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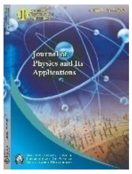

FOPDT Model Based on Experimental Data from Municipal Solid Waste Incineration Process Temperature Control in Fixed Bed

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ABSTRACT

Incineration is the waste combustion at controlled high temperatures which converts waste into flue gas with the main components being CO_2 and water. Temperature control aims to ensure safe combustion operation. In this study, the temperature controller uses a two-position temperature controller whose main components include two thermocouples, MAX6675, two burners, blower, Arduino, and one laptop. Temperature controllers were used to maintain the temperature in the combustion chamber and afterburner at the specified setpoint, namely 630°C and 850°C, respectively. To test the performance of the controller, two models were made. The modeling was made using the experimental data obtained. The results show that the model and experimental results are in good agreement.

1. Introduction

Incineration is one of the popular methods for waste management because this is capable to reduce, to produce energy, and destroy pathogen agents [1,2]. Mass combustion technology has been widely used to solve solid waste disposal problems such as in China and Japan [3]. There are 1179 incinerators in the worldwide that are used to generate electricity with a capacity of 700,000 tons/day [3]. The combustion process in primary chamber is included four successive sub-processes: drying, pyrolysis and volatile matter burning and char gasification, with the consequent formation of ashes.

Incineration is a super-stoichiometric high temperature solid waste combustion technique by applying a certain amount of oxygen. The incineration operating temperature ranges from 750-1100°C [4]. Combustion produces hot flue gases, mainly CO_2 and H2O. The incineration is a simple and proven technique that offers flexibility in processing solid fuels with a wide variety of compositions, sizes and properties. In addition, it is very suitable for treating waste containing toxic substances, because of the high operating temperature and the development of stack with adequate gas cleaning systems. Currently, the waste incinerators are classified mainly into fuel bed (fixed, moving, rotating) and fluidized bed [5–7].

Over the past 1 decade, many studies have been carried out on incineration processes, one area of major interest is the numerical model of waste incineration along with experimental validation [8–10]. A numerical model may be built on the basis of dynamic and thermodynamic models, but these models are usually too complex to be used in real-time control. The simplest of real-time control is two positions control to maintain control between two set points. The two positions temperature controller is the easiest controller to apply after the fire has self-ignited.

The most important temperature control objectives are to maintain a high temperature and stabilize temperatures ≥ 850°C. At this temperature ensures crushing of pathogens [11]. Higher temperatures offer benefits regarding MSW dryness, residual carbon combustion ratio, reduction of emissions, and steam production [2]. Among the emissions, dioxins or polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) are the most harmful. Dioxins generation in post-combustion zones can occur in two ways, via heterogeneous (200–400°C) and homogeneous synthesis (400–800°C) [11]. Control of dioxin levels in the combustion gas of the waste incineration can be achieved primarily by controlling temperature in the combustion chamber [12].

The dynamics of many industrial processes can be modeled by a stable first-order transfer function plus dead time (FOPDT) [13–15]. This method based on process step measurement responses, are still important because they are simple physical interpretation, and its easy implementation in industrial environments [13,14].

The purpose of temperature control is to stabilize the incineration temperature at the desired value. Therefore, this paper presents a method to modelling temperature control in the primary and secondary chambers of the household scale fixed bed incinerator.

2. Methods

2. 1 Experimental rig

The incinerator consists of the main combustion chamber, an after-burner, a wet scrubber, and a stack with a sampling hole, shown di Fig. 1. The combustion chamber and after-burner shave dimensions of 605 mm in length × 900 mm in diameter and 900 mm × 250 mm × 150 mm, respectively. A channel is used to connect the combustion chamber to the after-burner directly above it. The walls of the incinerator can withstand heat of up to 1000 °C, made of refractory bricks. The sampling hole is in the stack at a height of 2500 mm from the ground. The combustion chamber has a door 900 mm in diameter where the feedstock to be combusted enters. Experimental Rig includes the incinerator, air supply section, burner, after burner, and temperature monitoring and control system. The capacity of the incinerator is 30-80 kg/hr. of waste.

The required combustion air enters combustion chambers through the burner and after burner. Burner and after burner are tilted 45^{o}C and perpendicular, respectively.

Temperature monitoring is essential for process control by measuring temperatures in several critical areas of the incineration plant and for complying with incineration rules (i.e. 850°C/2s). The feeding process is continuous for one hour. The control operation is to control the combustion temperature. In this process, liquefied petroleum gas (LPG) is added to keep the temperature at a given setpoint.

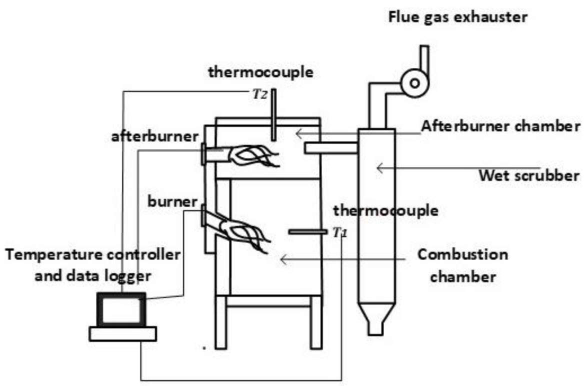

Fig. 1: Experimental rig.

Fig. 2 shows the flowchart temperature monitoring and control system. The temperature is using a K-thermocouple. Serial communication using Arduino. The relay functions to turn on/off the burner. The thermocouple T1 is placed on the combustion chamber door opposite the burner. The T2 thermocouple is mounted at the top of the afterburner chamber. All parameters are controlled via a computer.

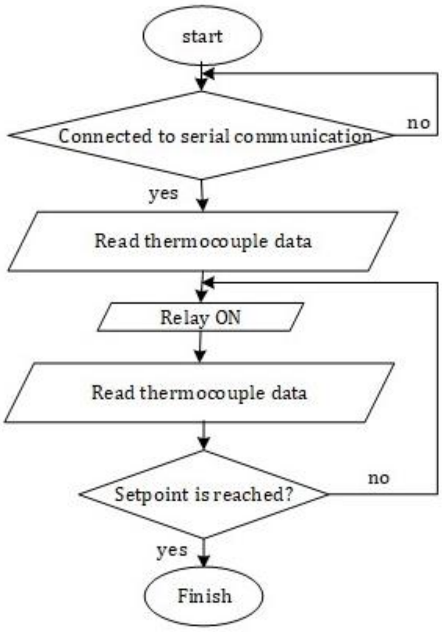

Fig. 2: Flowchart temperature monitoring and control system.

The two-position control strategy, which is the simplest automatic controller, inexpensive, simple construction, and energy saving capability. The controller output signal is $m\ (t)$ and the driven error signal is $e\ (t)$. In a two-position controller, the signal u(t) remains at its maximum M_1 or minimum M_2 value, depending on whether the actuation error signal$e\ (t)$ is positive or negative, so

$$m(t) = M_1\ for\ e(t) > 0$$
$$m(t) = M_2\ for\ e(t) < 0$$
$$e(t) = r(t) - y(t) \qquad (1)$$

Where M_1 and M_2 are constants, r (t) is the setpoint, and y (t) is the process output or controlled variable. The minimum value M_2 is usually either zero or $-M_1$.

2.2 FOPDT Model

In most control systems with feedback loops, the system cannot respond instantly to any disturbance and it takes time (delay) until the controller output gives any action on the measured output. This delay time is known as dead time. The first-order plus time delay (FOPTD) is a model the most commonly used to describe the dynamics of many industrial processes.

In the case of an incinerator, if the access door is opened, the temperature drops, the controller senses the difference, turns on the burner and the temperature is brought back to the setpoint, this takes time. Dead time has the effect of hiding disturbance from the controller and limiting its ability to react quickly. The transfer function $Gp(s)$ has the form [13,16–19]:

$$G_p(\mathrm{s}) = \frac{Y(s)}{M(s)} = e^{-\tau s}\frac{K}{Ts+1} \qquad (2)$$

where $Y(s)$ and $M(s)$ are output and input process, respectively. K is the gain of the system (K≠ 0), τ is the time delay and T is the time constant (T>0). Eq. (2) is written in the form of a differential equation (16):

$$y(t) + T\frac{dy}{dt} = Km(t - \tau) \qquad (3)$$

Eq. (2) and Eq. (3) is used to obtain for the FPODT approximation model. This model requires three parameters. These parameters provide important information about the behavior of the process variable (PV) which is measured whenever there is a change in the controller output signal (CO): (a) process gain K (tells the direction and how far the PV will travel), (b) Process time constant T (the length of time the PV moves after starting its response), (c) Process dead/delay time τ (delay time before the first PV begins to respond).

3. Results and Discussion

Both primary and secondary combustion chamber temperatures are controlled automatically using microcontroller by a two-positions controller with relay. The temperature in each chamber is monitored, this is controlled based on feedback from the thermocouple. Auxiliary burners are used to maintain the setpoint. Fig.3 shows the results of temperature control in the primary and secondary rooms.The combustion temperature setpoints in the primary and secondary chambers are 630°C and 850°C respectively. The determination of the setpoint is based on the temperature at which the pyrolysis occurs. Pyrolysis typically occurs at temperatures ranging from 300°C and 650°C (20,21). These graphs show that the initial or ambient temperature is 27°C.

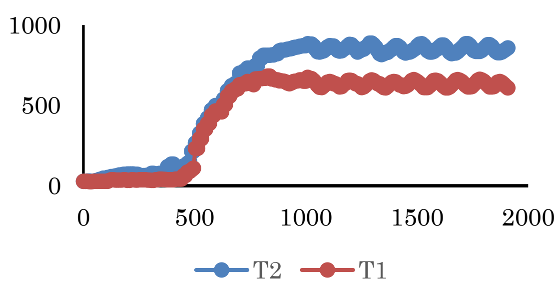

Fig. 3: Experiment Data of incineration on-off temperature control.

Experimental two positions controller performance testing is also carried out using the model. In this model, the model for thermal dynamics is derived only based on the recorded two-position controller response data. Examination of the recorded data shows that the dynamics of the thermal combustion process is a first order system.

From the investigation data recorded in Fig. 3, the temperature control parameters obtained are presented in table 1. The models are simulated using MATLAB based on table 1. The values rise time 1 and rise time 2 are the times where the response attains 28.3% and 63.2% of its final value. The calculations of the first-order-plus-deadtime responses are:

Setpoint 650°C:

$$G_{p1} = e^{-472s}\frac{609}{85.5s + 1}$$

Setpoint 850°C:

$$G_{p2} = e^{-410s}\frac{825}{216s + 1}$$

Table 1. Temperature Control Parameter.

Chamber	Setpoint (°C)	Steady State (°C)	Settling time (s)	Rise Time 1 (s)	Rise Time 2 (s)
Primary (red)	630	636	1035	500	557
Secondary (blue)	850	853	1044	481	626

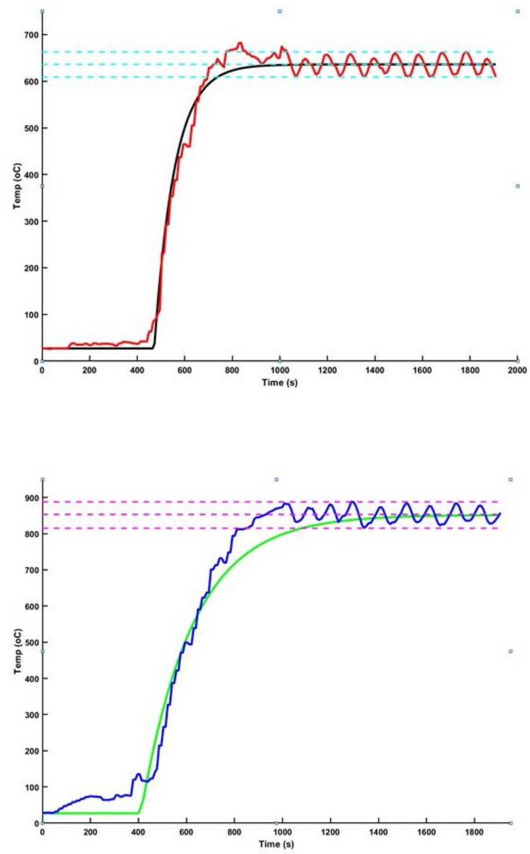

Fig. 4: Experimental vs simulated response to step change for setpoint (a). 630°C, (b). 850°C.

Fig. 4(a) –(b) show the model responses. The black and green line in graph represent the responses of the model in the primary and secondary chamber. The dotted lines in the middle indicate steady state. The model and the experimental data are in good agreement.

4. Conclusion

In this paper, a method for modeling the first order plus time delay is presented. The modeling is made based on the experiments that have been done. This model does not require complicated numerical calculations. This is derived based on the recorded two-position controller response data and the result shows in good agreement with the experimental.

5. Conflict of Interest

The authors declare that they have no conflict of interest.

Acknowledgements

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