# Predictive Control of Coagulant Dosage in Water Treatment Plant

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***Abstract***— **Coagulation is an important process in the drinkable water treatment plant. The traditionally used jar test is time consuming and less adaptive to the change in water quality. In this paper, the model predictive control (MPC) strategy is chosen to determine the optimal coagulant dosage. The predictive controller uses a model of the process and alters the dosage rate in order to fulfil the control objective.**

***Keywords***— ***Coagulation, Model Predictive Control.***



## I. INTRODUCTION

The dirty and turbid water contains microorganism and chemicals that may cause illness to the consumer. The removal of turbidity and to produce water that is acceptable to drink is an important aspect of water treatment plant. The water treatment involves a sequence of various physical and chemical processes. In many water treatment plants, the control process is accomplished based on the operator's experience and jar test. These are time consuming and less adaptive to the change in the water quality. This paper deals with the design of a predictive controller for a water treatment process. In the considered process the raw water is treated in order to obtain an effluent having the substrate concentration within the standard limits (below 40 mg/l). The predictive controller uses a model of the process and alters the dosage rate in order to fulfil the control objective.

## II. OVERVIEW OF WATER TREATMENT PLANT

There are various stages for the treatment of water in a plant. Firstly, the preliminary treatment or pretreatment is any physical, chemical or mechanical process used on water before
it undergoes the main treatment process. During preliminary treatment:

- Screens may be used to remove rocks, sticks, leaves and other debris;
- Chemicals may be added to control the growth of algae; and
- A pre-sedimentation stage can settle out sand, grit and gravel from raw water.

After preliminary treatment, the next step is coagulation. Coagulation removes small particles that are made up of microbes, silt and other suspended material in the water. Treatment chemicals such as alum are added to the water and mixed rapidly in a large basin. The chemicals cause small particles to clump together (coagulate). Gentle mixing brings smaller clumps of particles together to form larger groups called "floc". Some of the floc begins to settle during this stage. The next stage is flocculation. During the flocculation stage, the heavy, dense floc settles to the bottom of the water in large tanks. As you can imagine, this can be a slow process. Once the floc settles, the water is ready for the next stage of treatment. Clarification occurs in a large basin where water is again allowed to flow very slowly. Sludge, a residue of solids and water, accumulates at the basin's bottom and is pumped or scraped out for eventual disposal. Clarification is also sometimes called sedimentation. The coagulate used is aluminum sulphate.

## III. MODELLING OF WATER TREATMENT PLANT

In this paper, each process of the treatment plant is represented as a mixing process. The coagulation is a fast mixing process, so that the coagulant can get easily dispersed in raw water. The flocculation and the sedimentation is considered to be a slow mixing process. At the end of the sedimentation process, sludge gets settled at the bottom. The sludge is removed continuously.
The mass balance equation can be represented as:

$$qc_{ssi} - qc_{sso} = \frac{d}{dt}(vc_{sso})$$

Where,

Cssi = concentration of suspended solid particle in influent water (NTU)
Csso = concentration of suspended solid particle in outlet water (NTU).
V= Volume of the tank (gal)
q =flow rate of inlet water (gpm)

**Detention time** is the length of time water is retained in a vessel or basin or the period from the time the water enters a settling basin until it flows out the other end. When calculating unit process detention times, we are calculating the length of time it takes the water to flow through that unit process.

## IV. MODEL PREDICTIVE CONTROL

Model predictive control is a new generation of control-system design techniques that uses the fast computing power of modern computers. The techniques are simple and can be implemented on dedicated microprocessors. It has been used in industry for many years. Model predictive control offers several important advantages:

1) The process model captures the dynamics and static interactions between input, output and disturbance variables
2) Constraints on input and outputs are considered in a systematic manner
3) The control calculations can be coordinated with the calculation of optimum set points
4) Accurate model predictions can provide early warning of protection problems

Model predictive controllers rely on dynamic models of the process, most often linear empirical models.The applied models are determined to depict the behaviour of complex dynamical systems. The models shall compensate for the impact of non-linearities of variables and the chasm caused by non coherent process devolution.

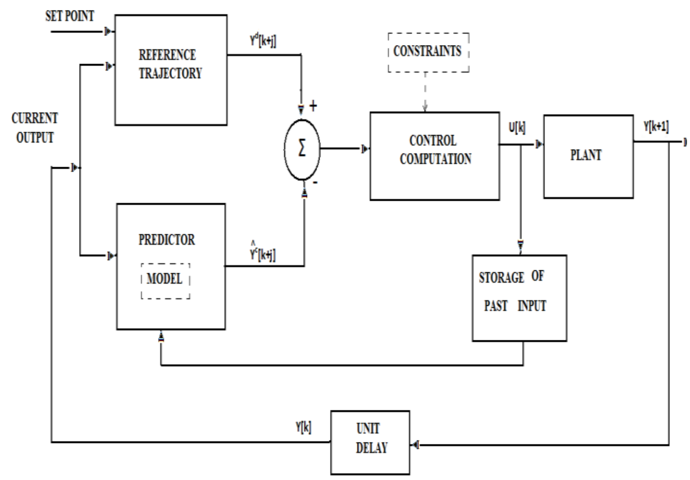


Fig 1. Block diagram of a model predictive control

Hence the models are used to predict the behavior of dependent variables (i.e. outputs) of the modeled dynamical system with respect to changes in the process independent variables (i.e. inputs). In chemical processes, independent variables are most often set-points of regulatory controllers that govern valve movement (e.g. valve positioners with or without flow, temperature or pressure controller cascades), while dependent variables are most often constraints in the process (e.g. product purity, equipment safe operating limits). The model predictive controller uses the models and current plant measurements to calculate future moves in the independent variables that will result in operation that honors all independent and dependent variable constraints. The MPC then sends this set of independent variable moves to the corresponding regulatory controller set-points to be implemented in the process.

A discrete model of the form

$$x[k+1] = A\,x[k] + B\,u[k]$$

$$Y[k] = Cx[k]$$

The control moves are obtained by minimizing a cost function which is square of the difference between the desired output and predicted output.

$$J = \sum_{i=1}^{p} w_i (y^d[k+i] - \widehat{y^c}[k+i])^2 + \sum_{i=1}^{m} r_i\,(\Delta u[k+i-1])^2]$$

Where $w_i$ and $r_i$ are the weights. P and m are prediction and control horizon.

$$min[J] = \min_{\Delta u[k],\ldots u[k+p-1]} \left\{ \sum_{i=1}^{p} w_i (y^d[k+i] - \widehat{y^c}[k+i])^2 + \sum_{i=1}^{m} r_i\,(\Delta u[k+i-1])^2 \right\}$$

In vector domain, J can be represented as

$$\min_{\Delta u[k]} J = \hat{E}[k+1]^T Q\,\hat{E}[k+1] + \Delta U[k]^T R\,\Delta U[k]$$

Where, Q is a positive definite matrix and R is positive semi definite matrix and $\hat{E}[k+1]$ and $\Delta U[k]$ are

$$\hat{E}[k+1] \triangleq \{Y^d[k+1] - \widehat{Y^c}[k+1]\}$$
$$\Delta U[k] \triangleq col[\Delta u[k], \Delta u[k+2], \ldots \Delta u[k+M-1]]$$

The constraints on the input and output are considered during the control computation.

$$u_{max} \geq u[k+i-1|k] \geq u_{min}, i = 1,..,m$$
$$\Delta u_{max} \geq \Delta u[k+i-1|k] \geq -\Delta u_{max}, i = 1,..m$$
$$y_{max} \geq y[k+i|k] \geq y_{min}, i = 1,\ldots,p$$

The cost function is minimized by calculating the differential of J with respect to $\Delta U$ and setting it equal to zero. This value of control signal is obtained when no constraints are enforced.

$$\Delta U[k] = (A^T \mathrm{Q}\,\mathrm{A} + \mathrm{R})^{-1} \mathrm{A}^T\,\mathrm{Q}\,\hat{\mathrm{E}}[k+1]$$

Where, $A=\begin{bmatrix} a_1 & 0 & 0\cdots 0 \\ a_2 & a_1 & 0\ldots 0 \\ & \vdots & \\ a_{R-1} & & 0 \\ a_R & a_{R-1}\ldots & 0 \end{bmatrix}$

$$a_i = \sum_{j=1}^{i} h_j$$
$$a_1 = h_1$$
$$a_2 = h_2 + h_1$$
$$\vdots \quad a_{R-1} = h_1 + h_2 + \cdots + h_{R-1}$$
$$a_R = h_1 + h_2 + \cdots + h_R$$

Once an input sequence is computed, the first input is applied to the plant and the cycle is repeated after the next measurement.To make the problem traceable, the error is considered only at a few points in the future, and the future controls are held constant over intervals(“block”) between the output-matching points. To improve control computations for general systems, a gradient-projection algorithm has been developed. The classic controller,of the PID type, cannot handle constraint requirements easily. On the other hand, MPC can satisfy these constraints each the predictive control action is taken. At each instant in time, an optimal direction and a step size according to a pre-specified criterion.

## V. SIMULATION RESULT

The response of the control strategies PID and MPC for the coagulant dosage are evaluated. The Block Diagram of PI with Feed forward control is shown in Fig 2.

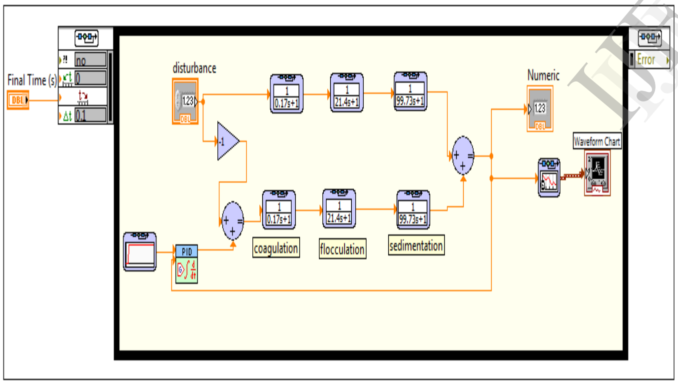


Fig 2 Block diagram of PI with Feed forward control

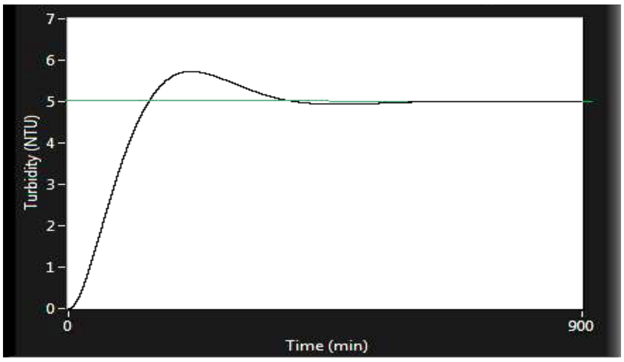


Fig. 3 Response of PI with Feed Forward control

The scope (in Fig.3) shows the response of PID controller, when step input of magnitude 5NTU is given as a set point. The parameter for the controller is chosen, using the zeigler-nicols tunning method, kp=4.481sec, ki=0.0645 $sec^{-1}$. An overshoot occurs due to the integral action. This is further removed when MPC controller. The settling time of the process is 500min. The variation in the inlet turbidity, which is the disturbance, is taken into account by including a feed- forward control.

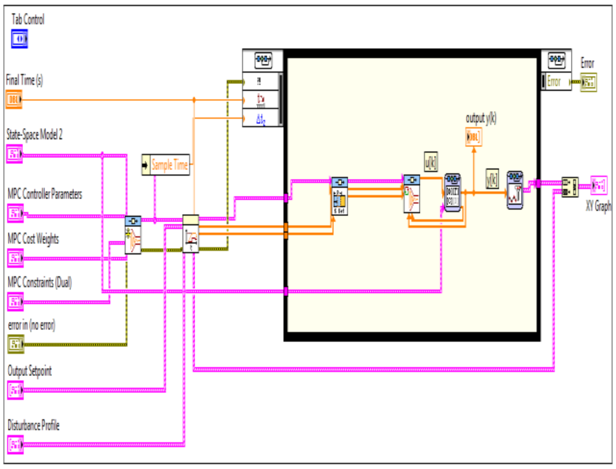


Fig.4 Simulation of MPC control in Labview

The parameters used for the control is, prediction horizon=100, control horizon =10, control error coefficient=10 with sampling instant 1sec.

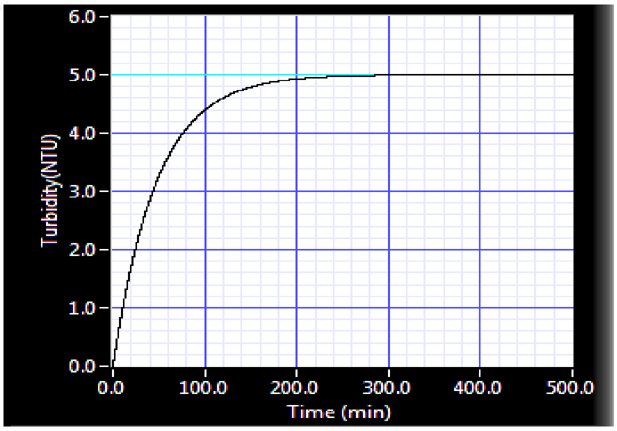


Fig.5: Response of MPC in Labview

In Fig.5 shows the closed loop simulation of MPC without any constraints. The model predictive control has eliminated the overshoot and reduced the settling time of the process output. The settling time is 300min. Thus the MPC gives a smooth and better response.

## VI. CONCLUSION

A novel control algorithm is proposed for the water treatment plant for the control of coagulant dosage in this paper. The model of the system is derived first. Then model predictive controller is used to control the dosage of coagulant based on the model. From the simulation results it is clear that the algorithm has good robustness and has obtained a good control result.

## VII. REFERENCES

[1] Abderrahim Abbas:- Model predictive control of a reverse osmosis desalination unit, Desalination 194 (2006) 268–280.

[2] Atalla F. Sayda , James H. Taylor :- Model predictive control of a mechanical pulp bleaching process. Proc. IFAC Workshop on Time-Delay Systems (TDS'03), Rocquencourt, France, 2003, 8--10.

[3] Bastiaan Blankert , Ben H.L. Betlem , Brian Roffel:- Development of a control system for in-line coagulation in an ultrafiltration process, Journal of Membrane Science 301 (2007) 39–45.

[4] Claude Gagnon, Bernard P.A.Grandjean and Jules Thibault:- Modelling of coagulant dosage in water treatment plant. Artificial Intelligence in Engineering 11 (1997) 401-404.

[5] C.L.Chen and P.L.Hou:-Fuzzy model identification and control system design for coagulation chemical dosing of potable wate, Water Science and Technology Vol 42 Nos 3–4 pp 403–408,IWA Publishing 2000.

[6] Frank R. Spellman: --Mathematics Manual for water and wastewater treatment plant operators,second edition 2004.

[7] Frank R. Spellman: ―Handbook of Water and Wastewater Treatment Plant Operations,2003.

[8] Guan-De Wu,Shang-LienLoc: ―Predicting real-time coagulant dosage in water treatment by artificial neural networks and adaptive network-based fuzzy inference system, Engineering Applications of Artificial Intelligence 21 (2008) 1189– 1195.

[9] Peter-Jules van Overloop, Steven Weijs, Sjoerd Dijkstra:- Multiple Model Predictive Control on a drainage canal system. Control Engineering Practice 16 (2008) 531–540.

[10] Vasile-Mircea Cristea, Cristian Pop, Paul Serban Agachi:- Model Predictive Control of the Waste Water Treatment Plant Based on the Benchmark Simulation Model No.1-BSM1,18th European Symposiumon Computer Aided Process Engineering,2008.