Design and Simulation of PSO Based PI Controller for a Non-Linear Two-Tank Interacting Level Process

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***Abstract*— In this work, a non linear two-tank interacting level process is taken-up for study. The mathematical model of the two-tank interacting process is derived. A conventional PI controller is designed based on process reaction curve with ZN technique. To improve the performance of PI controller, a Particle Swarm Optimization (PSO) based PI controller PSO-PI is proposed and implemented. The servo and regulatory responses with PI and PSO-PI are obtained and discussed. From the results and performance measures, it is observed that PSO-PI is producing better results than conventional PI controller.**

***Index Terms*— Two-tank interacting process, PI controller and PSO-PI.**

I. INTRODUCTION

The process industries require the liquids to be pumped, stored in tanks and then pumped to another tank. Many times the liquid will be processed by chemical or mixing treatment in the tanks, but always the level of the fluid in the tanks must be controlled. A level that is too high may upset the reaction equilibrium, cause damage to the equipment or result spillage of valuable or hazardous material [1]. If the level is too low, it may have bad consequences for the sequential operations. Hence, control of liquid level is an important and common in process industries. Conventional controllers are widely used in industries since they are simple robust and familiar to the field of operator. The most basic and pervasive controller algorithm used in the feedback control is proportional integral controller algorithm. PI controller is widely used control strategy to control most of industrial automation process because of its remarkable efficiency and simplicity. Hence, a mathematical model is derived and a simulation is carried out for the given mathematical equation. The conventional PI controller parameters are designed based on Ziegler-Nicholas. However, it will not give satisfactory response for change in operating point. Hence, the Particle Swarm Optimization technique is proposed and implemented to optimize PI controller parameters [4]. In this work, a simple performance criterion in time domain is proposed for evaluating the performance of a PSO-PI controller that is applied to a interacting two-tank process.

II. PROCESS DESCRIPTION

Fig.1 shows the photograph of the laboratory level process station. It consists of three pumps, two motorized control valves, six process tanks, two overhead tanks, two differential pressure transmitters, five level transmitters and rotameters .Instrumentation panel consists of two PID controllers, main power supply switch, pump switches, motorized control valve switches and auxiliary switches for individual components.

III. WORKING PRINCIPLES

Fluid level in the tank is measured by level transmitter (LT). Output of LT is given to the data acquisition setup. It consists of ADC and DAC. The differential pressure level transmitter (DPLT) measures the flow by sensing the difference in level between the tanks. The DPLT then transmits a current signal (4-20mA) to the I/V converter. The output of the I/V converter is given to the interfacing hardware associated with the personal computer (PC). Control algorithms are implemented in Lab view software. It compares and takes corrective action on the motorized control valve. Based on the valve opening flow rate is manipulated. Rotameter can visualize the flow rate.

Fig.1. Experimental setup of a two-tank interacting process.

The controller compares the controlled variable against set point and generates manipulated variable as current signal (4-20mA) [2]. Here the controlled variable is the level (h_2) and the manipulated variable is the flow rate (q_{in}).Specification dimension are tabulated in Table I and Table II ,respectively.

TABLE I

SPECIFICATION OF TWO-TANK INTERACTING PROCESS

COMPONENTS	SPECIFICATIONS

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MOTORISED CONTROL VALVE	Flow rate Characteristics Valve action	50LPH Equal% motorized control
ROTAMETER	Type Range float material	variable area (0-100)LPH i.e (0-1666 ^{3}/min) SS 316
PUMP	RPM Discharge Voltage	4500 1000(LPH) 220/230 volts AC&DC
PROCESS TANK	Capacity Height Diameter	3 litres 300 mm 120 mm
LEVEL TRANSMITTER	Input Height Type	24V DC 0-400 mm WC F capacitance
DIFFERENTIAL PRESSURE TRANSMITTER	Input Supply Output	0-400mm H_2O 24V DC 4-20mA at 24V DC

TABLE II
DIMENSIONS AND VARIABLES FOR TANK1 AND TANK 2.

Parameter	**Dimension**
Area(A_1,A_2)	113.0973 cm^2
Height(max)	25 cm
Diameter	12 cm
Inflow rate(MV),q_{in}	0-1666 cm^3/min
Process Variable (PV),h_2	0-25 cm
Flow rate (LV),q_{L1},q_{L2}	0-500 cm^3/min
G	Gravity (9.81N/m^2)
a_1 and a_2	Area of the pipe outlet (a_1=3.5735cm^2 , a_2=3.9012cm^2)
c_d	Discharge co-efficient (c_d=0.08)

MV- manipulated variable, PV-process variable LV- Load variable

B. int

Fig.2 shows the process consists of two interacting liquid tanks. The volumetric flow into the tank1 is q_{in}(cm^3/min) , the volumetric flow rate from tank1 to tank2 is q_1(cm^3/min), and the volumetric flow rate from tank2 is q_o(cm^3/min) [2]. The height of the liquid level is h_1(cm) in tank1 and h_2(cm) in tank2 (cm), respectively Both tanks have the same cross sectional area A_1(cm^2) and A_2(cm^2), q_{L1} is the inflow of tank1 as load disturbance (cm^3/min) and q_{L2} is the inflow of tank2 as load disturbance (cm^3/min) [1and 2].

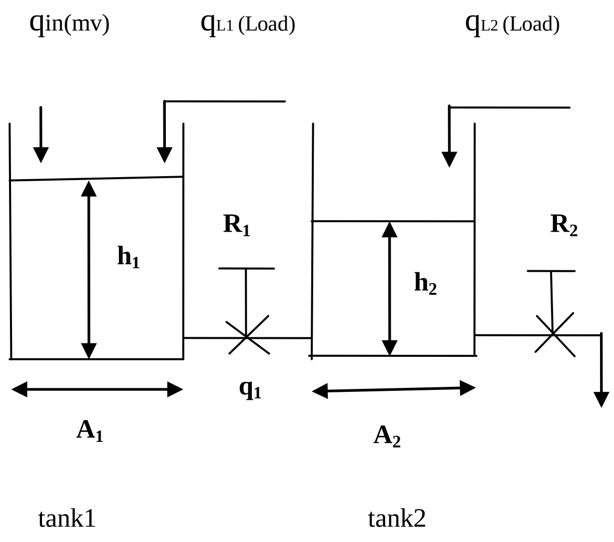


Fig.2.Two-tank interacting process

Mass balance equation for tank 1

$$A_1 \frac{dh_1}{dt} = q_{in} - q_1 \tag{1}$$

Assuming non -linear resistance to flow :

$$q_1 = \frac{c_d a_1}{A_1}\sqrt{2g(h_1 - h_2)} \tag{2}$$

Mass balance equation for tank 2

$$A_2 \frac{dh_2}{dt} = q_1 - q_o \tag{3}$$

Assuming non-linear resistance to flow:

$$q_o = \frac{c_d a_2}{A_2}\sqrt{2gh_2}$$

$$A_2 \frac{dh_2}{dt} = \frac{c_d a_1}{A_1}\sqrt{2g(h_1 - h_2)} - \frac{c_d a_2}{A_2}\sqrt{2gh_2} \tag{4}$$

IV. CONTROLLER TUNING

A. Process reaction curve for two-tank interacting process

Fig.3 shows the simulated open loop response of interacting process. The level (h_2) changes from 0 to 8.5 cm, when applying a step input in q_{in}(50*16.66cm^3/min) also the level (h_1) changes from 0 to 18 cm due to interaction. The simulated process reaction curve(PRC) of h2 for step change in q_{in} for ±499.8cm^3/min is shown in Fig.4.

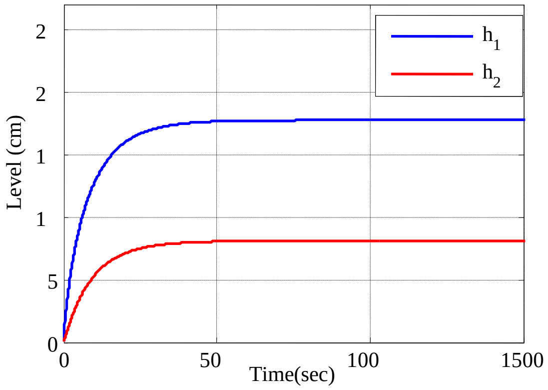


Fig.3. Simulated open loop response of h_1 and h_2 of interacting Process.

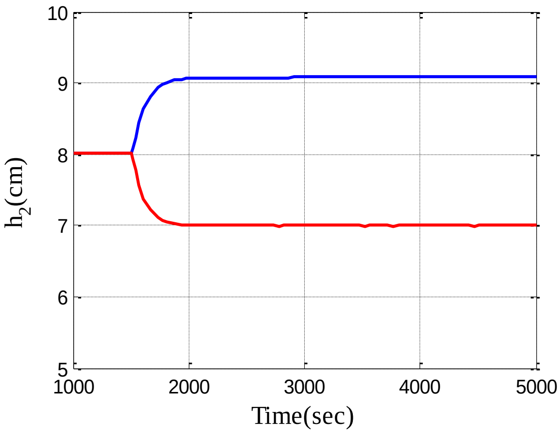


Fig.4. Simulated PRC of h_2 for step change in q_{in} for ±499.8cm^3/min.

From the fig.4 the transfer functions are obtained and tabulated in Table III. From the average transfer function, the controller parameters are obtained using Z-N tuning rule [2]. For two-tank interacting process the PI controller parameters are tabulated in Table IV.

TABLE III
TRANSFER FUNCTION MODEL OF TWO-TANK INTERACTING PROCESS

Step Input q_{in}	**Transfer Function**	**Average Transfer Function**
Positive Step Input, q_{in}	$\frac{0.81578}{93s+1}e^{-17s}$	$\frac{0.65049}{97.5s+1}e^{-17s}$
Negative Step Input, q_{in}	$\frac{0.4852}{102s+1}e^{-17s}$	

A. *Z-N tuning technique*

Based on the average transfer functionthe value of k_c and t_i are calculated using Z-Ntechniques.The values of k_c and t_i are tabulated in Table IV.

TABLE IV
PI CONTROLLER SETTINGS FOR TWO-TANK INTERACTING PROCESS USING Z-N METHOD.

Mode	K_c	$T_i(sec)$
PI	7.9351	56.61

C. *Particle swarm optimization (pso) algorithm*

Particle swarm optimization (PSO) algorithm, which is used for optimizing the PSO difficult numerical functions and based on metaphor of human social interaction, is capable of mimicking the ability of human societies to process knowledge [4]. It has roots in two main component methodologies: artificial life (such as bird flocking, fish schooling and swarming) and evolutionary computation. Although the PSO algorithm is initially developed as a tool for modelling social behaviour, it has been applied in different areas.

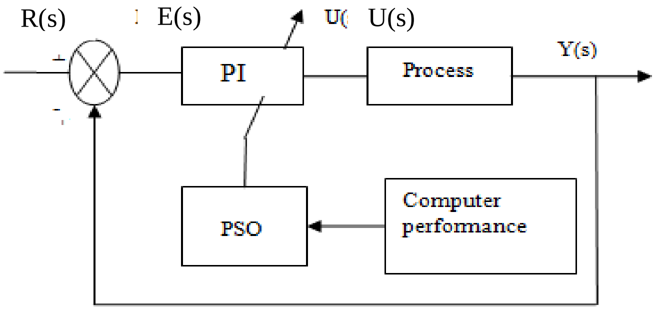


Fig.5 . PSO based PI controller to control the level of two- tank interacting process.

The block diagram of PSO based PI controller is shown in Fig 5. Also the flow chart to optimize the PI controller is shown in Fig 6.

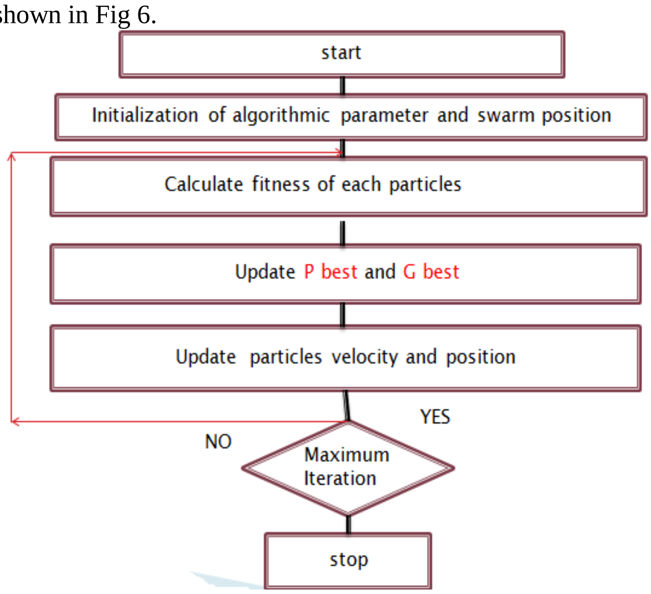


Fig 6. Flow chart PSO-PI

The equation for position and velocity

$V_{n+1} = v_n + c_1 rand1(\,)*(p_{best,n}\text{-current position}) + c_2 rand1(\,)*(g_{best,n}\text{-current position})$ (5)

$\mathbf{x}\ (\mathbf{t}+\mathbf{1}) = x_{id}(t) + v_{id}(t+1)$ (6)

D. *The PSO learning algorithm is represented by following steps*

Step1 Select the number of iterations (n) and the PSO learning rate (c_1, c_2).

Step2 Randomly generate position vector X and associated velocity V of all particles in the population.

Step3 Calculate each individual's fitness value, and then compare each individual's evaluation value with best global particle value g_{best} the personal best value p_{best} . Finally select the new best value (g_{best} and p_{best})

Step4 For every particle, update its own velocity and position value.

Step5 If iteration=n, then go to exit, otherwise go to step 3.

Step6 The best particle's value will be selected as the finial parameter set to form desired PI controller.

During simulation the values for PSO algorithm considered are tabulated in Table V.

TABLE V

PARAMETER OF PSO ALGORITHM

Parameter	**Values**	
Number of Iteration	20	
Dimension	3	
Swarm Size	90	
Correction Factor	C_1	1.2
	C_2	1.4

The optimized PSO-PI parameter using equation 5 and 6 are tabulated

TABLE VI

PARAMETERS OF PI AND PSO-PI CONTROLLERS

Mode	K_c	$T_i(sec)$
PI	7.9351	56.61
PSO-PI	2.03791	0.1005

V. SIMULATION RESULTS

A. Servo responses of level h_2 with PI and PSO-PI controllers.

The servo responses for two tank level interacting process for step change in h_2 from 6 to 8 cm, from 8 to 6cm is shown in fig.7 by implementing PI and PSO-PI. The corresponding change in h_1 and inlet flowrate q_{in} are also shown in fig.8 and fig.9, respectively. The performance measures for step change in h_2 from 6 to 8 cm is tabulated in Table VII. From the results and Table VII, it is observed that the PSO-PI gives better performances than PI controller.

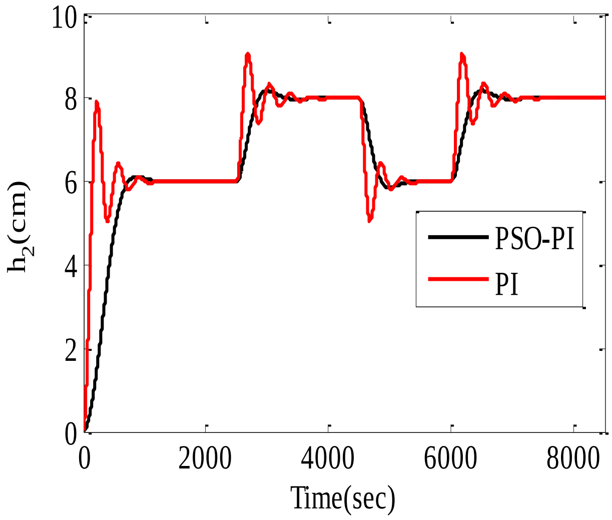


Fig.7. Servo response of h_2 with PI and PSO-PI controllers.

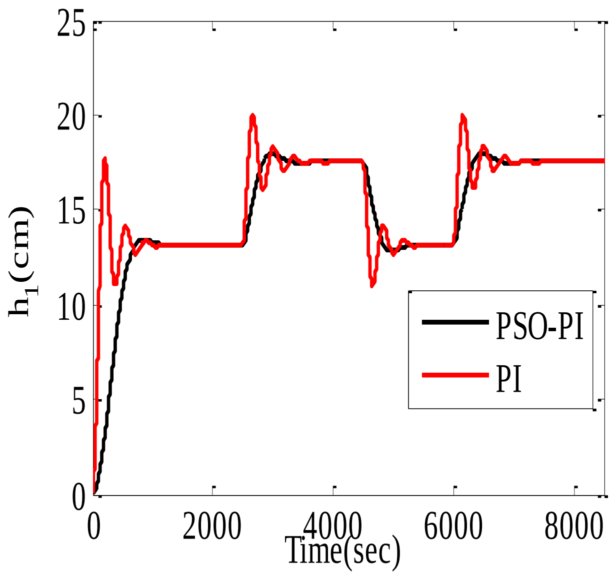


Fig.8.Servo response of h_1 with PI and PSO-PI controllers.

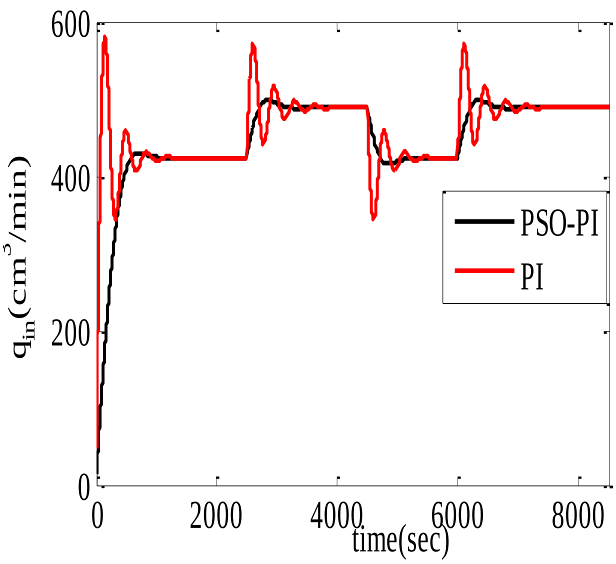


Fig 9. Response of PI and PSO-PI output qin for servo response.

TABLE VII
COMPARISON OF PERFORMANCE MEASURES LEVEL WITH PI AND PSO-PI FOR SERVO RESPONSE (6-8) CM

Servo response for h_2 (6-8)cm			
	t_s(sec)	%overshoot	ISE
PI	**1988**	**12.825**	**353.4**
PSO-PI	**978**	**33.66**	**254.2**

B. Regulatory response for Positive step change load variable $q_{L1}(+)$

A sudden load disturbance of +10% is given in inlet flow rate of tank1 at 4000 sample from $q_{L1}(+)$. Due to this level in h_1 increases for PI from 13.3 to 14.5 cm and PSO it increases from 13.3 to 15.4 as shown in fig.11. The level h_2 also increases for PI from 6 to 6.5 cm and PSO it increases from 6 to 6.9cm as shown in fig 10. The PI and PSO-PI Controller takes necessary action to reduce the flowrate q_{in} from 420 to 350 (ref fig12) In order bring back the level h_2 back to 6cm as shown in fig 10.

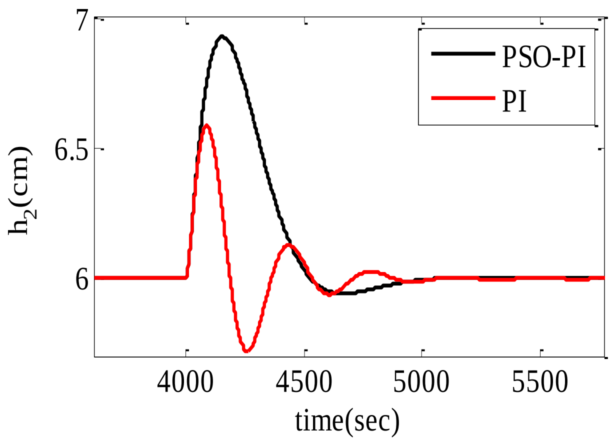


Fig 10. Regulatory response of h_2 with PI and PSO due to load variation in +10% from q_{L1}.

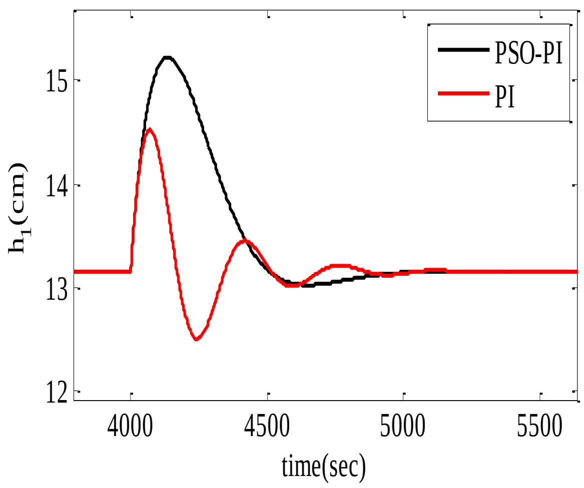


Fig 11. Regulatory response of h_1 with PI and PSO-PI due to Load variation in +10% from q_{L1}.

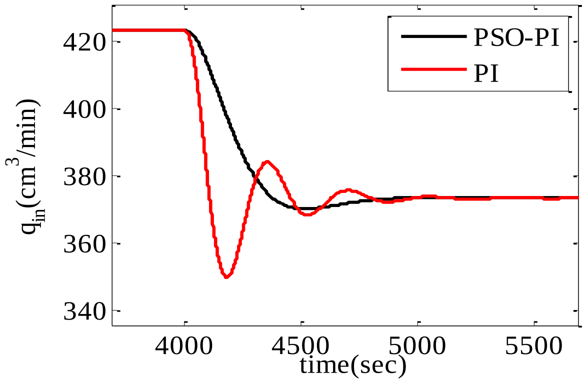


Fig 12. Response of PI and PSO output(q_{in}) for load variation in +10% from q_{L1}

C. Regulatory response for negative step change load variable $q_{L1}(-)$

A sudden load disturbance of -10% is given in inlet flow rate of tank1 at 4000 sample from $q_{L1}(-)$. Due to this level in h_1 decreases for PI from 13.3 to 12.1 cm and PSO it decreases from 13.3 to 11.1 as shown in fig 14. The level h_2 also decrease for PI from 6 to 5.5 cm and PSO it decreases from 6 to 5.1 cm as shown in fig 13. The PI and PSO-PI Controller takes necessary action to increase the flowrate q_{in} from 425 to 500 (ref fig 15) in order bring back the level h_2 back to 6cm as shown in fig 13.

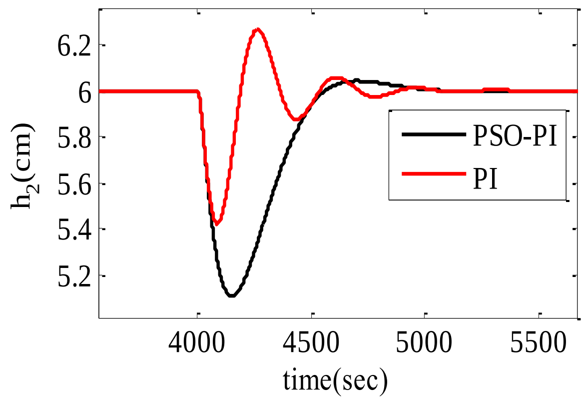


Fig 13. Regulatory response of h_2 with PI and PSO-PI due to load variation in -10% from q_{L1}

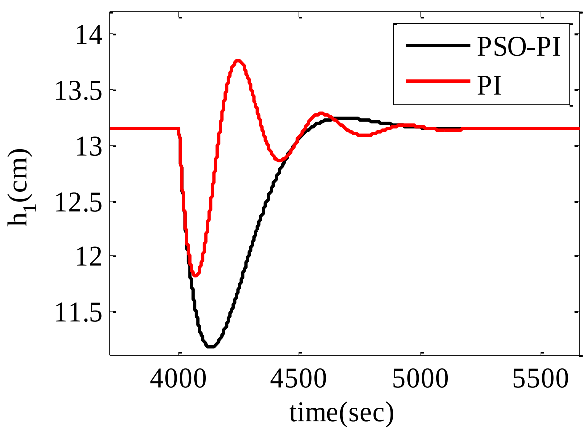


Fig 14. Regulatory response of h_1 with PI and PSO-PI due to load variation in -10% from q_{L1}.

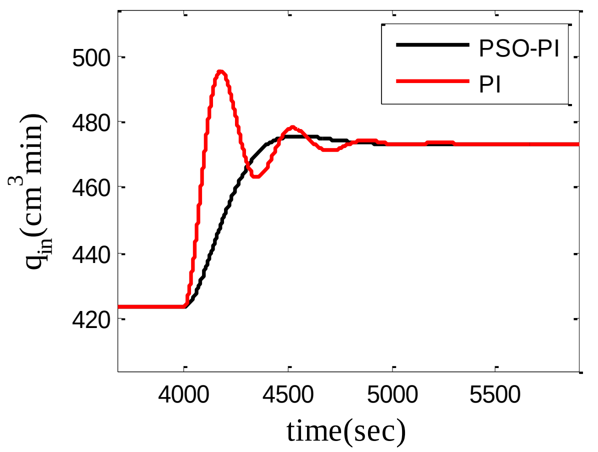


Fig 15. Response of PI and PSO-PI output (q_{in}) for load variation in -10% from q_{L1}.

TABLE VIII
COMPARISON OF PERFORMANCE MEASURE OF LEVEL WITH PI AND PSO FOR REGULATORY RESPONSE.

Regulatory Response h_2 (6-8)cm				
Controller	**+10% from q_{L1}**		**-10% from q_{L1}**	
	t_s(sec)	**ISE**	**t_s(sec)**	**ISE**
PSO-PI	1032	2822	1046	2821
PI	1460	9316	1275	9316

D. Regulatory response for positive step change load variable $q_{L2}(+)$

A sudden load disturbance of +10% is given in inlet flow rate of tank1 at 4000 sample from $q_{L2}(+)$. Due to this level in h_1 increases for PI from 13.3 to 13.5 cm and PSO it increases from 13.3 to 13.6cm as shown in fig 17. The level h_2 also increases for PI from 6 to 7 cm and PSO it increases from 6 to 6.9cm as shown in fig 16. The PI and PSO-PI Controller takes necessary action to reduce the flowrate q_{in} from 420 to 200 (ref fig18) in order bring back the level h_2 back to 6cm as shown in fig 16.

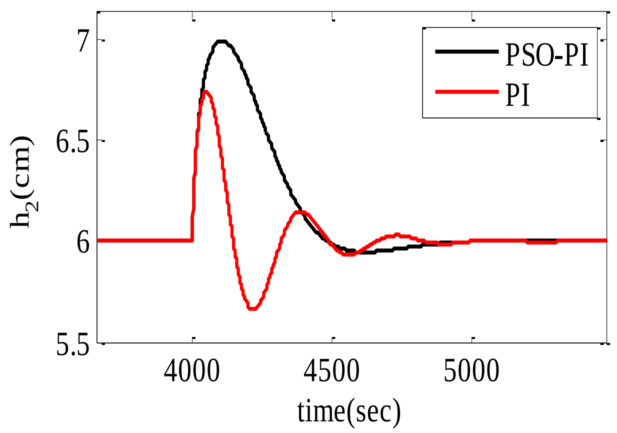
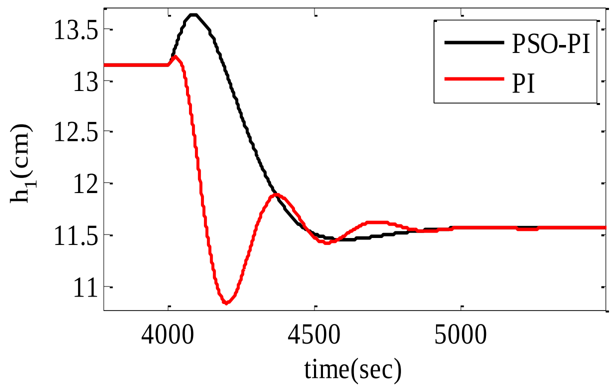


Fig 16. Regulatory response of h_2 with PI and PSO-PI due to load variation in +10% from q_{L2}



. **Fig 17**. Regulatory response of h_1 with PI and PSO-PI due to load variation in +10% from q_{L2} .

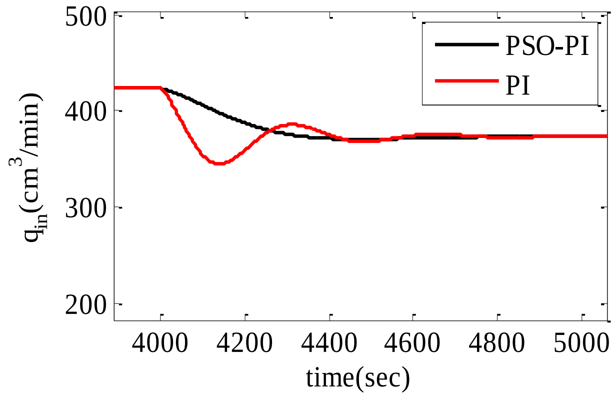


Fig 18. Regulatory response of h_1 with PI and PSO-PI due to load variation in +10% from q_{L2} .

E. Regulatory response for Negative step change load variable $q_{L2}(-)$

A sudden load disturbance of -10% is given in inlet flow rate of tank1 at 4000 sample from $q_{L2}(-)$. Due to this level in h_1 increases for PI from 13.3 to 15.6 cm and PSO it increases from 13.3 to 15 as shown in fig 20. The level h_2 also decreases for PI from 6 to 5.6 cm and PSO it decreases from 6 to 5.8cm as shown in fig 19. The PI and PSO-PI Controller takes necessary action to increase the flowrate q_{in} from 420 to 750 (ref fig21) in order bring back the level h_2 back to 6cm as shown in fig 19.

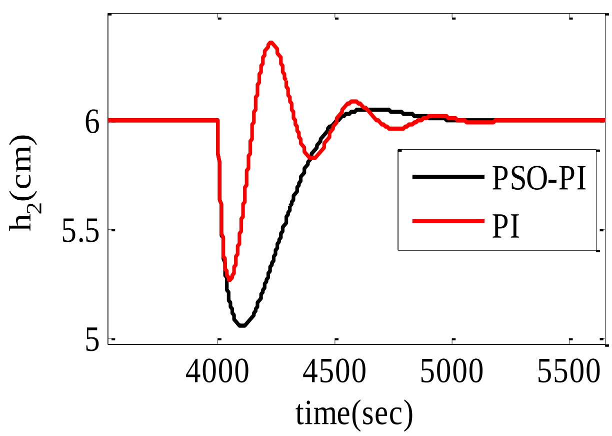


Fig 19. Regulatory response of h_2 with PI and PSO-PI due to load variation in -10% from q_{L2}.

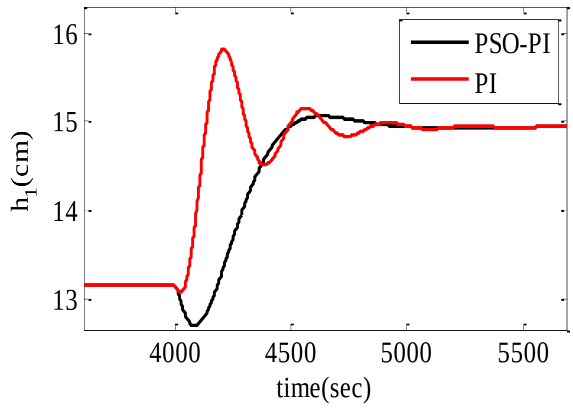


Fig 20. Regulatory response of h_1 with PI and PSO-PI due to load variation in -10% from q_{L2}.

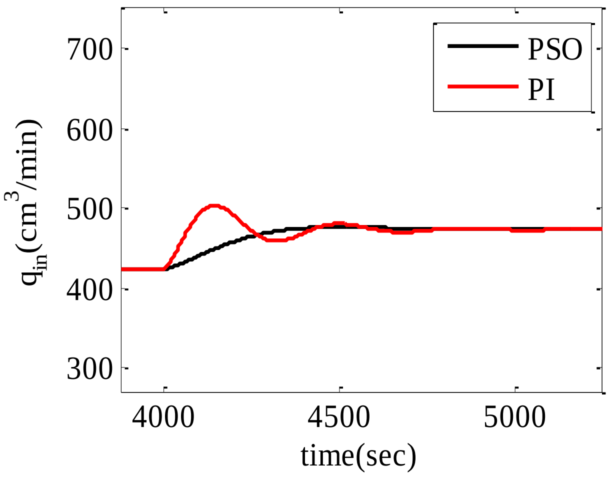


Fig 21. Regulatory response of q_{in} with PI and PSO-PI due to load variation in -10% from q_{L2}.

TABLE IX
COMPARISON OF PERFORMANCE MEASURE OF WITH PI AND PSO-PI FOR REGULATORY

Regulatory Response h_2 (6-8)cm				
Controller	**+10% from q_{L2}**		**-10% from q_{L2}**	
	t_s(sec)	**ISE**	**t_s(sec)**	**ISE**
PSO-PI	1036	2824	1045	2826
PI	1460	9321	1277	9311

VI. CONCLUSION

The non-linear mathematical model of a two-tank interacting process was derived. To improve the performance of closed loop control a PSO-PI was designed and implemented for a two-tank interacting process. The servo and regulatory responses were obtained with PSO-PI. The performances of PSO-PI were compared with that of conventional PI controller in simulation. The performance measures were tabulated. It is observed that the PSO-PI gives is better performance on terms of less integral square error, faster settling time and without oscillation.

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