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A Comparative Study of Kiln Process Using Advanced Control Strategy

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***Abstract-* In this paper, the model described in literature is applied to simulate the actual operating conditions of rotary lime kiln. The method of step response is adopted to identify the object with two inputs (the fuel flow rate and ID fan Speed position) and two outputs (the temperatures in the backend and oxygen) into a first order, strong coupling linear system model and the validity of the model is verified as well. The system model is developed using a system identification scheme based on the on-line input output data. The Cohen and coon method tuned PID and PI controller by taking the parameter values of K_p, t_d, □. The lime production in kiln process cannot be effectively controlled by the linear PID controllers. Hence advanced and intelligent controllers are best suited for improving energy efficiency. The simulation results shows the comparison of PID controller, IMC based PID controller and Fuzzy tuning with P controller which provides the efficient lime production at the output with high efficiency, high stability, less energy cost and control accuracy.**

***Index Terms-* Lime Kiln, System Identification, Cohen and coon tuned control, Decoupling Control, IMC based PID control and Fuzzy tuning P control.**

I.INTRODUCTION

Control of industrial processes is a challenging task for several reasons due to their nonlinear dynamic behavior, uncertain and time varying parameters, constraints on manipulated variable, interaction between manipulated and controlled variables, unmeasured and frequent disturbances, dead time on input and measurements. In the manufacture of paper, cooking liquors are formed on site by mixing quick lime, sodium carbonate and sodium sulfide together. A by-product of this process is lime sludge, which is a mixture of calcium carbonate, inorganic sulfur compounds, a small quantity of sodium hydroxide, and water. This lime sludge by-product is then reconverted to quick lime on site in a calcining rotary kiln. The backend temperature and oxygen is playing mainly a critical role in rotary lime kiln process. By manipulating fuel flow and ID fan speed, both the back end temperature and Excess oxygen content in the emission gases of the kiln will be controlled accordingly. To avoid the interaction between two system decoupler is designed and interactions have reduced if there is a interaction between two process.

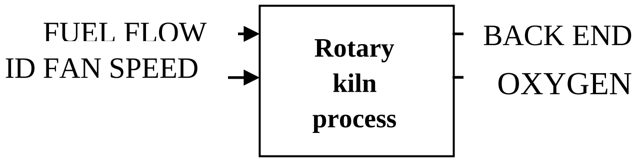
By using system identification technique, the transfer function has been found. From the transfer function the parameters such as K_p, t_d, □□have been taken and those values have tuned by cohen-coon method. Cohen-coon method which tunes the PID values for temperature because it has high dead time in the process and also it tunes the PI values for oxygen because it has less dead time in the process.

The best and easy use conventional PID controller is designed first to control the temperature and oxygen content of the kiln which provides lime production efficiency. When it comes to the control of nonlinear and multivariable processes, the controller parameters have to be continuously adjusted.PID controller will controls the temperature and oxygen at setpoint value but it will take time to attain the setpoint value. So IMC based PID controller is used.Internal model control (IMC) tuning offers an alternative tuning to increase the controller's speed overall, and to reduce time delay, but doing so will tend to make the controller less robust. In order to avoid time delays and to provide efficient lime production and to make the good efficiency in lime production Fuzzy tuned P controller have used.

II.MODELLING OF SYSTEM

The toolbox provides several linear and nonlinear black-box model structures, which have traditionally been useful for representing dynamic systems. Black-box modeling is usually a trial-and-error process, where estimate the parameters of various structures and compare the results. Typically, start with the simple linear model structure and progress to more complex structures.

Rotary Kiln System Identification



From the figure we can see that the input variables of the temperature control system of rotary kiln are the fuel flow rate and the Id fan speed. The outputs of the system are the back end temperature and oxygen.

The model can correctly describe the Kiln's actual working conditions. Because the model contains the object delay, coupling and coupling characteristics of the actuator, it is difficult to design a suitable controller directly from any descriptive models to achieve control targets. Therefore, we have to approximately identify the system into a linear system model, so the controller to the approximate linear system can be designed with the methods of linear systems. The problem of kiln temperatures and Excess oxygen of closed-loop control can be successfully resolved.

The S function model is treated as a "black box" to be identified, as shown in the above Figure.From the black box modelling, the transfer fuction can be obtained as,

$$\begin{bmatrix} Backend \\ oxygen \end{bmatrix} = \begin{bmatrix} \dfrac{0.52e^{-67s}}{8.7s+1} & \dfrac{-0.002e^{-12s}}{10s+1} \\ \dfrac{-0.0088e^{-0.67s}}{2.5s+1} & \dfrac{0.018e^{-0.17s}}{1.75s+1} \end{bmatrix} \begin{bmatrix} Fuel \\ IDfan \end{bmatrix}$$

The fuel which affects the process output temperature and oxygen content in the emission gases. Likewise, ID fan affects the oxygen and temperature changes. Hence there is no much interaction between processes so decoupler controller is not much needed for the process. From the transfer function dead time (t_d), time constant (τ), gain (k_p) can be found.

$$G_{11}(s) = \frac{0.52e^{-67s}}{8.7s+1} \quad ; \quad (2.1)$$

$$G_{12}(s) = \frac{-0.002e^{-12s}}{10s+1} ; \quad (2.2)$$

$$G_{21}(s) = \frac{-0.008e^{-0.67s}}{2.5s+1} ; \quad (2.3)$$

$$G_{22}(s) = \frac{-0.018e^{-0.17s}}{1.75s+1} ; \quad (2.4)$$

III. PID PARAMETER TUNING BY COHEN-COON METHOD

Step 1: Perform a step test to obtain the parameters of a FOPTD (first order plus time delay) model.

Step 2: Calculate process parameters such as t_d, τ , k

Step 3: Using the process parameters, use the prescribed values given by Cohen and Coon.

3.1 DESIGN OF PID CONTROLLER FOR G_{11}(s):

It has high dead time in the process G_{11}(s) so, PID Controller is designed mainly for fast reaction process.

$$Kp = \frac{1}{K}\frac{\tau}{t_d}\left(\frac{4}{3}+\frac{t_d}{4\tau}\right) \quad ; K_p=0.81372 \quad (3.1)$$

$$\tau_i = t_d\left(\frac{32+6\frac{t_d}{\tau}}{13+8\frac{t_d}{\tau}}\right) \quad ; \tau_i=0.014 \quad (3.2)$$

$$\tau_d = t_d\left(\frac{4}{11+2\frac{td}{\tau}}\right) \quad ; \tau_d=10.1506 \quad (3.3)$$

3.2 DESIGN OF PI CONTROLLER FOR G_{22}(s):

It has less dead time in the process G_{22}(s) so, PI controller is designed here for slow reaction process.

$$Kp = \frac{1}{K}\frac{\tau}{t_d}\left(0.9+\frac{t_d}{12\tau}\right) \quad ; K_p = 519.335 \quad (3.4)$$

$$\tau_i = t_d\left(\frac{30+3\frac{t_d}{\tau}}{9+20\frac{t_d}{\tau}}\right) \quad ; \quad \tau_i=2.1250 \quad (3.5)$$

3.3 SIMULINK MODEL OF COHEN-COON TUNED CONTROLLER

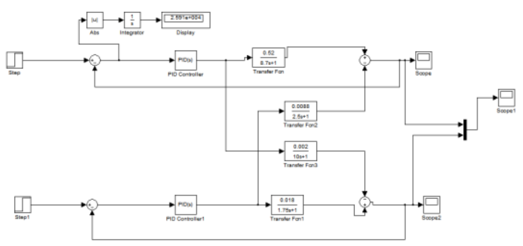


Fig 3.1 Simulink Model of Cohen-Coon tuned Controller for Kiln Process

Fig 3.1 describes the PID control for rotary lime kiln process. The Cohen and coon method tunes the parameter values PID which will control the backend temperature and achieves lime production with good energy efficiency.

IV. DIFFERENT CONTROL STRATAGIES

4.1 IMC TUNED PID

Internal model control tuning also referred as Lambda tuning method offers a robust alternative tuning aiming for speed. The tuning is very robust meaning that the closed loop will remain stable even if the process characteristics change dramatically. Lambda tuning is a form of internal model control (IMC) that endows a PI controller with the ability to generate smooth, non-oscillatory control efforts when responding to changes in the set point. Its name derives from the Greek letter lambda (λ), which designates a user-specified performance parameter that dictates how long the controller is allowed to spend on the task of moving the process variable from point A to point B. Like the more famous technique, Ziegler-Nichols tuning, lambda tuning involves a set of formulas or tuning rules that dictate the values of the PI parameters required to achieve the desired controller performance.The IMC based tuning parameters for PID controller can be obtained by determining the controller equation. Otherwise directly the parameters can be calculated by using the formulae below. The IMC based PID parameter tuning formula given in equation (4.1), (4.2),(4.3) are formulated below. Assume τ_c = 1sec,

PROPORTIONAL:

$$Kp = \frac{\tau}{(\tau_c + t_d)K} \qquad (4.1)$$

INTEGRAL:

$$K_i = \frac{K_p}{\tau_i} \quad ; \quad \tau_i = \tau \qquad (4.2)$$

DERIVATIVE:

$$Kd = \frac{Kp}{\tau_d} \quad ; \quad \tau_d = \frac{\tau + t_d}{2\tau + \tau} \qquad (4.3)$$

Where K_p = Proportional gain
K_I = Integral gain
T_i= Integral time
t_d = Delay time
τ_c =Closed loop time constant
k=Process gain

The calculated PID gain parameters can be given as,

FOR G_{11}(s),

K_P=0.049490
K_i=0.059770
K_d =0.0077612
FOR G_{22}(s),
K_p = 83.0959

K_i = 0.010285

K_d = 0.10588

4.2 SIMULINK MODEL OF IMC BASED PID CONTROL

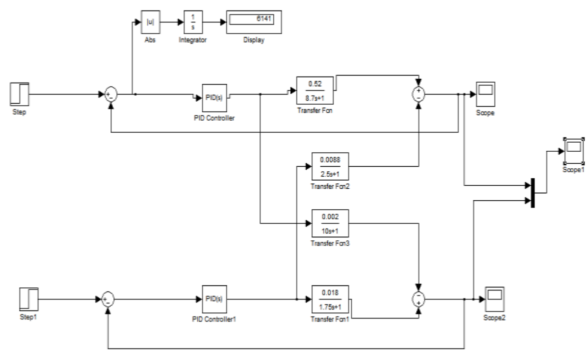


Fig 4.1 Simulink Model of IMC Based PID Control

The above figure 4.1 describes the IMC based PID control action for kiln process.IMC based PID controller tunes the parameters of k_p, K_i and K_d and obtain the desired point value for temperature and oxygen.

4.3 THE PROPOSED FUZZY CONTROLLER

With the aim of compensating system nonlinearities, the use of fuzzy controllers might be a proper solution to control nonlinear industrial plants. This work proposes a fuzzy-P system to control rotary kiln process. The controller structure has a feedback loop and three inputs: error, error variation and the measured temperature and oxygen. The fuzzy-P output is the control signal to operate the actuator/valve of kiln process. The block diagram of the controller is

4.4 SIMULINK MODEL OF FUZZY CONTROLLER

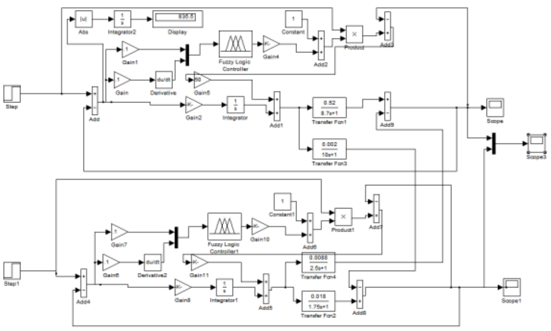


Fig 4.2 Simulink Model of Fuzzy Controller

The above figure 4.2 shows the Simulink model for fuzzy controller for rotary kiln process. The input and output membership functions are given along with the rules for the design of a fuzzy controller. A setpoint of 1 is given. The fuzzy controller has two inputs, error and derivative of error. The output is fed to the process.

4.5 FUZZY RULES

Whether it is traditional, precise logic, or fuzzy logic, which can be expressed by experiential knowledge rules. As the lime kiln flue gas temperature fuzzy controller used two-input, single-output structure, the rules could be clearly expressed. The fuzzy if then rules are defined for controlling the backend temperature of rotary kiln process.

1. If (FUELFLOW is VLF) and (ERROR is LE) then (output1 is LT)
2. If (FUELFLOW is LF) and (ERROR is LE) then (output1 is LT)
3. If (FUELFLOW is MF) and (ERROR is ME) then (output1 is MT)
4. If (FUELFLOW is HF) and (ERROR is HE) then (output1 is HT)
5. If (FUELFLOW is VHF) and (ERROR is HE) then (output1 is HT)
6. If (FUELFLOW is EHF) and (ERROR is HE) then (output1 is HT)

The fuzzy if then rules are defined for controlling the excess oxygen in the emission of gases of rotary kiln process.

1. If (IDFAN is LS) and (ERROR is LE) then (OXYGEN is LO)
2. If (IDFAN is MS) and (ERROR is ME) then (OXYGEN is MO)
3. If (IDFAN is HS) and (ERROR is HE) then (OXYGEN is HO)

V. RESULTS AND ANALYSIS

Cohen-coon method which tunes PID parameters for the process $G_{11}(s)$ because it has large dead time in the process. Closed loop response of cohen-coon tuned PID controller is shown in the Figure 5.1.

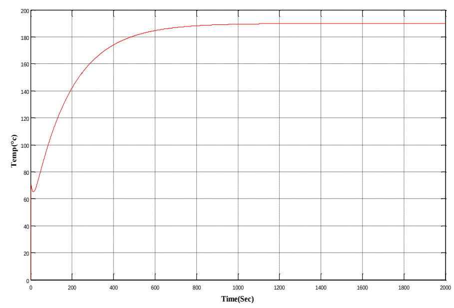


Figure 5.1 Closed loop response of cohen-coon tuned PID controller

Cohen-coon method which tunes PI parameters for the process $G_{22}(s)$ because it has only small dead time in the process. Closed loop response of cohen-coon tuned PI controller is shown in the Figure 5.2

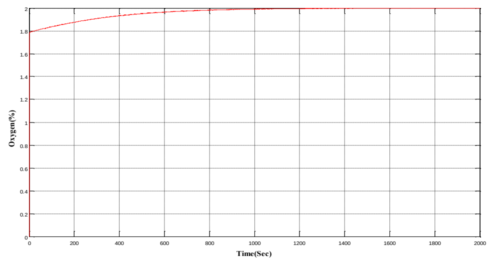


Figure 5.2 Closed loop response of cohen-coon tuned PI controller

5.1 CLOSED LOOP RESPONSE OF IMC TUNED PID CONTROLLER

The closed loop response is obtained using the Internal Model Control (IMC).This improves the robustness of the system. Closed loop response using IMC for the process is shown in the figure 7.3.

If the set point for the backend temperature is given as 190°c and for O2 as 2%,two separate controllers will be used to control both and it settles exactly at the set point given.

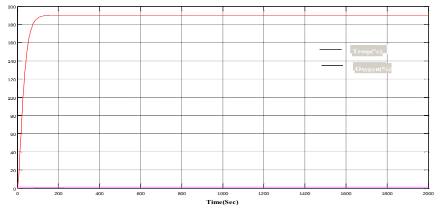


Figure 5.3 Closed Loop Response of IMC Tuned PID Controller

5.2 FUZZY TUNED P CONTROLLER

The error and change in error is given as input to the fuzzy. The fuzzy controller tunes the parameter P alone and controls the backend temperature and oxygen. If the backend temperature value is given as 190°c and oxygen as 2%, decentralized fuzzy controller is used to tune P parameter alone, and it settles at the setpoint value.

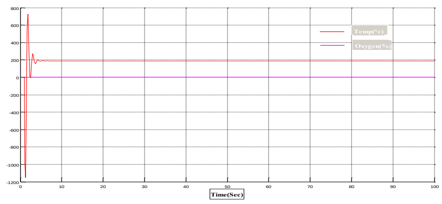


Figure 5.4 Closed loop Response of Fuzzy Tuned P Controller.

VI. COMPARISON OF RESULTS

Table 6.1 Comparison of results for Temp =190°c

S.No	Parameters	PID controller	IMC based PID	Fuzzy logic controller
1	Settling Time(sec)	1300	180	7
2	Rise time(sec)	420	50	3
3	Overshoot (%)	0	0	2.95
4	Integral Absolute Error (IAE)	25910	6141	834.5

Table 6.2 Comparison of results for Oxygen=2%

S.No	Parameters	PID controller	IMC based PID	Fuzzy logic controller
1	Settling Time(sec)	900	160	3
2	Rise time(sec)	0	0	0
3	Overshoot (%)	0	0	0
4	Integral Absolute Error (IAE)	71.07	2029	4.015

VII.CONCLUSION AND FUTURE SCOPE

The complex dynamics and multi-variable nature of the calcination process, with its non-linear reaction kinetics, long time delays and variable lime mud feed characteristics, make the lime kiln process inherently difficult to operate efficiently. The transfer functions were obtained from the system identification tool box and by considering the values K_p, t_d, the PID parameters were tuned by Cohen-Coon method. To control the back end temperature and oxygen, the simple and easy conventional PID controller is designed first .Advanced controllers like IMC tuned PID controller was used to satisfy the poor performance of PID controller. Even though to avoid less time delays and to achieve good lime production efficiency intelligent controllers like Fuzzy tuned P controller was used. Hence the parameters can be optimized by improved genetic algorithm.

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