TEMPERATURE CONTROL OF CSTR A COMPARATIVE APPROACH

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Abstract: **Most of the industrial processes including the chemical process industry are nonlinear in nature, but still control practitioners have been using linear control techniques to control such systems. In this paper the design of a nonlinear feedback controller is analyzed for temperature control of continuous stirred tank reactors (CSTR) which have strong nonlinearities. The reaction temperature is the most important process parameter in CSTR operation process, and the control of reaction temperature quality is closely related to the production efficiency and economic benefit. Here Particle Swarm Optimization (PSO) algorithm based PID controller tuning is used for the temperature control of CSTR, The performance is analyzed for the controllers designed by using PID, PID-GA and PID-PSO methods, identifying a suitable controller and enhanced the system performance. The Integral Square Error (ISE) criterion is used to guide PSO algorithm to search the controller parameters like K_p, K_i , K_d . A comprehensive simulation is carried out with PID and GA controller Structures. The simulation results show that the PSO based PID controller tuning approach provides better performance compared to other conventional PID tuning methods.**

Keywords: **PID controller, Particle Swarm Optimization Algorithm (PSO), Genetic algorithm (GA) Stochastic systems, CSTR.**

1. INTRODUCTION

The Continuous Stirred Tank Reactor (CSTR), also known as vat mix reactor is a common ideal reactor type in chemical and control engineering. It is a complex nonlinear system. Due to its strong nonlinear behaviour, the problem of identification of parameters and control of CSTR is always a challenging task for control systems engineer [1]. In a CSTR the heat is add or removed by virtue of the temperature difference between a jacked fluid and the reactor fluid. It is an exothermic reaction and heat generated is removed by the coolant, which flows in the jacket around the tank. 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 the temperature of CSTR is considered as a challenging issue especially for a control engineer corresponding to its nonlinear dynamics and its operation is also disturbed by external factor such as changes in the feed flow rate. The most of the traditional controllers are restricted just for linear time invariant system application. But in real world, the nonlinear characteristics of system and their function parameter changes, due to wear and tear, that’s why these changes can’t be neglected. One of the most important controllers both in academic and industrial application is PID. PID controller has been applied in feedback loop mechanism and extensively used in industrial Process control since 1950s. Easy implementation of PID controller made it more popular in control system application.

PID controller is linear and in particular symmetric, but it is not very efficient due to the presence of non-linearity in the system and it has quite high overshoot, high rise time and longer settling time.PID controller, when used alone, can give lack of smooth performance, more oscillations. It also takes much time to tracks the set point. To overcome these problems in PID controller, it is required to remove this problem, using different Optimization techniques for tuning of PID Controller. The model based controller tuning requires complex computations to identify the controller parameters. To overcome this, it is necessary to use soft computing based auto tuning methods [2]. There are two algorithms proposed as tuning methods.

(A) Genetic Algorithm (GA)

(B) Particle Swarm Optimization (PSO)

(A) Genetic algorithm (GA):

A GA is a stochastic optimization method based on the biological principles of Darwinian evolution [6]. GA has both global search and local search abilities .Gas are developed as a framework for a global search of the design space [6]. It offer, an alternative approach both for identification and control of nonlinear processes in process engineering.

Component needed for implementation for GA:

- Representation
- Initialization
- Evolution

Genetic Operators:

- Selection
- Crossover
- Mutation

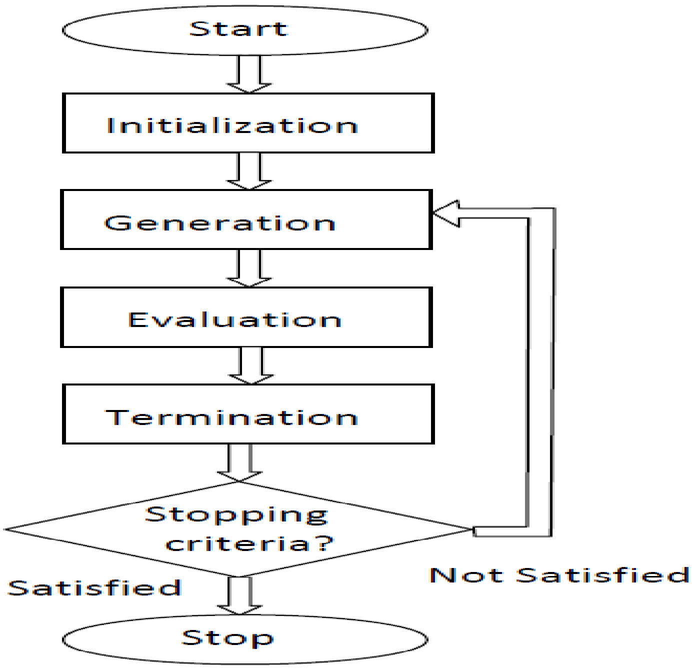

Fig.1. Operation Flowchart for the Genetic Algorithm.

(B) ParticleSwarm 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* 2.

Consider position $X_{i,m}$, of the i^{th}particle as it traverses an 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 far Position best (P best) and the position in the d-dimensional space.

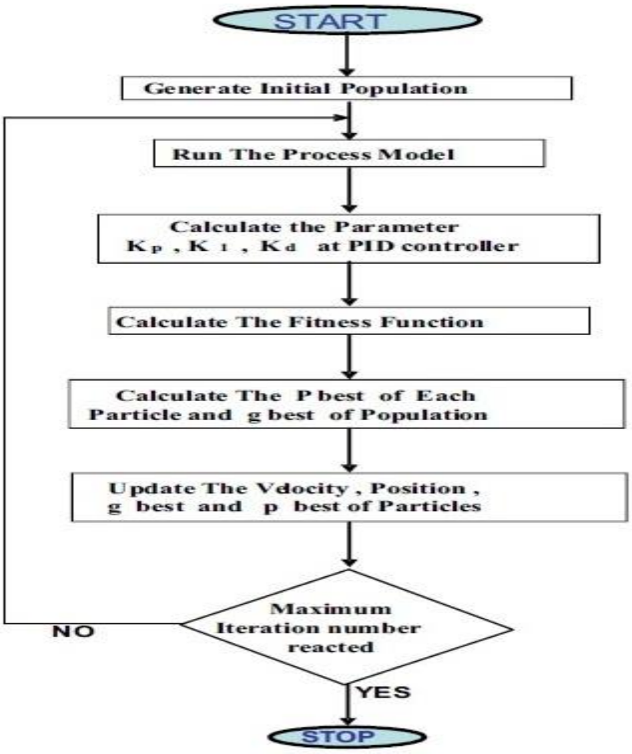

Fig.2. Flow Chart of Particle Swarm Optimization.

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

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

$V_i = (V_{i,1}$, $V_{i,2}$,…….., $V_{i,d}$)…........... (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.*(LocalBestPositionCurrentPosition))+C2.*(R2.*(GlobalBestPosition-CurrentPosition));

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

2. CONTINUOUS STIRRED TANK REACTOR (CSTR) MODELLING

The CSTR with single input and single output is shown in *Fig 3.* 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, the chemical A and B are mixed together and produce a product is 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.

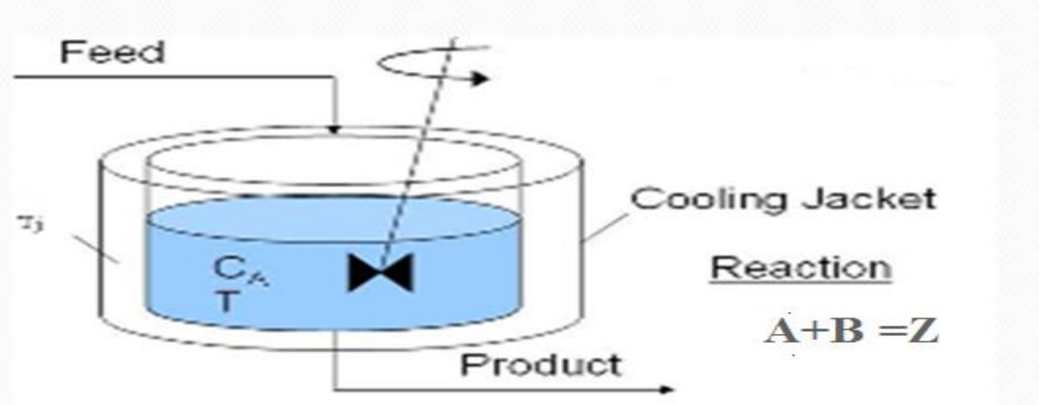

Fig. 3. CSTR with cooling jacket

The Stoichometric equation $A+B=Z$ ……………(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;a21a22]; …………… .(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 $(ActivationEnergy)$	32400	Btu/lbmol
K_0 $(FrequencyFactor)$	15e12	Hr^{-1}
U (Heat Transfer Coefficient)	75	Btu/luft^2 °F
ρC_ρ(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
$C_a(ConcenterationofReactant)$	0.132	Lbmol/ft^3
$T_f(FeedTemperature)$	60	°F

3. 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-

$G_{PID} = K_p e(t) + K_i \int_0^T e(t)dt + K_d de(t)/d(t)$………….(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. Basically PID tries to correct the error between measured outputs and desired outputs of the process in order to improve the transient and steady state response as much as possible.. 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 GA and PSO are shown in *Fig* 6 and *Fig* 7.

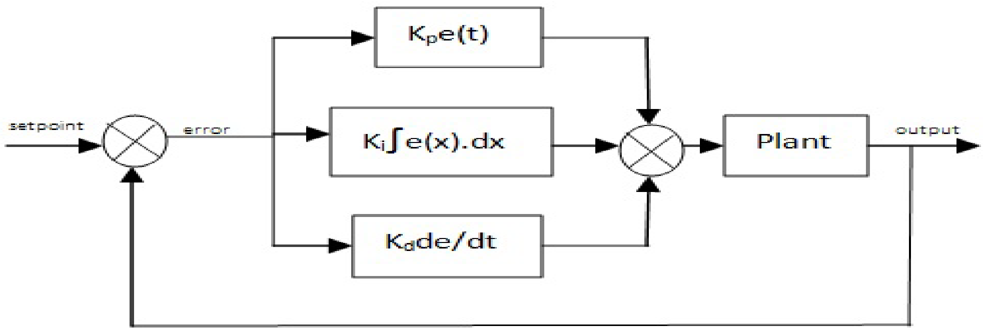

Fig.4. Block diagram of conventional PID Controller

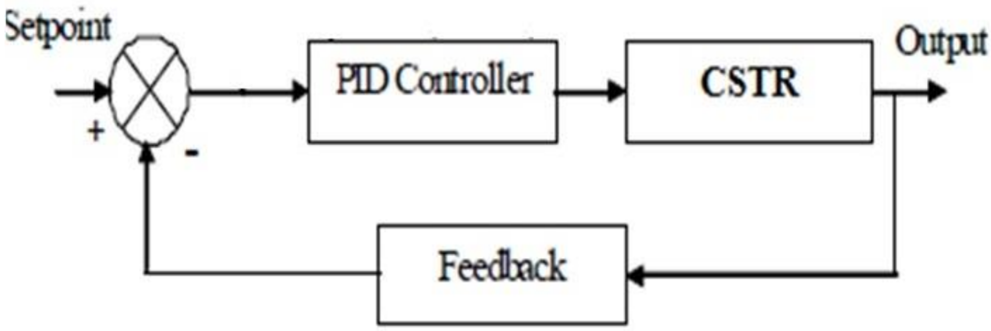

Fig.5. Block diagram of CSTR with PID

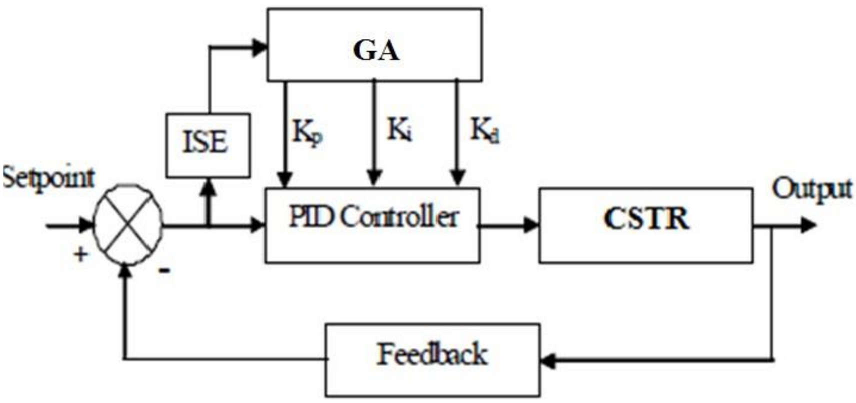

Fig.6. Tuning of PID-GA Controller

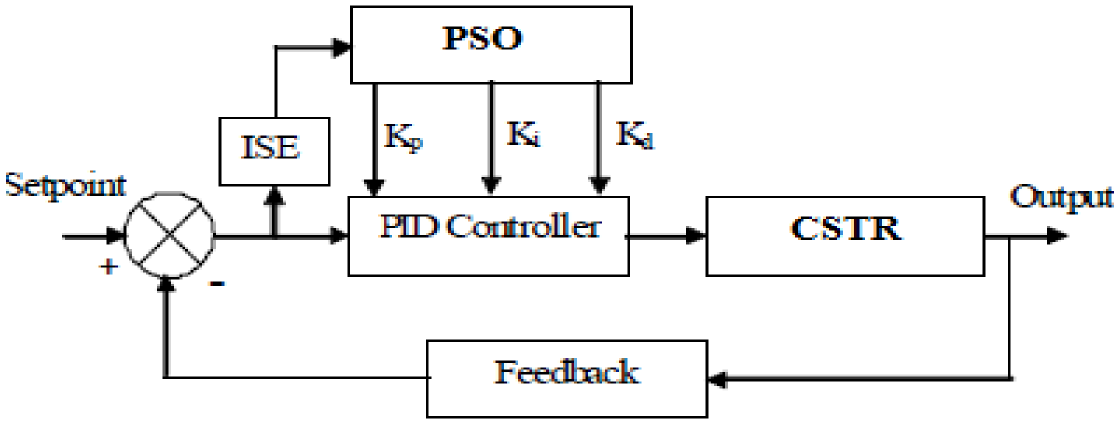

Fig.7. Tuning of PID-PSO Controller

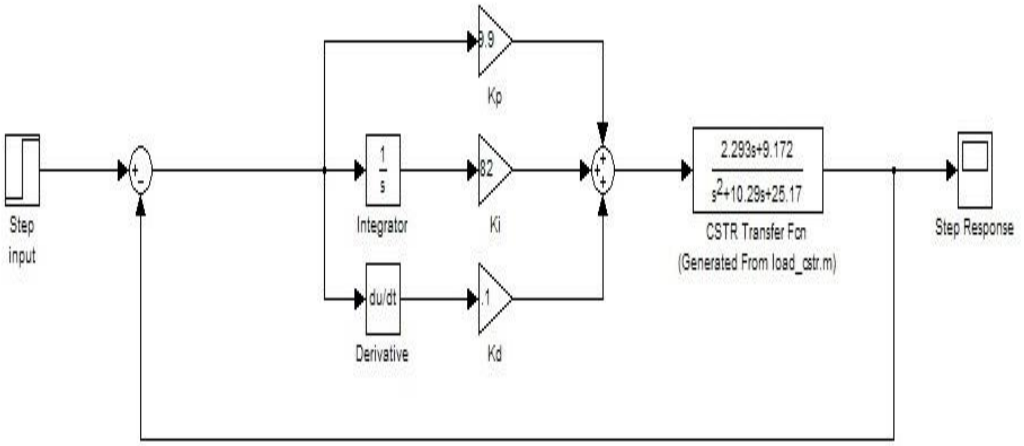

Fig.8. Simulation Model of CSTR with PID Controller

4. RESULT AND DISCUSSION (CASE STUDIES)

(A) Open Loop Response Method:-

Initially, open loop test has been done, In Fig.9; system response has not reached the set point without controller.

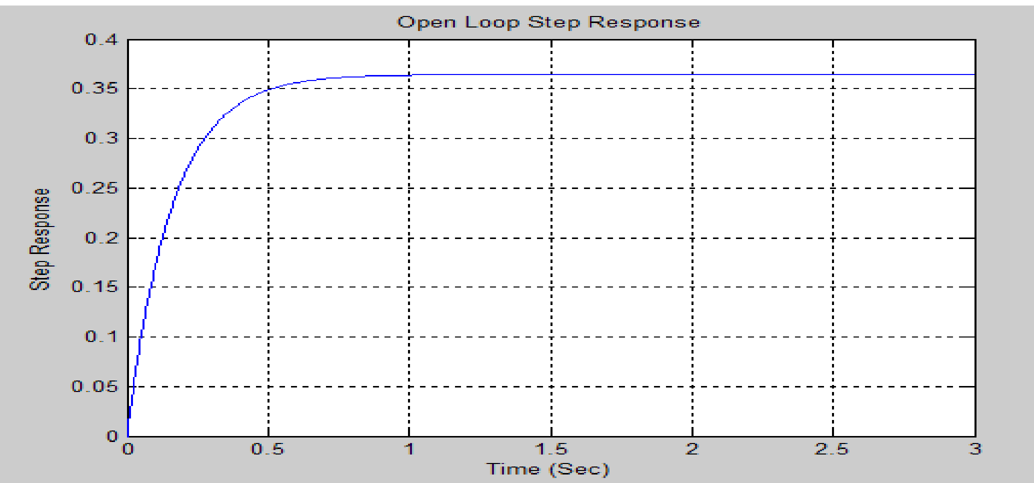

Fig.9. Response of open loop step response method.

(B) PID controller:-

When PID controller has been used then System response has reached the set point, in *Fig*10.PID improved the dynamic performance of a system but it has higher overshoot, high rise time longer settling time, and more Oscillation.

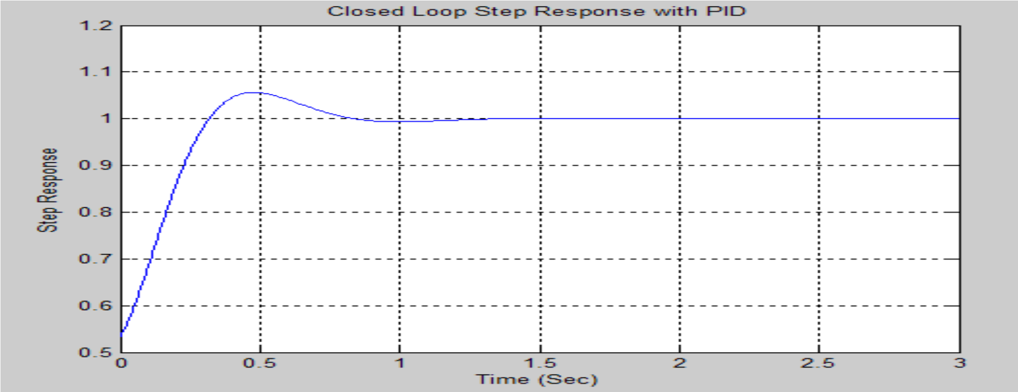

Fig. 10. System with PID controller

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

(C) Genetic Algorithm (GA):-

When PID-GA has been used, then the system response has reached the set point faster than PIDand it has improved the dynamic Performance of a system in *Fig*11.

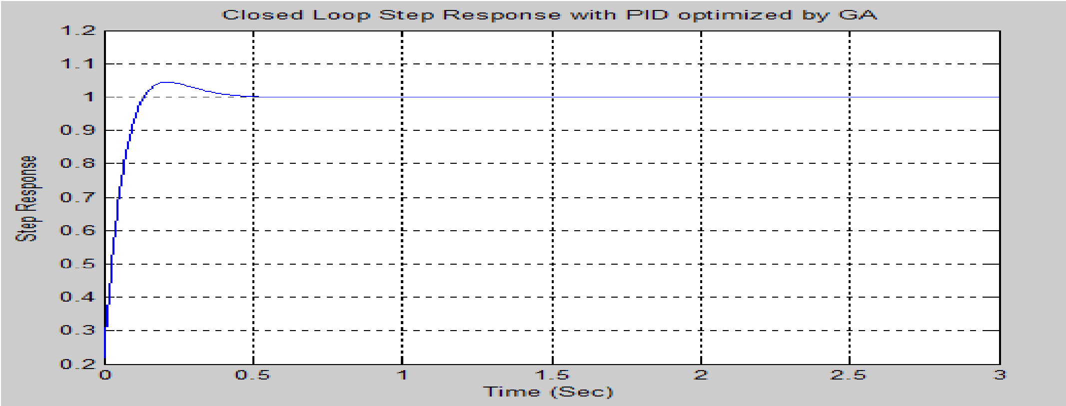

Fig.11. System with PID-GA Response

(D) 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 *Fig*12.

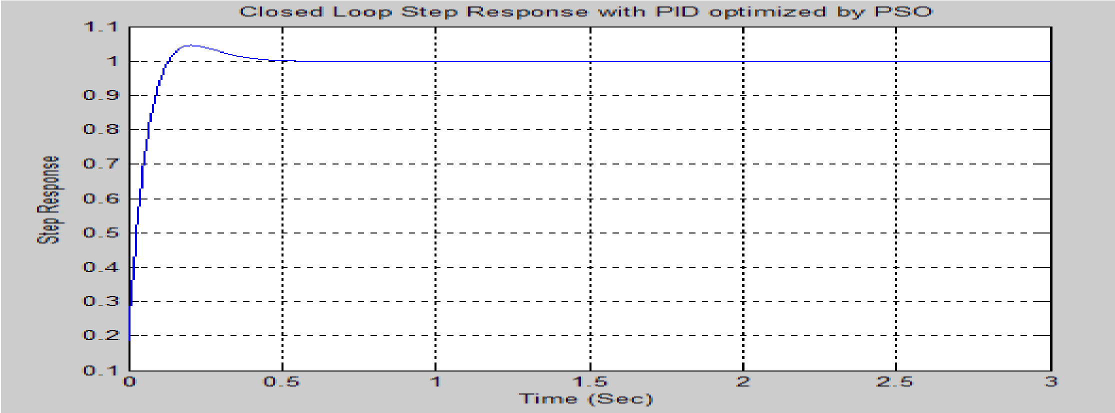

Fig.12. System with PID-PSO Response

(E) Comparison between OPENLOOP, PID, PID-GA, PID-PSO:-

In Fig.13, PID-PSO has better response than PID and Open loop method for all the dynamic performance.

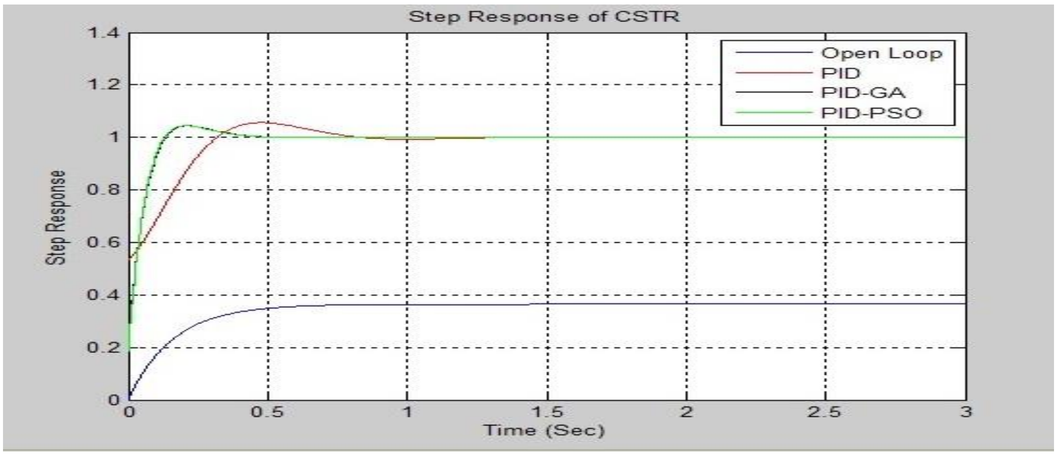

Fig.13. Tuned response of PID controller

Summarized Results:-

Table3. Controller Parameters

Tuning methods	**PID parameters**		
	K_P	K_i	K_d
PID-GA	10.0000	97.1831	0.1003
PID-PSO	10.0000	100.000	0.1000

In *Table4*, Integral Square Error found very minimum in case of PID-PSO than it is more efficient than PID-GA.

Table 4. ISE for the PID-GA and PID-PSO

Control structure	Integral Square Error (ISE)	Remarks
PID-GA	15.0025	In PID-PSO , ISE is minimum than PID-GA.
PID-PSO	14.9644	

In *Table5*, Dynamic performance of PID-PSO is better than PID and PID-GA because for all the time responses PID-PSO is taking less time than PID and PID-GA to reached the set point (temperature).

Table5. Comparison between OPEN LOOP, PID (1), PID-GA (2), PID-PSO (3)

Dynamic performance specification	**Tuning methods**			**Remarks**
	PID(1)	PID-GA (2)	PID-PSO(3)	
Rise time(tr)	0.2309	0.0937	0.0889	For all the Time Responses PID-PSO is taking Minimum Time. . Hence PID-PSO is better than PID.
Settling time (ts)	0.7631	0.3535	0.3509	
Settling min.	0.9543	0.9260	0.9228	
Settling max.	1.0563	1.0445	1.0361	
Overshoot	5.6336	4.4522	3.6141	
Undershoot	0	0	0	
Peak	1.0563	1.0445	1.0361	
Peak time	0.4775	0.2192	0.2072	

In *Table6*, PID-PSO is taking 38% less time than PID and PID-GA in case of Rise time,45%less time in case of settling time similarly for all the time responses PID-PSO is taking less time than PID and PID-GA. Therefore PID-PSO is more efficient than PID and PID-GA.

Table6. Efficiency with PID-PSO (3), PID-GA (2) over PID(1)

Dynamic performance specifications	**Tuning methods**			**Remarks**
	PID(1)	**PID-GA (2)**	**PID-PSO (3)**	
Rise time (tr) (sec)	0.2309	41%	38%	For all the time responses, PID- PSO taking minimum time than PID- GA w. r. t. PID. Hence PSO is more efficient among all.
Settling time (ts) (sec)	0.7631	46%	45%	
Settling minimum(sec)	0.9543	97%	96%	
Settling maximum(sec)	1.0563	98%	97%	
Overshoot (%)	5.6336	79%	64%	
Undershoot (%)	0	0	0	
Peak (sec)	1.0563	98%	97%	
Peak time (sec)	0.4775	45%	43%	

5. CONCLUSION

This research has proposed particle swarm optimization algorithm (PSO) for design and implementation of intelligent controller for CSTR system. The simulation results have proved that the proposed method is an intelligent way to determine the optimal PID controller parameters using the PSO for CSTR system. PID controller takes much time to reach set point but the PID-PSO based controller tracks the set point faster and maintains steady state. In addition, it has confirmed that the proposed controller can perform an efficient search for the optimal PID controller parameters with respect to minimizing objective function as ISE. By comparison with PID and GA methods, it shows that this method can improve the dynamic performance of the system in a better way by the selection of an appropriate objective function. The simulation results shows that compared to the traditional PID controller and PID-GA controller, PSO based tuning PID controller has a better dynamic response curve, shorter response time, small overshoot, high steady precision, good static and dynamic performance.

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