Evaluation of various solid wastes produced after the Great East Japan Earthquake

Hiroshi Koseki¹

¹National Research Institute of Fire and Disaster, Jindaiji-Higashi 4-35-3 Chofu, Tokyo 182-8508, Japan
E-mail: koseki@fri.go.jp

Abstract. In order to know the risk of fire of disaster waste, radioactive waste and recycled materials, thermal analysis and gas emission test were conducted. Huge amount of disaster waste and radioactive waste were produced after the Great East Japan Earthquake (March 2011). During recovery work, we experienced many fires and accidents due to spontaneous ignitions from massive disaster and radioactive wastes. Some of wastes should be recycled for biofuel and constructive materials. To know the risk of ignitions and fires, we conducted risk evaluation for these materials using high sensitive calorimeters and gas emission. The investigation process and results are shown. Microorganism in the wastes caused faint heat generation which might be a trigger of fires. However disaster wastes are much safer than most solid biofuel, because disaster wastes contained large amount of incombustible materials.

1. Introduction
The Great East Japan Earthquake (March 11, 2011) was the fourth greatest earthquake in the world since 1900, which caused huge damages in the north-east area in Japan, killed about 20,000 people. Especially the nuclear plants in Fukushima were severe damaged (INES level=7). And still Japan has not recovered yet [1,2].

After the earthquake occurred, huge amount of various disaster wastes were produced and some of them had radioactive contamination (mostly $^{137}$Cs). Therefore we have to try to reduce, recycle and re-use these materials. However we need long time to treat the massive wastes, which caused various troubles. For example, spontaneous ignitions and fires occurred from disaster and radioactive waste. They might cause explosion due to emission of combustible gas.

Some of waste materials should be recycled for biofuel and constructive materials. In order to know the risk of ignitions and fires during storage and treatment of these wastes, we conducted risk evaluation for these materials using high sensitive calorimeter and gas emission test. In this paper, these evaluation processes and research results are shown. That is, they produced faint heat generation which caused fires after it reached proper temperature in the materials. And they might emit combustible gas and gas explosion might occur.

2. Experimental

2.1. Samples
Samples were taken from massive material piles and treatment facilities in the disaster area, Natori and other places in the East-north area of Japan, and some of them might be radioactive but radiation was
very small, and we could not detect radiation from samples by dosimeter. Separated soil and wood pellet were obtained from recycling facilities. Separated soils (Soils A and B) were separated from mixture of wood and soil, and they were nearly pure soil but included some water and organic compound, which are used for various architectural material. RDF is not relation with earthquake disaster, but used for reference, which is very dangerous in our past tests. Figure 1 shows photos of some examples in current tests. And table 1 shows summary of sample materials. To prepare for test, all samples were crashed to powder and to be uniformed. To know effects of fermentation, water was added to the sample before the tests. Amount of water was 20% (w/w) of sample.

Natori area was suffered by tsunami wave and soil samples might include tsunami soil. RDF stands for Refuse Derived Fuel which was typical biofuel in Japan.

Figure 1. Example of samples. (a) Tatami, (b) Soil, (c) Wood pellet and (d) RDF.

Table 1. Summary of samples.

| Material       | Description                                             | Marks in figures          |
|----------------|---------------------------------------------------------|---------------------------|
| House holdings, Mat Tatami, from tsunami disaster area, Natori | Tatami, figure 1          |
| Wood pellet    | Taken from recycle facilities near Natori               | Wood pellet figures 1 and 2 |
| Soil           | Taken soil in tsunami disaster area, Natori            | Soil, figure 1            |
| Soil           | Kibushi clay, no organic soil (carbon exists)          | Kibushi-clay, figure 3    |
| Separated soil | Soil in which combustible material was taken, but still some combustible material existed | Soil A, Soil B, figure 4 |
| RDF            | Obtained from manufacturer, for reference              | RDF, figure 1             |
Figure 2. TAM results of wood pellet.

Figure 3. TAM results of soil (Kibushi clay).

Figure 4. Time history of gas concentration for soil A and soil B with 20% (w/w) water. (a) Oxygen and (b) Carbon dioxide.

Figure 5. TG-DTA results of (a) soil A and (b) soil B.

2.2. Experimental method and evaluation
Current evaluation method is the same way in previous reports [3,4], that is, combination of thermal analysis using isothermal method by TAM-3 and gas emission tests. Generally the wire mesh test in the UN recommendation for dangerous materials [5] is used for evaluation of characteristics of spontaneous-ignition, but we knew that this test method was not so good for measurement of small heat generation produced from biofuel because of its low sensibility, which was reported in our
previous study [3,4]. Correlative relationship between the TAM-3 isothermal method and the wire mesh test was not clear.

2.2.1. Self-ignition test by thermal analysis. The TG-DTA (Thermogravimetric/Differential Thermal Analyzer) test was conducted for all samples, which gives over-all thermal characteristics of samples. Measurement started from the room temperature, around 20 °C, to 550 °C. To conduct thermal properties, especially to know initial faint reaction at lower temperature is very important and TAM-3 (TAM=Thermal Analysis Monitor, Thermometric Co., Sweden) was used. TAM-3 is one of the most sensitive calorimeter among commercial available thermal analyser, and its sensibility is 0.2 μW/mL. We used it as isothermal mode, keeping test temperature at 50 °C. The wire-mesh basket test of the UN(United Nations) Div.4.2 was used widely for danger of spontaneous-ignition of coal, but we did not use the UN test because it needs litre order amount of samples and need long hours for testing, and could not detect such faint heat generation, μW/mL order.

2.2.2. Gas emission test. To know gas emission from sample is also important, because it may cause explosion if sample is stored in a closed area. About 50 mL sample was kept in a bottle at the room temperature for 10 days and then gas concentration in the sample bottle was measured by the gas chromatograph (GC, TCD). We also measured change of gas concentration with time for a month for soil A and soil B following previous paper [3].

3. Experimental results and discussion

3.1. Thermal tests using TG-DTA and TAM

Examples of TG-DTA data are shown in figure 5. Here results of soil A and soil B are shown. They contained water and soil A lost its weight about 16% and soil B lost 27% up to 100°C by water vaporization. Around 200 to 300°C, heat generation and weight loss was observed because of volatile organic compound burns. That is, total weight loss of soil A was about 17.5% and soil B was 49.9% between 100°C and 550°C which might be equal to concentration of organic compound. Summary and results of other samples are shown in table 2. Up to 550°C, most volatile organic compound burnt, and the difference of weight loss was nearly equal to concentration of organic compound. Soil had very small amount of volatile organic compound, that is, Soil A was 1.5%, Soil B was 22.9% and soil (Kibushi clay) 0.4%. The rest was incombustible materials. On the other hand, biofuel has high concentration of volatile compound, such as RDF (87.0%) and wood pellet (85.7%).

| Sample                  | Weight loss ~100°C | Weight loss ~550°C |
|-------------------------|-------------------|-------------------|
| House holdings, Mat     | 49.0              | 81.2              |
| Soil A                  | 16.0              | 17.5              |
| Soil B                  | 27.0              | 49.9              |
| Soil (Kibushi clay)     | 10.2              | 10.6              |
| Wood chip               | 9.9               | 94.0              |
| Wood pellet             | 8.7               | 94.4              |
| RDF                     | 10.1              | 97.1              |

The isothermal test with TAM-3 was conducted to know pattern of heat generation. The sample was kept at 50°C. Test condition was the same that in our previous papers [3,4]. There were two patterns of heat generations, first one was large heat generation just after starting measurement which was from chemical reaction or heat transfer between sample and sample cell. Second was from phenomenon of fermentation, which was produced several hours after the start of measurement. And second heat generation was generally much smaller than that of first one. Both heat generations
occurred in most cases. Wood chip, wood pellet and RDF were used for fuel, and lost their weight more than 90% (w/w) up to 550°C.

Figure 2 shows TAM results of wood pellet. Most tests were conducted in three different conditions, that is, 1) sample without addition of water, 2) sample + 20% (w/w) water in air, 3) sample + 20% (w/w) water in nitrogen. Wood pellet produced very small heat generation. When water was added, larger heat generation was observed immediately which might be no relation with fermentation because heat generation by fermentation need long time [3,4]. There was small difference between wood pellet with water in air and in N₂. This result meant that there was nearly no fermentation with aerobic organism with wood pellet in air/N₂. Peak value of test in air was slightly larger than that in nitrogen, which means no aerobic fermentation occurred. Heat generation of aerobic fermentation is much larger than that of anaerobic fermentation because aerobic fermentation is complete combustion reaction but anaerobic fermentation is incomplete combustion, produced various materials such as CH₄, CO, C₂H₅OH. When water was not added, most samples did not make heat generation or make very small heat generation.

Figure 3 shows TAM results of soil (Kibushi clay) which has no organic compound but carbon. So it made very small heat generation, even water added, and there was not large difference between heat release in air and in nitrogen (table 3). Therefore aerobic fermentation did not occur in soil (kibushi-clay). Heat generation during measurement was integrated from 0-24 hours and 24-72 hours and results are shown in table 3. These values of wood pellet and soil were much smaller than those of RDF, typical biomass fuel. Aerobic fermentation produced much heat generation than those of anaerobic fermentation and which also produced much gas emission (table 4).

Table 3. TAM results heat generation from samples.

| Sample                  | Heat generation (J/g) |
|-------------------------|-----------------------|
|                         | 0-24 hours | 24-72 hours |
| Wood pellet             |            |
| Wood                    | 0.12       | 0.01       |
| Wood+water, in air      | 1.23       | 0.13       |
| Wood+water, in N₂       | 0.9        | 0.07       |
| Soil (Kibushi clay)     |            |
| Soil                    | <0.01      | <0.01      |
| Soil+water, in air      | 0.01       | 0.01       |
| Soil+water, in N₂       | <0.01      | <0.01      |
| RDF                     |            |
| RDF                     | 2.03       | 3.21       |
| RDF+water               | 29.07      | 14.05      |

3.2. Gas emission test

The gas emission test was conducted following the method of previous paper [3]. Gas concentration of atmosphere of samples in the bottle was measured by the Gas Chromatograph (GC) and results are shown in table 4. House holdings (Mat) were most danger among samples, and caused fires after the earthquakes [2]. Its danger was similar to that of RDF. And the other soils were evaluated as relatively safe. On the other hand, RDF, typical biofuel, is the most danger. Sometimes RDF caused fires and explosions [2]. In regard to gas emission, most samples emitted very small amount of hydrogen, and wood chip emitted methane. Gas emission results such as carbon dioxide and oxygen concentration had good agreement with heat generation results (table 3).

Table 4. GC experiment results.

| Samples                  | Concentration of gas species (Vol. %) | Test condition |
|--------------------------|--------------------------------------|----------------|
|                          | O₂   | N₂    | H₂    | CH₄  | CO₂  |               |
| House holdings, Mat      | 11.49| 73.26 | -     | -    | 0.7  | Water added   |
|                          | 1.85 | 70.65 | 1.12  | -    | 4.05 |               |
Samples of soil A and soil B were tested for one-month to know change with time. That is, sample was kept in 1000 ml bottle at 20±2°C for a month. And we measured gas concentration inside the bottle, at first day, 5 days 15 days and 30 days after the start of the test.

All samples emitted only small amount of gas, and increased gas emission when water was added. Both soil A and soil B decreased oxygen concentration and increased carbon dioxide with time. In these tests we also measured concentration of carbon monoxide, methane, but they were not detected by GC. When 20% (w/w) water was added to sample, gas emission rate increased. However rates of change were very small. The rates of soil B were much higher than those of soil A. Decrease rate of oxygen concentration was very similar of increase rate of carbon dioxide, for soil A and soil B. Combustible gas was not detected in these tests, which meant activity of aerobic micro-organism might be main stream in this atmosphere.

3.3. Evaluation of samples
Combination of results of TAM and gas emission test [3] was used for evaluation of hazard of fire and explosion from samples. Soil (Kibushi clay) is the most safety among current all samples, because it included nearly no combustible component. And the other soils were evaluated as relatively safety. Among three soils, rank of danger was; Soil B > Soil A > Soil (Kibushi clay), which trend was similar to concentration of organic component in samples, shown in table 2. On the other hand, RDF was the most danger among all samples, based on heat generation and gas emission data. House holdings (Mat) were most danger among disaster wastes, and caused fires [2].

Considering recycle treatment of disaster waste, they are stored outdoor facilities in most cases. They produced very small amount of combustible gas such as hydrogen, which means no possibility to cause gas explosion. Results in this study show that gas emission was small, and mostly related with aerobic fermentation, and mostly carbon dioxide and water were emitted. Therefore TAM-3 measurement of small heat generation by fermentation should be most important for hazard evaluation of heat generation and fire.

4. Conclusion
Several samples which represented as disaster waste and recycle materials were tested for hazard evaluation. The heat generation for all samples except for RDF were smaller than most biofuel and emitted very small amount of combustible gas. RDF, typical biomass fuel, was tested for reference. So they are much safer than most solid biofuel, and the reason was they contained only small amount of combustible materials in samples. Combustible gas was emitted very small, which means we do not need to consider hazard of explosion by emitted gas during recycling work.

Acknowledgments
Samples were prepared by NIES (National Institute of Environmental Study, Japan), so author thanks people who helped this study.
References

[1] Dobashi R 2014 Fire and explosion disasters occurred due to the Great East Japan Earthquake (March 11, 2011) J. of Loss Prevention in the Process Industries 31 121-6

[2] Murasawa N, Koseki H, Iwata Y and Sakamoto T 2018 Fire caused by disaster waste after the 2011 Great East Japan Earthquake Loss Prevention Bulletin 259 p 2528

[3] Koseki H 2011 Evaluation of various solid biomass fuels using thermal analysis and gas emission tests Energies 4 616-27

[4] Li X, Koseki H and Momota M 2006 Evaluation of danger from fermentation-induced spontaneous ignition of wood chips J. of Hazardous Materials A135 15-20

[5] United Nations 2009 Recommendations on the Transport of Dangerous Goods: Manual of Tests and Criteria 5th rev. ed.