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MODEL PREDICTIVE CONTROL OF ROTARY DRYER

Duraid Fadhil Ahmed[1]* and Rana Mahdi Mohammed[2]

[1]Department of Chemical Engineering, Tikrit University, Iraq.
[2]Department of Chemical Engineering, Tikrit University, Iraq.

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***Corresponding Author**
Duraid Fadhil Ahmed
Department of Chemical Engineering, Tikrit University, Iraq.

ABSTRAT
In this paper, a model predictive control was applied to control the rotary dryer. The mathematical model based on mass and energy balances at unsteady state was simulated using MATLAB/SIMULINK software. The simulation results have been successfully compared with the other previous work. The model predictive control was compared with the PID controller using an integrated absolute error (IAE). The simulation results show that the MPC controller has rapidity, very good durability, more suitable, little offset, lower overshoot and less integral absolute error. The integral absolute error of MPC controller ranges from 882 to 1098, while for PID controller are 3478 to 4201.

KEYWORDS: Rotary dryer, Simulation, PID control, Model predictive control.

INTRODUCTION
Rotary dryers are considered one of the most common dryers in industrial dryers due to their importance. Rotary drying is a complex process, more energy consuming and not environmentally friendly. The process of controlling the rotary dryer is difficult due to the long delays, the process in the rotary dryer is not highly linear in addition to the turbulence that occurs and cannot be measured.[1] The traditional PID control method is poor in controlling the drying process in terms of reducing the energy required. Therefore, it is necessary to use advanced control methods, such as the MPC predictive control model, due to its superiority in controlling the rotary dryer by comparing with the traditional control method.

There are many attempts to develop a dynamic model and use entire modern control methods.[2-5] Also, various implemented controller architectures such as PID, fuzzy control, typical predictive control, artificial neural networks and optimum control were designed to solve spin drying problems through many trials.[6-8] All control methods applied to solve the problems attempt to reject high performance disturbance for a wide range of conditions at the lowest cost and lowest energy consumption. The most problems of these attempts are the development of the dynamic model, the validity of the simulation program, and modern and advanced control methods instead of the traditional control methods and manual methods that are still used to the present time. Many researchers have introduced advanced and intelligent control methods to control rotary dryers, as the advanced control methods are characterized by their accuracy in complex industrial control, especially operations that require a lot of time. Indriani and Rizal[9] used a programmable logic controller (PLC) to control the movement of equipment on a rotary drying system for effluent treatment. Mahmoud et al.[10] used a variable structure control pattern, where a variable structure integrative controller was designed, by transforming the system model equation and designing an integrative sliding surface by choosing a corresponding control matrix to obtain an optimal output. The control variable was the output air temperature. The manipulated variable was the fuel flow. Duchesne et al.[11] developed five rotary dryer control strategies. The comparison was made with industrial data. Neural network controllers gave better results using nutrient flow to control product moisture content, while secondary air flow rate to control gas temperature and reduce cost. Tsourveloudis et al.[12] two different techniques were used for the control of the drying process of olive stones. The process of controlling an industrial dryer sized dryer was not easy primarily because of its size and the corresponding long transfer times, and the delays between the control procedure and the results that can be observed due to these procedures. Each of the controllers has been tested for different operating conditions and compared. Despite the many studies that dealt with advanced control methods to control rotary dryers, the control of rotary dryers is still manually to this day. This is due to several reasons, including the complexity of the drying process and the long delay times, in addition to the inability to measure the moisture content and the lack of knowledge and clarity of the disturbances that occur.

The Model of rotary dryer

According to the general equation, a rotary dryer is a distributed parameter system in which both temperature and moisture are functions of time and space.

$$\frac{\partial x_i(l,t)}{\partial t} \pm v_i(t)\frac{\partial x_i(l,t)}{\partial l} = f_i(x_i, l, t) \qquad (1)$$

Where:

xi :is the moisture or temperature in the solids or gas phase

vi :is the linear velocity in the solids or gas phase

l:is the axial co-ordinate, and

t :is time

For con-current drying, a positive sign is used, while for counter-current drying, a negative sign is used.

The distributed parameter model is difficult to control, and temperature, particular solids content and drying air inside the dryer, are difficult to measure. As a conclusion, it is reduced to a lumped parameter model in which the entire length of the drum is equal to the partial derivative of the axial co-ordinate length. Because the gas moisture content is not measured in the pilot dryer, the equation for it is not included in the overall model for the dryer. The model has taken shape:

$$\frac{dX,out}{dt} = -vs\frac{(X,in - X,out)}{L} - Rw \qquad (2)$$

$$\frac{\partial Ts,out}{\partial t} = -\frac{vs(Ts,out - Ts,in)}{L} + \frac{UvVv}{FsCS}(Tg - Ts) - \frac{\lambda}{Cs}Rw \qquad (3)$$

$$\frac{\partial Tg,out}{\partial t} = -\frac{vg(Tg,out - Tg,in)}{L} + \frac{UvVv}{FgCg}(Tg - Ts) - \frac{Fs\lambda}{FgCs}Rw \quad (4)$$

Drying Rate Equation

The drying rate(Rw), which defines the drying path inside the solid, turns out to be non-linear, according to the equations of the mathematical model of the rotary drier. Many research has discovered from experimental data that the drying rate equation represents the properties of the material and the air temp in the fall time during the drying route [13]. As shown by, the drying rate was calculated as a linear function of solid moisture, air temp, and solid matter.[1]

$$Rw = k1\,.Xs + k2\,.Ts + k3\,.Tg \qquad (5)$$

Where:

k1 (1/s), k2 (1/s K) and k3 (1/s K) are constants determined experimentally.

Model predictive control

A predictive control model (MPC) is a set of functions (commands) developed to deal with the analysis and design of predictive control model (MPC) systems. The MPC algorithm is suitable for almost any type of problem, as it can handle[14] as a number of manipulated and controlled variables, and constraints on both manipulated and controlled variables and time delays. The most common algorithm associated with MPC is Dynamic Matrix Control (DMC). MPC determines the output that Tg indicates by solving a constrained optimization problem. MPC is one of the few control methods that are directly dependent on constraints. The time period used to predict the behavior of the system is referred to as horizon forecasting, as this type of control can be thought of as open-loop control. This type of control can also be used in linear and non-linear models. It has been used in many industrial fields.[15] A model predictive control scheme is shown in Figure 1.

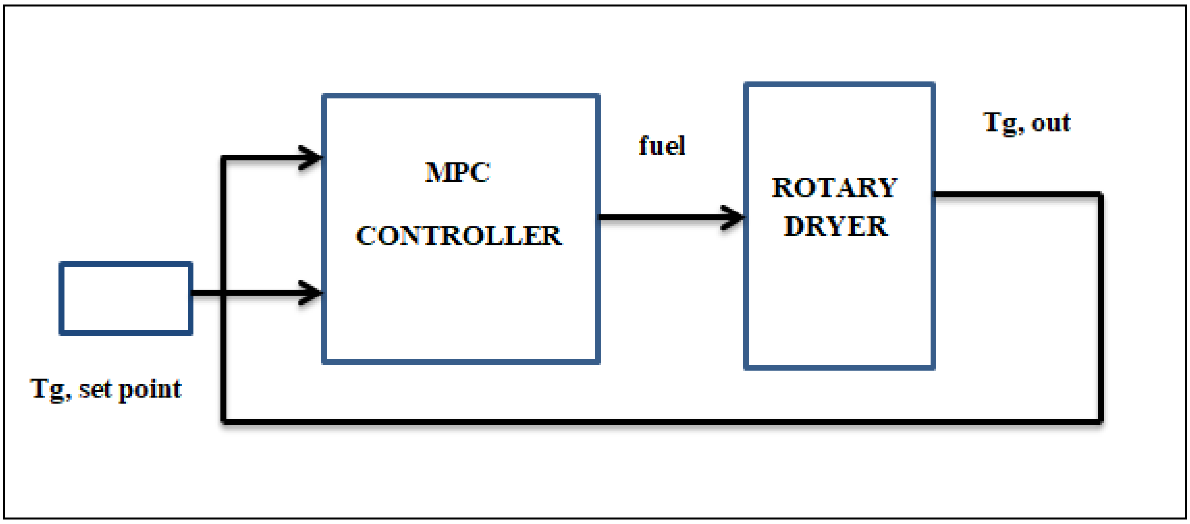

Figure 1: Block diagram of scheme of model predictive control.

Simulation work

MATLAB /Simulink software is used to simulate the rotary dryer. It is a strong program for dynamic system analysis simulation and control. The model of the rotary dryer used throughout the paper is developed by Ylinimie[1] composed by the mass and energy balance equations used as basis to implement the Simulink diagram. To simulate the model, steady state data were obtained from the pilot dryer. The parameters and steady state operating data are shown in Table 1. The MPC controller was simulated using MATLAB/SIMULINK (R2020a) from math works. The MPC controller was simulated by following a set of steps. it is necessary to specify the inputs in the rotary dryer model, as shown in the Figure (2), which are: Air outlet temperature (Tg) is a control variable and fuel flow rate(m, fuel) is the manipulated variable. The control objective is to maintain the moisture of the solid, at the nominal set point by adjusting the fuel flow rate.

Table 1: Operating parameters of Plant Dryer.

Variable	Steady State Value	Parameter	Steady State Value
N drum	1 r/min	Cg	1.01 kJ/ kg K
Vg	0.7 m/s	Cs	0.84 kJ/kg
Vs	$4.87 * 10^{-3} m/s$	K1	$1 * 10^{-3} \frac{1}{s}, k2 = 0$
Fg	0.12 kg/m	K3	$0.1 * 10^{-8} \frac{1}{s}$
Fs	8.77 kg/m	Uv	0.27KJ/s.m^3.K
Tg,in	472 K	Vv	019 m^3/m
Tg,out	421 K	λ	2261 kJ/kg
Ts,in	293 K		
Ts,out	360 K		
Xs,in	2.4 m-%		
Xs,out	0.001 m-%		

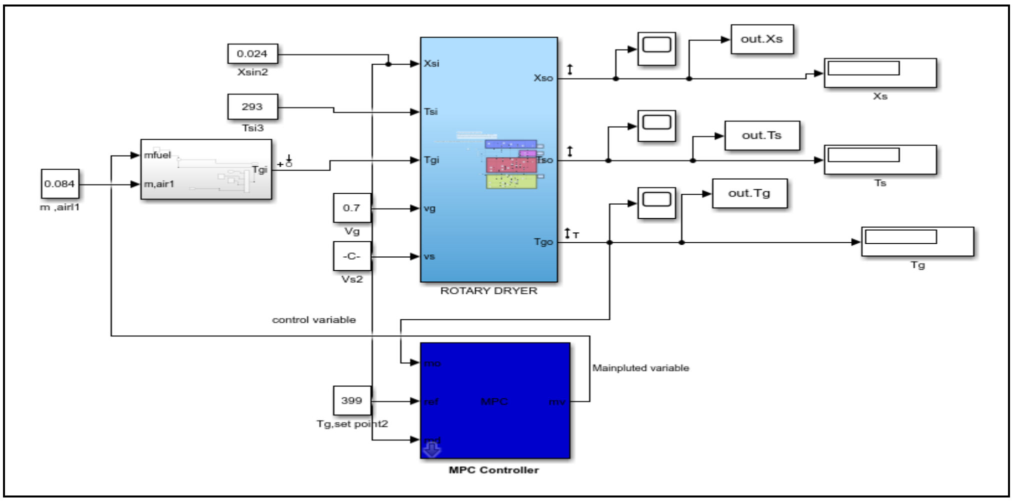

Figure 2: Simulation work of MPC controller for the rotary dryer.

RESULTS AND DISCUSSION

The validity of the simulation work

The present simulation work was validated by comparing the steady state prediction with simulation results of rotary dryer achieved by Ylinimie.[1] The criterion of this validation is the deviation difference which is calculated by using Eq. (6). The validation procedure includes the solid outlet moisture content, solid outlet temp and air outlet temp. The Table (2) shows the values of the present simulation, reference and deviation difference values of these variables at steady-state. The deviation difference ratio between the present simulation and Yliniemi results was as follows: The deviation for the solid outlet moisture is 500%, which was high, and the air outlet temperature is 5% and the solid outlet temperature is about 2.5%, which was a good agreement between the current simulation and the results of Yliniemi. Dev.%=|Simulation value-Reference value|/(Reference value)*100(6)

Table 2: Comparison of present results with (Yliniemi, 1999) results.

Variable	Present simulation	Results of Yliniemi	Deviation deference %
Solid outlet moisture content%	0.6	0.1	500
Solid outlet temperature K	369	360	2.5
Air outlet temperature K	398.7	420	5

Control of Rotary Dryer

The results of a closed loop simulation are executed. The main objective is to maintain the moisture content of the solid at the outlet by using the control variable the air outlet temperature and the manipulated variable the fuel flow rate. The model predictive control and its comparison with the traditional controller by integrated absolute error is used to evaluate the performance of the control method. The respective values are shown in Table 3. The solid inlet moisture and the set point in the air temperature is considered as a perturbation using the step change function. The comparison was made between the PID controller and MPC controller. Figure 3 shows comparison between PID and MPC methods to step change in solid inlet moisture from 2.4% to 5.3%. Here the response of the air outlet temperature of MPC is stabilized and applies to the set point without any offset with a stability time of 400 s. For the PID controller, the stability time was 900, as for the IAE, the value for MPC is 882 and PID is 3527. Thus, the performance of the controller MPC is better than PID in controlling air outlet temperature. Figure 4 shows comparison between PID and MPC methods to negative step change in solid inlet moisture from 2.4% to 1%. Here the response of the air outlet temperature of MPC and PID are stabilized and applie to the set point without any offset, as for the IAE, the value for MPC is 1024 and PID is 3478. Thus, the performance of the controller MPC is better than PID in controlling air outlet temperature, both controllers PID and MPC respond well for changing in solid inlet moisture content. Figure 5 shows comparison between PID and MPC methods to step change in set point air temperature from

398.7 K to 450 K. Here the response of the air outlet temperature of MPC and PID are stabilized and applied to the set point without any offset, as for the IAE, the value for MPC is 1109 and PID is 4201. Thus, the performance of the controller MPC is better than PID in controlling air outlet temperature. Figure 6 shows comparison between PID and MPC methods to negative step change in set point air temperature from 398.7 K to 350 K. Here the response of the air outlet temperature of MPC and PID are stabilized and applied to the set point without any offset, as for the IAE, the value for MPC is 1098 and PID is 4150. Thus, the performance of the controller MPC is better than PID in controlling air outlet temperature, both controllers PID and MPC respond well for changing in set point air temperature. The comparison between the PID and MPC methods confirms that the MPC stability is guaranted for all cases of simulation results conducted under various conditions. The MPC has a good potential for application to dryer process with desired properties.

Table 3: Comparison of control methods using absolute integral error.

Variable load	Step change	IAE for PID	IAE for MPC
Solid inlet moisture %	2.4-5.3	3527	882
	2.4-1	3478	1024
Set point air temperature K	399-450	4201	1109
	399-350	4150	1098

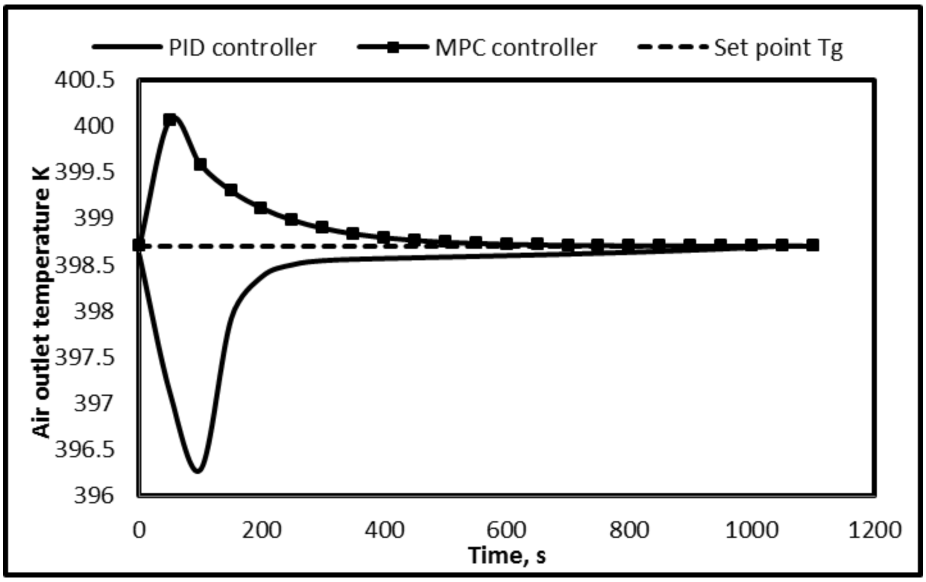

Figure 3: PID and MPC air outlet temperature responses due to a step changes in solid inlet moisture from 2.4% to 5.3% and manipulated variable was fuel flowrate at set point 398.7 K.

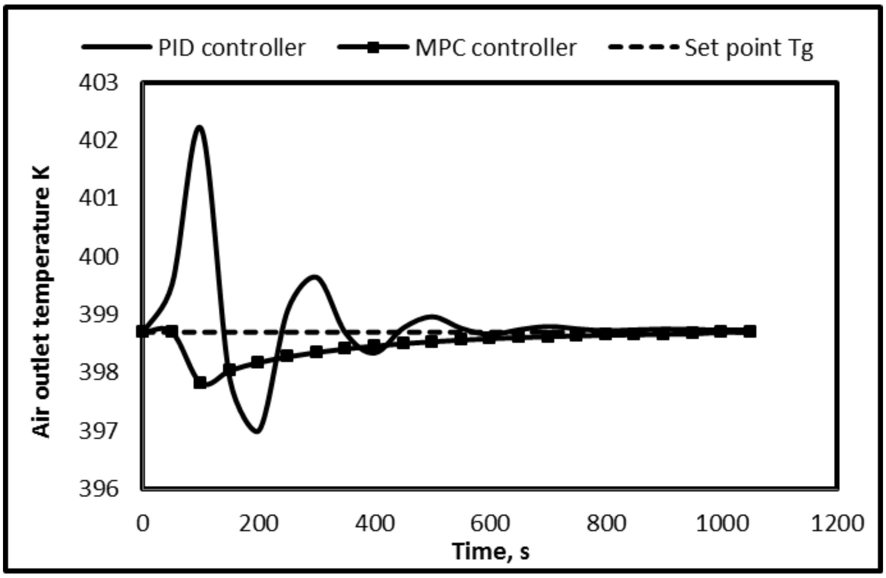

Figure 4: PID and MPC air outlet temperature responses due to a step-changes in solid inlet moisture from 2.4% to 1% and manipulated variable was fuel flowrate at set point 398.7 K.

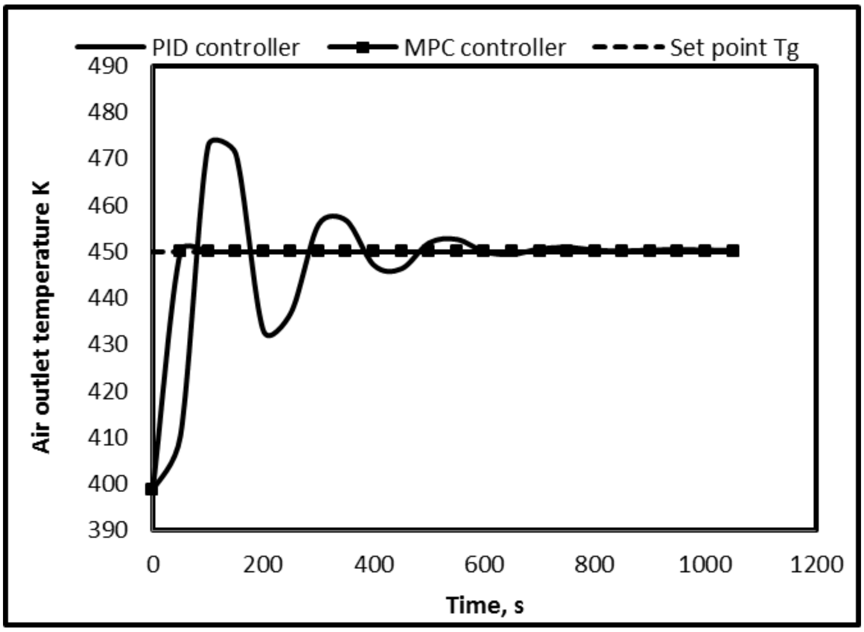

Figure 5: PID and MPC air outlet temperature responses due to a step changes in set point air temperature from 398.7 K to 450 K and manipulated variable was fuel flowrate at set point 450 K.

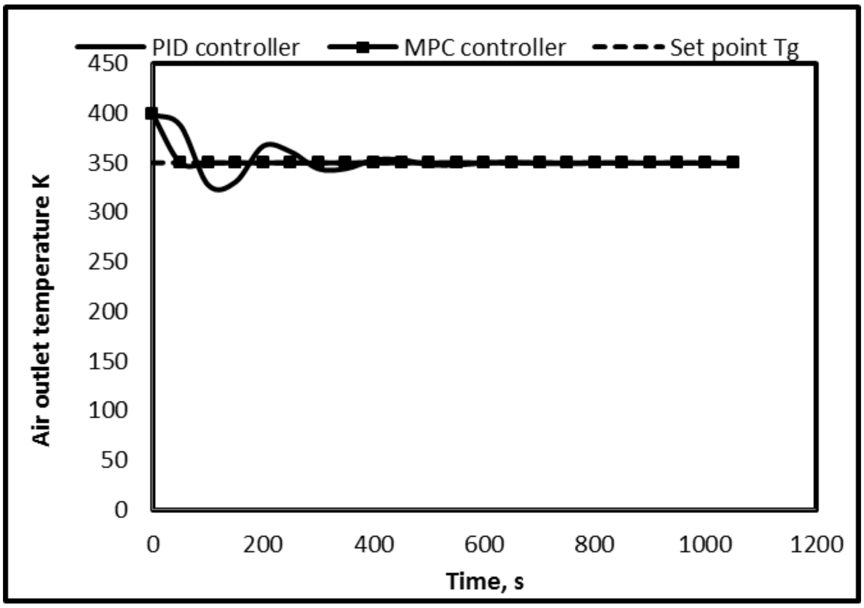

Figure 6: PID and MPC air outlet temperature responses due to a step changes in set point air temperature from 398.7 K to 350 K and manipulated variable was fuel flowrate at set point 350 K.

CONCLUSIONS

The paper introduces a dynamic simulation and control method for a rotary dryer. The simulation results showed that the stability condition predictions are in agreement with the Ylinimie[1] simulation results. A comparison was made between the traditional control method and the advanced control method, which is the model predictive control. The simulation results showed the controller's preference for the predictive model in the rotary dryer, as the MPC controller gave better results. The comparison was made using the integral absolute error (IAE). The integral absolute error of the MPC controller was lower than the IAE of the PID controller.

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