International Journal of ChemTech Research
CODEN (USA): IJCRGG ISSN: 0974-4290
Vol.7, No.4, pp 1843-1848, 2014-2015

# Nonlinear Block-Box Modelling And Control A Shell And Tube Heat Exchanger Using Generalized Predictive Controller

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**Abstract:** This paper describes the Generalized Predictive Control (GPC) intented for Shell and tube Heat exchanger. Essentially in many cases the conventional controller IMC based PID doesn't provide the satisfactory control action for a highly nonlinear system. So that here GPC is designed and it is used to control the outlet temperature of a tube side by varying the inlet cold fluid through the shell side. Here Recursive least Square technique used to estimate the parameters and build the extract model of a process. The MATLAB platform is used and accomplished of the GPC and Conventional IMC based PID controller.
**Keywords:** Heat exchanger, Generalized Predictive control (GPC), Recursive least squares (RLS), IMC (Internal model controller).

## I. Introduction:

Heat exchanger is one of the key elements of the petrochemical industries and thermal plants, which is having nonlinear, multivariable and non-stationary process. Both modeling and controlling a Shell and tube Heat exchanger is a very difficult task because it is highly nonlinear system purpose of heat exchanger is transfer the heat from one fluid to another with minimum loss[1-3]. There are different types of heat exchangers used in industries here we are used in shell and tube heat exchanger because it is higher efficiency [4-6]. Actually tubes of heat exchanger are fixed inside the shell. Both having separate inlets and outlets, no mixing and direct contact among the fluids. Hot fluid is flow through the tube and cold fluid flowing through the shell. In industries, large heat exchanger networks are engaged to operate wasted heat energy. Actually heat transfer process is highly nonlinear in nature. In many cases conventional PID controllers are used in industry, but they face difficulties in controlling non-linear process and cannot predict immediate change in an input[7- 9]. To overcome these difficulties MPC controller is used and it is mainly used for industries side[10]. Actually Heatexchanger mathematical model needs to be implemented the predictive controller so that here the real time data will be taken from the Heat exchanger and the model will be developed from with the help of system identification technique[,11] Some review articles consider MPC on academic perspective. Some paper deal with (SMPC) simplified model predictive control algorithm [12].Generalized predictive controller (GPC) is the most popular controller and it's generally used it can be accept the state space representation models and reduce the computational time[13-16].

## II. Recursive Least Square:

Linear model can be obtained by two ways one is system identification and another one is linearization of a nonlinear model. System identification techniques used through experimental study is possible, but the nonlinear model of the process having different open loop and closed loop studies as possible[17,18]. Actually linear block box model can be developed by correlating sequence relationship between input and output data. After obtaining the data model has been developed by using a Recursive least square algorithm[19] (RLS). The many practical causes it is necessary that parameter estimation takes place concurrently system operation it is parameter estimation problem is called online identification and it is methodology usually leads to recursive procedure for every new measurement for this region is also called as recursive identification. Fig.1 shows that experimental setup of heat exchanger.

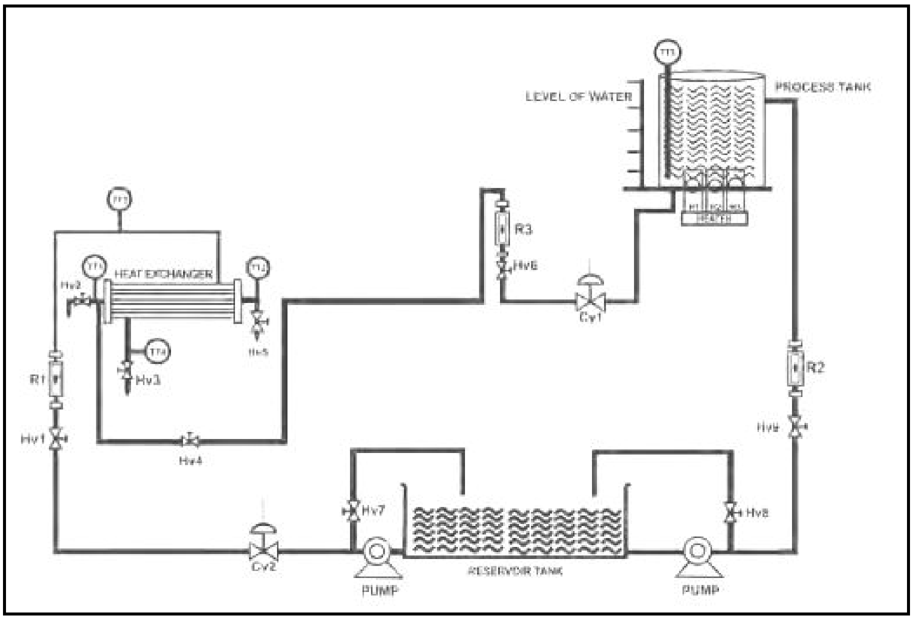


**Fig.1. Heat exchanger Experimental setup**

R1 – cold water flow rate
R2 – Tank filling water flow rate
R3 – Hot water flow rate
TT1 – Tube inlet temperature
TT2 – Tube outlet temperature
TT3 – Shell inlet temperature
TT4 – Shell outlet temperature
TT5 – Tank temperature
Cv1 – Tube flow control valve
Cv2 – Shell flow control valve
Hv1, Hv2, Hv3, Hv4, Hv5, Hv6 – Hand valves
Where is change in θ(N) because of the new (n+1) measurement

$$\theta(t) = \left(\sum_{k=1}^{t} \phi(K)\,\phi(K)^{T}\right)^{-1} \left(\sum_{k=1}^{t} \phi(K)\, y(K)\right)$$

Define P (t) as

$$P(t) = \left(\sum_{k=1}^{t} \phi(t)\ \Psi(K)^{T}\right)^{-1} \quad (1)$$

$$P(t)^{-1} = P(t-1)^{-1} + \phi(K)\, y(K) \quad (2)$$

θ is denoted as the estimated parameter vector

$$\theta(t) = P(t)\left(\sum_{k=1}^{t} \sum^{t}{}_{k=1}\phi(K)\, y(K)\right) + \phi(t)\, y(t) \quad (3)$$

$$\sum_{k=1}^{t-1} \phi(K)\, y(K) = P(t-1)^{-1}\,\theta(t-1) \quad (4)$$

$$= P(t)\,P(t-1)^{-1}\ \theta(t-1) + P(t)\,\phi(t)\,y(t)$$

$$P(t-1)^{-1} = P(t)^{-1} - \phi(t)\,\phi^{T}(t)$$

$$= P(t)\ (P(t)^{-1} - \phi(t)\,\phi^{T}(t))\ \ \theta(t-1) + \phi(t)\,y(t)\ ) \quad (5)$$

We will obtain new estimate to θ denoted as θ (N+1)

$$\theta(t) = P(t)\ (\ (P^{-1}(t)\ \ \theta(t-1) - \phi(t)\,\phi^{T}(t)\ \ \theta(t-1) + \phi(t)\,y(t) \quad (6)$$

$$\theta(t) = \theta(t-1) - P(t)\,\phi(t)\,\phi^{T}(t)\ \ \theta(t-1) + P(t)\,\phi(t)\,y(t)$$

$$\theta(t) = \theta(t-1) + P(t)\ \phi(t)\ \ (y(t) - \phi^{T}(t)\ \ \theta(t-1)\ )$$

$$E(t) = y(t) - \phi^{T}(t)\ \ \theta(t-1)$$

$$U(t) = \phi(t)\,\phi(t) \quad (7)$$

## III. **Generalized Predictive Controller**

The MPC provides various algorithms and best algorithm is Generalized Predictive Algorithm (GPC). MPC is one of the advanced control strategies, which can predict the future response of the plant and optimize the control input with the help of a model of the plant. The prediction model will be augmented by the model of state space matrices[20-23].

The augmented matrix given as

$$\begin{bmatrix} \Delta x_m(k+1) \\ y(k+1) \end{bmatrix} = \begin{bmatrix} \Delta x_m(k) \\ y(k) \end{bmatrix} + \overbrace{\begin{bmatrix} \beta_m \\ \gamma_m \beta_m \end{bmatrix}}^{\beta} \Delta u(k) \quad (8)$$

$$y(k) = \overbrace{\begin{bmatrix} 0_m & 1 \end{bmatrix}}^{\gamma} \begin{bmatrix} x_m(k) \\ y(k) \end{bmatrix} \quad (9)$$

Where $0_m = \underbrace{\begin{bmatrix} 0_m & 1 \end{bmatrix}}_{n_1}$

$\alpha_m, \beta_m$ and $\gamma_m$ are represented by the plant parameters. $\Delta u(k1) + \cdots + \Delta u(k_i + N_c - 1)$ are represented by the future control signals .Here the $N_C$ represents the control horizon and $N_P$ represents the prediction horizon. The future state variables are estimated as

$$x(k_i+1|k_i) = \alpha x(k_i) + \beta \Delta u(k_i)$$
$$x(k_i+2|k_i) = \alpha^2 x(k_i) + \alpha\beta\Delta u(k_i) + \beta\Delta u(k_i+1)$$
$$\vdots$$
$$x(k_i+N_p|k_i) = \alpha^{N_p} x(k_i) + \alpha^{N_p-1}\beta\Delta u(k_i) + \ldots + \alpha^{N_p-N_c}\beta\Delta u(k_i+N_c-1) \quad (10)$$

The future output is,

$$y(k_i+1|k_i) = \gamma\alpha x(k_i) + \gamma\beta\Delta u(k_i)$$
$$y(k_i+2|k_i) = \gamma\alpha^2 x(k_i) + \gamma\alpha\beta\Delta u(k_i) + \gamma\beta\Delta u(k_i+1)$$
$$\vdots$$
$$y(k_i+N_p|k_i) = \gamma\alpha^{N_p} x(k_i) + \gamma\alpha^{N_p-1}\beta\Delta u(k_i) + \ldots + \gamma\alpha^{N_p-N_c}\beta\Delta u(k_i+N_c-1) \quad (11)$$

From the eqn (4), output generalized use

$$Y = Fx(k_i) + \emptyset u \quad (12)$$

Where $F = \begin{bmatrix} \gamma\alpha \\ \gamma\alpha^2 \\ \vdots \\ \gamma\alpha^{N_p} \end{bmatrix}_{(N_p X 1)}$

$$\text{And } \emptyset = \begin{bmatrix} \gamma\beta & 0 & 0 & \ldots & 0 \\ \gamma\alpha\beta & \gamma\beta & 0 & \ldots & 0 \\ \vdots & \vdots & \vdots & \ldots & \vdots \\ \gamma\alpha^{N_p-1}\beta & \gamma\alpha^{N_p-2}\beta & \gamma\alpha^{N_p-3}\beta & \ldots & \gamma\alpha^{N_p-N_c}\beta \end{bmatrix}_{(N_p X N_c)} \quad (13)$$

Eqn (6) and Eqn (7) further used to minimize the cost function. The main objective is predicted output is near as possible to the set point. $\Delta U$ is mainly used to change the control signal and it should find the error between predicted output and the set point is minimized

$$R_s^T = \overbrace{\begin{bmatrix} 1 & 1 & \ldots & 1 \end{bmatrix}}^{N_p} r(kk) \quad (14)$$

Here we assume the set point is constant and the cost function J is defined by

$$J = (R_s - Y)^T (R_s - Y) + U^T \bar{R} U \quad (15)$$

$R = r_{W_{N_c X N_c}}$ Where the $r_w$ is tuning parameter,

Substituting the output (Y) equation and we get

$$J = (R_s - Fx(k_i))^T (R_s - Fx(k_i)) - 2\Delta U^T \Phi^T (R_s - Fx(k_i)) + \Delta U^T (\Phi^T \Phi + R)\Delta U \quad (16)$$

Here our objective cost function is minimized and we get J is respect to $\Delta U$

$$\Delta U = (\Phi^T\Phi + R)^{-1}\Phi^T(R_s r(k_i) - Fx(k_i)) \quad (17)$$

## IV. Results and Discussion:

The real time data are taken from the experimental Shell and tube Heat exchanger Table (I) shown shell flow rate and sampling instants and fig (2) shows that Temperature response of the process. The PID is adjusted by the internal model controller (IMC) method. Both the IMC based PID controller and GPC controller for the Shell and tube heat exchanger validated using MATLAB environment and the result is obtained. The GPC controller tunning strategies are shown in Table (II) and IMC based PID control tuning parameters are shown in Table (III) and then the performance indicates in tabulated in Table (IV).The GPC and IMC based PID response shown in fig(3) positive disturbance response shown in fig(4) and the negative disturbance response plotted in the fig (5) from the responses we prove that GPC gives fast response and quick setting time of the IMC based PID.

**Table.I. Shell Flow Rate And Sampling Instants**

| Shell inlet Flow rate (LPH) | Sampling Instants |
|---|---|
| 450 | 1500 |
| 450-300 | 1500-2500 |
| 300-250 | 2500-3500 |
| 250-200 | 3500-4500 |
| 200-150 | 4500-5800 |

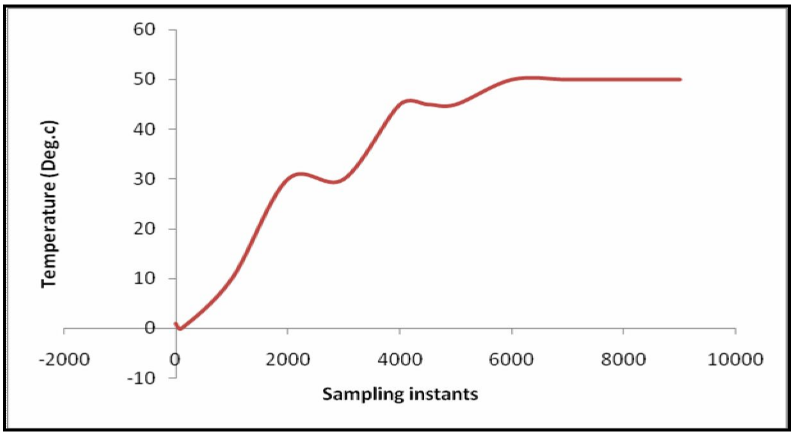


**Fig.2. Temperature Profile**

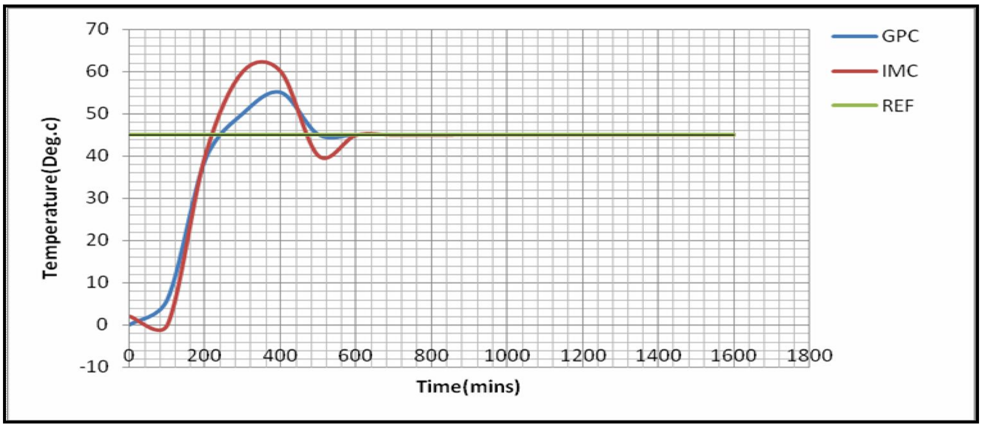


**Fig.3. Comparison the response of IMC and GPC**

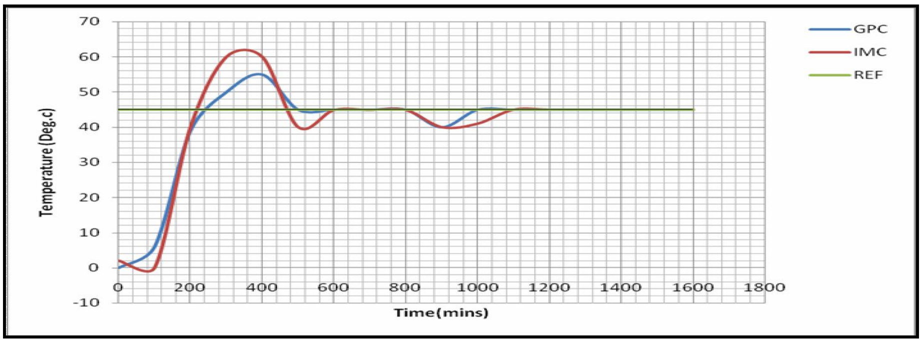


**Fig.4. Comparison the response of negative disturbance in PID and GPC**

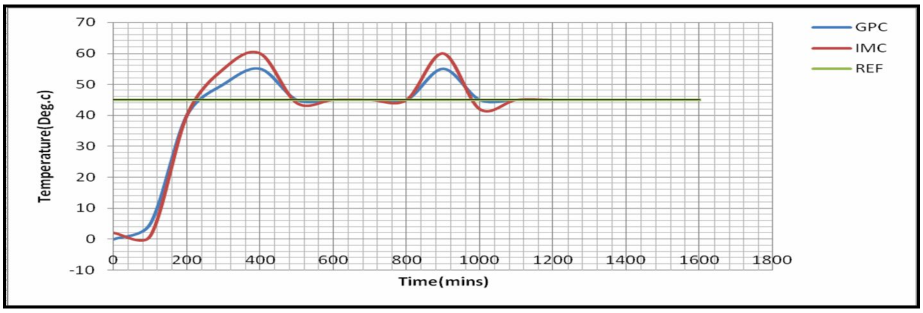


**Fig.5.Comparison the response of positive disturbance in IMC and GPC**

**Table II: Tuning the Parameters of GPC**

| Parameter | Value |
|---|---|
| $N_P$ | 10 |
| $N_C$ | 7 |
| T | 3 |

**Table III: Tuning the Parameters of IMC Based PID**

| Parameter | Value |
|---|---|
| P | 1.2 |
| I | 1 |
| D | 0.05 |

**Table IV: Performance Measure Characteristics**

| Controller | Ise | Iae | Itae |
|---|---|---|---|
| IMC | 180.860 | 500.60 | 7.210 |
| GPC | 120.450 | 221.45 | 2.456 |

## V. Conclusion:

In this work GPC is designed and control a shell and tube heat exchanger and its response compared with an IMC based PID. The comparison has been done between GPC and IMC based PID, it shows that GPC provided better performance than PID by observing ISE (Intergral square error), IAE( Integral absolute error) and ITAE (Integral time- weighted absolute error).

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