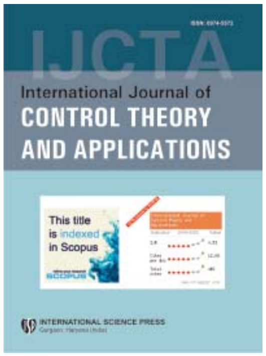

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An Optimization Tuning Method for Multivariable PID Controller using SA Algorithm for a MIMO Nonlinear System

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Abstract: In the process industry, PID controllers are commonly used than PI controller for control applications because of its simple design and easy construction. It provides more flexibility and stability while controlling the processes. The determination of proportional (KP), integral (Ki) and derivative (Kd) constants are known as tuning of PID controller. It is tough to tune the gains of PID controller since many industrial plants are often burdened with problems like high order, time delays, poor damping, nonlinearities, and time-varying dynamics etc. That means, the proper tuning of multi-loop PID controller for multivariable process is a challenging work. In this paper, a new optimal tuning algorithm called simulated annealing algorithm is introduced to tune the Proportional- Integral Derivative (PID) multivariable controllers for a highly non linear system. Better performance of PI, PID and SA-PID controller is studied and compared.

Keywords: *PID controller, SA-PID controller, Tuning, Optimization, MATLAB.*

1. INTRODUCTION

Proportional-Integral-Derivative (PID) control is the most common control algorithm used in industry and has been universally accepted in industrial control. The popularity of PID controllers can be attributed partly to their robust performance in a wide range of operating conditions and partly to their functional simplicity, which allows engineers to operate them in a simple, straightforward manner. As the name suggests, PID controller consists of three basic coefficients; proportional, integral and derivative which are varied to get optimal response.

Distillation is one of the very important operations to separate different kinds of components from a feed or for product purification. It is popularly used in chemical, pharmaceutical and oil refineries. Wood and Berry experimentally modelled a binary distillation column plant that separates methanol and water [1] & [2]. As the feed enters the distillation column the volatile contents in the mixture gets vaporized and separated as vapour rate. The remaining products get settled at the bottom as bottom product. The chances of coupling and loop interaction may be caused by the continuous flow of liquid mixture into the column. A decoupler is used to avoid such interactions.

The control of distillation column is important to get the desired product quality and to meet the desired product specifications. Many controllers are used for the controlling action but none of the controllers could replace the performance of PID controller. PID controller is the commonly used controller in industrial control applications. It was first introduced in 1910. More than 90% of control loops are PID controllers with a wide range of applications such as process control, motor drives, magnetic memories, automotive, flight control etc [3] because of its simple, reliable and robust in its performance. The three control parameters of the PID controller are proportional gain (K_p), integral gain (K_i), and derivative gain (K_d). The proportional value determines the reaction to the current error; the integral value determines the reaction based on the sum of recent errors and the derivative value determines the reaction based on the rate at which the error has been changing.

The main issue for PID controller is the accurate and efficient tuning of parameters. Tuning of PID controller used to ensure good stability, performance and robustness [4], [5] & [6]. Many researchers used several tuning techniques such as genetic algorithm, self-organizing migrating algorithm, particle swam optimization, chaotic evolutionary programming to tune PID controller parameters applied in SISO system. But most of the industrial processes are multivariable systems. Different conventional tuning methods used to tune the PID controller parameters in MIMO systems are genetic algorithm, differential evolution, ant colony optimization, particle swam optimization etc. Genetic algorithm has the disadvantage that it is hard to convert the off springs generated into binary bits. The DE suffers from long settling time and premature convergence. To overcome the above disadvantages of conventional methods simulated annealing algorithm is introduced in this paper.

It is a derivative - free stochastic search method for finding the optimum solution for a controller parameter. Ever since the method evolved, it has been used extensively to solve large - scale problems of combinatorial optimization [7]. The SA evolves a single solution in the parameter space with certain guiding principles during annealing process. It is similar to the physical process of heating up a solid until it melts, followed by cooling it down slowly until it crystallizes into a perfect lattice. The objective function here corresponds to the energy of the states of a solid .An attractive feature of SA is that it is easy to program and the algorithm typically has few parameters that require tuning [8]. This has led to its vast application in industries and research in recent years [9].

2. PROCESS DESCRIPTION

Distillation columns are generally used for the purpose of separation in process and chemical industries to achieve a purified product. In this paper Wood- Berry distillation column is considered. It is a 2x2 transfer function model that separates methanol and water. It has first order dynamics and time delay. It is an example for MIMO system ie two inputs and two outputs. This process is a highly nonlinear system with strong interaction between inputs and outputs. The controlled variables are the composition of top and bottom products in terms of weight % of methanol. The reflux and reboiler steam flow rates are the manipulated input variables expressed in lb/min. It consists of eight trays. The control of wood-berry distillation column is very essential because this system is affecting by many disturbances such as feed, reflux and heat etc. The transfer function model of this process is given by[11].

$$\begin{bmatrix} y_1(s) \\ y_2(s) \end{bmatrix} = \begin{bmatrix} \dfrac{12.8e^{-s}}{16.7s+1} & \dfrac{-18.9e^{-3s}}{21.0s+1} \\ \dfrac{6.6e^{-7s}}{10.9s+1} & \dfrac{-19.4e^{-3s}}{14.4s+1} \end{bmatrix} \begin{bmatrix} u_1(s) \\ u_2(s) \end{bmatrix} + \begin{bmatrix} \dfrac{3.8e^{-9.1s}}{14.9s+1} \\ \dfrac{4.9e^{-3.4s}}{13.2s+1} \end{bmatrix} D(s)$$

Where input signals are the reflux flow rate $u1$ and steam flow rate $u2$, the output signals are the top product composition $y1$ and bottom product composition $y2$ in mole fraction. The feed flow rate D is act as process disturbance. The linear model is valid around the set point $y1 = 0.96$ and $y2 = 0.02$. The time sampling is 1 min. The structure of distillation column is shown in Fig.1

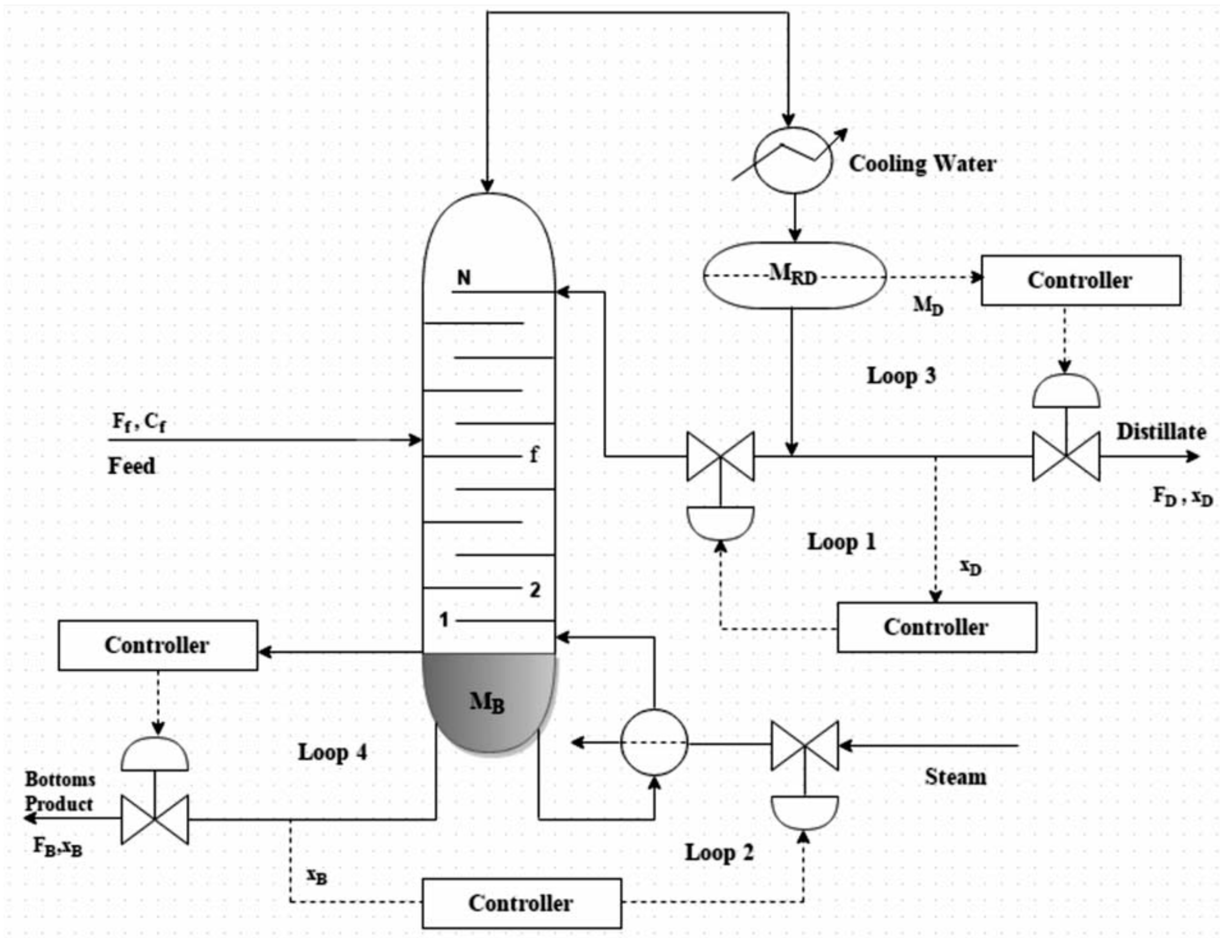

Figure 1: Structure of distillation column

3. DESIGN OF CONTROLLERS

In this paper PI and PID controllers are designed. PID controller parameters consist of three separate terms: proportional, integral and derivative values denoted by K_p, K_i, and K_d. The appropriate setting of these parameters will improve the dynamic response of a system, reduce overshoot, eliminate steady state error and increase the stability of the system. The transfer function of a PID controller is

$$C(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} + K_s s$$

The fundamental structure of PID controller is shown in Fig.2. Once the set point has been changed, error will be computed between the set point and actual output. The error signal E(*s*), is used to generate the proportional, integral and derivative control actions, with the resulting signals weighted and summed to form the control signal U(*s*) applied to the plant model M. New control signal, U(*s*), will be sent to the plant M. This process will run continuously until steady state.

In PI controller the derivative term is absent. The transfer function of PI controller is

$$C(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{s}$$

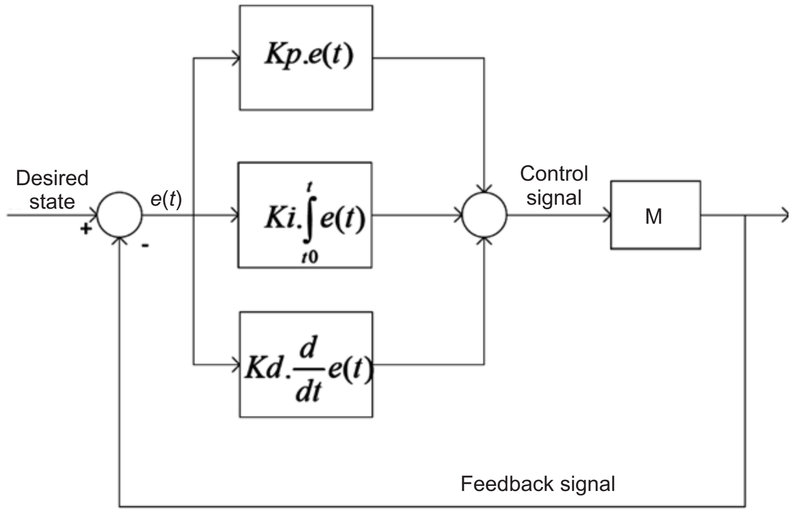

Figure 2: Structure of PID controller

4. TUNING METHOD

The diagram of multivariable controller design is given in Fig.3. It consists of error detector, PI or PID controller, plant (distillation column) and optimization tool. The error signal generated by the error detector is the difference between input signal and feedback signal. The controller modifies and amplifies error signal to produce better control action. This modified error signal is fed to the plant (distillation column) to correct its output.

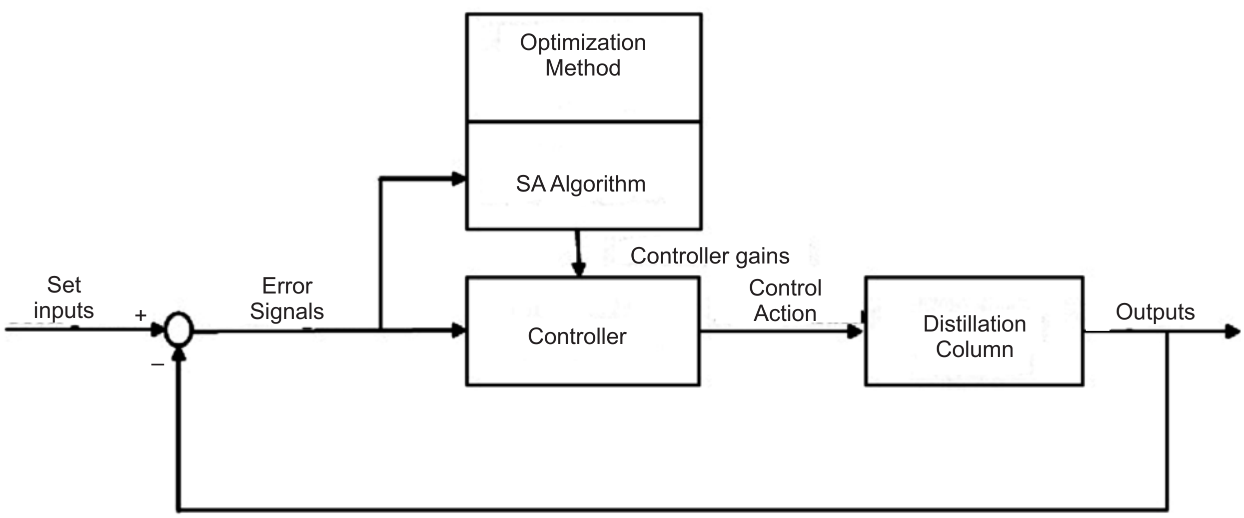

Figure 3: Design of multivariable controller

In the design of PI and PID controller, the controller parameters such as K_p, K_i, K_d are obtained using one of the conventional method called Ziegler / Nichols [10]. The parameter values are tabulated in the Table 1. This calculated controller parameter values are applied to the chosen process. The results are not in satisfactory since the process is a highly non linear system. Then the proposed SA tuning algorithm is used to tune the PID controller parameters as per the following procedure and the optimal value of controller parameters are tabulated in the Table 1.

SA is a numerical optimization technique based on the principles of thermodynamics. The Simulated Annealing method resembles the cooling process of molten metals through annealing. At high temperature, the atoms in the molten metal can move freely with respect to each another. But, as the temperature is reduced, the movement of the atoms gets reduced. The atoms start to get ordered and finally form crystals having the minimum possible energy. However, the formation of the crystal depends on the cooling rate. If the temperature is reduced at a very fast rate, the crystalline state may not be achieved at all; instead the system may end up in a polycrystalline state, which may have a higher energy state than the crystalline state. Therefore in order to achieve the absolute minimum state, the temperature needs to be reduced at a slow rate. The process of slow cooling is known as annealing in metallurgical parlance. SA simulates this process of slow cooling of molten metal to achieve the minimum function value in a minimization problem.

Table 1
Tuning values of controller parameters

Controller Parameters	*PI Controller*	*PID Controller*	*SA tuned PID Controller*
$K_{p,1}$	1.9866	1.9866	2.0282
$K_{i,1}$	0.2643	0.4643	0.6800
$K_{d,1}$	–	1.0242	0.8396
$K_{p,2}$	– 0.2254	– 0.2254	– 0.2046
$K_{i,2}$	– 0.07008	– 0.1008	– 0.0871
$K_{d,2}$	–	– 0.4123	– 0.4067

5. SIMULATION RESULTS

The calculated controller parameter values are applied to the chosen wood-berry distillation column process and the performances are evaluated. The performances and results are compared for all the three controllers such as conventional PI, PID and SA tuned PID.

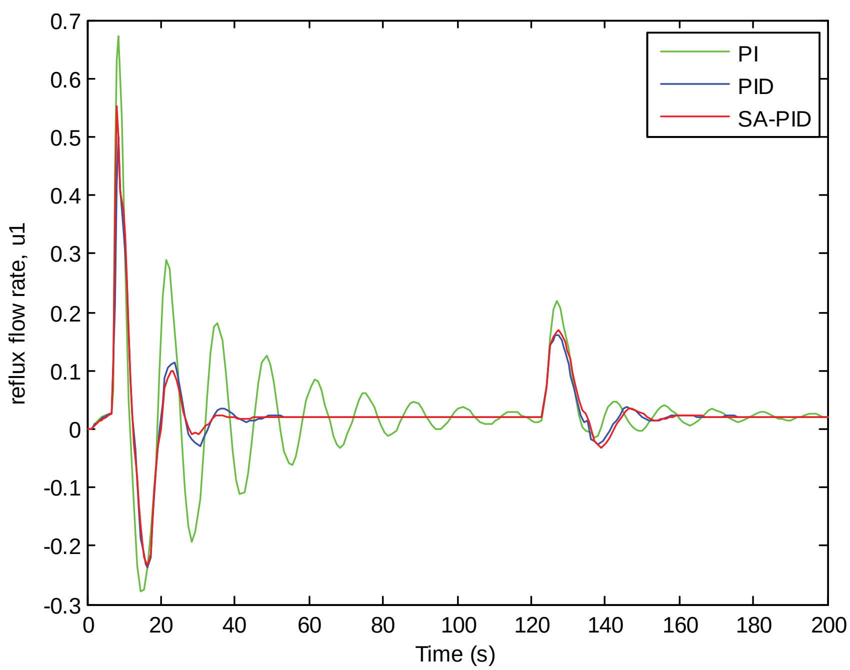

Figure 4: Control action of top product

The control action of PI, PID and SA tuned PID controller for top product is reflux flow rate $u1$ and bottom product is stream flow rate $u2$. That control actions are shown in Fig.4 and Fig.5

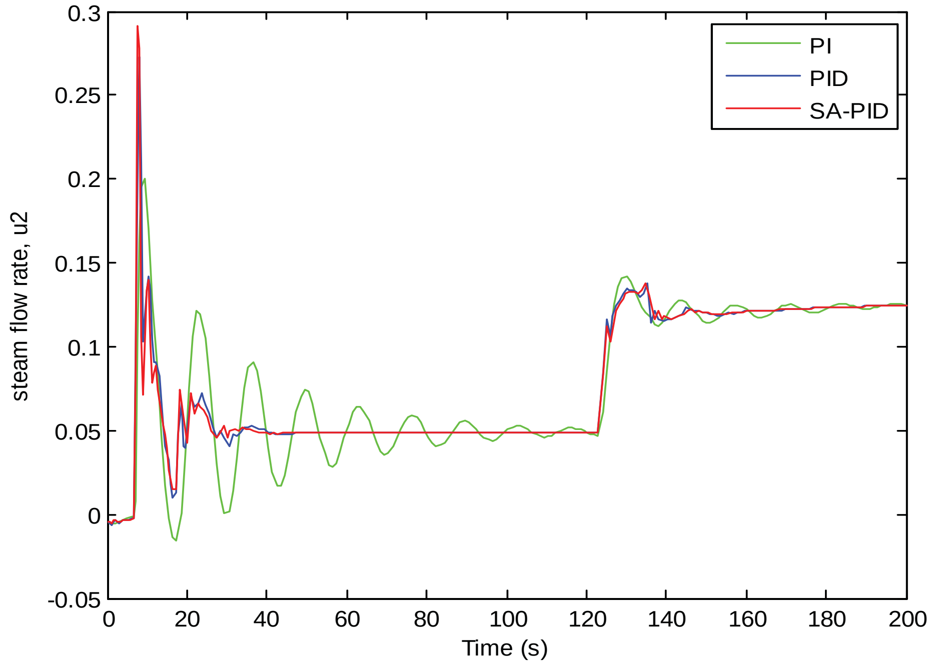

Figure 5: Control action of bottom product

The servo and regulatory responses of top and bottom products are given in Fig.6 and Fig.7. The disturbance is given at time 120second.

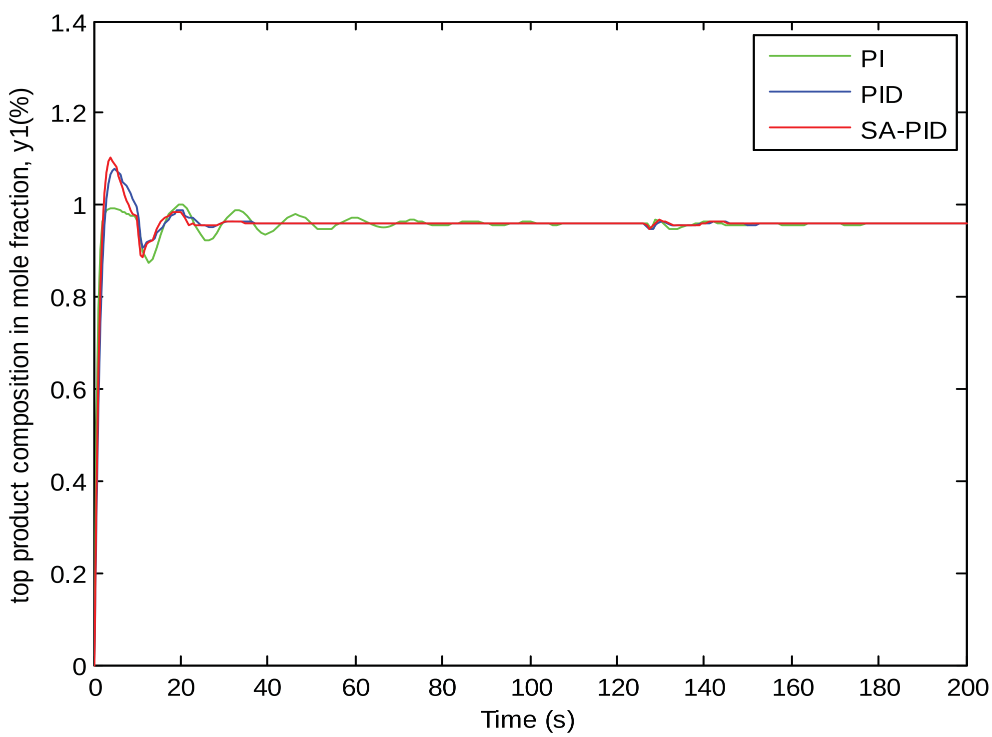

Figure 6: Output response of top product

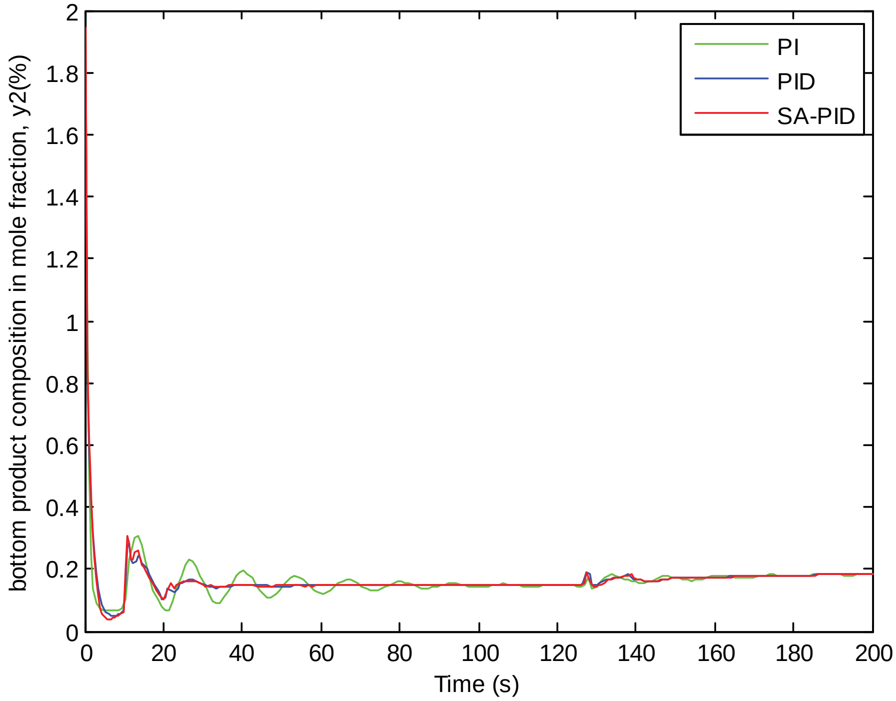

Figure 7: Output response of bottom product

The performances are analysed and tabulated in Table 2 for top and bottom products of PI, PID and SA tuned PID controllers.

Table 2
Performance analysis of top and bottom products

Criteria	*Top product*			*Bottom product*		
	PI	*PID*	*SA tuned PID*	*PI*	*PID*	*SA tuned PID*
Rise Time	2.5069	3.5695	2.9060	3.0657	5.9587	9.3115
Settling Time	53.5785	36.7542	23.8583	179.1720	172.1473	170.2310
Peak Overshoot	1.0009	1.0759	1.0503	0.6723	0.4815	0.5789
Undershoot	0	0	0	$1.4319e + 003$	$1.1438e + 003$	294.9463

Integral errors are also calculated and tabulated in Table 3.

Table 3
Error calculation

Error	*PI*	*PID*	*SA tuned PID*
IAE	122.3266	116.9923	115.7041
ISE	93.8403	90.0324	88.8566
ITAE	122.3266	116.9923	115.7041

6. CONCLUSION

In this paper wood-berry distillation column process was studied, analysed and simulated. The conventional PI, PID and SA tuned controllers were designed independently to control the process. The conventional PI, PID controller outputs were oscillating and more overshoot but SA tuned PID controller outputs were settled in a good manner with in a less duration and less overshoot. Therefore while comparing conventional PI, PID, SA tuned PID controller, SA tuned PID controller was given better performance than others. All these simulations were done by MATLAB tool in windows 7 operating system.

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