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Design and Control of Speodu Binary Fractionation Column

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ABSTRACT

The design of multicomponent distillation column requires many correlations and charts; these correlations are used to determine the column dimensions and operating conditions. The feed conditions specify the value of the q-line, Underwood (1) equation is used to determine the minimum reflux ratio and consequently the actual reflux ratio. Kirkbride equation (2) is used to calculate the position of feed plate. Fenske equation (3) is used to determine the minimum number of theoretical stages which is calculated by Gilliland equation (4). These correlations are always inconsistent and give misleading results. Gasmelseed and co-workers developed a method of using M[c]Cabe-Thiele for determination of the number of theoretical stages of multicomponent systems by taking the light key (Lk) and heavy key (hk) as speodu binaries. This methods is proved to be fairly accurate and specifies, the actual reflux ratio, the number of theoretical stages and feed plate location,. In this study examples are given for determination of the number of theoretical stages using speodu binary system and proved to be accurate. A control strategy was developed, Transfer functions were identified, tuning and stability analysis were carried out and the controller that gave the best performance was selected for the system, and found to be the proportional controller.

KEY WORDS: Tuning; stability analysis, Design, Multicomponent, speodu binary systems.

I. PREVIOUS STUDIES

Distillation is a method of separation of components in a mixture by treatment depending on their boiling point and relative volatilities. The more volatile component evaporates and rises up while the less volatile drops to stripping section of the column, The more volatile condenses in a condenser where the less volatile exits from the bottom of the column as a residue. The distillation column consists of several plates where contracts between the hot vapor and liquid

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occurs, during this simultaneous mass and heat transfer of the more volatile from the coming down liquid takes place, hence the concentration of the more volatile component increases while the concentration of the less volatile components increase in the down coming liquid[5]. The following figure showed the schematic diagram of the distillation column:

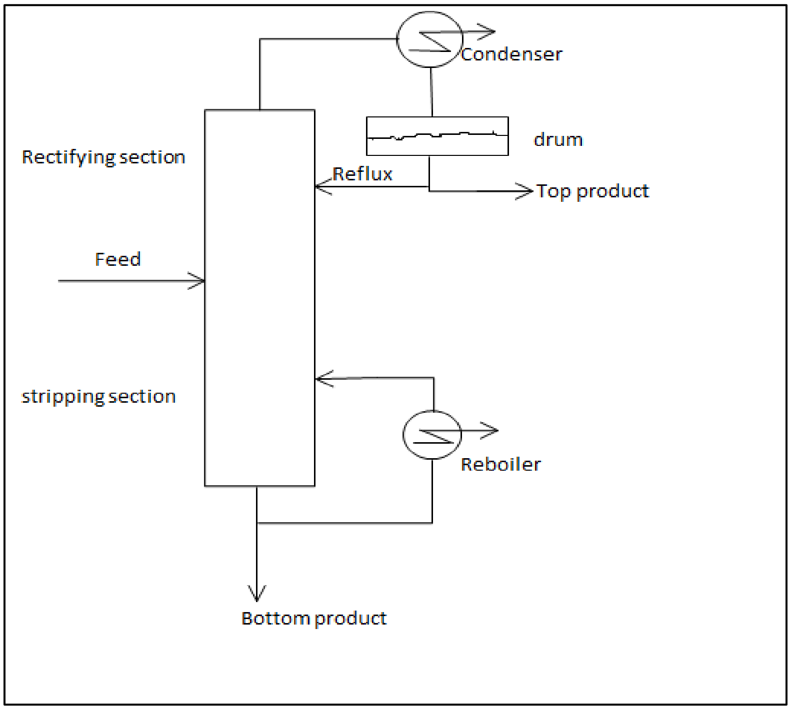

Figure1. Schematic diagram of the distillation column

The distillation column is used to separate binaries and multicomponent through the same principle but in separation of multicomponent, side streams are used to separate different components of different relative volatilities. The determination of the number of theoretical stages, the reflux ratio and feed plate location were calculated by M^{c}Cabe-Thiele method until recently the same were determined via empirical correlations which are not consistent and reproducible. Recently Gasmelseed and other used M^{c}Cabe-Thiele for determination of the theoretical number of stages using MATLAB program.

MATLAB is a software package for high performance numerical computation and visualization is one of the most widely used tools in the engineering field today. Its broad appeal lies in its interactive environment, which features hundreds of built in functions for technical computation, graphics and animation. In addition, MATLAB provides easy extensibility with its own high level programming language [6].

In mass transfer operation Control is necessary to avoid any problems that can make the process failed. The control system used in distillation column is feedback control system. In feedback control action the valve measured the output signal using the measuring device (sensor), which sends the signal through the transmitter to the controller. Controller compares this value with the desired value (reference or setpoint) and supplies the deviation signal to the final control element which in turn changes the value of the manipulated variable.

Transfer functions

Transfer function is an expression that represents the functional relationship between output and input system; it indicates the dynamic response of the system component or elements [7].

Controller tuning methods:

The methods for controller tuning are:

- Ziegler-Nicholas (Z-N).
- Cohen – Coon method

A. Ziegler-Nicholas (Z-N) tuning method

Ziegler-Nicholas is one of tuning techniques, in this method set up the system with proportional control only, make a set point step test and observe the response, evaluate the period of the constant oscillation; this period is called the ultimate period Pu, and the gain is the ultimate gain (k_u), finally calculate the adjustable parameters according to the following formulas [8]:

Table1. Zieglar-Nicholas closed loop relevant controller parameters

Controller type	Gain K_c	Integral time τ_i	Derivative time
P	0.5 k_u	-	-
PI	0.45 K_u	$P_u/1.2$	-
PID	0.6 K_u	$P_u/2$	$P_u/8$

II. METHODOLOGY

M^CCabe –Thiele method is used to determine the number of theoretical stages, reflux ratio and the feed plate location using binary data. The light and heavy keys are determined by the fact that the light key is of the maximum concentration in the top and least concentration at the bottom, while the heavy

Open the MATLAB Program:

Ente1 r the following data:

1- The Relative volatility

2- Feed composition,xf .

3- The top composition,xd.

4- The bottom composition,xw

5- The conditions of the feed,q=0.0,if the feed is at its boiling point.

From these data Mc Cabe-Theile diagram will be constructed with the following results:

i-Number of theoretical stages.

ii-Feed plate location.

iii-The reflux ratio. key has the least concentration at the top. The procedure to run the program is:

Routh array, root locus and Bode plot were used to determine the ultimate gain and ultimate period, hence the adjustable parameters (k_c, τ_i, τ_D). The overall transfer functions are used through MATLAB to simulate the system and determine the overshoots. From the step response of the system the minimum overshoot is taken as a guide for determination the type of controller.

III. RESULTS AND DISCUSSION

1. Design of multicomponent distillation column by M^{c}Cabe Thiele method

A mixture of hydrocarbons C_2 to C_7 is taken as a multicomponent feed entering the fractionators as saturated liquid at a temperature of 120^{o}C and a pressure of 13 bars

Table 2: composition of components C_2 – C_7 [9]

Component name	Feed mole fraction	D ,mole fraction	W, mole fraction
Ethane	0.0093	0.0475	0

Propane	0.1709	0.4196	0
Iso butane	0.1406	0.3462	0
Cis butane	0.085	0.1967	0.00105
i-pentane	0.1439	0.0004	0.2530
Iso prene	0.0162	0	0.28
Cyclo hexane	0.1229	0	0.2695
Toluene	0.3	0	0.5107

Where: D= distillate product, W= bottom product

C_2= Ethane; C_3 = Propane; C_4 = Iso butane, Cis butane; C_5 = i-pentane, Iso prene; C_6 = Cyclo hexane; C_7 = Toluene

Table3: compositions of light and heavy keys in top and bottom [5]

	Lk	**Hk**
x_D,mole fraction	0.1967	0.0004
x_B, mole fraction	0.0015	0.253

Manual determination of number of theoretical stages

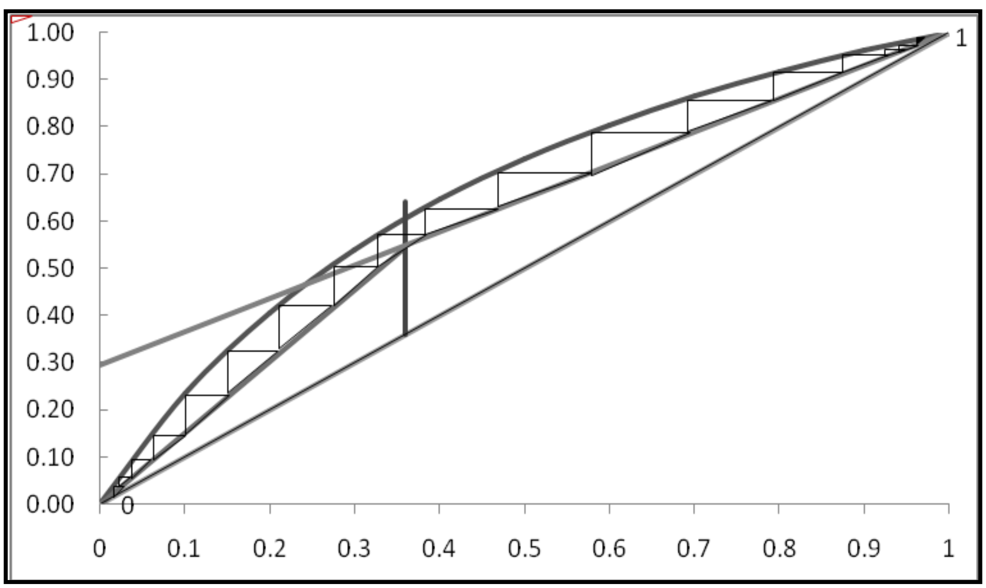

Figure 3: M^ccabe Thiele graphical method from (Hassan,2013, A short-Cut Method for Designing Multi-Component Fractionation Column) **[9]**

MATLAB determination of number of theoretical stages using speodu binary software

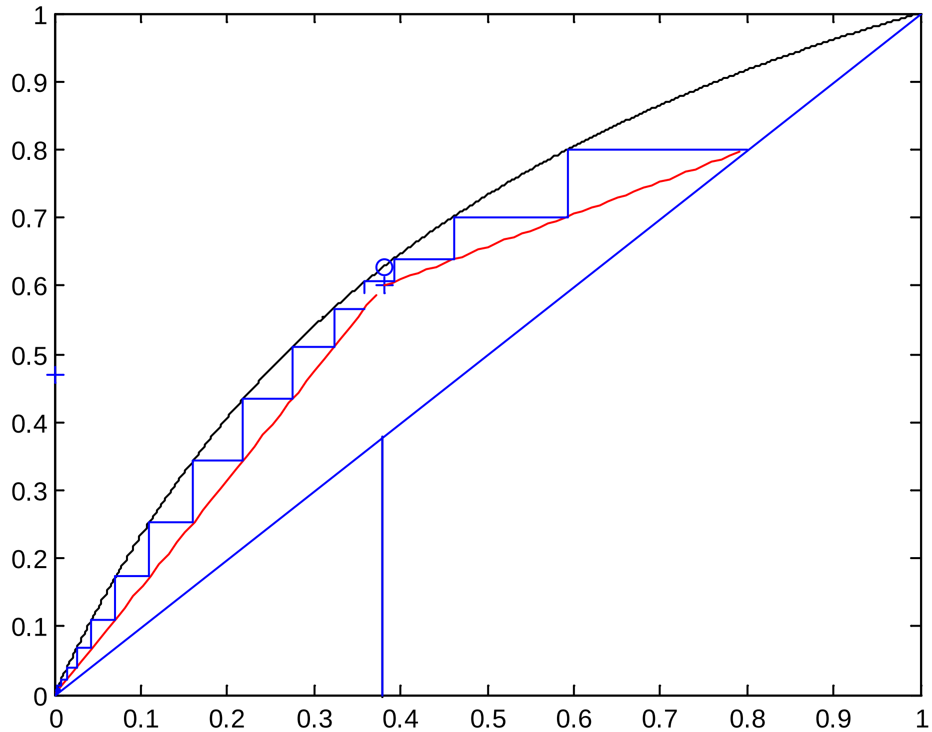

Figure 4: M^c cabe Thiele graphical method by MATLAB application

Table 4: Comparison of binary and pseodu **binary design methods**

Design parameter	**Mc Thiele method using MATLAB**	**Mc Thiele method**[9]
N	19 stages	19 stages
Eo	62.3%	62.3%
Na	31 stages	31 stages
Ht	22m	22 m
D	1.7 m^2	1.7 m^2
At	2.3 m^2	2.3 m^2
Ad	0.27 m^2	0.27 m^2
An	2.02 m^2	2.02 m^2
Aa	1.76 m^2	1.76 m^2
Ah	0.176 m^2	0.176 m^2

2. Control strategy of a distillation column

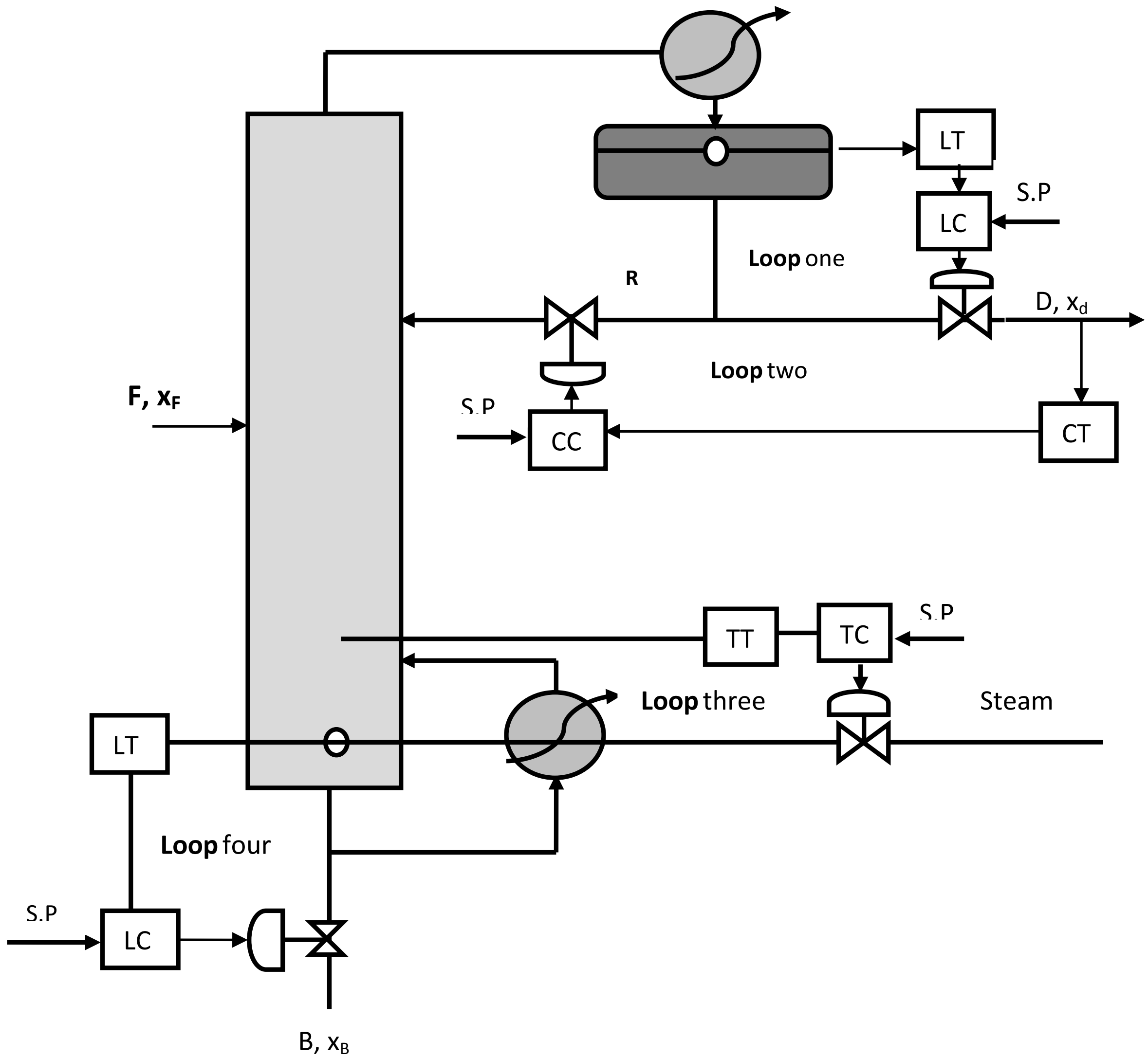

Figure 5: control strategy of a distillation column

2.1 Analysis of loop one

Transfer functions [7]:

$$G_P = \frac{2}{0.15S+1}$$

$$G_V = \frac{0.8}{1.5S+1}$$

$$G_m = \frac{1}{0.05S+1}$$

The overall transfer function $G(S) = \frac{\pi_f}{1+\pi_l} = \frac{1.6k_c}{(0.15S+1)(1.5S+1)(0.05S+1)+1}$

The characteristic equation for the system:

$0.01125S^3 + 0.03075S^2 + 1.7S + 1.6k_c = 0$

a) Using Routh array

$K_c = 29.2$

Pu = 0.51 sec

b) Using root locus

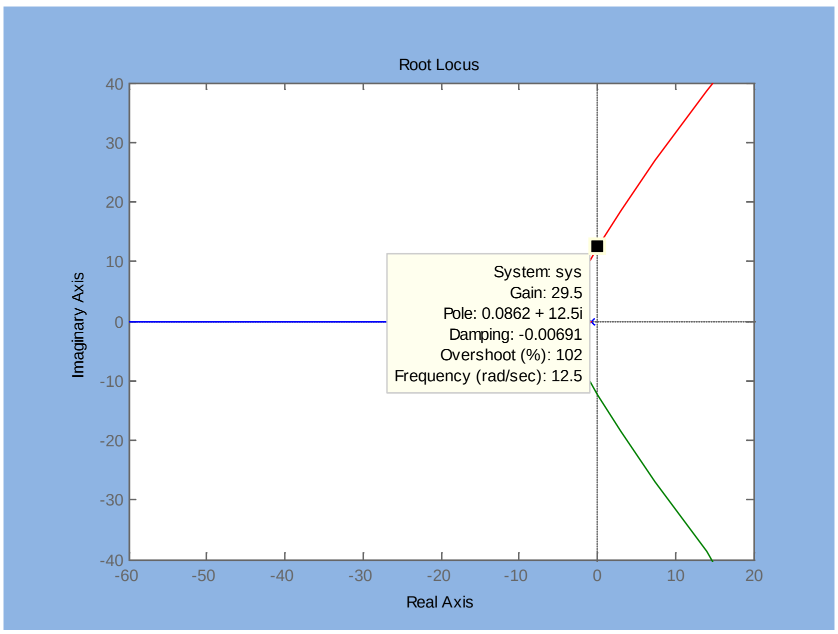

Figure6. Root locus plot of feedback system

From the figure:

$K_c = 29.5$, $\omega = 12.5$, $P_u = 2\Pi/\omega = 0.502$

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c. Using Bode plot

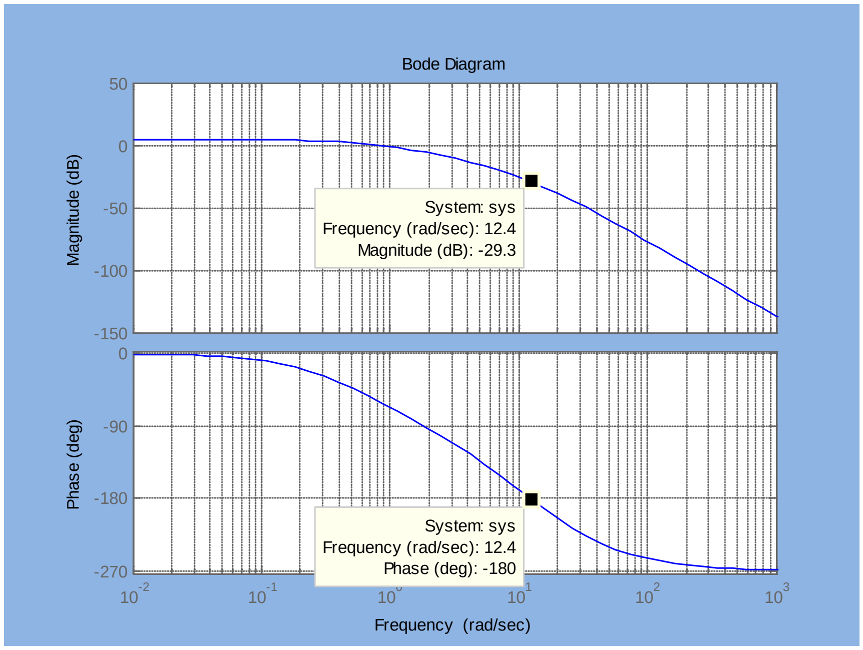

Figure7. Bode plot of feedback system

From the figure:

ω_{co} = 12.4rad/sec, p_u= 0.506 s

db = 20log AR, -29.3 = 20log AR , AR = 0.034

∴ k_c = 1/0.034 =29.4

The average of the three methods:

K_c average = (29.5+29.4+29.2)/3 = 29.37

Pu average = 0.506 s

From Z-N table:

P-action k_u = 14.6

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d. Step response of p-controller

$$TF = G(S) = \frac{1.6k_c}{(0.15S+1)(1.5S+1)(0.05S+1)+1}$$

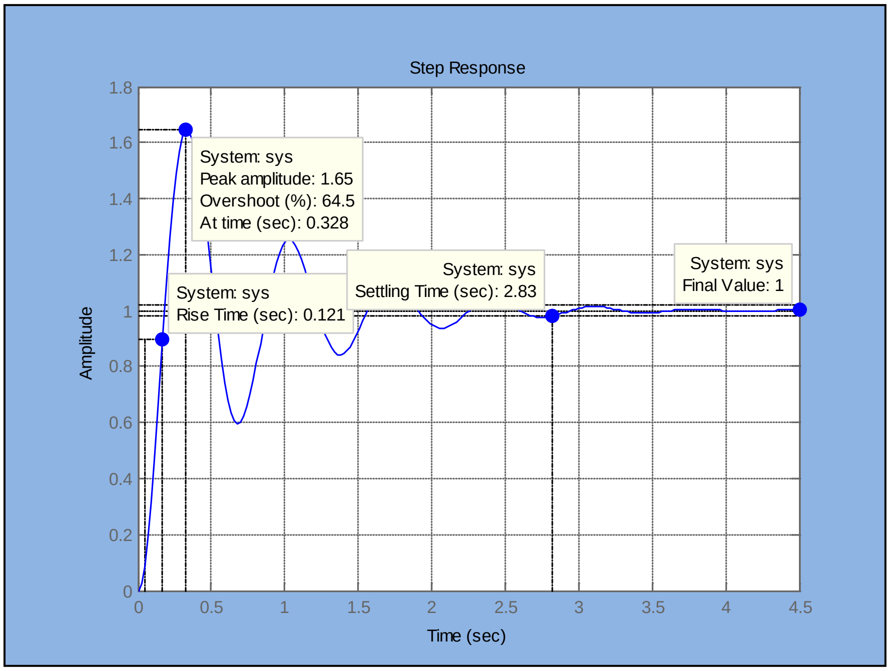

Figure9. Simulation of loop 1 using P-controller

e) Simulation of loop 1 using PI controller

TABLE 5.ADJUSTABLE PARAMETERS FOR PI-CONTROLLER

k_u	p_u (sec)	τ_i	k_p
29.37	0.506	0.42	13.14

f) Transfer function and simulation of PI controller

  4.406 s^2 + 98.64 s + 210.2

0.004016 s^4 + 0.2137 s^3 + 3.314 s^2 + 101 s + 210.2

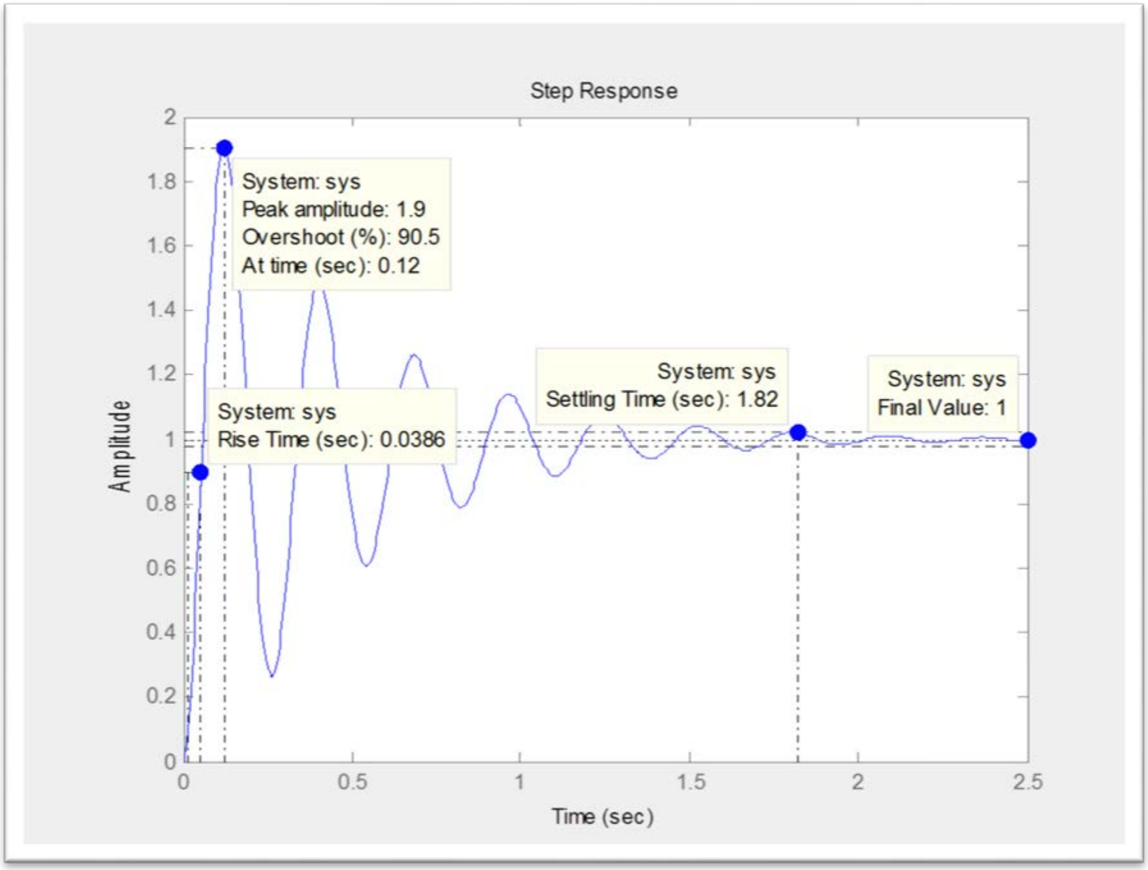

Figure 10: Simulation of loop 1 using PI controller

g) simulation of loop 1 using PID controller

TABLE 6.ADJUSTABLE PARAMETERS FOR PI-CONTROLLER

k_u	p_u	τ_i (sec)	τ_D (sec)	k_p
29.37	0.506	0.253	0.063	17.52

Transfer function of PID controller

0.2105 s^3 + 7.754 s^2 + 84.9 s + 280.3

0.002419 s^4 + 0.1287 s^3 + 6.206 s^2 + 78.66 s + 280.3

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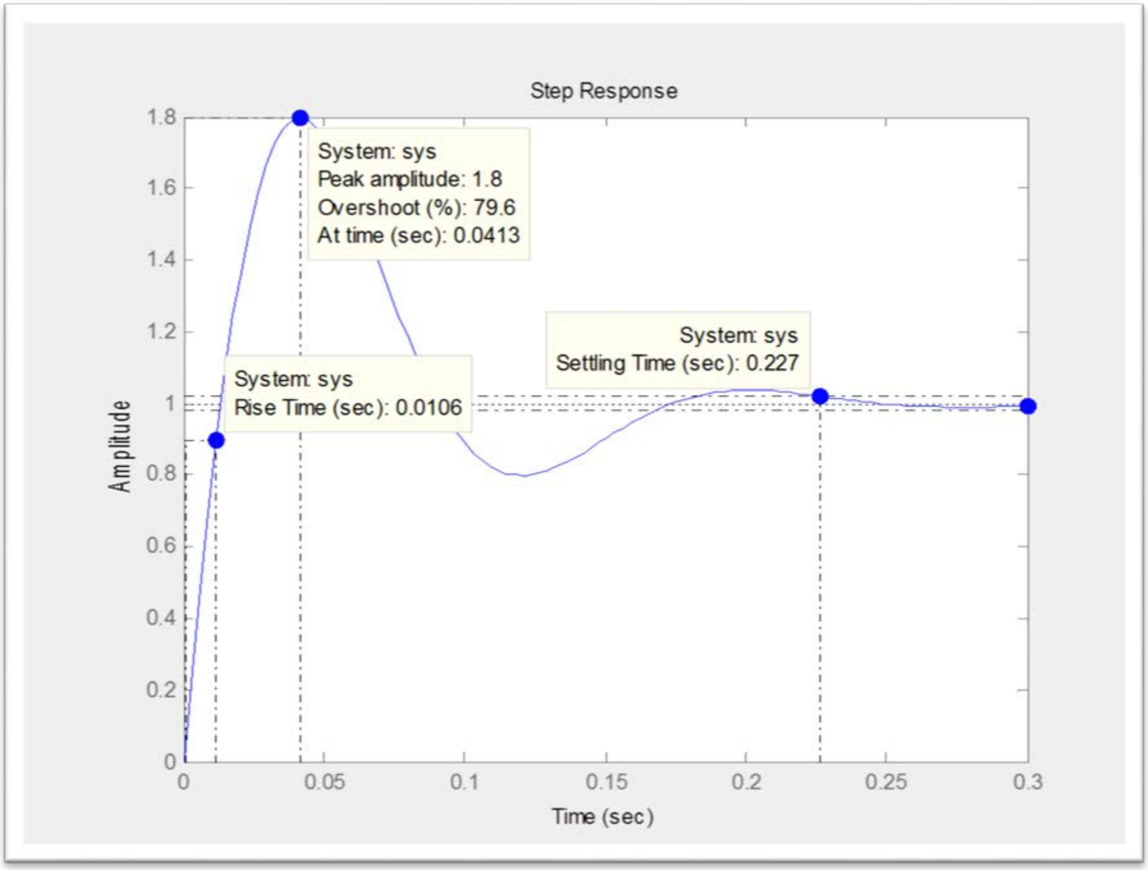

Figure11. Simulation of loop 1 using PID controller

TABLE7. COMPARISON BETWEEN P, PI, PID CONTROLLER

Characteristic	P	PI	PID
Overshoot (%)	64.5	90.5	79.6
Settling time (sec)	0.121	0.0386	0.223
Rise time (sec)	2.83	1.82	0.0106

From the table P-controller has a minimum overshoot of 64.5%, therefore it is selected to be installed into the control system for loop one.

IV. Discussion of the results

Multicomponent system calculations for the number of theoretical stages are carried out by M^cCabe Thiele using manual [5] and MATLAB procedure. The method showed good agreement for multicomponent as spsedo binary. The column is designed with dimensions shown in table

(4) cited from our previous paper [5]. The control strategy was developed, the system transfer functions were identified and the loops were simulated. The overshoot of each simulation was taken as indicative to the type of controller to be selected. This has done for loop one and the controller that gave the minimum overshoot is found to be the proportional controller which is consequently installed into loop one, other loops are delt with the same procedure.

V. Conclusion

A software program was written in MATLAB with an option of five types where (1) is selected. To run the program the following parameters: relative volatility, feed composition of the light key, the top product composition, the condition of the feed (q) and the bottom composition. The result is:

Total number of stages is ****

Feed plate location is *** stages from the top.

Reflux ratio is ******

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