Control Strategy of Flow Properties of Waxy Crude oil from Hegleig to Khartoum Refinery

Tayseir .M. Ahmed[1], Hassan.E .Elkhidr[2], Gurashi .A Gasmelseed[3]

[1]Red Sea University, Department of Chemical Engineering, Port Sudan, Sudan
[2]Shendi University, faculty of science and Technology, department of chemistry, shendi, Sudan
[3]University of Science and Technology, Omdurman, Sudan

---***---

ABSTRACT:

  A control strategy was developed from Hegleig to Khartoum refinery .The distance between station is 250 Km , each station has a control system of three loops , these are :loop1 , controls of additives rates ,loop 2 and 3 are the cascade of viscosity as master controller with temperature secondary controller , these have the duty for controlling and reporting to the SCADA system which intervenes as the case may require to adjust the set point. The transfer functions were determined and the overall transfer functions of the close and open loops were calculated .From these tuning and stability analysis were obtained and compared with each other . These parameter were found to be in agreement . The effect and response simulation were also determined and found to be reasonable with average offset of 0.484, and 0. This means that all the responses reach the final value without any overshoot .It is recommend Vis-breaking unit has to be installed at the central processing facilities; particularly if the reserve is promising for some more years of production.

Key Words: Control Strategy, cascade system, Waxy Crude oil, Khartoum refinery

1-Introduction:

        Wax is a compound of crude oil that remains in solution until operating conditions are favorable to its precipitation, a condition caused by changes in the   temperature –pressure equilibrium of the crude oil .Upon precipitation (crystallization),wax is deposited on the components of the production system by various mechanisms including molecular diffusion , shear dispersion, Brownian diffusion , and gravity settling .Brownian diffusion and gravity settling are not very significant in the dynamic condition obtainable in crude oil production Wax deposition has been reported in all facets of the production system including the reservoir, wellbore, tubing, flow lines , and surface facility .Wax deposition causes loss of production, reduced pipe diameter, and increased horsepower requirement, and negatively impacts production economic. The available remedial measure includes mechanical, chemical, and thermal techniques. Temperature reduction/heat loss is a dominant factor in wax problems, as wax begins to precipitate from crude when the temperature falls to or below the cloud point (wax appearance temperature) [1] .

2- Tuning of cascade control:

        The method of tuning cascade control is first to tune of secondary loop using proportional mode and then by direct substitution method, the primary loop is tuned .Then Z-N is used to calculate the adjustable parameter k_{c1}, K_{c2} ,l_{i1} , l_{i2}, l_{D1} Figure 3.1 and 3.2 show the physical and block diagram of cascade control.
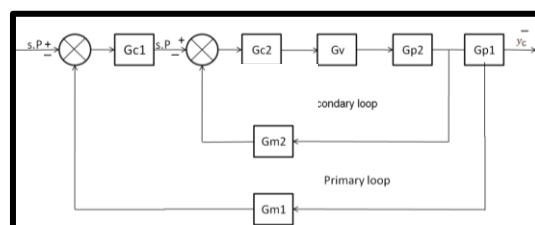

Fig. (1) General block diagram of cascade system

        The method namely: Direct Substitution method, Routh, Root locus, and Bode are used for tuning and compared with respect to offset and adjustable parameter [2] .

---

3 -.System Stability:

The stability of the control system is very important and almost should be checked using different methods .The stability of system deepens on the location of the roots of the characteristic equation on argand diagram .The roots are determined by direct substitution ,bode diagram ,root locus and nyquist plot .The stability of the system are also determined by Routh criterion which has special technique to show if the system critical stable ,stable or unstable from these methods the adjustable parameters can be obtained using Zeigler-Nichols technique[3].

3-1 Routh-Hurwitz criterion:

Apply the Routh test on the closed –loop characteristic polynomial to find if there are closed –loop poles on the right-hand –plane. Evaluated the establish limits on the controller gain .Generally, for an n-th order polynomial, we need (n+1) rows .The first two rows are filled in with the coefficients of the polynomial in a column –wise order .The computation of the array entries is very much like then negative of a normalized determinant anchored by the first column [4] .

3-2 Direct substitution:

Substitutes s=iω in characteristic polynomial and solve for closed –loop poles on Im-axis. The Im and Re parts of the equation allow the ultimate frequency to be solved. Evaluated the ultimate gain and ultimate period ($P_u = \frac{2\pi}{\omega}$)that can be used in the Ziegler-Nicholes continuous cycling relations .And results on ultimate gain is consistent with the Routh-array analysis and limited to relatively simple system [4] .

3-3 Ziegler-Nichols ultimate-cycle method:

This empirical method is based on closed-loop testing (also called on –line tuning) of processes which are inherently stable, but where the system may become unstable. We use only proportional control in the experiment. If it is not possible to disable the integral and derivative control modes, we set the integral time to its maximum value and the derivative time to its minimum .The proportional gain is slowly increased until the system begins to exhibit sustained oscillations with a give small step set point or load change [5].

Table (1): Ziegler-Nichols adjustable controller parameters (14)

Type of control	K_c	τ_i	τ_D
P	$0.5K_u$	_	_
PI	$0.45K_u$	$\frac{P_u}{1.2}$	_
PID	$0.6K_u$	$\frac{P_u}{2}$	$\frac{P_u}{8}$

3-4 Root -locus:

The idea of a root locus plot is simple, if we have a computer .We pick one design parameter, say, the proportional gain Kc, and write a small program to calculate root of the characteristic. Polynomial for each chosen value of Kc as in 0,1,2 …..100, etc. The results (the values of the roots) can be tabulated or better yet, plotted on the complex plane. Even though the idea of plotting a root locus sounds so simple, it is one of the most powerful techniques in controller design and analysis when there is no time delay.

Root locus is a graphical representation of the root of the closed –loop characteristic polynomial (i.e., the closed-loop poles) as a chosen parameter is varied .Only the roots are plotted. The values of the parameter are not shown explicitly. The analysis most commonly uses the proportional gain as the parameter .The value of the proportional gain is varied from 0 to infinity, or in practice, just" large enough [4]

3-5 Bode Method:

5 Bode Method: Bode plot is drawn for the secondary loop to calculate the ultimate gain and ultimate period, then the ultimate gain for primary loop is calculated from the secondary loop[2]

4- MATLAB Software:

MATLAB is integrated technical computing environment that combines numeric computation, and visualization, and a high level programming language. The MATLAB software was originally developed to a matrix laboratory .Its capabilities have expanded greatly in recent years and today it is a leading tool for engineering concepts in mathematics (15).Being able to plot mathematical functions and

data MATLAB, can be used in research, development and in industry. It is used in this research for tuning through different tuning techniques [6].

5- Tuning of Loop1:

Additives Loop:

Proportional Controller (P):

$$G_c = K_c \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 4.1$$

$$Process\ T.F, Gp = \frac{2}{(2s+1)(s+1)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 4.2$$

$$Valve\ T.F, Gv = \frac{1}{(0.1s+1)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 4.3$$

$$Sensor\ T,F, Gm = \frac{2}{(0.5s+1)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 4.4$$
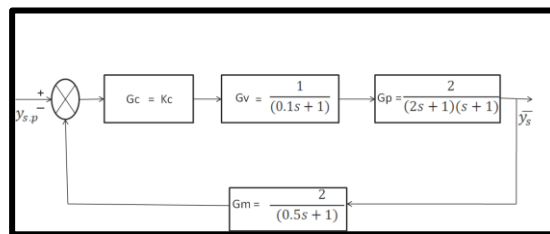

Fig. (2) Loop1 block diagram

Analysis and optimum settings:

5-1 Routh _Hurwitz Method:

The characteristic equation is:-

$$1 + OLTF = 0 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 1$$

$$1 + \pi l = 0 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad .2$$

$$1 + \frac{4Kc}{(0.1s+1)(2s+1)(s+1)(0.5s+1)} = 0 \dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 3$$

$$(0.1s+1)(2s+1)(s+1)(0.5s+1) + 4Kc = 0 \dots\dots\dots\dots\dots\dots\dots\dots \quad 4$$

$$Kc = \frac{3.22}{1.51} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 5$$

KC=2.13

The ultimate gain, Ku=2.13

5-2 Direct substitution method:

Set   S=iω

$$0.1s^4 + 4s^3 + 3.8s^2 + 3.6s + (4Kc + 1) = 0 \dots\dots\dots\dots\dots\dots\dots\dots \quad 6$$

$$40.1\omega^4 - 1.35i\omega^3 - 3.85\omega^2 + 3.6i\omega + (4Kc + 1) = 0 \dots\dots\dots\dots\dots \quad 7$$

Taking the auxiliary equation and from that the imaginary part of the characteristic equation is equal to zero:

$$1.35\omega^3 = 3.6\omega \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 8$$

$$\omega_{co} = 1.36 \frac{rad}{sec} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 9$$

$$p_{U=\frac{2\pi}{\omega_{co}}} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 10$$

5-3 Applying Ziegler-Nichols method:

Table (2): Ziegler-Nichols adjustable controller parameters for additives loop for Routh _Hurwitz

Type of controller	Kc	τ_i(sec)	τ_D(sec)
P	1.065	_	_
PI	0.553	3.21	_
PID	0.738	1.93	0.48

5-4 Offset investigation:-

$$G_{(S)=}\frac{y_{(S)}}{y_{(S.P)}} = \frac{\pi_F}{1 + \pi_L} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 11$$

Kc=1.065 from tuning,

$$Offset(\varepsilon) = c_{\infty - c_{id}} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 12$$

Where:

$$C_{\infty=} \lim_{S\to0}[sy_{(s)}] \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 13$$

C_{id}=*Magnitude of unit step change =1*

$$y_{(S.P)} = \frac{1}{S} \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 14$$

$$C_{\infty=} \lim_{S\to0}\left[S.\frac{1}{S}\left(\frac{2.12(0.5s + 1)}{(0.1s + 1)(2s + 1)(s + 1)(0.5s + 1) + 4Kc}\right)\right] \cdots\cdots\cdots\cdots 15$$

$C_{\infty=}0.498$

$$\varepsilon = 1 - 0.498 = 0.502 \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 16$$
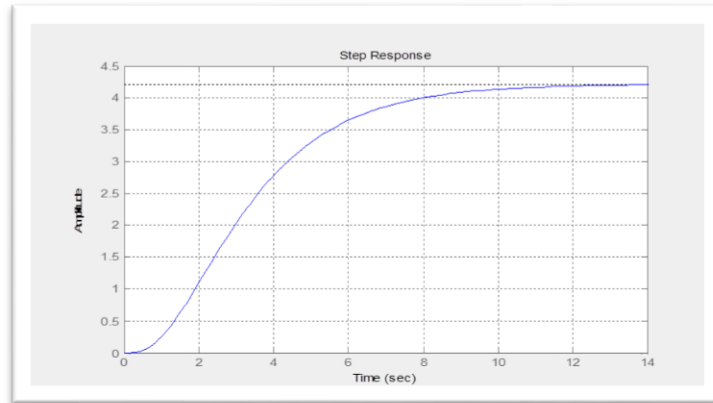
Using MATLAB Program:

5-5 Response of the step disturbance:

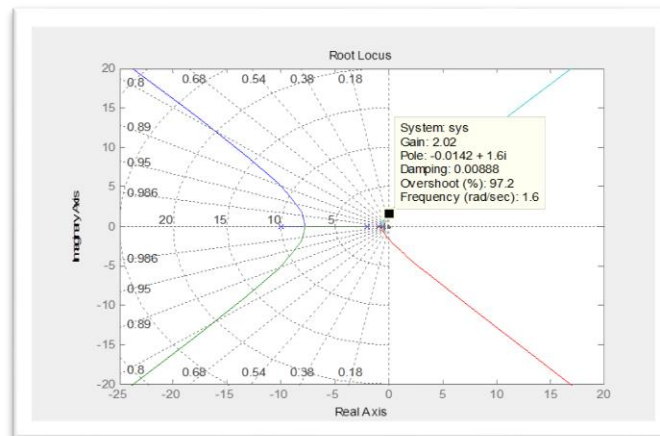This is made upon a step change in set point using the transfer function of the additives loop

$K_c = 1.065$

$$OLTF = \frac{4 * 1.065}{(0.1s+1)(2s+1)(s+1)(0.5s+1)} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad 17$$

Fig. (3) Step response input

5-6 Root -locus method:

Fig. (4) Root Locus

$$OLTF = \frac{4Kc}{(0.1s + 1)(2s + 1)(s + 1)(0.5s + 1)} \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad 18$$

$\omega_{co}=1.6$ rad/sec

$$p_{U=\frac{2\pi}{\omega_{co}}} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad 19$$

$$p_{u=\frac{2\pi}{1.6}=3.93} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad 20$$

Kc=2.02

5-7 Applying Ziegler-Nichols method :

Table (3): Ziegler-Nichols adjustable controller parameters for additives loop for Root-Locus

Type of controller	Kc	τ_i (sec)	τ_D (sec)
P	1.01	_	_
PI	0.909	3.275	_
PID	1.212	1.965	0.491

5-8 Offset investigation:

$$G_{(S)} = \frac{y_{(S)}}{y_{(S.P)}} = \frac{\pi_F}{1+\pi_L} \cdots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad 21$$

$$\pi_F = \frac{2Kc}{(0.1s+1)(2s+1)(s+1)} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad 22$$

Kc=1.01 from tuning,

$$\text{Offset}(\varepsilon) = c_{\infty - C_{id}} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \cdots \quad 23$$

Where:

$$C_{\infty} = \lim_{S \to 0}[s y_{(s)}] \cdots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \cdots 24$$

C_{id}=*Magnitude of unit step change* =1

$$y_{(S.P)} = \frac{1}{S} \cdots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \cdots 25$$

$$C_{\infty} = \lim_{S \to 0}\left[S.\frac{1}{S}\left(\frac{2.12(0.5s+1)}{(0.1s+1)(2s+1)(s+1)(0.5s+1)+4Kc}\right)\right] \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \cdots \quad 26$$

$$C_{\infty} = 0.525$$

$$\varepsilon = 1 - 0.525 = 0.475 \cdots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \cdots \quad 27$$

5-9 Response of the step disturbance

Using MATLAB Program:

This is made upon a step change in set point using the transfer function of the additives loop

$$OLTF = \frac{4*1.01}{(0.1s+1)(2s+1)(s+1)(0.5s+1)} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \quad 28$$
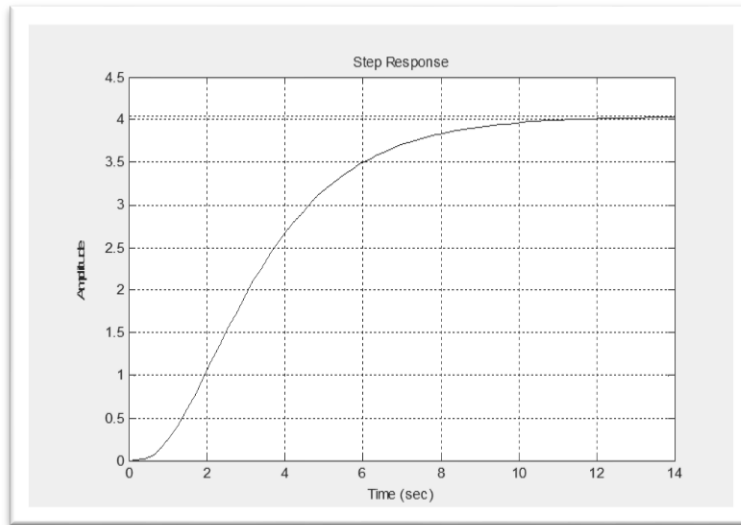
$K_c = 1.01 =$

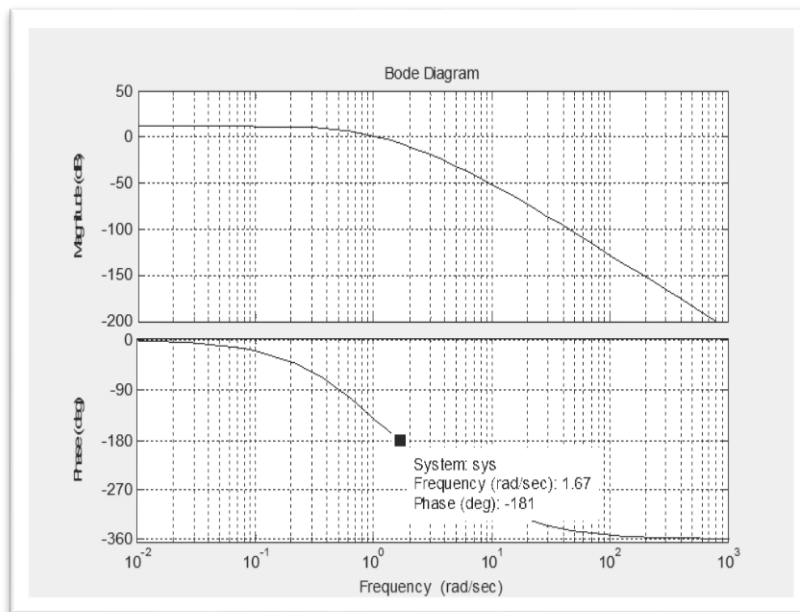**Fig. (5) Response Step response of P control by Root-Locus**

5-10 Bode diagram tuning method:

Fig. (6) Bode plot

$$AR = \frac{K_1 K_2 \dots K_N}{\sqrt{1+(\tau\omega_1)^2}.\sqrt{1+(\tau\omega_2)^2}.\sqrt{1+(\tau\omega_3)^2}.\sqrt{1+(\tau\omega_4)^2}} \dots\dots\dots\dots 29$$

At-180∘,$\omega_{CO} = 1.67 \frac{rad}{sec}$

AR=1

$$OLTF = \frac{4Kc}{(0.1s+1)(2s+1)(s+1)(0.5s+1)} \dots\dots\dots\dots\dots\dots\dots\dots 30$$

$$1 = \frac{4Kc}{\sqrt{1+(1.67*0.1)^2}.\sqrt{1+(1.67*2)^2}.\sqrt{1+(1.67*1)^2}\sqrt{1+(1.67*0.5)^2}}. \quad 31$$

$$Kc = Ku = 2.24$$

$$p_{U=\frac{2\pi}{\omega_{co}}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 32$$

$$p_{U=\frac{2\pi}{1.67}=3.76} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 33$$

Kc=2.24

5-11 Applying Ziegler-Nichols method:

Table (4): Ziegler-Nichols adjustable controller parameters for additives for Bode

Type of controller	K_c	τ_i(sec)	τ_D(sec)
P	1.120	–	–
PI	1.008	3.058	–
PID	1.344	1.835	0.459

5-12 Offset investigation:-

$$G_{(S)=\frac{y_{(S)}}{y_{(S.P)}}} = \frac{\pi_F}{1+\pi_L} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 34$$

$$\pi_F = \frac{2Kc}{(0.1s+1)(2s+1)(s+1)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 35$$

c=1.120 from tuning

$$Offset(\varepsilon) = c_{\infty-C_{id}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 36$$

Where:

$$C_{\infty=} \lim_{S\to 0} [sy_{(s)}] \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 37$$

C_{id}=*Magnitude of unit step change =1*

$$y_{(S.P)} = \frac{1}{S} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 38$$

$$C_{\infty=} \lim_{S\to 0} \left[S.\frac{1}{S}\left(\frac{2.12(0.5s+1)}{(0.1s+1)(2s+1)(s+1)(0.5s+1)+4Kc}\right)\right] \dots\dots \dots\dots \quad 39$$

$$C_{\infty=}0.473$$

$$\varepsilon = 1 - 0.473 = 0.527 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 40$$

$$\varepsilon = 1 - 0.525 = 0.475 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 41$$

5-13 Response of the step disturbance:

Using MATLAB Program

This is made upon a step change in set point using the transfer function of the additives loop.

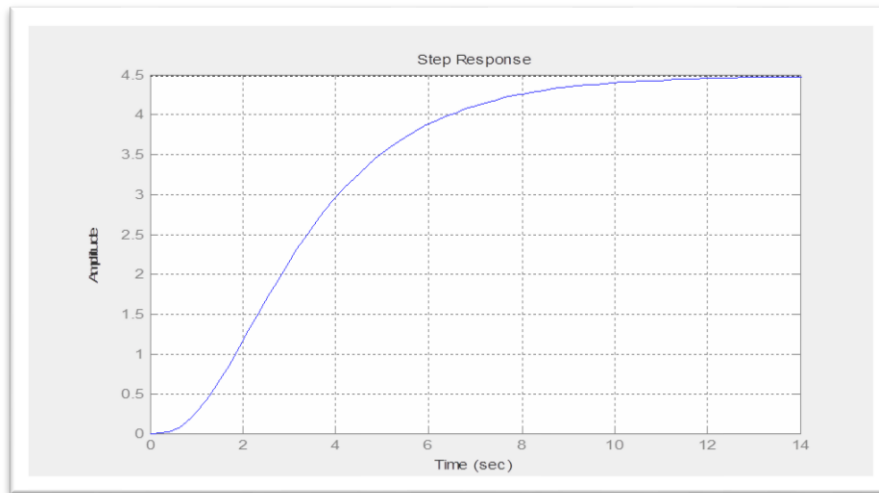$$OLTF = \frac{4 * 1.120}{(0.1s + 1)(2s + 1)(s + 1)(0.5s + 1)} \dots\dots\dots\dots\dots\dots\dots\dots \quad 42$$

Fig. (7) Step response of P control by Bode adjustable parameter

Table (4.6) Comparing between the adjust parameter using different method of tuning

6- Tuning of loop2

Secondary Loop:

$$Gv = \frac{1}{(3s + 1)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 43$$

$$Gc_2 = Kc2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 44$$

$$Gp = \frac{1}{(s+1)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \dots\dots\dots\dots\dots\dots\dots \quad 45$$

$$G_{m2} = \frac{1}{(0.1s+1)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 46$$
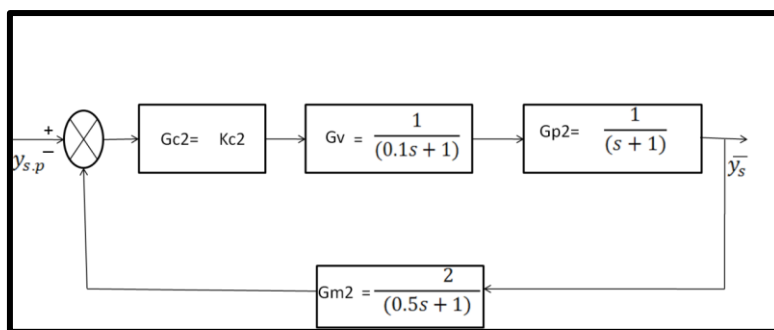

Fig. (8) Block diagram of secondary loop

6-1 Appling Ziegler-Nichols method:

Table (5) Ziegler-Nichols adjustable controller parameters for loop2 for Root-Locus

Type of controller	Kc	τ_i(sec)	τ_D(sec)
P	22.35	_	_
PI	20.12	1.43	_
PID	26.82	1.965	0.21

6-2 Response of the step disturbance:

Using MATLAB Program:

　　　This is made upon a step change in set point using the transfer function of the secondary loop.

K_{c2}= 22.40

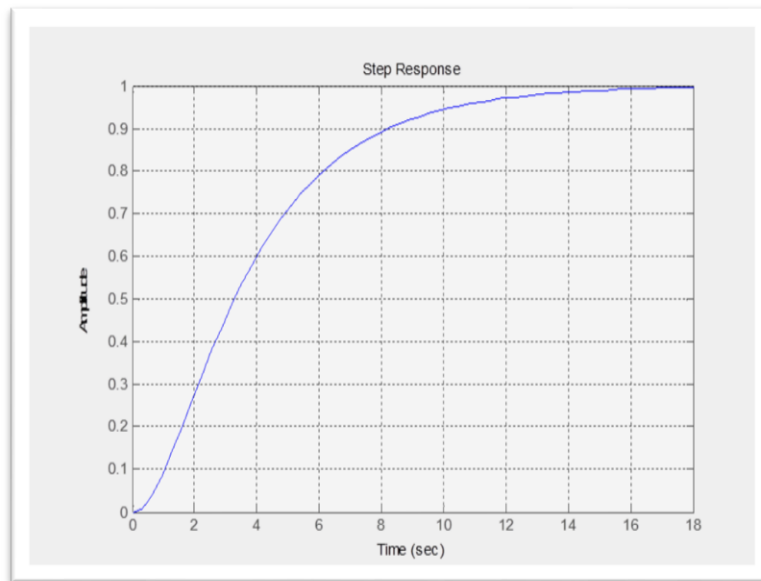$$OLTF = \frac{22.40}{(3s + 1)(s + 1)(0.1s + 1)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad 47$$

Fig (9) Step response P Bode adjustable parameter

6-3 Root -locus method:

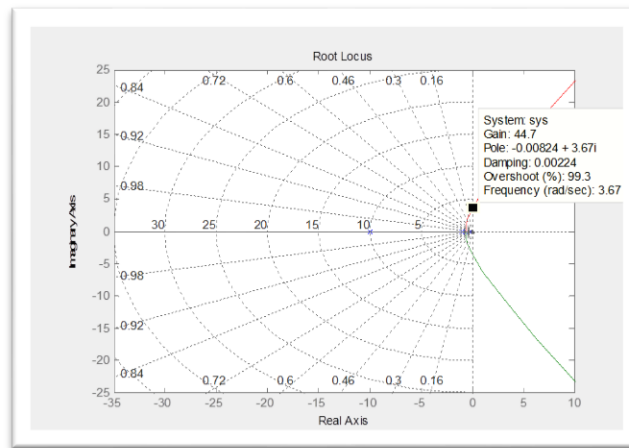$$OLTF = \frac{K_{c_2}}{(3s+1)(s+1)(0.1s+1)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .48$$

Fig. (10) Root Locus

Table (6): Comparing between the adjust parameter using different method of tuning

Parameter	Direct substitution method	Root-locus method	Bode plot method
K_{c2}	22.73	22.35	22.40
P_u	1.70	1.71	1.71

7- Response of the step disturbance of loop3 :

Using MATLAB Program:

$G_{c2} = K_{c2} = 22.35$ … . … … … …   49

$G_{c1} = K_{c1} = 0.5 K_{c2}$ …   50

$G_{m1} = 1$ … . . … … … … … . . … …   51

$Gv = \dfrac{1}{(3s + 1)}$ … . . …   52

$Gp_2 = \dfrac{1}{(s + 1)}$ … . . . … …   53
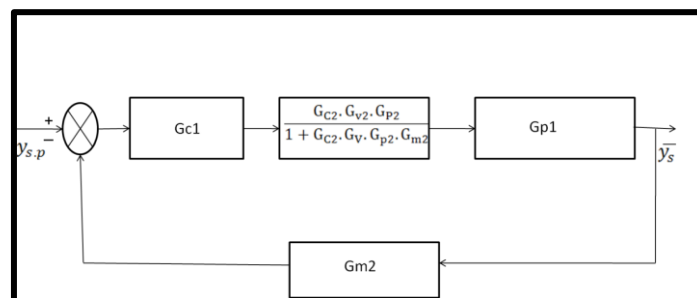
Fig. (10) Reduce cascade block diagram

$$G_{c1}.G_{c2}.G_{v.}G_{p2}.G_{m1}.G_{p1} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad 54$$

$$OLTF = \frac{0.7 * 22.35 * 11.18}{(3s + 1)(s + 1)(8s + 1)} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad 55$$
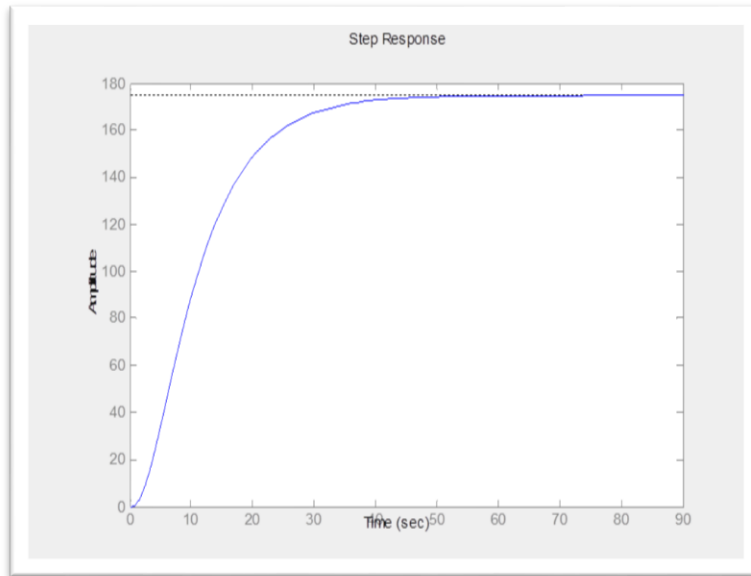

Fig. (11) Response of loop3

7- Conclusions

The control strategy was developed to control the temperature inside the pipeline cascaded with the viscosity at downstream point of measuring the viscosity which is transmitted to the master controller that reported to the SCADA system and adjust the set point of the slave controller as the case may require .On the other hand the viscosity depressant rate was controlled by single loop flow controller .This controller will reported to the SCADA which in turn adjusts the manipulated variable so that the controller variable tracks the desired value.

REFRENCES

1-Shreve, R .N .and Brink , J.A . , 1977, ' chemical process Industries,4th ed., New York Mc Graw-hill Book . CO.
2-Gurash. A .Gasmelseed ,ATEXT BOOKOF ENGINEERING PROCESS CONTROL ,2014.
　　3-Dale,E,Edger,T.F.and Duncan, A.M . (2011).,Process Dynamic and Control, John Wily and Sons, New York.

4-Stephanopoulos Gourge, 2005'Chemical Process Control', India Prentice Hall,pp248---257.
5- Stephanopoulos Gourge, 2005'Chemical Process Control', India Prentice Hall,pp248---257.
 6-Ramirez,W.F,1997,'Coputation Methods For Process Simulation,(Second Edition), Boston Butter Worth.