A STUDY ON THERMAL ENERGY AT FIRE RESISTANCE TEST FOR REESS

Hyuk JUNG
Bohyun MOON
Seulki LEE
Joongho BAE
Korea Automobile Testing & Research Institute (KATRI)
Republic of Korea
Paper Number 17-0348

ABSTRACT

Market share of electrically propelled vehicle is increasing due to high oil prices and environmental concerns. These electrically propelled vehicles demand to ensure high safety of electric energy storage system, high voltage system and mechanical structure which is equivalent to existing ICE vehicle.
Due to these social demands, UN/ECE WP29 GRSP established the Electric Vehicle Safety (EVS) Informal Working Group (IWG) in 2012 and finished phase1 discussion to enact Global Technical Regulation (GTR) for safety issues of electric vehicle by 2016.
Fire resistance test for REESS which is one of the test items of UN R.100 was proposed to EVS GTR. Since Korea proposed the LPG burner fire test of Korea Motor Vehicle Safety Standard (KMVSS) as an alternative to the gasoline pool fire test of UN R.100, this study was carried out to prove the equivalent thermal energy between the gasoline pool fire test and LPG burner test.

INTRODUCTION

The fire resistance safety test for traction battery was started in South Korea since 2009 for the first time in the world and is using an LPG burner. Korea proposed the LPG burner fire test as an alternative to the gasoline pool fire test in EVS GTR.

A comparison of thermal energy was needed for the equivalence of both tests. Firstly, the thermal energy of gasoline pool fire test according to UN R.100 and that of LPG burner fire test according to KMVSS was compared by CFD simulation. Secondly, the heat flux of both tests was measured and compared.

The performance of the LPG burner was further improved with the ratio control system for control the LPG mass flow rate. In this study, fire tests were conducted with traction battery mockup.

KMVSS ARTICLE 18-3 TRACTION BATTERY

The necessity of the legislation for safety standards of traction battery came to the fore since HEV were propagated to public organizations and provincial governments in the capital region by the Ministry of Environment, 2004. The Ministry of Land, Transport and Maritime Affairs consigned KATRI the government project and KATRI carried out research on the development of safety assessment procedures for HEV from Oct. 2006 to Sep. 2008. During this project, KATRI conducted research on not only traction battery but all aspects of Hybrid vehicles. Furthermore, figured out deficiencies of the safety standards and submitted a complement to safety standard proposals. Consequently, the Korean government revised the KMVSS 8 Articles in Jan. 2009. At that time, articles on definitions, motor and transmission system, brake system, fuel system, motor power and EMC were revised, and high voltage electric device and traction battery were newly included. Also, seven test procedures were revised according to the revision of KMVSS in Feb. 2009. After that, the Korean government revised the KMVSS articles and test procedures in 2014 through research on the development of safety evaluation technology for hydrogen fuel cell vehicle and the monitoring of electric vehicles on roads.

Table1.
Summary of KMVSS related to traction battery

Article	Description
Article 2 Definition	“Traction Battery” means the energy storage system of electrical energy to propel a vehicle

Article 18-3 Traction Battery (REESS)	General Structural Requirements Traction batteries in a vehicle shall meet each of the following requirements. 1. The batteries should be separated from a passenger compartment by bulkheads or protective plates. 2. The batteries should be equipped with functions to prevent an overcharge or over-current exceeding the range specified in the design. 3. Traction batteries should be free of the possibility for fire or explosion that can take place in physical, chemical, electrical, and thermal shock conditions as notified by the Minister of Land, Infrastructure, and Transport.

Table2.
Summary of KMVSS traction battery safety test (Annex 1 -Part 48)

Test	Procedure	Specimen	Criteria
Drop	Drop from 4.9m	package or system	Fire & Explosion
Immersion	Immerse completely in the salty water	package or system	Fire & Explosion
Over - charge	Charge up to 150% SOC	System	Fire & Explosion
Over - discharge	Discharge with 1C rate	System	Fire & Explosion
Short circuit	Closed circuit with total resistance of 50 mΩ or less for 1 hour	System	Fire & Explosion
Heat Exposure	Exposed to 80 ℃ heat for 4 hour	package or system	Fire & Explosion
Fire Resistance	Exposed to flame of 800 to 1,100℃ for 2 min.	package or system	Explosion

KMVSS Test Procedure Annex 1
48. Traction Battery Safety Test
48.7.7 Fire Resistance Test

1. Purpose

The purpose of fire resistance test is to verify the safety of traction battery to secure the evacuation time for driver and passengers when vehicle is on fire.

2. Test procedure

(a) The Tested-Device shall be placed on test equipment horizontally.

(b) The number of temperature sensors shall be at least 5. The sensor locations shall be representative locations which cover the whole area of traction battery. The sensors shall be placed 25±10mm downward from the bottom of traction battery.

(c) Whole bottom area of traction battery shall be uniformly heated by flames.

(d) Temperature shall reach 800℃ within 30 sec from ignition. Flames with temperature of 800℃ shall be maintained for 2 minutes, after that fuel supply shall be stopped. After 1 hour from the stop of fuel supply, the test shall be terminated. The temperature of flames shall not exceed 1100℃.

(e) Check the explosion of traction battery during the test and measure the voltage of traction battery before and after the test.

3. Review

The fire resistance test equipment in KATRI is as shown Figure 1. The combustion method of this equipment is Bunsen burner type which maintains a flame temperature of 800℃ to 1,100℃ by supply of LPG with a ratio control system.

Figure 1. LPG test equipment and test scene

The KMVSS fire resistance test equipment is appropriate for most traction batteries, unless the battery is larger than the burner.

Table 3.
Various traction batteries that can be tested with LPG burner

Appearance	specification
	RAY (M1) Li-ion 1.7×1.1×0.3m , 300kg 360v, 75Ah
	SM3 Z.E. (M1) Li-polymer 1.3×0.7×0.8m, 250kg 360v, 65Ah
	ELEC-CITY (M3) Li-polymer Sub Pack. 1.5×0.9×0.4m , 150kg 380v, 250Ah
	E-PRIMUS (M3) Li-polymer Sub Pack. 1.65×0.7×0.5m, 320kg 613v, 140Ah
	QTPE-BUS (M3) Li-ion 1.9×1.1×0.5m, 620kg 591V, 70Ah

UN R.100 Fire Resistance

This test procedure, based on existing ECE R-34 [“Uniform provisions concerning the approval of vehicles with regard to the prevention of fire risks” / 5. Requirements for liquid fuel tanks / Annex 5. Testing of fuel tanks made of a plastic material / Appendix 1 Test of resistance to fire], was suggested by SP Technical Research Institute of Sweden. Test procedures are as follows.

Purpose
The purpose of this test is to verify the resistance of the REESS, against exposure to fire from outside of the vehicle due to e.g. a fuel spill from a vehicle (either the vehicle itself or a nearby vehicle). This situation should leave the driver and passengers with enough time to evacuate.

Installations
This test shall be conducted either with the complete REESS or with related REESS subsystem(s) including the cells and their electrical connections. If the manufacturer chooses to test with related subsystem(s), the manufacturer shall demonstrate that the test result can reasonably represent the performance of the complete REESS with respect to its safety performance under the same conditions. If the electronic management unit for the REESS is not integrated in the casing enclosing the cells, then the electronic management unit may be omitted from installation on the tested-device if so requested by the manufacturer. Where the relevant REESS subsystems are distributed throughout the vehicle, the test may be conducted on each relevant of the REESS subsystem.

Procedures
1. General test conditions
The following requirements and conditions shall apply to the test:
(a) The test shall be conducted at a temperature of at least 0℃;
(b) At the beginning of the test, the SOC shall be adjusted to a value in the upper 50 per cent of the normal operating SOC range;
(c) At the beginning of the test, all protection devices which effect the function of the tested-device and are relevant for the outcome of the test shall be operational.

2. Test procedure
A vehicle based test or a component based test shall be performed at the discretion of the manufacturer:

(a) Vehicle based test
The tested-device shall be mounted in a testing fixture simulating actual mounting conditions as far as possible; no combustible material should be used for this with the exception of material that is part of the REESS. The method whereby the tested-device is fixed in the fixture shall correspond to the relevant specifications for its installation in a vehicle. In the case of a REESS designed for a specific vehicle use, vehicle parts which affect the course of the fire in any way shall be taken into consideration.

(b) Component based test
The tested-device shall be placed on a grating table positioned above the pan, in an orientation according to the manufacturer′s design intent.

The grating table shall be constructed by steel rods, diameter 6-10 mm, with 4-6 cm in between. If needed the steel rods could be supported by flat steel parts.

The flame to which the tested-device is exposed shall be obtained by burning commercial fuel for positive-ignition engines (hereafter called "fuel") in a pan. The quantity of fuel shall be sufficient to permit the flame, under free-burning conditions, to burn for the whole test procedure.

The fire shall cover the whole area of the pan during whole fire exposure. The pan dimensions shall be chosen so as to ensure that the sides of the tested-device are exposed to the flame. The pan shall therefore exceed the horizontal projection of the tested-device by at least 20 cm, but not more than 50 cm. The sidewalls of the pan shall not project more than 8 cm above the level of the fuel at the start of the test.

The pan filled with fuel shall be placed under the tested-device in such a way that the distance between the level of the fuel in the pan and the bottom of the tested-device corresponds to the design height of the tested-device above the road surface at the unladen mass if paragraph vehicle based test above is applied or approximately 50 cm if paragraph component based test above is applied. Either the pan, or the testing fixture, or both, shall be freely movable.

During phase C of the test, the pan shall be covered by a screen. The screen shall be placed 3 cm +/- 1 cm above the fuel level measured prior to the ignition of the fuel. The screen shall be made of a refractory material, as prescribed in Annex 8E - Appendix 1. There shall be no gap between the bricks and they shall be supported over the fuel pan in such a manner that the holes in the bricks are not obstructed. The length and width of the frame shall be 2 cm to 4 cm smaller than the interior dimensions of the pan so that a gap of 1 cm to 2 cm exists between the frame and the wall of the pan to allow ventilation. Before the test the screen shall be at least at the ambient temperature. The firebricks may be wetted in order to guarantee repeatable test conditions.

If the tests are carried out in the open air, sufficient wind protection shall be provided and the wind velocity at pan level shall not exceed 2.5 km/h.

The test shall comprise of three phases B-D, if the fuel is at least at temperature of 20 ℃. Otherwise the test shall comprise four phases A–D.

Phase A: Pre-heating (Figure 1)

The fuel in the pan shall be ignited at a distance of at least 3 m from the tested-device. After 60 seconds pre-heating, the pan shall be placed under the tested-device. If the size of the pan is too large to be moved without risking liquid spills etc. then the tested-device and test rig can be moved over the pan instead.

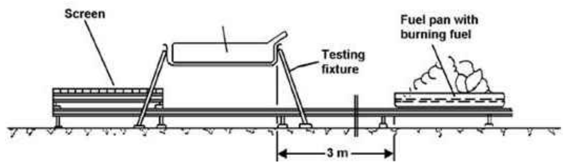

Figure 2. Phase A: Pre-heating

Phase B: Direct exposure to flame (Figure 2)

The tested-device shall be exposed to the flame from the freely burning fuel for 70 seconds.

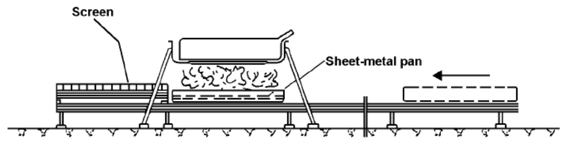

Figure 3. Phase B: Direct exposure to flame

Phase C: Indirect exposure to flame (Figure 3)

As soon as phase B has been completed, the screen shall be placed between the burning pan and the tested-device. The tested-device shall be exposed to this reduced flame for a further 60 seconds.

Instead of conducting phase C of the test, phase B may at the manufacturer's discretion be continued for an additional 60 seconds.

However this shall only be permitted where it is demonstrable to the satisfaction of the Technical Service that it will not result in a reduction in the severity of the test.

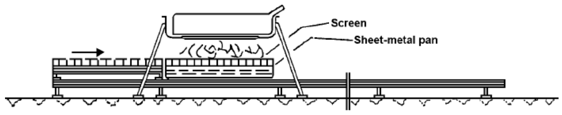

Figure 4. Phase C: Indirect exposure to flame

Phase D: End of test (Figure 4)

The burning pan covered with the screen shall be moved back to the position described in phase A. No extinguishing of the tested-device shall be done. After removal of the pan the tested-device shall be observed until such time as the surface temperature of the tested-device has decreased to ambient temperature or has been decreasing for a minimum of 3 hours.

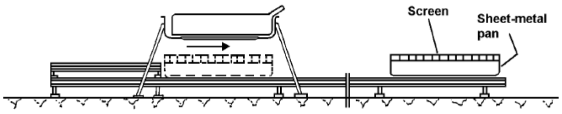

Figure 5. Phase D: End of test

Review

As examined previously, ECE R-100 fire resistance test procedure is complicated compared to LPG burner test. However, one cannot say that gasoline pool fire test is severe because it is more complicated. Compared both tests with CFD simulations and actual heat flux measurements.

COMPARISON THERMAL ENERGY BY CFD SIMULATION

FDS Simulation modeling

The Fire Dynamics Simulator (FDS) and Smoke view are the products of an international collaborative effort led by the National Institute of Standards and Technology (NIST) and VTT Technical Research Centre of Finland. Fire Dynamics Simulator is a computational fluid dynamics (CFD) model of fire-driven fluid flow. FDS solves numerically a form of the Navier-Stokes equations appropriate for low-speed (Ma < 0.3), thermally-driven flow with an emphasis on smoke and heat transport from fires. FDS has aimed at solving practical fire problems in fire protection engineering, while at the same time providing a tool to study fundamental fire dynamics and combustion. This software is used for simulating the gasoline pool-burning.

This simulation was performed by numerical modeling method used in 3D CFD. Also, gasoline fuels were also analyzed using a combustion model. The computational fluid dynamics tools used in the simulation were applied to the analysis using NIST's FDS and total six cases of studies were conducted. The total number of gratings is about 729,000 ~ 3,136,000 which varies depending on the size of analytical model.

ANSYS FLUENT software

ANSYS Fluent incorporates a comprehensive suite of reacting flow-modeling capabilities and simulates gaseous reactions using either reduced or complex chemistry. Pollutant models are built in to allow easy and accurate pollution emission predictions for NO, SO and soot. This software is used for simulating the LPG burner test.

Test configuration

The gasoline combustion model analyzes chemical species for gasoline, nitrogen, oxygen, carbon monoxide, carbon dioxide, water vapor, and soot. The ambient temperature was set to 20℃.

The following figure shows the sizes of the mockups and pools used in the analysis. The small mockup is 300x200x300mm. Its pool size is 700x600x130mm. Fuel Quantity is 10.5ℓ.

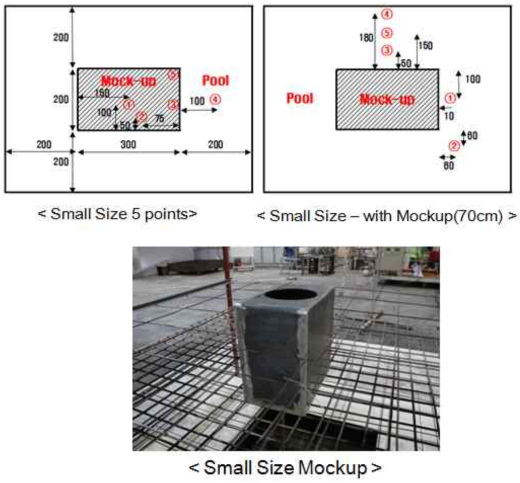

Figure 6. Dimension of small pool & mockup

The large mockup is 1,000x1,000x200mm. Its pool size is 1,500x1,500x130mm. Fuel Quantity is 56.25ℓ. All pools were filled with water and fuel, height was 25mm each.

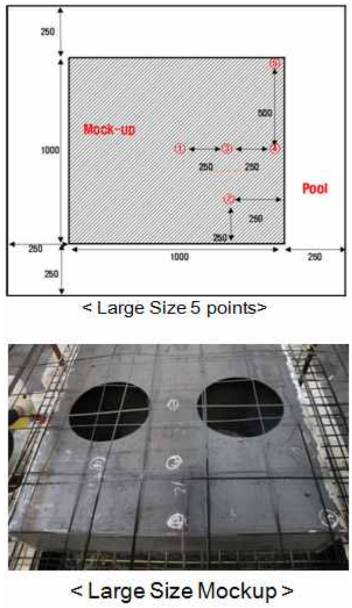

Figure 7. Dimension of large pool & mockup

The following figure shows the entire modeling geometry used in the gasoline pool fire CFD simulations, including fan, mockup, and screen geometry, corresponding to Phase A, B, and C, respectively.

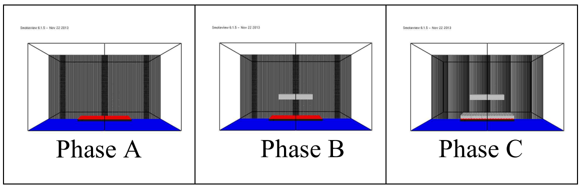

Figure 8. CFD modeling shapes of gasoline test

Small pool simulation
The following figure shows the indoor test results for small pool free burning and the temperature distribution of CFD results. The efficiency of gasoline combustion is set to 85%. The result of actual test and the CFD simulation were very similar as shown in the graph. Upper graph is the real burning test and the bottom is the CFD result.

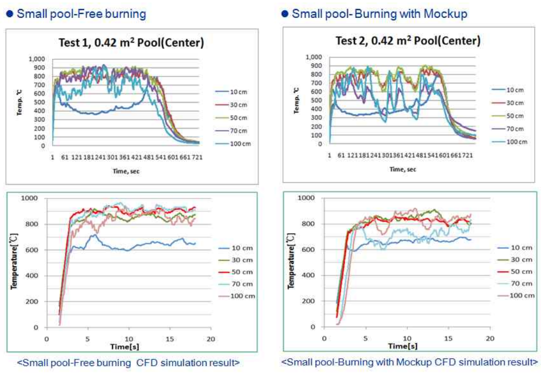

Figure 9. Graph of combustion test & CFD simulation in a small pool

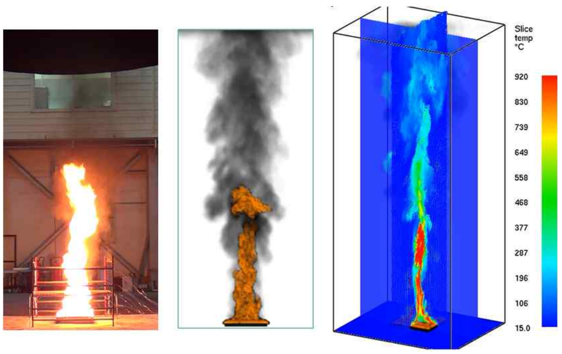

Figure 10. Figure of combustion test & CFD simulation in a small pool

Large pool simulation
The following figure shows indoor test results for large pool free burning and temperature distribution of CFD simulation. The efficiency of gasoline combustion is set to 90%. The result of actual test and the CFD simulation were very similar as shown in the graph. Upper graph is the real burning test and the bottom is the CFD result.

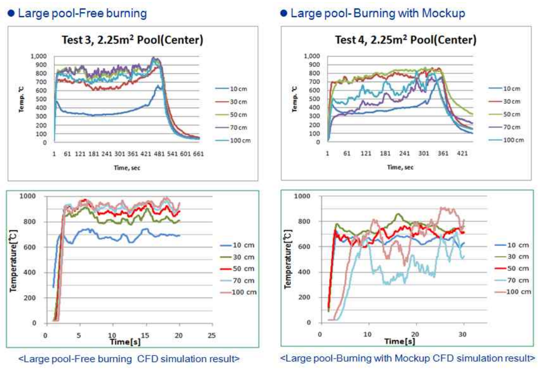

Figure 11. Graph of combustion test & CFD simulation in a large pool

<cf.> Heat flow is defined: $\dot{q} = \int c_p \rho (T - T_\infty)\mathbf{u} \cdot \mathbf{dS}$
where c_p is specific heat, T is temperature and ρu•dS is mass flow rate.

$\dot{q}$ represents the thermal energy passing through the reference area per unit time and the unit is [w].

c_p is the specific heat of the mixed combustion gas in units of [J/kg-℃]; T is the temperature of the mixed combustion gas in [℃]; ρu·dS is the mixed combustion gas passing through the reference area. Mass flow rate in [kg/s]. Through the calculation of heat flow, the thermal energy appearing in the gasoline test (Phase 1, 2, 3) is expressed as a quantified value. This is compared with the quantified value of the LPG test in KMVSS and the total amount of heat energy received from the outside of the mockup can be compared.

Comparison of gasoline and LPG test
Table 4 shows the heat flow received by battery mockup per unit time for each test. The ECE R100 test is a simulation result for gasoline combustion and KMVSS shows the simulation results for LPG fuel (30kg/h per nozzle module). The thermal energy measurement location is 25 mm vertically downward from the bottom surface of the battery mockup and the calculated area of the thermal energy is the projected area of the bottom of the battery. The size of the battery mockup is divided into small (300 x 200 x 300mm) and large (1000 x 1000 x 200mm).

Gasoline combustion test shows that direct exposure (phase b) is more powerful than indirect exposure (phase c) and large size mockup with cross-section has more power than small size mockup.

Table 4.
Heat flow received by battery mockup per unit time

Parameter	Heat Flow [kW]		
	ECE R100		KMVSS
	Phase B	Phase C	LPG
Small Pool	26	20	16.5
Large Pool	160	105	118

Table 5 shows the comparison of the thermal energy received by the battery mockup and the combustion exposure time of each test method is applied to the heat flow. ECE R100 is 3,020 kJ in the small mockup and 2,227.5 kJ in the KMVSS. In the large mockup, R100 is 17,500 kJ and KMVSS is 15,930 kJ.

Table 5.
Thermal energy received by battery mockup

● Total Thermal Energy by CFD simulation

ECE R100	Phase B, 70[s]		Phase C, 60[s]		SUM
Parameter	Heat Flow [kW]	Thermal Energy [kJ]	Heat Flow [kW]	Thermal Energy [kJ]	Total Thermal Energy [kJ]
Small Pool	26	1,820	20	1,200	3,020
Large Pool	160	11,200	105	6,300	17,500

KMVSS	Direct exposure, 120[s]		Pre-heating, 30[s]	☚ 800 ℃ Reaching Time	SUM
Parameter	Heat Flow [kW]	Thermal Energy [kJ]	Thermal Energy [kJ]		Total Thermal Energy [kJ]
Small Mockup	16.5	1,980	247.5		2,227.5
Large Mockup	118	14,160	1,770		15,930

Table 6 shows the heat flux and the energy density of the energy converted into thermal energy per unit area in order to compare the thermal energy received from the battery mockup. The energy density of the ECE R100 is 53,667 kJ in the small size mockup, 37,116 KJ in the KMVSS. In the large mockup, R100 is 17,500 kJ and KMVSS is 15,930 kJ. The energy density of small pool and mockup is higher than the large one.

Table 6.
Thermal energy density received by battery mockup

● Total Thermal Energy Density by CFD simulation

ECE R100	Phase B, 70[s]		Phase C, 60[s]		SUM
Parameter	Heat Flux [kW/m^2]	Thermal Energy Density [kJ/m^2]	Heat Flux [kW/m^2]	Thermal Energy Density [kJ/m^2]	Total [kJ/m^2]
Small Pool	433	30,333	333	23,333	53,667
Large Pool	160	11,200	105	6,300	17,500

KMVSS	Direct exposure, 120[s]		Pre-heating, 30[s]	☚ 800 ℃ Reaching Time	SUM
Parameter	Heat Flux [kW/m^2]	Thermal Energy Density [kJ/m^2]	Thermal Energy Density [kJ/m^2]		Total [kJ/m^2]
Small Mockup	275	32,992	4,124		37,116
Large Mockup	118	14,160	1,770		15,930

THE EQUIVALENCE OF BOTH FIRE RESISTANCE TESTS

Tests were conducted to measure the heat flux for comparing gasoline and LPG combustion test. Table 7 shows two tests. In the heat flux test, the gas supply was gradually increased to find the proper flow rate of LPG corresponding to the heat flux of gasoline.

Gasoline test procedure is the same as the R100. In the LPG burner test, mass flow rate was gradually increased from 175 kg/h to 275kg/h by 25kg/h. The exposure time at each mass flow rate is 60 seconds. Measure the flame temperature of 5 points for reference. Verification tests are tested according to R100 and KMVSS. Also, measure the temperature of 5 points.

Table 7.
Test configuration of heat flux test and verification test

Test	Condition		Procedure	Data output
Heat flux test	Gasoline Pool Fire	Free Burning	Phase A(Pre-heating 60sec), B(direct exposure 70sec), C(indirect exposure 60sec)	Heat flux, Flame Temp. (5 points)
	LPG Burner Fire		Direct exposure 60sec continuously at various mass flow rate(175, 200, 225, 250, 275, 300 kg/h) to find equivalent heat flux with Gasoline pool fire	
Verifica-tion test	Gasoline Pool Fire	With mockup	Test according to UN R100 with mock up. - Phase A(Pre-heating 60sec), B(direct exposure 70sec), C(indirect exposure 60sec)	Flame Temp. (5 points)
	LPG Burner Fire		Test according to KMVSS with mock up, applying mass flow rate determined by heat flux test. - Direct exposure : time to reach 800℃ (less than 30 sec), 120 sec at 800~1100℃	

Test configuration

LPG burner's maximum flow rate is 400 kg/h and it is equipped a ratio control system for flow rate control. Gasoline pool size was 1,100 x 750 x 130mm, and the amount of gasoline was about 20 liters. Mockup size was 888 x 540 x 210mm. The heat flux meter made by Medtherm, Gardon Gage. The heat flux meter measures up to 100kW/㎡ through the window 60° VA.

The location of heat flux sensor is decided by the size of mockup and distance from surface of flame. LPG and Gasoline tests are same. Distance is decided by

FTP code1(Thermal radiation test supplement to fire resistance tests for windows in "A", "B" and "F" class divisions). In FTP code (Fire Test Procedures code), guidance for determining a distance from flame.

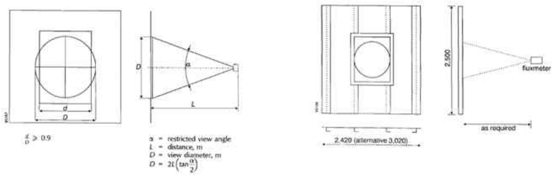

Figure 12. Figure of window 60° VA of heat flux meter

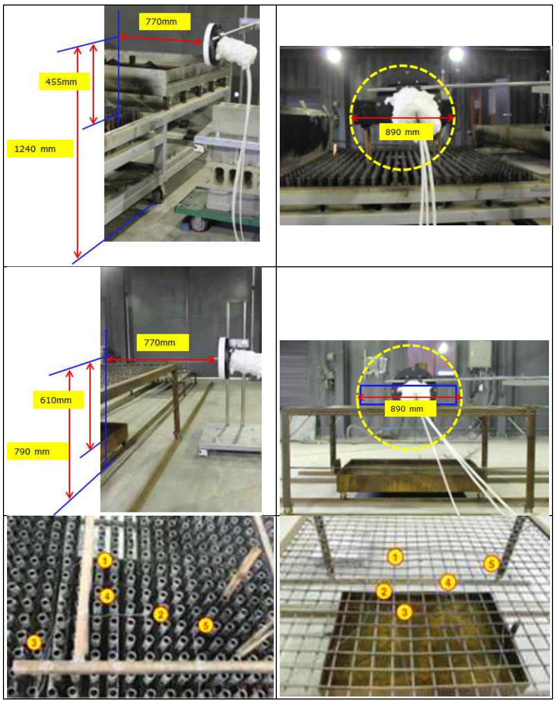

Figure 13.Ttest configuration of heat flux test

Test result

In LPG burner test, mass flow rate was gradually increased from 175 kg/h to 275kg/h by 25kg/h. The exposure time at each mass flow rate is 60 seconds. Measure the flame temperature of the 5 points for reference. The larger the flow rate, the larger the flame.

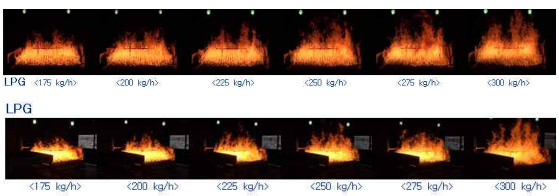

Figure 14. Comparison of LPG flame size according to supply flow rate

Gasoline test procedure is the same as the R100 including phase a, b and c, which are pre-heating, direct exposure, and indirect exposure. Measure the flame temperature of 5 locations for reference.

During the phase C (indirect exposure), flame is much smaller than direct exposure.

<Direct exposure> <Indirect exposure>

Figure 15. Comparison of gasoline flame size with direct exposure and indirect exposure

Heat flux and temperature in gasoline test

Temperature is left side index and heat flux is right side index. The above uneven lines indicate temperature measured at 5 points. The blue line at the bottom is heat flux.

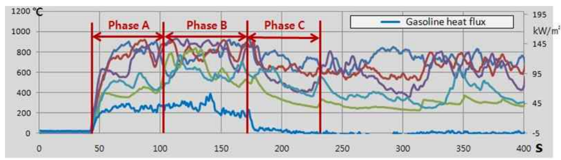

Figure 16. Heat flux of gasoline pool fire test

Heat flux and temperature in LPG test

The red line at the bottom is mass flow rate. Each step has 25kg/h increased mass flow rate. Heat flux is constant during in each 60 seconds and heat flux and temperature are dependent on mass flow rate.

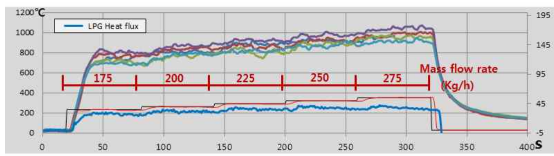

Figure 17. Heat flux of LPG test according to flow rate

Comparison of Heat flux

Heat flux of Gasoline is blue line, around 25~ 50 kW/㎡ and irregular peak heat. Heat flux of LPG is red line, around 30 to 40 kW/㎡. The heat flux shows a stable variation by the flow rate. Red number is mass flow rate. The mass flow rate was increased every 60 seconds. Heat flux rate goes up when gas flow rate is increased.

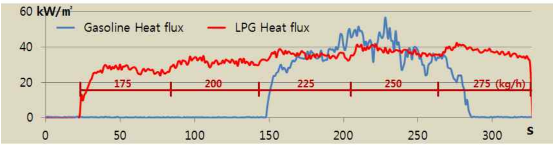

Figure 18. Comparison of heat flux of gasoline pool fire and LPG test

CONCLUSION AND FUTURE RESEARCH PLAN

To determine representative value of heat flux, heat flux was integrated at each time. At the mass flow rate of 200kg/h in LPG burner, heat flux integral is almost equivalent to gasoline.

Table 8.
Comparison of heat flux integration

Fuel	Time	Integral Heat flux
Gasoline	130s (Phase B + C)	4,460
LPG (200kg/h)	140s (Warm up 20s + 120s)	4,450

Measuring the heat flux has limitation. The test measures the radiant heat from the flame surface, so the inside heat flux of flame is unknown. Gasoline has lower flame temperature than LPG at the same heat flux, but LPG has higher flame temperature.
In verification test LPG burner at 200 kg/h with mockup, temperature was 850-950℃ which is much higher than Gasoline pool fire.

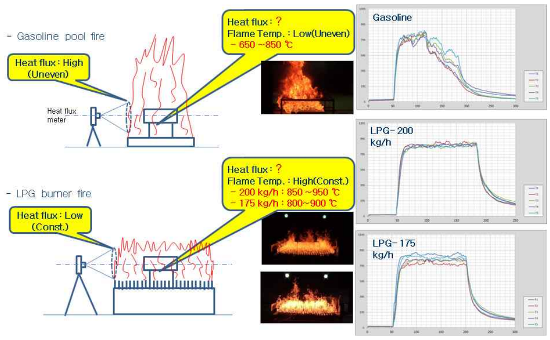

Figure 19. Limitation of measuring heat flux

According to the result of CFD simulation, the total thermal energy density of the LPG burner fire test is 37,000 kJ/m^2 for small mockup and 16,000 kJ/m^2 for large mockup. In the case of gasoline pool fire test, the energy density is 54,000 kJ/m^2 for small and 18,000 kJ/m^2 for large. The thermal energy per unit area of gasoline pool fire test is 44% higher than LPG burner fire test for the small. The gasoline pool fire test is 16% higher than LPG burner fire test for the large. In order to increase the thermal energy of LPG burner fire to the level of gasoline pool fire, the performance of LPG burner was improved, including LPG delivery nozzle and the heat flux of LPG burner fire test was measured by changing the LPG supply mass flow rate.
The result shows that the integral heat flux during the test in the condition of 200kg/h in LPG supply mass flow was similar to that of gasoline pool fire test.

Heat flux presented as a final result is not enough to represent the thermal energy transmitted to a DUT. This is because the heat flux measured by heat flux meter shows the heat flow rate per unit area of the fire source’s cross-section which is certain separation distance away from the meter.
Therefore, the following is planned for the future, the comparison and analysis between the thermal energy of gasoline pool fire test and that of LPG burner fire test in the final improved LPG burner condition by using the CFD simulation.

This study shows that the thermal energy equivalence of LPG burner fire test and gasoline pool fire test and LPG burner fire test are simple, effective and economically feasible to achieve the purpose of the fire resistance test.

ACKNOWLEDGEMENT

This research was supported by a ‘World Harmonization Program for Motor Vehicle Safety Standard funded by the Ministry of Land, Infrastructure, and Transport, Republic of Korea.

REFERENCES

[1] KMVSS. 2009. “Traction battery.” Article No. 18-3
[2] KMVSS Test Procedure. 2014. “Traction battery safety test.” Annex 1- Part No 48
[3] ECE/TRANS/505/Rev.2/Add.99/Rev.2. 2013, “Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train.” ECE Regulation No.100, 71-74
[4] Youngsoo Won, 2014, “Report for optimization the traction battery LPG fire resistance test condition”