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DESIGN OF PSO-PID CONTROLLER FOR A NONLINEAR CONICAL TANK PROCESS USED IN CHEMICAL INDUSTRIES

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ABSTRACT

Conical tank process has become increasingly popular in many industrial sectors like Chemical Industries, Paramedical Industries, Fermentation Industries, Drugs Manufacturing Industries, etc. Conical tank plays a vital role in chemical industries for chemical mixing, chemical storage & waste product draining. It is very difficult to control the level of the conical tank as it has a non-linear property of varying diameter and volume. Hence, it needs a sophisticated method to control the process and the most reliable one is using the PID controller. The PID controller is the generic feedback control technology and it makes up 90% of automatic controllers in process industries and is also the cornerstone for many advance control algorithms and strategies. For regulating the PID Controller, many tuning rules have been enclosed. Though, it provides proper tuning of the PID and it does not provide optimal tuning. In this paper we proposed the conventional tuning, internal model controller tuning and Particle Swarm Optimization (PSO) tuning. The three results are compared based on the tuning values, time domain specifications and error criteria and the best tuning method is identified for a nonlinear conical tank system.

Keywords: PID controller, non-linear system, PSO-particle swarm optimization.

INTRODUCTION

Conical tank process is a tough control problem due to their nonlinear dynamic behavior, uncertain and time varying parameter values, constraint on the manipulated variables, interaction between the manipulated and the controlled variables, unmeasured and frequent disturbances, dead time on input and measurements. Because of the inherent nonlinearity, most of the chemical industries are in need of optimized control techniques. Conical tank process find wide application in gas plants, cement plants, Petroleum industries, Fermentation Industries and so on. Control of a level in a conical tank is important, because the change in shape gives rise to the nonlinearity. Due to the nonlinearity of the conical tank system, adaptive control techniques are widely used. It is considered as an adaptive servo system where the desired performance can be expressed in terms of the reference model, which gives the desired response to a command signal. The nonlinearity arises due to the plant transfer function that varies with the height of the liquid in a tank and the controller output to be adaptive and robust for these changes. The primary job of the controller is to maintain the process under stable condition even at different kinds of unknown disturbances [10].

In Chemical Industries**,** Conical tanks are used for chemical mixing, chemical storage and the settlement of raw sewage can also be used for the secondary treatment of sewage, have been used in the Water Utilities, commercial or industrial waste water solutions. The industrial conical bottom tank is fast moving and a leading choice in industrial storage. Conical Bottom Tanks are suitable when a complete drain out of the stored liquid is required (i.e.) for total evacuation of liquids. Suitable for both indoor and outdoor installations. The tanks require stands to support the conical bottoms. The conical tank should offer treatment for various flow rates and solid loadings. They can be used in a wide variety of applications where settlement of wastewater is required either in conjunction with existing processes or as part of a 'modular' package plant installation. Conical tanks are manufactured from medium- or high-density polyethylene with U.V. inhibitors and designed for containment of liquids of up to 1.7 specific gravity. Tank walls are translucent for level viewing and equipped with gallon indicators [26, 27, 28].

PROBLEM FORMULATION

In this section the controller equations are formulated as well as the assumed process model structure and the optimization problem that is proposed in order to tune the PID controller. Optimization is a powerful tool for design of controllers. The important step before formulating a controller is to calculate the mathematical relationship or the governing dynamics between the input and the output of the system. The fundamental principle and knowledge of the system should be investigated to realize the incidence of nonlinearity in the system dynamics. Recently, the interest in Particle Swarm Optimization Algorithm is growing due to their difference from ordinary optimization tools [21].

There are wide collections of control techniques that can be useful to encounter the control objective of the system and these depend on the factors of which the suggested design objective might depend on. There are issues such as tracking, reducing the effects of opposing conditions and uncertainty, behaviors in terms of time response (e.g., delay time, rise-time, peak overshoot, and steady state error) and lastly engineering goals such as cost and consistency which is vital in industrial standpoint. Superiority of controller scheme primarily depends on the degree of how the nonlinearity can be endured and assumed using the linearization theory.

Moreover, apart from nonlinearities, there may be a consequence of unknown parameters which hinders the objective to obtain a complete detail model of a process available for control purpose. The factors that abstained many researchers to use conventional control theory and techniques can be listed as follows:-

- Systems are nonlinear and may contain unknown parameters. That unknown parameters may not be estimated accurately if reliable experimental data is absent.
- The delays present in the process of system (conical tank system specifically) might complicate achieving high performance control.
- There are several cases such as that of conical tank in industry where the process or disturbance characteristics are changing continuously. This requires simultaneous regulation of various variables in order to maintain the desired liquid level. Thus, a model must account for all of the most significant variables of the process.

Due to the above mentioned factors, it might be difficult to formulate a control strategy based on the analytical model because the mathematical model is usually linearized to FOPTD in account for complexity and nonlinearity which are inevitable in a complicated system. PID (proportional-integral-DERIVATIVE) control is one of a kind of control scheme that uses the approach of linearized model. However, the PID controller might not capable to satisfy the control objectives or requirement at all times as it need to be regularly tuned due to the varying system dynamics. Hence, it is desirable to have a robust and reliable control technique for modeling the complex and nonlinear system that prevails in all industrial process. Adaptive control is chosen as the conical tank's control scheme. The requirement to choose either two or three controller parameters has meant that the use of tuning rules to determine these parameters is popular. It is regarded as a novel approach in parameter adjustment for a system where process dynamics are nonlinear [23].

PID TUNING METHODS

"PID" is an acronym for "proportional, integral, and derivative". A PID controller is a controller that includes elements with those three functions. The conventional linear PID controller is combined by the following three terms linearly, the control error, the integral of the error, and the derivative of the error. Many researches and practices show that it is helpful to the control results when the three terms are constructed in some kind of nonlinear function forms. There are considerable papers present different ways to design nonlinear PID controller. Among them, those methods that modify linear PID controller using some kind of special nonlinear function are of more attractive to the engineering application [24].

Astrom and Hagglund Tuning Method

In 1984, Karl Astrom and Tore Hagglund of the Lund (Sweden) Institute of Technology proposed a less risky alternative to the Ziegler-Nichols open-loop test. Their relay method generates a sustained oscillation of the process variable but with the amplitude of those oscillations restricted to a safe range. The Astrom-Hagglund method works by forcing the process variable into a *limit cycle* as shown in the "relay test" graphic. With all three PID terms temporarily disabled, the controller uses an on/off relay to apply a step-like control effort to the process. It then holds the control effort constant and waits for the process variable to exceed the set point. At that point, it applies a negative step and waits for the process variable to drop back below the set point. Repeating this procedure each time the process variable passes the set point in either direction forces the process variable to oscillate out of synchronization with the control effort but at the same frequency [24].

PID Parameters for Astrom and Hagglund Method

Proportional constant:

$Kc= 5Tm/6(Km\ \tau_{m)}=0.73$

Integral constant:

$Ti= 1.5\ \tau_m=0.06$

Derivative constant*:*

$Td=0.25\ \tau_m=1.54$

Internal Model Control

Internal model control is model based controller structure that provides a suitable framework for satisfying our objectives. The IMC structure which makes use of a process model to infer the effect of immeasurable disturbance on the process output and then counteracts that effect. The controller consists of an inverse of the process mode. IMC design procedure depends exclusively on two factors: the complexity of the model and the performance requirements. The IMC based PID controller algorithm is robust and simple to handle the uncertainty in model. This method seems to be a useful trade-off for the performance of the closed loop system. It achieves robustness to model inaccuracies with a single tuning parameter. The IMC design procedure can be used to solve quite a few critical problems especially at the industrial level (using the concept of designing a model of the actual plant process). It also gives good solutions to processes having a significant time delay which actually happens when working in a real time environment. For tuning the controller the filter tuning parameter λ value is varied. According to that various effects of discrepancies enter in the system thus, best performance is achieved. Hence, a good filter structure is one for which the optimum λ value gives the best PID performance [3, 24].

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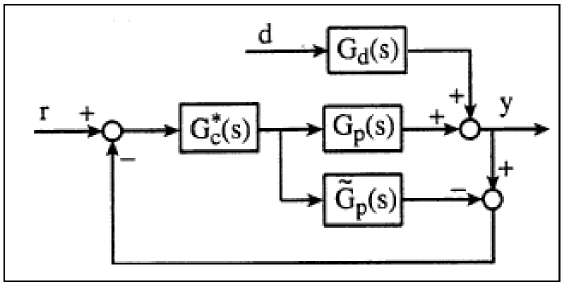

Figure-1. Internal model controller.

PID Parameters for IMC METHOD

Proportional constant:

Kc= 0.58

Integral constant:

Ti= 0.034

Derivative constant*:*

Td=1.31

Particle Swarm Optimization (PSO)

PSO is a robust stochastic optimization technique based on the movement and intelligence of swarms. PSO applies the concept of social interaction to problem solving. It was developed in 1995 by James Kennedy (social-psychologist) and Russell Eberhart (electrical engineer). It uses a number of agents (particles) that constitute a swarm moving around in the search space looking for the best solution. Each particle is treated as a point in a N-dimensional space which adjusts its "flying" according to its own flying experience as well as the flying experience of other particles.

The PSO algorithm consists of three steps, which are repeated until some stopping condition is met:

- Evaluate the fitness of each particle
- Update individual and global best fitness and positions
- Update velocity and position of each particle

Each particle keeps track of its coordinates in the solution space which are associated with the best solution (fitness) that has achieved so far by that particle. This value is called personal best, pbest. Another best value that is tracked by the PSO is the best value obtained so far by any particle in the neighborhood of that particle. This value is called gbest. The basic concept of PSO lies in accelerating each particle toward its pbest and the gbest locations, with a random weighted acceleration at each time step [1].

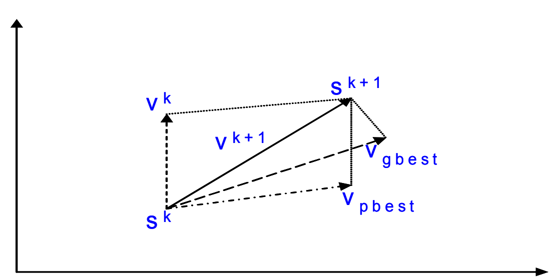

Figure-2. Graphical representation.

s^k: current searching point.
s^{k+1}: modified searching point.
v^k: current velocity.
v^{k+1}: modified velocity.
v_{pbest} : velocity based on pbest.
v_{gbest} : velocity based on gbest

Pseudo Code is a basic code for executing the PSO algorithm. The basic code is as follows,

```
For each particle
   Initialize particle
END
Do
   For each particle
      Calculate fitness value
      If the fitness value is better than the best fitness value
      (pBest) in history
      Set current value as the new pBest
 End
Choose the particle with the best fitness value of all the
particles as the gBest
   For each particle
      Calculate particle velocity according equation (a)
      Update particle position according equation (b)
End
While maximum iterations or minimum error criteria is not
attained.
```

In the PSO Algorithm, the system is initialized with a population of random solutions which are called 'particles' and potential solution is also assigned a randomized velocity. PSO relies on the exchange of the information between particles of the population called 'swarm'. Each particle adjusts its trajectory towards its best solution (fitness) that is achieved so far. This value is called pbest. Each particle also modifies its trajectory towards the best previous position attained by any member of its neighborhood. This value is called gbest. Each particle moves in the search space with an adaptive velocity.

The fitness function evaluates the performance of the particles to determine whether the best fitting solution is achieved. During the Run the fitness of the best individual improves over time and typically tents to stagnate towards the end of the run. Ideally, the stagnation of the process coincides with the successful discovery of the global optimum [6].

To start up with PSO, certain parameters need to be defined. Selection of these parameters decides, to a great extent, the ability of global minimization. The maximum velocity affects the ability of escaping from local optimization. The size of the swarm balances the requirement of global optimization and computational cost. Initializing the values of the parameters is as per the Table.

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Table-1. Parameter initialization.

Population size	100
Number of iterations	100
Velocity constant,c1	2
Velocity constant,c2	2

PID Parameters for PSO

When 100th iteration reached proportional gain(Kp), integral gain(Ki) and derivative gain(Kd) values are obtained. PID values are given below,

Proportional Constant:
Kp=0.3061
Integral Constant:
Ki=0.0117
Derivative Constant:
Kd=0.8657

Performance Index for the PSO Algorithm

The most critical step in applying PSO is to choose the objective functions that are used to evaluate fitness of each Particle. Some works use performance indices as the objective functions. The objective functions are mean of the Squared Error (MSE), Integral of Time multiplied by Absolute Error (ITAE), Integral of Absolute Magnitude of the Error (IAE), and Integral of the Squared Error (ISE). Here, four types of error criteria were calculated for the tuning rules and compare the error values for selecting the best tuning method to tune the PID controllers [4].

1) Integral of the absolute value of the error (IAE)

$$IAE = \int_0^t e(t)^2\, dt$$

2) Integral of the square value of the error (ISE)

$$ISE = \int_0^t |e(t)|\, dt$$

3) Integral of the time weighted absolute value of the error (ITAE)

$$ITAE = \int_0^t t|e(t)|\, dt$$

4) Mean square error (MSE)

$$MSE = \frac{1}{n^n}\sum_{n=1}^{t}(e(t)^2)$$

The PID controller is used to minimize the error signals, we can define more rigorously, in the term of error criteria: to minimize the value of performance indices mentioned above. And because the smaller the value of performance indices of the corresponding particles the fitter the particles will be, and vice versa [19].

EXPERIMENTAL SETUP

In real time chemical process, conical tanks are widely used for the mixing, storage and settlement of raw sewage and can be used in the Water Utilities, commercial or industrial waste water solutions. Conical tank facilitate an easy mixing, processing, or temporary storage process, these hoppers are constructed with an interior that is smooth and seam-free. This leaves no area or space for stored materials to get stuck or caught up in, on their way out of the tank. Additionally, cones are made at a sixty (60) degree angle, causing liquids to flow swiftly out of the tank. Conical tanks are manufactured from medium- or high-density polyethylene with U.V. inhibitors and designed for containment of liquids of up to 1.7 specific gravity. Tank walls are translucent for level viewing and equipped with gallon indicators [27, 28].

Real Time Setup

The real time conical tank used in Chemical Industries for chemical mixing, chemical storage and the settlement of raw sewage is shown in Figure-2 and the technical specifications are shown in Table-2 [18].

Figure-3. Real time model.

Technical Specifications of a Real Time Setup

Table-2. Technical specifications.

Model No.	Capacity	Dimensions (Dia. × Height)	Lid	Approximate Weight
CB0200-42	200 Gallon	42" × 54"	12" Lid	75 lbs
CB0300-42	200 Gallon	42" × 67"	16" Lid	100 lbs
CB0500-52	200 Gallon	52" × 79"	12" Lid	130 lbs

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Working Model

The working model has conical tank with elements which are reliable in control action in water level control in that real time process. The real time experimental system consisting of a conical tank, reservoir and water pump, current to pressure converter, compressor, Differential Pressure Transmitter (DPT), ADAM module, and a Personal Computer which acts as a controller forms a closed loop system.

The inflow rate to the conical tank is regulated by changing the stem position of the pneumatic valve bypassing control signal from computer to the I/P converter through digital to analog converter (DAC) of ADAM module. The operation current for regulating the valve position is 4-20 mA, which is converted to 3-15 psi of compressed air pressure. The water level inside the tank is measured with the differential pressure transmitter which is calibrated for 0-43 cm and is converted to an output current range of 4-20mA. This output current from DPT is passed through 1K ohms resistance converting it to 1-5V range, which is given to the controller through analog to digital converter (ADC) of ADAM module.

The ADAM module is used for interfacing the personal computer with the conical tank system thus forming a closed loop. It has four slots for four converter cards. In the current process, two slots are used, one containing Analog to Digital Converter (ADC) card and the other containing the Digital to Analog Converter (DAC) card. The ADC card has 8 analog input channels with a range of 4-20 mA and DAC has 4 analog output channels with a range of -10V to +10V accommodating both positive and negative terminals. The sampling rate of the module is 10samples/sec and the baud rate is set to 9,600 bytes per sec with a 16 bit resolution. The ADAM module is connected to the personal computer through RS-232, serial cable. The module can be operated manually through console software provided and also with programming software like LABVIEW, MATLAB etc., Here, MATLAB based script files and LABVIEW software with DAQ interfacing card are used in interfacing the controller with the real time system [12,14].

MATLAB software gives us the flexibility of interfacing the ADAM module with the personal computer. The system is prepared to access the module through m-files.

Figure-4. Working model.

Specifications of a Working Model

Table-3. Specifications.

Parts Name	Details
Conical Tank	Material :Sheet metal, Top Diameter – 20 cm, Height – 45 cm
Storage tank	Volume : 10 litres Stainless Steel
Milliamps source	Rps,1KResistance, Ammeter(0-25mA), connecting wires Output (4 - 20mA)
Control valve Size	¼" Pneumatic actuated" Type: Air to open Input (3 - 15) psi
Rotameter	Range (0 - 18) lpm
Air regulator Size	1/4" BSP Range (0 - 2.2)bar
I/P converter	Input -20 psi and current –(4-20) mA output –(3-15)psi
Pressure gauge	Range (0 - 30) psi Range (0 - 100)psi
Pump	Centrifugal 0.5 HP

RESULTS AND DISCUSSION

The results using PID controller for the conical tank system is analysed. The performance of the controllers are evaluated and compared in terms of set point tracking, disturbance rejection as well as in the presence of measurement noise. The performance index is computed to demonstrate a performance comparison between the two controllers with a justification that having a lesser value of error means better performance. In addition to that, termination criteria given for the values took from PSO algorithm among iteration. Those values are fitted values to design the controller for the non-linear system.

Comparision of PID Parameters

Table-4. PID parameters.

ASTROM AND HAGGLUND	IMC	PSO
0.73	0.58	0.3061
0.06	0.034	0.0147
1.54	1.31	0.8627

Response Curve

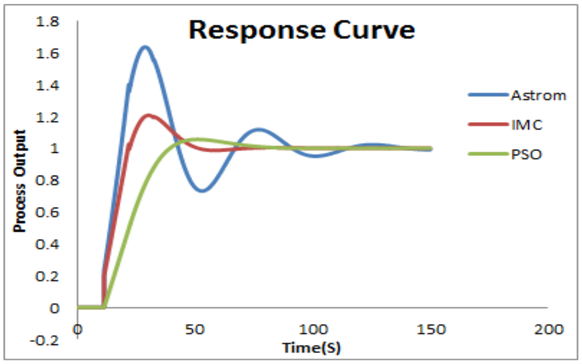

Figure-5. Response curve.

The response curve is plotted based on the PID tuning values. The graphical representation describes about the time domain specification of the selected process.

Time Domain Specifications

Table-5. Time domain specifications.

Specifications	Delay Time(Sec)	Rise Time(Sec)	Settling Time(sec)
ASTROM and HAGGLUND	11.2	14.2	163
IMC	11.4	15.3	62
PSO	11.6	22.5	69.9

Error Criteria

Table-6. Error values.

Error criteria/ Tuning rule	Astrom and Hagglund	IMC	PSO
ITAE	34.42	1.324	0.0085
IAE	146.98	152.38	175.83
MSE	74.11	11.052	1.0604
ISE	121.25	130.66	144.336

CONCLUSIONS

PSO-based optimized PID controller is capable of providing an improved closed-loop performance over the conventionally tuned PID controller parameters. Compared to the heuristic PID tuning method, the proposed method was more efficient in improving the step response characteristics such as reducing the steady state error, rise time and settling time in level control of conical tank employed in Chemical Industries. Comparison graph for the output with time is shown in Fig.5. PSO is chosen as the best tuning method by taking error as the selection criteria. The entire concept has been configured to implement in the Chemical Industries for chemical mixing, chemical storage and the settlement of raw sewage, where the conical tank plays a major role.

REFERENCES

[1] E. Nandhini , M.Balaji, " Implementation of Intelligent controller for a Non-Linear Process", International Journal of Advance Research In Science And Engineering IJARSE, Vol. No.4, Special Issue (01), March 2015.

[2] D.AngelineVijula, M.E., S.MonishaShamli, N.Nithyapriya, S.K.Rama Devi, "Model Predictive Control Design for Conical Tank System", IRACST – Engineering Science and Technology: An International Journal (ESTIJ), Vol.5, No.1, February 2015.

[3] D.Mercy, S.M.Girirajkumar, "Optimized Tuning of a PID Controller for a Non-Linear Spherical Tank System", Advances in Natural and Applied Sciences, 8(22) Special 2014, Pages: 10-18.

[4] D.Mercy, S.M.Girirajkumar,"Design of Intelligent controllers for Nonlinear Conical tank Process used in waste Water treatment", International conference on ICCICCT in Noourl Islam University, July 2014.

[5] P. Suganthini, P. Aravind, S. M. Girirajkumar, " Design of Model Based Controller for a Non-Linear Process", International Journal of Engineering Research & Technology (IJERT) Vol. 3 Issue 1, January – 2014.

[6] D.Mercy, S.M.Girirajkumar, "Tuning of Controllers for Non-Linear Process Using Intelligent Techniques", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Volume 2, Issue 9. Sep 2013.

[7] Abhishek Sharma and Nithya Venkatesan," Comparing PI controller Performance for Non Linear Process Model", International Journal of Engineering Trends and Technology- Volume 4, Issue 3- 2013.

[8] T.Pushpaveni, S.Srinivasulu Raju, N.Archana, M.Chandana, "Modeling and Controlling of Conical Tank System Using Adaptive Controllers and

Performance Comparison with Conventional PID", International Journal of Scientific & Engineering Research, Volume 4, Issue 5, May-2013.

[9] D.Mercy, Elamathi.E, BakusulRahman.A,Mohamed Ibrahim.T, "Modeling and implementation of Non-linear Controller for a Conical tank", 3rd National Conference on emerging technology in Electrical and Electronics Engineering organized by Department of EEE held at Valliammai Engineering College, April 2013.

[10] H.Kiren Vedi, K.Ghousiya Begum, D.Mercy, E.Kalaiselvan, "A Comparative Novel Method of Enhanced Tuning of Controllers for Non-Linear Process", National System Conference, pp., December 2012.

[11] R.Arivalahan, S.Hosimin Thilagar and D. Devaraj, "Investigation of Fuzzy Logic Controller for Conical Tank Process", European Journal of Scientific Research, Vol. 92 No.2, pp.191-202, December 2012.

[12] Ganesh Ram and S. Abraham Lincoln, "Fuzzy Adaptive PI Controller For Single Input Single Output Non-linear System", ARPN Journal of Engineering and Applied Sciences, Vol. 7, No. 10,pp.1273 – 1280,October 2012.

[13] V.R.Ravi, T.Thyagarajan "Application of Adaptive Control Technique to Interacting Non Linear Systems "Electronics Computer Technology (ICECT), 2011 3rd International Conference on 8-10 April 2012 pp: 386 – 392.

[14] K. BarrilJawatha, "Adaptive Control Technique for Two Tanks Conical Interacting System", International Conference on Computing and Control Engineering (ICCCE 2012), 12 & 13 April, 2012.

[15] Sukanya R. Warier, Sivanandam Venkatesh "Design of Controllers based on MPC for a Conical Tank System", IEEE-International Conference On Advances In Engineering, Science And Management (ICAESM -2012) March 30, 31, 2012.

[16] R.Valarmathi, P.R.Theerthagiri, S.Rakeshkumar, "Design and Analysis of Genetic Algorithm Based Controllers for Non Linear Liquid Tank System", IEEE-International Conference on Advances in Engineering, Science and Management (ICAESM - 2012) March 30, 31, 2012.

[17] V.R.Ravi, T.Thyagarajan, "A Decentralized PID controller for interacting non-linear systems."ICETECT 2011 pp 297-302.

[18] G. Sakthivel , T. S. Anandhi and S. P.Natarajan, "Modelling and Real Time Implementation of Digital PI Controller for a Non Linear Process"Journal of Innovative Research in Engineering and Sciences, September 2011.

[19] S.Nithya,N.Sivakumaran,T.K.Radhakrishnan, N.Anantharaman,"Control of nonlinear process using soft Computing" IUP 2010.

[20] W. D. Chang and S. P. Shih, "PID controller design of nonlinear systems using an improved particle swarm optimization approach" Communications in Nonlinear Science and Numerical Simulation, vol. 15, no. 11, pp. 3632–3639, 2010.

[21] S.Nithya, N.Sivakumaran, T.Balasubramanian, and N.Anantharaman, "Design of controller for nonlinear process using soft computing", Instrumentation Science and Technology, vol. 36, no. 4, pp. 437–450, 2008.

[22] N.S. Bhuvaneswari, G. Uma & T.R. Rangaswamy, Neuro based "Model Reference Adaptive control of a conical tank level process",Control and Intelligent Systems, Vol. 36, No. 1, 2008, pp. 1-9.

[23] B.Wayne-Bequette, Process Control—Modeling, Design and Simulation, Prentice-Hall, New Delhi, India, 2003.

[24] Aidan o'Dwyer, "Hand book of PI and PID controller tuning rules", 3rd edition.

[25] http://www.erosionpollution.com/pharmaceuticalstoragetank.html

[26] http://appliedmembranes.com/conical-bottom-storage-tanks.html

[27] http://www.acotainers.com/conical_bottom_tanks.php

[28] http://www.blazeplastics.ca/cone-bottom-tanks.html

[29] http://www.akiraengineers.com/storage-tanks.html

[30] http://www.directindustry.com/prod/enduramaxx-water-storage-tanks/product-80945-1320531.html