

Control Strategy of Vinyl Chloride Production from Ethylene

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Abstract

The production of Vinyl Chloride (VC) from Ethylene dichloride (EDC) was investigated and the control strategy was developed, the process flow sheet consisted of two reactors one for the direct chlorination and the other for the oxychlorination process, furnace for thermal cracking and two separation columns. Each control loop was taken separately and its transfer function was developed. The characteristic equation was determined and used in Routh Array to determine the ultimate gain (K_u), and the ultimate period (P_u) was determined by direct substitution. Then the open loop transfer function for each loop was developed and used in Root locus and Bode plot using MATLAB format. The ultimate gains and period were used to get the average values which were introduced in Ziegler-Nichols table to get adjustable parameters. It is concluded that the manufacture of VC is important in the petrochemical industry and its quality need to be controlled. The reaction is exothermic and the temperature is controlled to the optimum temperature, this is introduced as the set point. The three methods of Routh, Root locus and Bode are identical and they are almost giving the same tuning parameters, however the average was taken to give more precise and correct results. The responses obtained simulate the system with (Rise time, Peak amplitude, Over shoot, Settling time, Final value and Period of oscillation). Finally the system was checked for stability using the adjustable parameters obtained. All the systems were found to be stable, this is expected as the value of K_c was used after tuning.

Keywords: Vinyl chloride (VC), stability, tuning, and simulation

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:Introduction

Vinyl chloride is a colorless organic gas with a pleasant odor, is utilized to give Poly vinyl chloride (PVC), plastic and vinyl products. It is used in the manufacture of numerous products in building and construction, the automotive industry, piping, electrical wire insulation, medical supplies, construction and household equipment (U.S. EPA. Vinyl Chloride (VC), 2006). Chlorinating hydrocarbons is the essential idea to manufacture vinyl chloride monomer (VCM). Chlorinated hydrocarbons (CHCs) on an inherent C-Cl bond. Production of VCM is essential to the production of polyvinyl chloride (PVC). Materials made of PVC are light, need low-maintenance, and long lasting. PVC products are highly resistant to weathering, petroleum products, UV radiation and flame resistant. Hydrocarbons created during the process of producing VCM need to be mitigated or totally eliminated to be environment friendly (Alexandre, 2008).

The process is shown in figure (1):

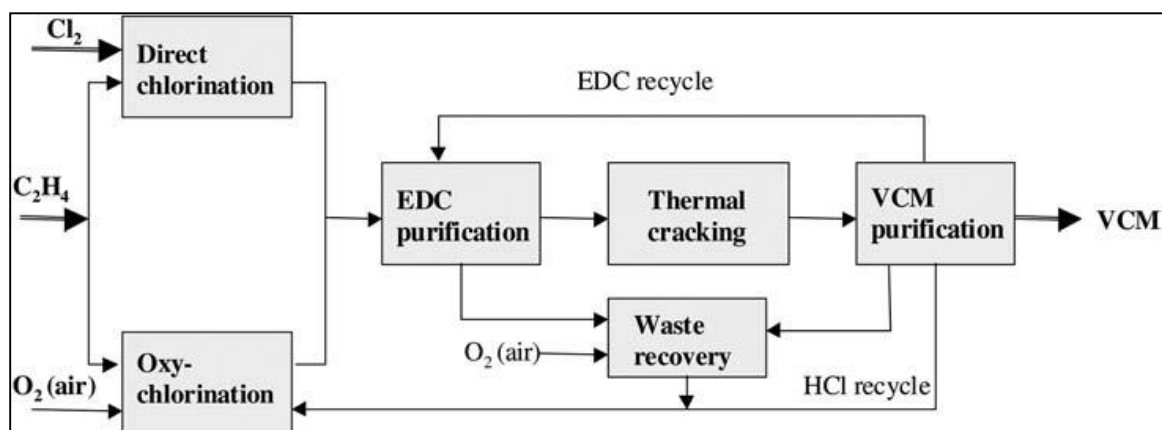


Figure (1) VCM manufacturing by a balanced process using oxychlorination

Thermal Cracking:

In thermal Cracking used high temperature. The EDC decomposes into VCM and HCl by a complex reaction mechanism. The endothermic reaction takes place at temperatures between 480 – 550°C and pressures from 3 to 30 bar. The reaction device consists of a long tubular coil placed in a furnace. The first part, hosted in the convection zone, preheats the reactant up to the temperature, where the pyrolysis reaction rate becomes significant. The second part, the reaction zone, is placed in the radiation chamber. The tube diameter is selected so as to give a superficial gas velocity between 10 – 20 m/s. The coil length should ensure a space - time of 5 to 30s.

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About 20 – 30 chemical components have been identified by EDC pyrolysis. Many originate from species carried with the EDC issued from the synthesis steps. For this reason, advanced purification of EDC sent to cracking is required.

Type of controllers:

Process control is the measurement of a process variables , the comparison of that variables with its respective set point , and the manipulation of the process in a way that will hold the variable at its set point when the set point changes or when a disturbance changes the process (Salgado,2005).

One way to improve the step response of a control system is to add a controller to the feedback control system, the closed loop systems can be controlled by Proportional control (P), Proportional Integral (PI) control and Proportional plus Integral plus Derivative (PID)control. Proportional control:

The proportional action is responding quickly to change in error deviation; however the proportion controller does not guarantee a zero steady –state control error. The proportional controller is considered to be simple controller which is the best and can be used when nonzero steady state error is acceptable or if the controlled system contains pure integrator. Generally, it is used in pressure control or level control.

Proportional Integral (PI) control:

PI is the most used controller. The tuning consists of a PI-controller the finding the dynamic characteristics called ‘ultimate gain’ (K_u) and ‘ultimate period’ (P_u). A step disturbance is introduced, and the gain of controller in P mode is slowly increased. The value where sustained bounded oscillations appear designates the ultimate gain (K_u). The ultimate period (P_u) can be measured directly (Alexandre, 2003).

Proportional plus Integral plus Derivative (PID) control:

The PID controller has three adjustable parameters K_c , t_I , t_D which define Proportional (P) integral (I) derivative (D) actions. The most important is the controller gain K_c . Higher gain gives faster response, but also more oscillatory behaviour. P-controller has always a steady state error. The error is reduced by integration over a time t_I known as reset time. The derivative component may be consider for faster response, the parameter t_D being known as rate time (Alexandre, 2003).

The objectives of this study were to design a control system for production of VC, determine the stability of the control loops and tune and simulate the process in each loop.

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Materials and Methods:

Modeling of the system:

The first step in the control design process is to develop appropriate mathematical models of the system derived either from physical laws or experimental data.

System stability and tuning:

Mathematical models of the system have been obtained in transfer functions form, and then these models can be analyzed to predict how the system will respond in both the time and frequency domains, the stability of a linear system can be determined by an analysis of the roots

of the characteristic equation from the differential equation describing the process (which corresponds to the roots of the denominator of the transfer function) (Dale and Stephen, 2009). To ensure a good performance of the system, each of the control loops should be analyzed for the stability, separately. For the present work, four methods have been used to check the stability of the system. Those methods are:

- Routh Hurwitz.
- Root Locus plot.
- Bode plot.
- Direct Substitution Analysis.

MATLAB Software:

MATLAB is integrated technical computing environment that combines numeric computation, advanced graphical and visualization, and high level programming language. The MATLAB software was originally developed to matrix laboratory. Its capabilities have expanded greatly in recent years and today it was a leading tool for engineering concepts in mathematics. Being able to plot mathematical functions and data MATLAB, can be used in research development and industry. It was used in this research for tuning through different tuning (Bela, 1995).

Tuning controllers

Tuning means setting the adjustable parameters (proportional band/gain, integral gain/reset, derivative gain/rate) of a controller to give best performance. For the PID controller.

Results and Discussions:

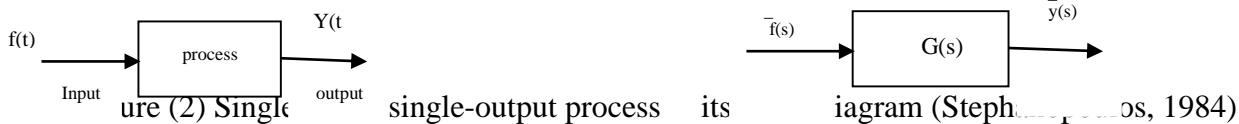
The principle of conservation of a quantity S state that:

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$$\frac{\text{accumulation of } S \text{ within a system}}{\text{time period}} = \frac{\text{flow of } S \text{ in the system}}{\text{time period}} - \frac{\text{flow of } S \text{ out of the system}}{\text{time period}} + \frac{\text{amount of } S \text{ generated within the system}}{\text{time period}} - \frac{\text{amount of } S \text{ consumed within the system}}{\text{time period}}$$

The quantity S can be any of the following fundamental quantity:

- Total mass
- Total energy
- Transfer function of the process
- Mass of individual component
- Momentum



Control Strategy for the system:

A control strategy was developed as shown in figure (2):

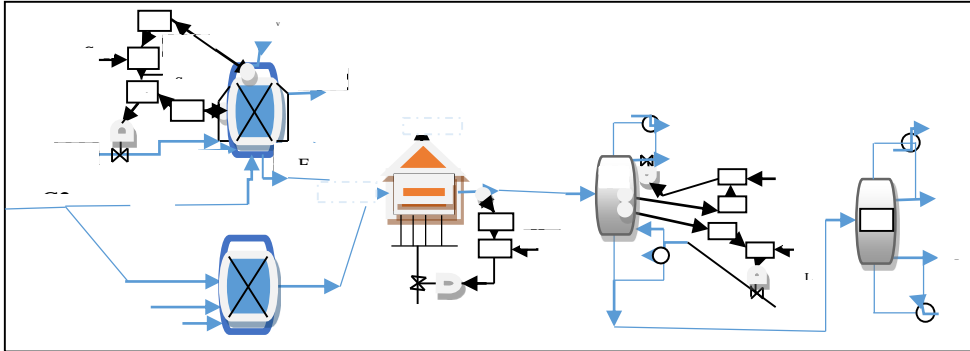


Figure (4) Control strategy of loop1
Reduction of the cascade block diagrams:
The inner loop (secondary loop):

$$G(s) = \frac{\pi f}{1+\pi l} \dots\dots\dots 1$$

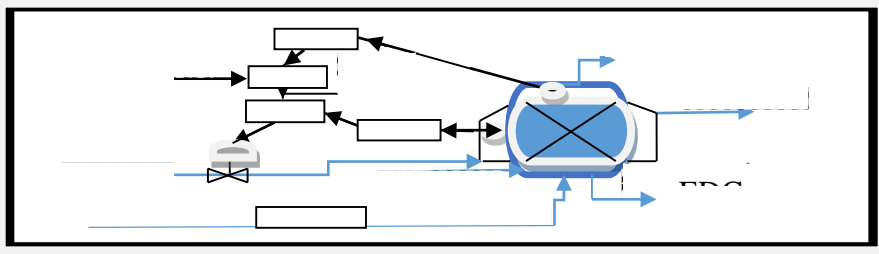
$$\Pi f = Gc2 Gv Gp2 \dots\dots\dots 2$$

$$1+\pi l = 1+ Gc2 Gv Gp2 Gm2 \dots\dots\dots 3$$

$$G(s) = \frac{Gc2 Gv Gp2}{1+ Gc2 Gv Gp2 Gm2} \dots\dots\dots$$

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Figure (3) Control strategy of the process



.4

The characteristic equation of the inner loop:

$$1 + G_{c2} G_v G_{p2} G_{m2} = 0 \dots \dots \dots 5$$

Transfer Functions identification of loop1:

$$G_{c1} = K_{c1}$$

$$G_{c2} = K_{c2}$$

$$G_v = \frac{1}{(0.3s+1)}$$

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$$G_{p2} = \frac{0.4}{(1.5s+1)}$$

$$G_{p1} = \frac{1}{(s+1)(0.1s+1)}$$

$$G_{m1} = 1$$

$$G_{m2} = \frac{1}{(0.15s+1)}$$

Block diagram of loop1, in Cascade advance system

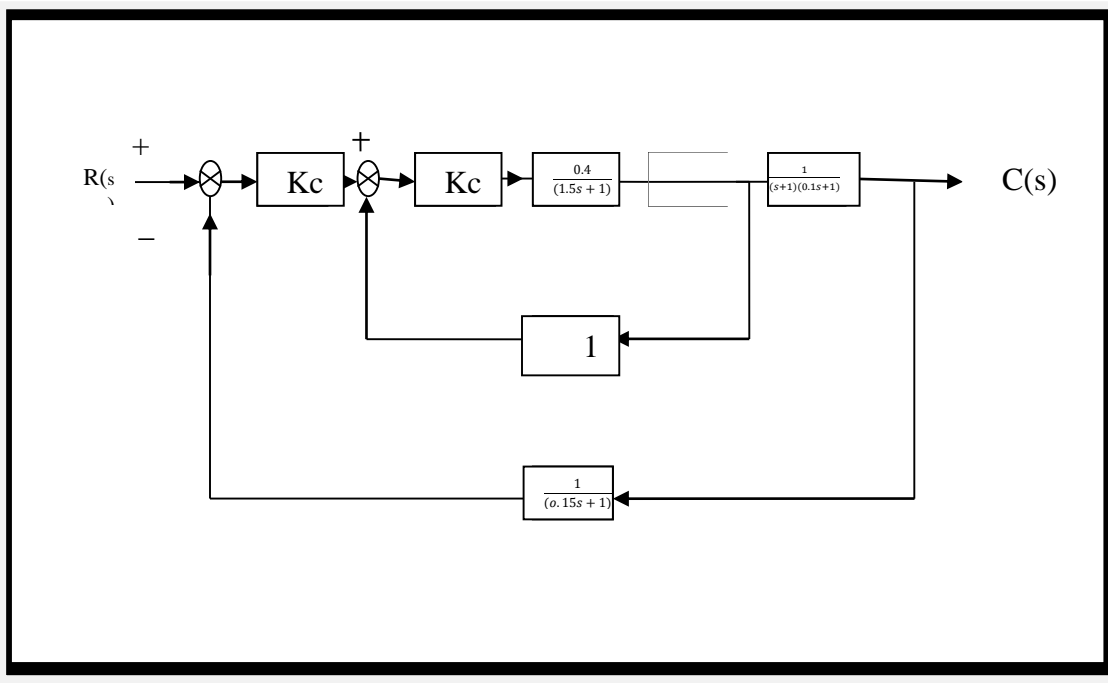


Figure (5) Block diagram of the cascade

The above figure was reduced to a single loop and the Open Loop Transfer Function (OLTF) , the Characteristic equation and the Overall Transfer Function were obtained, these GR=

$$OLTF = \frac{0.4Kc2}{(0.3s+1)(1.5s+1)(0.15s+1)} \dots\dots\dots 6$$

The Characteristic equation is:

$$0.0675s^3 + 0.72s^2 + 1.95s + (1 + 0.4K_{c2}) = 0 \dots\dots\dots 7$$

Determination of tuning ultimate parameters:

1. Using Routh Hurwitz and Direct Substitution:

$$\begin{bmatrix} 0.0675 & 1.95 \\ 0.72 & 1 + 0.4kc2 \\ 0.0375kc2 - 1.86 & 0 \\ 1 + 0.4K_c2 & 0 \end{bmatrix}$$

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For the system to be critically stable the row number n is equal to zero:

$$0.0375kc2 - 1.86 = 0 \dots\dots\dots 8$$

$$K_{c2} = \frac{1.86}{0.0375} = 49.6 \dots\dots\dots 9$$

The ultimate gain, $K_u=49.6$

To determine ω_{co}

Taking the auxiliary equation:

$$0.72s^2 + (1 + 0.4K_{c2}) = 0 \dots\dots\dots 10$$

$$0.72s^2 + (1 + 0.4 * 49.6) = 0 \dots\dots\dots 11$$

$$0.72s^2 + (20.84) = 0 \dots\dots\dots 12$$

$$0.72s^2 = -(20.84) \dots\dots\dots 13$$

Set $s = i\omega$

$$-0.72\omega^2 = -(20.84) \dots\dots\dots 14$$

$$\omega_{co} = 5.38rad/sec$$

Therefore

$$pu = 2\pi/\omega_{co} \dots\dots\dots 15$$

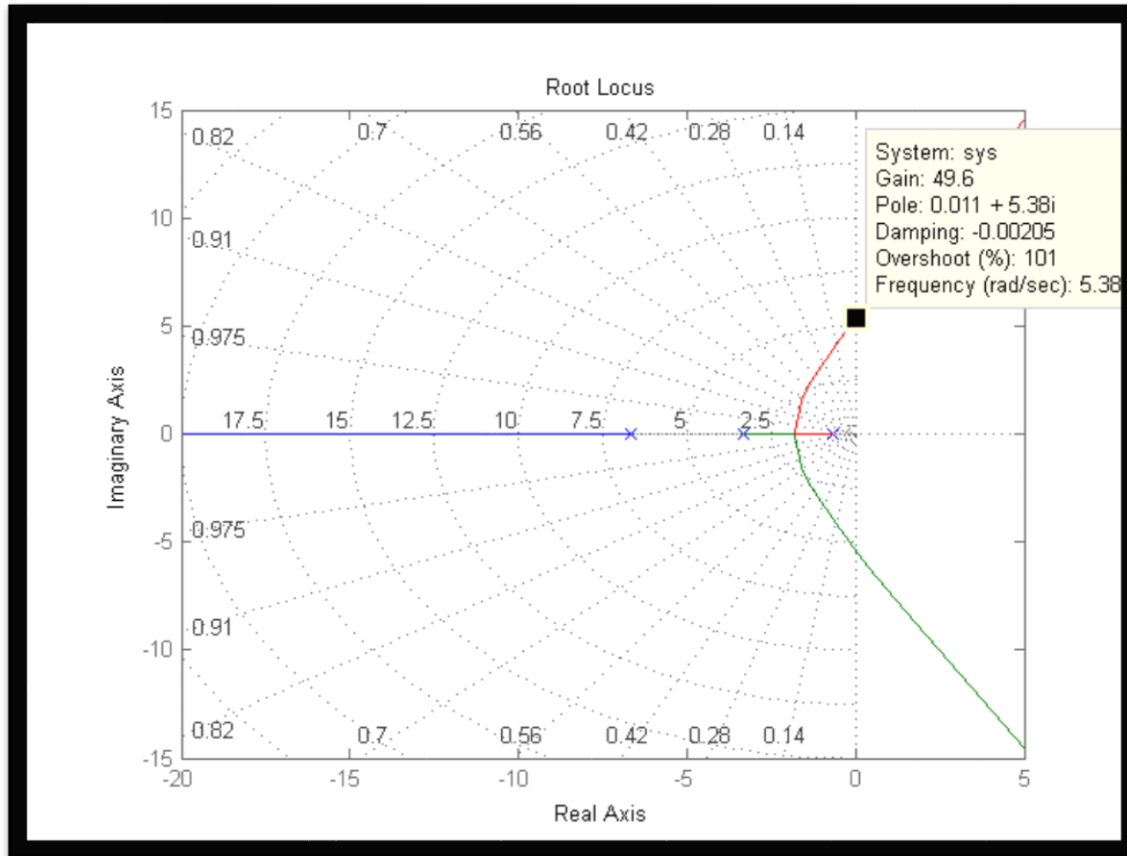
$$pu = 1.17 \text{ sec}$$

2.using root locus for the secondry loop:

$$OLTF = \frac{0.4Kc2}{(0.3s+1)(1.5s+1)(0.15s+1)} \dots\dots\dots 16$$

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Solving by MATLAB



Figure(6): Root Locous analysis for secondary loop

$$\omega_{co} = 5.38 \frac{rad}{s}$$

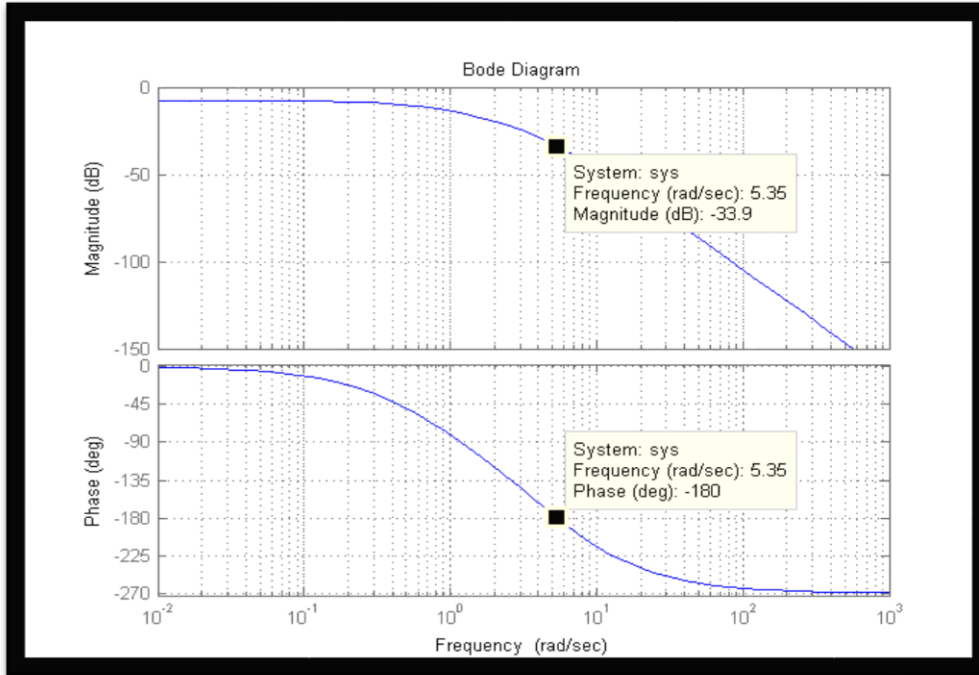
$$K_u = 49.6$$

$$P_u = \frac{2\pi}{\omega_{co}} = \frac{2 * 3.14}{5.38} = 1.17 \dots\dots\dots 17$$

Using Bode plot method:

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Solving by MATLAB



Figure(7) Bode plot for secondary loop.

$$\omega_{co} = 5.35 \frac{rad}{sec}$$

$$AR = 1$$

$$AR = \frac{K_1 K_2 \dots K_n}{\sqrt{1+(\omega\tau_1)^2} \cdot \sqrt{1+(\omega\tau_2)^2} \cdot \sqrt{1+(\omega\tau_3)^2}} \dots\dots\dots 18$$

$$G_s = \frac{0.4Kc2(0.15s+1)}{(0.3s+1)(1.5s+1)(0.15s+1)+0.4kc2} \dots\dots\dots 19$$

$$\therefore Kc2 = 49.01$$

$$\therefore Ku = 49.01$$

$$P_u = \frac{2\pi}{\omega_{co}} = \frac{2 \cdot 3.14}{5.35} = 1.17 \dots\dots\dots 20$$

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3.2.4 Average value for (ku and pu)from the three methods:

$$ku = \frac{ku1+ku2+ku3}{3} \dots\dots\dots 21$$

$$ku = \frac{49.6+49.6+49.6}{3} = 49.4 \dots\dots\dots 22$$

$$pu = \frac{pu1+pu2+pu3}{3} \dots\dots\dots 23$$

$$pu = \frac{1.17+1.17+1.17}{3} = 1.17 \dots\dots\dots 24$$

Determination of the adjustable parameters using Z-N.

Table (1) Ziegler-Nichols adjustable controller parameters for composition control loop for average value .

Type of controller	Kc	$\tau_i(min)$	$\tau_D(min)$
P	24.7	-	-
PI	22.23	0.975	-
PID	29.64	0.585	0.1463

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$K_c = 24.7$ Substituting for the valve of, $K_u = 49.4$ for P-action:

$$0.0675s^3 + 0.72s^2 + 1.95s + (1 + 0.4K_c) = 0 \dots\dots\dots 25$$

Simulation of the Cascade system using the reduced block diagram

The closed loop transfer function

$$G_s = \frac{0.4K_c2(0.15s+1)}{(0.3s+1)(1.5s+1)(0.15s+1)+0.4kc2} \dots\dots\dots 26$$

$$G_s = \frac{0.4*24.7(0.15s+1)}{(0.3s+1)(1.5s+1)(0.15s+1)+0.4*24.7} \dots\dots\dots 27$$

$$G_s = \frac{1.48s+9.88}{0.0675s^3+0.72s^2+1.95s+10.88} \dots\dots\dots 28$$

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Using MATLAB

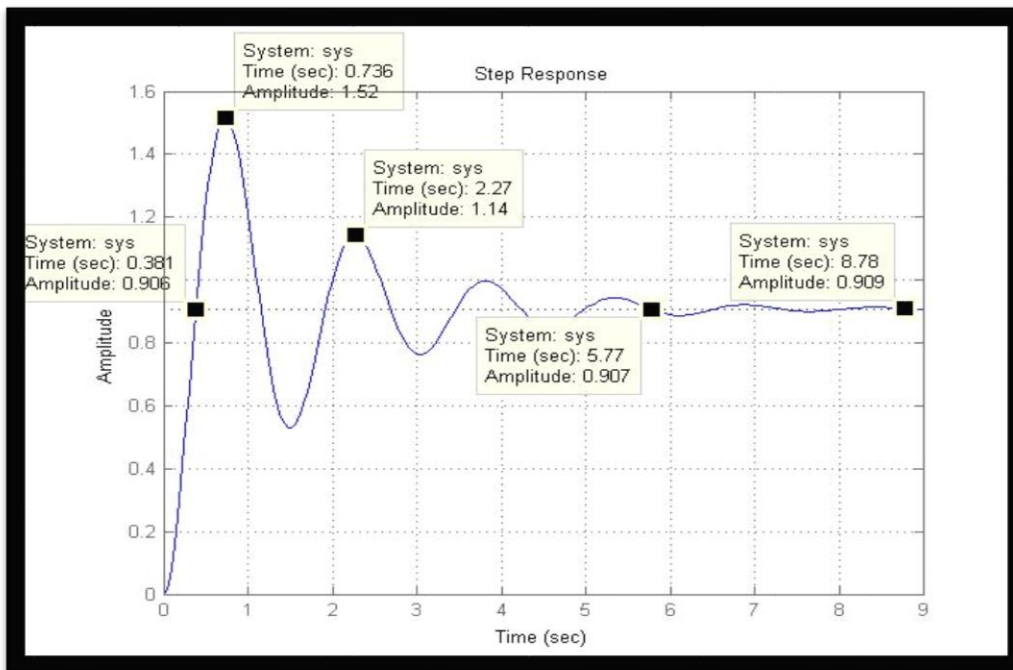


Figure (8) Simulation of the system using proportional controller (p-only)

Table (2) Characteristic parameter for the loops:

Characteristic	The Cascade (secondary loop) loop 1	The Cascade (primary loop) loop 1	loop 2	loop 3	loop4
Peak amplitude	1.52	0.455	0.877	1.25	1.24
Over shoot	0.906	0.398	0.576	0.804	0.804
Settling time (sec)	5.77	11.55	22.6	34.6	18.4

Rise time (sec)	0.381	0.973	2.16	3.39	1.51
Final value	0.909	0.405	0.575	0.817	0.803
Period of oscillation	1.53	10.53	20.44	31.21	17.59
Decay ratio	1.678	1.168	1.5399	1.55	1.542
Offset	-0.09	-0.11	-0.4	-0.18	-0.19

The same procedure was repeated for loop2, 3, and 4 with the simulation results in the table above.

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Discussion:

The flow sheet of the production of VC from EDC was drawn and from which the control strategy were developed as shown in figure (3).

The transfer functions for each element were cited from the literature (Stephanopoulos, 1984) and the block diagram was drawn putting each transfer function in its block. Then over all transfer functions and consequently the characteristic equation were developed. The Hurwitz and the direct substitution method to obtain characteristic equation was used by Routh the ultimate gain and period.

The open loop transfer function was used in Root locus and Bode methods to obtain the ultimate gain and period. The average value of ultimate gain and period were used and inserted in Ziegler – Nichols tuning table to get the adjustable parameters K_c , τ_I and τ_D . These were used to plot the response from which (Peak amplitude, Over shoot, Settling time, Rise time, Final value and Period of oscillation) were obtained as shown in table (2). Thus the design was completely analyzed and the control system was expected to work properly.

Conclusions:

Since the manufacture of VC is important in the petrochemical industry so its quality need to be controlled, the reaction is exothermic and the temperature was controlled to the optimum temperature which introduced as the set point. The three methods of Routh, Root locus and Bode were performed and gave the same tuning parameters, however the average was taken to give more precise and correct results and the responses obtained simulate the system with (Rise time, Peak amplitude, over shoot, Settling time, Final value and Period of oscillation).

Recommendations:

In order to control the temperature fluctuation, a cascade control is to be used in each of the three methods of tuning Routh, Root locus and Bode. This will give very reliable results. And the tuning analysis carried out by the conventional three methods is to be made in digital PLC and SCADA systems.

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استراتيجية التحكم في كلوريد الفينيل المنتج من ثنائي كلوريد الايثيلين

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الملخص

يتم تحضير كلوريد الفينيل (VC) من ثنائي كلوريد الايثيلين (EDC). حيث طورت استراتيجية تحكم لهذه العملية بواسطة مخطط انسيابي يتألف من مفاعلين احدهما للكلورة المباشرة والآخر للكلورة بالأكسجين وفرن للتكسير الحراري وعمودي فصل. أخذت كل حلقة تحكم على حدة وتم تطوير دالة نقلها، ثم اقترحت معادلة مميزة واستعملت في مصفوفة راوث لإيجاد المكسب النهائي (Ku) وفترة النهاية (Pu) من خلال الاستبدال المباشر. بعد ذلك طورت دالة نقل الحلقة المفتوحة لكل حلقة واستعملت في طرق تحليل روت لو كس وخطة بودي باستخدام تنسيق ماتلاب. المكسب النهائي والفترة النهائية بواسطة الاساليب الثلاثة استخدمت لإيجاد متوسط القيم التي وضعت في جدول زيغلر-نيكولاس للحصول على المعاملات القابلة للتعديل، يذكر ان تصنيع كلوريد الفينيل مهم في صناعة البتروكيماويات ويحتاج لضبط جودته، تفاعل التكسير الحراري طارد للحرارة فضبطت درجة الحرارة المثلي. طرق التحليل الثلاث راوث و روت لو كس وبودي اعطت تقريبا نفس نتائج التحليل، أخذ المتوسط للحصول على أدق وأصح القيم. الاستجابة اعطت محاكاة النظام ل(زمن الصعود، اتساع القمة، زمن الهبوط، القيمة النهائية وزمن التذبذب). والتي اخيرا اختيرت لاختبار استقرار النظام النتيجة كانت ان جميع الانظمة مستقرة وهو المتوقع عند استخدام قيمة KC بعد الضبط.