Validation Test And Analysis For Resistibility Of Firewall Materials To Protect Small LPG Storage Tanks

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Abstract: This paper is descried that validating reliability for the materials of five firewalls is practiced to protect leakage and explosion of a small LPG tank installed at an adjacent building when a fire broke out in the near surroundings. It is tested for fire resistibility to select the best fire-proof wall material after five materials used for making firewalls are defined. The firewall's materials are a 10mm-thick wooden panel, a wooden panel coated fireproof paint, a 75mm-thick polystyrene panel, a 75mm-thick sandwich panel filled glass fibers, and a 75mm-thick autoclave lightweight concrete(ALC) panel. To reappear a fire situation, first, the frame of LPG jet burners and their fittings are manufactured. After burners are ignited, numerous flames heated to a fire proof wall and a small LPG storage tank installed behind a firewall. The frame of jet burners is manufactured by 1m×1m iron materials with a matrix of 100 nozzles able to burn 120~140g/s LPG. It is measured that temperatures of double-faced panels, temperature of the front surfaces of a tank, and heat fluxes of surroundings of a tank. The resistibility against fire is analyzed in structure safety of fireproof walls after fire test. As the results, the fire-proof resistibility of the GWS and ALC panel are structurally safe and their temperature is less risen than others. In conclusion, it is verified that ALC panel is the best effective material of a firewall for protecting and preventing explosion of a small LPG tank when a fire is occurred. It is estimated that this study and validation test are a key point for inducing the performance test standard for a firewall material of a small LPG storage tank.

Index Terms: Firewall materials, resistibility, fire test and validation, a small LPG storage tank, a jet nozzle.

1 INTRODUCTION

THE small storage tank(SST) is a tank fixedly installed on and under the ground to store LPG at enforcement regulations of safety management and business law of LPG(liquefied petroleum gas). Its storage volume is less than 3 tons. In South Korea, the SST is generally used to supply fuel(LPG) into multiple public facilities. At the KGS code (FU432 star 20), a kind of gas safety management regulation from south Korea, a remote distance between input of buildings and input of an LPG tank is defined as from 0.5 to 3.5 meter according to refueling volumes [1]. Mostly its remote distance is from 1 to 2 meter between an outer surface of a tank and an outer wall of buildings. The easily fired outer materials of buildings can rapidly heat an adjacent LPG storage tank when a fire is occurred at the buildings. Also it can be caused to a larger explosion risk. In 2017, at Gwangju city, South Korea, an explosion risk of LPG storage tank was happened by a fire. In same year, when a fire was occurred at sports center, Jecheon city, fire fighter not saving people but spraying water to LPG tank for protecting explosion of its tank. Due to those risks, if a fire is occurred at buildings, an issue has become that it is to reduce heat flux for preventing explosion of the adjacent LPG storage tank. Meanwhile, for past 20 years, research on risks of LPG SST is limited as parts of diffusion of combustible gas, jet fire sources, boil off clouds and BLEVE (Boiling Liquid Expanding Vapor Explosion) after their risks [2], [3], [4], [5]. Also the range of test to repeat the BLEVE risk is reduced in south Korea [6]. In this research, we'd like to propose directivity of the risks evaluation through validation tests of resistivity of firewall materials for protecting an adjacent LPG small tank and preventing its explosion when a fire is occurred at buildings. The objective of resistivity performance of firewalls is time of heat transfer hindrance, which is 30 minutes [7]. It is based on “the Yearbook of Fire Statistics”, which is a document from the National Fire Agency, a government organization of South Korea. Its document is recorded that it takes 30 minutes for firefighters are arrived at a risk field and are acted with preventing and extinction of fires. That time also is recorded at the regulation of the fire resistivity performance test, API 607 and ISO 10497, for managing safety of plant facilities [8], [9].

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TABLE 1
MATERIALS AND THICK OF PANELS

No.	Panel Materials	Thick(mm)	Abbr.
1	Layered Wood	10	LWD
2	LWD coated with fire retardant paint	10	LWC
3	Expanded Polystyrene	75	EPS
4	Glass Wool filled with Sandwich Panel	75	GWS
5	Autoclave Lightweight Concrete	75	ALC

2 TEST MATERIALS AND DEVICES

2.1 Materials of Firewalls

Materials of firewalls are selected by two conditions. Those conditions are space usability to enable construction even though installation is narrow according to installation of small LPG storage tank and lightness of materials easily to be constructed. By this reason, firebrick or steel sheets are excluded. A piece of a firewall is consisted of a length and breadth 2×2m frame using matrix structure of a 6mm thick, 100×100mm angled steel. Table 1 shows inner fire resistive materials of firewalls with information of source and thick. The size of an original panel is 2m in height, 0.6m in width. The panel for testing is extended as 2m in height and 2m in width by adding 3 panel's pieces, which are two 2m×0.6m and 2m×0.2m in height and width. Fig. 1 appears sample of an installed firewall between a small LPG storage tank and a building.

2.2 Experimental Devices and Environment

Fig. 2 shows the whole composition layout for testing and validating firewall's materials. Fig. 3 shows the whole composition's side view for testing firewalls with distances and heights. Fig. 4 shows the layout of LPG jet burner of vertical structure as a real fire that horizontally radiate flames into an outer wall of buildings. The frame of jet burners is structured with 2×2m in height and width and includes a matrix form of 400 LPG Jet nozzles with 1.0mm in diameter. Amongst nozzles in the frame airways are made because air need to easily burn. To more supply air, two fans are installed with 30 inches in diameter and 300m/min in wind speed at back side of a burner frame as shown in Fig. 6. To equally supply LPG fuel to every nozzle, inner pipelines of the burner frame are connected from an LPG outlet. A rated flow speed is selected by 130±10g/s through international standard as shown in Table 2. A quarter of one burner frame is used in this experiments to control heat flux [10], [11], [12]. The surface temperature of an LPG storage tank was measured of 900±100℃ and heat flux was measured of 15±1kW/m^2 when before test is performed at heating conditions without a firewall. Damage influence can be serious at gas facilities if a radiant heat is 12kW/m^2 according to international and national standards [13], [14].

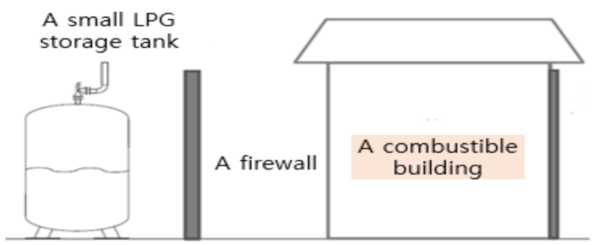

***Fig. 1**. The installed firewall between LPG tank and a building*

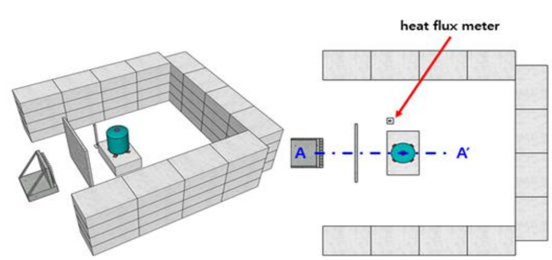

***Fig. 2**. The whole composition layout for testing firewalls.*

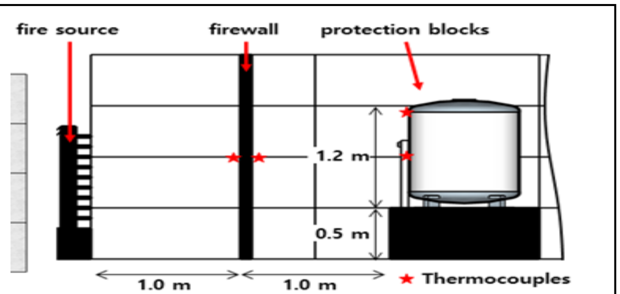

***Fig. 3**. The side view of firewalls test for protecting an LPG tank*

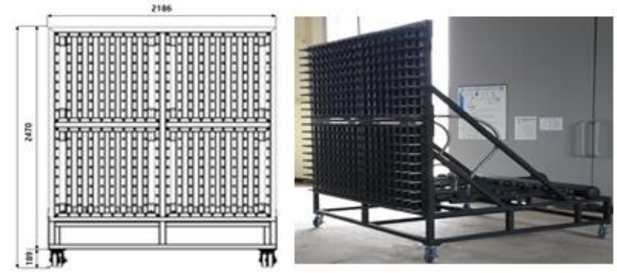

***Fig. 4**. The layout of LPG jet burner of vertical structure.*

TABLE 2

HEATING FUEL AND FLUX EVERY STANDARD

Item	NFPA 285	ISO 13785-2	ISO 13785-1	This Study
Fuel	LPG	LPG Or Wood	LPG	LPG
Heat Flux	398 kW/m^2	120g/s or 800℃ [5,520 kW/m^2]	100±5 kW/m^2	130±10g/s [5,980 kW/m^2]

***Fig. 5**. A real fire test for a gas cylinder without a firewall*

Fig. 5 shows a sample real fire test for a gas cylinder without a firewall through directly and horizontally radiate flames from jet burners to a gas cylinder. Fig. 6 shows a fire before test layout and a real test field for experimenting and validating five materials of firewalls through directly and horizontally radiate flames from jet burners to a firewall. Table 2 shows heating fuel and flux of standard such as NEPA, ISO, and our study.

***Fig. 6**. A real fire test for a firewall between an LPG tank and a burner.*

Small LPG storage tanks used for testing firewalls are three numbers, which's specifications are ten years old, 170kg weight, 1.2m height, 0.76 diameter, and 5mm thick with steel. To use testing tanks, we made inner gases empty, washed them with waters, and purged them by injecting nitrogen for 24 hours. Area for validation test is 5 square meter. Indirectly heated left, right and rear side of tank are surrounded by protection walls 2m in height using steel concrete blocks(1.5×1.0×0.5m) for preventing risks such as scorching flames and explosion of a tank while testing is processed. In real an explosion risk of gas storage tank can be happened because it is larger boiling phenomenon than gas emissions of a safety valve of a tank by large heating sources or because strength of steel is reduced by focusing fire sources to a tank and cutoff and damaged a safety valve by fire sources. To start testing firewalls, as shown in Fig. 3 and Fig. 6, we arranged a LPG tank, a firewall, and vertical burners in a straight line. In detailed, as shown in Fig. 3, we arrayed 2m distance between a front side of tank and a nozzle tip of a burner and located a firewall in the middle of a tank and a burner. A front of firewalls put opposite a burner each other. The bottom of Fire source is 0.3m in height from on the ground. Thermal sensors used by "Sheath STS316 K-type" with 3.2mm in diameter, 5m in length, and with shielded. They are equipped with one sensor on front and another sensor on rear of a firewall and two sensors on surface of the LPG storage tank, which positions are the welding part and center point of top cylinder. The heat flux sensor is used the Gardon & Schmidt-Boelter SBG01-100 from "Hukseflux thermal Sensor B.V" company. Four heat flux sensors are installed at right of tank and faced with fire sources as shown in Fig. 2. Measuring range of these sensors is 100kW/m^2 and their sensitivity is 10~70mV(W/m^2). Their cooling method is practiced by water. Signal of heat flux sensors are transformed to current(4~20mA) and amplified by the signal amplifier(KN-2210W) of Konics company every ten meters. The data logger is used by Graphtec GL840 to save temperature and heat flux. After these devices are set up, we practiced and analyzed test of materials resistivity of five firewalls through measuring temperature of a small LPG storage and heat flux of the rear side firewall.

3 Test Results

The results of fire test are released for measuring resistivity of firewall materials using our manufactured standard burner. Measured heat flux is as shown in Table 3. Before and after of experiments are like photographs shown from Fig. 7, Fig. 8, Fig. 9, Fig. 10, and Fig. 11.

TABLE 3
HEAT FLUX FOR BURNING OUT FIREWALLS

Firewall Type	Heat Flux	Burn Down
LWD	17 kw/m^2	O
LWC	24 kw/m^2	O
EPS	27 kw/m^2	O
GWS	-	X
ALC	-	X

***Fig. 7**. Photographs of a firewall(LWD) before and after experiments.*

***Fig. 8**. Photographs of a firewall(LWC) before and after experiments.*

***Fig. 9**. Photographs of a firewall(EPS) before and after experiments.*

***Fig. 10**. Photographs of a firewall(GWS) before and after experiments.*

***Fig. 11**. Photographs of a firewall(ALC) before and after experiments.*

In Fig. 12 and Fig. 13, LWD and LWC are completely burned out since 6 minutes from igniting at 3minutes. In Fig. 14 EPS is specially frame retardant product, but is all burned out and stopped to shield heat after 15 minutes from igniting. Upper 3 type materials are unnecessary to analyze thermal processing afterward. GWS and ALC materials are resistant since 30 minutes after they are exposed by jetting fire sources. As shown in Fig. 15, GWS was a little bending and curvature since 20 minutes from igniting and could sustain function of thermal shied because steeply rising temperature is not. It is measured that heat flux is 19.6kW/m^2 and maximum surface temperature of the LPG tank is over 150 °C while time interval is from 150 to 1800 seconds. As a GWS result, it is determined that the LPG tank can be exploded and risky because inner rising pressure rate of a tank is faster than emission rate of the relief valve to prevent an LPG tank. As shown in Fig. 16, ALC is nearly not bended and deformed is estimated to be reused. It is measured that heat flux is

17.48kW/m^2, front average temperature of an ALC firewall is 1,005 °C and maximum surface temperature of the LPG tank is only 115 °C, and steam pressure of propane is 45 bar while time interval is from 150 to 1800 seconds. This measured pressure (45 bars) is lower than 60 bar presupposed explosion pressure of a small LPG storage tank. So, it is determined that the LPG tank in the situation is not exploded because stream pressure is lower than presupposed explosion pressure and the relief valve to prevent over pressure is opened. On the other hand, the reason of estimated explosion for a LPG storage tank is based on KGS code AC111 from that inner pressure test pressure of a cylinder is 2.34 MPa and base on KGS code AC211 in that the burst test pressure is 5.265 MPa calculated by 9/4*2.34 MPa. So, the burst pressure is estimated of 6 MPa, which is about 60 [bar].

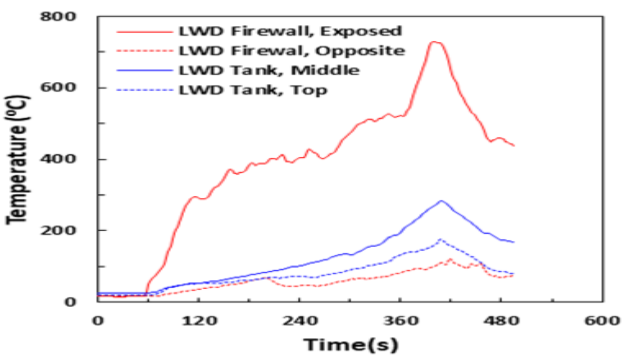

Fig. 12. *Temperature profiles on a firewall(LWD) test.*

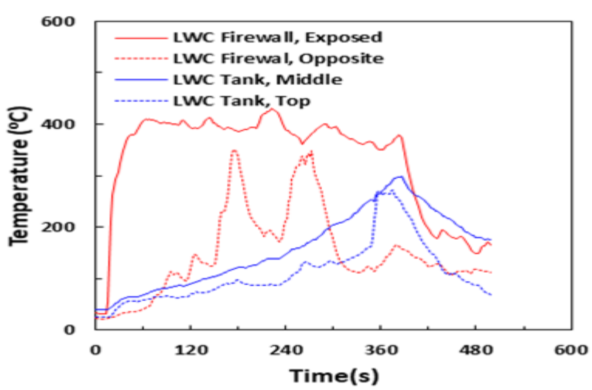

Fig. 13. *Temperature profiles on a firewall(LWC) test.*

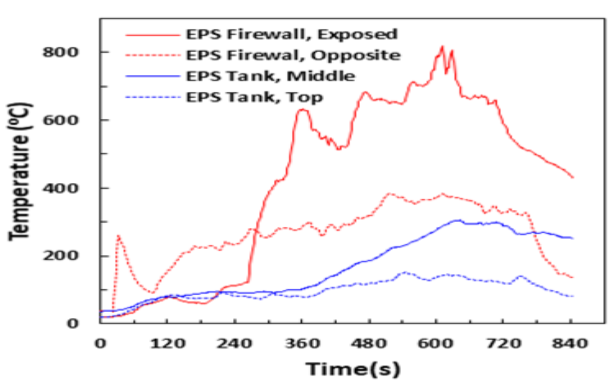

Fig. 14. *Temperature profiles on a firewall(EPS) test.*

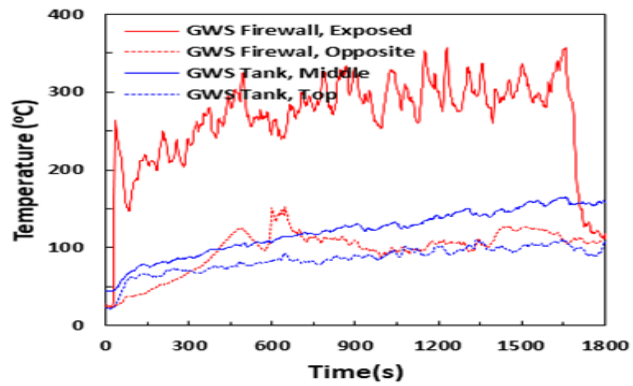

Fig. 15. *Temperature profiles on a firewall(GWS) test.*

Furthermore, the heat flux is analyzed that GWS's is average 9.55kW/m^2 and ALC's is average 5.47kW/m^2. But heat flux of GWS sometimes was over 12.5kW/m^2 which can be serious and risky limited values at gas facilities. But, in our experiments, it can be partially not guaranteed because heat flux was unstable and its peak is uneven every firewall even though fuel consumption is equal to 130 g/s. It is difficult to finely control flow rate not because heating valve and temperature are controlled but because larger LP gases are flowed into the firewall and response time of adjusting valve is slow. So to improve even heat flux and remove noises, we used the rolling mean filter according to GTR No. 13 as shown in Fig. 17.

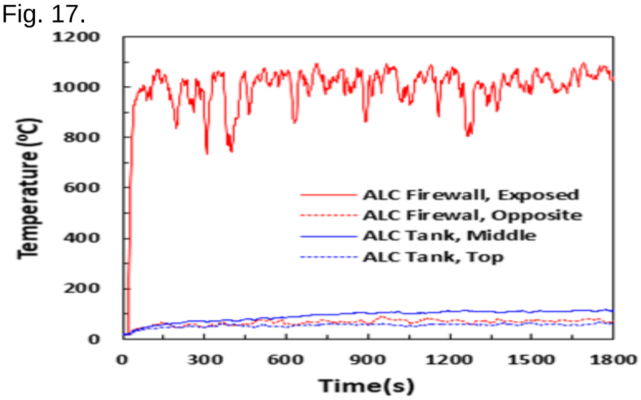

Fig. 16. *Temperature profiles on a firewall(ALCS) test.*

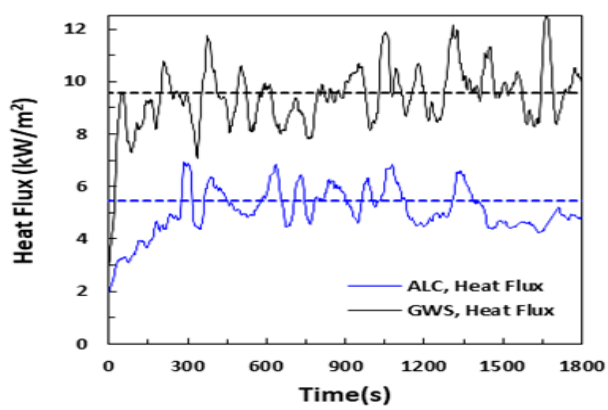

Fig. 17. *Heat flux data using rolling mean filters at GWS and ALC.*

4 CONCLUSION

In this paper, resistivity test of firewall materials is practiced and their reliability is validated to prevent gas leak and explosion of a small LPG storage tank due to increasing inner pressure of its tank from heat flux of burned outer materials of an adjacent building when a fire is happened at a building. Targets of test are five firewalls materials such as LWD, LWC, EPS, GWS, and ALC. They are all manufactured by the frame of 2×2m in size. The fire source is manufactured of the frame of 1×1m in size by using 100 LPG jet nozzles which combusts LPG 130g/s. Used small LPG storage tanks are ten years old, 170kg in weight, 1.2m in height, 0.76 in diameter, and 5mm in thick with steel. The target firewall is installed between the fire source and a LPG tank. Two meters is distance from between a firewall and the fire source. LWD and LWC are completely burned out since 6 minutes from igniting at 3minutes. EPS is specially frame retardant product, but is all burned out and stopped to shield heat after 15 minutes from igniting. GWS and ALC materials are resistant since 30 minutes after they are exposed by jetting fire sources. ALC is nearly not bended and deformed. It is measured that heat flux is 17.48kW/m^2, front average temperature of an ALC firewall is 1,005 °C and maximum surface temperature of the LPG tank is only 115 °C, and steam pressure of propane is 45 bar while time interval is from 150 to 1800 seconds, which are rather risky intervals. So, ALC is recommended to the material of a firewall. Through this research, we propose several conditions for experimental environments as followings. First volume of propane is about 130±10g/s with reference to ISO13785-1 standard. Second, testing time is about 30 minutes referred to time of arrival of fire car and the effect of heat transfer delay. Third, the frame of fire sources is about 1×1m in size by range and dimension of a flame. Fourth, the distance is about 1m between a fire source and a firewall for a small LPG storage tank installed in South Korea. Fifth, wind speed for simulating a real fire is about 300m/min. The last, thick of a firewall is minimum 75mm. We are certain that our research will be helpful to design, manufacture experimental devices and practice performance test of firewalls for preventing explosion and advancing safety of small LPG storage tanks.

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REFERENCES

[1] Korea Gas Safety Corporation, “Facility, Technical, and Inspection Code for Facilities and Using for LP Gas in Small Storage Tanks”, KGS FU432, 2020.
[2] S.K. Roh, T.H. Kim, Y.G. Ham, “A Study on Damage Effect from Boiling Liquid Expanding Vapor Explosion(BLEVE) of LPG Charging Facility,” Journal of the Korea Institute for Gas, vol. 3, pp. 45-50, 1999.
[3] S.L. Lee, Y.S. Lee, “A Study on the Probability of BLEVE of Above-ground LP Gas Storage Tanks Exposed to External Fire,” Journal of the Korea Institute for Gas, vol. 7, pp. 19-23, 2003.
[4] J.P. Yim, B.C. Ma, C.B. Chung, “A Study on the Safety of Small LPG Storage Tanks at External Fires,” J. Kor. Soc. Safety, vol. 30, pp. 64-72, 2015.
[5] J.H. Lee, Y.D. Jo, J.S. Moon, L.H. Kim, “An Availability Assessment of Protection Wall Installed in LPG Filling Station”, Journal of the Korea Institute for Gas, vol. 22, pp. 38-45, 2018.
[6] F. Heymes, L. Aprin, A.M. Birk, P. Slangen, J.B. Jarry, H. Frabcius, G. Dusserre, “An experimental study of an LPG tank at low filling level heated by a remote wall fire,” J. Loss Prev. Proc. Ind., vol. 26, pp. 1484-1491, 2013.
[7] Korean National Fire Agency, Fire Statistical Yearbook, 2018
[8] API 607, “Fire Test for Quarter-turn Valves and Valves Equipped with Nonmetallic Seats”, 2016.
[9] ISO 10497, “Testing of valves: Fire type-testing requirements,” 2010.
[10] NFPA 285, “Standard Fire Test Method for Evaluation of Fire Propagation Characteristics of Exterior Non-Load-Bearing Wall Assemblies Containing Combustible Components,” pp. 5-8, 2006.
[11] KS ISO13785-1 “Reaction to fire tests for facades Part 1: Intermediate-scale test,” 2002.
[12] ISO 13785-2, “Reaction-to-fire Tests for Facades Part 2: Large-scale Test,” pp. 1-16, 2002.
[13] Korean Occupational Safety Health Agency, KOSHA GUIDE P-102-2012, pp. 56-59, 2012.
[14] Health and Safety Executive, “Fire and Explosion Strategy, Issue 1,” 2013.