HIGH-SPEED MICROSCOPIC OBSERVATION AND MODELING OF THE MULTIPHASE PROCESS IN A MICRO SPHERICAL PET PARTICLE UNDER ABRUPT HEATING

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Abstract
High-speed expanded and direct observations of the multi-phase process within a micro particle of polyethylene terephthalate resin (abbreviated to PET in the following) under abrupt heating are made along with stereoscopic imaging of solid residuals. High-speed reflection images and stereoscopic images give the conclusive evidence of occurrences of violent multiple micro bubbling within the PET droplet, which is triggered by thermal decomposition of PET resin and flash vaporization of the decomposed products. Multiple and irregular explosions of micro bubbles follow just after the internal bubbling and cause irregular and random micro jets, resulting in randomly fluctuating micro diffusion flames downstream of the micro jets. It is concluded that the key factor to such high burning rate constants of PET particles as exceed those of well-known volatile liquid fuels can be attributed to the multiphase process due to the multiple and internal flash vaporization of thermally decomposed products, being particular to plastic resin combustion. Based on these considerations, a qualitative modelling of the multiphase process in the micro plastic particle is constructed.

1. Introduction
To obtain basic information on plastic powder combustion as one of the alternative fuels, detailed microscopic observations of the multiphase process within a micro spherical PET particle under abrupt heating have been made from the fundamental point of view [1 ~ 5]. In the preceding investigations an original optical system and three ingenious techniques have been devised and introduced for the abrupt heating and sudden extinguishment experiments of a micro PET particle under the same high temperature and oxidizing circumstances as those in the industrial burners. The former optical imaging system is a mini optical composite which is composed of two beam splitters and two prisms and enables simultaneous photographing of direct silhouetted image and schlieren image. The latter three devises are a reforming process of a rugged resin particle into a spherical one around a fine tungsten wire of 5 µm diameter, a vertical type cylindrical mini burner for abrupt heating and a mini-puff generator for sudden extinguishment of all flames around a micro PET particle at an arbitrary assigned timing after abrupt heating. The reforming process makes possible not only to improve the accuracy and reproducibility of data acquisition but also to solve the problem how to support surely and stationary such a tiny plastic resin particle as having a diameter in the range of 150 ~ 200 µm.

It was found that, when the heating process is ceased at an arbitrary assigned timing after abrupt heating, the solid residuals contain many bubbles within them, showing that internal multiple micro bubbling occurs during the heating process. It is well-known that, when plastic resin experiences abrupt heating, for example, by hot combustion gas, it does not vaporize after melting, but first thermally decomposes into some kinds of products having much lower
saturation temperatures than the thermal decomposition temperature, as shown in Table 1 [6, 7]. As a result, the decomposed products might instantaneously vaporize as soon as they were generated. Precise information concerning the latter flash vaporization process, however, could not be clearly obtained so far in the results of preceding investigations, because the silhouetted and schlieren images obtained using the proposed imaging system could not reveal the internal structure of a micro PET particle under abrupt heating.

To make up for the deficiency, the lighting technique is first altered from back-lighting to oblique-lighting in this paper, since the latter can give reflection images of micro bubbles in the PET droplet under abrupt heating, whereas the silhouetted images can only give an outline of the PET droplet. Detailed observation and analysis of the internal structure of a micro PET particle under abrupt heating are then attempted by taking a series of high-speed reflection images of the multiphase process within the PET particle along with a set of stereoscopic photographs of the solid residuals. Based on detailed considerations, a qualitative modeling of the multiphase process within the liquid plastic particle is finally proposed.

### 2. Experimental Apparatus and Methods

The experimental apparatus used in this experiment is almost the same as those in the preceding studies [1 ~ 5], except that the lighting technique is altered from back-lighting to oblique-lighting and Xenon light is applied to the particle obliquely-downward and normal to the camera axis. In this paper, for better understanding of a set of experimental procedures for

![Figure 1](https://example.com/figure1.png)

**Figure 1.** Combined arrangement of the mini-burner and the mini-puff generator and four typical stages during a single abrupt heating and extinguishment processes

| Table 1. Properties of PET resin and main decomposed products [6, 7] |
|--------------------------|--------------------------|
| **Property**             | **Value**                |
| Density [kg/m³]          | 1380                     |
| Melting point [K]        | 523 ~ 548                |
| Coefficient of linear expansion [1/K] | 7.0 × 10⁻⁵ |
| Temperature ranges of thermal decomposition [K] | 556 ~ 579, 673 ~ 923 |
| Char content [wt% at 973 K] | 17.0                     |
| Main products of thermal decomposition (Boiling point, K) | Benzene (353), Toluene (385), Styrene (418) |
abrupt heating and extinguishment of PET particle, a combined arrangement of the cylindrical mini-burner for abrupt heating and the mini-puff generator for sudden extinguishment is shown schematically in Fig. 1. The mini-burner is made of a quartz glass tube having inner and outer diameters of 7 mm and 9 mm and a length of 100 mm, from which a propane-air mixture with an assigned equivalence ratio of $\phi = 0.84$ is issued vertically upward at a mean velocity of $U = 0.50$ m/s. A pair of spark needles having a gap of 5.8 mm and made of a tungsten wire of 0.2 mm diameter is installed at the exit section of the mini-burner, and is discharged at ignition energy of 21.9 mJ.

The mini-puff generator, on the other hand, is constructed by connecting a rectangular nozzle with a rectangular box with a side of 215 mm. The former nozzle having a length of 40 mm contracts the sectional area from $120 \times 60$ mm to $40 \times 10$ mm, and is placed horizontally so that the exit section is 50 mm apart from the plastic particle. A speaker having a cone diameter of 140 mm is equipped inside it. In a single abrupt heating and blow-off experiment, a combustion gas downstream of a spark-ignited propane-air lean premixed flame stabilized on the vertical circular mini-burner is used as an abrupt and oxidizing heat source, and the mini-puff generator is operated once at a prescribed timing after abrupt heating using a delay time controller.

Four typical stages of a single abrupt heating and blow-off experiment are schematically illustrated in Fig. 1(a) ~ (d). To improve the accuracy and reproducibility of image processing, spherically reformed particles having an assigned diameter are used [1 ~ 5]. An original rugged PET particle is first attached to a fine supporting wire and is heated up to its melting point by radiation heat transfer from an incandescent Nichrome wire. Due to the surface tension of the PET droplet, it rounds and, once the incandescent Nichrome wire is removed, it condenses into a smooth spherical particle spitted by the fine supporting wire. As shown in Fig. 1(a), a micro spherical PET particle reformed around a fine supporting wire is first placed at the prescribed position on the axis of the propane-air lean mixture flow. Just after spark ignition at the burner exit, a combustion wave is initiated and propagates in the downstream direction, as shown in Fig. 1(b), and a small conical laminar flame is stationary stabilized at the burner exit, as shown in Fig. 1(c). Abrupt heating starts at the instant when the high temperature oxidizing combustion gas passes through the supported PET particle and the supporting wire becomes incandescent. When the change in appearances of solid residuals are observed and analyzed, the mini-puff generator is operated at the assigned timing after abrupt heating to extinguish all flames around the PET particle, as shown in Fig. 1(d). A series of high-speed expanded reflection images after abrupt heating is recorded on the high-speed CCD video camera operated at a framing speed of 1000 fps by synchronizing with the signal of spark ignition and is analysed.

The temperature profile along the burner axis is measured using an R-type fine thermocouple of 50 $\mu$m diameter, first, to determine the axial position where the average temperature is measured to be $1000$ °C and a PET particle is stationary placed. The position is determined to be 33 mm downstream of the burner exit in this paper, where the mean oxygen concentration is measured to be 11.3 %. In this investigation three kinds of supporting wires made of tungsten, silicon carbide (SiC) and quartz glass are used. Properties of three wires at $1000$ °C and their diameters are given in Table 2 [7]. It indicates that tungsten has greater heat

<table>
<thead>
<tr>
<th>Materials</th>
<th>Tungsten</th>
<th>Silicon-carbide</th>
<th>Quartz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat conductivity $\lambda$ [W/m $\cdot$ K(at 1000°C)]</td>
<td>129</td>
<td>10.1</td>
<td>2.55</td>
</tr>
<tr>
<td>Range of diameter D [$\mu$m]</td>
<td>5</td>
<td>12 ~ 20</td>
<td>3 ~ 10</td>
</tr>
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</table>
conductivity than SiC fiber and quartz glass by about 13 and 50 times, respectively.

3. Experimental Results and Discussion

3.1 High-speed reflection images of multiphase process

According to the preceding investigations [1 ~ 5], the overall heating process of a PET particle is divided into four periods; the period of moderate volumetric expansion due to thermal expansion: Period I, the period of remarkable volumetric expansion due to internal multiple micro bubbling: Period II, the period of steep linear reduction of particle surface area due to self-accelerating violent internal multiple bubbling and combustion: Period III, and the period of slow surface combustion of char: Period IV. Since this division of the entire heating process does not depend on both the initial particle diameter and the kinds of supporting wires, high-speed imaging of the temporal multiphase process is executed with a PET particle

![High-speed reflection images of multiphase process](image)

**Figure 2.** A series of high-speed expanded reflection images during the multiphase process in a micro PET particle under abrupt heating; the initial particle diameter \(d_0 = 321 \mu m\), SiC supporting wire of \(D = 14 \mu m\) and the heating temperature of \(T_h = 1000 \degree C\)
having a relatively large initial diameter and, therefore, a long life time for improving the time resolution in the image processing.

A series of high-speed expanded reflection images during the multiphase process in the PET particle is given in Fig. 2, by laying emphasis on the particle internal structure, where the initial diameter of PET particle is \( d_0 = 321 \, \mu m \) and the framing speed is 1000 fps. The number at the bottom of each image shows the time after abrupt heating. SiC fiber having a diameter of 14 \( \mu m \) is used as a supporting wire. A PET particle having a large initial diameter of 321 \( \mu m \) exhibits a relatively long life time exceeding 350 ms. Even if the oblique-lighting technique was employed instead of back-lighting, however, intense emission from a yellow diffusion flame formed behind the liquid particle makes still the internal structure almost invisible during the latter half period of its life time. A series of characteristic extracts is, then, presented at short intervals by accentuating the first half of its life time, where the particle internal structure is relatively clearly visible.

To present clearly the tendency of changes in the particle diameter and surface area with the internal structure, the temporal variation of \( d^2 \) is presented in Fig. 3 along with some extracts of the reflection images, where the ordinate indicates \( d^2 \) and the abscissa the time after abrupt heating. Discussion in the following will be made under the consideration that the internal micro bubbling is caused by the thermal decomposition of PET resin into some kinds of aromatic compounds having lower saturation temperatures than the thermal decomposition temperature and they vaporize in a flash.

According to the reflection images in Fig. 2, the behavior of multiple and micro bubbling within the transparent PET particle can be relatively clearly observed. In the initial solid and liquid heating period of \( t \leq 150 \) ms: Period I, the thermal decomposition and micro bubbling due to the flash vaporization of the decomposed products are only apparent sporadically in the peripheral annular zone of the droplet, and such a prominent increasing rate in the particle diameter as exceeds that of thermal expansion is hardly observed. In the time duration of 150 ms < \( t \leq 160 \) ms, however, the number and the size of micro bubbles within the PET droplet

![Figure 3. Temporal variation of the particle surface area \( d^2 \), where the initial particle diameter \( d_0 = 321 \, \mu m \), the SiC supporting wire of \( D = 14 \, \mu m \) and the heating temperature \( T_g = 1000 \, ^{\circ}C \).](image-url)
increase immediately, indicating that the thermal decomposition and internal bubbling take place more frequently and multiply, not only in the peripheral zone but also deep inside of the PET droplet. After this particular timing, Period II starts. The diameters of micro bubbles are evaluated to be in the range of 20 ~ 50 µm.

At \( t \approx 167 \) ms, a yellow diffusion flame is formed behind the droplet, as dimly observed and indicated by a white arrow in the wake region of the image. Once a diffusion flame is formed behind the droplet, intense flame radiation promotes the thermal decomposition of PET resin and instantaneous vaporization of the decomposed products. In Period II, therefore, the PET droplet experiences violent thermal decomposition and extremely frequent internal micro bubbling, and exhibits an unusual increase in the droplet surface area up to about 2.25 times of the initial one in the time duration of \( t = 220 \sim 225 \) ms. This is indicated by a clear stepwise increase at about \( t = 160 \sim 165 \) ms in the gradient in Fig. 3.

Once a diffusion flame is established behind or around the droplet, on the other hand, intense emission from the yellow diffusion flame makes almost invisible the internal structure of droplet under multiple bubbling, as seen in the images in the later half period of its life time of \( t \geq 170 \) ms. The incandescent images of the droplet, however, makes possible the observation of the characteristic changes of its outline. According to a series of incandescent images in the heating period of \( t = 170 \sim 225 \) ms, the droplet also exhibits rugged and swelled appearances corresponding to the irregular and multiple formation of micro bubbles and micro jets. The occurrence of the multiple micro jets has already been observed in a series of high-speed simultaneous movies of schlieren and silhouetted images of the PET droplet under abrupt heating [1, 2, 8]. It can be certified, therefore, that the main factor of an extreme increasing rate of the particle diameter and surface area is caused by the multiple internal micro bubbling within the PET droplet.

A change of either the initial particle diameter or the kind of supporting wires hardly alters overall constitution of the multiphase process during the abrupt heating of a spherical PET particle, except for a minor change in the time duration in each elementary period. However, char content greatly affects the particle life time through the existence of the slow surface combustion period in the final stage of the abrupt heating process. For example, polyethylene and polystyrene particles which are free from char exhibit shorter life times than PET particles by the solid burning period of char, according to the additional abrupt heating experiments using their micro particles [8].

3.2 Comparison of multiple bubbling behaviors with micrographs of solid embers

Five typical sets of reflection images and micrographs of solid residuals are given in Fig. 4, where the first set presents an original particle and the latter four sets indicate those obtained in the four periods of I ~ IV. The five reflection images on the left are extracted from the high-speed movie taken under the conditions of the initial diameter of \( d_0 = 321 \) µm, the heating temperature of \( T_g = 1000 \) °C and a SiC supporting wire of \( D = 14 \) µm, and are pointed by four white arrows I ~ IV in Fig. 3 at \( t = 80 \) ms, 203 ms, 242 ms and 300 ms. The embers on the right, on the other hand, are obtained by blowing-off all flame around the droplet at four corresponding timings of I ~ IV under the conditions of \( d_0 = 200 \pm 4 \) µm, \( T_g = 1000 \) °C and a tungsten wire of \( D = 5 \) µm [2, 4].

The image of Fig. 4(a) gives transparent appearances common to all original PET particles and clarifies that the thermal decomposition hardly takes place during the reforming process. The embers shown in Fig. 4(b) and the reflection image at the middle stage of Period I in Fig. 2 present the characteristic dependency of the particle diameter on the gradual increase in the frequency of internal bubbling, and show that the thermal decomposition and internal bubbling occur sporadically and are restricted to the peripheral zone of the droplet.

The reflection image around the middle stage of Period II in Fig. 2 indicates incandescent
appearances, so that the internal structure of droplet is not clearly visible. According to the corresponding reflection images during $t = 160 \sim 167$ ms just before the formation of a diffusion flame in Fig. 2, however, the PET droplet contains a lot of micro bubbles within it and provides the similar internal structure to that of embers, as presented in Fig. 4(c). It is clear that the extreme volumetric expansion up to about $3.4 \approx 1.5^3$ times the original particle can be attributed to the intense thermal decomposition and multiple internal bubbling.

The reflection image at the middle stage of the third period of steep reduction of Period III presents a distorted shape and an asymmetric wake-type diffusion flame behind it. The corresponding micrograph of embers shown in Fig. 4(d) exhibits a similar distorted shape and suggests that micro bubbles burst open to form irregular multiple micro jets to the surroundings. It can be considered that the irregular jets may break the thermal and concentration boundary layers around the droplet and promote indirectly heat and mass transfer to and from the droplet. Since the micrographs of embers were taken after extinguishing all the flame around the particle and cooling down to the atmospheric temperature, the size of bubbles can not be directly compared with those observed in the PET droplet under internal bubbling. However, the foamy and distorted appearances of solid residuals in the third Period III certify the extremely fast reduction of the particle surface area to be mainly due to irregular and random explosions of internal micro bubbles.

Finally, the micrograph of Fig. 4(e) and the reflection image at the initial half stage of the fourth period IV present ragged and foamy appearances and indicate that internal bubbling, micro explosions and micro jets may continue even in the fourth period of slow char
combustion; Period IV. The effect of char content is clearly apparent in the change in collar of embers, as can be observed in Fig. 4.

3.3 Stereoscopic images of solid embers extinguished at four typical timings

In Fig. 5(a) ~ (d) four typical stereoscopic images of solid residuals are presented, which are photographed after blowing-off all flames around a micro PET particle under abrupt heating at the four corresponding typical timings to the four typical heating periods I ~ IV, respectively. In order to improve the reproducibility and accuracy of image processing, the initial PET particle diameter is kept nearly constant in the range of $d_0 = 400 \pm 8 \, \mu\text{m}$. A tungsten wire of $D = 5 \, \mu\text{m}$ is used as a supporting wire and the heating temperature is set to $T_g = 1000 \, ^\circ\text{C}$. Each image is constructed by superimposing fifty micrographs to one image on the PC system, which are photographed separately by shifting successively the focus of the stereoscopic microscope from the surface of solid residual to its inside by $50 \, \mu\text{m}$ at $1 \, \mu\text{m}$ intervals. It is found that the four images demonstrate clearly the characteristic internal and surface structure of unburnt solid particles corresponding to the four heating periods.

According to Fig. 5(a), which is obtained in the final stage of Period I, the particle diameter is measured to be $d \approx 430 \, \mu\text{m}$, becoming larger than that of the initial diameter by about 7.5 %. The diameter increasing rate of 7.5 % can not be realized only by thermal expansion due to the temperature rise up to the thermal decomposition temperature ranging 673 ~ 923 K. By using the coefficient of linear expansion of PET resin, which is given as $7.0 \times 10^{-5} \, [1/\text{K}]$ in Table 1, thermal expansion of PET resin particle due to the temperature rise from 300 K to its maximum thermal decomposition temperature of 923 K, for instance, is calculated to be an increase of diameter up to about 4.4 %, being smaller than that obtained experimentally in this paper. The image indicates that many small bubbles having various diameters in the range of 20 ~ 60 $\mu\text{m}$ and coloring slightly light brown at their boundaries are observed mainly around the peripheral zone of the PET droplet. It can be certified that, concerning the excess diameter increasing rate above-mentioned, the existence of many small

![Figure 5](image_url)

*Figure 5. Four typical stereoscopic images of embers extinguished at four corresponding heating periods from I ~ IV, where the initial particle diameter; $d_0 = 400 \pm 8 \, \mu\text{m}$ ($\pm 2 \%$), the supporting wire; tungsten wire of $D = 5 \, \mu\text{m}$, the heating temperature; $T_g = 1000 \, ^\circ\text{C}$*
bubbles may cause the moderate increase in the particle diameter up to 7.5 % larger than the original during the heating period I. The light-brown-colored boundaries of bubbles confirm that, on the other hand, char may separate out by the thermal decomposition of PET resin in its early stage. Just after the initiation of thermal decomposition and instantaneous vaporization of the decomposed products, a diffusion flame is formed behind the particle and, as a result, flame radiation promotes further the thermal decomposition and flash vaporization.

The stereoscopic image of Fig. 5(b) obtained in the first stage of Period II indicates that large spherical and elliptic bubbles having diameters up to 250 µm are apparent within the entirely body of solid particle, and that its diameter increases up to \( d \approx 480 \mu m \), being greater than that of the initial by about 20 %. The latter extreme increasing rate of the particle diameter can be explained by the existence of multiple large bubbles. Such large bubbles exceeding 200 µm are considered to be attributed to combination of several neighboring small and/or medium bubbles. When the internal vapor pressure of growing bubbles exceeds the surface tension of thin liquid resin films around the bubbles, micro explosions of bubbles may occur and, therefore, micro vapor jets may issue into the surroundings. The thrust force caused by the multiple micro jets result in random movement of PET droplets on the supporting wire, as can be observed in the high-speed movies of the abrupt heating process.

When the abrupt heating of a micro PET particle proceeds to the middle stage of Period III, solid embers become self-acceleratingly smaller and smaller due to the combined effects of the intense thermal decomposition enhanced by flame radiation, the flash vaporization of decomposed products, the multiple micro explosions of bubbles and the multiple micro jets and, as can be seen in Fig. 5(c), exhibit characteristic change in color due to char separation, resulting in the appearances like umber. The size of embers at this timing reduces to \( d \approx 280 \mu m \), whereas the micro bubbles within it take small diameters ranging in \( d = 15 \sim 65 \mu m \).

Finally the stereoscopic image of embers extinguished at the first stage of Period IV of the slow surface combustion of char indicates that, as given in Fig. 5(d), it colors almost black due to residual char content and has a slowly reducing diameter of \( d \approx 230 \mu m \). The surface of embers exhibits a ragged and coarse appearances consisting of numerous tiny dots of about 10 µm diameter.

3.4 Qualitative modeling of the multiphase process in the micro PET droplet under abrupt heating

According to detailed observations and analyzes of a series of high-speed reflection images of a micro PET particle under abrupt heating and a set of stereoscopic images of solid residuals, a qualitative modeling of the multiphase process during Period I to Period III in the micro PET droplet under abrupt heating can be constructed and schematically presented in Fig. 6. On the left hand side of the figure, the concrete explanation of the multiphase process under progress within the droplet during the typical phases of abrupt heating is summarized briefly in four squares, whereas the result of each multiphase processes is expressed by each catch-word in four round square. Also given in Fig. 6 are the definitions of the point of thermal decomposition and bubbling. Based on Fig. 6, the following qualitative explanation is made with respect to the multiphase process in the PET particle under abrupt heating.

An original reformed PET particle first experiences solid heating, melting and liquid heating during Period I and expands spherically due to thermal volumetric expansion. Thermal decomposition then starts sporadically in the peripheral zone of the PET droplet. Once the thermal decomposition occurs, the heating process proceeds to Period II. Flash vaporization of the decomposed products then produces micro bubbles in the peripheral zone of the droplet and emits vapor of decomposed products to the surrounding to form a diffusion flame behind the droplet. During this period moderate volumetric expansion is realized due to the formation of multiple micro bubbles in the peripheral zone of the droplet.
Once a diffusion flame is established behind the droplet in Period II, radiation heat transfer from the diffusion flame to the droplet promotes remarkably the thermal decomposition and flash vaporization of the decomposed products not only in the peripheral zone but also over the entire droplet and leads to the extreme volumetric increase due to the activate and frequent micro bubbling and combination of neighboring bubbles. In the final stage of Period II, frequent combination of neighboring bubbles results in multiple micro explosions and multiple micro jets and, therefore, leads to the steep reduction of the droplet diameter in Period III.

3.5 Dependency of burning rate constant of PET particle on properties of supporting wires and comparison with those of typical liquid fuels

Figure 6. A qualitative model of the multiphase process within the PET droplet during the heating period from I to III under abrupt heating
Figure 3 indicates that the temporal variation of the particle surface area; \( d^2 \) exhibits approximately linear reduction during the burning period of Period III. Therefore, the burning rate constant can be estimated by adopting the method of least squares to the third period of heating process and evaluating the gradient, under the assumption that the burning process is purely diffusion-controlled. In this case, however, tungsten wire has greater heat conductivity than SiC fiber and quartz glass by about 13 and 50 times respectively, as already described concerning Table 2. It is interesting here to examine the effect of heat conductivity of the supporting wire on the burning rate constants of micro PET particles and to compare them with those of typical liquid volatile fuels.

The burning rate constants of micro PET particles are given in Table 3, where the three kinds of supporting wires are employed. Due to relatively wide variation of the diameter of SiC and quartz fiber, as shown in Table 2, the values of burning rate constant for SiC and quartz fiber are averaged over all data obtained. Also given in Table 3 are those of typical liquid volatile fuels; diesel light oil, benzene and iso-octane, when a liquid droplet of 1 mm diameter is suspended by a quartz fiber of 0.1 mm in high temperature air of 970 °C [9].

Table 3 indicates the following two characteristic results. The burning rate constants of a micro PET particle, at first, become larger in order of tungsten, SiC and quartz glass fiber. It is found therefore that the heat conductivity certainly exerts slight but positive influences on the burning rate constant. Secondly, the burning rate constants of micro PET particles are greater than those of well-known typical liquid volatile fuels by about 1.4 ~ 2.4 times, in spite of a favorable condition of high oxygen concentration. It is concluded here that the self-accelerating multiphase process, which is triggered by the thermal decomposition of PET resin and flash vaporization of the decomposed products and is composed of multiple internal bubbling, multiple micro explosions, multiple micro jets and multiple micro diffusion flames, plays an important role in the plastic powder combustion and results in higher burning rate constants than those of well-known liquid volatile fuels, which are controlled mainly by evaporation process, not by thermal decomposition.

4. Concluding Remarks

In this paper detailed high-speed observation and analysis of the internal multiphase process in a micro PET particle under abrupt heating are attempted by taking not only a series of expanded reflection images of the multiphase process within the PET particle, but also a set of stereo-scopic micrographs. The results obtained are summarized as follows.

(1) A series of high-speed expanded reflection images of PET particle under internal bubbling clarifies the details of multiphase process in the transparent droplet, and provides an exact basis to conclude that the extreme volumetric expansion is caused by internal bubbling.

(2) Once the thermal decomposition of PET and flash vaporization of the decomposed products occur sporadically in the peripheral zone of the droplet and a wake-type diffusion flame is established behind the droplet, the thermal decomposition and flash vaporization are promoted furthermore by the flame radiation. Multiple internal bubbling then permeates deep into the core region of droplet and gets violent more and more, resulting in the extreme volumetric expansion.

(3) Violent multiple internal bubbling is followed by multiple micro explosions, multiple
micro jets and micro diffusion flames. The multiphase process promotes self-acceleratingly heat and mass transfer to and from the environments through the disturbance effect of multiple micro jets on the boundary layer around the droplet.

(4) Based on the detailed observation and consideration of both the high-speed reflection images of the droplet internal structure and the stereoscopic micrographs of solid residuals, a qualitative modelling of the multiphase process within the droplet during the heating periods from I to III.

(5) The self-accelerating multiphase process enables extremely fast reduction of the droplet surface area and provides higher burning rate constants than those of well-known liquid volatile fuels by about 1.4 ~ 2.2 times. The effects of supporting wire heat conductivity on the burning rate constant are also examined by using three different wires; tungsten, silicon carbide fiber and quartz glass fiber. It is found that the burning rate constant depends slightly and positively on the heat conductivity.

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