



# Waste plastics as supplemental fuel in the blast furnace process: improving combustion efficiencies

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## Abstract

The possibility of using waste plastics as a source of secondary fuel in a blast furnace has been of recent interest. The success of this process, however, will be critically dependent upon the optimization of operating systems. For instance, the supply of waste plastics must be reliable as well as economically attractive compared with conventional secondary fuels such as heavy oil, natural gas and pulverized coal. In this work, we put special importance on the improvement of the combustibility of waste plastics as a way to enhance energy efficiency in a blast furnace. As experimental variables to approach this target, the effects of plastic particle size, blast temperature, and the level of oxygen enrichment were investigated using a custom-made blast model designed to simulate a real furnace. Lastly, the combustion efficiency of the mixture of waste plastics and pulverized coal was tested. The observations made from these experiments led us to the conclusion that with the increase of both blast temperature and the level of oxygen enrichment, and with a decrease in particle size, the combustibility of waste polyethylene could be improved at a given distance from the tuyere. Also it was found that the efficiency of coal combustion decreased with the addition of plastics; however, the combustion efficiency of mixture could be comparable at a longer distance from the tuyere.

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## 1. Introduction

The last 50 years have witnessed an explosive growth of the plastic industry. The production of synthetic polymers represented by polyethylene (PE), polypropylene (PP),

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polystyrene (PS), and poly(vinyl chloride) (PVC) world wide has increased more than 100 times for the last three decades [1–3]. These plastics are widely used in many important everyday applications such as clothing, household appliances, automotive products, and even aerospace. While we are enjoying the conveniences that plastics can provide, the treatment of waste plastics becomes an unavoidable and imminent issue. The situation in Korea is no exception. The generation of waste plastics in Korea has almost linearly increased for the last decade from less than 1 million tons to over 3 million tons [4,5]. Among these, PE, PP and PS take up the majority, slightly over 70%, and other plastics such as poly(ethyleneterephthalate) (PET) and PVC being minor constituents. To make the situation worse, among these tremendous amounts, less than 20% of waste plastics are being recycled/reused and the rest, over 80%, is either landfilled or burned. Needless to say, synthetic polymers do not readily degrade, and upon burning, they often generate environmentally hazardous materials including carbon dioxide, chloride, phenyl, sulfur, and even dioxins, the environmental hormone. In this regard, it can be safely stated that we are in urgent need of new ways to recycle waste plastics.

Recently new ways of environmentally-friendly waste plastic recycling have been of interest, and among them, in the steel making industry, the use of waste plastics as a supplemental fuel with coal has attracted interest [6,7]. The merits of this recycling method are first, one large furnace can consume over 150,000 t of waste plastics per year [8], second it has higher energy efficiency up to 80% [9], and lastly environmentally less hazardous due to the lack of dioxin generation [10]. In fact there exists one report claiming that Bremen Steel Company in Germany successfully substituted heavy oil that was used as a supplemental fuel with recycled plastics up to 50,000 t [11]. We are also aware that a similar effort has been conducted in Japan [12–14]. In Korea, Pohang Iron and Steel Making Company (POSCO) has shown the possibility of using waste plastic for a similar purpose in 1996; however the higher cost and relatively low combustibility (i.e. low energy efficiency) of waste plastics compared with pulverized coal hinder the application [15].

In the present work, as an effort to improve the combustibility of waste plastics in a blast furnace, the effects of several processing variables were investigated, and particular interests were placed on the effect of the size of plastic pallets, blast temperature, which implying the temperature of blast injected into furnace, and oxygen contents. Lastly, to simulate a real situation, the combustibility of the mixture of waste plastics and pulverized coal was tested. We anticipate that this information will be useful in optimizing the process conditions.

## 2. Materials and methods

In the present study, considering that in volume-wise PE makes up the largest portion in waste plastics, recycled PE was used as a representative. The bulky samples, obtained from local recycling center located in Seoul, Korea, were cleaned and dewatered before use, and exposed to liquid nitrogen for easier fracture in a ball mill. Thus, prepared pallets were classified into three types based on the final particle size (1.0–1.5, 3.0–5.0, and 8.0–10.0 mm) and were stored in a desiccator for further use.

Fig. 1 shows a schematic of a simulated blast furnace, named as *hot model*, used in this study. To match the combustion conditions to a real situation, three LPG type gas heaters

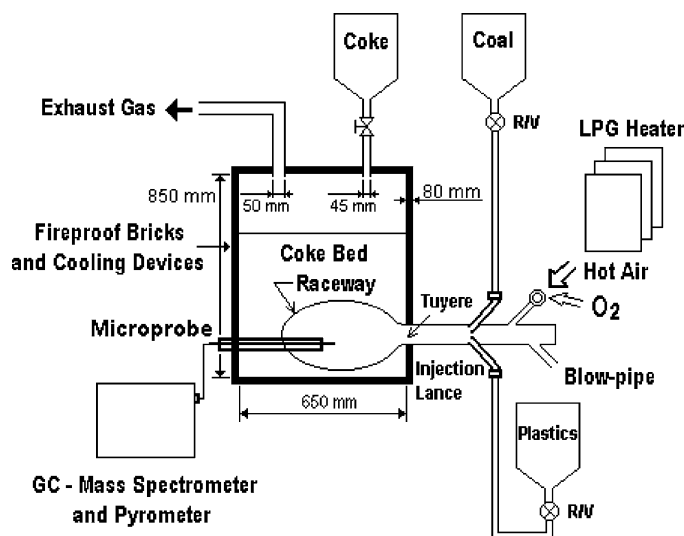


Fig. 1. Schematic diagram of hot model used in the experiment.

were used to blow hot air through the blow-pipe, and by this set up the temperature could be efficiently controlled in the range of 900–1100 °C. Oxygen could be also injected simultaneously with hot air. In the upper part of the blast, a coke injection chamber was installed, and blast could be operated continuously for 30 min with one fill-up. Upon reaching the preset temperature, waste plastics and/or pulverized coal (size is about 75  $\mu$ ) were injected at a rate of 45 kg/h through the side of the blow-pipe. One characteristic of this equipment is that we could measure in situ the kinds as well as amounts of gases released during the combustion of plastics using gas chromatography (GC) and mass spectroscopy (MS) (Hewlett-Packard, HP 5973), which was connected with a gas-type microprobe for the sampling of combustion gases. We could also measure the temperature along the raceway by pyrometer (Minolta, TR-630/630A). Raceway means the zone in the furnace with an elevated temperature due to blast introduction and its temperature is determined mainly by the blast characteristics. As will be shown later, these provided us with the insight of the reactions on going in the blast.

### 3. Results and discussion

#### 3.1. Thermal decomposition of PE

In general, PE thermally decomposes into oily liquid and gas phase successively. In Fig. 2, thermogravimetric results for commercial low-density polyethylene (LDPE) and waste PE are shown. Detectable weight decrease starts from ca. 300 °C followed by fast thermal decomposition that ends around 400 °C. The overall decomposition behavior for both samples were similar; however the inflection points of 50% of weight loss are, respectively, about 392 and 385 °C for commercial LDPE and recycled PE, and this may be ascribed to more

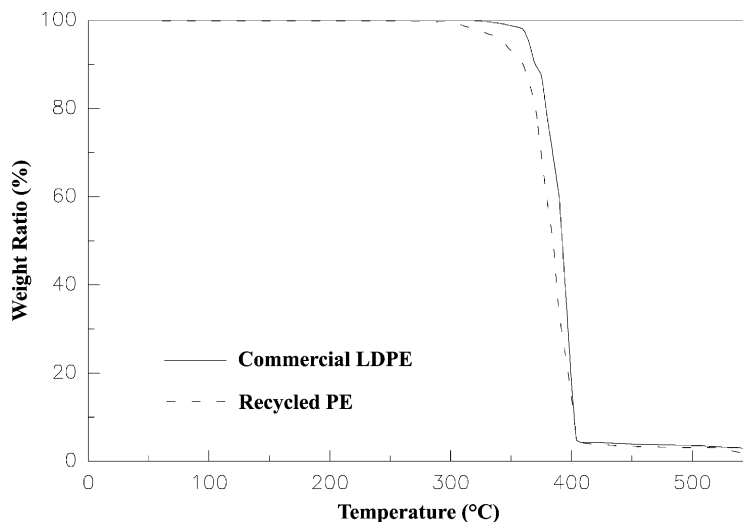
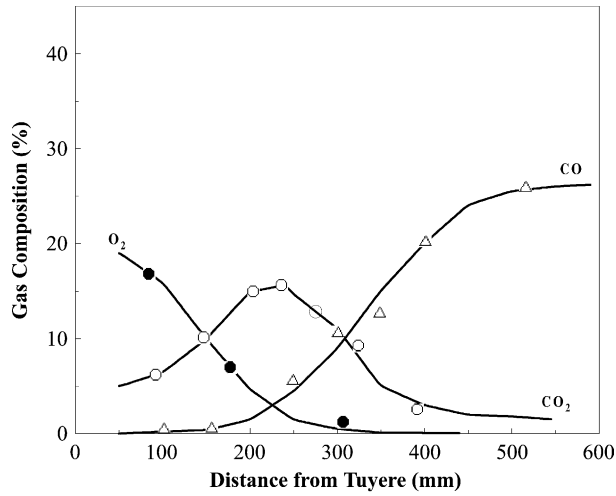


Fig. 2. TG curves for commercial LDPE and recycled PE.

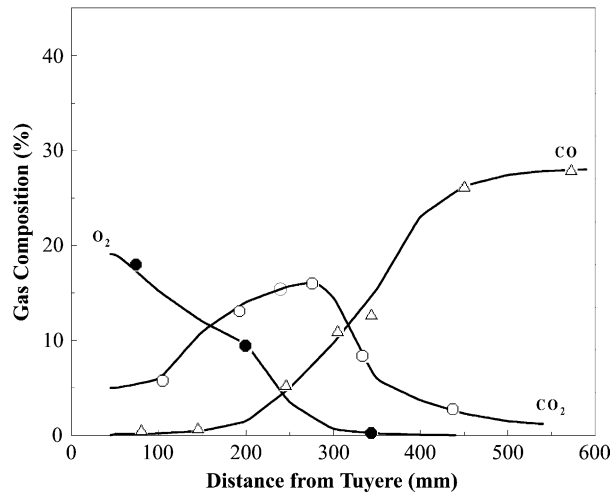
porous structure of recycled PE. These results that both commercial and waste LDPE experience 50% weight loss around 390 °C is in good match with a recent report [16]. It needs to be noted, however, polyethylene has quite a broad range of specs such as HDPE, LDPE, and LLDPE depending on their macroscopic density, and the type and length of branching. TGA characteristics of these different types of PE, therefore, will be different [17].

### 3.2. The effect of particle size

Three types of waste PE particles were injected through the blow-pipe at 1100 °C of blast temperature. Combustion characteristics of each sample, based on the concentration changes of three gases (i.e. CO, CO<sub>2</sub> and O<sub>2</sub>), were analyzed using GC–MS. Fig. 3 presents gas composition as a function of distance from tuyere for each sample: 1.0–1.5 mm (a); 3.0–5.0 mm (b); and 8.0–10.0 mm (c). Keeping in mind that the generation of CO<sub>2</sub> at the expense of O<sub>2</sub> will directly show the characteristic of combustion reaction, Fig. 3 leads to an insight of the combustion process for PE. The distance from the tuyere showing the peak position of CO<sub>2</sub> concentration increases from 240 mm (1.0–1.5 mm particle size) to 280 mm (3.0–5.0 mm particle size) and further grows to 310 mm in the case of the largest size sample (8.0–10.0 mm particle size). Oxygen concentration, which decreases with the increase in CO<sub>2</sub> composition, approaches zero beyond the point where CO<sub>2</sub> concentration shows its maximum. This, again, must be related to the combustion of PE. The systematic increase of CO<sub>2</sub> peak distance with the increase of particle size indicates that larger particles require more time, thus at farther location from tuyere, through which the blast is introduced, they undergo combustion. This is consistent to the notion that plastics generally melt from surface to core due to low thermal conductivity. The behavior of CO in Fig. 3 may deserve some comments. Regardless of particle size, the concentration of CO slowly increases at



(a)



(b)

Fig. 3. Variation in the gas compositions with the distance from tuyere for different sizes of waste PE particles: (a) 1.0–1.5 mm; (b) 3.0–5.0 mm; (c) 8.0–10.0 mm.

or near the maximum of CO<sub>2</sub> concentration, and further grows and reaches its plateau with the distance from the tuyere. This may be associated with the imperfect combustion of hydrocarbons. That is, around the region of efficient combustion (near the maximum of CO<sub>2</sub> peak), CO generated upon combustion will transform to CO<sub>2</sub>. However, as distance increases from the tuyere, blast temperature decreases so that CO may remain as it is. This explanation is consistent to the temperature profile of raceway as will be shown in the

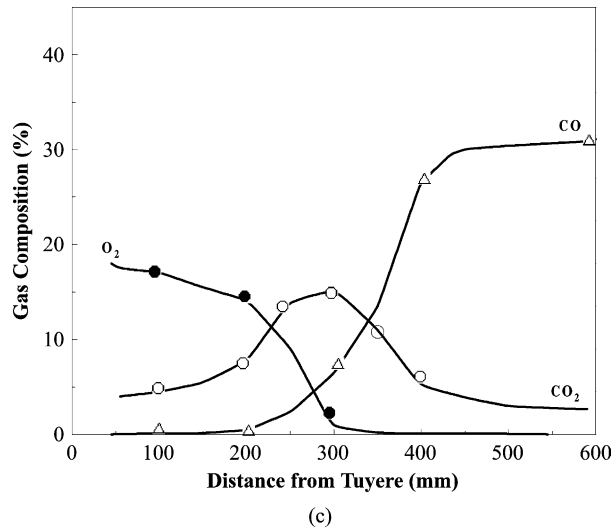


Fig. 3. (Continued).

following sections. As for reasons to the imperfect combustion, either insufficient supply of oxygen (i.e. sub-stoichiometric combustion conditions) or oxygen limited access due to diffusion (i.e. mass-transfer) controlled process could be at play, although definite answer is not available at this moment.

### 3.3. The effects of O<sub>2</sub> content and blast temperature

Besides the effect of particle size, as for process variables in blast, we can think of O<sub>2</sub> content and blast temperature. In Fig. 4, raceway temperatures obtained at three air temperatures for two different O<sub>2</sub> enrichments: 0.7% (a) and 1.2% (b) are summarized. In these experiments medium size PE particles (3.0–5.0 mm) were used. Clearly we observe the downshift of the position of the maximum raceway temperature to the direction of tuyere with the increase of both O<sub>2</sub> enrichment and blast temperature. Quantitatively, in the case of 0.7% of O<sub>2</sub>, the distance window of maximum raceway temperature is, as noted by the dotted line, 30 mm (from 260 to 290 mm), and at 1.2% O<sub>2</sub> enrichment the window expands to 50 mm as well as shifts to shorter distance from tuyere (from 230 to 280 mm). These observations may be understood in that, for a given size of waste plastic particles, blast air with higher temperature will increase the surface temperature of plastic faster; therefore combustion occurs at a shorter distance from tuyere. Similar explanation can be given to the effect of O<sub>2</sub> enrichment: higher O<sub>2</sub> content provides a better environment for combustion. The last noteworthy point in Fig. 4 is that regardless of O<sub>2</sub> enrichment and blast temperature, the maximum raceway temperature is always close to 1950 °C. This observation strongly suggests that the above two variables only affect the combustion kinetics, thus rates, but not thermodynamics; as long as plastic particles start burning, the maximum temperature that must be related to the enthalpy of combustion remains constant.

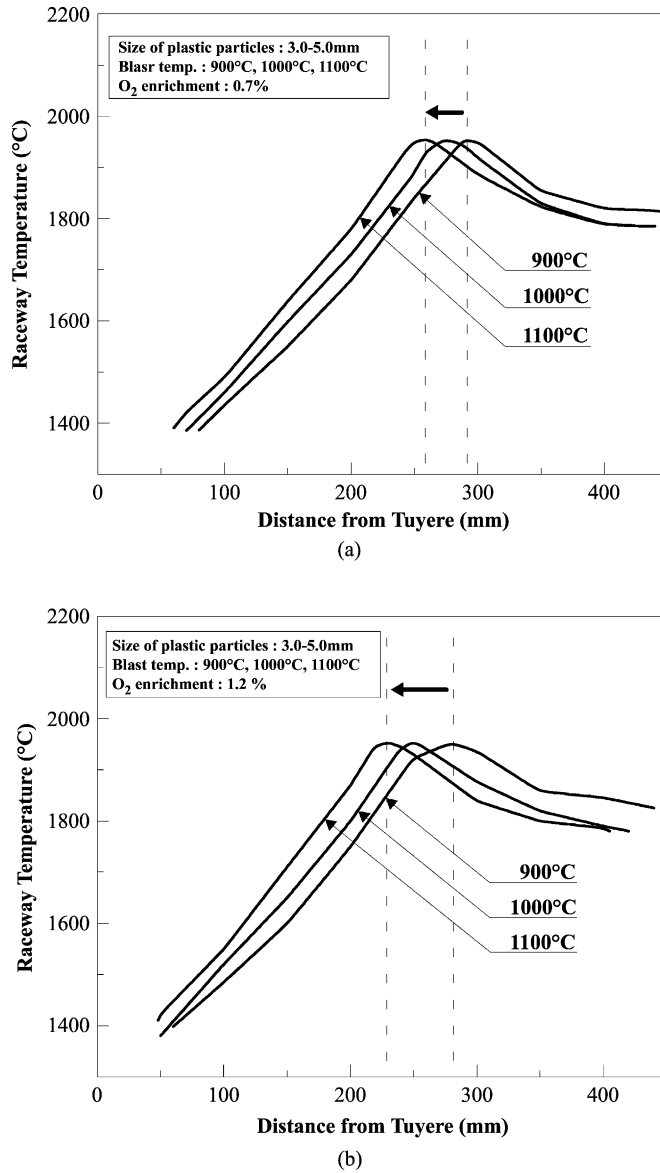


Fig. 4. Effect of blast temperature on the profile of raceway temperatures according to the distance from tuyere for O<sub>2</sub> enrichment of: (a) 0.7%; (b) 1.2% in the blast.

### 3.4. Combustion characteristics of mixture of pulverized coal and waste PE

Up to now we have examined several variables that may affect the combustibility of waste PE, targeting the use of recycled plastic as a substitute for the secondary fuel such

as heavy oil and pulverized coal in blast. In reality, however, for a continuous process, the mixture of recycled plastics with proper secondary fuel is used. In this regard, it will be desirable to simulate the combustion behavior of a mixture of pulverized coal and recycled PE. Blast temperature and O<sub>2</sub> enrichment were, respectively, controlled at 1100 °C and 0.7%. In the present case, two types of mixture both having 10 wt.% of recycled PE but with different particle sizes were used. As for a reference, the combustion behavior from 100 wt.% pulverized coal was compared with that of the mixture. For a quantitative comparison of combustion efficiency, which implying the amount ratio of burnt fuel to the total fuel injected, the remaining carbon contents of samples along the raceway were normalized based on 100% combustion. The results are summarized in Fig. 5. As anticipated, the increase of distance from the tuyere enhances the combustion efficiency, for instance, 100% pulverized coal shows an increasing efficiency from 68 to 81% along the raceway. Two mixtures also exhibit a similar trend. The difference, however, can be found from the slope of the efficiency. While the efficiency of 100% pulverized coal virtually saturates at or above 150 mm from the tuyere, the efficiency of a mixture keeps increasing. The size effect is also visible. The combustion efficiency of mixture with smaller size PE particles catches up with 100% pulverized coal at 250 mm, yet the mixture with bigger PE particles takes longer distance, or equivalently longer time to meet the efficiency. In other words, the addition of plastic particles hinders the combustion of coal particles, and the degree will be a function of size of plastic particles. Although we did not pursue the effects of other variables, logically speaking, waste plastic concentration, feeding rate, blast temperature, and oxygen content would be the most important ones. Hypothetically the energy efficiency of a mixture may be raised by increasing blast temperature and/or oxygen content. The optimization of these variables, however, will not be straightforward,

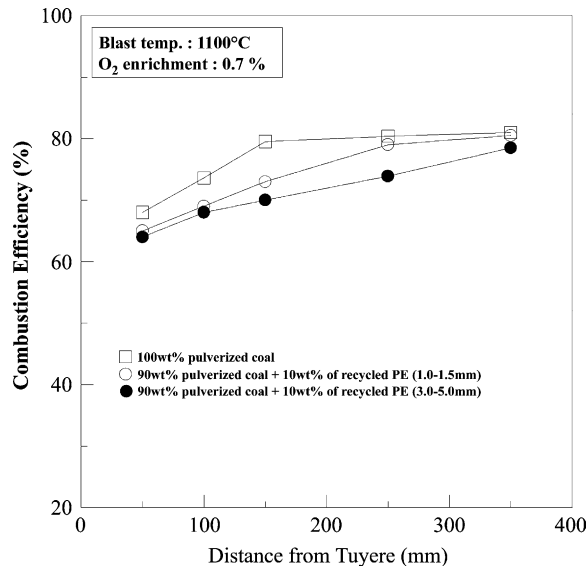


Fig. 5. Combustion behaviors of pure pulverized coal and mixtures of recycled plastics and pulverized coal.



since the overall cost of process needs also to be optimized. Although this issue will not be further discussed here, the optimization of energy efficiency considering the overall cost will be essential for the successful application of waste plastics in the steel making industry.

#### 4. Conclusions

We examined the effects of several variables such as particle size, blast temperature, and the level of oxygen enrichment on the combustibility of waste PE. To simulate a blast furnace, we designed a lab scale model furnace, by which the effects of the above variables could be pursued. It was found that with the increase of both blast temperature and the level of oxygen enrichment, and with the decrease of particle size, the combustion of waste PE occurred at shorter distance from the tuyere. This strongly suggests that the combustibility of waste plastics can be improved by controlling these variables. Lastly the combustion behavior of the mixture of pulverized coal and waste PE was investigated. Although the efficiency of coal combustion was found to decrease with the addition of plastics, the combustion efficiency of the mixture could be comparable at longer distance from the tuyere. We believe that the optimization of the steel making process utilizing recycled plastics as a source of secondary fuel will only be possible by considering all these variables.

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