Fire Test Evaluation using the Kerosene and Aviation Fuel

K. S. Bang, J.C. Lee, C. S. Seo, K. S. Seo, H. J. Kim*
Korea Atomic Energy Research Institute, 150 Dukjin-Dong, Yuseung-gu, Daejeon, Korea 305-353
***Korea Radioactive Waste Management Corporation, 150 Dukjin-Dong, Yuseung-gu, Daejeon, Korea 305-353**

nksbang@kaeri.re.kr

Abstract

The fire test was performed by using kerosene and Jet-A-1 as the fire source under a compartment condition in order to evaluate the flame temperature in the fire due to the release of the kerosene involving the impact of a vehicle, and the fire due to the release of Jet fuel involving the collision of an airplane. The combustion time of the Jet-A-1 was shorter than the kerosene. And the flame temperature in the Jet-A-1 was measured higher than the kerosene. The opening became bigger; the fuel consumption rate became bigger. Therefore, the flame temperature was higher when the size of the opening was big. In the compartment fire, the flame temperature gradually increased.

Keywords: Fire Test, Compartment, Opening, Combustion, Flame Temperature

1. Introduction

Regulatory requirements for a Type B package are specified in the Korea MEST Act 2009-37, IAEA Safety Standard Series No. TS-R-1, and the US 10 CFR Part [1~3]. These regulations are adequate to ensure the shipping package containment effectiveness for the transport conditions including most credible accident conditions; a 9 m drop onto an unyielding surface, a 1 m puncture onto a puncture bar, 30 minutes under 800 °C thermal, and an one hour immersion under a head of water of 200 m .

So far, the evaluation for the Type B package was evaluated about these conditions. However, the need of the evaluation for an extra regulation condition has been raised after a fire accident generated at the Howard Street railroad tunnel in Baltimore on July 18, 2001. Therefore, the United States Nuclear Regulatory Commission, one of the agencies responsible for ensuring the safe transportation of radioactive materials, performed an evaluation on a long duration fully engulfing fire for the TN-68, HI-STAR 100, and LWT cask [4]. Greiner from Nevada University and Lopez from SNL, and etc. performed the research on fire accidents using Jet fuel [5-6].

In this paper, the fire test was performed by using Kerosene and Jet-A-1 as the fire source under a compartment condition in order to evaluate the flame temperature in the fire due to the release of the kerosene involving the impact of a vehicle, and the fire due to the release of Jet fuel involving the collision of an airplane.

2. Fire Test

2.1 Description of the Fire Test Facility

As shown in figure 1, the test facility for performing the fire test was constructed as a compartment with 4 m (W) × 4 m (L) × 4 m (H) size by using a light concrete of 10 cm thickness. An opening was made in order to control the size from 40 cm (H) × 70 cm (W) to 50 cm (H) × 80 cm (W) in the front and rear side of the compartment. On the roof, a hole of 30 cm in diameter was designed with the intention of having a chimney effect.

All thermocouples used in these tests are Type *K*, sheathed in inconel tubing, ungrounded, and insulated using magnesium oxide. A total of 63 thermocouples were installed at heights of 80 cm, 200 cm, and 320 cm above the bottom of the inside of the compartment to measure the flame temperature in the compartment. Ten of the thermocouples were selected and calibrated at 100, 300, and 800°C. And the uncertainty of them was found to be ± 1.0°C at a 95 % confidence level.

Figure 1. Fire test facility

2.2 Heat Transfer Mode and Measurement System

The fire in the compartment may be progressed in 4 phases as shown in figure 2. And the fire is affected by the heat release rate, the enclosure size, the enclosure construction, and the enclosure ventilation [7].

The heat transfer in the compartment fire occurs by convection and radiation from the enclosure, and then conduction through the walls. Heat is generated by the fire source within the compartment and transferred from the combustion zone to the upper layer through convection and radiation. This heat is then transferred to the adjacent wall by the radiation and conduction, and the compartment lower layer by the radiation. Also, this heat is transferred to the ambient atmosphere by convection through the openings.

The temperature data acquisition system used in the fire test consists of a thermocouple scanner, a signal conditioner, an A/D converter, and a PC. The signal, which is detected in the thermocouple scanner, is filtered and amplified through the signal conditioner, and converts an analog signal to a digital signal through the A/D converter. This signal is stored and analyzed via the software installed in the PC.

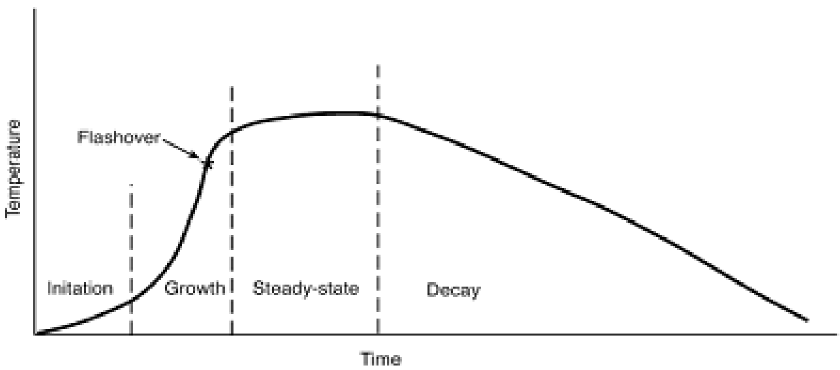

Figure 2. Phases of fire development in the compartment fire

2.3 Compartment Fire Test

The compartment fire tests were performed by using kerosene and aviation fuel as the fire source under a compartment condition in order to evaluate the flame temperature in the fire due to the release of the kerosene involving the impact of a vehicle, and the fire due to the release of Jet fuel involving the collision of an airplane.

2.3.1 Compartment Fire Test using Kerosene

The compartment fire tests using kerosene as the fire source were carried out for three cases in accordance with the size of the opening.

In the first case, as shown in figure 3, the compartment fire test was performed by filling the 350 liters of kerosene as the fire source in the compartment with an opening of 50 cm (H) × 80 cm (W). If this fuel amount is burned in an open pool with 4 m × 3.5 m size, it is the amount which can be burned for about 10 minutes. However, it continued more than 2 hours in the compartment fire. And the average engulfed flame temperature in the upper part was measured at 561 °C.

Figure 3. Compartment fire test

In the second case, to increase the flame temperature, the size of the opening applied was 50 cm (H) × 80 cm (W) including a hole 30 cm in diameter, and then the 50 liters of kerosene was filled in the compartment. The engulfed flame time continued for approximately 15 minutes, and the average engulfed flame temperature in the upper part was measured at 675 ˚C.

In the third case, the size of the opening applied was 40 cm (H) × 70 cm (W) including a hole 30 cm in diameter, and then the 50 liters of kerosene was filled in the compartment like the second case. The engulfed flame time was lasted for approximately 23 minutes, and the average engulfed flame temperature in the upper part was measured at 611 ˚C.

2.3.2 Compartment Fire Test using Aviation Fuel

The compartment fire tests using aviation fuel as the fire source were carried out for three cases in accordance with the size of the opening. The JP-4 is very hard to obtain as it is used by the military. The Jet-A-1 may be easier to get than the JP-4, but only through the refueling team of the Korea Airport Service. In the compartment fire test, therefore, the Jet-A-1 was used as the aviation fuel.

In the first case, the compartment fire test was performed by filling the 50 liters of Jet-A-1 as the fire source in the compartment with an opening of 50 cm (H) × 80 cm (W).

Table 1. Engulfed flame temperature and time.

Fire Source	Opening Size (cm)	Engulfed Flame Temp. (˚C)			Engulfed Flame Time(min.)	Fuel (liter)
		Upper Part	Middle Part	Lower Part		
Kerosene	50 × 80	561	-	-	120	350
	50 × 80 + 30	675	-	-	15	50
	40 × 70 + 30	611	-	-	23	50
Jet A-1	50 × 80	618	602	551	15	50
	50 × 80 + 30	692	677	616	12	50
	40 × 70 + 30	646	623	568	17	50

Table 1 shows comparisons of the average engulfed flame temperature, engulfed flame time, and fuel consumption according to the size of the opening and fire source. The temperature profile of the flame in the first case is shown in figure 4. The engulfed flame time was continued for approximately 15 minutes. The average engulfed flame temperatures measured in the first case was 618 ˚C in the upper part, 602 ˚C in the middle part, and 551 ˚C in the lower part.

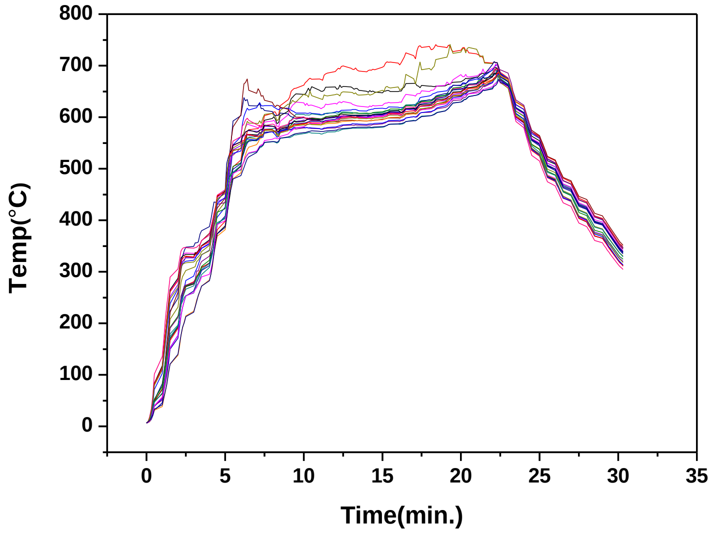

Figure 4. Flame Temperature in the Upper Part(50 cm×80 cm)

In the second case, the size of the opening applied was 50 cm (H) × 80 cm (W) including a hole 30 cm in diameter, and then the 50 liters of Jet-A-1 was filled in the compartment. The engulfed flame time continued for approximately 12 minutes. The average engulfed flame temperatures measured in the second case was 692 ˚C in the upper part, 677 ˚C in the middle part, and 616 ˚C in the lower part.

In the third case, the size of the opening applied was 40 cm (H) × 70 cm (W) including a hole 30 cm in diameter, and then the 50 liters of Jet-A-1 was filled in the compartment. The engulfed flame time lasted for approximately 17 minutes. The average engulfed flame temperatures measured in the third case was 618 ˚C in the upper part, 602 ˚C in the middle part, and 551 ˚C in the lower part. According to the compartment fire test results, the engulfed flame temperatures in the case of using the Jet-A-1 as the fire source were higher than the case of using the kerosene. And the consumption time was short.

Table 2. Heat release rate and mass flow rate

	Kerosene		Jet-A-1	
	50×80 + 30	40×70 + 30	50×80 + 30	40×70 + 30
Heat release rate (kJ/s)	1,714	1,155	2,160	1,524
Mass flow rate (kg/s)	0.040	0.027	0.050	0.035
Ventilation factor ($m^{5/2}$)	0.566	0.354	0.566	0.354
Density (kg/ m^3)	820	820	797.6	797.6
Combustion time (s)	930	1380	720	1020

In the compartment fire, the important factor having an effect on the temperature of the flame is the heat release rate. The heat release rate in the compartment fire can be calculated as follows [8];

$$\dot{Q} = \dot{m}_F \Delta H_C, \Phi < 1$$
$$\dot{Q} = \dot{m}_{Air} \Delta H_{Air}, \Phi \geq 1$$
$$\dot{m} = k_0 A_0 \sqrt{H_0} \Lambda$$

where, $\dot{Q}$ is the heat release rate(kW), $\dot{m}$ is the mass flow rate(kg/m^2.s), ΔH is the effective heat of combustion(kJ/kg), Φ is the equivalence ratio, k_0 is the effective constant(kg/s.$m^{5/2}$) , A_0 is the flow area(m^2), and H_0 is the opening height(m).

Table 2 shows the heat release rate, the mass flow rate, ventilation factor, and the fuel consumption time from test results under various conditions. The effective heat of combustion of the Kerosene applied was 43,200 kJ/kg[9]. And, the effective heat of combustion of the Jet-A-1 applied was 43,333 kJ/kg calculated from the results of quality assurance of performing in accordance with the ASTM method by SK energy Co., Ltd [10].

In the compartment fire tests, the 50 liters of fuel was used. If the fuel consumption in the fire growth phase and the decay phase is considered, the fuel consumption in the steady state phase could be estimated at about 45 liters.

As shown in table 2, the fuel consumption rate of the jet-A-1 is bigger than that of the Kerosene. Therefore, the combustion time of the Jet-A-1 was shorter than that of the Kerosene, and the flame temperature in the Jet-A-1 was higher than that of the Kerosene.

As the opening became bigger; the fuel consumption rate became bigger. Therefore, we can know that flame temperature was highest when the size of the opening was big.

In the compartment fire tests, the engulfed flame temperature was continuously increased. NUREG-1805 state that the temperature of the flame in the compartment fire increases gradually, and reached to 1,260 ˚C, after an elapsed time of 8 hours.

3. Conclusions

The fire test was performed by using kerosene and Jet-A-1 as the fire source under a compartment condition in order to evaluate the flame temperature in the fire due to the release of the kerosene involving the impact of a vehicle, and the fire due to the release of Jet fuel involving the collision of an airplane. The main results are as follows:

First, the combustion time of the Jet-A-1 was shorter than that of the Kerosene. And the flame temperature in the Jet-A-1 was higher than that of the kerosene.

Secondly, the openings became bigger; the fuel consumption rate became bigger. Therefore, the flame temperature was higher when the size of the opening was big.

Thirdly, in the compartment fire, the flame temperature gradually increased.

ACKNOWLEDGMENTS

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