Fire Safety Journal 63 (2014) 101–112

Contents lists available at ScienceDirect

Fire Safety Journal

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

Analytical and experimental study on multiple fire sources in a kitchen

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ARTICLE INFO

Article history:
Received 26 September 2012
Received in revised form
9 October 2013
Accepted 9 December 2013
Available online 3 January 2014

Keywords:
Kitchen fire
Multiple sources of ignition
Limited ventilation
Soybean oil

ABSTRACT

Experiments were carried out earlier in a room calorimeter to study cooking oil kitchen fires with multiple fire sources under natural ventilation with burning characteristics observed. Air and fire temperatures inside the room and heat release rates were measured before. In this paper, average heat release rate, burning time and average oil mass flux were investigated by analytical studies together with those experiments. Average heat release rate, burning time and average oil mass loss rate for 2 woks, 4 woks and 6 woks were compared. Three typical burning conditions were identified and analyzed. Rapid burning rate in the experiments was observed. A mathematical model on heat transfer from the flame to the pan surfaces was developed. Analytical results were justified by the earlier experimental observations. This would compare the results better with 2 woks, 4 woks and 6 woks. In the calorimeter, each pan was placed at different distances away from the door. The burning process, mass loss rate of kitchen oil and burning time are different. Therefore, only the average values were used to get more reasonable results.

1. Introduction

Most Chinese kitchens have two and more cooking stoves in a residential flat. Restaurants have a stove with several burners using at the same time as in Fig. 1. Large amount of soybean and sunflower seed oil is used for stir-frying or deep-frying Chinese food. During cooking, various reasons, such as carelessness, the cooking oil is heated on stove to ignition. Nearby items were burnt to give a big fire. Statistics show that most kitchen fires are caused by ignition of items near fire sources [1]. A fire can easily start by heating cooking oil to its ignition temperature.

Kitchen fire behavior is greatly affected by ventilation, such as the status of forced ventilation system and sizes of openings such as doors and windows for natural ventilation. Studies on heat release rates and burning characteristics under different ventilation conditions provide important information for the design of kitchen fire suppression systems and fire-fighting methods. These detailed studies will also be important reference to more scientific assessment of kitchen fire risk factors.

The risks of kitchen fires have been reported and studied in the literature [1–6]. An investigation report in 2007 [1] pointed out that from 1980 to 2002, residential fires accounted for 29% of all fires in the United States. 33% of those residential fires were related to kitchen fires which accounted for 47% of deaths caused by residential fires. A recent study [7] even reports that an accidental kitchen fire broke out after a deep frying pan was left attended for less than 10 min. Some research [1] has also made recommendations on the design of residential kitchen fire suppression systems. Most kitchens are not completely enclosed from the other part of the buildings. In such case, a fire will develop rapidly and even cause flashover, once cooking oil reaches its ignition temperature and catches on fire. More detailed studies should focus on areas such as ignition time of cooking oil and effects of ventilation on fire development.

Full-scale burning tests [4–7] had been carried out to evaluate the performance of sprinkler and water mist on controlling a fire. Kitchen fire scenarios with and without the operation of sprinkler or water mist system were considered. These experiments were done in a facility in a remote town Lanxi at about 150 km from Harbin, Heilongjiang, China.

Experiments were conducted to study cooking oil fires in a kitchen with multiple burners using at the same time under natural ventilation. Burning characteristics were observed while heating up air and fire temperatures inside the room. The heat release rates were measured and reported in this paper. A mathematical model on heat transfer from the fire to the pan was developed based on experimental observations. Modeling results are compared with experimental data.

Although the experimental data used in this paper were obtained from the same experiments focused primarily on sprinkler and water mist suppression in the literature [4–7], this paper

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http://dx.doi.org/10.1016/j.firesaf.2013.12.001

Nomenclature

a	thermal diffusivity ($m^2\,s^{-1}$)
A	sum of A', A_n and A_g (m^2)
A'	oil surface area (m^2)
A_g	pan surface area in contact with oil for film boiling (m^2)
A_n	pan surface area in contact with oil for nucleate boiling (m^2)
A''	pan surface area not in contact with oil (m^2)
$\overline{A'}$	average oil surface areas (m^2)
C_p	specific heat capacity ($J\,kg^{-1}\,K^{-1}$)
c_{wl}	constant, $c_{wl}=0.013$
g	acceleration of gravity ($m\,s^{-2}$)
Gr	Grashof Number
H	pan depth (m)
h	heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
h_{conv}	convective heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
h_{rad}	radiative heat transfer coefficient ($Wm^{-2}\,K^{-1}$)
Δh_v	latent heat of vaporization ($J\,kg^{-1}$)
L	pan characteristic length (m)
l	oil depth (m)
l_0	initial oil depth (m)
m	mass (kg)
m_0	initial oil mass (kg)
$\dot{m}$	mass loss rate ($kg\,s^{-1}$)
$\dot{m}''$	average mass flux ($kg\,m^{-2}\,s^{-1}$)
Nu	Nusselt Number
Pr	Prandtl Number
Q	heat released (MJ)
q	heat release rate (kW)
$\dot{q}$	heat flux ($kW\,m^{-2}$)
R	radius of pan surface sphere (m)
r	pan radius (m)
r_0	initial radius of oil surface (m)
S	surface area of pan surface sphere (m^2)
s	constant, $s=1.7$
T	temperature (K)
T_f	the flame temperature (K)
T_{sat}	oil boiling temperature (K)
ΔT	temperature difference (K)
t_0	total burning time (s)
v	volume (m^3)
$\dot{V}$	average oil volume loss rate ($m^3\,s^{-1}$)

Greek letters

β	thermal expansion coefficient (K^{-1})
ε	emissivity
γ	gasification rate ($m^{-1}\,s^{-1}$)
λ	thermal conductivity ($W\,m^{-1}\,K^{-1}$)
μ	dynamic viscosity (Pa s)
ν	kinetic viscosity ($m^2\,s^{-1}$)
ρ	density ($kg\,m^{-3}$)
σ	Stefan–Boltzmann constant ($W\,m^{-2}\,K^{-4}$)
σ_s	surface tension ($N\,m^{-1}$)

Subscripts

1	inner pan surface
2	outer pan surface
∞	ambient
g	related to film boiling
n	related to nucleate boiling
l	liquid oil
v	gasified oil
w	pan wall surface

studied the burning of heated oil in different numbers of woks. Only the heat release rates of 2, 4 and 6 woks without adopting the sprinkler and water mist suppression data were used. Systematic theoretical analysis of the heat release rate data of 2, 4 and 6 woks were carried out specifically.

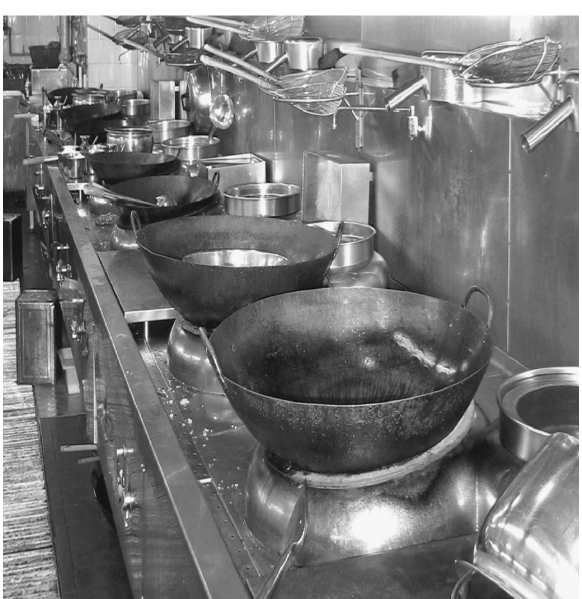

Fig. 1. A typical Chinese restaurant kitchen.

This paper introduced the concept of average burning time and average heat release rate of 2, 4 and 6 woks. In the room calorimeter, each pan was placed at different distances away from the door. The wok near to the door had a higher mass loss rate with a shorter burning time. The wok close to the room inside had a lower mass loss rate with a longer burning time. Therefore, an average value is needed. As the total burning time t_0 was recorded and both the total loss rate of fuel and the variation of surface area in the combustion process were known, the impact of having different burning environment can be estimated for three typical states. For each typical state, it is assumed that the combustion was steady and independent with each other to estimate the average mass loss rate.

Kitchen fires are mostly caused by human negligence, such as the ignition of oil or other dried food by burning gas. In the experiment, it is found that two adjacent woks are not easy to ignite each other, because no combustibles are present. However, if the fire is big enough, it will burn all combustible materials. Therefore, experiments were designed with 2, 4 and 6 woks burning at the same time. Such experiments were designed so as to find out if the same amount of oil is burned completely within the same time, and if there is a difference in burning rate. It is found that the burning states of several woks are not consistent with each other, the mass loss rate also depends on the supply of fresh air.

2. Experimental setup

Geometry of the room calorimeter, positions of the stoves with burners and test points are illustrated in Fig. 2. The room calorimeter