Characteristics of PE Gasification by Steam Plasma

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Abstract: Currently, steam plasma gasification systems for recycling of waste polymers are among the most technologically advanced in the world. They provide environmentally friendly and simple processes for converting waste polymeric materials into a commercially valuable raw material, the so-called synthetic gas for use as a fuel or in the petroleum chemical industry. Using a steam plasma gasification system, PE, as a model compound, has been completely decomposed and converted into low-molecular-weight gases, dominantly carbon monoxide and hydrogen. The yields of these valuable gas products obtained through gasification increased upon increasing the temperature in the secondary gasification reactor and upon decreasing the steam-PE ratio. Product gases were obtained containing 65 % of H2 and 30 % of CO under the conditions of a steam-PE ratio of 1.2 and a temperature of 1200 °C in the second gasification reactor, respectively. The operation of a V-type plasma torch is stable and reliable within the necessary range of parameters.

Keywords: steam plasma gasifier, gasification, polyethylene, V-steam torch, synthetic gas

Introduction

The recycling rate of polymer waste products is very poor. To improve this situation, much research into pyrolysis technology is being conducted both domestically and overseas. However, progress in the development of commercially feasible processing techniques remains slow, because most research is focused on emulsification techniques rather than pyrolysis gasification [1-6]. This situation exists because the large quantities of char and tar produced in the pyrolysis emulsification process present problems. To overcome them, the widely known coal gasification technology is being extended and applied to the gasification of solid waste products [7,8]. Research on the pyrolysis gasification of mixed polymer waste products mainly utilize fluidized-bed reactors with steam as the fluidizing gas. Entrained beds have also been used in some studies [8]. Such gasification research is scientifically based on thermodynamic equilibria. For example, in the graphite-steam reaction, the percentage yield of synthetic gas (CO and H2) is 74.3 % at 727 °C, as opposed to nearly 99 % at 1727 °C. The thermodynamic simulation of the pyrolysis reaction on PE and steam conducted in this study gave the following results. When 2 moles of steam were added to 1 mole of C2H4, the monomer of polyethylene (henceforth, PE), at a pyrolysis temperature of at least 1027 °C, the possibility exists to completely gasify C2H4 and obtain a synthetic gas containing CO and H2 at a 1:2 ratio.

\[
C_2H_4 + 2H_2O \xrightarrow{1100^\circ C} 2CO + 4H_2
\]  

(1)

As shown in the following equation, these gases are at a stoichiometric ratio for their immediate conversion into methanol in the Fischer-Tropsch process:

\[
CO + 2H_2 \xrightarrow{F-T \text{ process}} CH_3OH
\]

(2)

Furthermore, at temperatures below 1300 °C, the reaction is endothermic, but it switches to exothermic above that temperature. Here, the heat of reaction was -8.401 kcal/mol. Therefore, the development of a gasification system utilizing high-temperature plasma, which can maintain a stable pyrolysis gasification reaction tempera-
ture of at least 1300 °C, is being researched actively [9,10]. Ever since development in the space industry in the 60s, high-temperature plasma technology has been expanding its scope to plasma spraying, wire arc spraying, thermal plasma chemical vapor deposition (TPCVD), nano-powder manufacture from thermal plasma synthesis, material science, such as thermal plasma densification, and metal cutting. Its application to the processing of hazardous waste products has also been developing constantly [11]. Examples of pyrolysis processes utilizing high-temperature plasma technology are as follows. Australia’s Plasma Limited [12], together with the CSIRO (Commonwealth Scientific and Industrial Research Organization), has developed the PLASCONTM process. They constructed and operated a chlorophenol waste processing facility in 1992, and a second plant in 1995. Equipment for processing ozone depleting agents was commercialized in 1996 and for PCB in 1997. Canada’s Resorption Limited [13] developed the RCL’s Plasma Gasification System that utilized steam and a high-temperature arc torch to convert municipal waste, medical waste, and other various waste products into synthetic gas and slag. The U.S.’s PEAT [14], Startech [15], and Vanguard Research, Inc. [16] have also developed Thermal Destruction and Recovery (TDR), Plasma Converter, and Plasma Energy Pyrolysis SystemTM (PEPSTM) systems for the pyrolysis gasification and emulsification of medical waste, solid and liquid organic waste, including ash, and contaminated soil. These systems were designed so that synthetic gas can be obtained as recycled by-products when organic wastes are applied. Sweden’s ScanArc Plasma Technologies AB [17] developed the PYROARC Process in which polymer wastes are first partially oxidized into gas and liquid wastes through primary gasification at 475~800 °C and then transported into a 1200 °C plasma reaction area where they are completely decomposed, cooled, and separated. All high-temperature plasma pyrolysis/melting/gasification processes for liquid or solid wastes are non-incineration heat processing techniques that utilize very high temperatures with no oxygen to simply pyrolyze wastes into CO, H2, C, and CnHm [18,19]. Furthermore, if the target waste products contain significant quantities of hazardous wastes, sludge, or hydrocarbon compounds, such as coal, filtration of the combustion gas exhaust, as well as recycling, effects, can be expected from the pyrolysis/gasification reactions. In addition, the high-temperature plasma can be used to convert residues into emulsified slag to decrease the volume.

For the processing of mixed plastic wastes, which are largely composed of hydrocarbons, the high-temperature plasma pyrolysis gasification technologies that have been developed to date mainly place their focus on processing mixed plastic wastes and recovering raw materials. In other words, air or steam is used as a reactant to completely pyrolyze the wastes and, as a means to recycle the gas generated, power generation systems and recovery/manufacturing processes for chemical raw materials and fuels, such as methanol or gasoline, are also being considered.

The objective of this study was research to develop a recovery process for synthetic gas, with at least 90% purity, in order to process mixed plastic waste and recover raw materials by utilizing a steam plasma gasification system. The synthetic gas obtained in the process can be utilized directly as a fuel or in power generation systems [11]. The Fischer-Tropsch synthesis can be used to obtain methanol or high-octane gasoline efficiently [20].

In this experiment, PE was used as a model plastic for the primary design of a steam plasma system for converting mixed plastic waste into synthetic gas. In the pyrolysis reaction, steam was used as the steam gas to induce the production of a synthetic gas rich in hydrogen, with CO and H2 in a 1:2 ratio. Here, as reaction variables affecting the percentage yield of gas, the steam ratio (actual mass of steam input/theoretical mass of steam input) and temperature changes in the secondary gasification reaction were considered to determine the gasification characteristics.

**Description of Developed Equipment Design**

Figure 1 shows the overall schematic diagram for the steam plasma gasification system designed for this experiment. As shown, the system consists mainly of a V-type steam torch, power supply, feeding system, steam generator, 1st reactor, 2nd reactor, combustion chamber, and cooling chamber. Detailed design characteristics for each system part are described as follows.

The reactor contains two vertical cylinder chambers - a plasma chamber and a mixer connected through a horizontal channel. The chambers are built of blocks that were made from silicicated graphite, glued together with a high-temperature adhesive, and set in a hermetically sealed steelwork on a light-weight chamotte foundation. The steelwork is knock-down for convenient mounting of interior structures. The junctures of the steelwork components are sealed with rubber gaskets. Free space inside the steelwork is filled with kaolin wool. The reactor walls have provisions for branch pipes with thermocouple pockets. The demountable cover of the plasma chamber is equipped with a water-cooled insert, which accommodates the plasma torch, a branch pipe for raw
Table 1. Design Conditions of the Plant for Plasma Thermal Treatment of Plastic Wastes

<table>
<thead>
<tr>
<th>Name of index</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Wastes capacity of the plant, max., kg/h</td>
<td>15</td>
</tr>
<tr>
<td>2. Predetermined power of the plasma torch</td>
<td>100</td>
</tr>
<tr>
<td>3. Temperature, °C</td>
<td></td>
</tr>
<tr>
<td>- in the reactor</td>
<td>1,200</td>
</tr>
<tr>
<td>- in the combustion chamber</td>
<td>1,100</td>
</tr>
<tr>
<td>- after the cooler</td>
<td>200</td>
</tr>
<tr>
<td>4. Methane flow rate, max., mm³/h</td>
<td>20</td>
</tr>
<tr>
<td>5. Argon flow rate, mm³/h</td>
<td></td>
</tr>
<tr>
<td>- to the plasma torch</td>
<td>3.5</td>
</tr>
<tr>
<td>- to the hopper of the feeder</td>
<td>2.5</td>
</tr>
<tr>
<td>- to the peepholes</td>
<td>0.1</td>
</tr>
<tr>
<td>6. Steam flow rate, max., kg/h</td>
<td>25.0</td>
</tr>
<tr>
<td>- to the plasma torch</td>
<td>18.0</td>
</tr>
<tr>
<td>- for wastes feeding, max.</td>
<td>7.0</td>
</tr>
<tr>
<td>7. Compressed air flow rate for starting-up and heating of the system (under working conditions - for water spraying), mm³/h</td>
<td>30.0</td>
</tr>
<tr>
<td>8. Service water flow rate for spraying, max., kg/h</td>
<td>100.0</td>
</tr>
<tr>
<td>9. Circulating water body for cooling of the equipment, m³/h</td>
<td>5.0</td>
</tr>
<tr>
<td>- to the plasma torch</td>
<td>3.0</td>
</tr>
<tr>
<td>- to the reactor units</td>
<td>2.0</td>
</tr>
<tr>
<td>10. Blast air flow rate, max., mm³/h</td>
<td>2,500</td>
</tr>
<tr>
<td>- to the combustion chamber</td>
<td>250</td>
</tr>
<tr>
<td>- to the gas cooler</td>
<td>2,250</td>
</tr>
</tbody>
</table>

material feeding, a peephole with a light guide, and a branch pipe intended for mounting a pressure pick-up. The mixer is connected to the plasma chamber by means of a horizontal channel having a small cross-section, which provides for gases entering into the mixer with a high velocity. Gases are admitted tangentially to an imaginary circle in the combustion chamber cross-section that assures flow swirling and intensification of the processes taking place in the gaseous atmosphere. A water-cooled tube and a branch pipe for methane feeding are mounted in the mixer bottom. In the upper part there exist a channel to remove gases out of the reactor and a water-cooled chamber that accommodates a water-cooled sampler, permitting the connection of an automatic gas analyzer and the extraction of gases for analytical control, a peephole with a light guide, and a branch pipe to mount a pressure transducer. On the water-cooled branch pipe connecting the reactor and combustion chamber, branch pipes are placed to mount the instrumentation transducers. Concrete block protects the inner surface of the water-cooled branch pipe.

To feed granules into the reactor, a screw feeder is used. It is equipped with a hopper having a hermetically closed cover. The cover is fitted with a peephole and a safety valve. To create an inert medium in the system for granule feeding, branch pipes for argon supply were designed into the feeder. A funnel was placed in the process of the granule feed. The feeder capacity can be controlled by changing the velocity of the screw conveyor rotation.

The combustion chamber is a vertical cylinder with a pinch in its upper part. The interior structure of the combustion chamber is built of blocks produced from heat-resistant concrete, and it is housed in a knock-down metal jacket that contains separate sections connected together at the flanges with the aid of bolts. The concrete block in the upper part of the combustion chamber has a tangential channel designed to supply gases out of the reactor. Two air-blast nozzles, through which air is fed for combustion of conversion gases, and two air-atomizing burners, through which water is sprayed to reduce the temperature of the flue gases, are placed in two tiers (layers) through the combustion chamber.

The nozzle arrangement, the positioning of the gas channel tangential to the imaginary circle, and the high velocity of the gas outflow ensure an intense twisting of the gas flow in the chamber and good mixing of the combustion components. In the lower part of the chamber there exists a pinch, through which flue gases are fed into the cooler. Over the pinch branch pipes are placed that are designed to mount the instrumentation transducers.

The gas cooler contains a vertical cylinder chamber and a horizontal gas conduit. The vertical chamber is built of blocks made from heat-resistant concrete and mounted on a heat-insulating brick foundation. The horizontal gas conduit is lined with two layers, a brick-inner refractory layer and an outer heat-insulating layer. The metal casing of the cooler consists of two sections connected together at the flanges by means of bolts. The clearance (space) between the concrete blocks of the vertical chamber and the casing walls is packed with kaolinite wool. In the upper part of the vertical chamber exist two nozzles designed to supply air for flue gas cooling. In the horizontal part there exist branch pipes to mount the instrumentation transducers.

The design conditions of the plant for the plasma
thermal treatment of plastic wastes are given in Table 1.

**Description of the Process**

Polyethylene wastes are fed to the plant in the form of granules of 3–5 mm size. A steady raw material feed into the plasma chamber of the reactor is performed by means of a screw feeder. To prevent the formation of explosive mixtures, the working space of the feeder, hopper, and raw material feeding system as a whole is filled with argon.

The synthesis-gas is formed in the process of polyethylene steam conversion at temperatures beyond 1100 °C. The temperature of 1100–1200 °C in the plasma chamber of the reactor is provided through the use of a 100-kV plasma torch. Compressed air is used to ensure the initial start-up of the plasma torch. Argon is used to protect (stabilize) the arc.

The required ratio of the conversion products (CO : H₂ = 1 : 2) is provided by changing the specific flow rate of the steam and maintaining the necessary temperature of the process. An excess pressure of 0–100 Pa should be constantly maintained in the plasma chamber of the reactor to exclude an inflow of free air and ensure the required ratio of the products of conversion.

The conversion gases are fed out of the plasma chamber of the reactor into a mixer, wherein they are stabilized during the process of intense mixing. A finely measured feed of methane in the mixer can provide an additional adjustment of the process temperature level and ratio of carbon monoxide and hydrogen.

The content of off-gases formed in the process of conversion is controlled by analyzing samples taken at the reactor outlet. The gases generated in the reactor are directed for combustion.

The products of conversion are burnt in the combustion chamber at a required temperature (1000–1100 °C) and an excess air coefficient (α = 1.2–1.5). The required temperature level is provided by the heat of conversion of the burning gases. To heat the chamber during the start-up of the plant and to maintain a pilot flame, an additional fuel, methane, is used.

The designated temperature level in the combustion chamber is maintained by means of a two-stage feed of blast air and injection of a necessary amount of water. Water spraying is performed by air-atomizing burners with the aid of compressed air. Flow turbulization in the combustion chamber is attained because of the tangential feed of the gas flows with high velocity, i.e., the gases out of the reactor, and the fan air. This arrangement provides for intense twisting and effective mixing of the components of combustion.

Gases leaving the combustion chamber are directed into the cooler. The temperature of the gases is reduced to 200 °C as a result of mixing with cold air. Air feeding into the cooler chamber through two nozzles mounted tangentially provides good mixing of flows and effective cooling of flue gases.

At the exit of the gases out of the cooler it is necessary to provide a vacuum of 1.5–2.0 kPa, which will allow the gas flow to move throughout the length of the path at the assured pressure of 0–100 Pa in the plasma chamber of the reactor.

The plant components placed in the high-temperature zone are cooled with chemically purified water, which should circulate through a closed recycling circuit, including the system for its cooling and conveying.

**Experimental Conditions**

In the pyrolysis gasification of PE, the major reaction variables include the steam ratio (henceforth denoted α), the PE particle size, and the second gasification reactor's temperature. In this study, the gasification efficiency as affected by the two most important variables, the steam ratio (α) and second gasification reactor's temperature changes, was investigated.

The steam ratio (α) in the pyrolysis gasification reaction between ethylene and steam was based on the calculation of the following mass balance. At high temperatures (1100 °C or more), polyethylene reacts with steam to produce CO and H₂. Based on the given equation (1), when α = 1.0, the theoretical mass of steam consumed per kg of polyethylene is

\[
M_{\text{St}}^{\text{PE}} = \frac{M_{\text{H₂O}}}{M_{\text{CH₂}}} = 36 / 28 = 1.2857 \text{ kg}
\]

For example, when the steam ratio α is 1.2, the mass of steam consumed per kg of polyethylene is

\[
M_{\text{St}} = M_{\text{St}}^{\text{PE}} \cdot \alpha = 1.2857 \text{ kg} \cdot 1.2 = 1.5428 \text{ kg}
\]

In this calculation, the mass flow rate of PE is fixed at \( M_{\text{PE}} = 13.7 \text{ kg/h} \). Here, the volume flow rate of steam necessary for gasification is

\[
V_{\text{St}} = M_{\text{St}} \cdot \frac{1.5428 \text{ kgSt/kgPE} \cdot 13.7 \text{ kgPE/h}}{21.136 \text{ kg/h} = 21.136 \text{ kg/h} \cdot 1.2444 \text{ Nm}^3/\text{kg(kg)}} = 26.3 \text{ Nm}^3/\text{h}
\]
Table 3. GC Conditions for Gas Analysis in the Plasma System

<table>
<thead>
<tr>
<th>Inlet temperature</th>
<th>Room temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling time</td>
<td>20 sec</td>
</tr>
<tr>
<td>Injection time</td>
<td>40 sec</td>
</tr>
<tr>
<td>Column</td>
<td>Temperature (°C)</td>
</tr>
<tr>
<td>Molecule sieve 5Å</td>
<td>200</td>
</tr>
<tr>
<td>Porapak Q</td>
<td>40</td>
</tr>
</tbody>
</table>

![Image](image1.png)

(A) Construction

![Image](image2.png)

(B) Torch Arc

Figure 2. Construction and Torch Arc of the Plasma Torch.

Therefore, the PE pyrolysis reaction conditions in the plasma gasification system were set as follows. The power supplied to the plasma torches was adjusted to 100 kW. The first reactor temperature was maintained within the 1400 ~ 1500 °C range, independent of each reaction condition. The amounts of steam, PE, and argon supplied for each value of \( a \) are shown in Table 2.

The values of \( a \) were 0.9, 1.0, and 1.2. The retention times for gasification products were calculated assuming complete gasification of PE. After pyrolysis, to measure the gasification efficiency, the second reactor’s temperature was varied between 800 and 1200 °C.

Collection and Analysis

To collect the test sample from the second gasification reactor exit, a vertically adjustable collection device equipped with a water-cooling system was designed. In addition, to collect and remove incomplete-combustion particles, a cyclone particle collection and filtration system was attached to the gas collection line. Finally, for GC analysis of the generated gas, the moisture in the gas was removed using a condenser. The system was then connected to the GC on-line, and a micro-GC apparatus (Varian CP-4900) was attached for real-time analysis of the gas composition. In the gas composition analysis, a 5Å molecule sieve column was used to analyze \( \text{O}_2, \text{N}_2, \text{H}_2, \text{CO}, \text{and CH}_4 \) and a Porapak Q column was used to analyze \( \text{CO}_2 \) and \( \text{C}_2\text{H}_6 \). The GC conditions are listed in Table 3.

![Image](image3.png)

Figure 3. Calculated and experimental volt-ampere characteristics of the V-plasma torch. Steam: 1) calculation: firm lines - 1\(^{st}\) variant; dotted lines - 2\(^{nd}\) variant; 2) x - experiment; 3 g/s, \( \triangle \) - experiment, 5 g/s.

Results and Discussion

V-Plasma Torch Experiment Results

The torch used in the pyrolysis gasification reaction was a V-type torch. Compared to a general line-type torch, it can create a wider reaction temperature field to improve the efficiency of pyrolysis. Figure 2 (A) shows the shape and (B) shows the arc shape from the plasma torch.

Figure 3 displays the experimental volt-ampere characteristics for operation on air. The voltage rises together with the electric current, as expected.

While working on steam, the start was realized initially on air, the arc current was established at 300 A, the argon flow rate was \( G_{\text{Ar}} \geq 0.5 \) g/s, and the air flow rate was \( G_{\text{Air}} = 5 \) g/s. The air flow rate was then smoothly decreased up to zero and, at the same time, the steam flow rate was increased up to \( G_{\text{steam}} = 3 \) g/s. The obtained values of the arc voltage in the V-plasma torch operating on steam, for currents of 300 and 250 A, are also shown in Figure 2. It is clear that the experimental values of the voltage are ca. 15 % less than the calculated ones. In
addition, the volt-ampere characteristics are closer to the "hard" one, i.e., they are characterized by a weak dependence of the voltage on the current.

For the gasification of PE in the steam plasma system, adjusting the first pyrolysis reactor temperature is possible by adjusting the current supplied to the torch to form the plasma arc. For an efficient pyrolysis reaction, in other words, the pyrolysis/gasification of PE with steam changes from being endothermic to exothermic at a temperature of ca. 1300 °C. This process causes a sharp rise in the reactor temperature. Therefore, the first pyrolysis reactor temperature was maintained constant within the range 1400 ~ 1500 °C.

Distribution of Pyrolysis Gas Products Following Changes in Steam/PE Ratio (α)

To compare the gasification efficiencies following changes in the value of α at a second gasification reactor temperature of 1200 °C, the distribution of gasification products, theoretically calculated from mass balance, is shown in Figure 5. As the value of α increases from 0.9 to 1.2, the percentage of H₂ decreases and that of CO increases. The ratio of H₂ to CO decreased from 2.11 to 2.00.

At a second gasification reactor temperature of 1200 °C, the distribution of gasification products, with respect to changes in α, is shown in Figure 6. The experimental values are similar to the values calculated from the mass balance. In other words, as α increases from 0.9 to 1.2, the percentage of H₂ decreased and that of CO increased. The ratio of H₂ to CO decreased from 2.48 to 2.26. Here, small amounts of CO₂ and CH₂ were detected in the gasification products. This result implies that not all of the PE was converted into synthetic gas. Furthermore, the percentage concentration of CH₄ decreased upon increasing α, whereas CO₂ underwent only a minute increase. Nevertheless, their amounts were very minute.

Comparing the experimental values for H₂ to the theoretical values calculated from mass balance, the former were greater. For CO, the experimental values were lower. This finding probably results from a few oxygen molecules in the steam converting to CO₂ during the steam/PE reaction.
Figure 7. Gas concentrations and \( \text{H}_2/\text{CO} \) ratios obtained from the 2\textsuperscript{nd} reactor with different temperatures and in the 1\textsuperscript{st} reactor with \( \alpha = 0.9 \).

Figure 8. Gas concentrations and \( \text{H}_2/\text{CO} \) ratios obtained from the 2\textsuperscript{nd} reactor with different temperatures and in the 1\textsuperscript{st} reactor with \( \alpha = 1.0 \).

Figure 9. Gas concentrations and \( \text{H}_2/\text{CO} \) ratios obtained from the 2\textsuperscript{nd} reactor with different temperatures and in the 1\textsuperscript{st} reactor with \( \alpha = 1.2 \).

Figure 10. \( \text{H}_2/\text{CO} \) ratios of product gases obtained from the 2\textsuperscript{nd} reactor with different temperatures and in the 1\textsuperscript{st} reactor with different steam ratios.

Distribution of Gasification Products Following Changes in the Second Gasification Reactor’s Temperature

While maintaining the first pyrolysis reactor’s temperature to within 1400~1500 °C, the second gasification reactor’s temperature was varied to 800, 1000, and 1200 °C, and the gasification products were measured in each case. Figure 7 shows the experimental results when \( \alpha = 0.9 \), Figure 8 when \( \alpha = 1.0 \), and Figure 9 when \( \alpha = 1.2 \).

We observe that as the second gasification reactor’s temperature increased, the \( \text{H}_2 \) yield increased and the \( \text{CO} \) yield decreased. The yield of \( \text{CH}_4 \) showed a sharp common decrease at 1200 °C for each steam ratio.

From these results, comparisons between the \( \text{H}_2/\text{CO} \) ratios with respect to the changes in the second reactor’s temperature and value of \( \alpha \) are shown in Figure 10. The \( \text{H}_2/\text{CO} \) ratio for the gas produced for each reaction temperature decreased upon increasing the value of \( \alpha \). In addition, looking at the effects of the second gasification reactor temperature, when it was 800 °C, the \( \text{H}_2/\text{CO} \) ratio decreased from 1.30, at \( \alpha = 0.9 \), to 1.18, at \( \alpha = 1.2 \). When the temperature was 1200 °C, the \( \text{H}_2/\text{CO} \) ratio decreased from 2.48, at \( \alpha = 0.9 \), to 2.26, at \( \alpha = 1.2 \). On the other hand, with constant \( \alpha \), increasing the reactor temperature increased the \( \text{H}_2/\text{CO} \) ratio greatly. At \( \alpha = 0.9 \), the ratio increased from 1.3, at a temperature of 800 °C, to 2.48, at a temperature of 1200 °C. At \( \alpha = 1.2 \), the ratio increased from 1.18, at a temperature of 800 °C, to 2.26 at 1200 °C. Because the objective of this research was to produce a synthetic gas having a stoichiometric \( \text{H}_2/\text{CO} \) ratio of 2, it appears best to maintain the gasification reactor temperature ca. 1100 °C.

From these results, for each gasification reactor temperature, increases in the value of \( \alpha \) displayed an overall tendency for the \( \text{H}_2/\text{CO} \) ratio to decrease, although the differences were not large. However, for each value of \( \alpha \), the \( \text{H}_2/\text{CO} \) ratio exhibited large increases following changes in reactor temperatures. Therefore, as factors affecting the gasification efficiency of the second reactor, the reactor temperature is more significant than the steam
ratio ($\alpha$).
As the second gasification reactor’s temperature increases, the $\text{H}_2/\text{CO}$ ratio increases and the amount of $\text{CH}_4$ decreases, demonstrating an efficient gasification reaction. Therefore, to maximize the gasification efficiency, maintaining the second gasification reactor’s temperature to within the range 1100–1200 °C is an important factor.

Conclusion

Using PE as a model plastic and steam as the plasma gas, the objective of this study was to produce a synthetic gas comprising CO and $\text{H}_2$, from the pyrolysis of PE with steam, at a ratio of 1:2. From our results obtained when changing the steam ratio and the second gasification reactor’s temperature, the following features can be concluded.

1) The experiments demonstrated the reliable and stable operation of the V-type plasma torch.
2) In the theoretical calculations of the distribution of gasification products, as $\alpha$ increased from 0.9 to 1.2, the percentage yield of $\text{H}_2$ decreased and that of CO increased. The $\text{H}_2/\text{CO}$ ratio decreased from 2.11 to 2.00.
3) When the second gasification reactor’s temperature was 1200 °C, the experimental results showed similar tendencies as did the values calculated from the mass balance. In other words, as $\alpha$ increased from 0.9 to 1.2, the percentage yield of $\text{H}_2$ decreased and that of CO increased. The $\text{H}_2/\text{CO}$ ratio decreased from 2.48 to 2.26. Here, minute amounts of $\text{CO}_2$ and $\text{CH}_4$ were detected in the gasification products.
4) While maintaining the first pyrolysis reactor’s temperature to within 1400–1500 °C, the second gasification reactor’s temperature was varied to 800, 1000, and 1200 °C. The results from measuring the gasification products for each temperature showed that an increase in the reactor temperature increased the $\text{H}_2$ yield and decreased the CO yield. The $\text{CH}_4$ yield underwent a common large decrease for each steam ratio at 1200 °C.
5) Comparing the $\text{H}_2/\text{CO}$ ratios following changes in the second reactor’s temperature and value of $\alpha$, the $\text{H}_2/\text{CO}$ ratio showed a tendency to decrease upon increasing $\alpha$ for each reactor value. On the other hand, at a constant value of $\alpha$, increasing the reactor temperature showed a tendency to greatly increase the $\text{H}_2/\text{CO}$ ratio.
6) In addition, in each gasification reactor temperature range, the $\text{H}_2/\text{CO}$ ratio underwent an overall decrease upon increasing $\alpha$, although the differences were not large. However, the increase in the $\text{H}_2/\text{CO}$ ratio following changes in reactor temperature was large. Therefore, the reactor temperature has a more significant effect on the gasification efficiency than does the steam ratio ($\alpha$). Therefore, we conclude that, to maximize the gasification efficiency, it is important to maintain the second gasification reactor’s temperature within the range 1100–1200 °C.

References