International Journal of Applied Engineering Research ISSN 0973-4562 Volume 16, Number 2 (2021) pp. 89-93


# OPTIMIZATION OF RESIDUAL GAS IN ROTARY KILN USING PID CONTROL

[1]Rafael David and [2*]Hadi Sutanto

[1,2,3] *Department of Mechanical Engineering, Atma Jaya Catholic University of Indonesia, Jl. Jenderal Sudirman 51, Jakarta, 12930, Indonesia.*

* *Corresponding author*

**Abstract**

A rotary kiln is a pyro-processing device to raise materials into a high temperature (calcination) in a continuous process. Materials produced using rotary kiln include: cement, lime, or refractories. Exhaust gases are representing a large percentage (approx. 20%) of the total heat input used in the system. Optimization of residual hot gas from rotary kiln process is important to make the process more efficient. A blower is used to take the residual gas and the heat transfer mechanisms is forced convection heat transfer. Differential equation is solved to determine the suitable mathematical model. Based on the data, the temperature is increased exponentially. A differential pressure (DP) transmitter sensor is installed at the end of exhaust gas pipe to control fluid velocity. Data is analysed for optimization in MATLAB simulation and the Proportional Integral Derivative (PID) controller parameters are: Kp = 1.803, Ki = 0.08 and Kd = 0.03. Rise time is 0.238.

**Keywords**: Rotary Kiln, Hot gas, PID control, Differential Pressure (DP) transmitter, Forced Convection.

## 1. INTRODUCTION

Automation is one of vast developing technology in industries [1]. It is a process to change control system of a machine or device to become more automatic, like controlled by computer or electronics. Automation also has significant role in manufacturing to maintain product quality.

Widely used Rotary Kiln types by cement factories will emit residual hot gas. Residual hot gas is a usable source of energy to dry sand as one of material in mortar cement making process. Residual hot gas can be gathered manually when it is on standby (not producing). It is also can be gathered with automatic process to maintain quality of the product in Rotary

Kiln. The most important part is the device to set up the PID controllers.

## 2. THEORY

### 2.1 Bernoulli Principles.

Distance from the ground in figure 1 are h1 and h2. If the diameter of pipes are much smaller than their heights then itis assumed that the pipes have same heights.

$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2 \qquad (1)$$

where

P : Fluid Pressure (Pa).

ρ : Density ($Kg/m^3$).

v : Velocity (m/s).

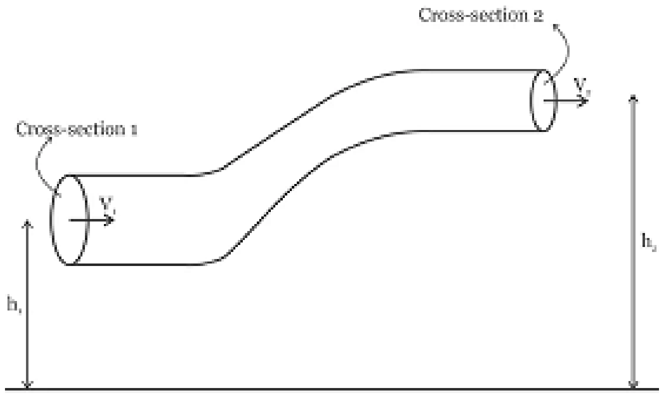


**Figure 1**. Pipe diagram.

The flow rate for both pipes are dependent of fluid velocity v and cross section area A of pipes given by:

$Q = A_1 v_1 = A_2 v_2$ (2)$Q = A_1 v_1 = A_2 v_2$(2)$Q = A_1 v_1 = A_2 v_2$(2)$Q = A_1 v_1 = A_2 v_2$(2)$Q = A_1 v_1 = A_2 v_2$(2)$Q = A_1 v_1 = A_2 v_2$(2)Q = Av(2)

Q = Av(2)Q = Av(2)By subtituting equation 2 into equation 1, the fluid velocity that can be obtained from pressure and measured by Differential Pressure (DP) transmitter is:

$$v_1 = A_2 \sqrt{\frac{\Delta P.2}{\rho\left(1 - \frac{A_2}{A_1}\right)^2}} \qquad (3)$$

Note: Both end of DP sensors transmitter are connected.

### 2.2 Forced Convection Heat Transfer.

Heat transfer rate with forced convection between metal surface of pipe is calculated using principle of conservation of energy and given by :

$$\frac{d\theta}{dt}(\rho V c) = q_{in} - q_{out} \tag{4}$$

The velocity of fluid is derived from equation 4 :

$$\frac{d\theta_f}{dt}(\rho V c) = v\, c(\theta_{ih} - \theta_f) \tag{5}$$

where

$\rho$ : Air density(1,2 kg/m$^3$).

V : Volume m$^3$.

c : Specific heat.

v : Fluid velocity (m/s).

$\theta_{ih}$ : Inlet pipe temperature ($^0$C).

$\theta_f$ : Fluid temperature ($^0$C).

### 2.3 PID Control

Response system is a change in output behaviour according to changes in input signal. Basically this is a method to analyze system characteristics other than using equation or mathematic model.

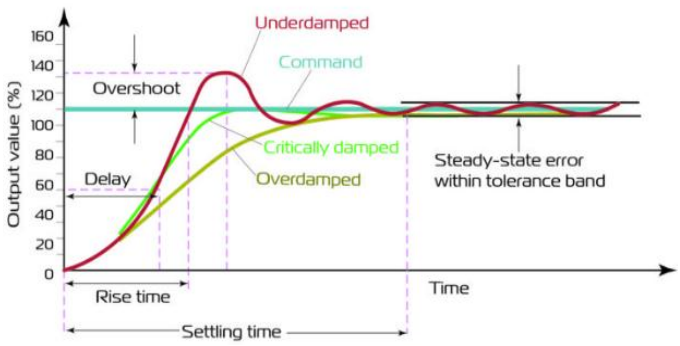


**Figure 2**. Response signal foam.

Proportional Integral Derivative (PID) is a method in Control System. PID consists of 3 controllers; Proportional controller (Kp), Integral controller (Ki), and Derivative Controller (Kd). Each action controller has its own advantage. Proportional action controller has fast rise time, Integral action controller is able to reducing error and Derivative action controller is able to dampen overshot or undershot. These three controllers are combined to get output with fast rise time and small error. Mathematic model of PID Control is :

$$CO = K_p . E + K_i \int E \, .dt + K_d \frac{dE}{dt} \tag{6}$$

where,

CO : Controller output.

Kp : Proportional constant.

Kd : Deriative constant.

Ki : Integral constant.

e : Error = Ysp –Ym.

Ysp : Setpoint.

Ym : Prosess Value.

$\tau$ : Integral time atau reset time.

### 2.4 Transfer Function

Relation between input and output of a closed loop system with negative feedback in forced convection heat transfer can be described with this transfer function diagram:

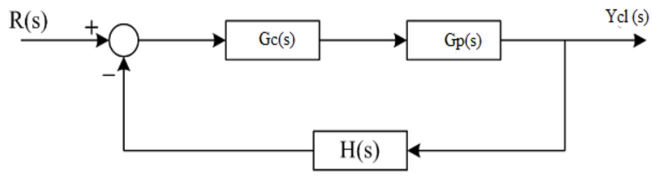


**Figure 3**. Block diagram of a closed loop system with negative feedback.

The Mathematical model of Figure 3 is:

$$\frac{Y_{cl}(s)}{R(s)} = \frac{G_p(s).G_c(s)}{1 + G_p(s)G_c(s).H(s)} \tag{7}$$

where,

Gp(s) : Plant Constant.

Gc(s) : Control Constant.

H(s) : Sensor Constant.

Ycl(s) : Output Close loop.

R(s) : Input.

NOTE : (s) is a Laplace Transform.

## 3. SYSTEM DESIGN

### 3.1. Mathematical Modeling of Hot Gas System.

This research is based on new cement factory plant in Citereup, Bogor, Indonesia. All equipment used are more or less like in the Figure 4. Damper is considered constant because valve only opens and shuts the flow of fluid. A booster fan equiped with an inverter is used to control the fluid velocity. Differential Equation of forced convection heat transfer can be obtained using energy conservation formula in equation 4.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 16, Number 2 (2021) pp. 89-93
© Research India Publications. http://www.ripublication.com

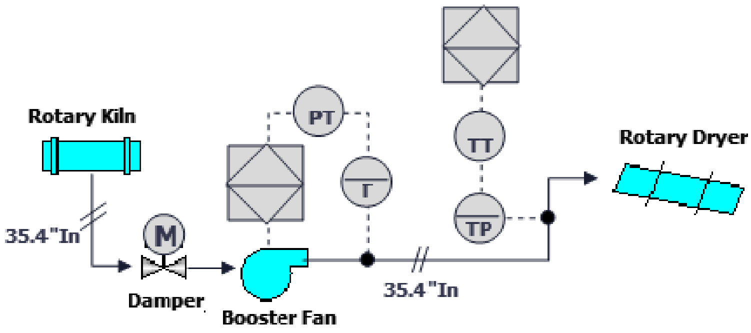


**Figure 4**. P&ID plant

The volume of hot gas pipe is 19,44 $m^3$. If air density ρ is 1.2 kg/$m^3$, using equation 5 the system's response time τ is:

$$\tau = V.\rho \ = 19.44m^3 \,.1.2$$

$$= 23.32 \ {}^{kg}/_{m^3} \qquad (8)$$

Based on the measurements, the average temperature of hot pipe gas inlet is 29.96 °C. The value of average temperature and response time are substituted into mathematic model in the form of transfer function. The complete mathematic model for forced convection heat tranfer sistem is:

$$\frac{\theta_f(s)}{v(s)} = Gp(s) = \frac{\theta_{in}}{\tau s + 1} = \frac{29.96}{23.32s + 1} \qquad (9)$$

### 3.2. Mathematical Sensor Model.

The temperature on hot gas pipe is measured with a type K thermocouple sensor. By using a tranmitter, output form sensor is amplified in the form of electric signal. The electric output signal vary from 0 – 45.119 mV according to temperature range 0 – 1100 °C. Input signal for control system is 4 – 20 mA. Resistance R ratio in type K thermocouple sensor can be derived using Ohm Law:

$$R(s) = \frac{V(s)}{I(s)}$$

$$= \frac{(45.119 - 0)mV}{(20 - 4)mA}$$

$$= \ 2.81 \ (10)$$

where,

R : Resistance (Ohm).

V : Thermocouple output voltage. (Volt)

I : Input current from transmitter to controller (A).

Thermocouple wire diameter is 0,39 mm and sensor response time τ from graph [4] is 0,5 s. These values are substituted into first order transfer function and the result is:

$$H(s) = \frac{2.81}{0.05\ s + 1} \qquad (11)$$

### 3.3 PID Control Mathematical Model.

Transfer function for PID Control from eq. 6 after Laplace Transform is given by:

$$Gc(s) = \frac{Kps + Ki + Kds^2}{s} \qquad (12)$$

### 3.4 Force Convection heat transfer simulation Modeling.

By substituting all the value of transfer function system and sensor into eq 7, the complete transfer function is :

$$z(s) = \frac{1.498\ s + 29.96}{1.166s^2 + 23.37s + 86.18} \qquad (13)$$

## 4. RESULTS AND ANALYSIS

### 4.1 Manual Setting.

The experiments for taking residual hot gas has been done manually, by adjusting the booster fan's velocity, resulting in exponential temperature's increase. An optimum control system is needed in order to not disrupt cement production in Rotary Kiln.

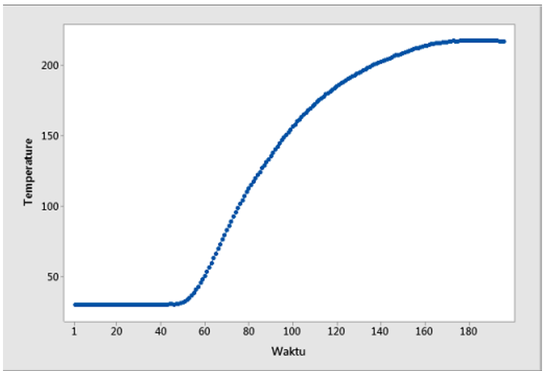


**Figure 5**. Graph of temperature vs time.

Closed loop system simulation with negative feedback is conducted to see how much optimization can be achieved in taking residual hot gas using PID Control. The system simulation with manual setting is shown in figure 6.

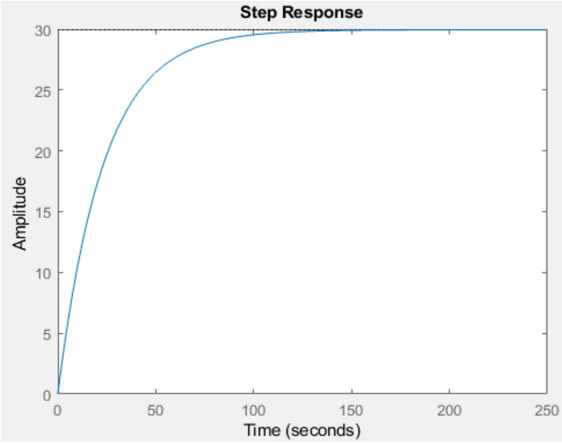


**Figure 6**. Graph of the closed loop system rise time.

Based on the rise time in Figure 6, the system has slow response time. System's response time can be seen in figure 7.

A PID Control is needed to fix the system, with aim of to achieve:

1. Faster Rise time.
2. Faster Settling time.
3. Minimum Overshoot.

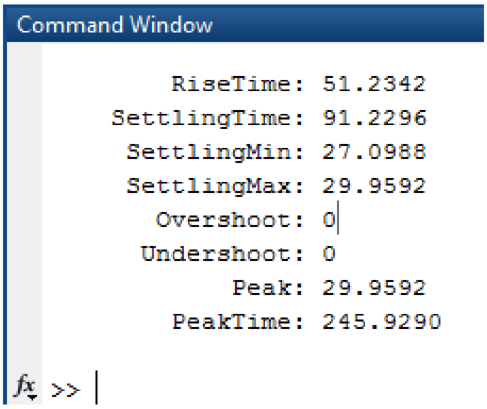


**Figure 7**. Data of system rise time.

### 4.2 Automatic setting.

PID Control parameters is obtained with trial and error methods of Equation 13 and MATLAB software. The result is shown in figure 8 below:

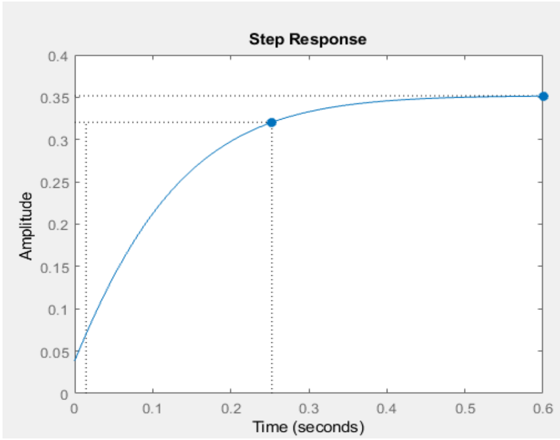


**Figure 8.** Graph of response system time using PID control.

**Table 1.** Parameters comparison before and after using PID control.

| | Before | After |
|---|---|---|
| Rise Time | 51.23 | 0.2 |
| Settling Time | 91.2296 | 0.3968 |
| Overshoot | 0 | 0 |

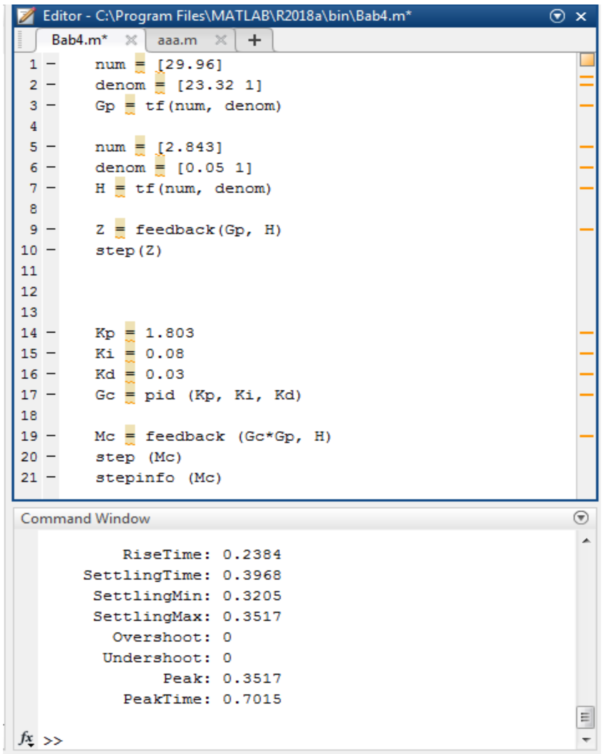


**Figure 9**. Results of PID control constants using MATLAB simulation.

## 5. CONCLUSIONS

Based on simulation result and analysis, these are the conclusions:

1. PID Control simulation is applicable in residual hot gas gathering process to optimize system's performance.
2. Residual hot gas can be gathered automatically by submiting the value of Kp, Ki, and Kd into technology function provided in the Programmable Logic Controller (PLC).
3. The mathematic model used to find Gp system is easier using electric current differential equation than forced convection differential equation.
4. To maintain the function of the blower system, it is recommended that the speed of hot gas be adjusted by the cross-sectional area of the damper while the blower is made constant

## REFERENCES

[1] Asa, Panji Saka Gilap. & Sigit Priyambodo (2016) PID (Proportional Integral Derivative) Control learning system on DC motor Speed Controller. Jurnal Electrical, vol.3 no.1, pp. (72-77).

[2] D. Haliday, R.Resnick, *Fundamental of Physics* John Wiley and Sons, 1974.

[3] Vu, Hung V, Ramin S. Esfandriari, *Dynamic system modeling and analysis* Mc Graw Hill, 1998.

[4] Prasanna, N Merrin & Polaiah Bojja. (2019). "Optimization of Rotary Kiln in cement industry using conventional control system". Helix, 9, 4843 – 4849.

[5] "*Thermocouple Response Time*". Omega.com. 17 April 2019 13 November 2020 https://www.omega.com/en-us/resources/thermocouples-response-time.