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Effects of floating beads on the flash/fire temperatures and occurrence of boilover

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Abstract

Effects of floating beads on the flash/fire temperatures and occurrence of boilover were studied. To avoid crisis such as huge crude oil fires and boilover in oil and chemical complexes after great earthquakes, floating beads have been developed. Therefore, in order to know effects of beads, experimental study was conducted in small scale pan (Diameter: up to 0.3m). Addition of beads into pan increased the fire/flash points, and delayed and minimized boilover. So addition of small beads into oil tank is one of countermeasure against incidents after great earthquake.

1. Introduction

An oil tank fire is one of the most dangerous cases in oil and chemical complexes because the radiation from the flame may ignite the neighboring oil tanks if the separation between the fire and neighboring tanks is not sufficient. Additionally, fire fighters may expose themselves to strong radiation from large tank fires. Moreover, the tank fire is particularly dangerous when boilover occurs in crude oil or heavy oil tank. The spilled hot oil produced by boilover may cause fire fighters injured, and ignite oil tanks, and consequently enlarge the fire area. Therefore it needs long time to distinguish the full burning tank fire especially after great earthquakes when public fire brigades may not able to conduct fire-fighting such fires in oil complexes. Therefore many researches were conducted [1-7], and we have studied new methods to control and delay of boilover in oil tank fires [8].

A new material, vapor suppression sphere, named dry foam (here, we just call 'beads'), was developed [8] was used in our experiments. This paper evaluates the performance of this new design to suppress the tank fire and to delay subsequent boilover. This new method is proposed to release beads into the burning tank when a fire occurs, and the beads can float on the surface of fuel. Therefore the effects of using of the beads were investigated.

2. Experimental

2.1 Beads

Vapor suppression sphere, named 'dry foam' of Trelleborg Offshore Co. was used, and we called it just beads in this paper. Its summary is shown in Table 1 and its diameter was about 3.97(±0.30) mm in our experimental. Its specific gravity is about 0.17 (±0.01) and is easy to float above the fuel.

In order to know effects of heat from the flame, the TG-DTA tests were applied into the beads. They endured up to 260 ℃ (Figure 1), and it was found that they kept their figures up to 600℃ and did not burn by the observation using micro camera (Figure 2).

Table 1 Summary of beads

Specific gravity	0.17 (±0.01)
Char activation temperature, ℃	300
Volume expansion	25 times
Shell thickness, mm	0.15～0.20
Diameter, mm	3～10
Coating	Oleophobic/Antistatic

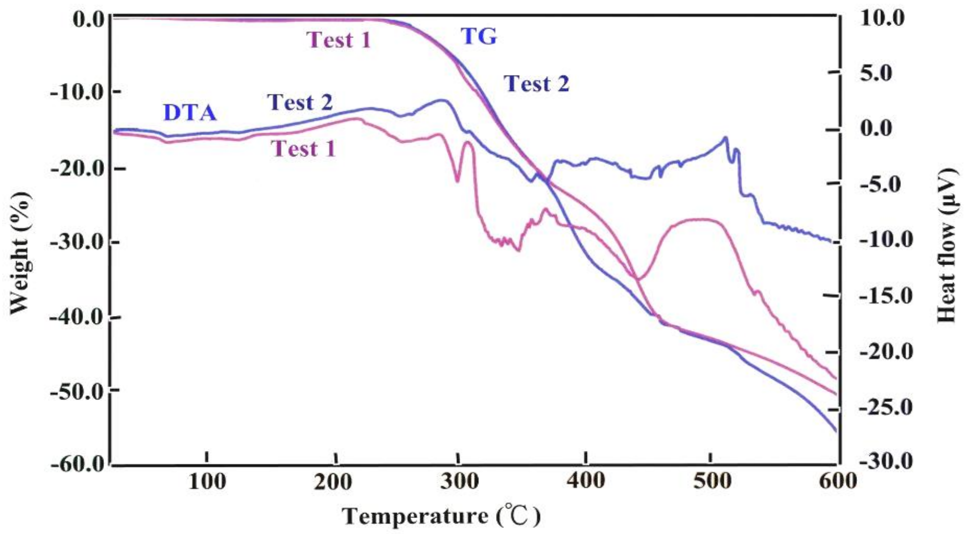

Figure 1 TG-DTA result (Sample bead, heat rate 10 ℃/min)

Figure 2 Photo of bead (heated to 600℃)

2.2 Experimental

Two series experiments were conducted at the Fire Safety Laboratory in the National Kaohsiung First University of Science and Technology, Kaohsiung, Taiwan, which is an indoor burn test facility, and 0.6 m diameter pool fire test can be done.

First test was a flash/fire point measurement to know effects of beads to increase flash point and sustainable fire point using kerosene. The other one was to investigate whether beads can prevent the occurrence of boilover of diesel fires. Diesel did not cause boilover during its burning in oil tank but cause thin layer boilover, in which a hot zone was not produced in the fuel layer during burning, but caused fuel splash and might increase burning rate (mass loss rate) and radiation after long burning [7]. In this paper, thin-layer boilover was observed, but it is just called ‘boilover’.

2.2.1 Flash temperature and fire temperature experiment

An ignition is that flammable vapor of the liquid mixed with air and produced a flash or a sustainable fire by countering an ignition source. So amounts of the vapor are the key factor. In order to know the effect of the beads on the flash and fire point temperatures, two tests, flash point and fire point measurements were conducted in the different size pans.

2.2.1.1 Flash point measurement

Two round fuel pans were used in diameter with 0.1 and 0.3 m, and with which depth of 0.1 m. One of the fuel pans was installed in a larger heating pan (0.4 m in diameter), and vegetable oil was injected between the fuel pan and heating pan to keep steady burnings. The heating pan with a fuel pan inside was put above a heating apparatus which the setting temperature was 200 ℃. This experimental design allows the fuel to be heated gradually. A

K-type thermocouple (Diameter: 0.1 mm) was positioned in the center of the fuel surface. To know effects of beads, none, 1, 2 or 4 layers of beads layers were put above the fuel. The weight of one-layer beads for the fuel pans with diameter of 0.1 and 0.3 m is 3.58 and 32.10 g, respectively. Figure 3 shows the temperature of the fuel surface (0.3 m in diameter) with 1-layer beads. A handy ignitor was put at 5 mm above the center of the fuel surface when the temperature of fuel was increased for 1℃ to observe if a flash or sustainable fire existed.

Kerosene was used as fuel. The nominal close-cup flashpoint of kerosene is 47℃. Kerosene with a depth of 0.09 m was poured in the fuel pans. Tests did not follow the ISO standard flash point measurement (ISO 2592:2000, Cleveland open-cup) exactly, but gave similar results. That is, 48℃ for 0.1m pan, and 43℃ for 0.3m pan were obtained.

2.2.1.2 Fire point measurement

The fire point measurement was very similar with the flash point measurement. In this test, the heating temperature was sustained at the flash temperature which was measured in the no beads test. And a handy ignitor was put at 5 mm above the center of the fuel surface with an interval of 30 s to observe if a flash or sustainable fire existed for 5 seconds. Effects of addition of beads were examined.

2.2.2 Boilover experiment

Figure 3 shows the schematic of the boilover test and Figures 4 shows the schematic of experimental set-ups. Two round fuel pans with diameter of 0.1 and 0.3 m and depth of 0.1 m were used. Depths of fuel and water were 0.02m and 0.05 m respectively. Diesel oil was used as fuel. The nominal close-cup flashpoint of diesel is 70℃. Gasoline of 0.020 g and 0.060 kg were put into the diesel to do smooth ignition for the 0.1 and 0.3 m experiments, respectively. External radiation and mass burning loss rate were measured every second. Horizontal distance between pan center and heat flux meter was set to be 3D, and D is pan diameter.

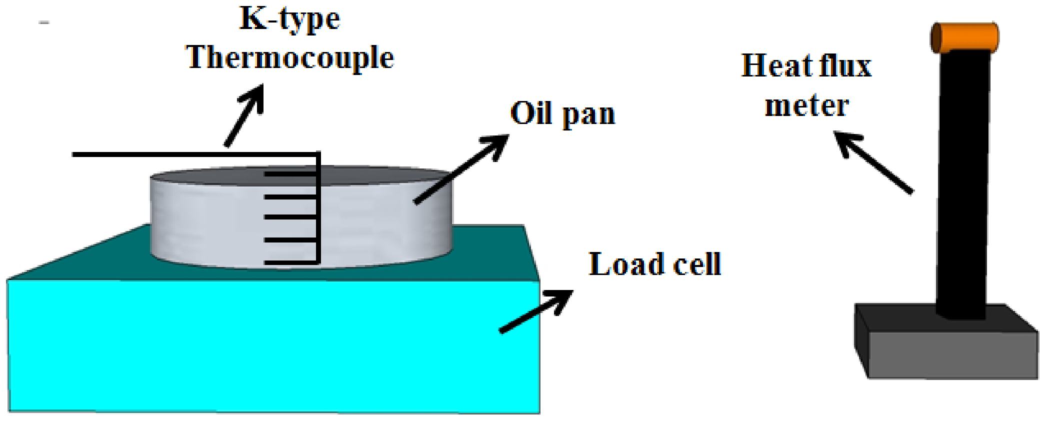

Figure 3 Schematic of the boilover test.

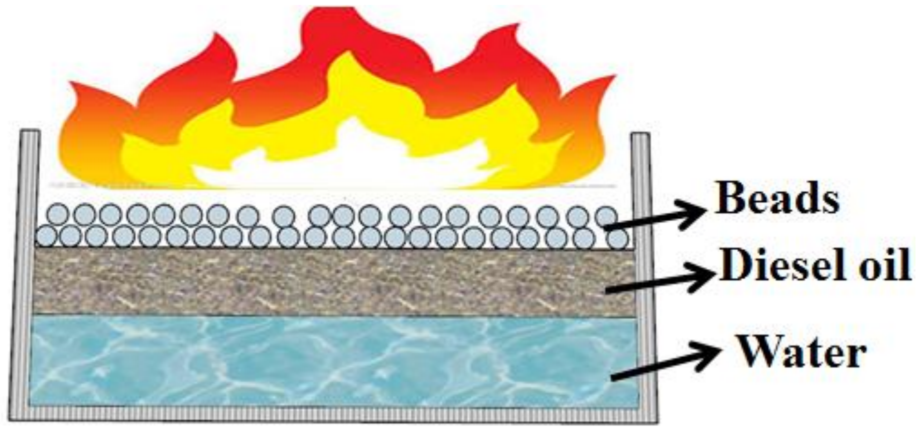

Figure 4 Schematics of sectional view.

3. Experimental results

3.1 Flash and fire point and vaporization rate measurements

3.1.1 Flash and fire point measurements

Figure 5 shows the effect of layer number of beads on the flash point and fire point. Clearly, the flash and fire point temperatures increased when beads were added. When beads were not added, flash point was 48.7℃ and fire point was 57.3℃. The more layers of beads were used, the higher flash and fire temperatures were observed. Finally they reached 97.7℃ (flash point), 108.1℃ (fire point) in 0.1 m pan when 4-layer beads was added.

The same tests were conducted in 0.3 m pan, and the increase of flash and fire points was lower in the tests in 0.3 m fuel pan than those in the 0.1 m pan. When the diameter of fuel pan is large, the depth of beads was not flat due to convection flow inside the fuel layer. The depth of beads in the central part of the pan was higher than that in the edge area. In the 0.3 m tests, the flash occurred near the pan edge, where the depth of beads was lower than the averaged depth. So concertation of fuel vapor might be much higher and mixture of vapor/air was formed in pan edge.

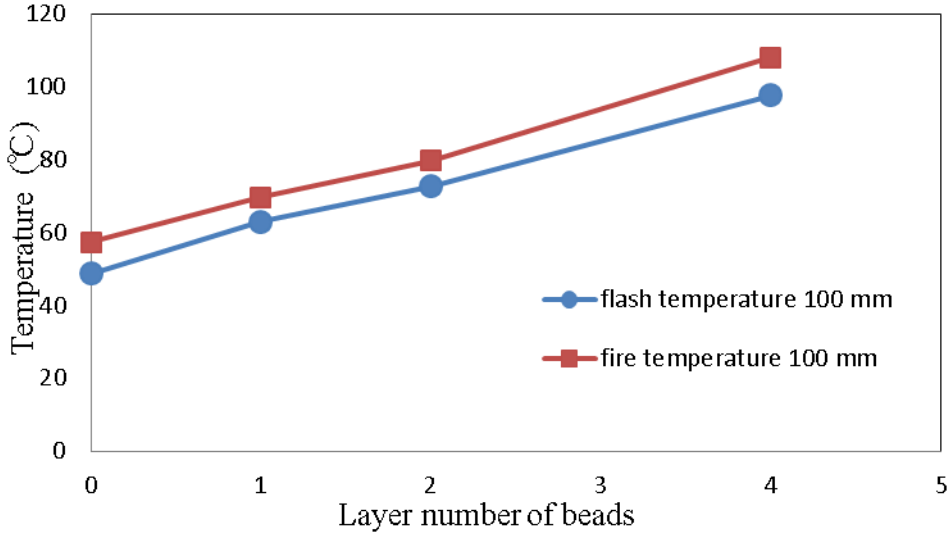

Figure 5 Effects of layer number of beads on the fuel continued rising temperature ignition test.

3.1.2 Fuel vaporization rate test

In order to know effects of beads on fuel vaporization and flash/fire points, vaporization rate (or mass loss rate) was measured during measurement of flash point/fire points. Figure 6 shows results of 100mm diameter kerosene tests. Both tests with beads and without beads, the fuel temperatures at the same time were very similar, difference was less than 1K. However vaporization rates were large difference, that is, addition of beads (1 layer) decreased vaporization to 16 % at 5 minute, and 9.1 % at 10 minute of those fuels without beads. Therefore addition of beads decreased net fuel surface, and suppressed fuel vaporization even in the no burning condition. This is the reason flash/fire points decreased.

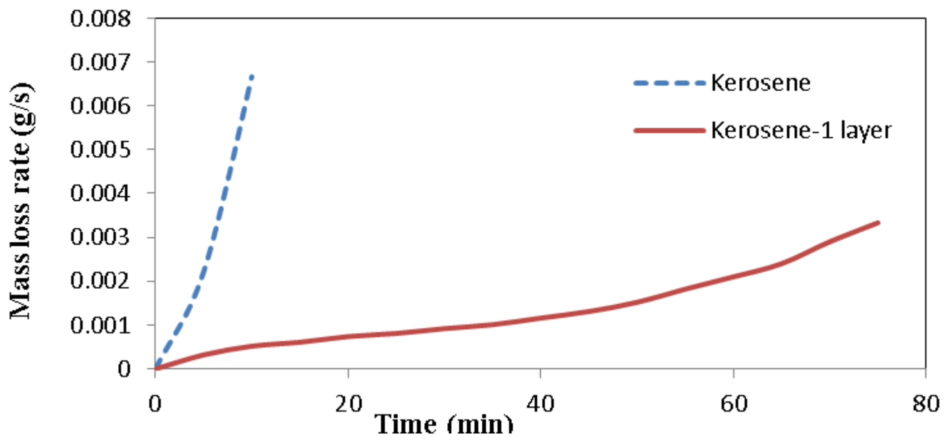

Figure 6 Effects of layer of beads on the mass loss rate (vaporization rate) during the 0.1 m-in-diameter flash/fire tests. Temperatures increased with time, but temperatures for both fuels were very similar at the same time.

3.2 Boilover experiment

Figure 7 shows the boilover phenomenon with no bead in 0.3 m pan, but no boilover with beads. It indicated that the violence of the fire with beads was much smaller than that of the test without beads.

Figure 7 Example of photo of boilover (no bead, D=0.3m)

Table 2 lists the observations of the boilover experiment. In the tests without beads, boilover occurred at 1273 seconds and 575 seconds in the 0.1 and 0.3 m boilover tests, respectively, and mass loss rate (burning rate) and heat flux (radiation) increased drastically. Hot zone was not made in these cases, but heat wave regression rate, u, was calculated assuming that boilover occurs when high temperature fuel reaches water layer boilover occurs suddenly. It was calculated following equation.

u = fuel layer depth / time to boilover

Results were 0.95 mm/min for 0.1 m pan test and 2.08 mm/min for 0.3 m pan test.

Table 2 Observations of boilover experiments

Pan diameter, D	0.1m	0.3 m
No bead	Boilover occurred at 1273 seconds.	Boilover occurred at 575 seconds.
1 layer of beads	No boilover occurred but some burning beads were spilled out at 1112 seconds.	No boilover occurred but some burning beads were spilled out at 702 seconds.
2 layers of beads	No boilover occurred but some burning beads were spilled out at 1051 seconds.	No boilover occurred but some burning beads were spilled out at 751 seconds.
4 layers of beads	No boilover occurred but some burning beads were spilled out	No boilover occurred but some burning beads were spilled out

	at 1678 seconds.	at 892 seconds.

After putting beads into the fuel, boilover did not occur although some burning beads were spilled out. Additionally, the amounts of beads spilled out were decreased when the layer number of beads increased. Heat wave regression rate of 0.3 m pan, increased with addition of beads.

3.2.1 0.1 m pan experiment

Figure 8 shows the effect of layer number of beads on the mass loss rate (burning rate) during the 0.1 m boilover tests. During steady state burning, mass loss rates for all tests gave similar values, so effect of beads addition was not clear. No bead addition test, boilover occurred after 1273 seconds after ignition, and mass loss rate increased about 3.7 times as much as that of steady burns. Although the effect of layer number of beats on mass loss rate was not significant, it can obviously indicate that boilover phenomenon was not occurred in 0.1 m oil pan when beads were added. Addition of beads mitigated boilover.

Figures 9 shows the effect of layer number of beads on the heat flux (radiation) during the 0.1 m boilover tests. The effect of layer number of beads on heat flux was very similar with that of layer number of beads on the mass loss rate. Heat flux increased about 4.1 times as much as that of steady state burning.

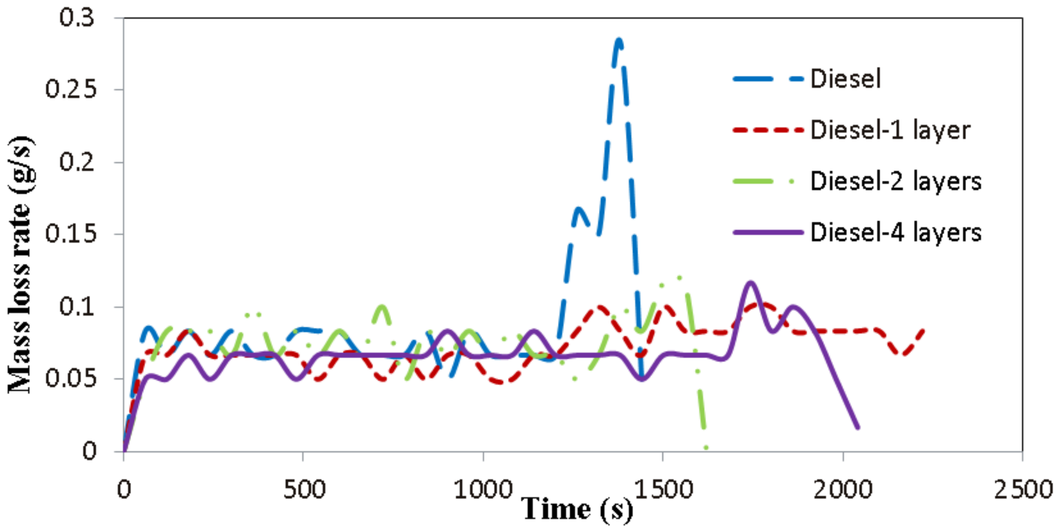

Figure 8 The effect of layer number of beads on the mass loss rate during the 0.1 m boilover tests.

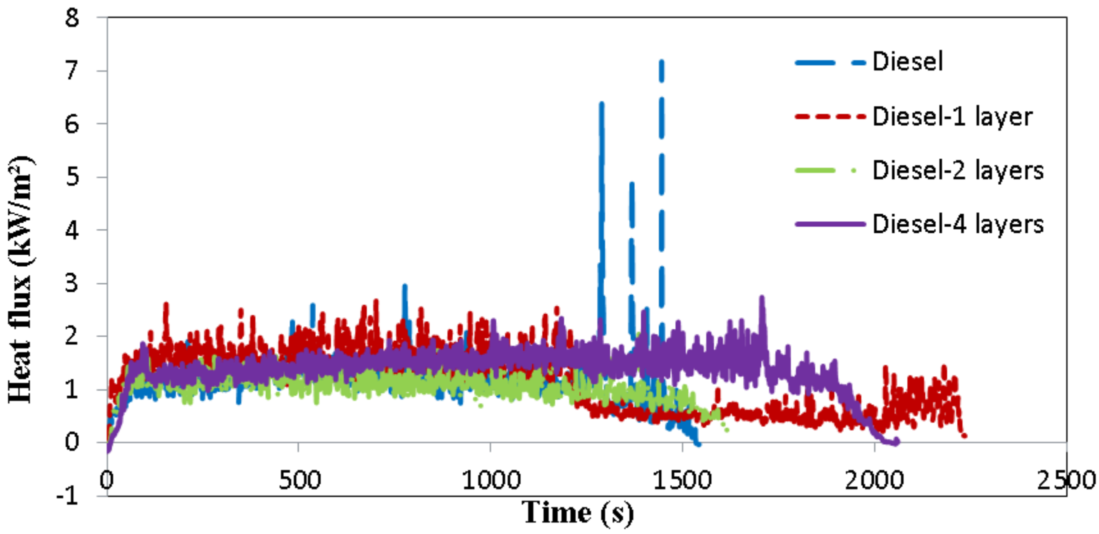

Figure 9 Effect of layer number of beads on the heat flux during the 0.1 m boilover tests.

3.2 2 0.3 m pan experiment

Results in 0.3 m pan burning are shown in Figure 10 (mass loss rate), and Figure 11 (heat flux). In burning in 0.3 m pan, similar results were obtained in regard to addition of beads. In no bead test, mass loss rate increased 18.3 times as much as that of steady state burning, and heat flux increased 11.2 times as much as that of steady burning. Addition of beads mitigated boilover drastically.

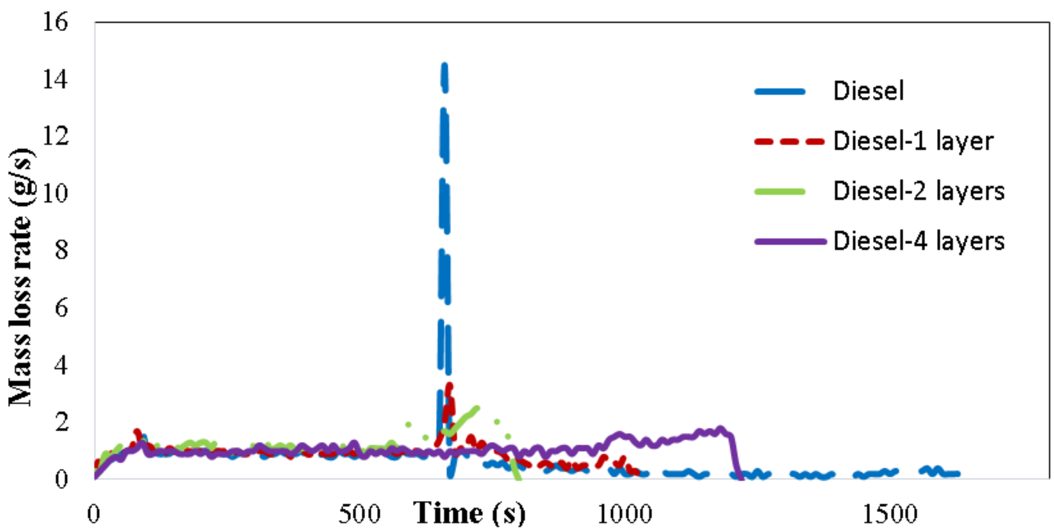

Figure 10 Effect of layer number of beads on the mass loss rate during the 0.3 m boilover tests.

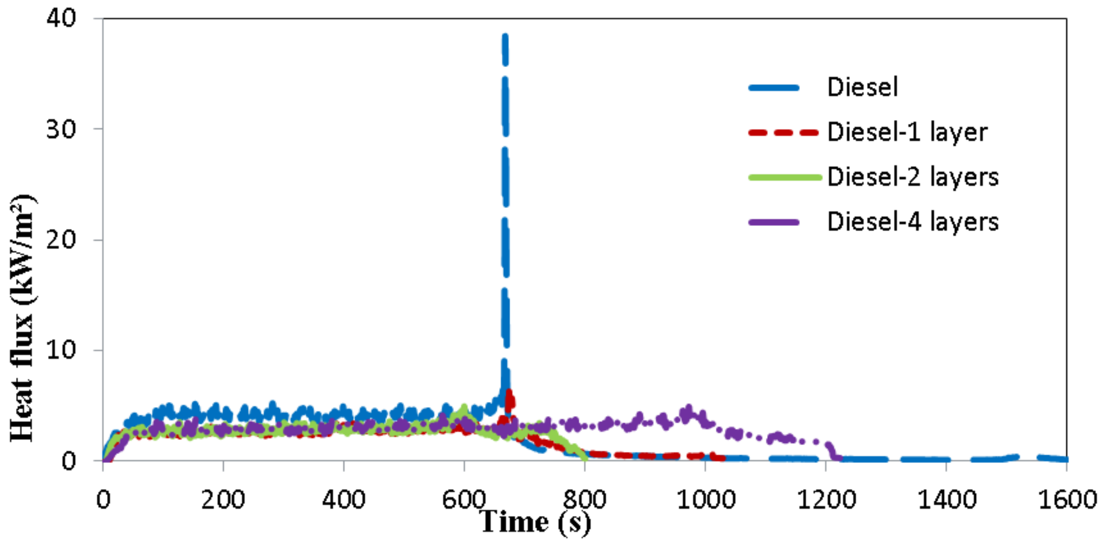

Figure 11 Effect of layer number of beads on the heat flux during the 0.3 m boilover tests.

3.3 Evaluation of beads against boilover and recommendations

This research has just started, but shows beads are so useful against boilover phenomenon. That is, beads decreased the area of net fuel surface and fuel vaporization which increased flash point/fire point, and mitigated boilover, to delay onset of boilover and to decrease its violence. So beads are very effective, but they do not have cooling effect to reduce fuel surface temperature and mitigate boilover. Therefore combination beads and foam extinguishment should be more effective against oil tank fires. Application of beads into real burning tank, we may study more.

4. Conclusions

(1) The use of beads can significantly increase the temperature to produce a flash and sustainable fire. The rise of flash/fire temperature increased with the layer of beads. These results mean existence beads give less fuel vaporization and much safer against fire occurrence..

(2) The use of beads can significantly prevent the occurrence of boilover. When beads were used, no boilover occurred although a few burning beads were spilled out. The more beads were used, the less burning beads were spilled out. Additionally, the mass loss rate of fuel and heat release rate were not changed when beads were used.

(3) We strongly recommend use of beads to prevent boilover occurrence, but still we need larger pool fire tests to insure the effects of beads.

(4) It may be much effective against fire using with combination with normal foam because beads do not have cooling effect against oil tank fires, though foam cools oil surface.

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