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PERFORMANCE EVALUATION OF PI AND IMC CONTROLLER FOR BINARY DISTILLATION COLUMN

M.Sharmila[1], Ms. V. Mangaiyarkarasi[2]

[1]PG student, [2]Asst professor
Department of C&I, Valliammai Engineering College, Kancheepuram District, Tamilnadu, India
[1]sharmila.saravanan84@gmail.com, [2]mangai.manikandan@gmail.com

Abstract— *Distillation is a continuous process in the petroleum and the chemical industries. In the distillation process, a high amount of energy consumed in the chemical and petrochemical industries, since large amount of heat transfer takes place between the trays of distillation column. Hence, there is a need of controller in order to make the final and the intermediate products of the distillation process of desired quality and the process being economical. This paper deals with convention controllers such as PI (Proportional+ integral) and IMC (internal model control) .To eliminate the offset and to increase the speed of the response, PI controller will be implemented .The IMC controller is generally embedded with plant transfer function and the number of parameter to be tuned is less. For continuous process of enhancing the performance of the system leads to the development of robust and optimal controllers. Bacteria foraging optimization Algorithms (BFO) is an evolutionary algorithm that is proposed for optimization of IMC controller for Binary distillation column.. The structure of the models has been implanting using MATLAB.*

Keywords— modeling, binary distillation column, controllers, simulation.

1. INTRODUCTION

Distillation column plays a important role in petro -chemical and refinery industries. Distillation is a process in which a liquid or vapour mixture of two or more substances is separated into its component fractions of desired purity, by the application and removal of heat. Binary distillation column is used to separate two components (Component A & component B) . Example for Binary mixture is methanol and water. Fig 1.1 shows the schematic diagram of distillation column. Distillation column generally made up of tray of tower/column. Tray types have more efficient than other type. The distillation column consists of many trays, condenser, reboiler, and a vertical column for the separation purpose. In this paper, distillation is a continuous process. It means that the feed is given in continuous manner. Here feed is the input to the column. Distillation column is separated into two sections. They are stripping section and rectification section. The trays above the feed tray is called stripping section.

The binary mixture is fed into the feed tray with flow rate F_f and a molar fraction of component A, C_f. The overhead product is completely condensed using condenser and it is allowed to flow in the reflux drum. The liquid in the reflux drum partly pumped back to the top tray F_R and it is partially removed as distillate product with molar flow rate of F_D . let us consider M_{RD} is the liquid hold up in the reflux drum and X_D is the molar fraction of component A of liquid in the reflux drum.

At the bottom of the column, a liquid stream is removed with flow rate of F_B and composition of X_B. A liquid stream with molar flow rate of v is also drawn from the bottom of the column and after that it has been heated in the re boiler, it returns back to the base of the column. The composition of the column base is X_B. Let M_B is the liquid holdup in the base of the column.

The column contains N trays numbered from bottom of the column to top of the column.

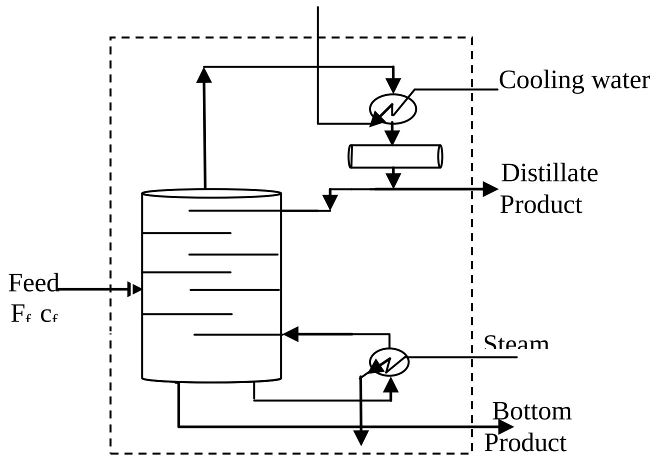

Figure 1: schematic diagram of distillation column.

The output equation is given as ,

$$\begin{bmatrix} x_D(s) \\ x_B(s) \end{bmatrix} = \begin{bmatrix} \dfrac{12.8e^{-s}}{(16.7s+1)} & \dfrac{-18.9e^{-3s}}{(21s+1)} \\ \dfrac{6.6e^{-7s}}{(21s+1)} & \dfrac{-19.4e^{-3s}}{(14.4s+1)} \end{bmatrix} \begin{bmatrix} R(s) \\ S(s) \end{bmatrix} \quad -(1)$$

When there is a change in feed to bring the product composition to its desired level there occur interaction between the loops. Loop interaction should be avoided, because change in one loop might cause destabilizing changes

in other loops. A Decoupler is been introduced before the Binary Distillation Column. The objective of Decoupler is to eliminate the effect of loop interactions. The role of Decoupler is to decompose a multivariable process into a series of independent single loop susystems .
After using decoupler,the output equation becomes

$$x_D(s) = \frac{s^2 + 0.15s + 0.005}{2.3s^3 + 0.46s^2 + 0.03s + 0.0007} R(s) \qquad -(2)$$

Where,
X_D (s)=Top product (Distillate) composition, X_B (s)= the bottom product composition , R(s)=Reflux Rate and S(s)= Vapour Boil up Rate .
The Internal Model Control (IMC) philosophy relies on the Internal Model Principle, which states that control can be achieved only if the control system encapsulates, either implicitly or explicitly, of the process to be controlled .
BFO is worked on the base of natural selection tends to eliminate animals with poor foraging strategies and favour those having successful foraging strategies. After many generations, poor foraging strategies are either eliminated or reshaped into good ones.

2. PI CONTROLLER

The design of a PI controller contains two main parameters Kp, Ki. The transfer function of PI controller is given by the following equation,

$$u(t) = kpe(t) + ki \int_0^t e(t)\ dt \qquad -(3)$$

Where, u(t) is the control signal, e(t) the error signal. Kp the proportional gain, Ki the integral gain, and Kd the derivative gain respectively. The proportional term P provides a control action proportional to the error and reduces rise time. The integral term reduces steady state error by performing an integral control action based on past errors .The derivative term D improves the stability of the system.

3. IMC CONTROLLER

BLOCK DIAGRAM

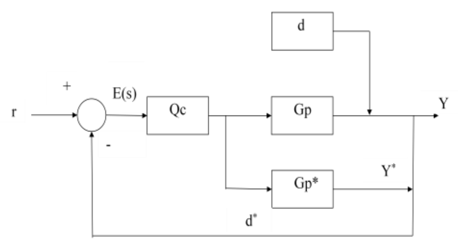

Figure 2: Block diagram of process with IMC controller

Internal Model Control (IMC) is a commonly used technique that provides a transparent mode for the designing and tuning of various types of control architecture In internal model control process model is connected in parallel with the actual process, with the help of this it compare both of process .Hear, to design a liner controller based on a linearized model for chemical processes all model based control strategies is used. Internal model control provides a useful range of all stable controllers for open loop stable systems. For the perfect model assumption, the design of a stable internal model control becomes an insignificant task for close-loop stability. Although most of the process is nonlinear in nature, the internal model controller performs acceptable result for this process.
Where Q(s) is the primary controller (IMC) transfer function, Gp(s) is the process transfer function, Gm(s) is the process model transfer function, r(s) is set point, e(s) is error d(s) is disturbance represent estimated disturbance and y(s) is controlled variable (process output).
If the model is perfect which gives GP(s) =Gm(s) and there are no effect of disturbance (d(s)=0) then

y(s) = Gp(s) Q(s) r(s) -(4)

$$Q(S) = {}^{1}\!/_{Gp(s)} * f(S) \qquad -(5)$$

Where filter $f(s) = \frac{1}{(\lambda s+1)^n}$ -(6)

λ is filter constant and n is constant (123..n) and chosen to make the controller proper or semi proper.
Here

$$Q(s) = \frac{2.3s^3 + 0.46s^2 + 0.03s + 0.0007}{3s^3 + 1.45s^2 + 0.165s + 0.005} \qquad -(7)$$

4. BFO ALGORITHM

The BFO algorithm is a biologically inspired computing technique**.** BFO algorithm is a novel evolutionary computation algorithm, it is proposed based on the foraging behavior of the Escherichia coli (E. coli) bacteria live in human intestine. Natural selection tends to eliminate animals with poor foraging strategies such as locating, handling and ingesting food and favor the propagation of genes of those to achieve successful foraging . The foraging behavior of E.Coli bacteria is adopted for the evolutionary computation algorithm, and it is named as Bacterial Foraging Optimization. In the bacterial foraging optimization process four motile behaviours are mimicked:-
Chemotaxis, Swarming, Reproduction, Elimination and Dispersal.
Steps in algorithm:
Step 1)
Initiallize parameters S ,D , N S,NC ,Nre Ned ,Ped , ,C(i), Dattract ,Wattract, Hrepellant and Wrepellant, where
S: Number of bacteria to be used for searching the total region.
D: Number of parameters to be optimized.
NS: Swimming length after which tumbling of bacteria will be done in a chemotactic step.
Nre: Maximum number of reproductions to be undertaken.
Ned: Maximum number of elimination-dispersal events to be imposed over the bacteria.
Ped: Probability with which the elimination-dispersal will continue.
C(i): This is chemotactic step size assumed constant for our design.

Step 2)
Elimination-Dispersal loop : l=l+1
Step 3)
Reproduction loop : k = k+1
Step 4)
Chemotaxis loop : j = j + 1
Step 5)
If j < NC go to step 3. In this case , continue chemotaxis , since the life of the bacteria is not over.
Step 6)
Reproduction:
a)For a given k and l,and for each i = 1,2,3,4.......S, let Ji Health = Σ J(i,j,k,l) be the healt of bacterium
b)The Sr bacteria with highest JHealth values die and the other Sr bacteria with the best values split and the copies that are made are placed at the same location as their parent.
Step 7)
If k<Nre , go to step 2. In this case, we have not reached the number of specified reproduction steps, let start the next generation in the next chemotactic step.
Step 8)
Elimination-Dispersal : For i = 1,2,3,4.......S, with probability Ped , eliminate and disperse each bacterium (this keeps the number of bacteria in the swarming population constant). To do this, if we eliminate a bacterium, simply disperse one into a random location in the optimization domain.
Step 9)
If l < Ned , then go to step 1, otherwise end.

5. RESULT AND DISCUSSION

The IMC controller and PI controller discussed above were carried out in simulink and the simulation results have been obtained. In IMC controller, value for filter constant was obtained using BFO algorithm.

The filter constant value was selected based on fitness function. The fitness function is minimum of IAE (integral of absolute error). Formula for fitness function is given below.

$$IAE = \int_0^{\infty} e(t)dt \qquad -(8)$$

Where,

$$e(t) = r(t) - [G_{imc} * G_p - G_{imc} * G_p^*] \qquad -(9)$$

G_p^* is gain of process model,

G_{imc} is gain of the IMC controller.

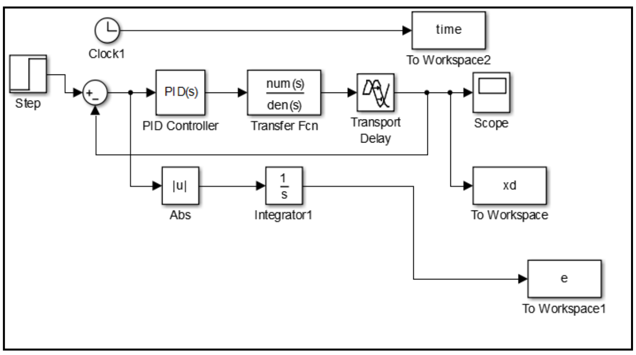

Figure 3: Simulink model of feedback PI controller.

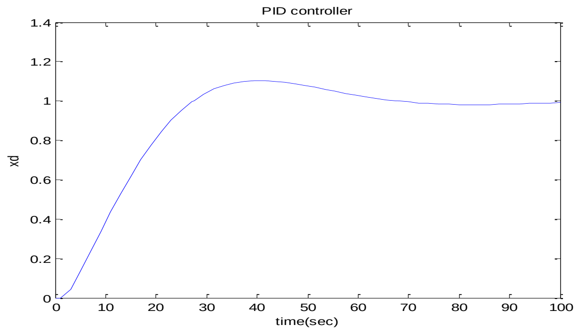

Figure 4: step response of feedback PI controller.

In the simulations using BFO algorithm, here the swarm population had varied from 100 to 1000 keeping other constraints fixed. the performance of designs with different values of swarming population was studied and it shows in table1.

Table 1: Study of design performance

Population size	Optimal best fitness function	Optimal bestvalue for x
100	1.749	14.9893
200	1.769	15.0197
300	1.78	15.0371
400	1.775	15.0291
500	1.774	15.0281
600	1.774	15.0272
700	1.770	15.0208
800	1.764	15.0117
900	1.778	15.0338
1000	1.764	15.0112

Based on the above table the optimal best value for filter constant is 14.9893. Using this value the simulation was carried and structure of the simulation is shown in fig. 5 and response of the IMC controller is shown in fig.6.

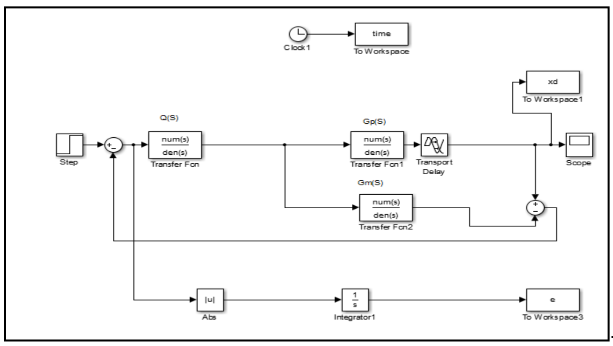

Figure 5: Simulink model of IMC controller

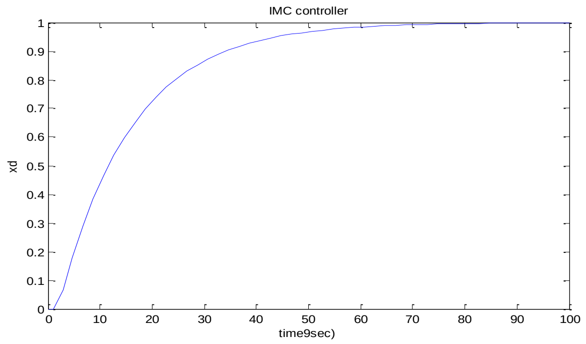

Figure 6: Step response of IMC controller

Comparative analysis of controllers:
Various parameters which depict the performance of the control strategy applied to the model are summarized in the following table 2.

Table 2: List of Different parameters depicting the performance

Type of controller	%overshoot	Settling time(sec)	IAE
PI	11.1%	88	14.432
IMc	-	83	1.749

6. CONCLUSION

This paper takes a case study of binary distillation column system and analysis the different method of controller in order to maintain the desired distillate output. Two type controllers are implemented to control the output and the performance of this controller is evaluated by one of the method of time domain specification such as percentage peak overshoot, settling time and performance index IAE. IMC controller has less settling and negligible percentage of peak overshoot and performance index value is very less compare to PI controller. Performance index should be minimum. Hence IMC controller is acceptable. So as a further work PSO based PID and PSO based IMC will be implemented for effective control of binary distillation column.

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