

# Design and Implementation of Fuzzy Logic Controller for Dynamic System

S.Rajendran<sup>1</sup>, Dr.S.Palani<sup>2</sup>

<sup>1</sup>Mookambigai College of Engineering, Keeranur, Pudukkottai, Tamil Nadu, India-622502

<sup>2</sup>Director / Sudharsan College of Engineering, Sathyamangalam, Pudukkottai, TamilNadu, India

Email:subbiahrajendran69@gmail.com

**Abstract**— A real time implementation of Fuzzy logic controller (FLC) for a spherical tank to control liquid level is studied. Control of liquid level in a spherical tank is highly non-linear due to variation in the area of cross section of level system with change in shape .System identification of spherical tank system is done using black box model which is identified to be non-linear and approximated to be a First order plus dead time model .Here the conventional controller parameters are designed based on Ziegler-Nicholas method and its servo and regulatory responses are compared with Fuzzy logic controller based on Mamdani model. From the response curve, obtained using the above controllers, that fuzzy logic controller gives much improved performance which is measured in terms of overshoot, rise time, set point tracking and performance indices when compared to other conventional controllers

**Index Term**— Fuzzy Logic Controller, PI Controller, Spherical Tank, System Identification

## I. INTRODUCTION

The industrial application of liquid level control is tremendous especially in refineries petroleum and chemical process industries. Usually, level control exists in some of the control loops of a process control system. An evaporator system is one example in which a liquid level control system is a part of control loop. Evaporators are used in many chemical process industries for the purpose of separation of chemical products. Level control is also very important for mixing reactant process. The quality of the product of the mixture depends on the level of the reactants in the mixing tank. Mixing reactant process is a very common process in chemical process industries and food processing industries. Many other industrial applications are concerned with level control, may it be a single loop level control or sometimes multi-loop level control. In some cases, level controls that are available in the industries are for interacting tanks. Hence, level control is one of the control system variables which are very important in process industries. Nowadays, chemical engineering systems are also at the heart of our economics. The process industries such as refineries petrol, petro-chemical industries, paper making and water treatment industries require liquids to be pumped, stored in tanks, and then pumped to another tank. In the design of control system, one often has a complicated mathematical model of a system that has been obtained from fundamental physics and chemistry. The above mentioned industries are the vital industries where liquid level and flow

control is essential. Many times the liquids will be processed by chemical or mixing treatment in the tanks, but always the level fluid in the tanks must be controlled, and the flow between tanks must be regulated. Level and flow control in tanks are the heart of all chemical engineering systems

The controller designed using fuzzy logic implements human reasoning that has been programmed into fuzzy logic language (membership functions, rules and the rules interpretation). It is interesting to note that the success of fuzzy logic control is largely due to the awareness to its many industrial applications. An industrial interest in fuzzy logic control as evidenced by the many publications on the subject in the control literature has created an awareness of its interesting importance by the academic community.

## II. MATHEMATICAL MODELING

It is quite often the case that we have to design the control system for a process before the process has been constructed. In such a case we need a representation of the process in order to study its dynamic behavior. This representation is usually given in terms of a set of mathematical equations whose solution gives the dynamic or static behavior of the process. The process considered is the spherical tank in which the level of the liquid is desired to be maintained at a constant value. This can be achieved by controlling the input flow into the tank. The spherical tank is shown in Fig.1. Using the law of mass, Rate of accumulation of mass in the tank = Rate of mass flow in – Rate of mass flow out.

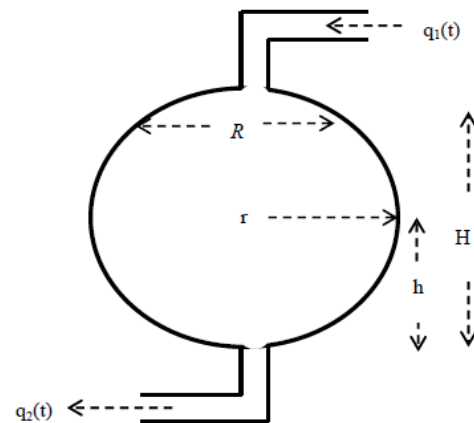


Fig.1 Spherical tank

Let

$q_1$ -Inlet flow rate to the tank( $m^3/min$ )

$q_2$ -Outlet flow rate to the tank( $m^3/min$ )

$h$ -Height of the spherical tank(m)

$H$ -Height of the liquid level in the tank at any time' $t$ '(m)

$R$ -Top radius of the spherical tank(m)

$r$ -Radius of the spherical tank at a particular level of height  $h$ (m)

The level in spherical tank at any instant is obtained by making mass balance equation as indicated below:

$$\frac{dv}{dt} = q_1 - q_2 \quad (1)$$

where  $V$  is the Volume of the tank

$$V = \frac{4}{3} \pi h^3 \quad (2)$$

Applying the steady state value,

$$V - V_s = \frac{4}{3} \pi h_s^2 (h - h_s) \quad (3)$$

$$V(s) = 4\pi h_s^2 H(s) \quad (4)$$

$$q_2 = c\sqrt{h_s} \quad (5)$$

where ' $c$ ' is the valve coefficient

$$q_2 - q_2(s) = \frac{1}{2} c h_s^{-1/2} (h - h_s) \quad (6)$$

Linearizing the nonlinearity in the spherical tank

$$Q_2(s) = \frac{c}{2\sqrt{h_s}}, H(s) = \frac{H(s)}{R_t} \quad (7)$$

Where  $R_t = \frac{2h_s}{Q_2(s)}$

$$Q_1(s) - Q_2(s) = sV(s) \quad (8)$$

$$Q_1(s) - \frac{H(s)}{R_t} = s(4\pi h_s^2)H(s)$$

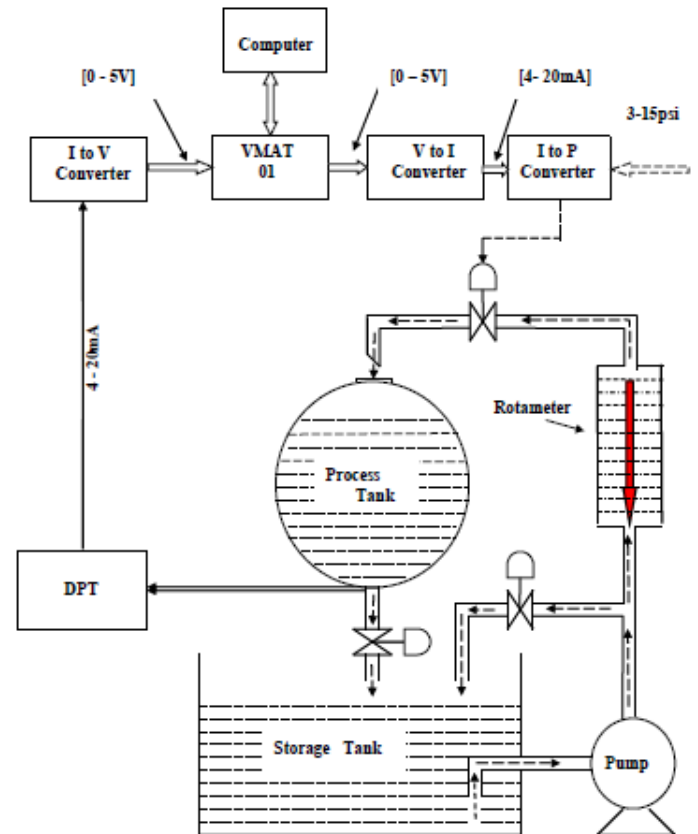
$$Q_1(s)R_1 = (4\pi R_1 h_s^2 s + 1)H(s)$$

$$\boxed{\frac{H(s)}{Q_1(s)} = \frac{R_t}{\tau s + 1}} \quad (9)$$

where  $\tau = 4\pi R_1 h_s^2$

Thus the equation.9 gives the model of the system.

### III. REAL TIME SYSTEM



A. Block diagram

Fig. 2. Block diagram of real time system

The real time experimental system consisting of a spherical tank, reservoir and water pump, current to pressure converter, compressor, Differential Pressure Transmitter (DPT), VMAT01 DAQ CARD, I/V converter, V/I converter and a Personal Computer which acts as a controller, forms a closed loop system. The block diagram of this system is shown in Fig.2

### B. Real time system

Fig.3 shows the real time implementation of the system. The flow rate to the spherical tank is regulated by changing the stem position of the pneumatic valve by passing control signal from computer to the I/P converter through VMAT01 DAQ CARD and V/I converter. The operation current for regulating the valve position is 4-20mA, which is converted to 3-15psi of compressed air pressure. The water level inside the tank is measured with the differential pressure transmitter which is calibrated for 0-40cm and is converted to an output current of 4-20mA. This output current is converted into 0-5V using I/V converter, which is given to the controller through VMAT01 DAQ CARD. The VMAT01 USB based DAQ CARD is used for interfacing the personal computer with the spherical tank.



Fig. 3. Real time implementation

### C. Specifications of real time system

The specifications of the real time can be represented as follows

Parts Name	Details
Spherical tank	Body Material :SS 316 Diameter :500mm Capacity :200 litres
Storage Tank	Capacity :200 litres Body Material :SS 316
Differential Pressure Transmitter	Make : AB Type : Capacitance Input : 2.5 -250)mbar Output : 4-20mA
Rotameter	Make :Tellien/Equivalent Flow Rate :(100 – 1000)LPH Type :Variable Area Float Material :SS 316
Control Valve	Type : Pneumatic air to close Input : 3-15psi
Pump	Make :Tullu/Kirlosker Flow Rate :1500 LPH Supply Voltage :230VAC/50Hz
Air Regulator	Size : 1/4" BSP Range : 0-2.2bar
I/P Converter	Make : ABB Input : 4-20mA Output : 0.2 -1bar
V/I Converter	Model : Electronic Input : 1-5V Output :4-20mA
I/V Converter	Model : Electronic Input : 4-20mA Output :1-5V
Pressure Gauge	Range : (0-30)psi Range :(0-100)psi
NI6009 DAQ CARD	Input : 8 Nos. Output : 2 Nos.

## IV. SYSTEM IDENTIFICATION

System identification for the spherical tank system is done using black box modeling in real time. For fixed input flow rate and output flow rate, the spherical tank is allowed to fill with water from (0-40)cm height. At each sample time, the data from differential pressure transmitter i.e. between (4-20) mA is being collected and fed to the system through the serial port RS-232 using VMAT01 interface module. Thereby the data is scaled up in terms of level (cm). Using the open loop method, for a given change in the input variable, output response for the system is recorded. Ziegler and Nichols have obtained the time constant and time delay of a FOPTD [First order plus time delay] model by constructing a tangent to the experimental open loop step response at its point of inflection. The tangent intersection with the time axis at the step origin provides a time delay estimate; the time constant is estimated by calculating the tangent intersection with the steady state output value divided by the model gain. Cheng and Hung have also proposed tangent and point of inflection methods for estimating FOPTD model parameters. The major disadvantage of all these methods is the difficulty in locating the point of inflection in practice and may not be accurate. Prabhu and Chidambaram have obtained the parameters of the first order plus time delay model from the reaction curve obtained by solving the nonlinear differential equations model of a distillation column. Sundaresan and Krishnaswamy have obtained the parameters of FOPTD transfer function model by letting the response of the actual system and that of the model to meet at two points which describe the two parameters  $\tau$  and  $L$ . The proposed times  $t_1$  and  $t_2$ , are estimated from a step response curve. This time corresponds to the 35.3% and 85.3% response times. The time constant and time delay are calculated as follows.

$$\tau = 0.67(t_2 - t_1) \quad [10]$$

$$L = 1.3t_1 - 0.29t_2 \quad [11]$$

At a fixed inlet flow rate, outlet flow rate, the system is allowed to reach the steady state. After that a step increment in the input flow rate is given and various readings are noted till the process becomes stable in the system. The experimental data are approximated to be a FOPDT. Therefore the model for the above system is given by

$$K_p = \frac{\text{Change in output}}{\text{Change in input}}, \quad K_p\text{-Proportional gain}$$

$$\text{Transfer function} = \frac{K_p e^{-Ls}}{\tau s + 1} \quad [12]$$

where

$$L = 1.3 \times t_1 - 0.29t_2 \rightarrow \text{delay time}$$

$$\tau = 0.67(t_2 - t_1) \rightarrow \text{time constant}$$

TABLE I  
Model Parameters for Different Regions

Operating Region	Height (cm)	$K_p$	$\tau$	$L$
I	0 -7.5 cm	2.01	270.68	60.6
II	7.5 -11 cm	4.94	387.93	835.02
III	11-13 cm	6.273	575.53	822.5
IV	13- 18 cm	5.78	894.45	502.66
V	18 -23 cm	6.32	866.98	506.47

## V. CONTROLLER DESIGN

### A Design of PI Controller:

After deriving the transfer function model, the design of controller tuning is done using the method proposed by Skogestad. The PI controller settings are

$$K_p = \frac{1}{K} \frac{\tau}{L + \tau_c}, \tau_I = \tau \quad [13]$$

Controller gain  $K_p$  depends inversely on model gain  $K$ . It is also reasonable that  $\tau_I = \tau$  as slow processes have large values of  $\tau$ , and thus  $\tau_I$  should also be large for satisfactory

control. As  $\tau_c$  decreases,  $K_p$  increases. This is because a quicker approach to set point requires more strenuous control

action and thus there is justification for a larger value of  $K_p$ . Using the PI controller tuned values; the setup was run for the different set points in real time. Then load disturbances at different intervals were given in the tank. The variation in the level was recorded in both the cases. The above mentioned Skogestad setting is also used to find the controller settings for different zones which are given in Table 2

### B Design of Fuzzy Logic Controller

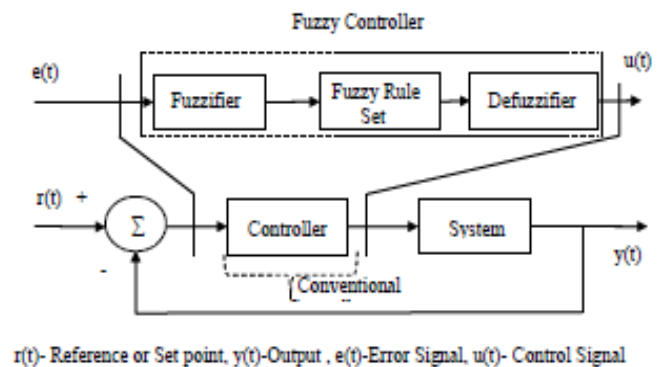
Fuzzy logic is a part of artificial intelligence or machine learning which interprets a human's actions. Fuzzy techniques have been successfully used in control in several fields. Fuzzy logic is a form of logic whose underlying modes of reasoning are approximate instead of exact. The general idea about fuzzy logic is that it takes the inputs from the sensors which is a crisp value and transforms it into membership values ranging from 0 to 1. Unlike crisp logic, it emulates the ability to reason and use approximate data to find solutions. Fuzzy logic controllers (FLCs) are knowledge-based controllers consisting of linguistic "IF-THEN" rules that can be constructed using the knowledge of experts in the given field of interest. Variety

controller structures are used in the literature. However for the present study, the fuzzy logic controller whose block diagram represented in Fig. 4 is used.

TABLE II  
PI Tuning Parameters for Different Regions

Region	Tuning Parameters	
	$K_p$	$\tau_I$ (sec)
0 -7.5 cm	0.0456	0.0136
7.6 -11 cm	0.029	0.0063
11-13 cm	0.1912	0.028
13- 18 cm	0.1389	0.00609
18 -23 cm	0.116	0.00346

Fig. 4. Block diagram of Fuzzy Logic Controller



The design of fuzzy logic controller for a spherical tank in real time is attempted using cost effective data acquisition system. To implement FLC for a non-linear spherical tank system in real time, level and level error are taken as the two inputs and controller as output by changing the position of valve opening. Here triangular membership functions are chosen for model of FLC since both the linear and nonlinear behavior can be achieved for the FLC as shown in Fig.5 to Fig.7. For fuzzification min-max method is used. For defuzzification using the properties of triangles is employed for the measurement of height. The universes of discourse for these parameters are scaled from 0 to 100, -30 to +30 and (4-20) mA for the two input variable and one output variable respectively. The scaling is very essential because the fuzzy system can be retrofitted with other devices or ranges of operation by just changing the scaling of the input and output variables. The rule base developed for the FLC model is shown in Table 3.

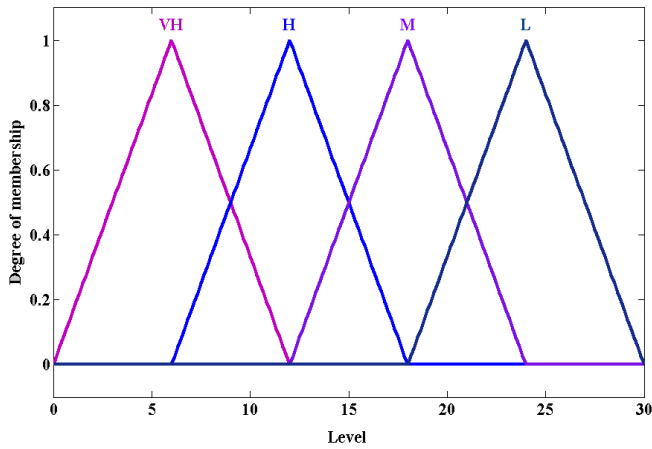


Fig. 5. Membership Function for Error

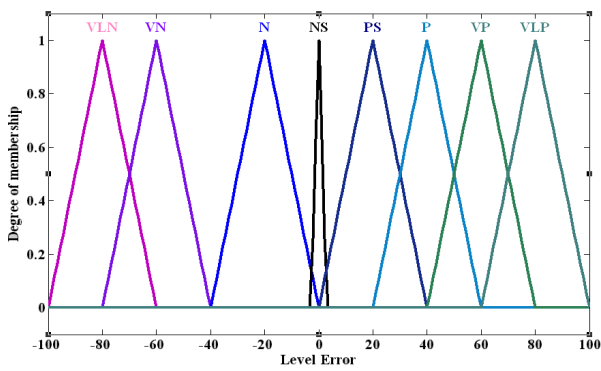


Fig. 6. Membership Function for Change of Error (CE)

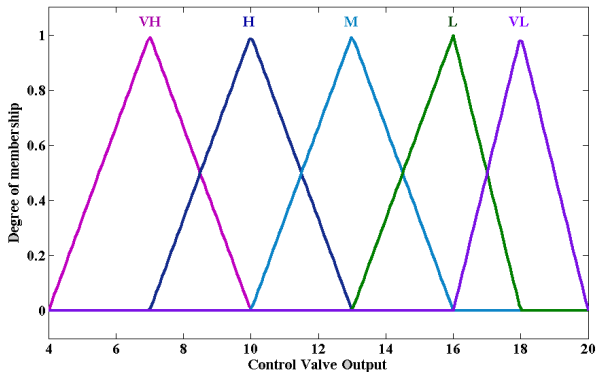


Fig. 7. Membership Function for Control valve output (CV)

TABLE III  
Rule base for Fuzzy Logic Controller

CE \ E	VH	H	M	L
VLN	VL	VL	VL	VL
VN	VL	VL	VL	VL
N	VL	VL	L	L
NS	L	L	L	L
PS	M	M	M	M
P	H	H	H	H
VP	VH	VH	VH	VH
VLP	VH	VH	VH	VH

VI. RESULTS AND DISCUSSIONS

The FLC is applied to the real time control of liquid level system using VMAT01 module. The performance of the fuzzy controller is compared with conventional PI controller. The FLC is implemented for a sequence of set points 7.5 cm, 11cm, 13 cm, 18 cm, and 23 cm and is compared with a PI controller. The variations of level with time for the sequence of set point changes for both the controllers are shown in Fig.8 to Fig.12. It is observed that FLC tracks the set point changes faster than the conventional controller. The FLC follows the set point without oscillation than the PI controller. The response to track the given set point in a FLC is immediate when compared to the PI controller even though the initial rise time is higher as shown in Fig 8. The settling time of the FLC for a set point change is better than the PI as shown in Fig 10 to Fig.12. The peak time, maximum overshoot and settling time are calculated for both controllers and are shown in Table 4 for set point changes. From the calculated values it is clear that FLC is having lesser peak time, and provides no oscillatory behavior and exhibits no overshoot compared to PI controller.

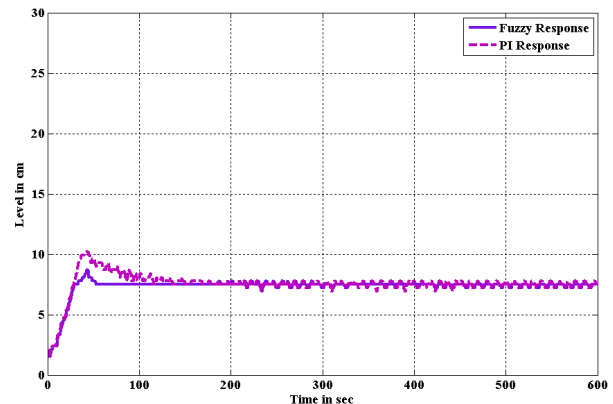


Fig. 8. Servo Response for a set point 7.5cm

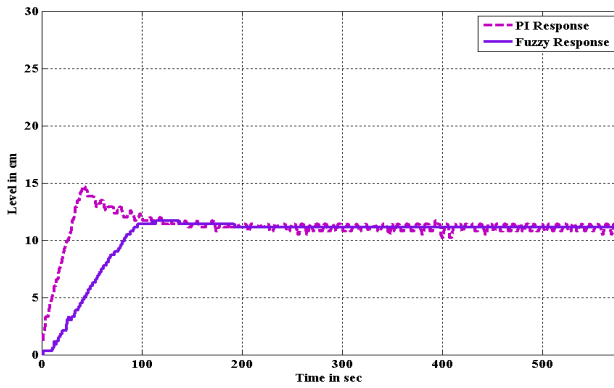


Fig. 9. Servo Response for a set point 11 cm

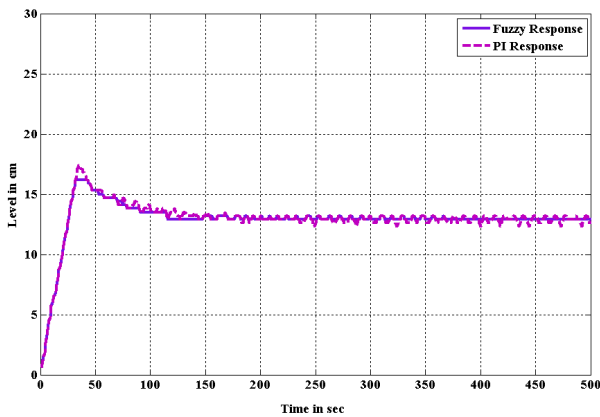


Fig. 10. Servo Response for a set point 13 cm

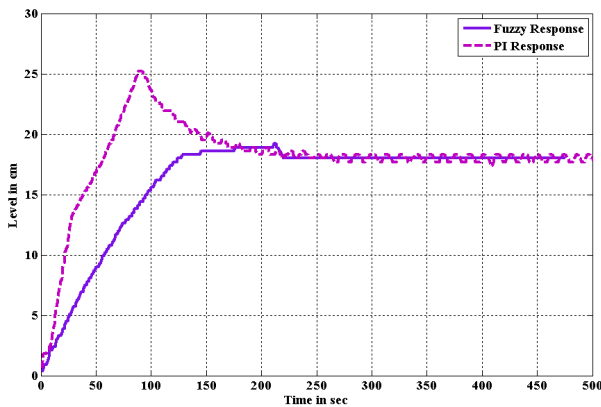


Fig. 11. Servo Response for a set point 18 cm

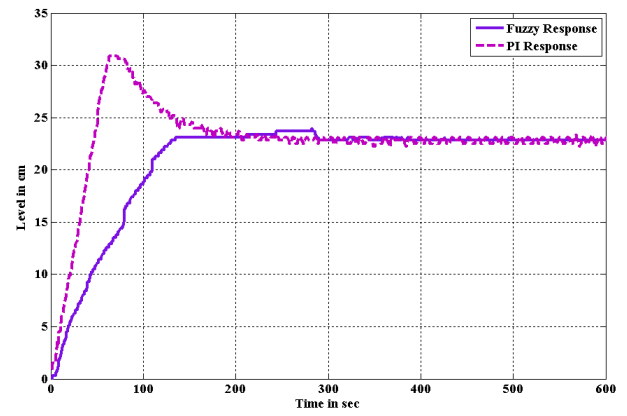


Fig. 12. Servo Response for a set point 23 cm

TABLE IV  
Time domain Comparison of Controllers for Different Set Point

PARAMETER	SET POINT	CONTROLLER	
		PI	FUZZY
Peak Time(Sec)	7.5 cm	3.9	3.85
	11 cm	3.9	10
	13 cm	3.39	3.15
	18 cm	8.65	20
	23 cm	6.19	28.12
Overshoot	7.5 cm	9.18	7.75
	11 cm	13.75	10.73
	13 cm	16.45	15.22
	18 cm	24.21	18.25
	23 cm	29.91	24
Settling Time(Sec)	7.5 cm	168	61
	11 cm	152	96
	13 cm	178	117
	18 cm	249	218
	23 cm	247	141

VII. CONCLUSION

For non-linear processes an Fuzzy Logic Controller is designed. Its performance is tested in real time by using the VMAT-01 module for a Spherical tank level process. Comparison with a fuzzy logic and conventional PI controller gives testimony to the effectiveness of the fuzzy logic based PI control technique in the non-linear system. Experimental results prove that the response is smooth for Fuzzy Logic Controller compared to PI controller. The settling time, rise time and overshoot in the Fuzzy Logic Controller show the better response than PI controller. It is concluded that for a nonlinear system the Fuzzy Logic Controller outperforms well when compared to conventional controller in real time using cost effective data acquisition system.

## REFERENCES

- [1] Abdelelah Kidher Mahmood, Hussam Hamad Taha. Design Fuzzy logic controller. IJESE, Vol.1, Issue- II, 2013: pp.23-26
- [2] Ziegler G and Nichols N B. Optimum setting for Automatic controllers. Trans ASME1942; 64:pp. 759-768.
- [3] Chidambaram M. Applied Process Control. Mumbai, INDIA: Allied Publishers PVT. Limited, 2004
- [4] Sathish Kumar J, Poongodi and Rajasekaran. Modelling and Implementation of LabVIEW Based Non- linear PI Controller for a Conical Tank. Journal of Control & Instrumentation, 2010; 1: pp.1-9
- [5] Bhubaneswar N S, Uma G and Rangaswamy T R. Adaptive and optimal control of a non-linear process using intelligent controllers. Applied Soft Computing, 2009; 9: pp.182-190
- [6] Takagi T and Sugeno M. Fuzzy identification of systems and its application to modeling and control. *IEEE trans Syst Man Cybernetics*, 1985; 15:pp.116-132
- [7] Anandanatarajan R, Chidambaram M and Jayasingh T. Design of controller using variable transformations for a nonlinear process with dead time. *ISA Trans* 2005; 44:pp. 81-91.
- [8] Berk P, Stajanko D, Vindis P, Mursec B and Lakota M. Synthesis water level control by fuzzy logic. International OCSCO World Press, 2011; 45: pp.204- 210.
- [9] Sivanandam S N, Sumathi.S and Deepa S N. Introduction to Fuzzy Logic using MATLAB Springer. Verlag Berlin Heidelberg, 2007

**Dr. Palani Sankaran is Director and Professor, Department of Electronics & Communication Engineering.** He has obtained Bachelor Degree in Electrical Engineering from University of Madras 1966, M. Tech in Control Systems Engineering from IIT, Kharagpur in 1968 and Ph.D. in Control Systems Engineering from University of Madras in 1982. He has wide teaching experience over four decades in National institute of Technology, Government of INDIA

He has published more than 100 research papers in reputed national and international journals and conferences. He is the author of the books titled **Automatic Control Systems, Signals and Systems, and Digital Signal Processing**. Under his guidance six candidates were awarded Ph.D degree and 10 candidates are doing Ph.D in Anna University, Chennai

Currently he is working as Director and Professor in the department of Electronics and Communication Engineering, Sudarsan Engineering College, Anna University Chennai, India

**Rajendran Subbiah** received B.E. degree in Electrical and Electronics Engineering in 1993 from Alagappa Chettiar Government College of Engineering and Technology Karaikudi, India and M. E. in Power Systems from Regional Engineering College, Tiruchirappalli, India and currently pursuing Ph.D. degree in Intelligent Controller Design for Dynamic Systems from Anna University, Chennai, India. He is a Professor and Head in the Department of Electronics and Instrumentation Engineering, Mookambigai College of Engineering, Anna University, Chennai, India since 1995.