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PRODUCTION AND CONTROL OF SODIUM DICHROMATE FROM CHROMITE ORE

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ABSTRACT

Sodium chromate and dichromate are the most important chromium products, used chiefly for manufacturing chromic acid and chromium pigments used in leather tanning and corrosion control. Chromite is crushed, roasted with soda ash to produce sodium chromate. Sodium chromate are to be reacted with concentrated sulphuric acid to produce sodium dichromate. The two reactions will be investigated, designed and controlled. The control strategy was developed to control of their actor, the block diagram of the system was constructed and the process transfer function was identified using MATLAB Black Box model. Then the overall transfer function, the closed-loop, and the characteristic equation was determined, and the control system was tuned to obtain the adjustable parameters using Routh-Hurwitz, Direct Substitution, Root locus, and Bode methods. The adjustable parameters were appropriately inserted into the characteristic equation for the stability analysis and response simulation. It is found that using of PI- controller for the Primary loop provides the lowest overshoot than P and PID controllers.

KEYWORDS: Production and Control of Sodium Dichromate.

1. INTRODUCTION

500kg of chromite was crushed and entered the roaster with sodium carbonate to produce chromate by the reaction:

$$2Cr_2O_3 + 4Na_2CO_3 + 3O_2 \rightarrow 4Na_2Cr\,O_4 + 4CO_2 \text{ (1)}$$

The produced chromate entered CSTR reactor with a sulfuric acid (98%) to produce dichromate by the reaction:

$$2Na_2Cr\,O_4 + H_2SO_4 \rightarrow Na_2Cr_2O_7 + Na_2SO_4 + H_2O \text{ (2)}$$

The dichromate is then entered the evaporator to increase the concentration of the dichromate from (80% to 85%) and followed by entering the spray dryer to produce the dichromate (powder) with concentration 85 %.[2]

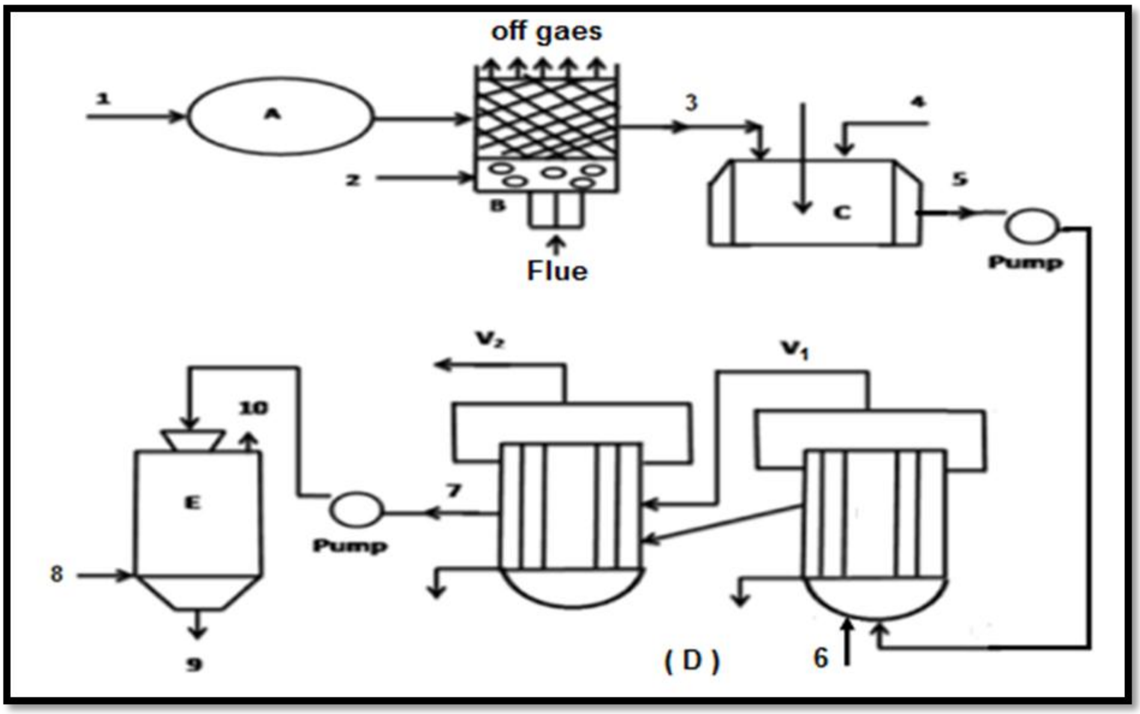

Figure 1: Flow diagram for production of dichromate.

1.1 Process Details

- Equipment

A- Crusher, B- Roaster, C- CSTR reactor,

D- Double effect evaporator, E- Spray dryer,

- Streams

1- Chromite, 2- Sodium carbonate (Na_2CO_3), 3- Chromate, 4- Sulfuric acid (H_2SO_4), 5- Dichromate, 6- Steam, 7- Dichromate (85%), 8- Air in, 9- Dichromate (powder),10- Air out.

There are four objectives of this study, to design the chromate and dichromate reactors, to develop a control strategy for the manufacturing of sodium dichromate, to analyse, make stability analysis, tuning and simulation of the control system, and to selection of the appropriate controller for each loop.

2. MATERIALS AND METHODOLOGY

System Control, Tuning, and Stability analysis .A control strategy was developed as shown in figure below, the block diagrams were constructed, the transfer functions were identified using System Identification Toolbox in MATLAB and the characteristic equations were obtained. These characteristic equations are used for tuning, stability analysis and simulation responses using Routh-Hurwitz, Direct Substitution, Root locus and Bode methods.[3]

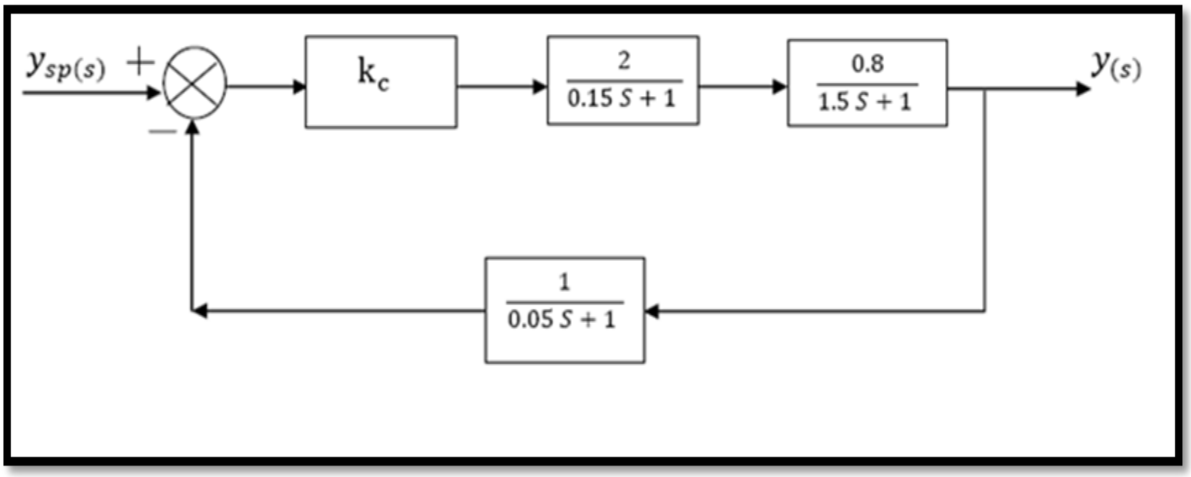

Figure 2: The block diagram for P-only.

The characteristic equation:

$0.1125s^3 + 3.075s^2 + 17s + 10 + 16\,k_c = 0$ (3)

3. RESULT AND DISCUSSION

Design, stability, tuning and simulation Using MATLAB:

Table 1: The design of CSTR.

No	Specified	Symbol	Value
1	Total volumetric flow rate	V_r	0.25 m^3/h
2	Volume of the reactor	V_t	98.1 m^3
3	Diameter of the reactor	D	3.5 m
4	Actual diameter	D_{ac}	4.33 m
5	Height of the reactor	h	10.4 m
6	Actual height	h_{ac}	13 m
7	Thickness	t	10mm

Table 2: The design of spray dryer.

No.	Specified	Symbol	Value
1	Volume of spray dryer	V	506.87m^3
2	Chamber diameter	D	4.08m
3	Height of conical section	Hcon	3.5m
4	Height of cylindrical section	Hcyl	8.16m
5	Total height of chamber	H_t	11.66m
6	Cone angle of conical section	-	60^o
7	Material of construction	Stainless Steel	

- For P-Controller Using

(i) Routh-Hurwitz method

Putting the characteristic equation into Routh array:

Number of rows =3 + 1 = 4

Rows	Coefficients
s^3	0.1125 17
s^2	3.075 10 + 16 k_c
s^1	b_1 0
s^0	10 + 16 k_c 0

$$b_1 = \frac{(3.075*17)-(0.1125*(10+16kc))}{3.075} = \frac{52.275-1.125-1.8kc}{3.075}$$

b_1 =16.63 – 0.59 k_c

To get the ultimate gain, let:

16.63 – 0.59 k_u= 0 $\longrightarrow$ k_u = 28.2

This is ultimate gain: k_u = 28.2

$$P_u = \frac{2\Pi}{\omega co} = \frac{2\Pi}{12.3} = 0.51 \text{ sec}$$

(ii) Direct substitution method

-Set s = iω in the characteristic equastion

$0.1125(i\omega)^3 + 3.075(i\omega)^2 + 17(i\omega) + 10 + 16\ k_c = 0$

Taking the imaginary part: $-0.1125\omega^3 + 17\omega = 0$

$\omega = \sqrt{\frac{17}{0.1125}} = 12.3$ rad/sec

Taking the real part and substitute the value of cross over frequency

$-3.075\omega^2 + 10 + 16\ k_u = 0$

$K_u = 28.5$

$P_u = \frac{2\Pi}{\omega co} = \frac{2\Pi}{12.3} = 0.51$ sec

(iii) Root-locus and MATLAB

$$\text{OLTF} = \frac{16\ kc}{0.1125s3 + 3.075s2 + 17s + 10}$$

MATLAB format

```
>> num=[16];
>>den=[0.1125 3.075 17 10];
>>rlocus(num,den)
```

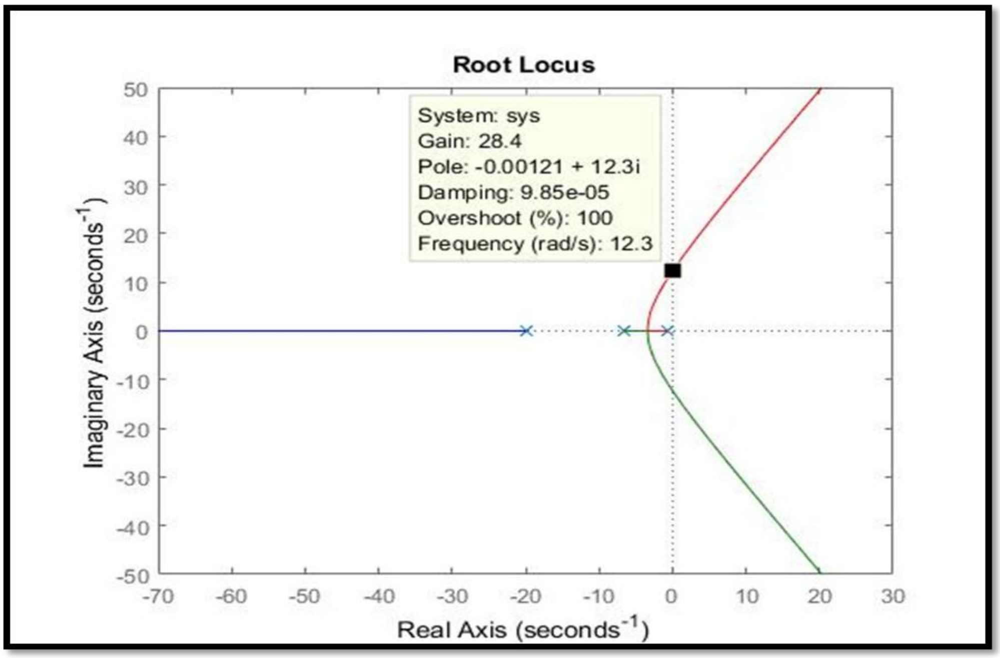

Figure-3.

From the figure

$K_u = 28.4$ $\omega_{co} = 12.3$ rad/sec

$P_u = \frac{2\Pi}{\omega co} = \frac{2\Pi}{12.3} = 0.51$ sec

(vi) Bode plot and MATLAB

$$OLTF = \frac{16\ kc}{0.1125s3 + 3.075s2 + 17s + 10}$$

MATLAB format

```
>> num=[16];
>>den=[0.1125 3.075 17 10];
>>bode(num,den),grid
```

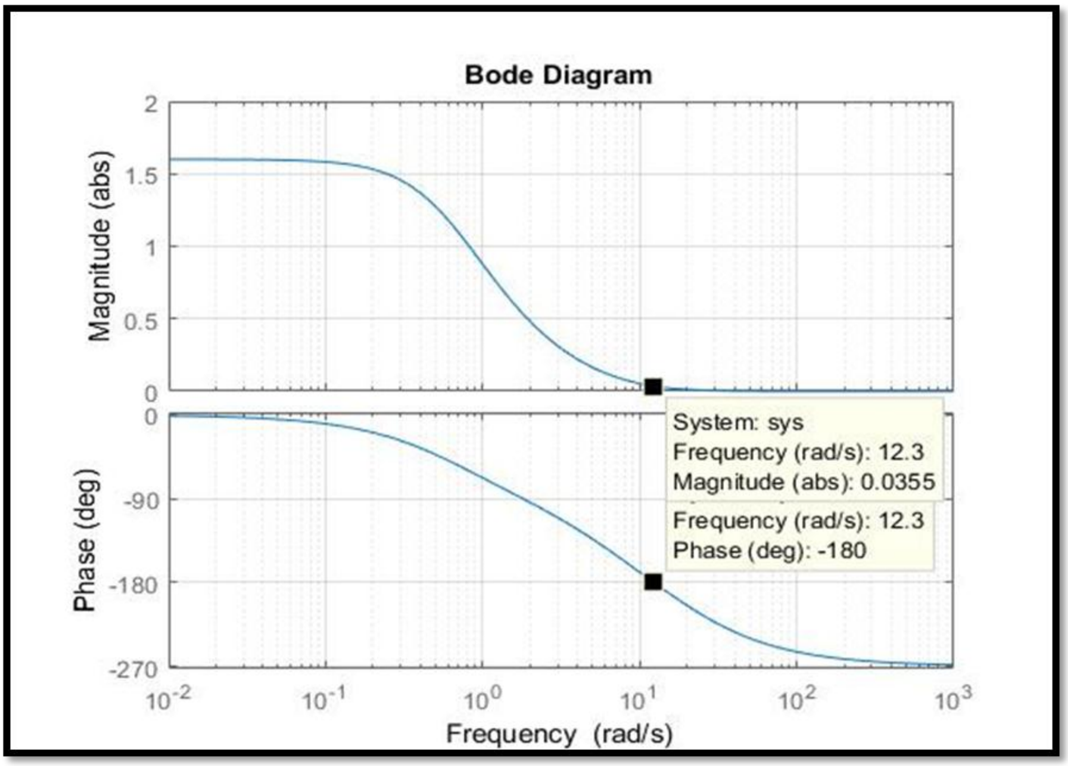

Figure 4: The Bode Diagram.

-From the figure at (-180) and the phase angle curve read the cross-over frequency

$\omega_{co} = 12.3$ rad/sec

$P_u = \frac{2\Pi}{\omega co} = \frac{2\Pi}{12.3} = 0.51$ sec

From the figure

AR = 0.0355

$k_{u4} = \frac{1}{AR} = = \frac{1}{0.0355} = 28.17$

Simulation

$k_{u,average} = \frac{ku1 + ku2 + ku3 + ku4}{4} = \frac{28.2+28.5+28.4+28.17}{4} = 28.32$

$P_{u,average} = = \frac{Pu1 + Pu2 + Pu3 + pu4}{4} = \frac{0.51+0.51+0.51+.51}{4} = 0.51$ rad/sec

Ziegler-Nichols tuning

The following is Z-N tuning table

Table 4: Z-N tuning parameters.

Type of controller	k_c	τ_I	τ_D
P	$0.5k_u$	-	-
PI	$0.45k_u$	$P_u/1.2$	-
PID	$0.6k_u$	$P_u/2$	$P_u/8$

-From P-Controller

$k_c = 14.16$

$$G(s) = \frac{22.656+1.133\,s}{0.01125s3 + 0.3075s2 + 1.7s + 23.656}$$

-For PI-Controller

$k_c= 12.744$

$$G(s) = \frac{20.39+1.0195\,s}{0.01125s3 + 0.3075s2 + 1.7s + 21.39}$$

-For PID-Controller

$k_c = 16.992$

$$G(s) = \frac{27.187+1.359\,s}{0.01125s3 + 0.3075s2 + 1.7s + 28.187}$$

MATLAB is used to plot the step response from the closed loop transfer function

MATLAB format

```
>>num=[1.133 22.656];
>>den[0.01125 0.3075 1.7 23.656];
```

```
>>tf(num,den)
>>step(tf)
Hold
>>num=[1.0195 20.39];
>>den[0.01125 0.3075 1.7 21.39];
>>tf(num,den)
>>step(tf)
>>num=[1.359 27.187];
>>den[0.01125 0.3075 1.7 28.187];
>>tf(num,den)
>>step(tf)
```

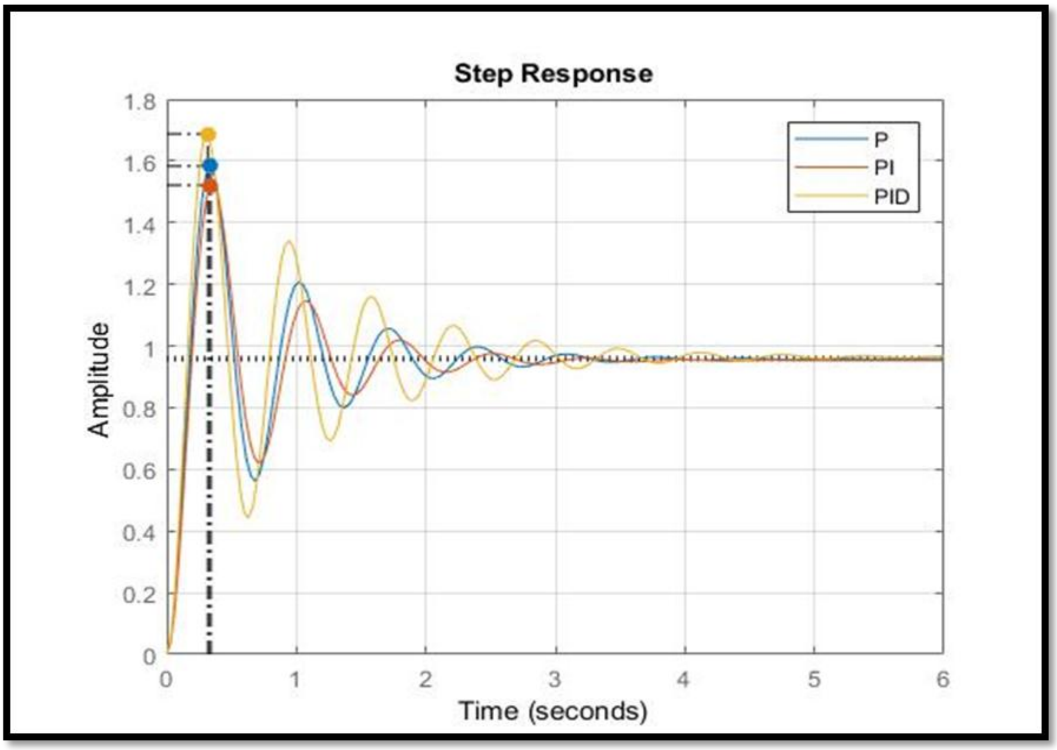

Figure 5: The step response from the closed loop.

Table 5: The over-shoot for all type of controller.

Control Method	Over-shoot(%)
P-Controller	65.3
PI-Controller	59.6
PID-Controller	75.0

-Selection of the control

From table above we select PI-Controller.[4]

4. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This study concluded for the following points:

1- Production of sodium dichromate can successfully be produced from chromite ore available in ingassana mountain.

2- The sodium dichromate can be used as liquid or it may be spray dried and used as powder.

Recommendations

From the above, the following improvements are recommended:

1- To improve the tanning factories and benefit from the availability of chromite ore in sudan to improve the country's economy.

2- To stop exporting chromite ore and use it locally.

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