Applied Thermal Engineering 107 (2016) 863–869

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Cooling characteristics of cooking oil using water mist during fire extinguishment

Zhang Tian-wei [a,b], Han Zhi-yue [a,*], Du Zhi-ming [a], Liu Kai [a], Zhang Ze-lin [a]

[a] State Key Laboratory of Explosion Science and Technology, Beijing Institute of Technology, Beijing 100081, China
[b] Department of Fire Commanding, The Chinese People's Armed Police Forces Academy, Langfang, Hebei 065000, China

HIGHLIGHTS

- The cooling characteristics of a home scale of cooking oil fire was first successfully studied.
- The influence factors of the boiling over layer was proved by temperature analysis.
- The suppression efficiency of the boiling over layer using additives are higher than pure water.
- The mechanism of suppression expansion of the boiling over layer by the six additives are different.

ARTICLE INFO

Article history:
Received 28 March 2016
Revised 6 July 2016
Accepted 6 July 2016
Available online 7 July 2016

Keywords:
Water mist
Additive
Cooking oil
Boiling layer
Cooling

ABSTRACT

This study analyzed the effects of both water mist and water mist with different additives on cooling of cooking oils during fire extinguishment. The sizes of water mist drops with different additives were measured using a split-type laser particle analyzer. Full-scale extinguishment–cooling experiments using different fire extinguishing agents and oil temperatures were also conducted. The boiling over layer formed during the cooling of cooking oil using water mist could significantly enhance the cooling rate. Moreover, the expanding rate of this boiling over layer is related to oil temperature and water mass in oils. Although additives reduce water evaporation and hinder oil cooling, such additives also inhibit the expansion of the boiling over layer, thereby reducing the risk of secondary damage caused by abundant oil overflow after the fire extinguishment.

1. Introduction

The rapid development of kitchen equipment and production technology of cooking oils has resulted in the extensive use of highly efficient and high-energy cookers and cooking oils with high spontaneous ignition points. However, using these innovations also increases the risk of kitchen fires. Cooking oil, small pan, and large-scale oil tank fire accidents in food processing industries are all caused by spontaneous ignition of oils at several hundred degrees Celsius. Oil temperature in combustion is substantially higher than the boiling point of water [1]. Although dry powder and gaseous extinguishing agents could extinguish the surface fires of cooking oils, these substances cannot cool fuels effectively and can easily cause a recrudescence phenomenon [2]. Water could cool both flame and fuel effectively because of its high heat capacity. However, water will cause splash and boiling over upon contact with the hot oil surface; these situations are dangerous to people, including firefighters, near the fire. Therefore, hot oil fire accidents should not be extinguished using water [3]. Splash refers to the rapid evaporation that occurs when water surpasses its boiling temperature and reaches a superheated steam temperature [4–6]. As water evaporates and absorbs heat, oil temperature decreases while liquid drops remaining on the oil surface are heated and develop into bubbles. Hot oil will be extruded from the container with the expansion and breakage of bubbles, thereby causing boiling over. The overflow of oil will ignite surrounding combustibles rapidly, which intensifies the fire immediately. In previous boiling over experiments of oil products [7,8], water was placed under the fuel bottom and oil burned on the water layer. Only a few studies have been conducted on the boiling over phenomenon caused by water mist during extinguishment; hence, the corresponding influencing factors remain unknown. Nam [9] performed a full-scale experiment using water spray to extinguish large-scale industrial oil tank fires. Water spraying could extinguish oil tank fires effectively without causing splashing. However, abundant oil boiling over was observed in every set of experiments conducted, thereby causing extensive flowing fire. A similar result

* Corresponding author.
E-mail address: hanzhiyue@bit.edu.cn (Z.-y. Han).

http://dx.doi.org/10.1016/j.applthermaleng.2016.07.043
1359-4311/

was reported in another study of Nam [10], although he did not conduct further theoretical analysis on the boiling over phenomenon. Liu [11–13] conducted a full-scale experiment on extinguishing cooking oil fire using water mist, in which only small boiling over was observed. Subsequently, he studied the cooling characteristics of oil products during this extinguishment and proposed boiling over and splash as influencing factors. Nevertheless, he selected a fire model for large-scale food processing enterprises and did not consider the effects of environment-friendly additives on the cooling process.

Water mist is extensively used in restaurants or hotels with high risks for kitchen fire. The uniqueness of these cooking sites entails that fire extinguishing agents must be non-toxic, harmless, and should prevent the after-combustion of oils. Therefore, performing small-scale extinguishment–cooling experiment for kitchen fire accidents is necessary.

Using a small-scale fire model, this study conducted experimental and theoretical analyses of splash and boiling over during oil cooling under different oil temperatures and additives. The results could provide several references in designing water mist fire extinguishing systems for places with potential cooking oil fire risks to decrease the number of firefighter casualties while extinguishing hot oil fires.

2. Experimental apparatus and methods

The experiment was conducted in a 3 m × 2.1 m × 2.8 m confined space. The water mist fire extinguishing system comprised a water storage tank, nitrogen gas cylinder, pressure regulator, water mist spray nozzle, and connecting lines, a split-type laser particle analyzer was placed in the middle of the nozzle and oil pan, and connected with the computer which measured the droplets size in real-time, as shown in Fig. 1.

The drip pan was 20 cm in diameter and 12 cm high, and was placed underneath the water mist spray nozzle. The upper edge of the drip pan was 1 m away from the water mist spray nozzle. Three thermocouples (labeled 1#, 2#, and 3#) were placed vertically; the vertical distances between them and the drip pan bottom were 3, 6, and 9 cm, respectively.

The tested cooking oil was peanut oil, which a total of 1500 ml was placed in the oil pan. The height of the cooking oil in the oil pan was 4.7 cm, thereby immersing thermocouple 1#. A resistance wire pan was placed under the oil pan with a steel sleeve which diameter was 20 cm. On one hand, the steel sleeve could avoid the hot resistance wire from contacting water mist, it could also played the uniform heating of oil pan. The cooking oil was heated at a temperature rising rate of 10.8 °C/min by controlling the heat resistance wire until the spontaneous combustion point was reached. Thereafter, the reducing valve was adjusted to 0.4 MPa. Water mist was applied when the temperature of thermocouple 1# was 390 °C. After the fire was extinguished, water mist was applied continuously until the temperature of thermocouple 1# measured 300 °C.

Six additives for water mist were selected: $K_2C_2O_4$, KNO_3, CH_3COOK, KCl, KH_2PO_4, and $NH_4H_2PO_4$. All additives were manufactured by Beijing Chemical Works and were analytically pure. The additives were prepared into 5% (mass fraction) solutions and used as fire extinguishing agents.

3. Results and discussion

3.1. Cooling process of cooking oils

Oil surface cooling while extinguishing cooking oil fires with pure water mist can be divided into two stages according to temperature changes. The first stage is from the application of water mist to the extinguishment of the naked flame. The second stage is from the extinguishment of the naked flame to the end of the water mist application. The extinguishing effect is shown in Fig. 2.

Fig. 3 is the temperature-time curve during cooking oil fires cooling process which shows that the oil surface temperature in the first stage is high and retains its temperature for a short period after water mist is applied. The naked flame has not been completely controlled by the water mist and only a few water mist drops reach the oil surface because of the fire plume. Cooking oils increase volume during the heating process. The temperature of thermocouple 2# was the same as that of thermocouple 3# during the heating process, thereby indicating that the volume expansion of the cooking oil did not immerse the former. The temperature measured on thermocouple 2# was equivalent to the flame temperature, which dropped significantly under the effect of the water mist. No splash was observed during this stage.

Reid [14] explained that the critical condition of splash is $1 \leqslant \frac{T_{oil}}{T_{sup}} \leqslant 1.1$, where T is the temperature in K and the subscripts *oil* and *sup* represent the oil and superheated steam of water, respectively. In the current experiment, the spontaneous ignition temperature range of the cooking oil ranged between 357.3 °C and 362.7 °C. The superheated steam temperature of pure water in Ref. [15] was 279–302 °C. The ratio between the spontaneous ignition temperature range of the cooking oil and superheated steam temperature of pure water was over 1.1, thereby causing

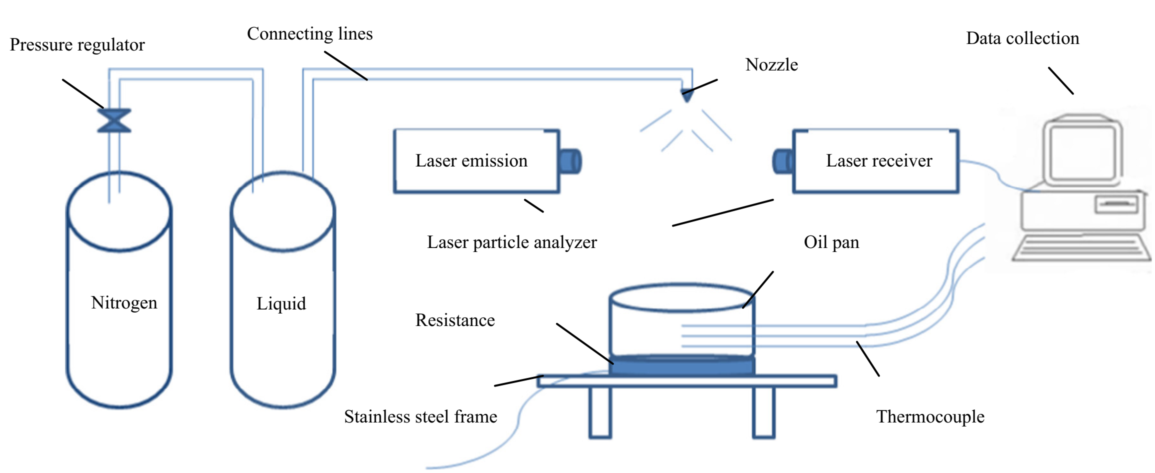

Fig. 1. Schematic of the experimental set-up.