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CONTROL AND SIMULATE OF LIQIUD LIQUID EXTRACTION COLUMN

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Abstract—**The control strategy was developed in which a cascade control system was constructed where the level is taken as a master loop and the extract composition as a secondary loop. The transfer functions were identified from the literature and characteristic equations were determined. The ultimate gains and periods were obtained, using the average between direct substitution, Root locus and Bode methods. The ultimate gains and periods were inserted in Ziengler tuning table and the optimum adjustable parameters (K_c, τ_i, τ_d) were taken for P,PI&PID .These were inserted into each overall transfer functions and the controller that gave minimum overshoot was taken and introduced into either loop, the controller was the secondary loop is P controller and for the primary loop is also P controller. It's recommended that the controller system obtained in this process is to be made into digital computer system where each controller is a PLC.**

Keywords— **strategy, cascade, transfer function, tuning**

I.INTRODUCTION

Acetic acid is one of the most widely used carboxylic acids. It is used in many reactions, for example in synthesis of acetic esters, or it can be used as a solvent, for example in the manufacture of cellulose acetate or pharmaceutical products. Acetic acid biosynthesis produces important quantities of aqueous solutions from which acetic acid should be economically recovered [1-2].

The separation of acetic acid from aqueous solutions by simple rectification is difficult, requiring a column with many stages and a high reflux ratio, the whole process being very expensive . Other processes may be used, depending on the acetic acid concentration in the solution. For example, extractive distillation is used for acid concentrations between 50 and 70 % w/w. By adding a third component water volatility is increased and the process may be carried out with low energy consumption. For acetic acid concentrations lower than 40 % w/w the liquid- liquid extraction can be an appropriate process .This process is also useful when other components interfere with direct distillation[3-4].

Until recently, however, the acid waste has been mostly subjected to neutralization without any proper treatment. However, the conventional neutralization treatment has problems of formation of precipitation in a large quantity, cost of alkali, sludge disposal and treatment of waste water to reduce BOD and COD, which consequently cause an increase in the treatment cost. On the other hand, in this era of recycling it is important to minimize the waste by possibly reusing several components of the waste. This is not only important from economical point of view but also from the environmental aspects.

In this paper the control strategy will be discussed for liquid-liquid extraction column, the control of these units can often be problematic, partially due to their multiphase nature, and partially due to the difficulty of on-line measurements of output variables. Thus, the reliable simulation of the transient behavior of these columns is extremely valuable. The column hydrodynamics including flooding, entrainment, weeping, and phase inversion will be controlled.

Controller stability:

The stability of a linear system is determined from the system characteristic equation. The controller stability methods are following:

Routh-Hurwitz Method

The Routh criterion determines the number of the roots of the characteristic equation that lie on the left-half plane, the right -half plane or on the imaginary axis if the system is stable, unstable or critically stable respectively.

The Root Locus Method

This method gives an approximate graphical representation of the root as the gain is varied. This is very useful in the design of a system since it gives the position of the poles of the system in the S-plane for all values of the gain [5 -6]

Bode plot Method
Bode plot is the graph on semi log paper of the amplitude ratio and phase angle as the frequency is varied from zero to infinity. From the plot the ultimate gain and period can be determined and used for tuning[5-7].

Direct substitution method
The direct substituaton method is a simple and useful method for finding the value of parameter in the characterstic equation that put the system just at the limit of stability. We know the system is stable if all the roots of the characterstic equation are in the LHP and unstable if all the roots are in the RHP

Control systems with multiple loops
The feedback control configuration involves one measurement (output) and one manipulated variable in a single loop. There are other simple control configurations which may be used. If there are more than one measurement and one manipulated variable or one measurement and more than one manipulated variables in such case the control systems with multiple loops may arise, typical example is the cascade control. [9 - 10]

Cascade control
In a cascade control configuration one manipulated variable and more than one measurement exist. Cascade control is a strategy that in some applications significantly improves the performance provided by feedback control.
This strategy has been well known and used for a long ago[11].

Industrial Controllers
These are a combination of two or three modes together. They are usually in actions of P, PI and PID. [7, 8]

Controller Tuning
Is to choose the values of controller parameters K_C and, τ_D and τ_I, to ensure that the response of the controlled variable remains stable and returns to its steady-state value (disturbance rejection), or move to a new desired value (set point tracking), quickly. However the action of controller tends to introduce oscillations [11].

II.MATERIALS AND METHODS

A complete physical diagram of the loop will be setup; the transfer function will be identified or cited from the literature. The closed loop and open loop, the characteristic equation and overall transfer function will be drawn, stability analysis, tuning and simulation of the extraction system will be investigated. In conclusion a complete digital control system for the column, will be designed.
To control an extraction column is to put the column hydrodynamic in tight control and to operate the column at high capacity up to 95% of flooding velocity, many control configurations are possible. Cascade control is selected in this study due to its safety and tightness. In this study the raffinate flow rate is cascaded with the rotor speed and the level is cascaded with flow rate of the extract, the physical and block diagrams are shown in figure (1) and (2) respectively
The original block diagram consists of:
i. The major outer loop: loop1(secondary loop)
ii. The inner loop: loop2. (primary loop)

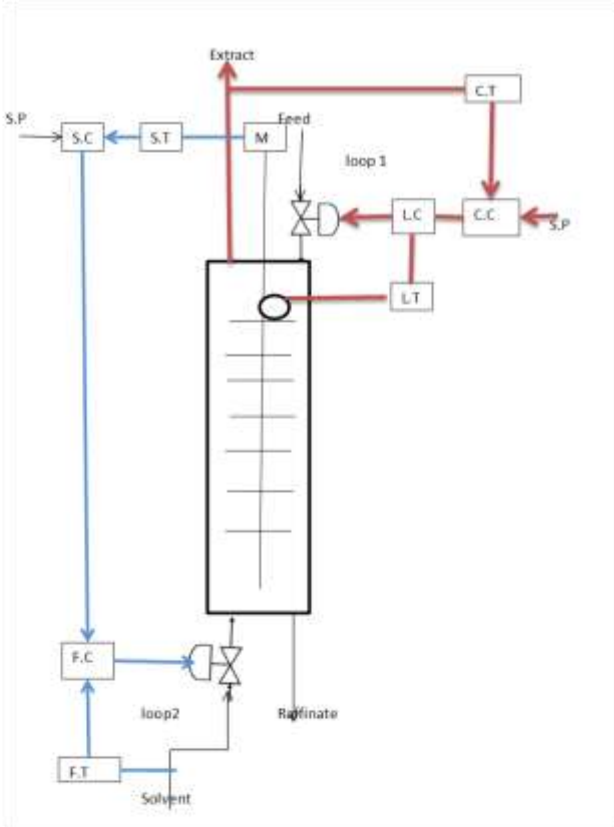

Figure 1: Cascade control system of the extraction column

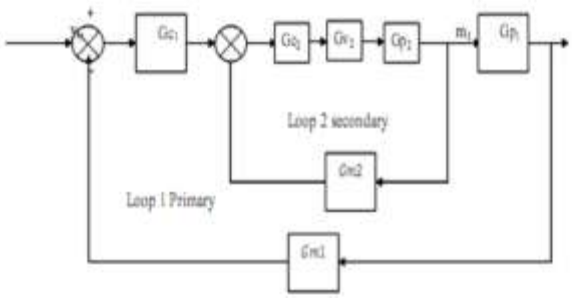

Figure 2: Block Diagram of the Top Cascade Loop of the extraction column

Where:
$G_{C1} = K_{C1}$....$G_{C2} = K_{C2}$......$Gp_2 = 1/(3S+1)(S+1)$.....
$Gp_1 = 0.8/(4S+1)(S+1)$....
$Gv_1 = 3/(0.2S+1)$.....$Gm_1 = Gm_2 = 0.5$.....[11]
Procedure for stability analysis and tuning

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- The appropriate transfer functions were cited [11].
- The overall transfer functions were determined and the open loop and close loop characteristic equations were derived.
- The characteristic equations developed in the previous step were used for tuning, stability analysis and offset investigation.
- The response by each criterion were graphically determined and compared for the best performance with regard to overshoot, decay ratio, rise time and recovery time (Fig. 6,7,8 &9).

Top of the extraction column ,the secondary loop:

The inner loop (Secondary loop)

$$G_{(s)} = \frac{\pi_f}{1+\pi_l}$$

$$\Pi_f = G_{c2}\, Gv\, G_{p2}$$

$$1+ \Pi_L = 1+ G_{c2}\, G_v\, Gp2\, G_{m2}$$

$$G_{(s)} = \frac{Gc2\ Gv\ Gp2}{1+Gc2\ Gv\ Gp2Gm2}$$

The characteristic equation of the inner loop:-

$$1 \quad + G_{c2}\, G_v\, G_{p2}\, G_{m2} = 0$$

III RESULTS AND DISCUSSION

$$\pi_F = k_{c2}\cdot\frac{3}{0.2S+1}\,\frac{1}{(3S+1)(S+1)}$$

$$\pi_l = \frac{1.5\ k_{c2}}{(0.2S+1)(3S+1)(S+1)}$$

The closed-loop transfer function:

$$\frac{3\ k_{c2}}{(0.2S+1)(3S+1)(S+1)+1.5\ k_{c2}}$$

The characteristic equation: $1 + \pi_L = 0$

$$1+\frac{1.5\ k_{c2}}{(0.2S+1)(3S+1)(S+1)} = 0$$

$$(0.2S+1)(3S+1)(S+1)+1.5KC2\ =\ 0$$

$0.6S^3+3.8S^2+4.2S+(1+1.5K_{C2})= 0$

To get the ultimate gain K_{C2} for the secondary loop:
1.Routh-Hurwitz method

Rows	Coefficients	
S^3	0.6	4.2
S^2	3.8	$1+1.5k_{c2}$
S^1	$4.04-0.237k_{c2}$	0
S^0	$1+1.5k_{c2}$	0

$4.04-0.237\ K_{C2} = 0$
$K_{C2} = 17.05$
To get the ultimate period, Pu:
Let $3.8\ S^2 +(1+1.5\ K_{C2})=0$,and Set $s = i\omega$ and $i^2 = -1$
$-\ 3.8\ \omega^2+1+1.5k_{C2} = 0$
$-3.8\ \omega^2+1+1.5*17.05=0$
$\omega= \sqrt{(25.575/3.8)} =2.59$ Rad/sec
$Pu=2\pi/\omega =2\pi/2.59 = 2.42$ sec

2.direct substitution method:
Set $s = i\omega$ and $i^2 = -1$,in the characteristic equation:
$-0.6\ i\omega^3-\ 3.8\ \omega^2+4.2\ i\omega+1+1.5k_{C2} =0$
Taking the imaginary part:
$-0.6\ i\omega^3+4.2\ i\omega =0$
$\omega= \sqrt{(4.2/0.6)} =2.64$ Rad/sec
The ultimate period, Pu:
$Pu=2\pi/\omega =2\pi/2.64 = 2.38$ sec
Taking the real part:
$-\ 3.8\ \omega^2+1+1.5k_{C2} = 0$
$-3.8*2.64^2 +1 + 1.5\ k_{C2} =0$
$k_{C2} = 16.99$

3.Root-locus method using MATLAB

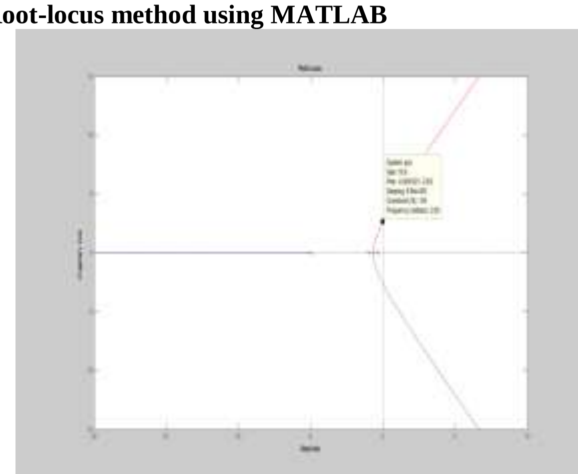

Fig 3:Root locus plot for the secondary loop using Matlab

From the figure: the system is stable scince the root of the charcteristic equation is not have positive real parts (i.e root locus plot does not cross the imaginary access)
$k_{C2} = 16.8$ and $\omega= 2.63$ Rad/sec
$Pu=2\pi/\omega =2\pi/2.63 = 2.39$ sec

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4.Bode plot method using Matlab for the secondary loop

$$\pi_F = k_{c2}\cdot\frac{3}{0.2S+1}\frac{1}{(3S+1)(S+1)}$$

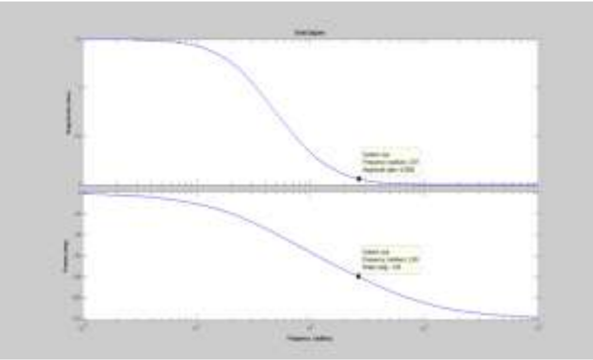

Fig4. bode plot for the secondary loop bottom level loop

From the figure:the system was stable up to -180C
Pu=2π/ω =2π/2.65 = 2.38 sec
AR = 0.0598
k_{C2} =1/AR =1/0.0598= 16.72
The average of ultimate gains ku and ultimate periods Pu
Ku average =($ku_1+ku_2+ku_3$ +ku_4)/4=(17.05+16.99+16.8+16.72)/4 = 16.89
And the Pu average=($Pu_1+Pu_2+Pu_3+Pu_4$)/4 =(2.42+2.38+2.39+2.38)/4=2.39

The primary loop

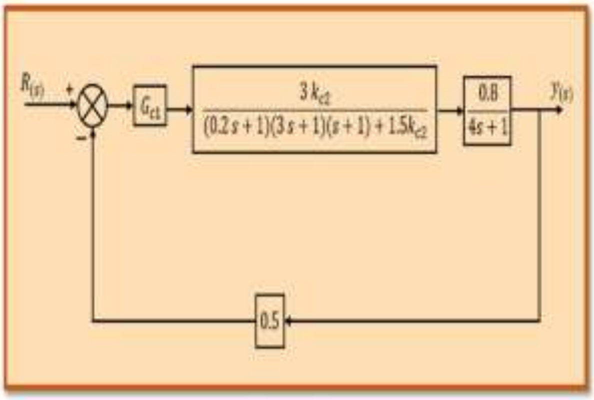

Fig 5:The reduced block diagram for the primary loop

With the same methods for the seondary loop, the primary loop
The average of ultimate gains ku and ultimate periods Pu
Ku average = (ku1+ku2+ku3)/3 =(7.15+7.2+7.09)/3 = 7.15
And the Pu average =($Pu_1+Pu_2+Pu_3$+)/3=(4.08+4.08+4.08)/3=4.08 sec

Controller tuning: Using Z-N tuning controller for

- proportional controller: the adjustable parameters

kc1=0.5*ku average = 0.5*7.15 =3.57

- and for PI controller :

kc2=0.45*ku average =0.45*7.15=3.22 and τ_I=Pu average/1.2 =4.08/1.2 =3.4

- for PID controller :

kc2=0.6 ku average = 0.6*7.15 =4.29 and τ_I=Pu average/2=4.08/2 =2.04 , τ_D=Pu average/8 =4.08/8 =0.51

The response of the system after tuning:
MATLAB is used to plot the step response from the closed loop transfer function:
The closed-loop transfer function:
G(s)

$$=\frac{20.268kc1}{2.4S^5+18.2S^4+36.4S^3+79.47S^2+72.54S+13.67+10.134kc1}$$

step response for P control

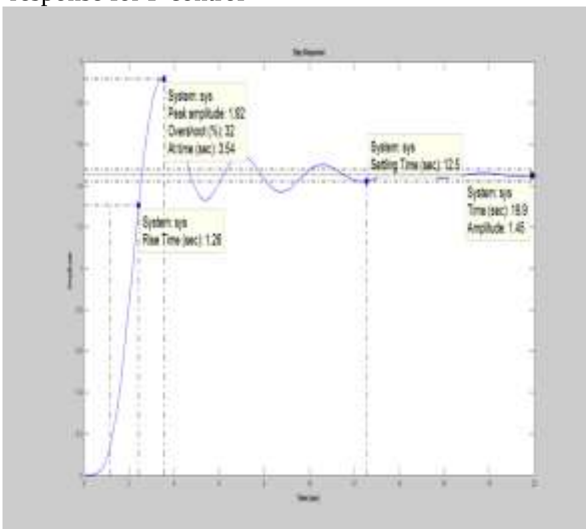

Fig 6: step response for P control

Step response for PI controller :

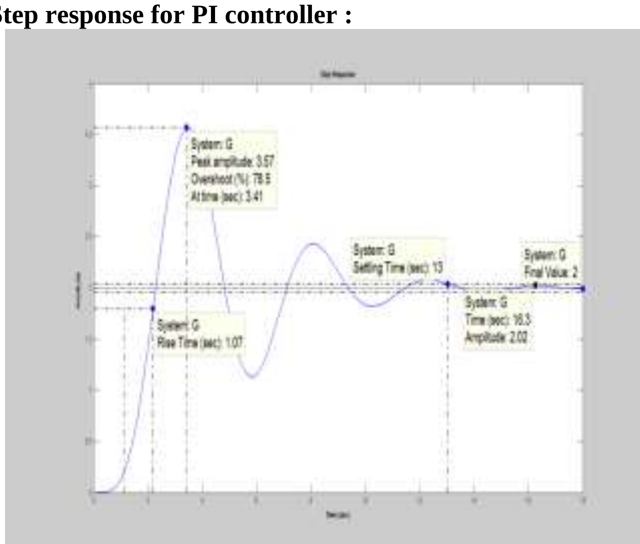

Fig7: step response for PI control

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Step response for PI controller :

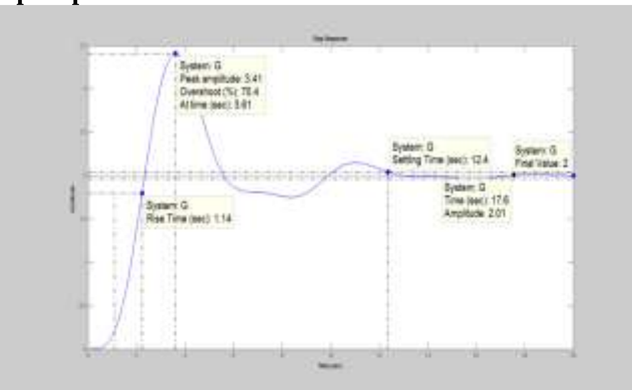

Fig 8: step response for PID control

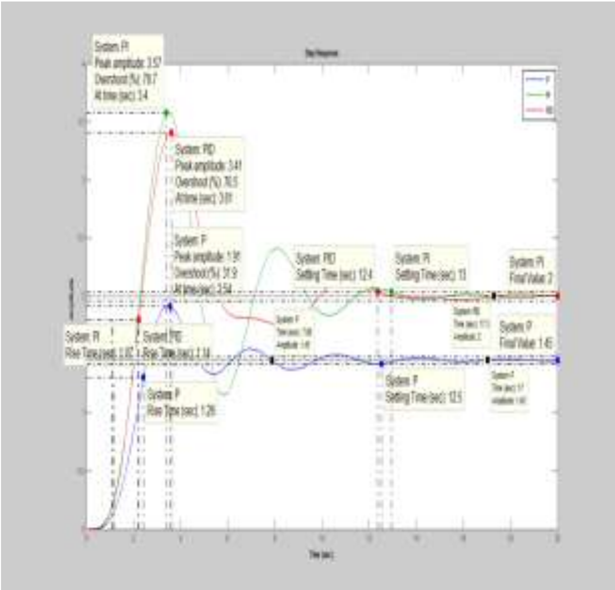

Fig 9: System step response for three type of controller

Table 1: comparisons of the three types of controllers:

	P	PI	PID
RiseTime sec	**1.26**	**1.07**	**1.14**
SettlingTime sec	**12.5**	**13.0**	**12.4**
SettlingMax sec	**19.9**	**16.3**	**17.6**
Overshoot% @ time sec	**31.9 @ 3.54**	**78.7 @ 3.41**	**70.5 @ 3.61**
Peak amplitude	**1.91**	**3.57**	**3.41**

The selected controller for the primary loop from above table is P (min overshoot)

IV CONCLUSIONS:

A control strategy was devolved , the transfer functions were identified from the literature ,then the block diagram was constructed and used to determine the ultimate gains and periods from which the adjustable parameters (K_c ,τ_i , τ_d) were obtained and used for simulation , determination of the minimum overshoot and the controller that gave the minimum overshot was selected and introduced in each loop (primary and secondary). These data were used for the top of the column as the bottom loops is to be treated similary. The stability and tuning methods are compared with each other and it is found that they are in agreement .It is observed that the responses of the system are stable with reasonable rise time, overshoot, undershoot, decay ratio and settling time.

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