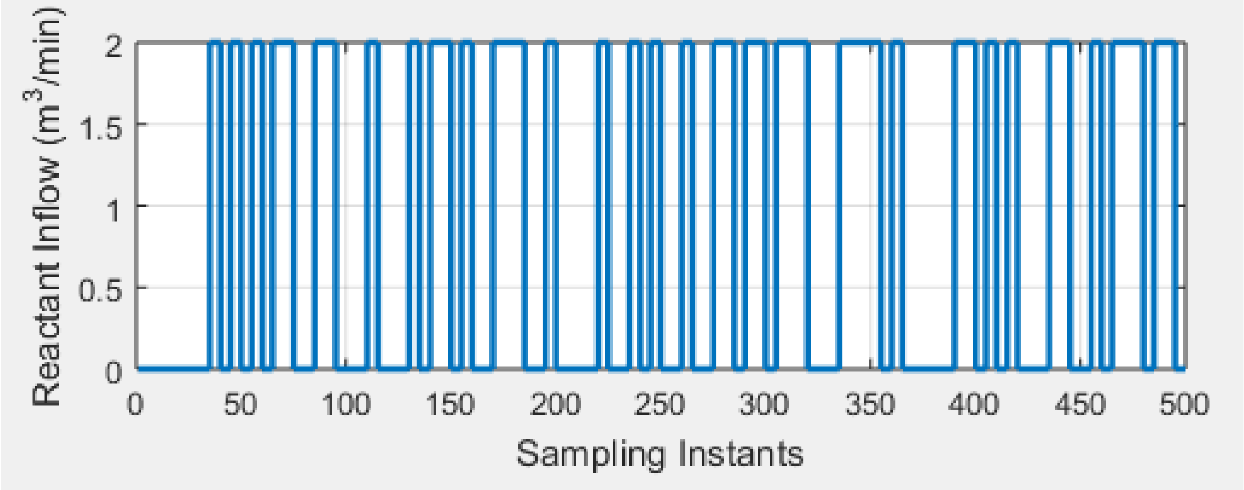
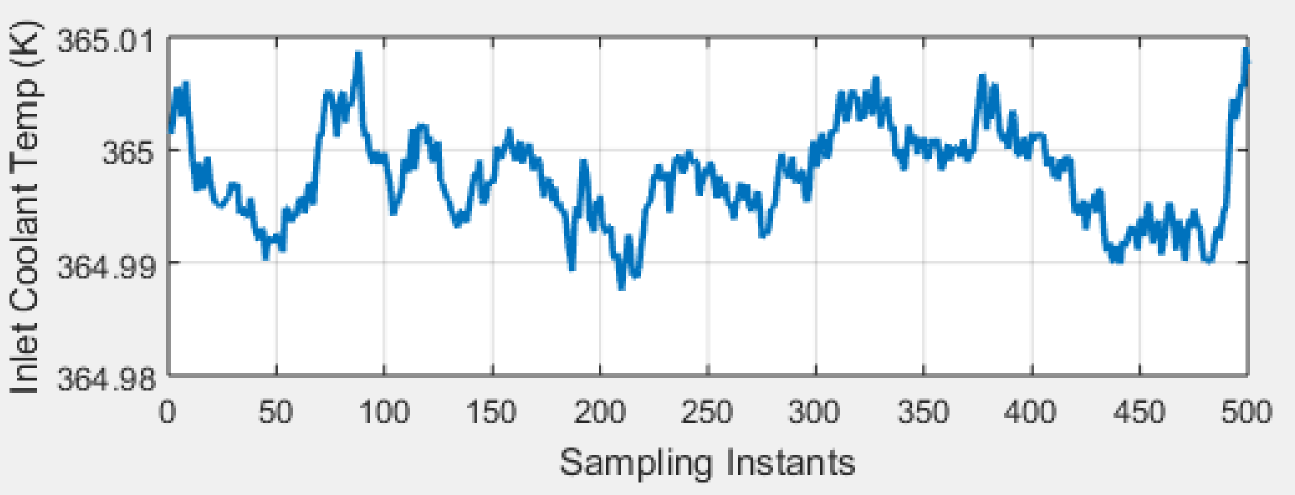
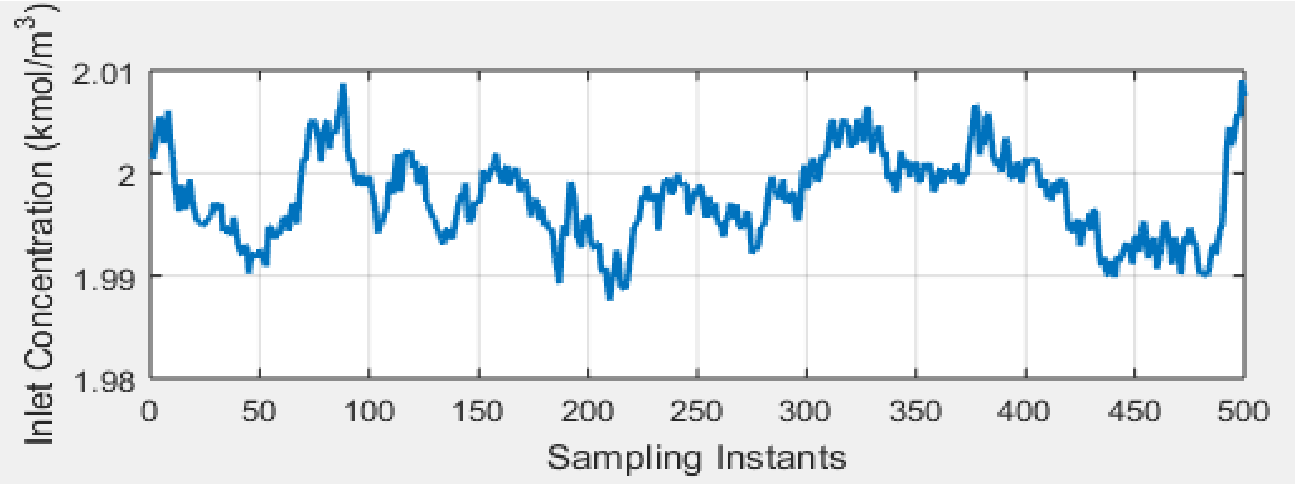


Fig : Coolant Inflow & Reactant Inflow


Inlet Coolant Temp (K)
365.01
365
364.99
364.98
0
50
100
150
200
250
300
350
400
450
500
Sampling Instants


Inlet Concentration (kmol/m^3)
2.01
2
1.99
1.98
0
50
100
150
200
250
300
350
400
450
500
Sampling Instants

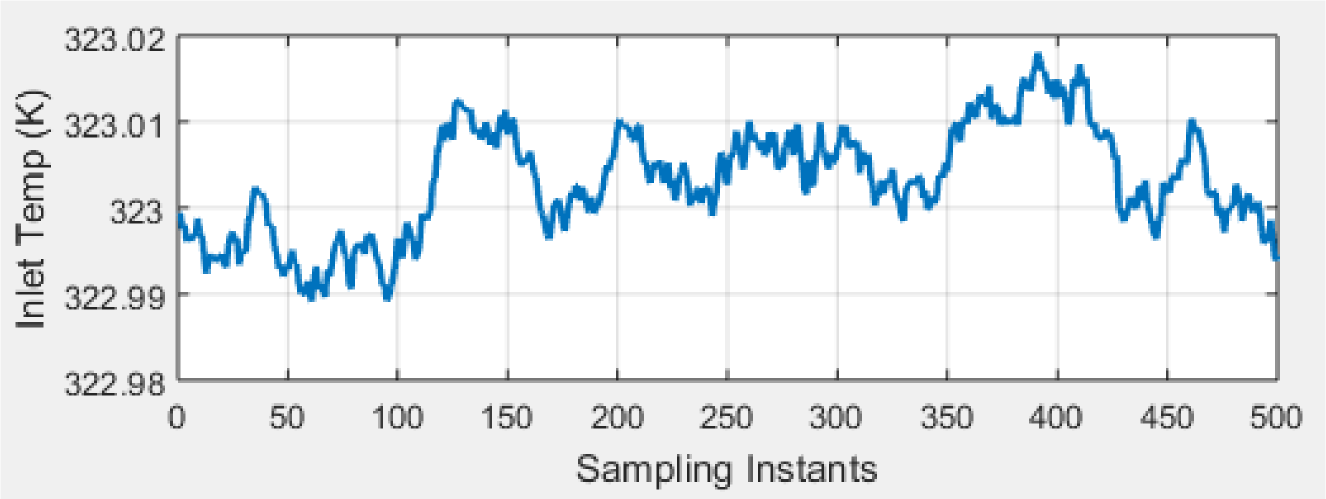
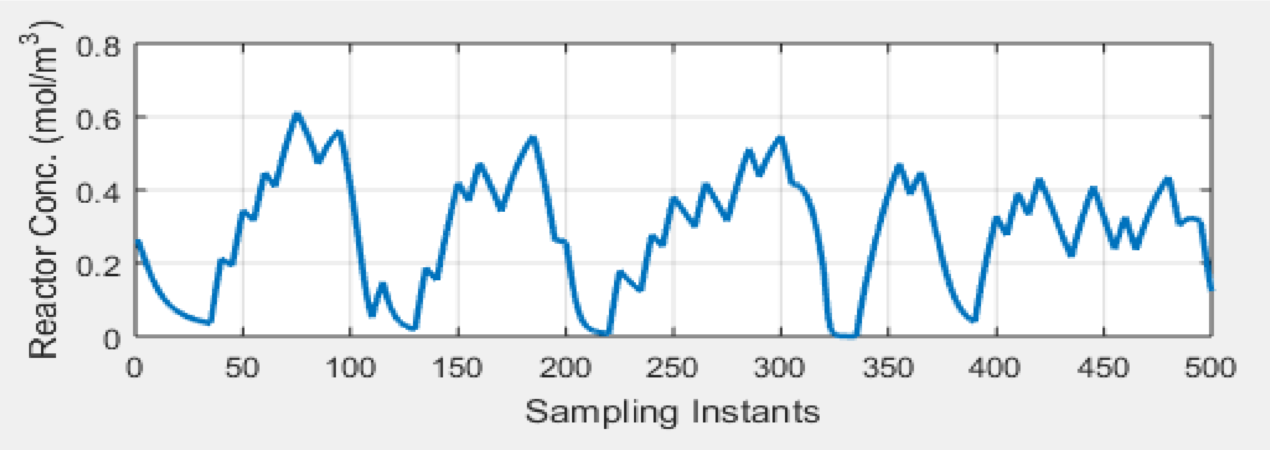


Fig : Disturbance Variables



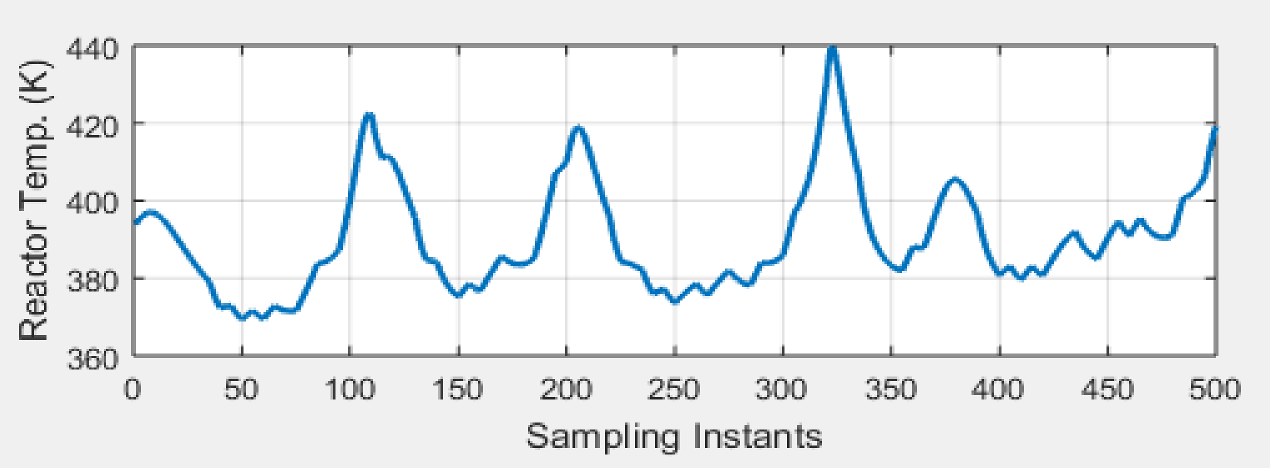
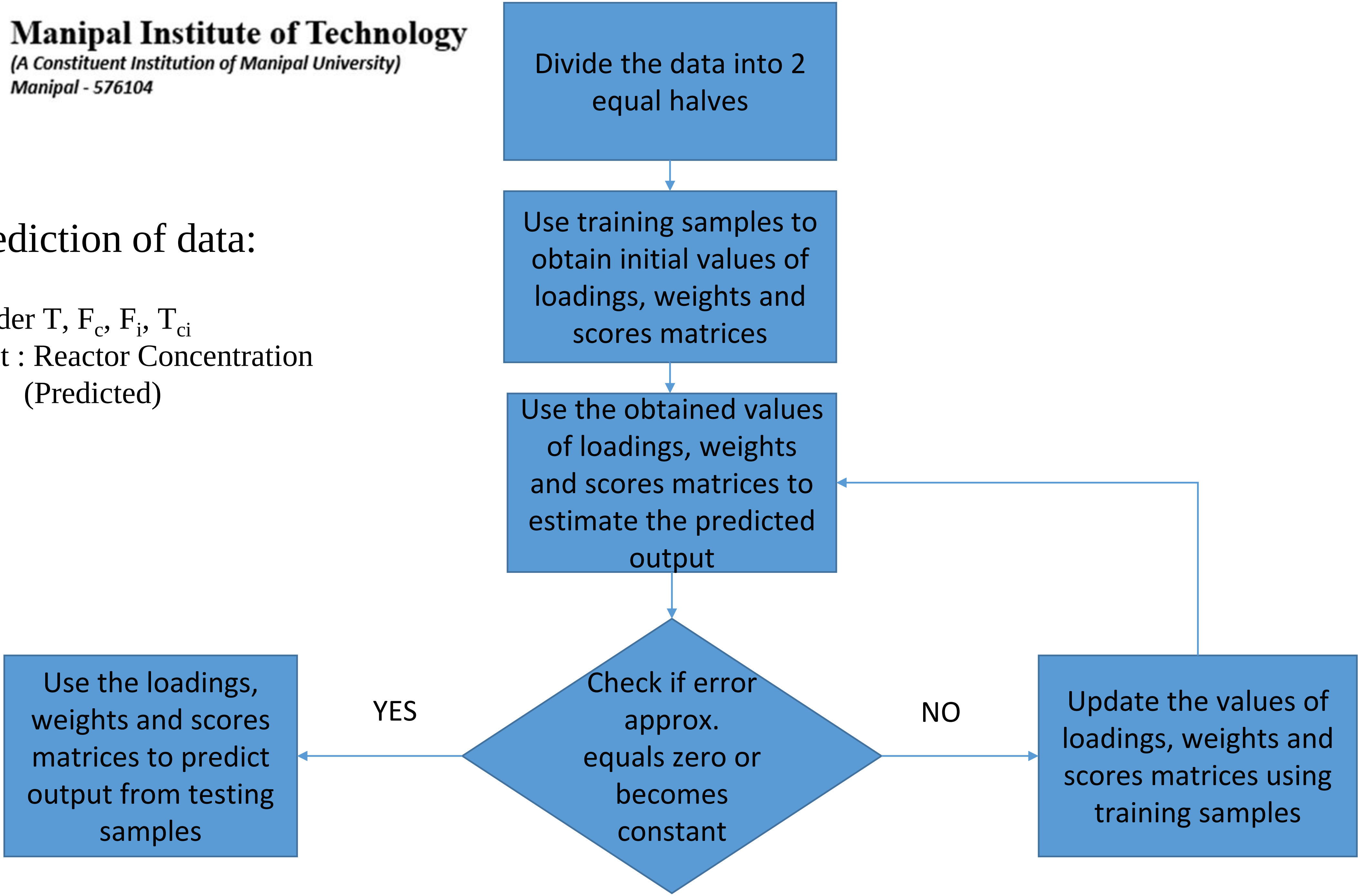


Fig : Resultant Concentration & Temperature

For Prediction of data:

- Consider T, F_c, F_i, T_{ci}
- Output : Reactor Concentration
  (Predicted)



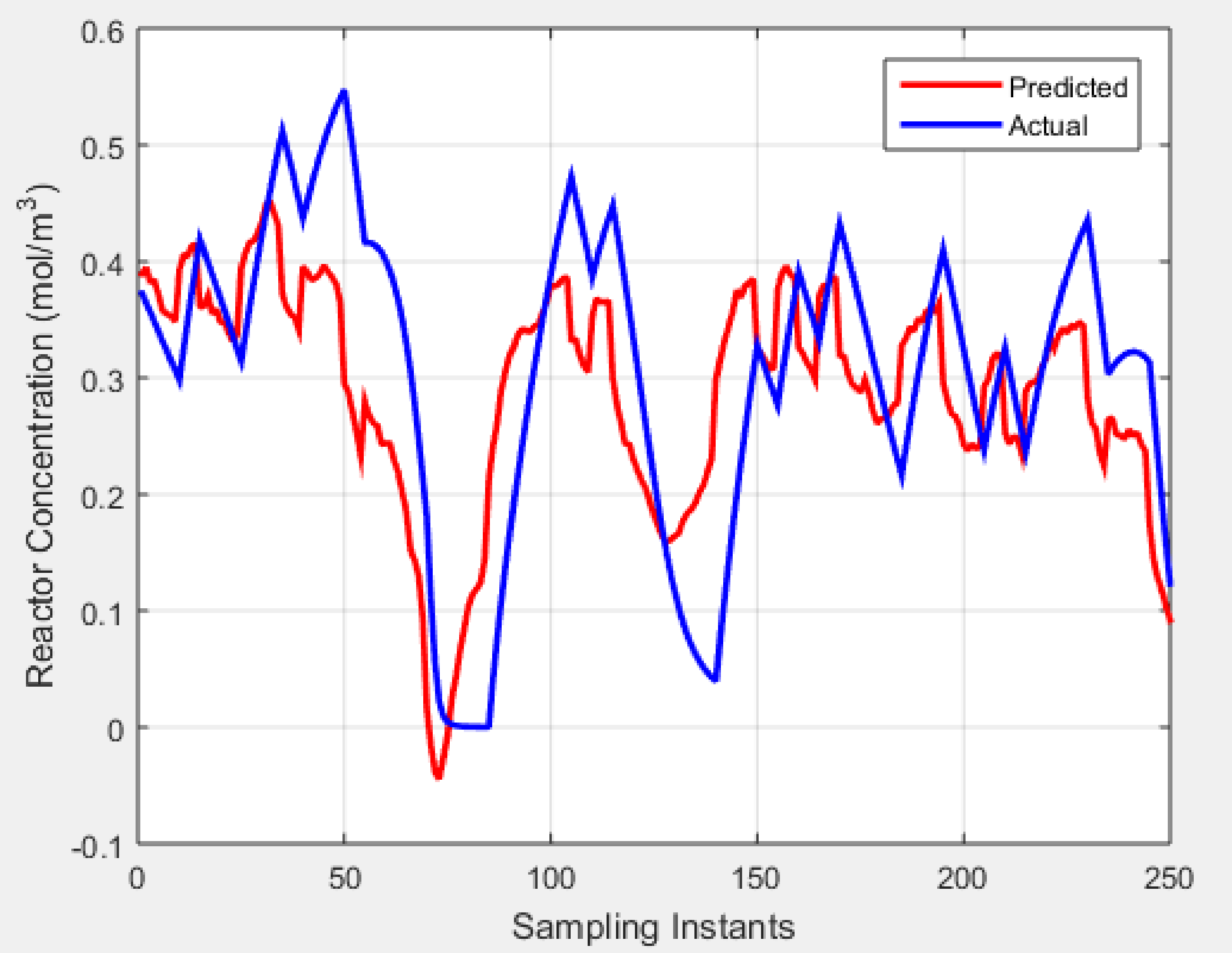


Fig : Predicted Reactor Concentration

Some more outputs for Prediction of Concentration :

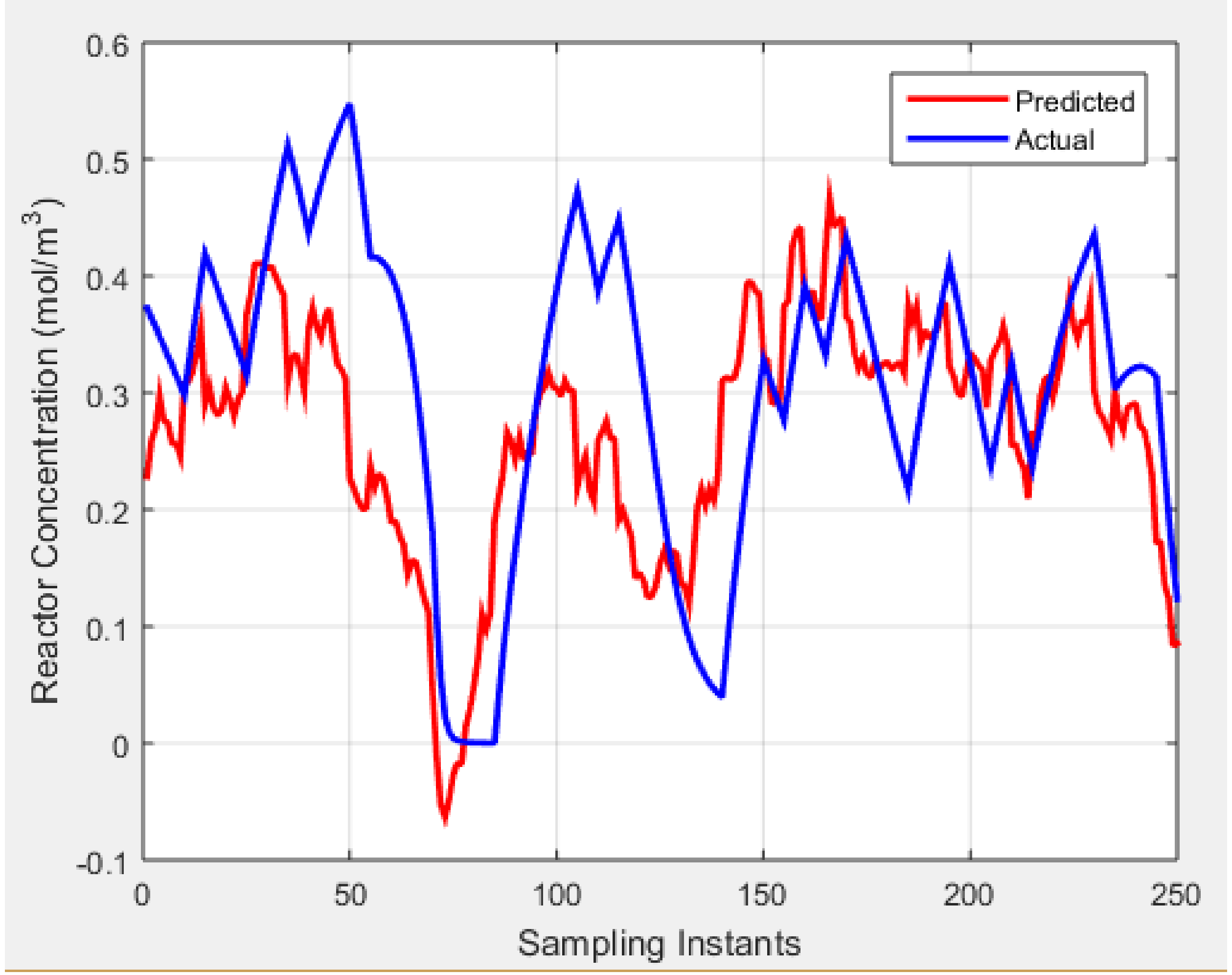


Fig : Predicted Reactor Concentration

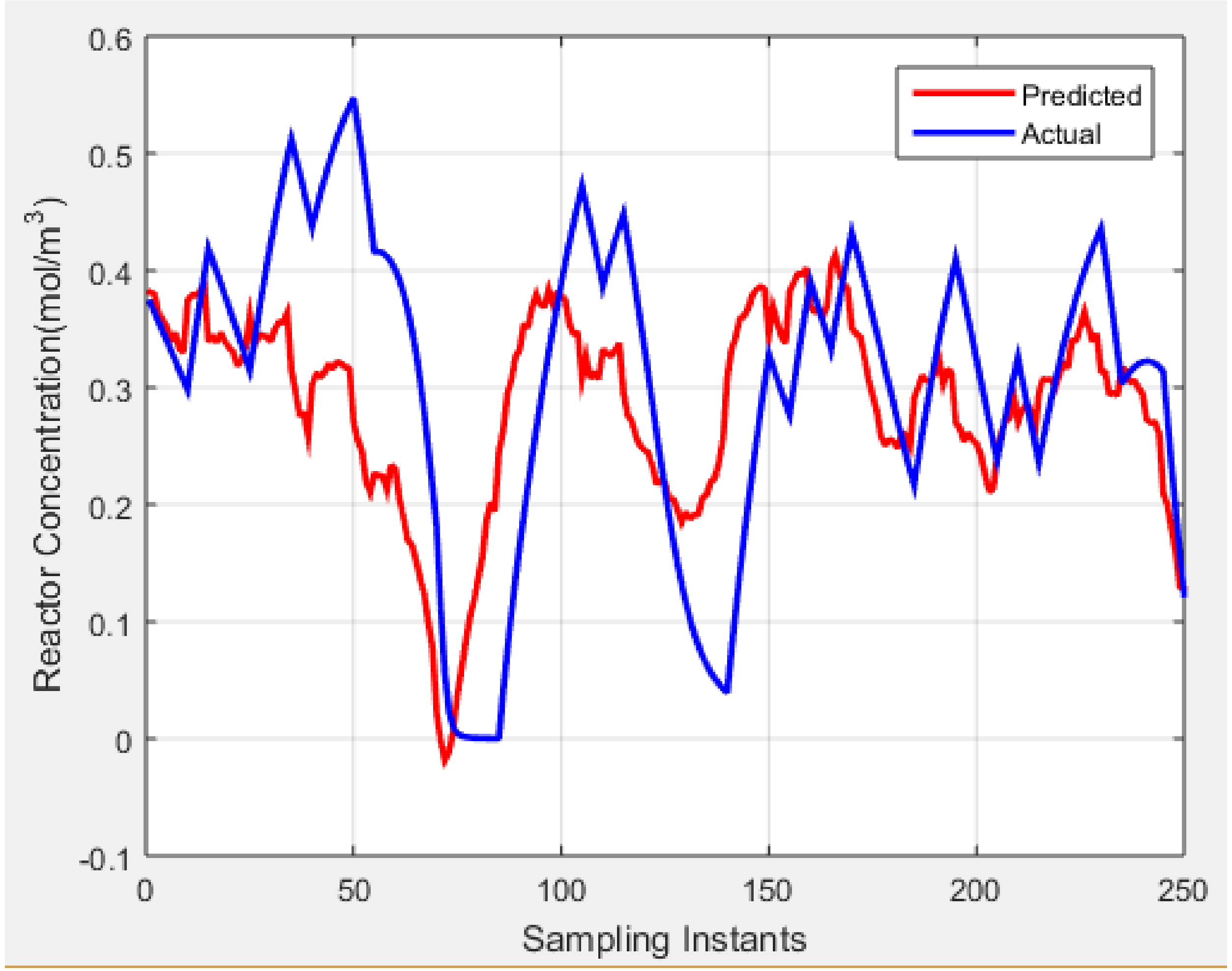


Fig : Predicted Reactor Concentration

Prediction outputs using Dynamic PLS :

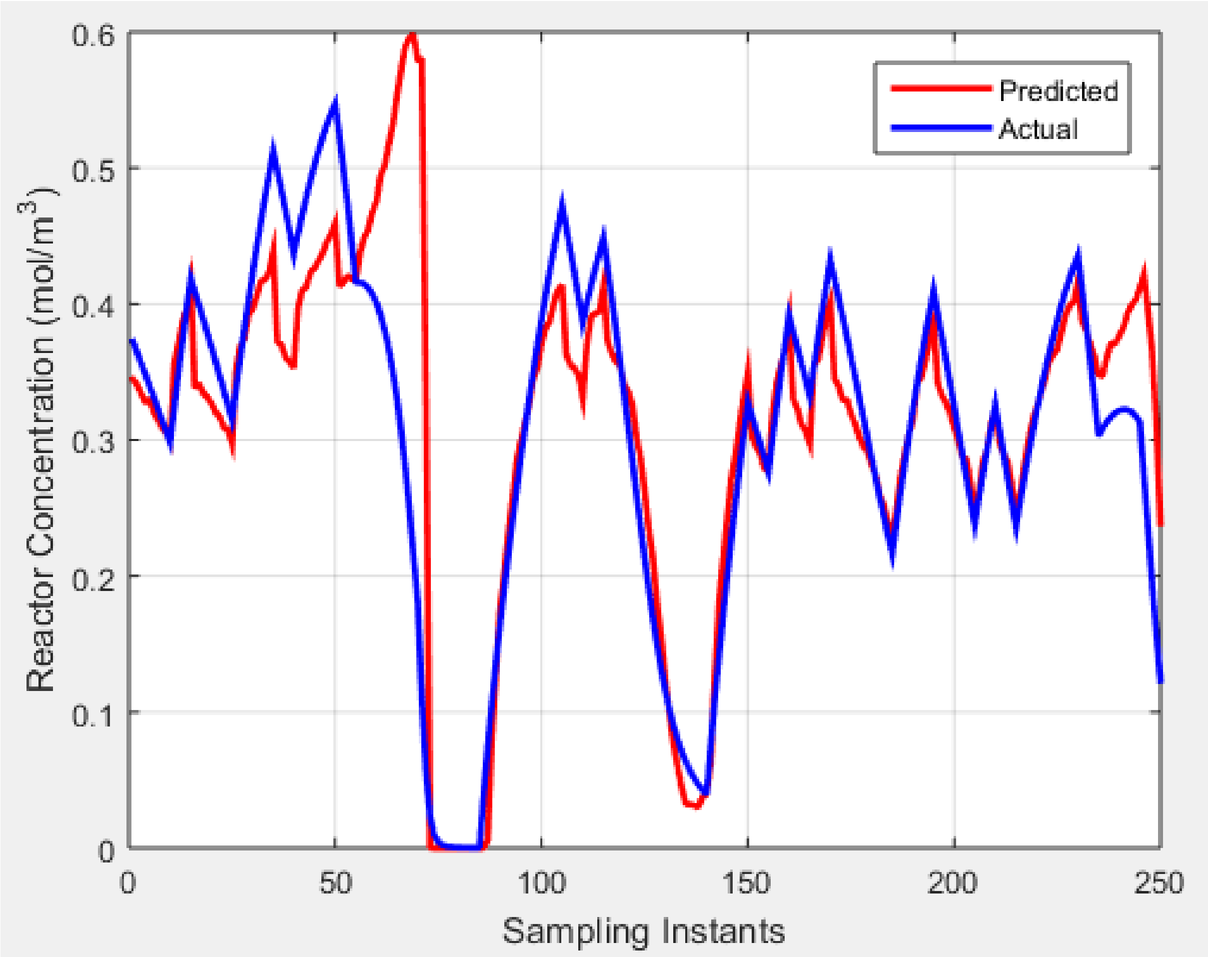


Fig : Predicted Reactor Concentration

Some more outputs for Prediction of Concentration (Using Dynamic PLS):

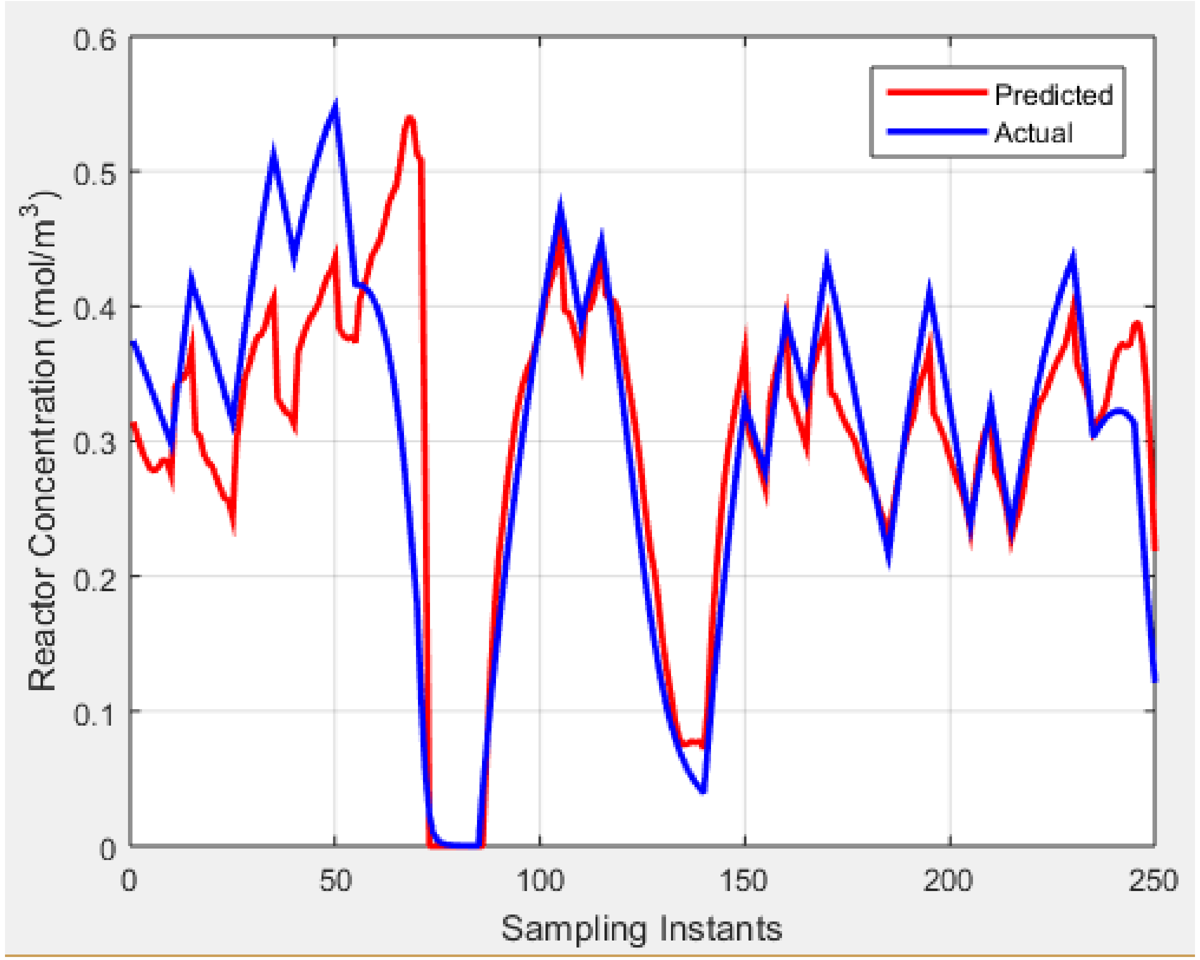


Fig : Predicted Reactor Concentration

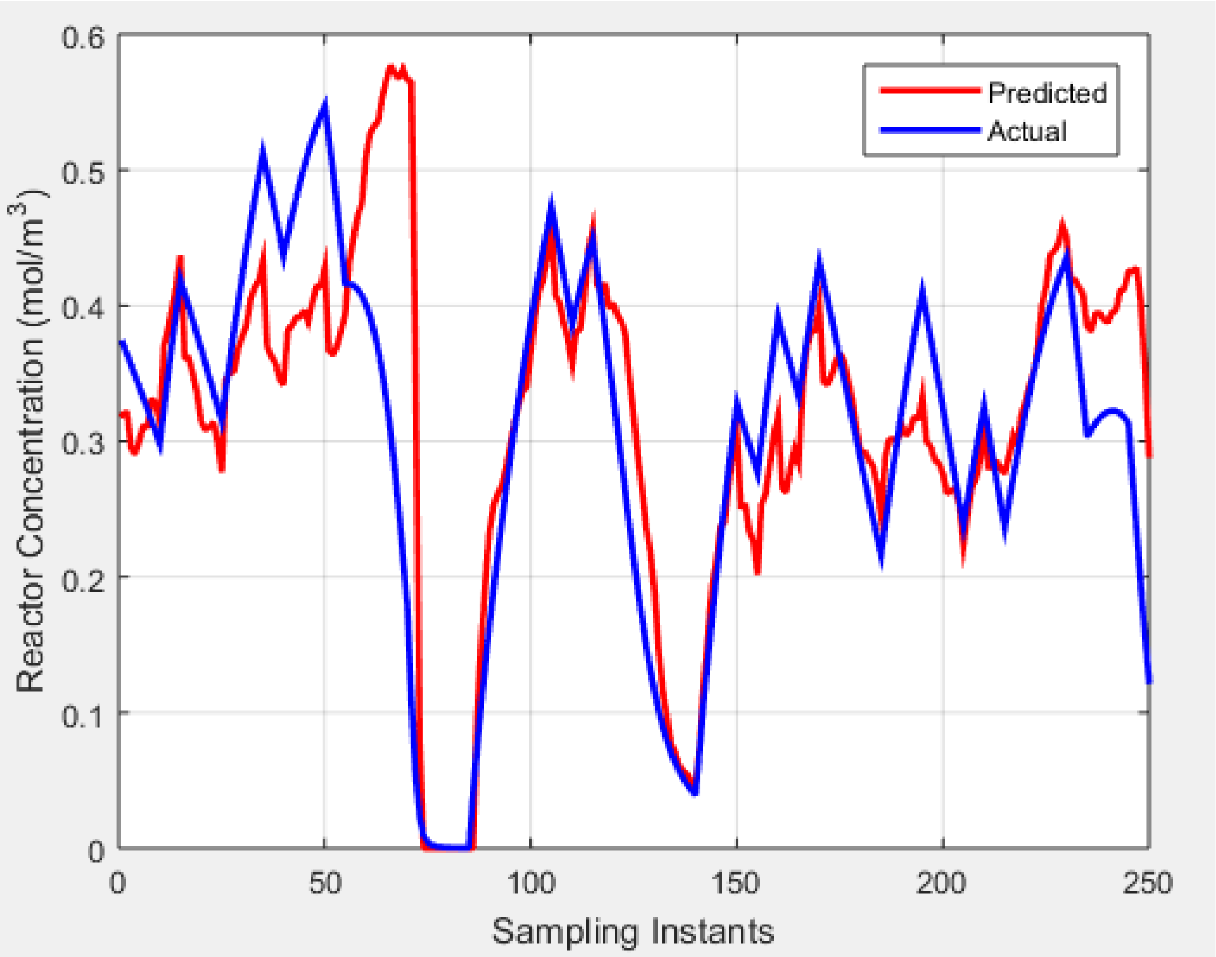


Fig : Predicted Reactor Concentration

THANK YOU