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Experimental Study of Induction Cooker Fire Hazard

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Abstract

Induction cookers are popular in the modern family in Hong Kong. Since these cookers do not use naked flame, some people believed that these induction cookers will not create any fire hazard and can be considered as a fire safety feature. Therefore, with induction cookers installed in the kitchen, it is possible to relax some fire safety measures in buildings such as kitchen walls. However, there is still a lack of understanding of induction cooker fire hazards. Thus experimental study of induction cooker fire hazard is necessary. The present study focused on time to ignition, cooking oil surface temperature at ignition, smoke layer height and flame height by an induction cooker fire.

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Keywords: induction cookers; fire hazard; oil

1. Introduction

Recent year, induction cookers are being promoted as clean, safe cooking device for kitchen. Consequently, as advertised, induction cookers are designed to reduce kitchen fire hazards and it is now popularly used in the modern family.

Induction cooker has a few advantages when compared with traditional cooker. There are two major advantages of the induction cooker, namely, energy saving and safety enhancement. The induction cooker has provided different types of built–in safety functions to reduce potential fire hazard. The safety functions of induction cooker include.

- No further power output when cookware is removed from the hob
- It has automatically cut–off function in case of overheating
- No radiated heat and unnecessary heating of the room from the hot cooking range
- Free from naked flame and smoke
- Reduce the risk of burn and ignition of spilled fat or oil.
- No emission of harmful gas

However, the above points are not clearly justified. In present study, the fire hazard of induction cookers is reviewed. There are three major elements that may contribute to the induction cooker fire hazard including induction cooker, cookware and fuel (cooking oil) as shown in Fig 1. The induction cooker provides the energy to heat up the cookware and in turn heat up the content (oil fuel) inside the cookware. Therefore, improper use of one of the three elements may easily leads to induction cooker fire.

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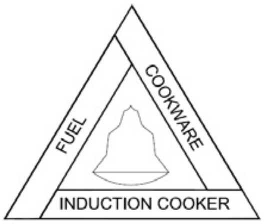


Fig. 1. Three components of induction cooker fire hazard

2. Literature review

2.1. Review of induction cooker

The major components in an induction cooker are the magnetic coil and ceramic plate. The principle of operation of the induction cooker is based on the high-frequency magnetic field generated by the magnetic coil. The field penetrates the ferrous cookware (magnetic –materials) such as stainless steel cookware and set up an eddy current that generate heat at the base of the metallic cookware. The heat in cookware is then transferred to the cookware's contents as shown in Fig 2. [1]

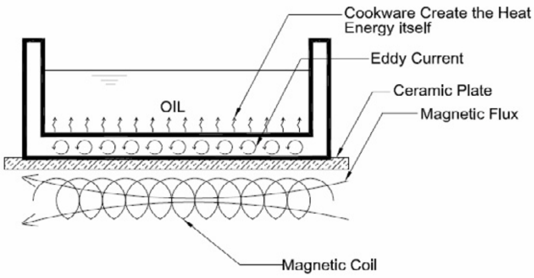


Fig. 2. Construction and operation of induction cooker

2.2. Review of induction cooker in Hong Kong

In present study, 10 different brand names of induction cookers in Hong Kong are surveyed. Products from different countries such as Japan, China, Italy, German and Sweden are investigated. For different brand names, a total of 43 items of induction cookers are reviewed. For induction cooker design, the induction cooker either has one hob, two hobs and three hobs design and provide different safety measures of the induction cooker. The present investigation shows that more than 50% of the induction cookers provide timer and temperature controller as safety measures as shown in Fig 3.

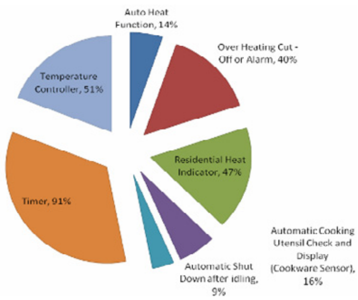


Fig. 3. Different function of induction cooker

2.3. Review of cookware characteristics

Cookware is another important element in induction cooker fire hazard. Not all cookware can be used for induction cooker. First of all, manufacturers of induction cooker recommended the cookware to be made of stainless steel materials.

Whether the cookware is suitable to be used for induction cooker is indicated by the "Magnetic Label Test Method" using a simple a magnetic label only. If the selected cookware has a label as shown in Fig 4, the cookware can be used for the induction cooker.

Fig. 4. Cookware label (magnetic label) [2]

The recommended cookware materials also include stainless steel, cast–iron and carbon steel. In considering the performance of cookware materials, the thermal inertia is also taken into account [3]. The thermal properties of cookware such as stainless steel, cast–iron and carbon steel are shown in Table 1. Among these three materials, stainless steel cookware has the lowest heat transfer efficiency.

Table 1. Thermal properties of three induction compatible cookware material

Materials	Thermal Conductivity (k) $W\ m^{-1}\ K^{-1}$	Specific Heat Capacity (c) $kJ\ kg^{-1}\ K^{-1}$	Density (ρ) $kg\ m^{-3}$	Thermal Inertia (I) $W^2\ s\ m^{-4}\ K^{-2}$
Cast iron	80	0.460	7900	539.18
Carbon steel	51	0.500	7500 – 8000	437.32 – 451.66
Stainless steel	16	0.500	7500 – 8000	244.95 – 252.98

To investigate the performance of induction compatible cookware, different types of cookware are selected, including pans, woks and pots. The pans, woks and pots have various dimensions and shapes for selection in accordance with the research of the induction compatible cookware as shown in Table 2.

Table 2. Diameter of induction compatible cookware [4]

Type of Cookware		Cooker Diameter (cm)											
		50	40	36	32	30	28	26	24	22	20	18	16
Pan	Frying				✓		✓	✓	✓		✓		
	High Sided						✓		✓	✓	✓	✓	
Wok	Round Base			✓									
	Flat Base			✓									
	Cast Iron			✓									
Pot	Full Height	✓	✓	✓		✓			✓		✓		
	Half Height			✓		✓	✓	✓	✓	✓	✓	✓	✓
	Half Height Saucepan with Handle									✓	✓	✓	✓
	Low Saucepan with Handle			✓			✓		✓				

In addition, manufacturers have designed different patterns of cookware bottom. The aim of this design is to allow more even heat transfer and distribution. Two different cookware bottom designs are shown in Fig 5.

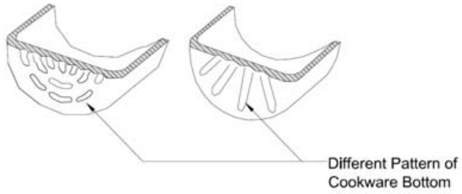


Fig. 5. Two different patterns of cookware bottom

The design of cookware bottom and the dimension of cookware are important elements that affect the design of safety devices of the induction cooker. As shown in Fig 6 (a), (b) and (c). When under-size and uneven base cookware is used, the response time of the sensor will increased.

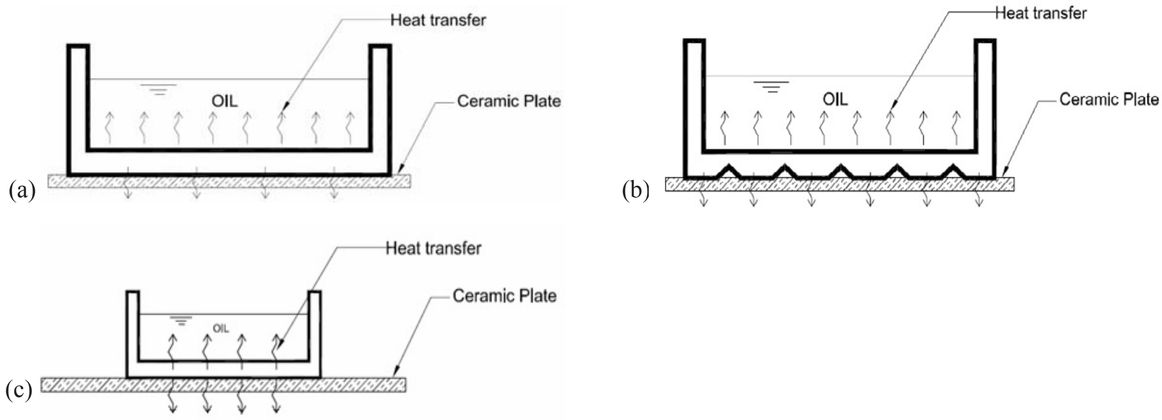


Fig. 6. (a) Heat transfer with (a) different cookware material, (b) uneven cookware bottom and (c) undersized cookware

2.4. Review of typical fuel (cooking oil)

In considering induction cooker fire hazard, cooking oil properties such as smoke point temperature, flash point temperature and fire point temperature are taken into account. [5] The smoke point temperature is the temperature of heated up oil that begins to give–off smoke. The flash point temperature is the temperature of heated oil that gives flashes of burning when exposed to a flame. The fire point temperature is the temperature of heated oil sustains burning after ignited by a flame. Different oils have different smoke point, flash point and fire point temperature as shown in Table 3.

Table 3. Smoke point, Flash and Fire Point temperature for different cooking oils [6 - 8]

Substance	Smoke Point Temperature °C	Flash Point Temperature °C	Fire Point Temperature °C
Cottonseed Oil	185 – 223	252 – 333 318 – 322 333	342 – 357
Palm Oil	223	162 - 203 314	341
Peanut Oil	160 – 207	282 290 – 333	342 – 363
Soybean Oil	213	220 – 320 317 320	342
Sunflower Oil	209	320 316	341

3. Experimental study

The objective of the present study is to analyze the time to ignition and burning condition of an induction cooker fire. For the experiment, the quantities of peanut oil were adjusted from 500mL to 30mL and the induction cooker was maintained at a maximum power input of 2.6kW in each experiment. The temperature change during the experiment was recorded by thermocouple and the experimental process was record using a digital camera. The parameters measured in the experiments included.

1. Oil temperature change in case of fire
2. Cookware surface temperature change in case of fire
3. Hot air temperature change above the cookware in case of fire
4. Smoke layer in the experiment
5. Flame height in case of fire
6. Cooking oil surface temperature at ignition
7. Time to ignition of oil

The experiment apparatus consisted of:

1. A stainless steel cookware of 220 mm diameter and 130 mm high is shown in Fig. 7 (a) and (b). The stainless cookware was filled with peanut oil in different quantities and the test cookware complied with the magnetic sticker test.

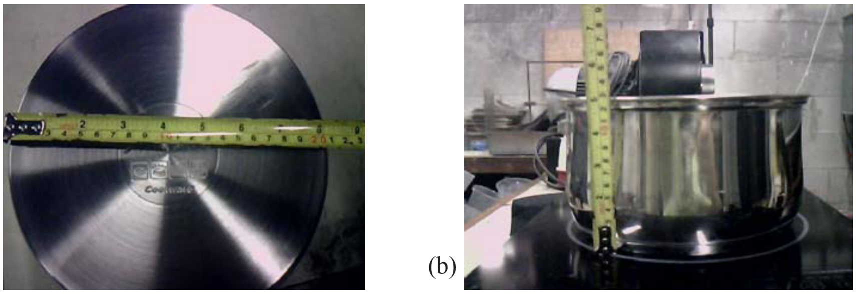


Fig. 7. (a) Base diameter of cookware: 220mm and (b) Cookware height is approximate 130mm

2. A 2.6 kW Induction cooker with a surface of 340 x 320 mm was used. The input voltage was 220 V 50/60 Hz. The weight was 3.4kg. The safety devices of the induction cooker included:
   - ✓ Small Articles heat preventer
   - ✓ Auto turn – off for not operation over 2 hours
   - ✓ Auto turn – off for overheat ceramic glass plate
   - ✓ Auto turn – off for internal parts overheat

The main parts of the induction cooker included the control area, top case and ceramic plate. From previous induction cooker survey result, the ceramic plate can stand a temperature of approximately 600^{o}C. However, the power cord is not a fire resistant cable. It can be ignited easily and damaged by fire. The induction cooker typical design also includes an internal ventilation fan to prevent heat accumulation inside the induction cooker. The induction cooker control panel includes different function control switches. The function switches include Cook / Warm Option Key, Power Level Key , On / Off Key and Temperature / Power Indicator as shown in Fig. 8 (a) and (b).

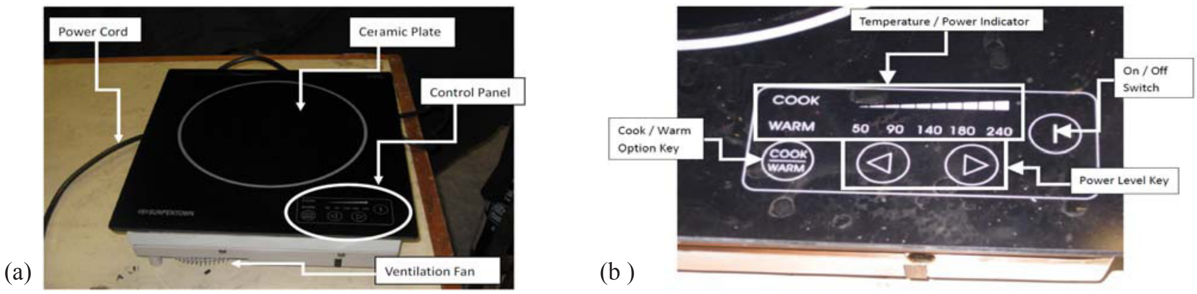


Fig. 8. (a) Main part of induction cooker and (b) Control panel of induction cooker

3. 2 liters peanut oil is used as fuel source in the experiment as shown in Fig. 9

Fig. 9. Peanut oil for experimental study

4. The K–type thermocouples are used for monitoring the temperature of the oil, fire, stainless steel pot surface temperature and the hot air temperature at different level above the pot. The exact locations of thermocouple are indicated in Fig 10 (a) and (b) and Table 4.

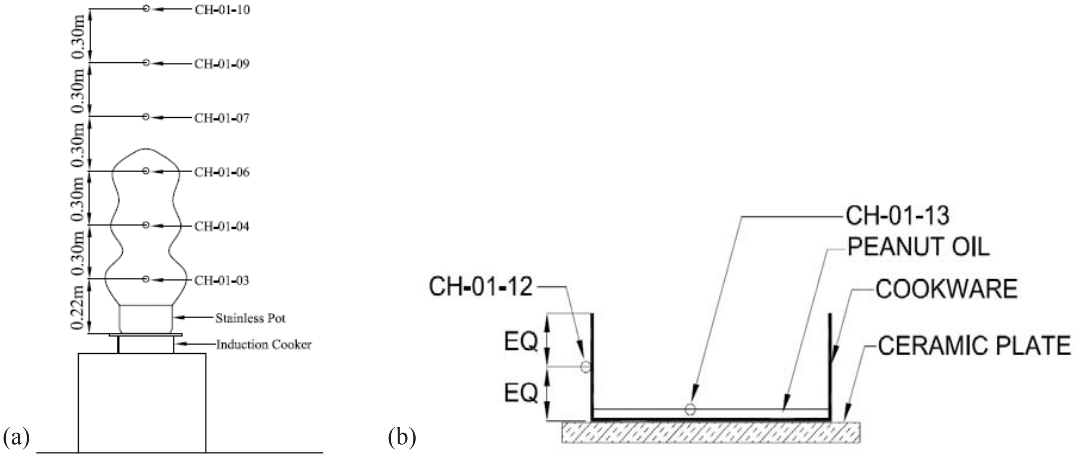


Fig. 10. (a) Location of thermocouples at different level and (b) Location of thermocouple in oil and cookware surface

Table 4. Thermocouple measuring points

Thermocouple No.	Location of Thermocouple	Description
CH-01-03	Above the base 0.22m	Hot Air / Fire Temperature
CH-01-04	Above the base 0.52m	Hot Air / Fire Temperature
CH-01-06	Above the base 0.82m	Hot Air / Fire Temperature
CH-01-07	Above the base 1.12m	Hot Air / Fire Temperature
CH-01-09	Above the base 1.42m	Hot Air / Fire Temperature
CH-01-10	Above the base 1.72m	Hot Air / Fire Temperature
CH-01-12	Cookware Surface	Cookware Temperature
CH-01-13	Inside the Cookware / Surface of Oil	Oil / Fire Temperature

5. Two individual steel plates with scales are used to measure the flame height and the smoke layer height. Individual computers are used to record the mass loss and temperature of thermocouple. The flame height and smoke layer height are recorded by digital video camera as shown in Fig. 11 (a) and (b).

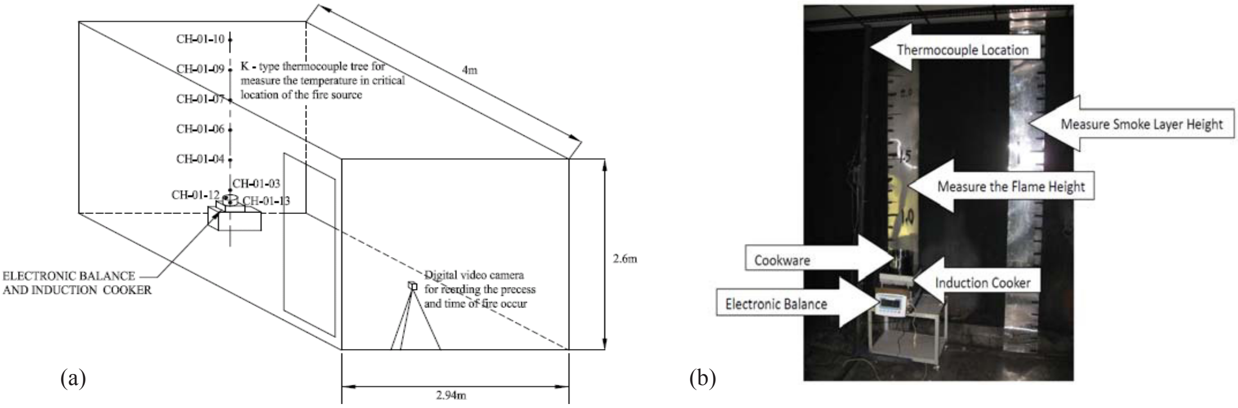


Fig. 11. (a) The physical dimensions in fire chamber 4m(L) x 2.9m(W) x 2.6m(H)and (b) Set up of experiment

4. Experimental result

In the first experiment, the time to ignition is measured and the digital camera recordings are made. The time to ignition is approximately 12 minutes. The cooking oil surface temperature at ignition is not recorded in this experiment. In the initial stage of experiment, the oil generated a large amount of smoke from the cookware until auto–ignition. The smoke filled–up the chamber very fast as shown in Fig 12 (a) and (b). After the fire started in the cookware, the induction cooker did not turn–off by any safety devices until the power was shut–down manually.

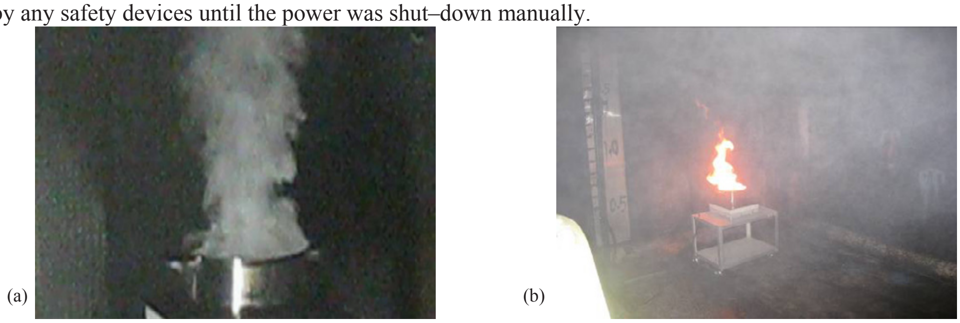


Fig. 12. (a) Smoke occur before the peanut oil auto – ignition and (b) Fire occur after peanut oil auto – ignition

In the experiment, the cooking oil was self–ignited and fires occurred after the induction cooker heat–up the peanut oil for a period of time. This happened when different quantity of fuel was used. The experimental results are shown in Table 5 and Fig 13 (a) (b) (c) (d) and (e).

Table 5. Experimental result of time to ignition, cooking oil surface temperature at ignition

Quantity of Fuel (mL)	Time to Ignition (Sec.)	Cooking oil surface temperature at ignition (^{o}C)
500	704	401.3
110	270	381
70	214	364.1
50	200	304.8
30	232	192

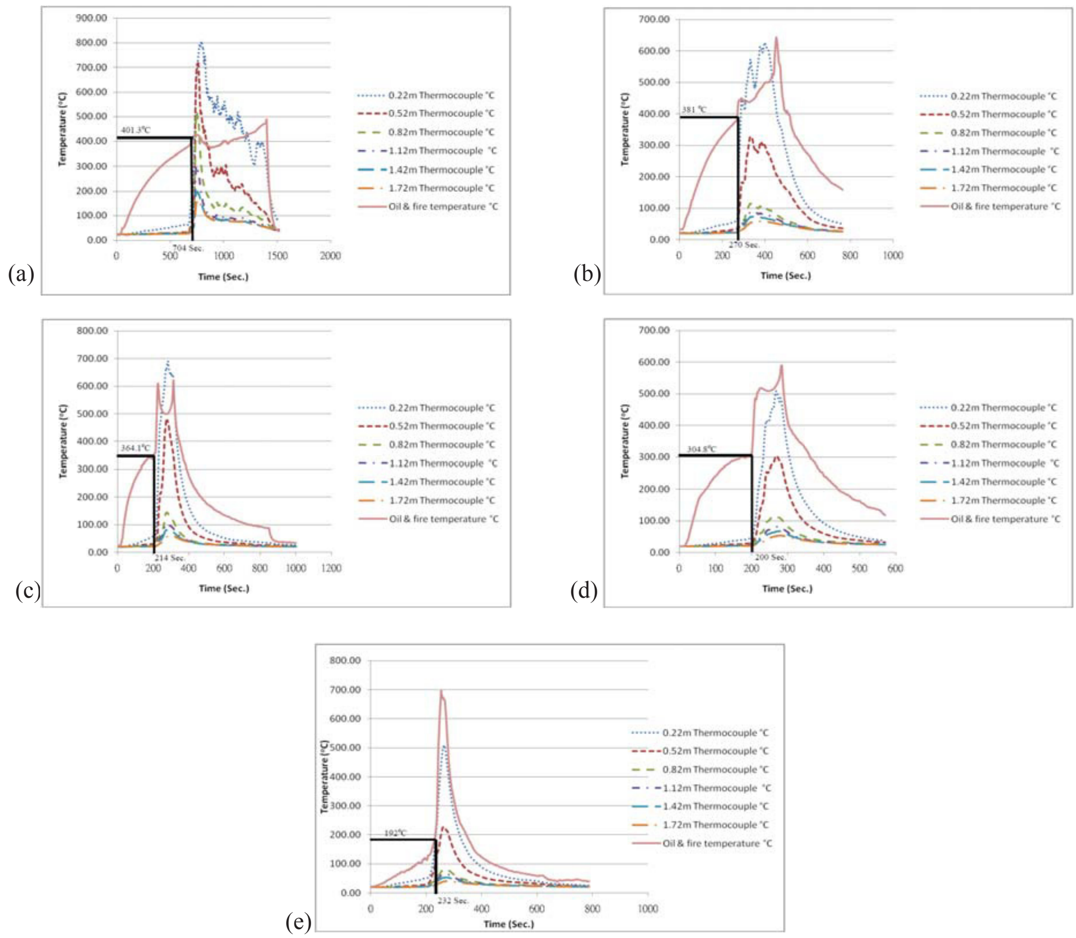


Fig. 13. Time to Ignition and temperature in (a) 500mL (b)110mL (c) 70mL(d) 50mL and (e) 30mL peanut oil

When the quantity of oil increased, the cooking oil surface temperature at ignition would also increase as shown in Fig. 14 (a). With the quantity of oil increased, the time to ignition would vary as shown in Fig 14 (b). The experimental results showed the time to ignition was approximately 232 second for 30mL peanut oil but the time to ignition was only approximately 200 second for 50mL peanut oil.

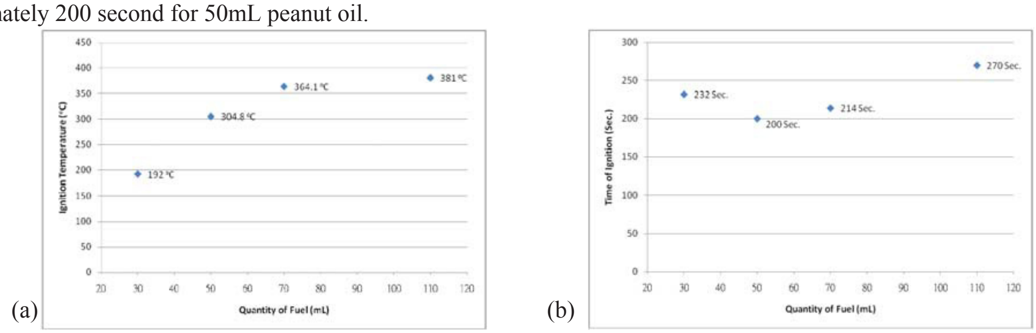


Fig. 14. (a) Cooking oil surface temperature at ignition due to 4 quantities of oil and (b) Time to ignition with 4 quantities of peanut oil

The cookware temperatures were not successfully recorded in all experiments because the thermocouple could not be fixed completely on the surface of the cookware. Temperature curves suddenly dropped when the thermocouple disconnected from the cookware. In the total five experiments, only for experiments with 500mL and 70mL peanut oil, cookware temperature from oil ignition to fire decay were successfully recorded as shown in Fig 15.

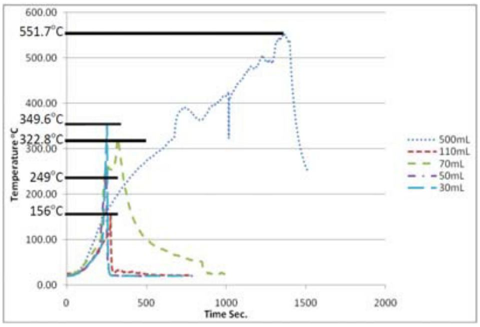


Fig. 15. Cookware temperature result

4.1. Smoke Layer Clear Height

The smoke layer clear height depends on the observation by the human eyes. The smoke layer clear height is determined by reading scale on the wall mount steel plate. The distance of the smoke layer clear height is considered from the floor to the smoke layer interface. It is considered as part of fire hazard. The smoke can affect the visibility of occupants during evacuation if the smoke layer clear height is approximately 2.0m from the floor. The digital video camera recorded the approximate smoke layer clear height during the experiments as shown in the Fig 16(a) and (b).

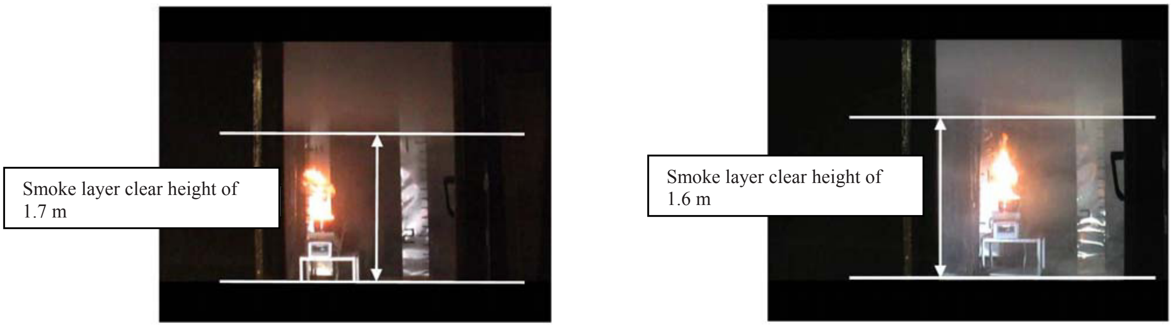
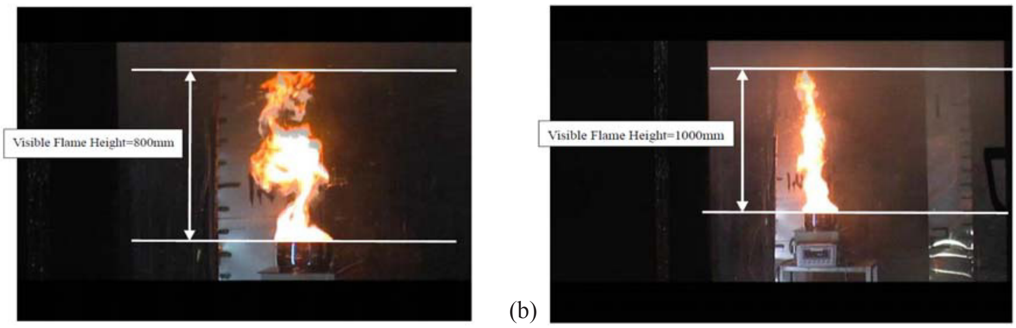


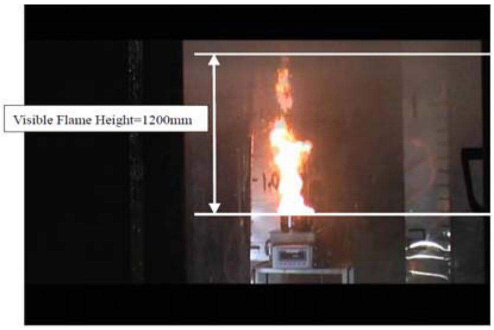
Fig. 16. Smoke layer clear height of (a) 1.7m and (b) 1.6m

4.2. Flame Height

The visible flame height is defined as the flame that arises which can clearly be observed by the human eye. This was recorded by the digital camera in the experiments. According to the record of digital video camera, the flame height was approximate from 0.8m, to 1.2 m as shown in Fig 17 (a) (b) and (c).

(a)





(c)

Fig. 17. Visible flame height was approximately (a) 0.8m (b) 1.0m and (c) 1.2m

5. Conclusion and Experimental Analysis

In the experiments, the following items were observed. It included flame height, smoke layer clear height, time to ignition, cooking oil surface temperature at ignition, cookware temperature and the operation of induction cooker. The experimental results showed that flame height can reach up to of 1.2 m as shown in Fig 17(c). In case of the presence of any inflammable materials at 1 m above the induction cooker, direct flame impingement would be expected and the inflammable materials will be easily ignited.

The smoke has filled – up the fire chamber before the fire started. Although this was recorded by the video camera, it was also difficult to record the actual smoke layer height. The time to ignition was subjected to the quantity of oil in the cookware. In case of small fuel quantity, the time to ignition might be faster. For example, in the experimental result, the time to ignition in 30 mL is 232 sec. The cooking oil surface temperature at ignition might also change subjected to the quantity of oil in the cookware.

When the quantity of fuel increased, the cooking oil surface temperature at ignition also increased, clearly for the 50, 70 and 110 mL peanut oil tests in the cookware. The time to ignition was 200, 214 and 270 second. However if 110 mL of peanut oil was used, the cooking oil surface temperature at ignition increased from 381 to 401.3^{o}C. This indicated that with more fuel quantity, the cooking oil surface temperature at ignition increased slightly. Based on the experimental result, the cookware temperature change was subjected to the heat transfer from the inside of the cookware to the outside surface of the cookware. The record of the cookware surface temperature has a maximum of 551.7 ^{o}C for 110 mL peanut oil and 322.8 ^{o}C for 70 mL peanut oil. The induction cooker safety device did not operate until the oil temperature reached 500 ^{o}C with 110 mL peanut oil experiment.

The operation of induction cooker continued to operate after the fire started during each experiment. The safety devices did not turn off the induction cooker in all cases. This may be due to the improper selection of cookware that did not trigger the operation of safety devices. The operation mechanism of the induction cooker safety device mainly depends on the heat transfer between the heated cookware and ceramic plate of the induction cooker. If the contact between the cookware bottom surface and the ceramic plate is poor, the heat transfer efficiency is reduced. Thus, the safety device is not triggered.

After the study, it is found that induction cooker fire hazard cannot be prevented by the safety devices provided. Overheating the fat and oil will also lead to fire hazard. The fire hazard is subjected to the quantity of fuel oil, fuel oil type, selection of cookware and the induction cooker. Improper use of induction cooker by the user will certainly leads to kitchen fire hazard.

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