

Comparison of Fires in Lithium-Ion Battery Vehicles and Gasoline Vehicles

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ABSTRACT

Electric vehicles have become more popular and may be involved in fires due to accidents. However, characteristics of fires in electric vehicles are not yet fully understood. The electrolytic solution of lithium-battery vehicles is inflammable, so combustion characteristics and gases generated may differ from those of gasoline cars. Therefore, we conducted fire tests on lithium-ion battery vehicles and gasoline vehicles and investigated the differences in combustion characteristics and gases generated. The fire tests revealed some differences in combustion characteristics. For example, in lithium-ion battery vehicles, the battery temperature remained high after combustion of the body. However, there was almost no difference in the maximum CO concentration measured 0.5 to 1 m above the roof and 1 m from the side of the body. Furthermore, HF was not detected in either type of vehicle when measured at the same positions as for CO.

The experiment results did not reveal any reason to treat vehicles with lithium-ion batteries differently from gasoline vehicles with regard to safety measures against harmful gases that may be generated around the burning vehicle.

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INTRODUCTION

The use of electrically powered vehicles is rapidly advancing. Lithium-ion batteries have inflammable electrolytes, so their combustion and the gasses generated may differ from those of gasoline vehicles. Few results of fire tests on single units of lithium-ion batteries and on lithium-ion battery installing vehicles have been reported. Therefore, what occurs when an electrically powered vehicle is involved in a fire is not commonly known. Results of fire tests on single units (module or pack) of lithium-ion batteries [1, 2, 3] indicate no explosion of batteries or scattering of battery materials, although some extension of flame was observed when the safety vent opened. However, some results of fire tests on lithium-ion battery installing vehicles [4, 5, 6, 7] indicate that heat flux around the vehicle during combustion of a lithium-ion battery installing vehicle does not differ greatly from that of a gasoline vehicle. Although the results of combustion of a vehicle in a relatively small space and analysis of the volume of gas generated during tests have been reported, the concentration of gasses has not been measured within the range in which people can approach during firefighting in a nearly open space.

In the present study, we conducted fire tests on lithium-ion battery installing vehicles and on gasoline vehicles in a nearly open space, and compared the combustion characteristics of both types of vehicle and the concentrations of harmful gasses (CO and HF) around the vehicle in the area where people may approach.

EXPERIMENTAL PROCEDURE

Testing Facilities

The tests were conducted in JARI's explosion-resistant fire test cell, which allows indoor fire tests on vehicles (Figure 1). Indoor tests are not affected by bad weather (e.g., wind and rain), so highly reproducible data can be obtained. The test apparatus is cylindrical with a ceiling height of 16 m and a internal diameter of 18 m and is constructed so that air is blown into the apparatus at a rate of 750 m³/min through a suction hole opened under the floor to enable tests in a nearly open space. Combustion gasses generated from the fire test were discharged from the ceiling and then sent to the exhaust gas and smoke treatment equipment in order to remove soot and other harmful components before exhausting it into the atmosphere [8].

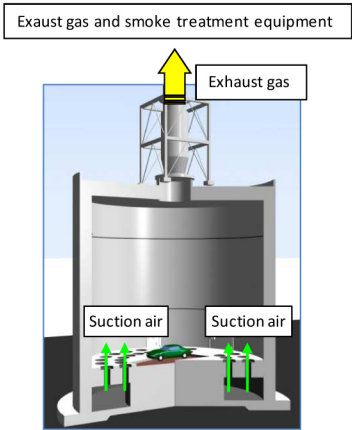


Figure 1. Graphic model of Explosion resistant fire test cell

Experimental Vehicles

The test vehicles were a 1,300 cc hatchback gasoline vehicle, a gasoline vehicle, and two lithium-ion battery-powered vehicles (Figure 2). The gasoline vehicle contained 10 L of gasoline. For tests on the lithium-ion battery installing vehicles, two vehicles carrying different types of battery between the rear seat and the trunk (LIB Vehicle-1 and LIB Vehicle-2) were used. The prismatic battery mounted on LIB Vehicle-1 had a resin cell case, electric energy of 8 kWh, and a mass of 90 kg. The cylindrical battery mounted on LIB Vehicle-2 had electric energy of 5 kWh and a mass of 40 kg. No gasoline was used in the lithium-ion battery installing vehicles. The heating value of the anode and electrolyte of a fully charged lithium-ion battery is 2.5 kJ/g [9], so the total heating value of 10 L of gasoline is 1.5 to 3.5 times that of a lithium battery used in the tests; thus, the total heating value of gasoline is slightly larger, but the difference is not extreme.



Figure 2. Experimental vehicle

Ignition Method

It was assumed that fire was caught from another vehicle involved in an accident and the ignition point was a rear tire (Figure 3). The right rear tire was ignited with a propane gas burner (premixed burner) from a diagonal 45° direction. Flame was held using a propane gas burner for 60 s; then the propane gas supply was stopped.



Figure 3. Ignition by propane gas burner

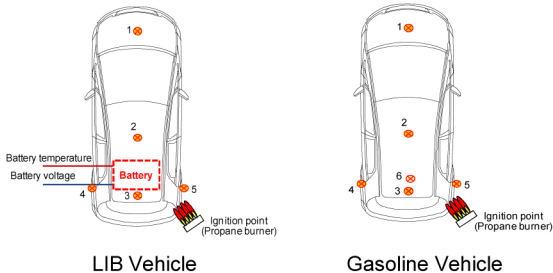
Measurement Items

Temperature and Voltage

Temperature and voltage measurement data are listed in Table 1. Temperature measurement on the gasoline vehicle was conducted at six positions. Temperature measurement on LIB Vehicle-1 was conducted at five positions in the body portion and four positions in the battery, and temperature measurement on LIB Vehicle-2 was conducted at five positions in the body portion and one position in the battery. Battery voltage was measured during the test.

Table 1. Measurement points of temperature and battery voltage

Measurement points		Gasoline vehicle	LIB Vehicle-1	LIB Vehicle-2
Temperature	1 Engine compartment	✓	✓	✓
	2 Center of passenger area	✓	✓	✓
	3 Center of rear trunk	✓	✓	✓
	4 Left rear wheel	✓	✓	✓
	5 Right rear wheel	✓	✓	✓
	6 Bottom of gasoline tank	✓		
	7 Top of battery		✓	
	8 Center of battery		✓	
	9 Left side of battery		✓	
	10 Right side of battery		✓	✓
Battery voltage			✓	✓



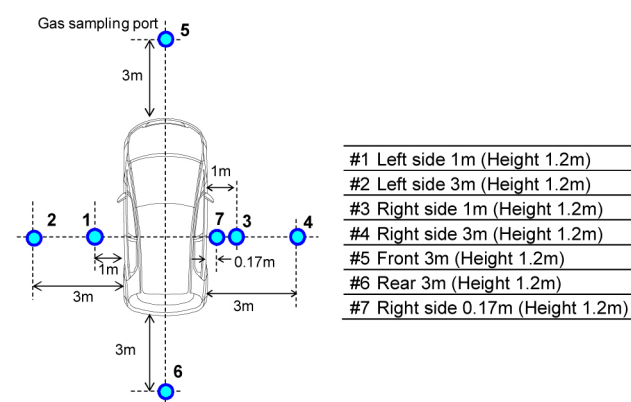
Combustion Gas Analysis

Combustion components were analyzed for harmful gasses such as CO and HF. CO was analyzed continuously during the test using three NDIR (non-dispersive infrared) gas analyzers. Two or three sampling positions were switched in turn per analyzer while sucking the same flow rate of gas with a pump at each of six or seven gas sampling positions. The interval of

analysis was 5 to 6 min, considering the time for switching and stabilizing the analysis value. HF was collected in a sampling bag during the test and then analyzed with Ion Chromatography.

Gas sampling positions are illustrated in Figure 4. Seven gas sampling positions were set for LIB Vehicle-1: 1 m and 3 m from both sides of the body, 3 m from the front and rear faces, and 0.17 m from the right side of the body. For the gasoline vehicles and LIB Vehicle-2, six gas sampling positions were set: at heights of 0.5 m, 1 m, and 1.5 m above the roof (with a roof height of 1.6 m from the ground); and at distances of 1 m from both sides of the body and 0.17 m from the right side of the body. The measurement positions in the horizontal direction on the roof were 0.4 m from the B pillar in the running direction and 0.5 m from the right end of the vehicle toward the center in the lateral direction.

LIB Vehicle-1



Gasoline Vehicle and LIB Vehicle-2

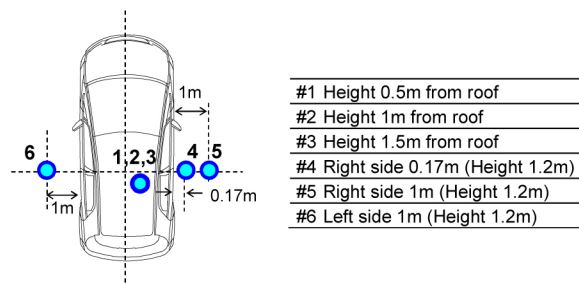


Figure 4. Gas sampling positions

RESULTS AND DISCUSSION

Gasoline Vehicle

The tests on gasoline vehicles are described in Table 2 and Figure 5. The temperatures at each part of the vehicle are presented in Figure 6. The elapsed time was indicated by setting the burner igniting time to 0 min. Flame from the fuel filler was detected 10 min after the test started. The fire intensity increased after 37 min and 40 s as the windshield broke, and the temperature at the center of the passenger area reached a

maximum of 891 °C after 40 min. Combustion of the vehicle had almost ended after 100 min. Gas samples for HF analysis were collected after 24 to 31 min at sampling positions 1, 3, and 5; after 32 to 39 min at sampling positions 2, 4, and 6; and then a second time at position 1 after 39 to 44 min.

Table 2. Combustion process of Gasoline Vehicle

Elapsed time	Combustion process	Gas sampling
5 min	Flame into the cabin	
9 min	Flame reaches at left rear wheel	
14 min 30 s	Breakage of rear window	
24-31 min		#1,3,5
32-39 min		#2,4,6
37 min 40 s	Breakage of windshield	
38 min 45 s	Burst of dumper	
39-44 min		#1 (2nd time)
39 min	Flame reaches at engine compartment	
100 min	End of combustion	



Figure 5. Video images of combustion process by Gasoline Vehicle

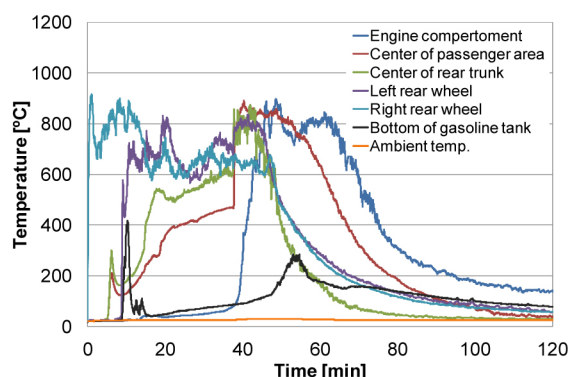


Figure 6. Temperature of each measurement points by Gasoline Vehicle

CO analysis results are presented in Figure 7. Three analyzers (A1, A2, A3) were used: A1 for sampling positions 1 and 2; A2 for sampling positions 3 and 4; and A3 for sampling positions 5 and 6. The analyzers were rotated among sampling positions. Data with measured CO of less than 10 ppm were treated as a reference in this case because it is less than the quantitative lower limit. Furthermore, data obtained within 1 min after switching were also treated as a reference.