Auto-tuning of PID Controller for Distillation Process with Particle Swarm Optimization (PSO) Method

Mehul Pragjibhai Girnari[1] **Prof. Vinod P. Patel**[2]
[1,2]Department of Instrumentation and Control Engineering
[1,2]L.D. College of Engineering, Ahmedabad, 380015

Abstract— Distillation column is the most common thermal separation unit used in various types of industries, i.e. Petroleum refineries, Chemical process industries, Pharmaceutical industries, water purification and desalination plants, etc., understanding its behaviour and accordingly designing a control system has been defined a good characteristic of a process control engineer. In order to perform separation distillation column requires a huge amount of energy for both heating and cooling. Thus, to make the whole process more economic, it is desirable to design and control the energy efficient process in order to improve the purity of finality and the intermediate products. As the distillation column is a multivariable, non-linear and highly interactive process, to control it efficiently, there is always a need to develop innovative and advanced control strategies in order to obtain high economic performance. When traditional PID controller tuning methods fail to provide optimal values of PID parameters, we need to go for advanced control strategies. In order to use these advanced control strategies, the process model is required to obtain. In recent times, many advanced control strategies are available like Particle Swarm Optimization (PSO) and many other soft-computing techniques can be used for an optimal tuning of PID controller.

Key words: Binary, Distillation, PID, PID tuning, PSO

I. INTRODUCTION

The term distillation refers to a physical separation process or a unit operation. Distillation is a thermal separation method for separating mixtures of two or more substances into its component fractions of desired purity, based on differences in volatilities of components, which are in fact related to the boiling points of these components by the application and removal of heat.

A simple two-product continuous distillation column is shown in Fig. 2. The column has N stages on which the vapor-liquid equilibriums occur. The feed enters the column on the stage N_F. This stage divides the column into a rectifying section and a stripping section. At the bottom of the column there is a reboiler which provides energy to the column in order to produce vapor. The mixture is heated to form a flow of vapor rising up inside the column. In the stripping section, the less volatile component is enriched while in the rectifying section the more volatile component is enriched. The top product is condensed by the condenser from which there is a reflux flow back to the top of the column to enhance the purity of the product.

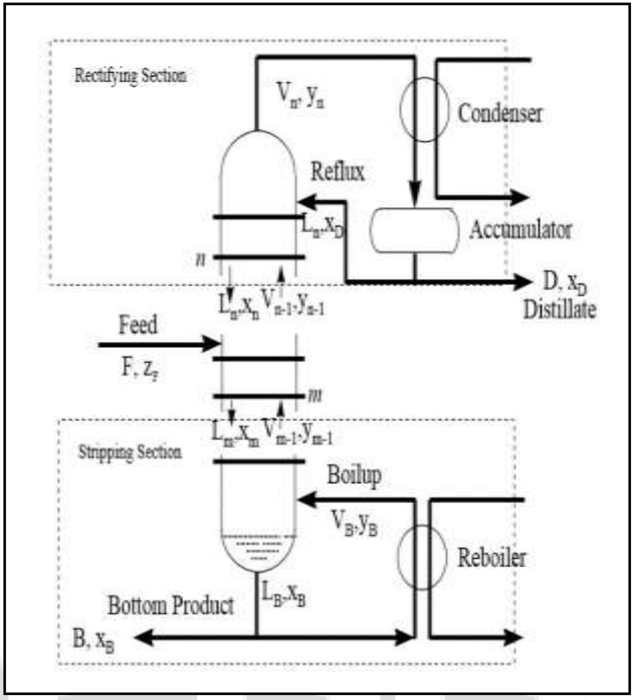


Fig. 1: A Binary Distillation Column Operation

In order to achieve the purest form of a component or to achieve the desired composition of a product depending according to the requirement, we need to manipulate & control various variables of the distillation column such as temperature of trays, reflux flow rate, distillate flow rate, vapor boil up rate and the pressure in the column. These variables may vary in practice due to different reasons.

This paper is organized as follows. Section-II shows open loop and closed cool simulation model of binary distillation column by using fundamental modelling approach. Section-III gives the details about PSO technique and tuning using the same. Section-IV will shows the performance comparison of PSO based PID tuning with Cohen-Coon tuning. Finally in Section-V, conclusion is made.

II. MODEL SIMULATION IN MATLAB TOOL

In order to develop the dynamic momdel of binary distillation column, fundamental modelling technique is used which is based on the material balance, energy balance and momentum balance equations. How to develop dynamic model of distillation column is discussed in my previous paper.[1] reference of which was taken from [4].

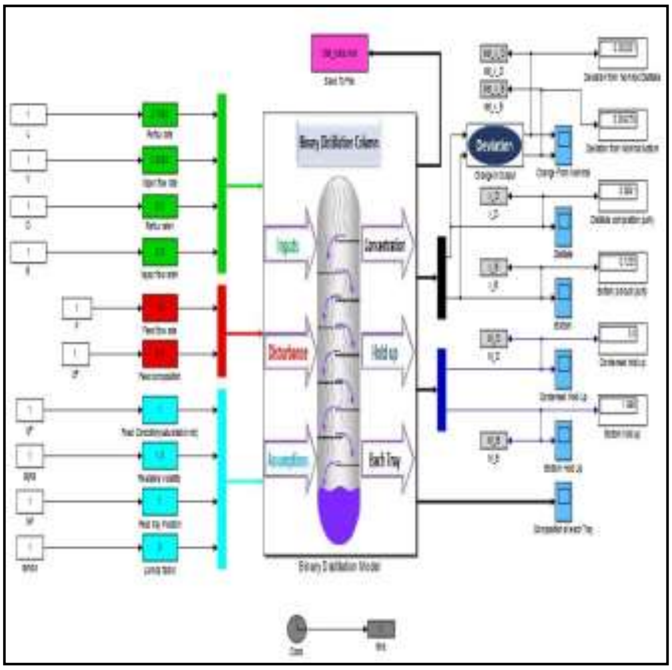


Fig. 2: Binary distillation column open loop simulation mode

Here, for this work simulation is performed in Matlab tool with the help of S-function block. An open loop model of binary distillation column is shown in the figure below.

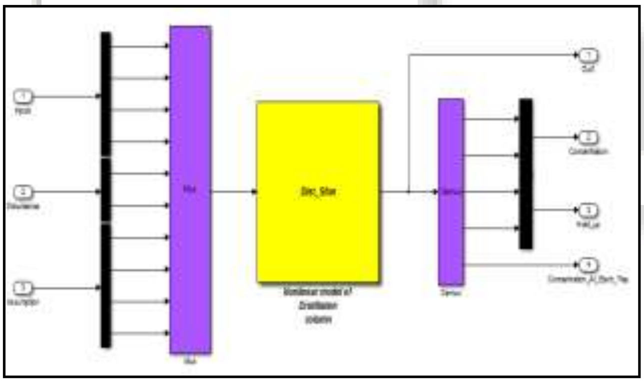


Fig. 3: Internal view of Binary distillation model block with S-function

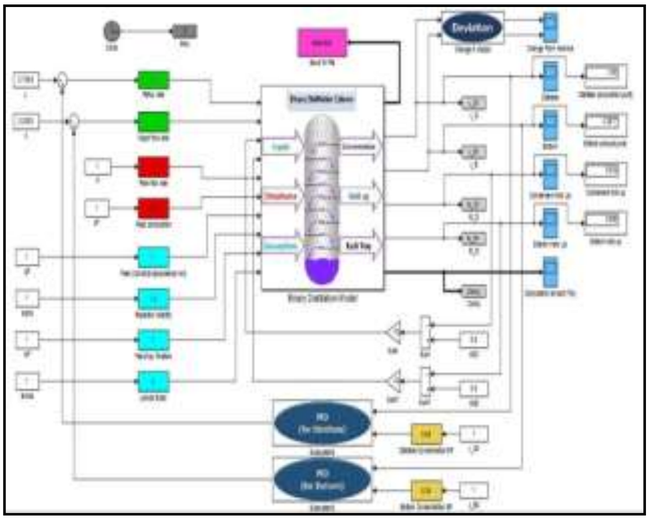


Fig. 4: Binary distillation column closed loop simulation model

The nominal values of distillation column dynamics are shown in the table 1.

Parameter	Value
Total number of trays ($\boldsymbol{N_T}$)	16
Feed tray location ($\boldsymbol{N_F}$)	7
Feed flow rate ($\boldsymbol{F}$)	1
Feed composition ($\boldsymbol{z_F}$)	0.5
Feed condition ($\boldsymbol{q_F}$)	1
Relative volatility ($\boldsymbol{\alpha}$)	1.5
Effect of vapour on liquid ($\boldsymbol{\lambda}$)	0
Reflux rate ($\boldsymbol{L}$)	2.70629
Vapor boil-up rate ($\boldsymbol{V}$)	3.20629
Distillate flow rate ($\boldsymbol{D}$)	0.5
Bottom flow rate ($\boldsymbol{B}$)	0.5

Table 1: Steady-State Data For Distillation Column Dynamics

III. PARTICLE SWARM OPTIMIZATION TECHNIQUE

Particle swarm optimization (PSO) is a population based stochastic soft computing optimization technique proposed by Dr. Eberhart and Dr. Kennedy in 1995. Actually, at the start, they were developing the computer simulation software for a bird moving around food sources in a large number, then later they realize how well their proposed algorithm can work for the solution of different kinds of optimization problems. The PSO technique is inspired by the social behaviour of a group of individuals such as a flock of birds, animals moving in herds, or schools of fish moving together.

To understand the working of PSO technique in a simple manner, suppose a group of birds flying over a search area where they can smell a hidden source of food. The one who is nearest to the food, chirps the loudest and the other birds start to fly towards it by changing its direction. If any of the other flying birds comes nearer to the food than the first, it chirps more loudly and the other birds will change the direction over toward him. This searching pattern continues until one of them reach to the food.

A. Particle Swarm Optimization (PSO) Algorithm

The algorithm for particle swarm optimization method is shown in the table 2.

Steps	An operation to be performed
Step-1	Initialize i_{max},w_1,ϕ_1,ϕ_2, n (population size), $\mathbf{x}_{i,min}$, and$\mathbf{x}_{i,max}$.
Step-2	Initialize the starting position and velocities of the variables as $\mathbf{x}_{i,k}= \mathbf{x}_{i,min} + (\mathbf{x}_{i,max} - \mathbf{x}_{i,min})u_i$ $k = 1 \cdots n$ and $\mathbf{v}_{i,k} = 0$
Step-3	Compute $p_{i,k}=f(\mathbf{x}_{i,k})$ $k = 1 \cdots n$
Step-4	Compute $pbest_{i,k}= p_{i,k}$and $gbest_i$ = minimum($pbest_{i,k}$) The location of $p_{i,k}$ and gbest is given by $p_{i,k}$ and $g_{i,k}$.
Step-5	Update velocity $v_{i+1,k} = w_1 v_{i,k} + \phi_1 (p_{xik} - x_{i,k}) u_i + \phi_2 (g_{ix} - x_{i,k}) u_i$
Step-6	Update current position to new position by $x_{i+1,k} = x_{i,k} + v_{i+1,k}$
Step-7	Evaluate fitness function $p_{i+1,k} = f(x_{i+1,k})$

Step-8	Check for local best If $p_{i+1,k} < pbest_{i,k}$ then $pbest_{i+1,k}=p_{i+1,k}$
Step-9	Update global best $gbest_{i+1}$ = minimum($pbest_{i+1,k}$)
Step10	Check for termination criteria If $i > i_{max}$ then stop, else $i = i + 1$ and go to step-5.

Table 2: Particle Swarm Optimization (PSO) algorithm

Where,

- i_{max} = maximum number of iteration
- w_1 = weight factor
- ϕ_1, ϕ_2 = acceleration parameter
- n = swarm population size
- $x_{i,k}, x_{i+1,k}$ = position of swam at i and i+1 iteration respectively.
- $pbest_{i,k}, pbest_{i+1,k}$ = local best at i and i+1 iteration respectively.
- $gbest_i, gbest_{i+1}$ = global best at i and i+1 iteration respectively.
- $v_{i,k}, v_{i+1,k}$ = velocity at i and i+1 iteration respectively.
- u_i= random number

B. Particle Swarm Optimization (PSO) Based PID Tuning

An optimal PID tuning is a process of finding out the best value of the PID parameter namely, (K_p, K_i, K_d) that provides an optimal control performance. There are a large number of methods available to tune PID controller such as Ziegler-Nichols tuning, Cohen-Coon tuning, Internal Model Control (IMC) tuning, Integral Time Absolute (ITAE) tuning, Lambda tuning, etc. In this section it is shown that how we can tune PID controller optimally with Particle Swarm Optimization (PSO) algorithm.

Steps	*Operation to be performed*
Step-1	*Initialize following PSO parameters.*
Step-2	*Initialize the starting position* (K_p, K_i, K_d)*and velocities of the swarm particle.*
Step-3	*Evaluate fitness function.*
Step-4	*Compute Pbest and gbest for* (K_p, K_i, K_d).
Step-5	*Update the velocities for* (K_p, K_i, K_d).
Step-6	*Update current position to new position for* (K_p, K_i, K_d).
Step-7	*Evaluate fitness function.*
Step-8	*Check for local best.*
Step-9	*Update global best.*
Step10	*Check for termination criteria, if satisfied then terminate the algorithm else go to step-5.*

Table 3: PSO based PID tuning algorithm

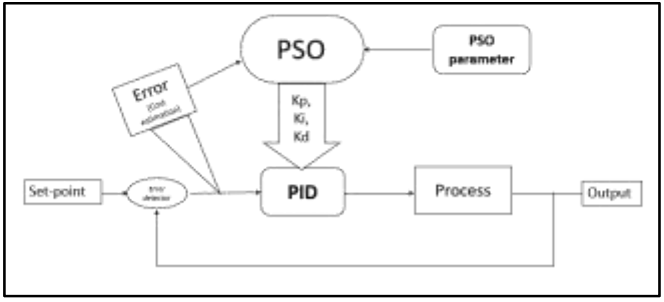


Fig. 5: PSO Based PID Tuning Technique

The flowchart for PSO based PID tuning is shown in the figure below.

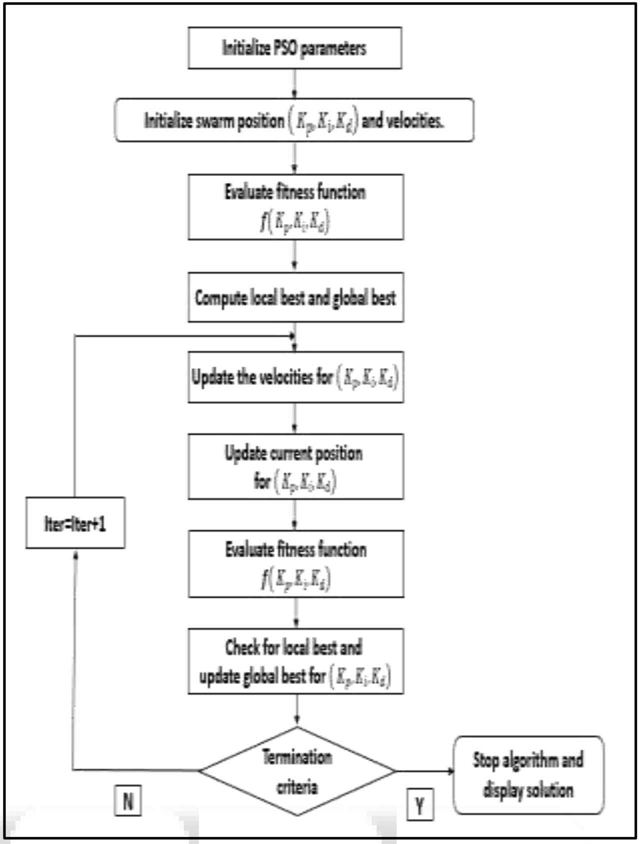


Fig. 6: Flowchart of PSO based PID tuning

C. PSO Based PID Tuning Toolbox Design In GUI

I have developed a GUI (Graphical User Interface) model for PSO based PID tuning in Matlab as shown in the figure below:

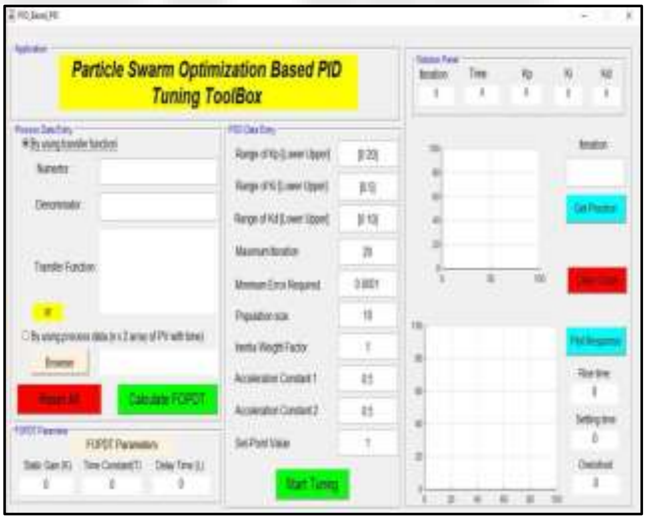

Particle Swarm Optimization Based PID Tuning ToolBox

Fig. 7: GUI model for PSO based PID tuning

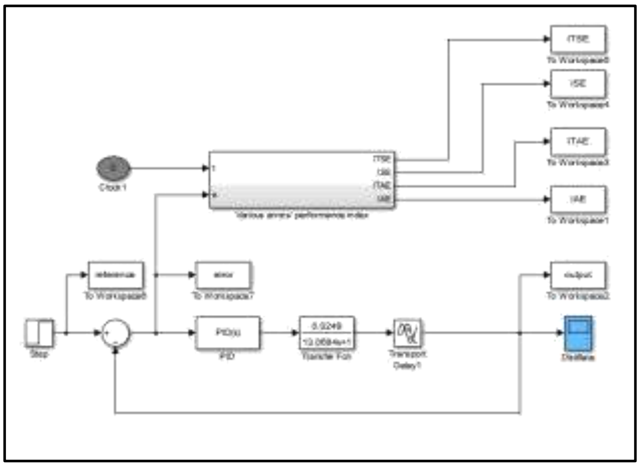
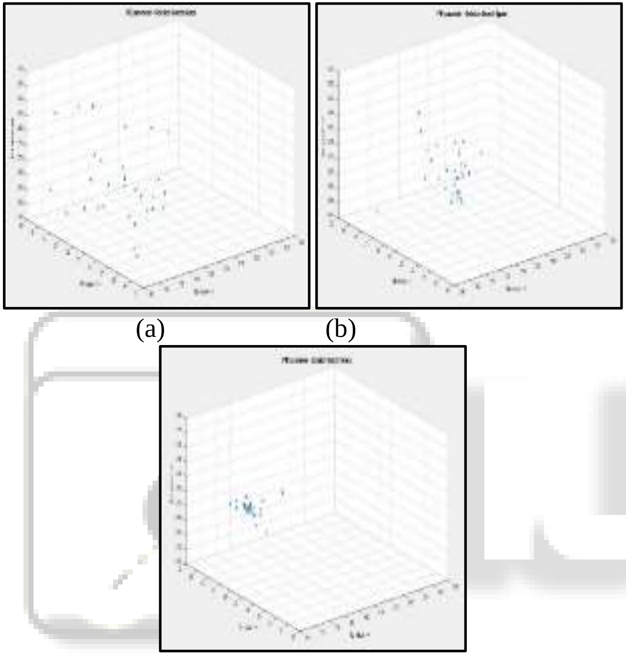


Fig. 8: Simulation model of PSO based PID tuning



(a) (b)

(c)

Fig. 9: a, b, c. swarm position Initial, after 10 iteration, at end

IV. PERFORMANCE ANALYSIS

In this section, the performance comparison of proposed ACO based PID tuning is shown with other conventional methods for set-point tracking well as disturbance rejection.

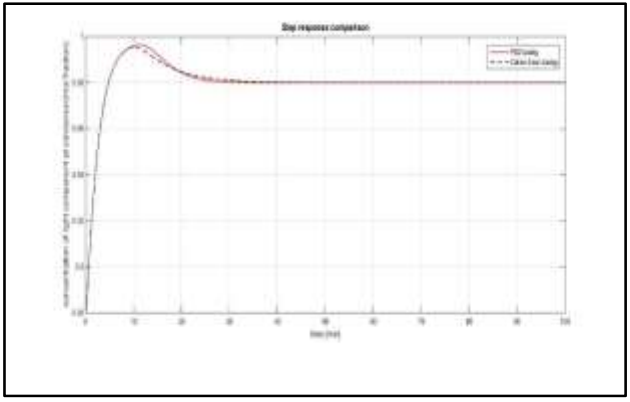


Fig. 10: Step response comparison of PSO based PID tuning with Cohen-Coon tuning

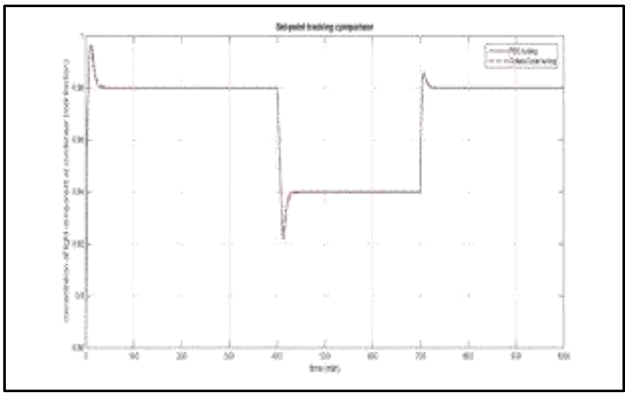


Fig. 11: Set-point tracking comparison

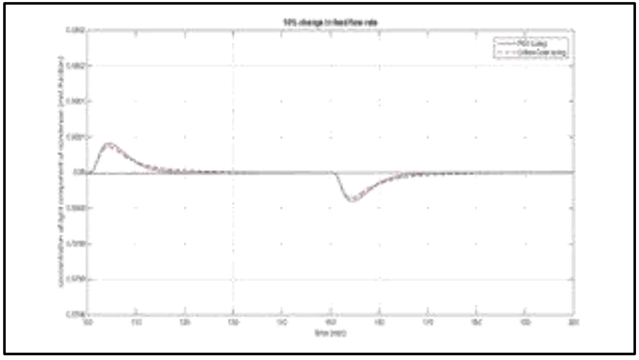


Fig. 12: Disturbance rejection comparison (10% change in feed flow rate)

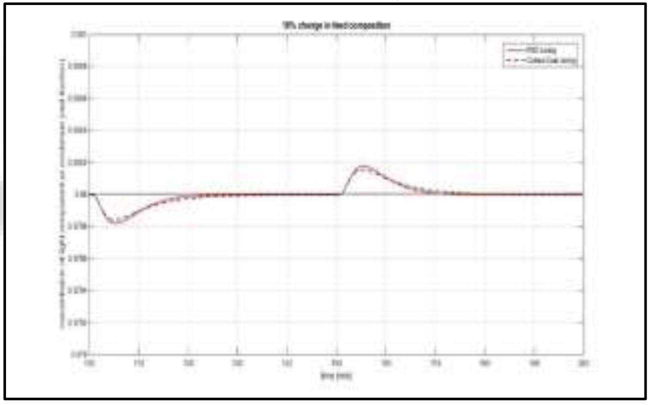


Fig. 13: Disturbance rejection comparison (10% change in feed composition)

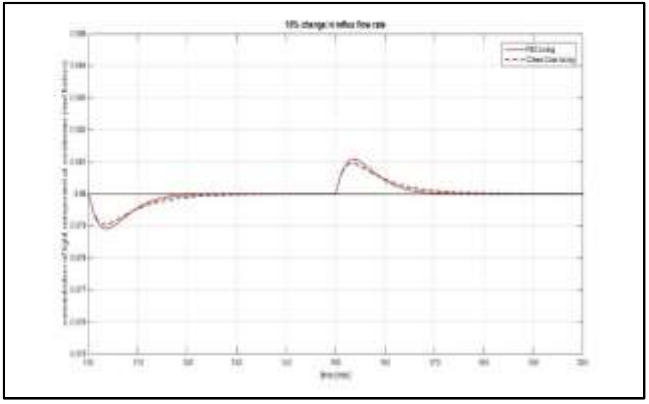


Fig. 14: Disturbance rejection comparison (10% change in reflux flow rate)

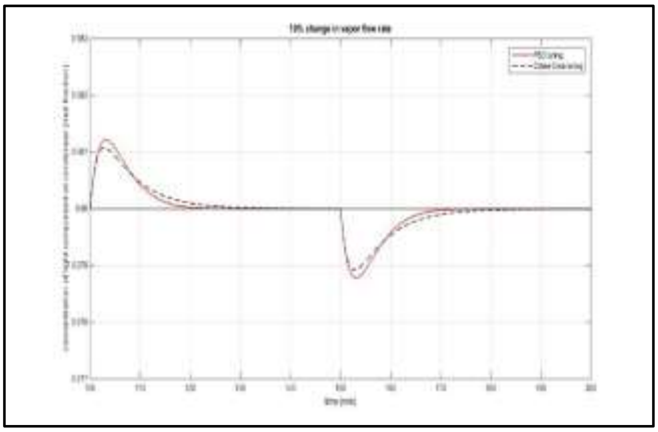


Fig. 15: Disturbance rejection comparison (10% change in vapour flow rate)

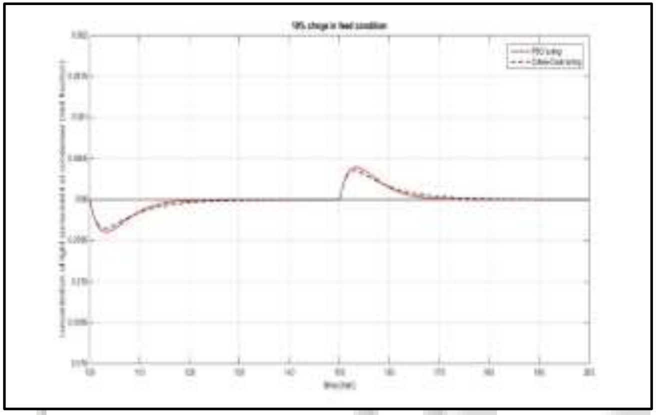


Fig. 16: Disturbance rejection comparison (10% change in feed condition)

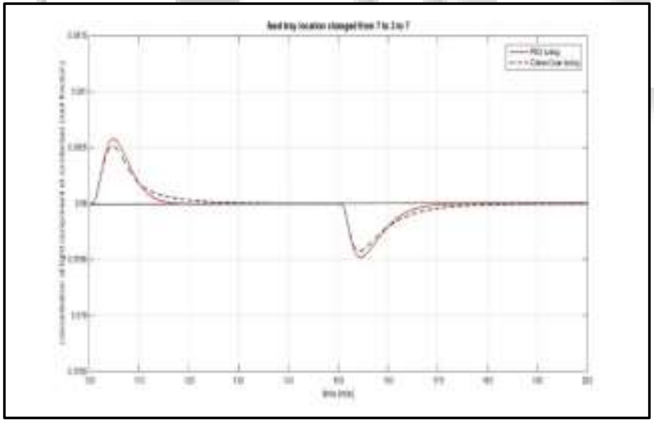


Fig. 17: Disturbance rejection comparison (when feed tray location varies from 7 to 3 to 7)

The analysis is also made in terms of rise time, settling time, overshoot and steady-state error.

Tuning method	**Rise time (t_r)**	**Settling time (t_s)**	**Overshoot (%)**	e_{ss}
Cohen-Coon	3.3487	25.7266	1.5750	0
PSO	3.3487	22.9882	1.6856	0

Table 4: Response analysis for different tuning methods

Also, the comparison is made for performance indexes i.e. IAE, ITAE and ISE etc. as shown in the table 5.

Tuning method	IAE	ITAE	ISE
Cohen-Coon	0.3712	2.930	0.01319
PSO	0.3708	2.673	0.01354

Table 5: Performance index comparison

V. CONCLUSION

From the statistical analysis as shown in the section-IV, it is concluded that PSO (Particle Swarm Optimization) method based PID tuning is giving optimal values of PID parameters which will lead to provide more effective control performance as compared to conventional PID tuning methods in terms of both set-point tracking as well as disturbance rejection. Also, PSO based PID tuning provides better performance in terms of performance indices.

REFERENCES

[1] Mehul Pragjibhai Girnari, "Dynamic Modeling and Control of Binary Distillation Column", IJSRD, volume-4, issue-2, pp-1779-1786, April-2016.
[2] H. S. Truong, I. Ismail, R. Razali, "Fundamental Modeling and Simulation of Binary Continuous Distillation Column", IEEE, International Conference on Intelligent and Advance systems (ICIAS), pp. 1-5, June-2010.
[3] Islam, Irraivan and Noor Hazrin, "Monitoring and Controlling System for Binary Distillation Column", Proceeding of 2009 IEEE Student Conference on Research and Development, pp.453-456, Nov. 2009.
[4] Skogested and Ian, Multivariable Feedback Control Analysis and Design, book (2nd Edition) 2005.
[5] B. Wayne Bequette, "Process Control: Modeling, Design and Simulation", book, Prentice-Hall International Series in the Physical and Chemical Engineering Sciences), 2002 edition.
[6] Pradeep B. Deshpande, "Distillation Dynamics and Control", ISA, Tata McGraw-Hill, (1st edition).1985.
[7] Antonio Visioli, "Practical PID Control", Book 2006 Edition, Springer publication.
[8] Su Whan Sung, Jietae Lee, In-Beum Lee, "Process Identification and PID Control", Book 2009 Edition.
[9] Rajesh Kumar Arora, "OPTIMIZATION Algorithms and Applications", Book, CRC press, 2015 edition.