

Simulation Control of Crude Oil Desalter of Khartoum Refinery

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Abstract

Desalting unit of crude oil is required to reduce salts content in the crude to an acceptable value. Then the control technique is required to change the desalting process properly in order to eliminate the unfavorable effect of the disturbances which is reflected on the amount of salts that existed in the desalted crude. The concentration of calcium salts that exist in the crude oil of Khartoum refinery is about 450 – 600 ppm to be reduced to about 11 ppm, hence different control mechanisms were proposed for controlling the concentration of calcium salts in the desalted crude oil of Khartoum refinery. The flow rate of decalcium agent (decalciner) was used to manipulate the deviation in concentration from the set point, then the mathematical model was determined using Matlab software and the transfer function was estimated using system identification tool box. Simulink feature of Matlab was used to draw the control loop and the optimum settings of controller parameters were estimated by tuning the controller under PID-action, P-action, and PI-action, using two different methods, which are PID tuner method and Ziegler-Nichols (Z-N) tuning method. These settings were used for overshoot and peak deviation investigation, then the response curve was drawn for three types of controller and the proportional integral derivative controller (PID Controller) results in highest value of controller gain lowest overshoot and peak deviation, and shortest settling time. Root Locus Niquist and bode criteria were used to investigate the system stability and the last two methods result in stable system. Another mechanism for concentration control using the flow rate of the inlet water as manipulated variable was proposed, the results were compared with that obtained from the flowrate of decalciner, and the decalciner flow rate gave better results than the inlet water flow rate.

Key words-Desalting unit, system identification, controller parameters, system stability, controller tuning

I. INTRODUCTION

Crude oil is surrounded by a film of iron sulfites and asphaltenes, which prevent the droplets of water from combining together and settling down. These droplets represent a suitable environment for salts dissolving. The dissolved salts have a significant effect on the refining process such as fouling and corrosion of equipment, decomposition of the mineral chlorides to hydrochloric acid at high temperature, hydrochloric acid is considered to be highly corrosive when water is presence, in addition to the presence of the less decomposable and stable salts such as magnesium, calcium, and Sodium chlorides.[1] Water is separated from crude by using electrostatic separation in combination with dehydration and gravity. To remove salts from crude oil, the water-in oil emulsion has to be cracked to produce continuous water phase which is separated in decanting process.[2] The desalting process consists of the following steps:

- 1) Washing step: At this stage the crude oil is mixed with water to enable distributing and dissolving the salts in water, and hence tiny droplets of water are produced, by adding the demulsifying agents the emulsion will be broken and the asphaltenes will be removed from the droplets surface.[3]
- 2) Heating step: The separation of oil and water is highly affected by the physical properties of the oil mainly the density and viscosity, then at this stage the crude oil is heated to about 48.9–54.4 °C.
- 3) Coalescence step: At this step large droplets of water are produced in order to be settled by gravity, because

the droplets that produced at the first step are very fine with 1-10 μm in diameter that is hard to be settle by gravity.[3] This process is achieved by using agitation and electrostatic field between two electrodes, the water droplets will be ionized, oriented and then collected together. The main components of the desalter are the metal electrodes (two), where high voltage is applied between them. By using desalting process 90% of salts can be removed from the crude before further treatment. The objective of the controller in chemical processes is to reduce and reject the external loads. Then the control technique is required to change the desalting process properly in order to eliminate the unfavorable effect of the disturbances. Tuning the controller is a difficult process, and any insufficiency in controller settings represents a major problem in plant operation. The tuning plays an essential role to ensure that the plant's performance satisfies the objectives of the operation. The controller settings must be chosen to ensure a stable response of the controlled variable by rejecting the disturbance, or quickly moving to a new set point.

II. METHODOLOGY

The concentration to be controlled in the desalter of CDU unit at Khartoum Refinery is the concentration of calcium salt, so different systems were proposed for feedback control. Controlling the concentration of calcium in the desalted crude oil by manipulating the inlet flowrate of water. Controlling the

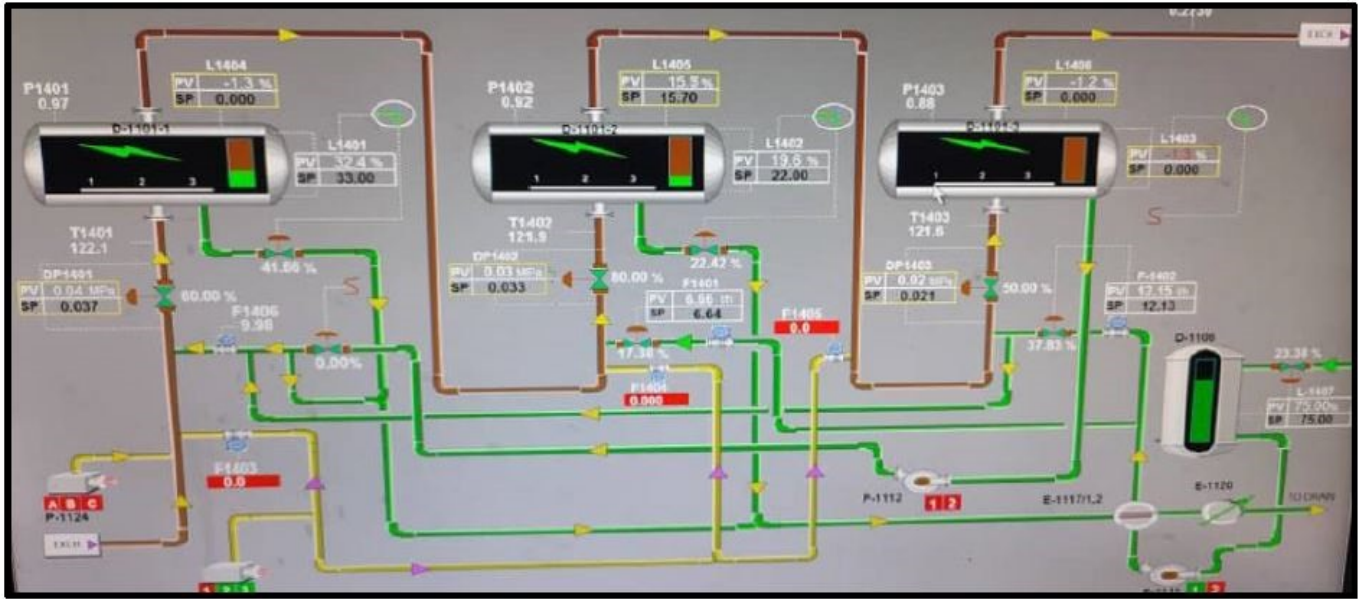


Fig. 1: Crude oil desalter of Khartoum Refinery.

concentration of calcium in the desalted crude oil by manipulating the flowrate of de-calcinizer (CGE) were investigated and the optimal values identified.

A. Mathematical model building

MATLAB system identification tool box was used to build the mathematical model[4] by using the Graphical User Interface and hence the transfer functions were determined.[5] Padé approximation was applied so that the exponential terms in the transfer function was converted to the standard format.[6] The characteristic equation was obtained and feedback control system was proposed. [7]

B. Tuning of controller

Ziegler-Nichols (Z-N) tuning method and PID tuner method were used in order to determine the optimum settings of controller parameters. Ziegler-Nichols (Z-N) tuning method was applied in MATLAB using SIMULINK feature, the steps of this method are:[8]

- 1) Initially the system was run under proportional control only which is equivalent to setting τ_D equal to zero and τ_I equal to infinity.
- 2) Then step signal was introduced as excitation in the set point and the response was observed.
- 3) The controller gain was increased slowly until the cycles continue with constant amplitude, the period of these cycles (P_u) was obtained.
- 4) The controller settings K_c , τ_I , and τ_D were adjusted from Z-N table.

The system was tuned under proportional action controller, proportional integral action controller, and proportional integral derivative action controller, the results were compared and the best controller was chosen. PID tuner method was used to tune the controller gain automatically by using the Tune button

which required simulink control design. The performance of the system was obtained under P, PI and PID, for unit step signal in the desired value, the controller that resulted on the best performance was selected.

C. System stability

Three different criteria were used to investigate the system stability which are Root Locus, Niquist, and bode criteria.[9]

III. RESULTS AND DISCUSSION

Figure(2) below represents the GUI window, and hence the process transfer function for controlling the concentration of calcium in the desalted crude oil by manipulating the flowrate of de-calcinizer was obtained. The transfer function is:

$$Gp2(s) = \frac{-0.1691s + 0.3381}{0.5s^2 + 1.29S + 0.5795} \quad (1)$$

The negative sign in the transfer function represents the positive feedback with negative sign that inserted when the block diagram was constructed.

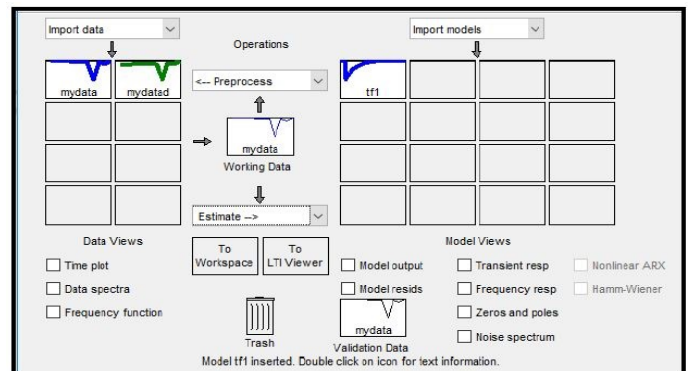


Fig. 2: transfer function identification[6]

A. Tuning using Ziegler-Nichols method:

Simulink was used to draw the control loop as shown in figure(3) below:

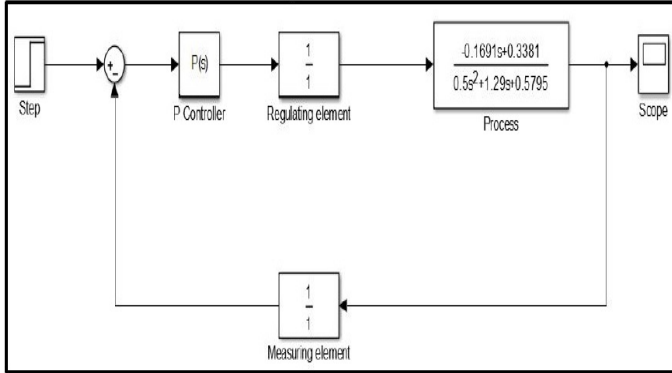


Fig. 3: control loop of crude oil de-salter tuned by P-controller manipulated by decalcinizer flow rate

B. Proportional controller

According to Ziegler-Nichols table the value of $K_c = 0.5 K_U$, hence $K_U = 7.63$ then $K_c = 3.815$ The overall transfer function is:

$$G4(s) = \frac{-0.6449s + 1.29}{0.5s^2 + 0.6448s + 1.869} \quad (2)$$

The resultant response curve for a unit step signal on the desired value was represented in figure(4) below:

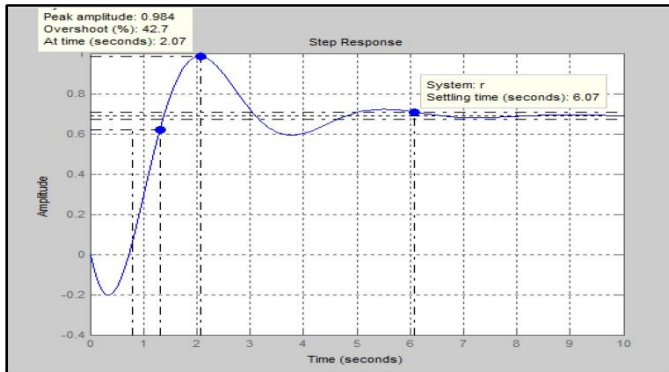


Fig. 4: response for P-controller manipulated by decalcinizer flow rate

C. Proportional integral controller

The integral and derivative actions were set to be zero and the loop is tuned using numerous trials of the gain K_c . According to Ziegler-Nichols table the value of $K_c = 0.45 K_U$ and $\tau_I = \frac{P_u}{1.2}$, $K_U = 7.63$ and $P_u = 2.6$ sec then $K_c = 3.434$ and $\tau_I = \frac{2.6}{1.2} = 2.167$ sec The overall transfer function after tuning became:

$$G5(s) = \frac{-1.258s^2 + 1.935s + 1.161}{1.083s^3 + 1.537s^2 + 3.191s + 1.161} \quad (3)$$

The resultant response curve for a unit step signal on the desired value was represented in figure(5)below:

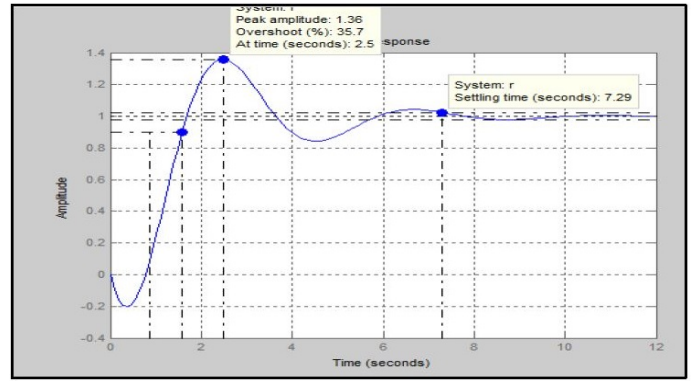


Fig. 5: response for proportional integral controller by manipulating decalcinizer flow rate

D. Proportional integral derivative controller

The integral and derivative actions were also set to be zero and the loop was tuned using numerous trials of the gain K_c . According to Ziegler-Nichols table the optimum settings of the controller were found to be: $K_c = 4.578$, $\tau_I = 1.3$ sec, and $\tau_D = 0.325$ sec The overall transfer function after tuning became:

$$G6(s) = \frac{-0.2477s^3 - 0.5111s^2 + 1.238s + 1.548}{0.4023s^3 + 1.166s^2 + 1.991s + 1.548} \quad (4)$$

The resultant response curve for a unit step signal on the desired value was represented in figure(6) below:

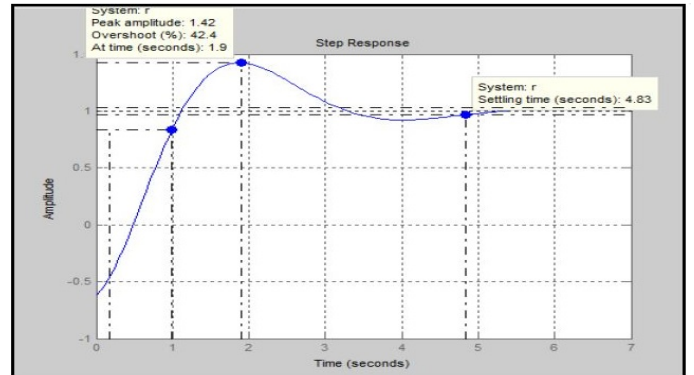


Fig. 6: response for proportional integral derivative controller manipulated by decalcinizer flow rate

E. Tuning using PID tuner

As seen from figure(4) and figure(7), the tuning results obtained using trial and error (Ziegler-Nichols method) and using PID tuner are so close, the trial and error results in higher gain of 3.815 but the PID tuner method results in lower overshoot of 39.9% and lower peak deviation of 0.955.

From figure(8) above $P = K_c = 3.3377$ and $I = 1/\tau_I = 0.475$, $\tau_I = 2.105$

From figure(9) above, $P = K_c = 4.01$ and $I = 1/\tau_I = 0.867$, $\tau_I = 1.153$, $D = \tau_D = 0.679$ It was being noticed that for PI controller and PID controller the trial and error (Ziegler-Nichols method) results in higher gain but also results in

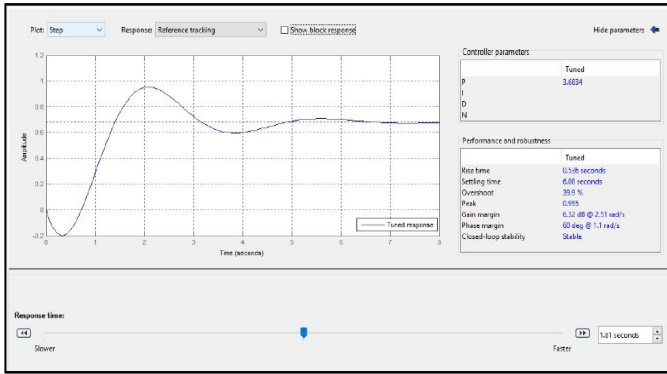


Fig. 7: response curve and controller parameter of PID tuner of proportional action manipulated by decalcinizer flow rate

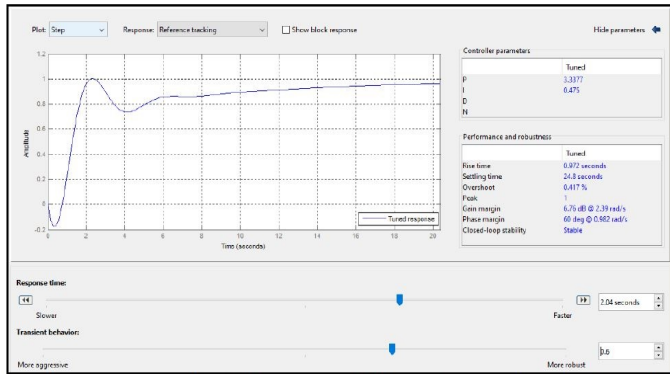


Fig. 8: response curve and controller parameter of PID tuner by manipulating decalcinizer flow rate assuming proportional integral action

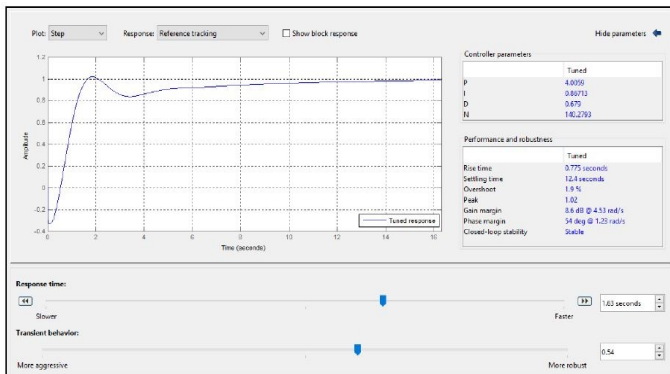


Fig. 9: response curve and controller parameter of PID tuner assuming proportional integral derivative action manipulated by decalcinizer flow rate

higher overshoot and peak deviation, so PID tuner method is much better and results in more accurate values P, PI, and PID controllers. In comparison between three types of controllers table(I) below summarize the values of controller parameters. From the previous results the proportional controller was excluded from comparison because it results in higher overshoot, if PI- controller and PID- controller were compared, it can be seen that PI-controller gave the lowest overshoot but higher

settling time. The addition of D- action to PID controller allowed to use higher value of the gain K_C , and increases the stability of the system and reduces the settling time even though the overshoot is a little higher than the PI- controller, hence PID- controller is chosen to control the concentration of calcium in the desalter. In comparison with the previous studies the method of PID tuner for tuning the controller gives more accurate results, because it implements the PID control algorithm and it include advanced features such as external setup, anti-windup and signal tracking which make the process of tuning much easier and more accurate.

TABLE I: Summary of parameters of the three controllers by manipulating decalcinizer flow rate

Controller	Gain (KC)	τI (sec)	τD (sec)	Overshoot (%)	Rise time (sec)	Settling time (sec)
P	3.683	-	-	39.9	0.536	6.08
PI	3.334	2.105	-	0.417	0.972	24.8
PID	4.01	1.153	0.679	1.9	0.779	12.4

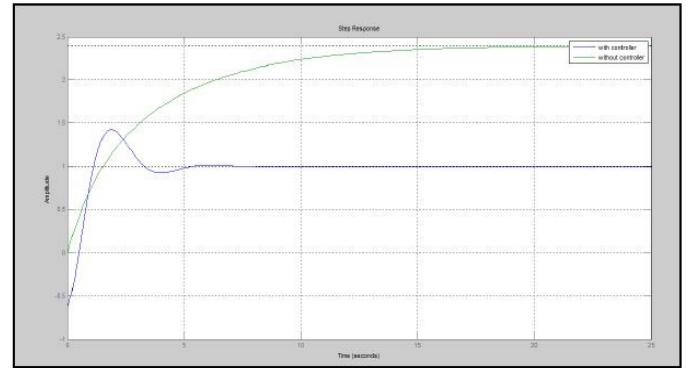


Fig. 10: the response curve with and without the use of controller

Figure(10) represents the effect of using controller to manipulate the deviation or the error when the system is subjected to external load, it can be seen that without the use of controller the response curve (green) drifts away from the stability line, and the system becomes unstable. The blue curve represents the manipulation using PID controller, where the system starts to oscillate around stability line, after a period of time the system recovers its stability.

F. System stability

Three different criteria were used to investigate the system stability, the results of each criterion are as follow:

1) *Root Locus criteria:* For the obtained transfer function root locus plot is in figure(11) as follow:

According to root locus criteria the system is stable until the gain reach the value of ultimate gain which is equal to 6.68 on the imaginary axis

2) *Nyquist criteria:* For the obtained transfer function nyquist plot is in the figure(12) below:

From figure(11) above, the plot neither passes nor encircled the point (-1), then according to nyquist criteria the system is stable.

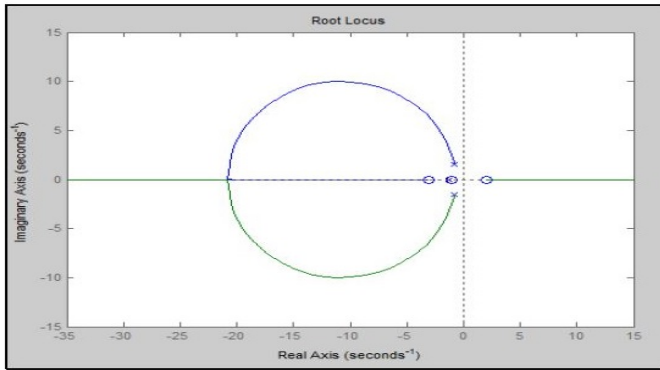


Fig. 11: Root Locus plot for concentration Control by manipulating decalcinizer flow rate

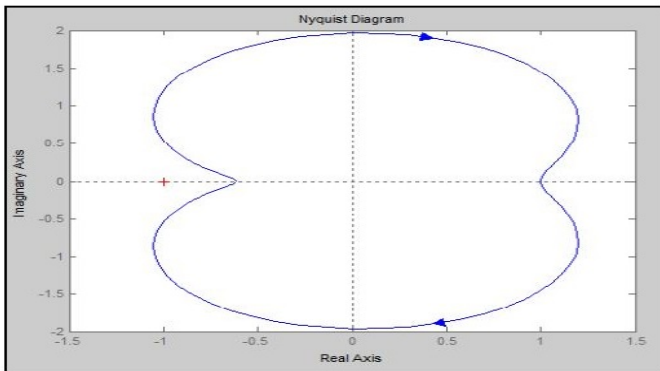


Fig. 12: Nyquist plot for concentration Control by manipulating decalcinizer flow rate

3) *Bode criteria:* For the obtained transfer function bode plot is in the figure(13) below:

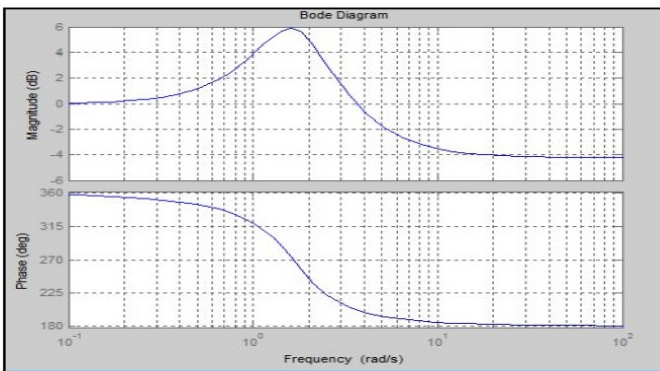


Fig. 13: Bode plot for concentration Control by manipulating decalcinizer flow rate

The system will be stable if the phase shift of bode plot does not reach (-180). In this case and according to bode criteria the system is stable

IV. CONCLUSION

The desalter in fractionation unit of Khartoum Refinery represents an important component of the unit because the

salts content of the crude affects the efficiency of refining operations and the quality of the products. Transfer function was identified using graphical user interphase based on the data collected from the desalter in Khartoum refinery. According to literatures the transfer function of concentration control in the desalter is of first order, in this study the time delay effect is included and the process transfer function become second order process. Different tuning methods were used to find the optimum settings of controller parameters. These are: Ziegler and Nichols method, automatic tuning using PID tuner. Then the dynamic performance of the system was investigated, and PID-Controller was chosen for controlling calcium salts. Several stability criteria were applied; such as Root locus criterion, Nyquist and bode stability criteria, all of them result in stable system. Two variables were proposed to manipulate the process, (the flowrate of water in and the flowrate of decalcinizer), according to this analysis the decalcinizer flow rate give better results than the inlet water flow rate.

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