Possibility of Refuse Derived Fuel Fire Inception by Spontaneous Ignition

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Abstract

The possibility of fire inception caused by spontaneous ignition of piled RDF was elucidated. Various properties of RDF were measured. Pyrolysis behavior of RDF was examined by TG-DTA and apparent activation energy of RDF was calculated. In addition, the critical ignition temperature (T_c) of RDF was predicted by the theory of thermal explosion by Frank-Kamenetskii, and the relation between the T_c and the height of RDF pile was calculated. The results show that the relation between the T_c and the height of RDF pile is almost identical for RDFs of different states, although the thermal conductivity and bulk density of RDF sample depend on its state. This implies that the powdering of RDF does not lower the T_c largely.

1. Introduction

On August 2003, serious fire and explosion occurred at a refuse derived fuel (RDF) power station in Mie Prefecture, Japan. In the fire and explosion, two fire fighters were killed and 5 workers wounded.

The fire occurred in a RDF storage, where no ignition source was reported. In the initial stage of investigation, the cause of the fire was considered to be spontaneous ignition of piled RDF [1-6]. The process of spontaneous ignition of this fire needs to be confirmed by experiments and/or theoretical analyses. The present study has been conducted to investigate this process [6].

It is true that effective energy recovery of municipal solid waste is important for protection of global environment. One of these methods is the use of RDF, which is produced by shredding, screening, drying and pelletising. For effective energy recovery, a large-scale power station is needed. In such a power station, a large capacity storage is constructed for continuous operation.

The objective of this study is to elucidate the possibility of fire inception caused by spontaneous ignition of piled RDF. Various properties of RDF were measured. Pyrolysis behavior of RDF was

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examined by TG-DTA and apparent activation energy of RDF was calculated. In addition, the critical ignition temperature (T_c) of RDF was predicted by the theory of thermal explosion by Frank-Kamenetskii, and the relation between the T_c and the height of RDF pile was calculated.
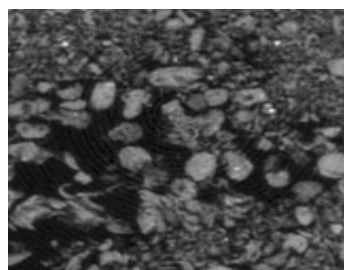
2. Experimental

Three kinds RDF were used to predict the possibility of fire inception by spontaneous ignition. RDF-A was the sample from the crash site in Mie Prefecture. RDF-B and RDF-C were made from municipal solid waste by different manufacturing factories of RDF. Figure 1 shows the photographs of RDF. Table 1 is the results of analyses of three kinds RDFs. The result of analysis shows that the various properties of RDFs are almost similar except for the moisture.

To examine the pyrolysis and combustion characteristic of RDF by TG-DTA analyses, RDF was crushed. The experimental conditions of TG-DTA are as

Table 1 The results of analysis of tested RDF

analysis item	unit	RDF-A	RDF-B	RDF-C
moisture		26.8	2.9	7.3
ash	(wt%)	12.9	11.4	11.7
volatile matter		72.6	76.3	74.7
fixed carbon		14.5	12.3	13.6
higher calorific value	(MJ/kg)	22.84	22.94	21.44
lower calorific value		21.22	21.34	19.96
C		51.8	47.6	46.2
H		7.11	7.04	6.60
N	(wt%)	1.11	1.12	1.30
S		0.54	0.59	0.48
Cl		0.80	0.9	0.53
Ca		2.2	2.1	2.7

follows: the reaction atmospheres are nitrogen and air for pyrolysis and combustion, respectively; The gas flow rate is 50 ml / min; About 10 mg of crushed RDF sample is heated at constant heating rate of 10 °C / min; The final temperature is raised to 1000 °C.

The thermal conductivity of RDF was measured by the laser flash method (state of RDF is pellet) and the needle probe method (state of RDF is powder).

The heat of reaction of RDF is calculated and the value of ΔH is assumed to be 5.5 % higher calorific value than the measured one because the mass loss rate is 5.5 % at the ignition temperature of RDF by TG curve. The specific heat of RDF is measured using the DSC (Differential Scanning Calorimeter). The various properties of RDF are shown in Table 2.

Digital camera

X-ray CT image

Fig.1 Photographs of RDF

Table 2 Conductivity and bulk density of RDF sample

properties of RDF	unit	powder	pellet
measurement temperature, K	(K)	298	298
gas constant, R	(J mol^{-1} K^{-1})	8.31	8.31
bulk density, ρ	(kg m^{-3})	4.21×10^2	9.91×10^2
specific heat, c	(J kg^{-1} K^{-1})	1.42×10^3	1.42×10^3
thermal diffusivity, α	(m^2 s^{-1})	9.80×10^8	1.21×10^7
thermal conductivity, λ	(J s^{-1} m^{-1} K^{-1})	5.87×10^2	1.62×10^1
apparent activation energy, E	(J mol^{-1})	89.82×10^3	-
apparent frequency factor, A	(s^{-1})	3.60×10^5	-
heat of reaction, ΔH	(J kg^{-1})	1.26×10^6	-
δ c (cube)	-	2.52	-
δ c (infinite cylinder)	-	2.00	-
δ c (infinite plane layer)	-	0.88	-

3. Results and Discussions

3.1 Pryolysis behavior of RDF

Pyrolysis behavior of RDF was examined by TG-DTA. Figure 2 shows a TG curve of RDF in the air atmosphere. Pyrolysis of RDF takes place with about three stages. It seems that RDF dehydrated in a range of temperatures from room temperature to 150 °C, and pyrolysis of organic element and combustion took place in a range of temperatures from 150 °C to 550 °C. Carbide component and inorganic element in RDF burned in a range of temperatures more than 550 °C. Pyrolysis processes of tested RDFs from other origins are similar to that presented in Fig.2.
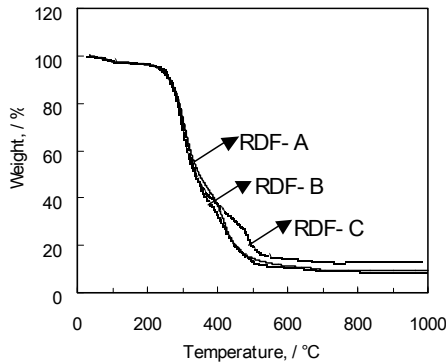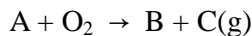

Fig.2 TG curve of RDF in the air atmosphere

3.2 Calculation of apparent activation energy

The combustion reaction of the combustibles in RDF can be expressed as:

$$A + O_2 \rightarrow B + C(g)$$

Since the concentration of O_2 is excessive, the rate for the disappearance of reactant of A from the mixture can be expressed as follows:

$$\frac{d\alpha}{dt} = k(1-\alpha)^n, \qquad (1)$$

where α is the conversion of combustion reaction, k is the reaction rate constant, n is the reaction order, and t is reaction time.

According to the Arrhenius expression, the reaction rate constant can be expressed as

$$k = Ae^{-E/RT}, \qquad (2)$$

while heating rate can be given by

$$\phi = \frac{dT}{dt} \qquad (3)$$

Substitutions of Eqs.2 and 3 into Eq.1 lead to the following equation:

$$\frac{d\alpha}{dT} = \frac{A}{\phi}e^{-E/RT}(1-\alpha)^n, \qquad (4)$$

where E is the apparent activation energy, A is the apparent frequency factor and ϕ is the heating rate, respectively.

In determination of the kinetic parameters by means of the above equations, various analysis methods have been suggested [7-11]. In the present study, the nonisothermal analysis method proposed by Ito et al. was used [11].

Introducing logarithm into Eq.4, the following equation is obtained:

$$\ln\left[\frac{\frac{d\alpha}{dT}}{(1-\alpha)^n}\right] = \ln A - \frac{E}{RT} \qquad (5)$$

The values of $d\alpha/dT$, α, and T can be obtained from results of TG analysis. α can be calculated from the weight-losing curve of TG using the following equation:

$$\alpha = \frac{(w-w_0)}{(w_c-w_0)} , \qquad (6)$$

where w_0, w, and w_c are the sample weight before the combustion reaction, in the combustion reaction, and after the combustion reaction, respectively.

To determine the apparent kinetic parameters in Eq.5, combustion is generally analyzed as a first-order reaction. Assuming that n is equal to 1, the calculated results of the left-hand term in Eq.5 are plotted against the reciprocal of absolute temperature. It shows a straight line in $\ln((1-\alpha)^{-n}(d\alpha/dT)\phi)$ versus $1/T$, and then the apparent activation energy E and the apparent frequency factor A can be obtained from slope and intercept of the straight line according to Eq.5. It is seen that the apparent activation energies and the apparent frequency factors are different in different reaction stages. To predict the possibility of RDF fire inception by spontaneous ignition, it is important that considering the effect of the apparent activation energy under ignition temperature on spontaneous ignition of RDF. Since the ignition temperature of RDF is 240 °C, while RDF was dehydrated from room temperature to 150 °C, so the apparent activation energy of RDF between 150 °C-240 °C was calculated. The value of the apparent activation energy E and the apparent frequency factor A are 89.82 kJ / mol and 3.60×10^5 1 / s, respectively.

3.3 Prediction of critical ignition temperature (T_c) on the basis of the thermal explosion theory of Frank-Kamenetskii

The ignition phenomenon has been explained or predicted on the basis of thermal explosion theories, such as the Semenov, Frank-Kamenetskii and Thomas theories [12-18]. Considering that RDF is practically stored with a large pile (the size of storage of RDF in Mie Prefecture is 15 m in inside diameter and 25 m in height), in which temperature is not uniform due to low thermal conductivity. Therefore, in the present analysis using the Frank-Kamenetskii theory, an assumption of non-uniform temperature is adopted.

The theory of Frank-Kamenetskii is shown by the following expressions [13]:

$$\delta_c = \frac{\Delta H \cdot E \cdot r^2 \cdot A \cdot C_0^{\,n}}{\lambda \cdot R \cdot T_c^2} \exp\left(-\frac{E}{R \cdot T_c}\right), \quad (7)$$

where ΔH, E, A, R and C_0 are the heat of reaction, the apparent activation energy, the apparent frequency factor, the gas constant and the initial concentration of sample, respectively. The RDF is solid, and the initial sample density is considered to be equal to the bulk density of RDF. n is a reaction order, and in the present study, the pyrolysis reaction of RDF can be assumed to be of a first-order, i.e., n is equal to 1. In Eq.7, δ_c, λ, and r are the critical parameter for explosion, thermal conductivity of sample, and radius of the RDF pile, respectively. T_c is the critical ignition temperature.

Napierian logarithm is taken and arranged in both sides of the Eq.7. Then it becomes as follows:

$$\ln T_c + \frac{E}{2R \cdot T_c} = \ln r + \frac{1}{2}\left(\ln\frac{\Delta H \cdot A \cdot E \cdot C_0}{\delta_c \cdot \lambda \cdot R}\right) \quad (8)$$

Each parameter about RDF shown in Table 2 is substituted to Eq.8. Consequently, the relation between the T_c and the height of pile of RDF can be predicted. Figure 3 shows the result.

It is seen that T_c decreases with the height of RDF pile. The T_c is lowest in the case of infinite plane layer of T_c in the cases of other configuration of similar thicknesses of RDF piles. For the RDF stored in a storage, the prediction for an infinite cylinder was adopted to investigate the relation between the T_c and the height of the RDF pile. For example, when RDF is assumed to store up to 5 m in height, the T_c

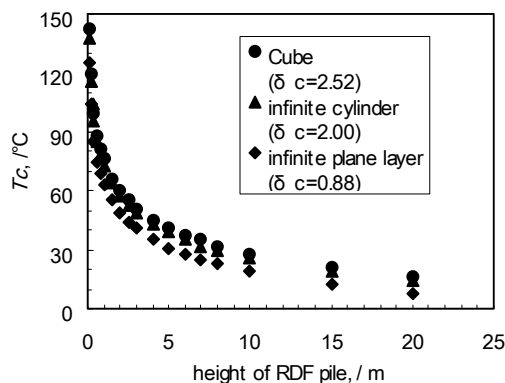is about 40 °C. While in the case of Mie Prefecture, RDF was stored in a storage that

T_c and the height of RDF pile are the heat of reaction ΔH, the apparent activation energy

Fig.3 The relation between the T_c and the height of RDF pile
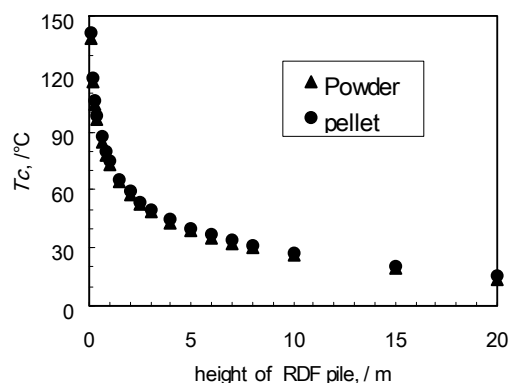
Fig.4 Effect of the RDF state on the relation between the T_c and the height of RDF pile

the inside diameter is 15 m, the T_c will be about 20 °C. It means that the process to store RDF in a large pile, there is a possibility that a fire happens even though the surrounding environmental temperature is the room temperature. In fact, serious fire and explosion have occurred at the RDF power station in Mie Prefecture, Japan on August 2003.

3.4 Effect of the RDF state on the possibility of fire inception

It was considered that crushed RDF causes the fire by spontaneously igniting in a RDF pile at the initial stage of investigation. To confirm effect of the RDF state on the possibility of fire inception, two kinds of RDF with different states (powder and pellet) are used.

It is seen that the thermal conductivity and bulk density of RDF sample depend on its state as shown in Table 2. The thermal conductivity of crushed RDF (powder) is lower than that of the pellet, and the bulk density of crushed RDF is smaller than pellet of RDF. When the critical parameter δ_c for explosion is constant, that is, in case of the state of the RDF pile is constant, the factors influencing the relation between the

E, the apparent frequency factor A, the thermal conductivity λ, and the initial concentration C_0 of sample (or bulk density ρ of sample), respectively. The effect of E is the largest because other influence factors are in the logarithm term. In addition, in the case when the bulk density and the thermal conductivity of sample decrease at the same time, it can be presumed that the value of ln (ρ / λ) scarcely changes. Figure 4 shows the calculation result of the relation between the T_c and height of RDF pile for various bulk densities and thermal conductivities. It is seen that the relation between the T_c and the height of RDF pile is almost identical for powder and pellet of RDF. This indicates that the powdering of RDF does not appreciably lower the T_c.

4. Conclusions

1. Pyrolysis processes of RDFs from different sources are similar and take place in three stages. The main process is pyrolysis of organic element and combustion that takes place in a temperature range of 150 °C-550 °C.
2. The apparent activation energy E at the

ignition temperature of RDF was calculated, which is 89.82 kJ / mol.

3. The critical ignition temperature (T_c) of RDF was predicted on the basis of the Frank-Kamenetskii theory, and the relation between T_c and the height of RDF pile was calculated. It is shown that 40 °C is enough to ignite RDF if the pile is 5 m in height.

4. Although the thermal conductivity and bulk density of RDF sample depend on its state, the relation between T_c and the height of RDF pile is almost independent of the state. This result implies that the powdering of RDF scarcely lower T_c.

Acknowledgement

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