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Original Article

Effects of highly preheated combustion air on characteristics of burner operation and fuel consumption in controlled-air incinerator

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Abstract

A experiment was conducted in a laboratory scale controlled-air incinerator in to observe the effect of secondary combustion air temperature to secondary burner operation and its fuel consumption. Sawdust was partially burned in a primary combustion chamber while feeding with primary air at 30% of stoichiometric condition. An incomplete product of combustion flowed into the secondary combustion chamber to be re-burned with preheated secondary combustion air. It was discovered that increased secondary combustion air temperature affected the characteristics of the operation of the secondary burner and reduced its fuel consumption to a factor of 7.7 and 22.9% at a preheated secondary combustion air temperature of 500°C and 1000°C, respectively.

Keywords : auxiliary fuel consumption, highly preheated combustion air, controlled-air incinerator

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1. Introduction

A controlled-air incinerator is commonly used to destroy unwanted waste. It is desirable to operate the incinerator at a high enough temperature to sustain combustion in the chamber as well as to generate sufficient volatile combustion gases and heat to maintain the desired temperature level in the secondary combustion chamber (SCC), in order to eliminate health and environmental risks before being released into the environment. In the primary combustion chamber (PCC) and the SCC, the recommended U.S. EPA for infectious-material destruction is from 540°C to 980°C and 980°C to 1200°C, respectively (Jangsawang and Kerdsuwan, 2001). The temperature is controlled at near preset values by using an auxiliary fuel injection. This is done by using thermocouple signals from each chamber to the controller where they are compared to the preset values. A differential signal temperature is used to actuate the on-off control of the burners. The combustion chamber equipped with an auxiliary burner results in having increased operating costs that primarily come from the auxiliary fuel (Kerdsuwan, 2000a). To have a reduction in operating costs requires auxiliary fuel consumption to be reduced. From the site survey of existing hospital waste incinerators in Thailand by Kerdsuwan (2000b), it was found that the operating costs of conventional incinerators were between 0.20-0.25 US$/kg waste. However, a newly developed prototype controlled-air infectious waste incineration system was found to have operating costs per kilogram of waste of approximately 0.0625 US$ (Kerdsuwan, 2000b). Although this operating cost is lower than the conventional incinerators, it is still high and thus does not appeal to the waste treatment process of incineration. Preheated combustion air is not a new technology. On the contrary, it has previously attracted numerous studies. The high temperature air com-

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bustion technique has been developed over the past 15 years as its merits in saving energy, enhancing flame stability and reducing NO_x emissions all show promising applications in various processes of industrial power and energy conversions. As a result a number of researches have mainly been focused on industrial furnace and burner technology (Nishimura *et al.*, 1996; Wünning and Wünning, 1997; Flamme, 2001; He *et al.*, 2004; Weber *et al.*, 2005; Yang and Blasiak, 2005). Highly preheated combustion air is believed to have potential in solid waste thermal treatment for reducing auxiliary fuel.

Thus, the research and development of incineration technology to burn waste with minimum auxiliary fuel requirements is worth investigating. In this research, the operating costs of incinerators and characteristics of the auxiliary burner operation were investigated using different highly preheated secondary combustion air.

2. Experimental section

2.1 Apparatus

A schematic diagram of laboratory-scale controlled-air incinerator is illustrated in Figure 1. The incinerator has two combustion chambers made of 3mm thick mild steel, thermally insulated inside with 5mm ceramic fiber and lined with 5mm of castable cement. Sawdust was burned under substoichiometric conditions with the primary air supply in the PCC, and volatile gases were expelled from the PCC and passed to the SCC. The secondary air was preheated by an electric heater at a different temperature before being introduced into SCC. The air supply system consists of 11 kW two-stage air compressor equipped with air filters with maximum pressure set at 8 bar at the accumulator and maximum flow rate of 45 Nm^3/h. Mass flow meters with an accuracy of ±1%, using a thermal mass flow sensing technique, were used to control the flow rate of the combustion air ranging between 0 to 60 Nm^3/h and 0 to 10 Nm^3/h. A primary burner in the PCC with a capacity between 14-39 kW and a secondary burner with a capacity between 30-60 kW were used to preheat the combustion chambers. The temperature in the SCC was controlled to near preset values (1000°C) by using thermocouple signals inside the SCC linked to the temperature controller (Sigma Model: SF-48) where it was compared to the preset values. The differential signal temperature was used to actuate the on/off control of the secondary burner. Fuel material was continuously fed into the PCC by a fuel feed system, which consisted of a hopper, a screw feeder, and a 0.37kW AC synchronous, 3-phase motor inverter.

2.2 Measurement and data acquisition systems

Chromel-alumel thermocouples (K-type) with diameters of 1.6 mm protected by ceramic rods were used for continuous measurement of the temperature. Temperature controller sensed the thermocouple signal (T_2) and compared it to the preset value. All data signals were sent to the data logger (Yokogawa: DA100 & DS600) and were shown in real time on a personal computer. By reading a scale in the fuel tank, fuel consumption was recorded at between 0-500ml.

2.3 Raw material and auxiliary fuel

Sawdust measuring between 0.85-5mm was used as feedstock in this study. The properties of sawdust are given in Table 1. Diesel oil was used to fuel the burners in both the combustion chambers.

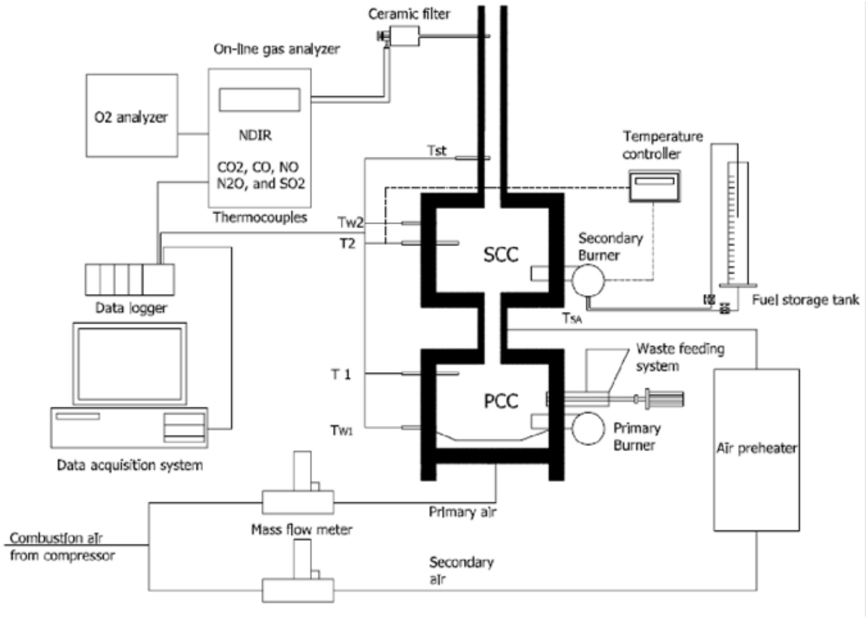

Figure 1. A schematic diagram of a lab-scale controlled-air incinerator.

Table 1. Average properties of sawdust.

Properties	As-received basis	Dry ash-free basis
Proximate analysis (%wt)		
Moisture	8.45	-
Ash	2.20	-
Volatile matter	73.40	82.15
Fixed carbon	15.95	17.85
Ultimate analysis (%wt)		
Carbon, C	51.20	57.35
Hydrogen, H	6.50	6.20
Nitrogen, N	0.055	0.065
Sulphur, S	0.06	0.07
Oxygen, O	40.00	36.35
Ash	2.20	-
Net calorific value, kJ/kg	18,000	20,300

2.4 Experimental procedures

Diesel oil burners were used to preheat the PCC and the SCC to a required preheated wall temperature of 500°C and 700°C, respectively. At the same time, primary air and preheated secondary air were supplied into the two chambers at feed rates of 5.77 m^3/h (equivalent to 30% of stoichiometric air) and 15.40 m^3/h, respectively. The total air provided was in excess of 10%. When the wall temperatures reached the required values, the primary burner switched off. Thereafter, sawdust was fed at 3.5 kg/h. The temperature was continuously recorded and shown in real time on a personal computer. The diesel oil level was measured every two minutes.

3. Results and Discussion

3.1 Temperature history

The temperature history for different secondary combustion air at preheated temperatures is illustrated in Figures 2, 3 and 4, presenting non-preheated secondary air and preheated secondary air at 500°C and 1000°C, respectively. The temperature history shows the same trend in Figures 2, 3 and 4. The SCC particularly shows an oscillating temperature as the result of the characteristics of the secondary burner operation. An increase in temperature was the result of the secondary burner switching to the on position and a temperature decrease resulted when the secondary burner was switched to the off position. When the controlling temperature (T_2) reached the preset value (1000°C), the temperature signal was sent to the temperature controller unit, which then sent a command to the secondary burner to switch off. The heat from the combustion of a volatile gas is not enough to lift-up the temperature in the SCC to the required degree. The temperature in the SCC dropped after the secondary burner was switched off. After a certain amount of time, the secondary burner switched on again after which the temperature increased. It was discovered that the feeding of secondary air at an ambient temperature resulted in a maximum drop in temperature compared to the other conditions. The minimum temperature drop was shown in the case of preheated secondary air at

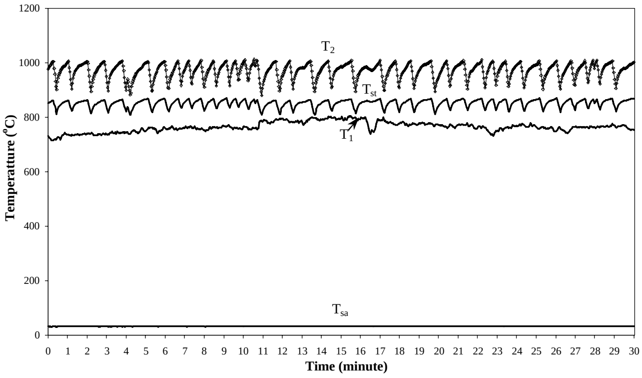

Figure 2. Temperature history at non-preheated secondary air.

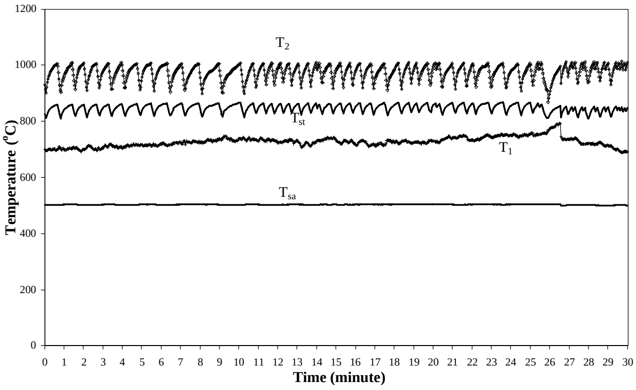

Figure 3. Temperature history at preheated secondary air temperature at 500°C.

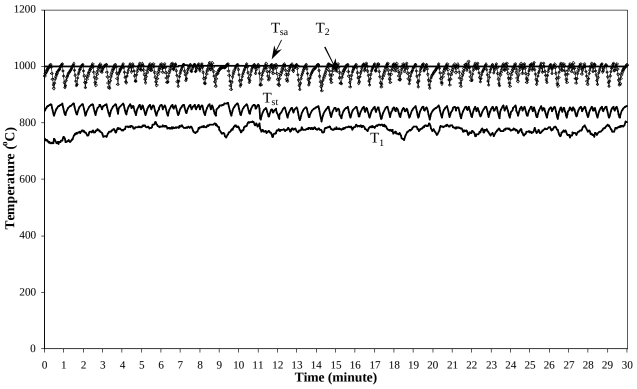

Figure 4. Temperature history at preheated secondary air temperature at 1000°C.

1000°C. These results can be observed by the characteristic operation of the secondary burner. The number of the secondary burner switching to the on position along the testing period is counted from temperature history graphs; the higher the temperature of preheated secondary air, the higher the frequency of the secondary burner switching to the on position, as illustrated in Figure 5. From Figure 5, the frequencies of the burner being switched on were 39, 58, and 90 times for ambient temperature, preheated secondary air at 500°C, and 1000°C, respectively. This had an impact on the fuel consumption rate of the secondary burner.

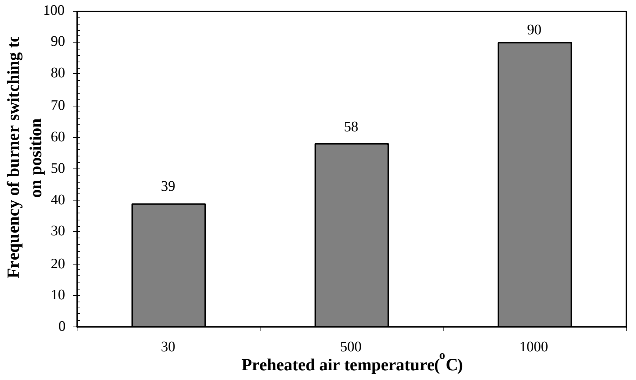

Figure 5. Frequency of secondary burner switching to on position.

3.2 Secondary burner operation characteristics

The controlling temperature signal (T_2) was analyzed for all case studies and is shown in Figure 6. The temperature controller was set at 1000°C to switch the burner to the off position, after which the temperature signal drop and the burner switched to the on position. The average maximum ($T_{\max,ave}$) and minimum temperatures ($T_{\min,ave}$) and their difference (ΔT) were calculated. The cycle time was also determined and is defined as the time counted from off to off or on to on position. As a result of the study, it was discovered that there was no significance in the difference of the overage maximum temperatures. By contrast, the average minimum temperatures significantly vary depending on the secondary air temperature: 907°C, 920°C, and 935°C in case of non-preheated secondary air, 500°C preheated secondary air and 1000°C preheated secondary air, respectively. The lowest drop in the average minimum temperature was found in the higher preheated combustion air temperature where the lowest difference in temperature had a value of 72°C at the preheated secondary air temperature of 1000°C. The preheated secondary air temperature not only showed a drop in temperature signal, but also had a decrease in the cycle time of the signal as shown in the values 50, 32 and 17 seconds for nonpreheated air, preheated at 500°C and preheated at 1000°C, respectively.

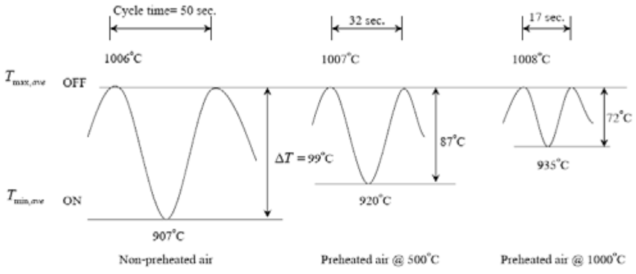

Figure 6. Control temperature signal analysis.

3.3 Auxiliary fuel consumption

Auxiliary fuel consumption of the secondary burner was related to the operating time as shown in Figure 7. The correlation of auxiliary fuel consumption with time (minutes) for non-preheated air, preheated at 500°C, and preheated at 1000°C are 38.73X, 35.74X, and 29.86X, respectively. The correlation of the rate of fuel consumption with preheated air temperature was analyzed and is shown in Figure 8. The results show that the secondary air temperature supplied at an ambient condition consumed auxiliary fuel at the highest rate of 0.664 l/kg-sawdust. The rate of fuel consumption was lower at the higher secondary combustion air temperature at 0.613 l/kg-sawdust, and 0.512 l/kg-sawdust for preheated air temperatures of 500°C and 1000°C, respectively. Thus, increasing combustion air temperature experimentally proved to have an affect on the reduction of the fuel consumption of the secondary burner at a factor of 7.7 and 22.9% at preheating air temperature of 500°C and 1000°C, respectively. The fuel consumption rate is related to the secondary burner operation characteristic. Fuel consumption is less when there is a higher frequency of the burner being switched on/off.

4. Conclusions and Recommendation

The secondary combustion air temperature enhances

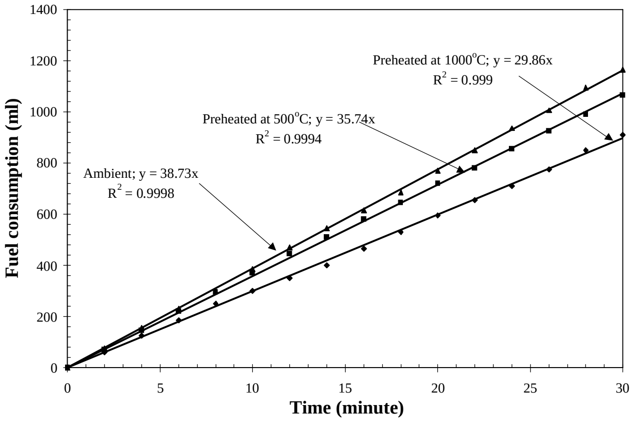

Figure 7. Correlation of fuel consumption with preheated air temperature.

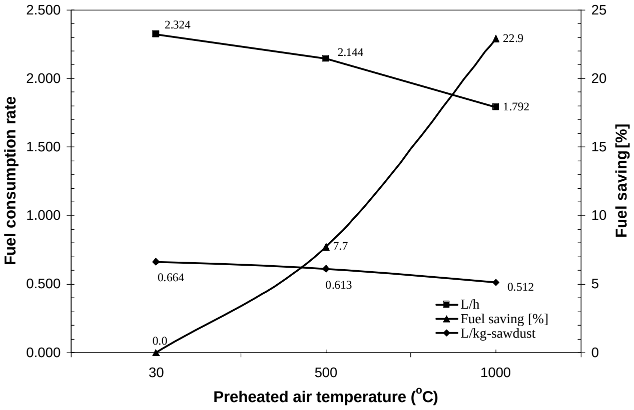

Figure 8. Fuel consumption rate and fuel saving at different preheated air temperature.

the fuel saving concept in reducing the operating costs for thermal destruction of solid waste. The higher temperature or higher enthalpy of combustion air results in a lower drop of signal temperature after the secondary burner is switched off. This is represented by the curves of the temperature history, characteristics of the secondary burner. It was found that an increase in combustion air temperature increases the frequency of the secondary burner being switched on/off and decreases the difference on the signal temperature and cycle time to reduce secondary burner fuel consumption at a factor of 7.7 and 22.9% at preheating air temperatures of 500°C and 1000°C, respectively.

The preheated secondary air temperature is to be kept constant throughout the entire lab-scale experiment. Therefore, electrical air heater with automatic temperature control was used instead of heat exchanger. Electrical air heater might not be used in the real application and can be replaced with heat exchanger to recover heat from flue gas to preheat combustion air. However, whether it is an economical success or what an appropriate air temperature should be, further tests are required beyond the scope of this experiment and shold be conducted during the real applications.

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References

Flamme, M. 2001. Low NO_x combustion technologies for high temperature application. Energy Conversion and Management. 42, 1919-1935.

He, R., Suda, T., Takafuji, M., Hirata, T., and Sato, J. 2004. Analysis of low NO_x emission in high temperature air combustion for pulverized coal. Fuel 83, 1133-1141.

Jangsawang, W., and Kerdsuwan, S., 2001. Optimization of the operating conditions of infectious waste incineration in a controlled-air incinerator: effects of primary chamber temperature on the combustion efficiency. *In*: 94th Annual Conference of Air&Waste Management Association, Orlando, Florida, USA, 24-28 June.

Kerdsuwan, S., 2000a. Experience of hospital waste incineration in Thailand, *In*: ISWA Symposium in Solid Waste Management, Hong Kong Waste Management Association, Hong Kong.

Kerdsuwan, S., 2000b. On the performance testing of the 50 kg/hr prototype controlled-air infectious waste incineration system. In: 16th International Conference on Solid Waste Technology and Management, Philadelphia, USA, 10-13 December.

Nishimura, M., Suzuki, T., Nakanishi, R., and Kitamura, R. 1996. Low-NO_x combustion under high preheated air temperature condition in an industrial furnace. Energy Conversion and Management. 38, 1353-1363.

Weber, R., Smart, J.P., Kamp, W. 2005. On the (MILD) combustion of gaseous, liquid, and solid fuels in high temperature preheated air. Proceeding of the Combustion Institute. 30, 2623-2629.

Wünning, J.A., and Wünning, J.G. 1997. Flameless oxidation to reduce thermal NO-formation. Progress in Energy and Combustion Science. 23, 81-94.

Yang, W., and Blasiak, W. 2005. Numerical study of fuel temperature influence on single gas jet combustion in highly preheated and oxygen deficient air. Energy 30, 385-393.