Communication

Hydrogen Gas Generation from Refuse-derived Fuel (RDF) under Wet Conditions

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An explosion has recently occurred at a silo containing refuse-derived fuels (RDF) in Japan. There is a possibility that microorganisms are involved in generation of combustible gas from RDF and this study was aimed at showing the presence of bacteria that can ferment RDF pellets. All RDF samples tested contained a relatively high number of viable bacterial cells, \(1.4 \times 10^5\) to \(3.2 \times 10^6\) viable cells/g. These bacteria in the RDF samples fermented them to generate heat and hydrogen gas.

Key words: refuse-derived fuels (RDF); hydrogen gas; combustible gas; viable cell

Refuse-derived fuels (RDF) used for a power plant cover a wide range of waste materials, which have been processed to fulfill guideline, regulatory or industry specifications mainly to achieve a high calorific value. RDF typically consists of pelletized or “fluff” municipal solid waste (MSW) that is the by-product of a resource recovery operation. Processing removes iron materials, glass, grit, and other materials that are not combustible. In the RDF production process, Ca(OH)\(_2\) or CaO is added to waste materials for the prevention of the rot of food wastes and the acceleration of drying of solid wastes.\(^1\) RDF is thought to have a number of merits, e.g., low burden on the environment, low construction cost, good storage ability, stable calorific power, easy, handling, and good transportability.\(^2\)

Unfortunately, despite the good storage ability of RDF, an explosion occurred on August 19th, 2003, at a silo containing RDF of the Mie RDF Power Station (a garbage-powered electricity generating plant) in Tado Village, Mie Prefecture, Japan. Before the explosion, generation of irregular heat was observed. Although the real cause of the explosion at the silo has not been clear, therefore, it may be possible that microbial fermentation on RDF generates heat at the initial stage and combustible gas such as methane and hydrogen gases. To our knowledge, there are few reports describing microorganisms related to RDF.\(^3\) In this communication, we describe the presence of viable cells in RDF, and rapid heat generation and hydrogen gas production from RDF under a wet condition.

Cylindrical pellets of RDF are manufactured mainly from house garbage in addition to paper and plastics in Mie. RDF pellets are produced at 7 plants in Mie, and transported to and stored at different storehouses until they are transported to the silo at Tado. Since RDF samples could not be obtained from Tado, we used three different samples, two (referred to as RDF1 and RDF2) from the Suzuka storehouse and one (RDF3) from the Yokkaichi storehouse. Since RDF pellets from different plants are mixed at storehouses, the origins of the samples cannot be identified.

Viable cell numbers in the samples were counted as follows. Several pellets (10 g) of each sample were suspended well in 90 ml of sterile physiological salt solution and homogenized with a Universal Homogenizer (Nihon Seiki Seisakusho Co., Tokyo) at 10,000 rpm for 20 sec. The resulting suspension was serially diluted with sterile physiological salt solution. Viable counts of bacteria were made by the usual plate-counting technique. For counting the sum of aerobic and facultatively anaerobic bacteria, SCD broth (Wako Pure Chemical Industries, Ltd., Osaka) containing 1.5% agar was used and the plates were incubated at 37°C. For counting the sum of facultatively and obligately anaerobic bacteria, SCD broth supplemented with 0.5% yeast extract, 0.5% soluble starch, 0.03% cysteine-HCl, and resazurin (1 \(\mu\)g/ml) was used and plates were incubated at 37°C under anaerobic atmosphere using a BBL GasPak anaerobic jar system (Becton Dickinson and Company, Sparks, Md.). The number of facultatively anaerobic bacterial cells was found by cultivating the replica plates from the anaerobic cultures under aerobic conditions. The number of aerobic bacteria was estimated from the difference between the total cell numbers under the aerobic condition and those of facultative anaerobes, and the number of obligately anaerobic bacteria was calculated from the difference between the total cell numbers under the anaerobic condition and those of facultative anaerobes. As shown in Table 1, relatively high cell numbers were detected in all samples, i.e., \(10^3\) to \(10^6\) of aerobes and \(10^4\) to \(10^5\) of anaerobes. This observation indicated that drying of the...
waste materials by hot air at 500°C and the addition of Ca(OH)₂ to them could not efficiently sterilize microorganisms in them. Actually, pHs of the RDF measured in suspensions (Table 1) seem to allow the usual microorganisms to survive in RDF.

Since normal preparations of RDF include a moisture content of less than 10%, it is unlikely that microorganisms ferment the waste materials in normal RDF. However, if drying of the pellets is not enough during the manufacture process or if RDF pellets are moistened for any unexpected reasons, microorganisms occurring in RDF pellets would become active immediately. We examined fermentation of RDF materials by RDF-derived microorganisms in wet conditions. First, we measured generation of heat during the fermentation of wetted RDF pellets. Each RDF sample (2.8 l; about 1.4 kg) was moistened with 560 ml of sterile distilled water and put in a stainless steel jar (3 l volume, 30 cm height, and 12 cm diameter) equipped with thermometer to monitor temperature, and incubated at room temperature without forced aeration. An increase in temperature by the fermentation of RDF materials by RDF-derived microorganisms in wet conditions. First, we measured generation of heat during the fermentation of wetted RDF pellets. Each RDF sample (2.8 l; about 1.4 kg) was moistened with 560 ml of sterile distilled water and put in a stainless steel jar (3 l volume, 30 cm height, and 12 cm diameter) equipped with thermometer to monitor temperature, and incubated at room temperature without forced aeration. An increase in temperature by the fermentation of RDF1, RDF2, and RDF3 was observed as shown in Fig. 1. Temperature in all the samples began to increase on the second day of incubation and reached a plateau at 65 to 68°C on the fourth day. When dry air was metered (150 ml/min) during the incubation of sample 1, a similar pattern of heat generation was observed (data not shown). Second, we monitored the production of fermentation gas during the fermentation of aqueous suspensions of RDF pellets.

Table 1. Viable Cell Numbers in RDF Samples

<table>
<thead>
<tr>
<th>Sample</th>
<th>pH</th>
<th>Aerobes (cfu / g-dry basis)</th>
<th>Anaerobes (cfu / g-dry basis)</th>
<th>Facultative anaerobes (cfu / g-dry basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDF1</td>
<td>8.33</td>
<td>$3.2 \times 10^6$</td>
<td>$2.2 \times 10^6$</td>
<td>$1.1 \times 10^5$</td>
</tr>
<tr>
<td>RDF2</td>
<td>6.93</td>
<td>$1.4 \times 10^3$</td>
<td>$1.4 \times 10^3$</td>
<td>$1.0 \times 10^4$</td>
</tr>
<tr>
<td>RDF3</td>
<td>9.68</td>
<td>$1.9 \times 10^3$</td>
<td>$1.4 \times 10^3$</td>
<td>$7.0 \times 10^3$</td>
</tr>
</tbody>
</table>

RDF pellets of RDF2 (100 g) were suspended in 250 ml sterile deionized water, placed in a glass bottle (500 ml volume) with a butyl rubber stopper, and incubated at 37°C. Fermentation gas evolved was collected by the water displacement method with graduated cylinders which had been filled with water of pH 3 or less as described previously. As shown in Fig. 2, gas production started within 6 h and continued for more than 48 h. The composition of the fermentation gas was analyzed by gas chromatography, using Gas Chromatograph GC-323 online with the EZChrom Elite Chromatography Data System (GL Science Inc.) and the amount of hydrogen gas evolved was calculated based on hydrogen standard curves. As a result, it was shown that 2,370 ml of fermentation gas was produced from 100 g of RDF pellets and that about 68% of the fermentation gas was hydrogen gas and the residual 32% was carbon dioxide. No methane gas was detected. These results indicated that microorganisms in RDF pellets could ferment organic materials to generate heat and hydrogen gas as combustible fermentation gas immediately after the pellets became wet.

Although this study was not aimed at resolving the cause of the explosion at the silo for RDF storage, the possibility that microorganisms are involved in generation of heat and combustible gas cannot be denied. It seems necessary to investigate microorganisms in RDF for more safe use of RDF.

References