CONCEPT DESIGN AND TESTING OF MULTI-NOZZLE WATER MIST FIRE SUPPRESSION SYSTEM

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Abstract

In this work a flexible design of multi-nozzle arrangement of water mist fire suppression system was studied. The source of fire was a 65 mm diameter cooking oil fire. An investigation on the impact of nozzle arrangement on the temperature profile of fires was conducted. The occurance of oil splash due to the application of water mist was also studied. The water mist systems developed in the present work can effectively extinguish cooking oil fires and prevented them from re-ignition. The spray angle, discharge pressure, and water flow rate were important factors to determine the effectiveness of water mist in extinguishing cooking oil fires.

Keywords: cooking fires, fire safety engineering, fire suppression, multi nozzle design, water mist

1. Introduction

Nearly all accidental fire in hotels, restaurants, and fast food outlets start in kitchens, and the majority of these involve cooking oil [1]. Usually the average burning rates of cooking oils are higher than those of other hydrocarbon oils, and cooking oil fires (K class fire) are more difficult to extinguish than other liquid fires [2,3]. During a cooking oil accident, the oil could be heated up to a temperature above its flash point. Once the oil was ignited, it is difficult to cool down below its auto ignition temperature. Observations show that cooking oil fires come into complete combustion stage shortly after ignition accompanied by a lot of smoke and strong heat radiation.

At normal temperature, cooking oil hardly vaporizes. The concentration of cooking oil vapor above oil surface is far below the combustible concentration, so it cannot be ignited. The evaporation rate of cooking oil becomes faster when it is heated up to about 310 °C, and the concentration of cooking oil vapor quickly reaches to the combustible concentration and is easy to be ignited. Auto ignition occurs when the cooking oil is heated up to 350 °C–370 °C. The surface temperature of burning cooking oil ranges from 340 °C to 380 °C according to the different species of cooking oil.

Deploying an effective fire suppression system is an important aspect of the fire safety design of a modern building and industrial premises. Drawbacks on the use of excessive amount of water in a sprinkler system, and a ban on the use of ozone depleting Halon 1301 would make research on finding an alternative protection system for fire control become a necessity [2].

Foam, powder and carbon dioxide can effectively extinguish the flames over the oil surface but it is very difficult to cool the oil below its auto-ignition temperature and to prevent re-ignition due to their limited cooling capacity [4]. Wet chemical agents are the most commonly used agents in commercial cooking areas. They are effective in extinguishing cooking oil fires, but it takes a long time for a wet chemical agent to cool the oil below its auto-ignition temperature, depending on quantity of agents used. They may irritate skin and eyes and bring up clean-up problems after fire extinguishment.

The use of fine water sprays as alternative method for fire control has been widely recognized [1-3,5-9]. The smaller size water mist droplets offer larger surface area for the same amount of water, allowing faster evaporation of the droplets, and more effective heat extraction from a fire. The mist vapor dilutes the concentration of oxygen as well as of the pyrolysis fuel vapor, thus slowing or arresting combustion. Water mist can also block the thermal radiation and pre-wet other combustibles in the neighborhood to reduce their temperature and delay the ignition. However, there is still a need to quantify the properties of water mist using sophisticated tools such as PIV and PDA systems [10]. In addition there is still limited general consensus on the design method for water mist fire protection systems, despite some water mist an attractive alternative for fire control [4].

Recently some experiments of extinguishing class K fires with water mist are carried out [1,6-8]. It is necessary to thoroughly investigate the interaction of water mist with class K fires, and disclose the related principles so as to provide scientific guidance for the use of water mist in kitchens. The purpose of this work was to develop a water mist system to effectively extinguish cooking oil fires. In order to achieve this purpose, the mechanisms of water mist in extinguishing cooking oil fires were investigated, and the impact of pool fire characteristics on the effectiveness of water mist in suppressing cooking oil.

2. Experiment

The experimental systems include water mist fire suppression system, and temperature data acquisition system (Fig. 1). During each test, a fresh commercial vegetable oil (palm oils) with an auto-ignition temperature above 350 °C was used, diameter of pool fire each were 6.5 cm and 10 cm. The water mist was formed using twelve APO-TW-3 nozzles and pressurized water from pressure vessel with the working pressure 400 psi. Twelve water mist nozzles were located align to the side of pool fire and aimed at the centre of the cooking area (Fig. 3). The distance of the nozzle from the fuel surface were 10 cm, 20 cm and 30 cm.

The temperature was measured by K type thermocouples. Four thermocouples were used to measure flame and oil temperatures. As shown in Fig. 1, Thermocouple #1 was located below the surface of the cooking oil to measure the cooking oil temperature. Thermocouple #2 was located in the surface of pool fire. Thermocouples #3, and #4 each were located 10 cm and 30 cm from the surface of pool fire to measure air and flame temperatures during entire course of the fire tests.

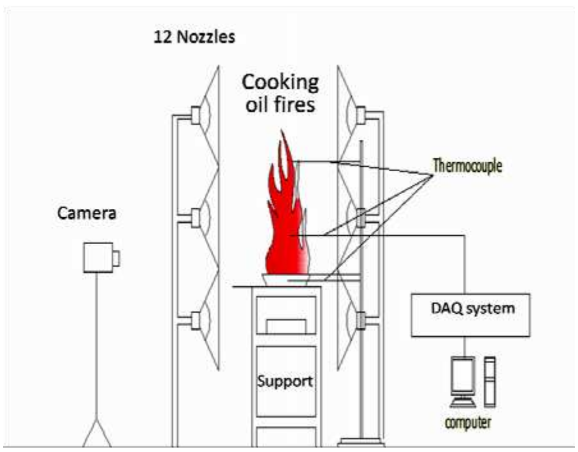

Figure 1. Experimental Set-up

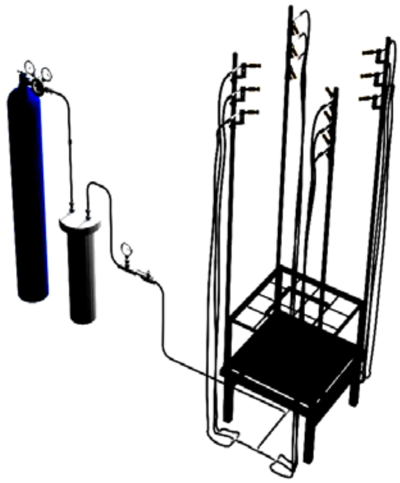

Figure 2. Water Mist System

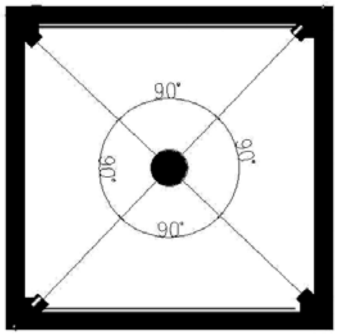

Figure 3. Nozzles Oriented

Figure 4. Experimental System

Table 1. Experimental Scenario

Scenario	Pool fire diameter (cm)	Volume of cooking oil (ml)	Height of container (cm)
1	6.5	50	4
2	6.5	100	4
3	6.5	50	10
4	6.5	125	10

A burner below the pool fire (as shown in Fig. 4) was used to provide a heat flux source to heat the fuel and ignite cooking oil. The burner was shut off and removed from pan area when the oil was ignited on the surface.

The experimental scenarios are summarized in Table 1. Every scenario was conducted for two times to get the average result. For the cooking oil fires, pre-burning was allowed to reach steady burning conditions. Then water mist was applied and the fire extinguishment time was recorded.

The fire suppression process was observed and recorded by a data acquisition system with 1 second sampling interval. One video camera was used to provide visual records of the cooking oil fire, water mist discharge, oil splashing, and fire suppression. The experimental environment temperature was 25 °C.

3. Results and Discussion

Table 2 summarizes experimental conditions and results. Characteristics of cooking oil fires, oil splash caused by water mist discharge as well as effectiveness of water mist against cooking oil fires were investigated.

During the experiments, palm oil was heated continuously. After the oil was heated over 230 °C, smoke appeared over the oil surface. During seven experiments, the oil auto ignited at temperatures ranging from 350 °C to 368 °C. The flame consumed all the fuel vapor over the oil surface that was generated in the heating period and quickly spread to the whole oil surface. During free burning, the fire was fully developed. A large amount of dark smoke was produced. The flame temperatures were high at the center of the oil pan and they decreased with an increase in distance from the center of the oil pan.

Fig. 5 shows the variation of the cooking oil temperature with time in a typical experiment. It takes aproximately 9 minutes for each scenarios for cooking oil fire to extinquised without applied water mist.

Fig. 6 shows variation of temperatures measured above the oil surface at four different locations of thermocouple with time. Once the water mist discharge was activated, the temperatures below the nozzle tip were quickly dropped as fine water drops cooled the flame. After the fire was extinguished, the temperatures far from the oil surface. However, the temperatures near the oil surface were still high, as significant hot steam was produced.

During the experiments, the extinguishing times ranged from 5 seconds to 20 min, depending on the type of scenarios.

Table 2. Fire Test Conditions and Results

Scenario	Auto ignition temp. (^{o}C)	Oil splash	Extinguisment time (s)
1	368	No	5s, no re-ignition
2	350	No	50s, no re-ignition
3	368	No	5s, no re-ignition
4	358	No	5s, re-ignited twice

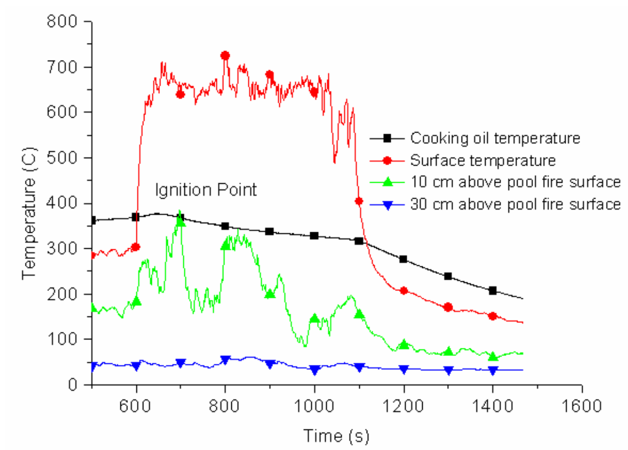

Figure 5. Temperature Against Time History for Pool Diameter of 6.5 cm with 50 mL Volume of Oil (Scenario #1)

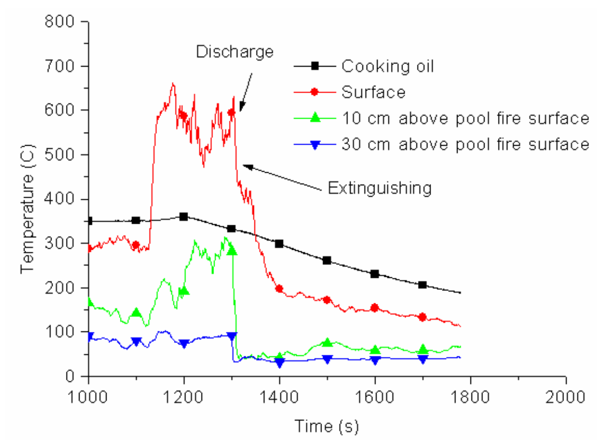

Figure 6. Temperature Against Time History for Pool Diameter of 6.5 cm with 100 mL Volume of Oil (Scenario #2).

In the experiments the temperature did not decrease quickly at the initial stages but jumped up and down with water mist applied. When the fire was extinguished, the temperature of cooking oil decreased to 220 °C. The temperature jump was not obvious at the initial stages of applying water mist.

The results given in Figs. 5-10 show that the water mist envelope and coverage play important roles in extinguishing the pool fires. Although there were some temperature increase during the initial period of mist introduction, however in general the fires can be extinguish in a relatively short period of time. In addition, according to the literature the spray characteristics of individual nozzle, as well as multi nozzle arrangements, which are represented by spray coverage area, fluxs of water mist, and spray momentum are also important factors for extinguishing cooking oil fires [1-4,10]. Water mist coverage must be large enough to cover the entire oil surface and extinguish the whole flames over the oil surface at once, otherwise the flames will not be extinguished. The amount of

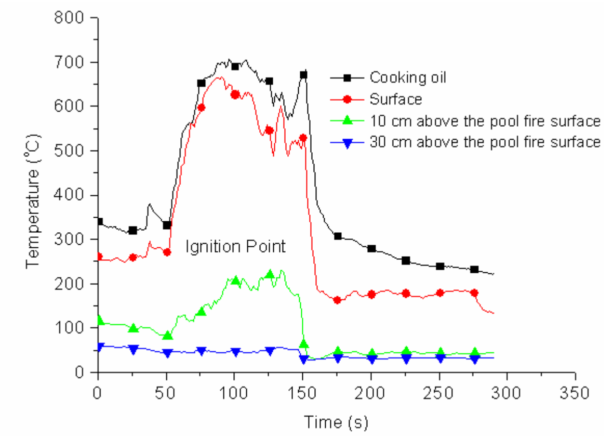

Figure 7. Temperature Against Time History for Pool Diameter of 6.5 cm with 50 mL Volume of Oil (Scenario #3).

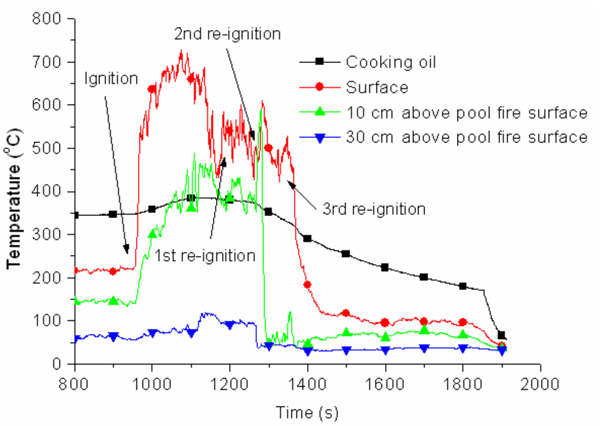

Figure 8. Temperature Against Time History for Pool Diameter of 6.5 cm with 125 mL Volume of Oil Scenario #4).

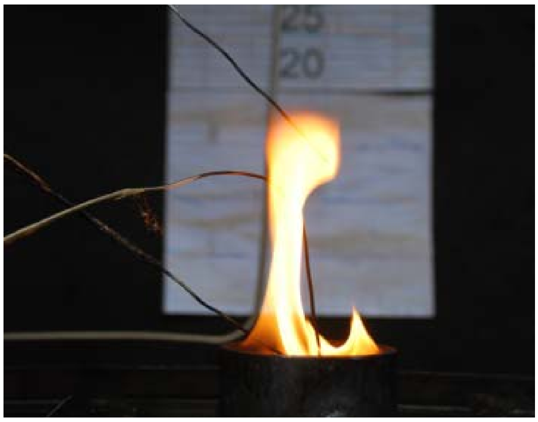

Figure 9. The Variation of Cooking Oil Temperature During Free Burn Period for Pool Diameter 6.5 cm, 10 cm and vol. 50 mL

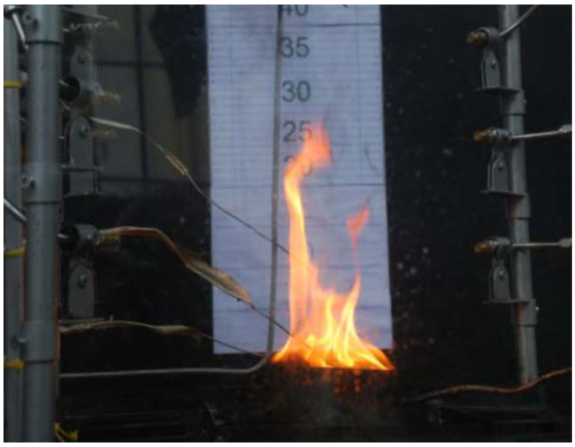

Figure 10. The Variation of oil and Fire Temperatures with Time, when the Cooking Oil Fire was Suppressed by Water Mist

discharged water must be sufficient enough to absorb sufficient heat from the flame and cool the oil below its ignition temperature. Lastly, water mist should have sufficient momentum to penetrate the fire plume and reach the fuel surface [3, 5-9].

4. Conclusion

Compared to other types of liquid pool fires, cooking oil fire are difficult to extinguish, because they burn at high temperature and re-ignite easily. Experiment results indicated that the interaction of pool fires and water mist coverage determines the effectiveness of water mist system for extinguishing cooking oil fires. Water mist extinguishes cooking oil fires mainly by surface cooling effect at once, and it not only cooled the oil surface, it also mixed and enhanced the heat transfer between the hot oil and cold oil below to rapidly reduce the oil temperature near the surface, below its auto-re-ignition temperature and prevents re-ignition. Water mist has limited effect on water drop splashing and oil splattering compared with water droplet [11]. The experiments demonstrated that the water mist fire suppression systems developed in the present work were capable of extinguishing cooking oil fires and preventing their re-ignition.

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