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Autoignition of Urethane Foam to be Used as the Insulator of the Household Refrigerator

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Abstract : This study was performed by measuring the minimum ignition temperature of polyurethane form recovered from the recycling process of the end-of-life home appliances. The critical ignition temperature of polyurethane form was lower as the size of the sample vessel was increased, and that of polyurethane form using cyclopentane as the forming agent was relatively lower than the polyurethane form using CFC and the combustion of cyclopentane-polyurethane form occurred fiercely. It is considered that the recycling process of end-of-life home appliances using cyclopentane-polyurethane form as the insulator would require a special fire and dust explosion prevention measures since there exists a high potential hazard of fire and dust explosion during crushing and storage processes.

Key words : minimum ignition temperature, recycling process, polyurethane form, dust explosion

1. Introduction

As we enjoy the abundance of our lives based on the advanced industrialization, the demand for home appliances such as refrigerator and washing machine has grown drastically. As these end-of-life appliances are worn out and thrown away, they became the source of pollution and the relevant regulations have been much tighter throughout the world.

In Korea, recycling regulation has been implemented for those end-of-life home appliances such as refrigerator, washing machine, TV, air-conditioner and so on through the Resource Conservation and Recycling Promotion Law [1].

Recycling process that recycles the end-of-life home appliances recovers the reusable materials such as glass, plastics, copper, steel, aluminum, and polyurethane through disassembly → crushing → separating processes. Among these recycled materials, urethane is treated as the foam used as the insulator and bears the possibility of fire and explosion the crushing and separation process. In fact, there have been some urethane fire and explosion cases reported.

As the foaming agent for polyurethane during the manufacturing process, cyclopentane is used as the alternative to previous CFC that has been prohibited to use according to Montreal Protocol (1986). In this study, we wish to provide the base data for preventing any fire and explosion during the recycling processes by determining the auto-ignition characteristics of both types of polyurethane foams using CFC and cyclopentane, respectively.

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2. Experiment

2-1. Sample

As the sample for this experiment, we have used the raw polyurethane foam recovered by ○○ recycling company.

2-2. Experimental Apparatus

The experimental apparatus for this study is as shown in Fig. 1, comprised of sample vessel, oven, temperature controller, thermocouples, and appropriate recorder.

The sample vessel was made to allow the heat transfer in one dimensional direction between front and back using 300 stainless mesh and other parts were insulated using the asbestos plate of 1cm thickness as the infinite flat plate structure.

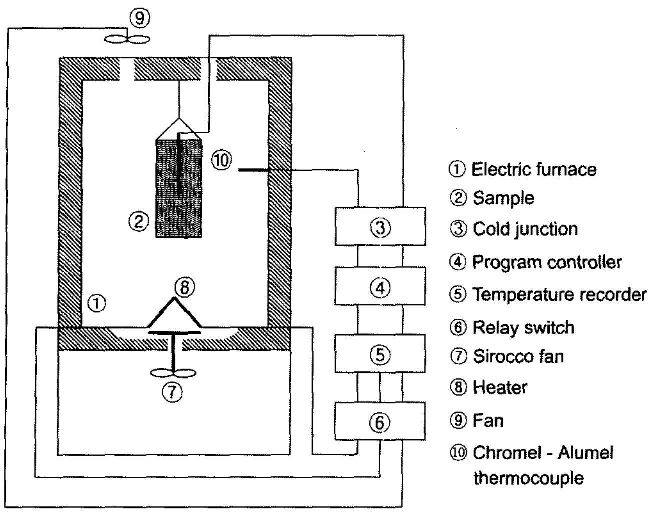

Fig. 1. Schematic diagram of experimental apparatus.

Different sizes of sample vessel (20 cm × 20 cm × 14 cm (width × height × thickness), 20 cm × 20 cm × 7 cm, 20 cm × 20 cm × 5 cm, and 20 cm × 20 cm × 3 cm) were used to determine the change in the auto-ignition temperature based on the thickness of the sample.

Hot-air circulating type oven of internal volume of 90 *l* (45 cm × 45 cm × 45 cm) was used with Sirocco fan attached for forced air circulation to constantly maintain the internal temperature distribution. Two heaters (1000W) that can raise the temperature up to 1200°C were installed in the oven.

For the temperature controller, Konic-made EC-5600 was used to control the ambient temperature by the program configuration. It controls the compensated temperature through cold junction, compares it to the setting temperature and controls the current value using that temperature deviation.

Two sets of Chromel-Alumel thermocouple with the diameter of 0.35 mm were used for measurement and control of the ambient temperature and sample's center temperature, respectively. The former was installed to the center between sample vessel and oven wall and the latter was installed to the center of sample vessel.

For the temperature recorder, Yokogawa-made pen type recorder was used to continuously record the setting temperature as well as the center temperature of the sample.

2-3. Experimental Procedure

Set the temperature control program for the auto-ignition experimental apparatus, hang the sample vessel filled with the sample polyurethane in the center of the pre-heated oven, and install the thermocouples to the center of the sample vessel and mid point between the oven wall and the sample vessel so that they are aligned at the same height.

By continually observing the change of center temperature after placing the sample vessel to the experiment apparatus, the moment when the center temperature was raised steeply that the set temperature, was considered as ignition and when it was maintained similar to the set temperature, was considered as non-ignition [2].

By repeating the experiments with the same condition, the experiment was ended when the temperature difference between the minimum ignition temperature of the sample and the maximum non-ignition temperature is 1°C. The average temperature between these two temperatures was determined as the critical auto-ignition temperature [3].

3. Result & Discussion

3-1. Polyurethane Foam using CFC

Fig. 2 shows the non-ignition status when the thickness of the sample vessel was 5 cm. When it was left in the oven for more than 6 hours with the setting temperature of 219°C, the inner sample temperature and the inner oven temperature were maintained almost the same, leading to non-ignition.

Fig. 3 shows the occurrence of ignition in about 30 minutes after setting the oven temperature to 220 as the inner sample temperature is suddenly increased to 372°C. Therefore, the critical auto-ignition temperature

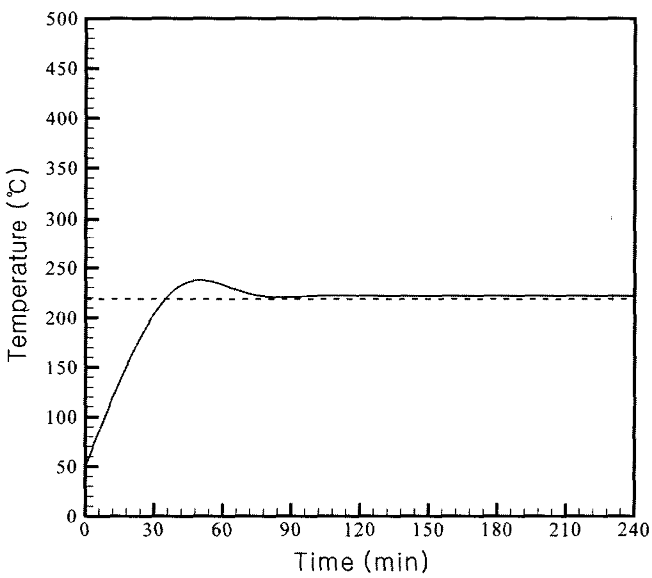

Fig. 2. Relation between time and temperature in 5 cm vessel (at 219).

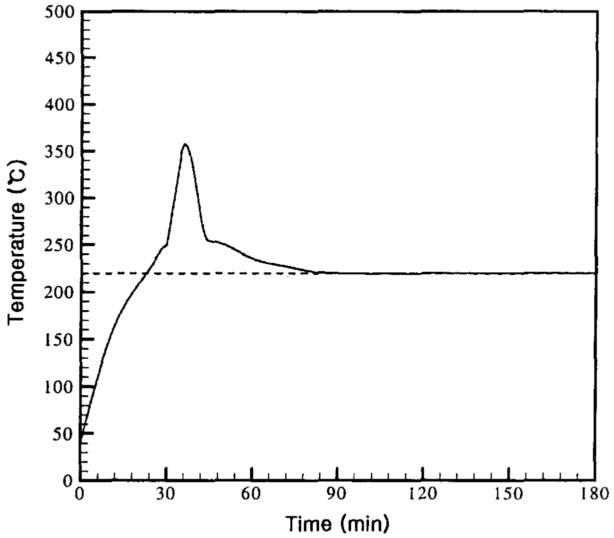

Fig. 3. Relation between time and temperature in 5 cm vessel (at 220°C).

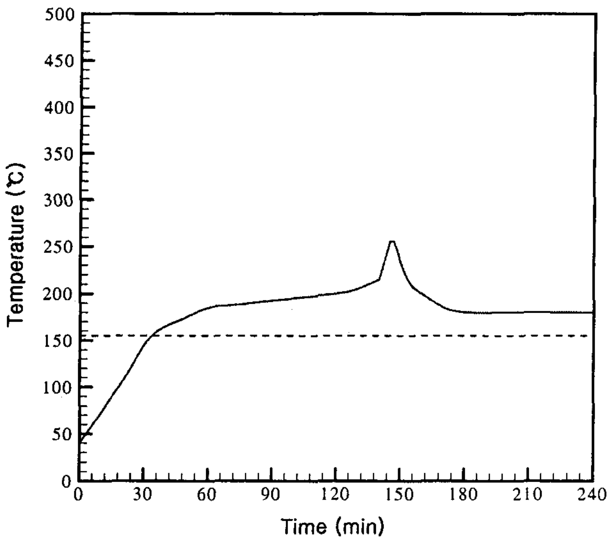

Fig. 4. Relation between time and temperature in 14 cm vessel (at 155°C).

for this sample vessel was 219.5 which is the average between non-ignition and ignition temperatures.

Also, for the sample vessel of 14 cm thickness, there was no ignition when the oven temperature was set to 154°C. As shown in Fig. 4, when it was set to 155°C, the ignition occurred in about 60 minutes as the temperature was raised through 200 up to 255°C. In this case, the critical auto-ignition temperature was calculated to 154.5°C.

Similarly, the critical auto-ignition temperature was 240.5 and 201.5 when the sample vessel thicknesses of 3 cm and 7 cm was used, respectively.

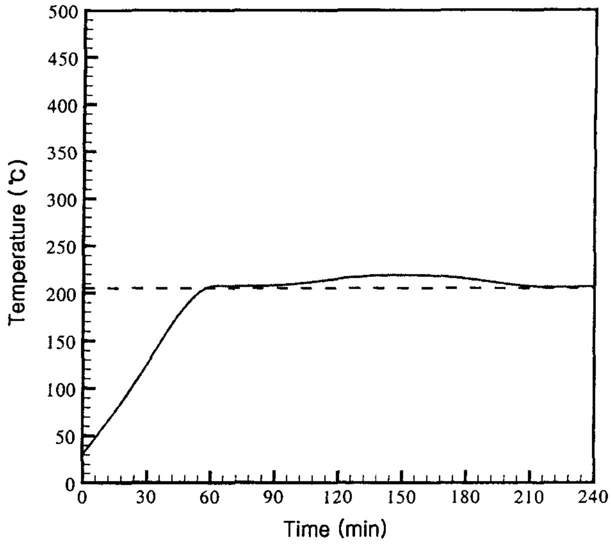

Fig. 5. Relation between time and temperature in 5 cm vessel (at 205°C).

3-2. Polyurethane Foam using Cyclopentane

Fig. 5 shows the non-ignition status when the thickness of the sample vessel was 5cm. When it was left in the oven for more than 6 hours with the setting temperature of 205°C, the inner sample temperature and the inner oven temperature were maintained almost the same, leading to non-ignition.

Fig. 6 shows the occurrence of ignition starting in about 40 minutes after setting the oven temperature to 206°C as the inner sample temperature is suddenly raised to 454°C for 20 minutes after then. Therefore, the critical auto-ignition temperature for this sample

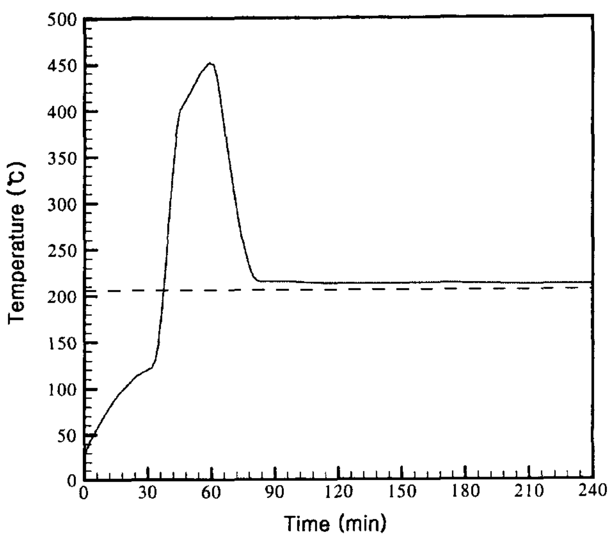

Fig. 6. Relation between time and temperature in 5 cm vessel (at 206°C).

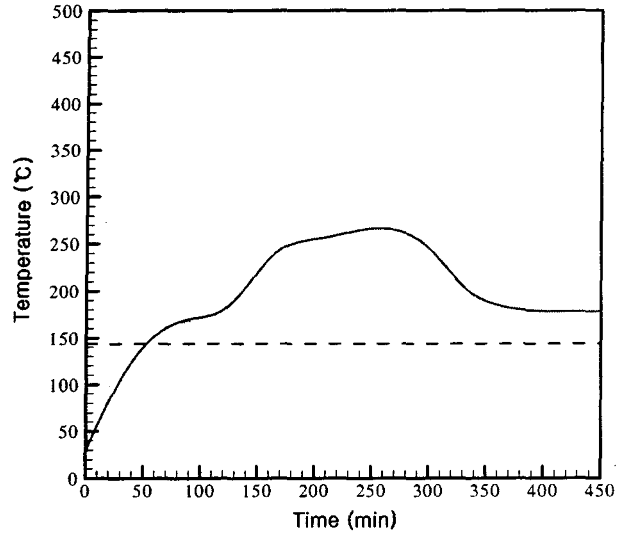

Fig. 7. Relation between time and temperature in 5 cm vessel (at 144°C).

vessel of 5 cm thickness was 205.5°C.

As we compare Fig. 3 and Fig. 6, we can see that the instant complete combustion occurs for the polyurethane foam that uses cyclopentane due to the combustion of cyclopentane present in the foam. In contrast to this, polyurethane foam using CFC as the foaming agent shows slow combustion rate due to the extinguishing property of CFC.

Also, for the sample vessel of 14 cm thickness, there was no ignition when the oven temperature was set to 143°C. As shown in Fig. 7, when it was set to 144°C, the ignition occurred in about 50 minutes as the temperature was raised through the setting temperature and the combustion occurs for about 5 hours raising the temperature up to 263°C. In this case, the critical auto-ignition temperature was calculated to 265.5°C.

As we compare Fig. 4 and Fig. 7, we can see that ignition and combustion of the polyurethane foam sample containing cyclohexane lasts longer than that of CFC polyurethane foam.

Similarly, the critical auto-ignition temperature was 228.5°C and 185.5°C when the sample vessel thicknesses of 3 cm and 7 cm was used, respectively.

3-3. Apparent Activation Energy

As we manipulate Eq. (1), the Frank-Kamenetskii Parameter formula [4] for calculating the auto-ignition of solid, in order to determine the apparent activation energy, it can be expressed as Eq. (2).

$$\delta_c = \frac{EQa^2A_0\exp^{-E/RT_0}}{KRT_0^2} \tag{1}$$

Table 1. Relation between critical spontaneous ignition temperature and thickness in each sample vessel for CFC-ployurethane foam

a [m]	T_c [K]	δ_c	ln ($\delta_c T_c^2/a^2$)	$1/T_c \times 10^3$ [k^{-1}]
1.5×10^{-2}	514.66	0.88	20.7586	1.9430
2.5×10^{-2}	493.66		19.6536	2.0257
3.5×10^{-2}	475.66		18.9064	2.1023
7.0×10^{-2}	428.66		17.3120	2.3329

Table 2. Relation between critical spontaneous ignition temperature and thickness in each sample vessel for cyclopentane-ployurethane foam

a [m]	T_c [K]	δ_c	ln($\delta_c T_c^2/a^2$)	$1/T_c \times 10^3$ [k^{-1}]
1.5×10^{-2}	502.66	0.88	20.7114	1.9894
2.5×10^{-2}	479.66		19.5961	2.0848
3.5×10^{-2}	459.66		18.8379	2.1755
7.0×10^{-2}	417.66		17.2600	2.3943

$$\ln\frac{\delta_c T_c^2}{a^2} = -\frac{E}{R}\frac{1}{T_c} + \ln\frac{QA_0E}{KR} \tag{2}$$

By plotting $\ln(\delta_c T_c^2/a^2)$ for $1/T_c$ shown in Table 1 and Table 2 in order to use Eq. (2) formula, we can get Eq. (3-1) formula for the CFC-polyurethane foam and Eq. (3-2) formula for the cyclopentane-polyurethane.

Using the least square method, we deterime for Eq. (2). The correlation plots between the expermental data and the values predicted by the Eq. (3-1) and Eq. (3-2) is shown in Fig. 8 and Fig. 9.

$$\ln\frac{\delta_c T_c^2}{a^2} = 37.0427 - 8.5132\times10^3\times\frac{1}{T_c} \tag{3-1}$$

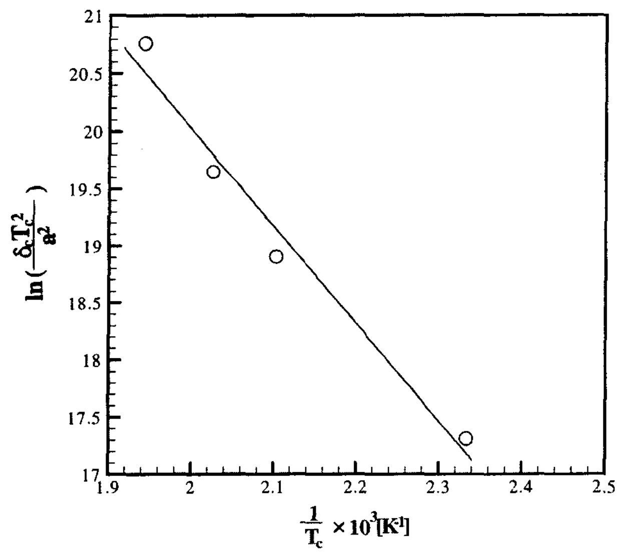

Fig. 8. Determination of activation energy for CFC-polyurethane foam.

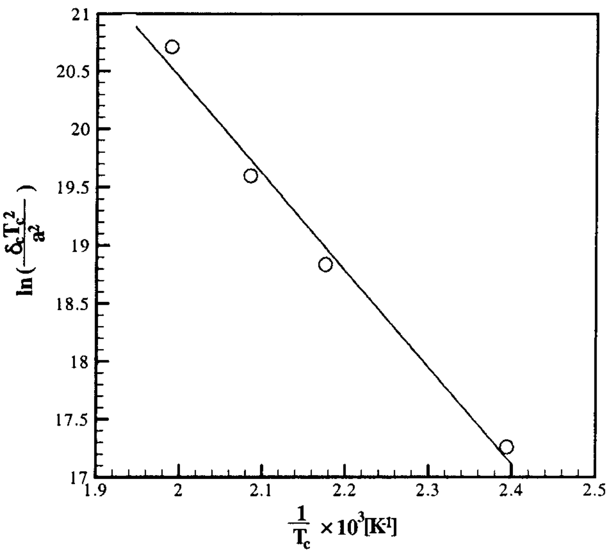

Fig. 9. Determination of activation energy for cyclopentane-polyurethane foam.

$$\ln\frac{\delta_c T_c^2}{a^2} = =37.0686 - 8.3143 \times 10^3 \times \frac{1}{T_c} \qquad (3\text{-}2)$$

If we calculate the apparent activation energy from Eq. (3-1) and Eq. (3-2) formula, E=16.9157 Kcal/mol (r=0.9999) can be obtained for CFC-polyurethane and E=16.5025 Kcal/mol (r=0.9998) for cyclopentane-polyurethane, and the values of apparent activation energy are almost the same.

4. Conclusion

As the result of experiments for determining the autoignition characteristics using CFC-polyurethane and cyclopentane-polyurethane foam recovered from recycling process of end-of-life home appliances, we could obtain the following conclusions:

1) For the polyurethane foam using CFC or cyclopentane as the foaming agent, the critical auto-ignition temperature was lower as the size of the sample vessel was increased.

2) The critical auto-ignition temperature of CFC-polyurethane foam was relatively higher and different than that of cyclopentane-polyurethane foam upon the use of the same size of the sample vessel. Combustion of cyclopentane-polyurethane foam occurred fiercely.

3) The apparent activation energy of CFC-polyurethane foam and cyclopentane-polyurethane foam was almost the same, and the average value was 16.7091 kcal/mol.

4) It is considered that the recycling process of end-of-life home appliances using cyclopentane-polyurethane foam as the insulator would require a special fire-prevention measures since there exists high potential and risk of fire during crushing and storage processes.

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