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Temperature Control of CSTR Using New Particle Swarm Optimization Algorithm

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Abstract: **In Industry nowadays the control of chemical process is important task. Mostly all the chemical processes are highly nonlinear in nature and this causes instability of process. Continuous Stirred Tank Reactor (CSTR) is an important subject in chemical process. Therefore various control approaches have been applied on CSTR to control its parameters. Here Particle Swarm Optimization (PSO) algorithm based PID controller tuning is attempted for the temperature control of Continuous Stirred tank reactor (CSTR), Based on the Performance indices and optimization criterion controller, can be estimated. The Integral Square Error (ISE) criterion is used to guide PSO algorithm to search the controller parameters like K_p, K_i, K_d. The main focus of this paper is to apply soft computing technique that is PSO to design and tuning of PID controller to get better dynamics and static performance at the output .The simulation results show that the PSO based PID controller tuning approach provides better performance compared to the conventional PID controller.**

Keywords: **PID controller, Particle Swarm Optimization Algorithm, Stochastic systems, CSTR.**

I. INTRODUCTION

The Continuous Stirred Tank Reactor (CSTR), also known as vat mix reactor is a common ideal reactor type in chemical and control engineering. CSTR involves complex reactions with high nonlinearity, and it is very hard to be controlled by the conventional methods [6]. Chemical reactors often have significant heat effects, so it is important to be able to add or remove heat from them. In a CSTR the heat is added or removed by virtue of the temperature difference between a jacked fluid and the reactor fluid. Often, the heat transfer fluid is pumped through agitation nozzle that circulates the fluid through the jacket at a high velocity.

The problem of controlling of CSTR is considered as an attractive and controversial issue, especially for control engineers, corresponding to its nonlinear dynamic. Most of the conventional controllers are restricted just for linear time invariant system applications. However, in real environment, the nonlinear characteristics of the systems and their functional parameters changes, due to wear and tear, cannot be neglected. Therefore to overcome these problem, adaptive and intelligent controllers are uses.

One of the most popular controllers for the academic and industrial application is PID. PID controller has been applied in feedback loop mechanism and extensively used in industrial process control since 1950s. It tries to correct the error between the measured outputs and desired outputs of the process in order to improve the transient and steady state responses as much as possible. Easy implementation of PID controller, made it more popular in system control applications. In one hand, PID controller appear to have an acceptable performance in the most of systems, but sometimes there are functional changes in system parameters that need an adaptive based method to achieve more accurate response. Several researches are available that combined the adaptive approaches on PID controller to increase its performance with respect to the system variations [1], [2].

Here soft computing based, auto tuning method Particle Swarm Optimization (PSO) algorithm has been used for tuning of PID Controller.

II. PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM

Particle Swarm Optimization is a population based stochastic optimization technique first introduced by Kennedys and Ebert in 1995 [3], inspired by social behaviour of bird flocking or fish schooling, It is also based on swarm intelligence. The PSO has no systematically calculation method and it has no definite mathematic foundation. At present, the method can only be used successfully in the aspect of Evolutionary neural network, and its other applications are still being explored [3]. PSO is widely used in engineering applications due to its high computational efficiency, easy implementation and stable convergence and there are few parameters to adjust and has been successfully applied in many areas such as function optimization, fuzzy gain scheduling, PID Auto tuning and fractional order PID controller design [7].

The algorithm proposed by Kennedy and Ebert uses a 1-D approach for searching within the solution space. For this study the PSO algorithm will be applied to a 2-D or 3-D solution space in search of optimal tuning parameters for PI, PD and PID control. PSO algorithm will be applied to a 2-D or 3-D solution space in search of optimal tuning parameters for PI, PD and PID control. The flowchart of the PID-PSO control system is shown in *Fig* 1.

Consider position $X_{i,m}$, of the i^{th} particle as it traverses a n −dimensional search space: The previous best position for this i^{th} particle is recorded and represented as $Pbest_{I,n}$. The best performing particle among the swarm population is denoted as $gbest_{I,n}$, and the velocity of each particle within the n −dimension is represented as $V_{i,n}$. The new velocity and position for each particle can be calculated from its current velocity and distance respectively [4] .In the PSO algorithm, instead of using evolutionary operators such as mutation and crossover, to manipulate algorithms, for a d-variable optimization problem, a flock of particles are put into the d-dimensional search space with randomly chosen velocities and positions knowing their best optimized values so for position best (P best) and the position in the d-dimensional space.

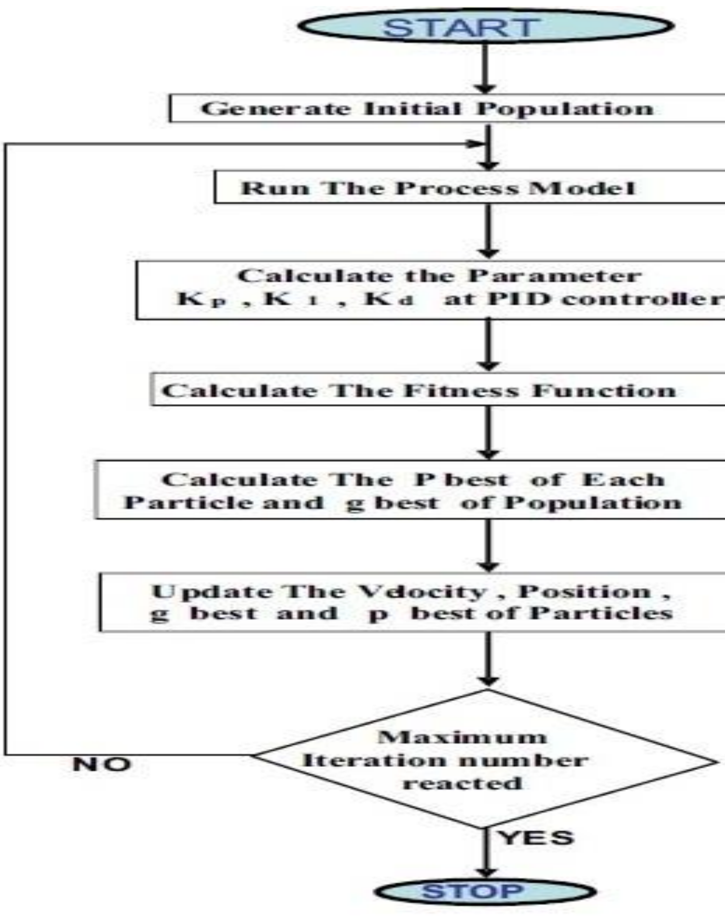

Fig 1: Flow Chart of Particle Swarm Optimization.

For example, the i^{th} particle is represented, as $x_i = (x_{i,1} , x_{i,2} ,\ldots\ldots, x_{i,d})$ in the d-dimensional space The best previous position of the i^{th} particle is recorded as,

$Pbest_i = (Pbest_{i,1}, Pbest_{i,2},\ldots\ldots, Pbest_{i,d})$….... (1)

The index of best particle among all of the particles in the group in g best d .The velocity for particle i is represented as

$V_i = (V_{i,1} , V_{i,2} ,\ldots\ldots, V_{i,d})$…........... (2)

The modified velocity and position of each particle can be calculated using the current velocity and distance from $Pbest_{i,d}$ to $gbest_d$ as shown in the following equations:

Velocity=
W.*Velocity+C1.*(R1.*(Local Best Position Current Position))+C2.*(R2.*(Global Best Position-Current Position));
Current Position = Current Position + Velocity ;………………………………..(3)

PSO Parameters for CSTR Problem:

Table 1: PSO Parameters

PARAMETER	VALUE
Velocity constants (C1)	1.494
Velocity constants (C2)	1.494
Inertia w factor	0.8
No. of particles	25
Searching iterations	1000
Fitness	ISE

III. CONTINUOUS STIRRED TANK REACTOR (CSTR) MODELLING

The CSTR with single input and single output is shown in *Fig2.* Usually the industrial reactors are controlled using linear PID control configurations and the tuning of controller parameters is based on the linearization of the reactor models in a small neighbourhood around the stationary operating points.

In this paper, CSTR has been considered in which temperature of two chemicals is controlled for better results of mixing. The chemical A and B are mixed together and produce a product Z. The jacket temperature (Tj) is directly proportional to reactor temperature (T).Our objective is to control the reactor Temperature by manipulating the jacket temperature.

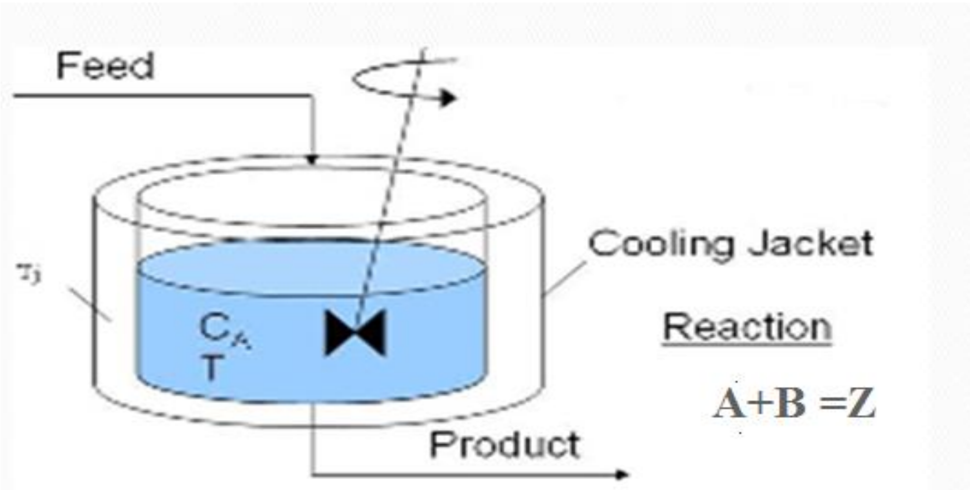

Fig 2: CSTR with cooling jacket

The Stoichiometric equation is

A+B=Z …………… (4)

%% State Space Equation:-

```
a11 = -F/V - k0*exp (-Ea/(R*T));
a12=k0*exp(Ea/(R*T))*(Ea/(R*(T^2)))*Ca;
a21 = -(dH/rhocp)*k0*exp(-Ea/(R*T));
a22=F/V((U*A)/(V*rhocp))+((dH/rhocp)*k0*exp(-Ea/(R*T)))*(Ea/(R*(T^2)))*Ca;
a = [a11 a12;a 21 a22];…….(5)
b11 = 0;
b21 = (U*A)/(V*rhocp);
b = [b11; b21];……………..(6)
c = [0 1];…………………….(7)
d=[0]………………………..(8)
```

Reactor Parameters:

Table 2: CSTR Parameters

PARAMETERS	VALUES	UNIT
E_a (Activation Energy)	32400	Btu/lbmol
K_0 (Frequency Factor)	15e12	Hr^{-1}
U (Heat Transfer Coefficient)	75	Btu/luft^2 °F
ρC_p(Density x Heat capacity)	53.25	Btu/ft^3 °F
R (Ideal Gas Constant)	1.987	Btu/lbmol °F
F (Feed Rate)	3000	Ft^3/hr
V (Reactor Volume)	750	Ft^3
C_a(Concenteration of Reactant)	0.132	Lbmol/ft^3
T_f(Feed Temperature)	60	°F

IV. CONTROLLER DESIGN

Industrial PID controllers usually available as a form and to perform well industrial process problems, the PID controllers structures requires modifications [5]. The structures are given below-

$$G_{PID} = K_p e(t) + K_i \int_0^T e(t)dt + K_d\, de(t)/d(t) \quad \ldots\ldots\ldots\ldots..(9)$$

Where *e*(*t*) is the error signal between the set point and actual output, *u*(*t*) is the controller output and K_p , K_i , K_d are the PID controller gains. A basic PID controller directly operates on the error signal and this may produce a large overshoot in the process response due to the proportional and derivative kick. The process is unstable and to overcome the effect of proportional and derivative kick, a modified PID structure with PSO are shown in *Fig* 4 . .

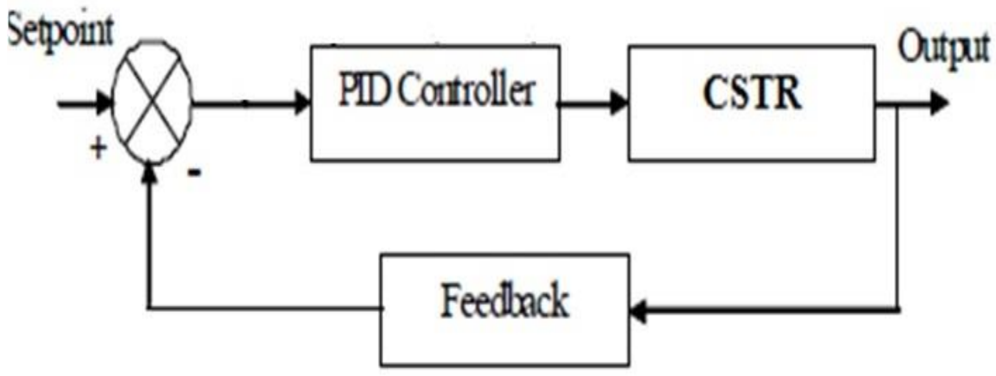

Fig 3: Block diagram of CSTR with PID

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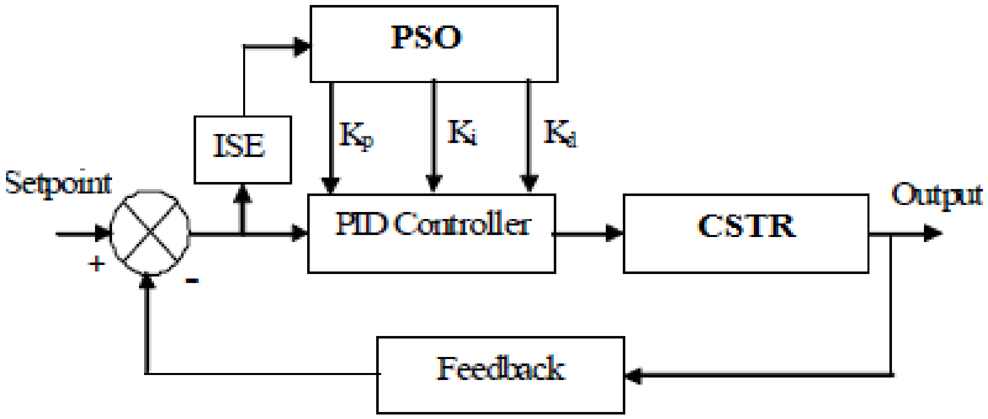

Fig 4: Tuning of PID-PSO Controller

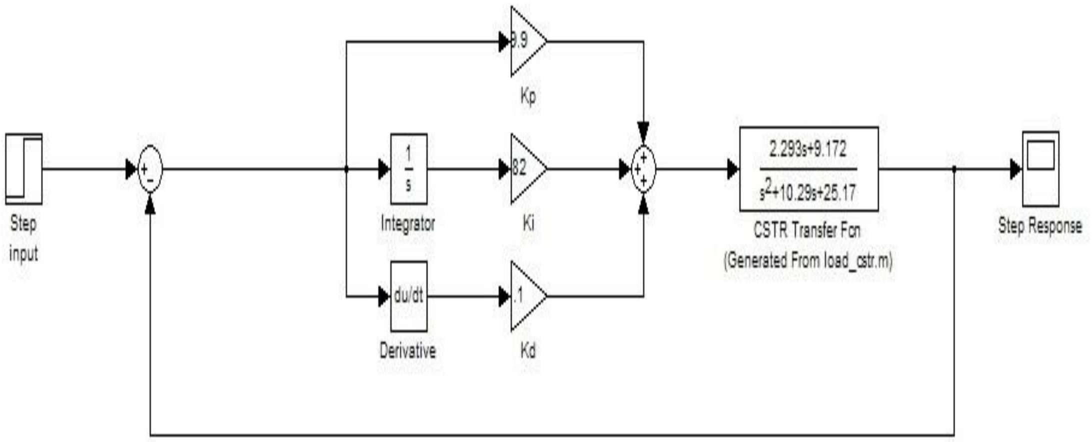

Fig 5: Simulation Model of CSTR with PID Controller

V. RESULT AND DISCUSSION

(A) Open Loop Response Method:-

Initially, open loop test has been done, In *Fig6*, system response has not reached the set point without controller.

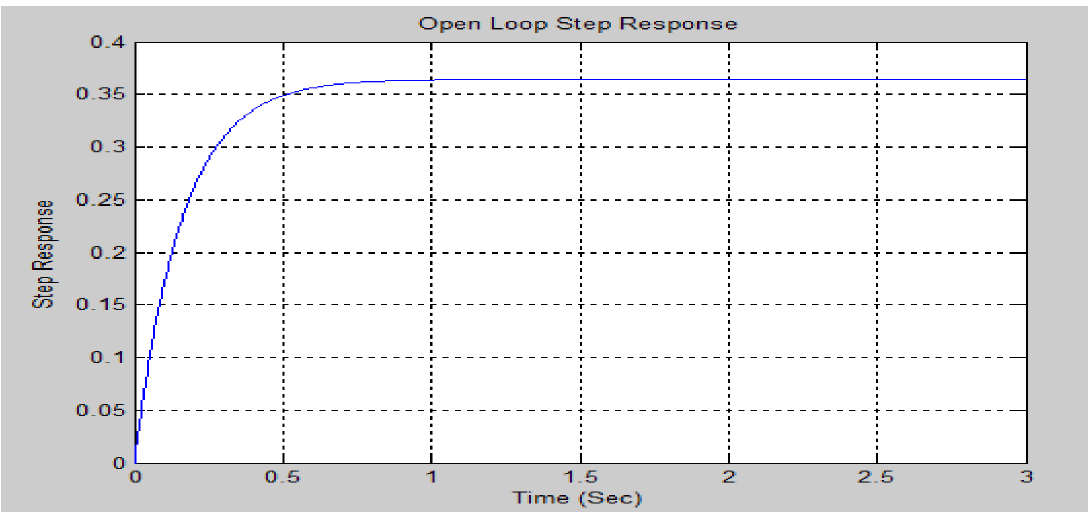

Fig 6: Response of open loop step response method.

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(B) PID controller:-

When PID controller has been used then System response has reached the set point, in *Fig7*. In this *Fig* PID improved the dynamic performance of a system but it has higher overshoot, high rise time longer settling time, and more Oscillation.

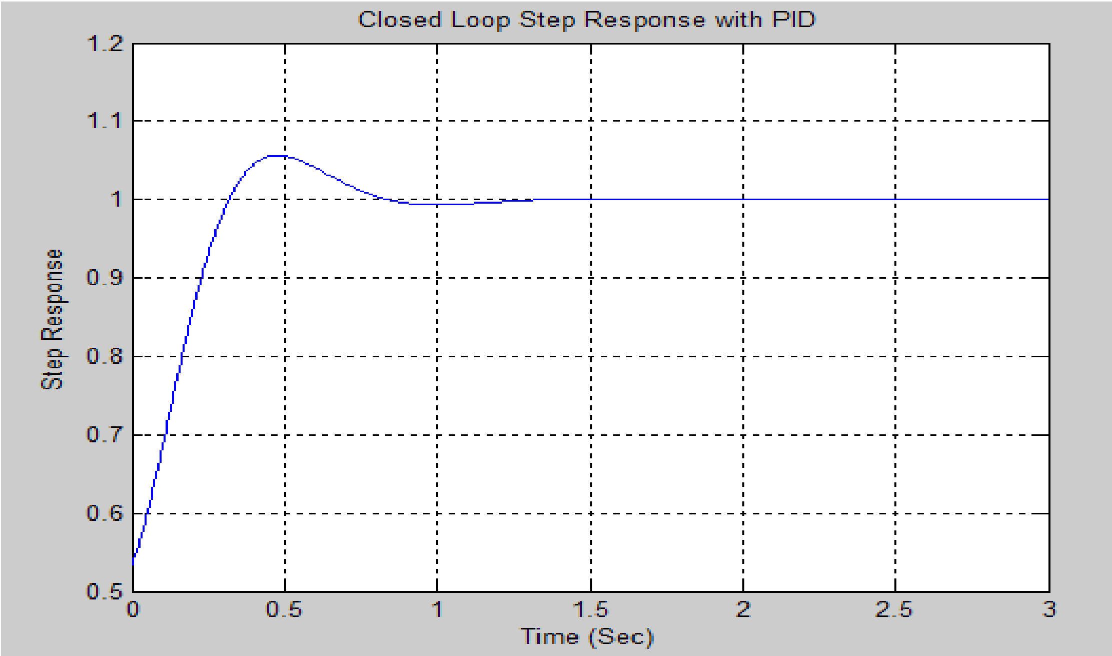

Fig 7: System with PID controller

All the drawback of the conventional PID can be eliminated while using the PSO optimization method.

(C) Particle Swarm Optimization (PSO) Algorithm:-

When PID-PSO has been used, then the system response has reached the set point very faster and it has improved the dynamic Performance of a system in *Fig8*.

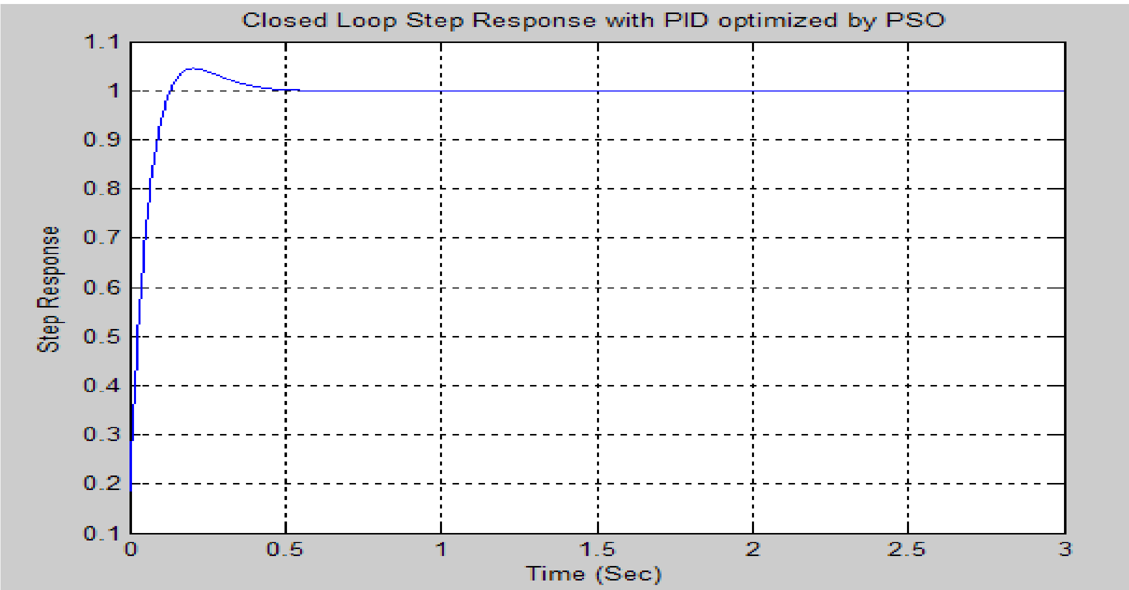

Fig 8. System with PID-PSO Response

(D) Comparison between OPEN LOOP, PID, PID-PSO:-

In *Fig.9*, PID-PSO has better response than PID and Open loop method for all the dynamic performance.

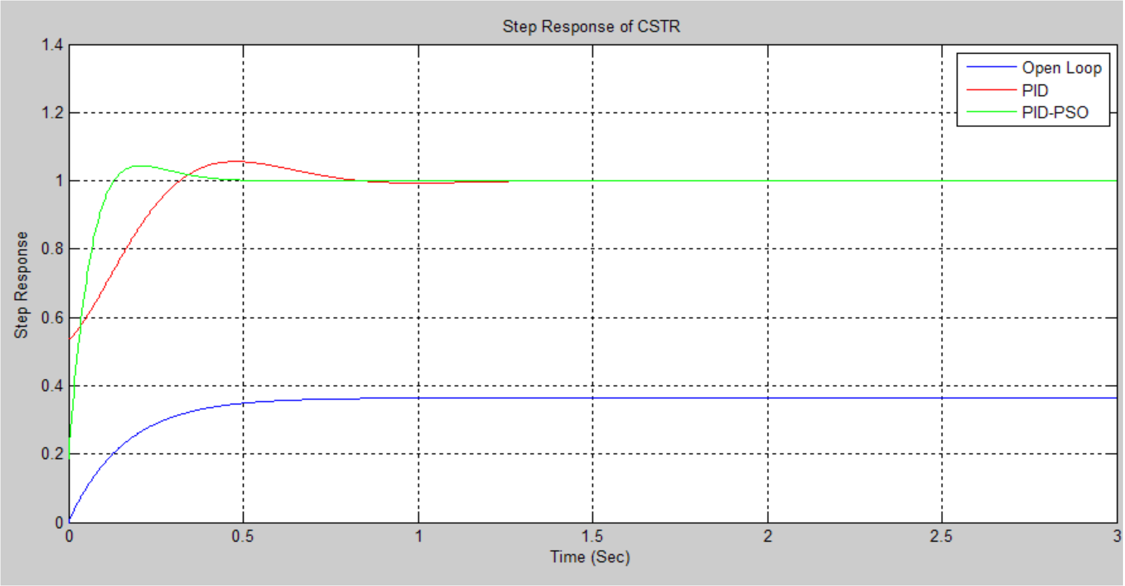

Fig 9: Tuned response of PID controller

Summarized Results:

Tuning methods	**PID parameters**		
	K_P	K_i	K_d
PID-PSO	10.0000	100.000	0.1000

Table 3: Controller Parameters

In Table4, Dynamic performance of PID-PSO is better than PID because for all the time responses PID-PSO taking less time than PID to reached the set point (temperature).

Dynamic performance specifications	**Tuning methods**		
	PID (1)	**PI D-PSO (2)**	**Remarks**
Rise time (tr) (sec)	0.2309	0.0889	For all the time responses PID-PSO taking Minimum Time. . Hence PID-PSO is better than PID.
Settling time (ts) (sec)	0.7631	0.3509	
Settling minimum(sec)	0.9543	0.9228	
Settling maximum(sec)	1.0563	1.0445	
Overshoot (%)	5.6336	3.6141	
Undershoot(%)	0	0	
Peak (sec)	1.0563	1.0361	
Peak time (sec)	0.4775	0.2072	

Table 4: Comparison between PID (1) and PID-PSO (2.)

In Table5, PID-PSO taking 38% less time than PID in case of Rise time,45%less time in case of settling time than for all the time responses PID-PSO taking less time than PID. Therefore PID-PSO is more efficient than PID.

Dynamic performance specifications	**Tuning methods**		
	PID (1)	**PID-PSO (2)**	**Remarks**
Rise time (tr) (sec)	0.2309	38%	For all the time responses, PID- PSO taking minimum time w. r. t. PID. Hence PSO is more efficient among all.
Settling time (tr) (sec)	0.7631	45%	
Settling minimum(sec)	0.9543	96%	
Settling maximum(sec)	1.0563	97%	
Overshoot (%)	5.6336	64%	
Undershoot(%)	0	0	
Peak (sec)	1.0563	97%	
Peak time (sec)	0.4775	43%	

Table 5: Efficiency with PID-PSO over PID.

In Table6, Integral Square Error found very minimum in case of PID-PSO than it is more efficient than PID.

Control structure	Integral Square Error (ISE)	Remarks
PID-PSO	14.9644	In PID-PSO, ISE is minimum .

Table 6: Integral Square Error (I S E) for the PID-PSO

VI. CONCLUSION

The PID and tuning method have been implemented on flow control loop and a comparison of control performance using these methods has been completed. For the PID controller set point tracking performance is characterized by lack of smooth transition as well it has more oscillations. Also it takes much time to reach set point But the PID-PSO based controller tracks the set point faster and maintains steady state. The ISE is also found to be very minimal compared to the PID. It was found for all control loops the performance of the PID-PSO based controller was better compared to the PID. Compared to conventionally tuned system, PID-PSO tuned system has good dynamic response and steady state response.

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