REPORT of RESEARCH on DETECTION of KITCHEN FIRE

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and

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EXECUTIVE SUMMARY

This report speaks of the enthusiasm for the safety of 'homes' in the States. Studying the previous trends of Household Fires, Kitchen Fire has played a dominant part in deaths and injuries occurring from fire over the last 25 years.

The report is an attempt to study the nature of a normal cooking fire, mostly resulting due to unattended cooking. The report also deals with designing a reliable detection system that can detect the possibility of fire before it actually occurs because “the best way to stop a fire is not to have it at all”. Hence in the research carried out here, we have focused on the detection of Cooktop Fire and alarming / alerting the household dwellers before the fire takes an uncontrollable form

Three oils namely, Canola, Corn and Peanut have been used for the experimental study for detection of Cooktop Fire. The experiments involved temperature and smoke measurements. The five thermocouples employed measured the temperatures of the electronic cooktop coil, oil in the pan, six inches above the pan and 3 feet above the pan. An additional thermocouple was utilized to measure the spread-ability of the temperature due to the fire at 3 feet, 1 feet from the pan center. Total smoke amount and its Optical density were also measured for more refinement of the results and better understanding of the phenomenon. Different volumes of oils were experimented with and the graphs were drawn to make a comparative study.

The data acquired, through per second electronic data accumulator were analyzed both tabular-ly and graphically before and after the Ignition Point in the oils. Moving average graphs were also studied for the noisy data. The conclusions drawn from the results were then detailed out and made into a "Logic Gate Matrix", where the inputs were two predicted conditions for possible fire and the output was the predicted time of Ignition Time.

The research here is an initial step towards building safer cooktops for USA households where this report can be carried out for further studies and experiments not only for different oils and different cooktops but also under different conditions.

INTRODUCTION

Let’s retard Fire! History has imaged Fire as a demon, a destructor. However, the benefits of Fire can also not be overlooked. Here, we face a challenge to exploit the best of Fire and in comes the word ‘safety’.

Simply put there is an accident caused by Fire when it is not required. It now becomes important to extinguish this unwanted Fire even before it is born. And we propose a detection model. This Detection Model will help keep the Fire restrained to its domain of useful range and thereby prevent Fire Accidents.

Let’s play safe!

This report focuses on the Residential Fires, which originates mostly in the Kitchen. This report will discuss the origination of Kitchen Fire and will then analyze the experimental results obtained.

We hereby present and discuss our views on the experimental observations, technical gaps, and possible new models. This paper talks about our research, perspectives, ideas and our enthusiasm for our safe future.

History of Kitchen Fire

Cooking is, and has long been, the leading cause of home structure fires and civilian home fire injuries. This is true for both fires reported to fire departments and those handled without fire department assistance. During the four-year period of 2003-2006, U.S. fire departments responded to an estimated average of 150,200 home structure fires in which cooking equipment was involved in the ignition or in which the fire department used an incident type that identified a cooking fire that did not spread beyond the cooking vessel. These fires caused an average of 500 civilian deaths, 4,660 reported civilian fire injuries, and $756 million in direct property damage. Overall, these incidents accounted for 40% of all reported home fires, 17% of home fire deaths, 36% of home civilian injuries, and 12% of the direct property damage resulting from home fires. These statistics are estimates derived from Version 5.0 of the U.S. Fire Administration's National Fire Incident Reporting System and NFPA's annual fire depart[1]ment experience survey. The number of reported home fires involving cooking equipment hit a new high in 2006. These fires have increased fairly steadily as NFIRS 5.0 became widely used. Because it is so much easier to document these "confined fires," it is hard to tell how much of the increase is due to changes in the data collections system. The 1980-1983 annual average for cooking fire deaths was 500, the same average seen in 2003-2006.

Some of the recent kitchen fires include the famous "Truckee" fire incident where the fire sent off a blast that killed 27-year-old Isela Minutti and sent the 30-year-old man to the hospital with severe burns. Three children also were injured.

The blast tore through the ground floor of the two-story apartment, blowing out windows and causing "considerable damage. Investigations suggested that gas leak was the cause for the explosion after the kitchen was set ablaze by flash in the frying pan while cooking. The location of the Truckeee fire incident in shown in Figure 1 :

Figure 1 – Location of Truckee Kitchen Fire Incident

[1] Source www.truckeefire.org
October 2004,tropical fire research series ,volume 4-issue 4,FEMA

Some other major kitchen fires include:

- April 2004: A fire started by unattended cooking that resulted in severe damage to a house in Goldsboro, NC. A 13-year old boy put food on the stove to cook, then, left the home. He returned later to find the house on fire.
- February 2005: In Randolph, VT, a resident of a 48-unit apartment building left food on the stove to cook while he left his apartment for a short time. The fire was extinguished, but one whole floor was filled with smoke. There were no injuries.
- May 2005: Cooking oil left to heat unattended on a stovetop caused a lethal fire in Syracuse, NY. A three-year-old child perished in the blaze.

Incidents, such as these have made it very necessary for research and development of better technologies to reduce or eliminate these fire incidents that cause injuries, deaths and property loss.

Kitchen Fire Statistics

The report on home structure fires by Marty Aherns (March 2010) national fire states that

- Four of every ten reported home fires were cooking fires.
- One of every 22 occupied households had a cooking fire. They found that cooking equipment was involved in roughly two-thirds of home fire incidents,
- Cooking equipment was the leading cause of home fires and home fire injuries, the third leading cause of home fire deaths, and the second leading cause of direct property damage resulting from fire.
- Human error was a factor in many of these fires.
- Unattended equipment was a contributing factor in roughly one-third of the cooking fires reported in 2003-2006.
- Ranges or cooktops were involved in more than half of all fires involving cooking equipment and 23% of all reported home fires.

Figure 2, Table1, Table 2 depict in detail the major findings of the report.[2]

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[2] Home structure fires, Marty Ahrens ,march 2010
home fires involving cooking equipment, November 2009

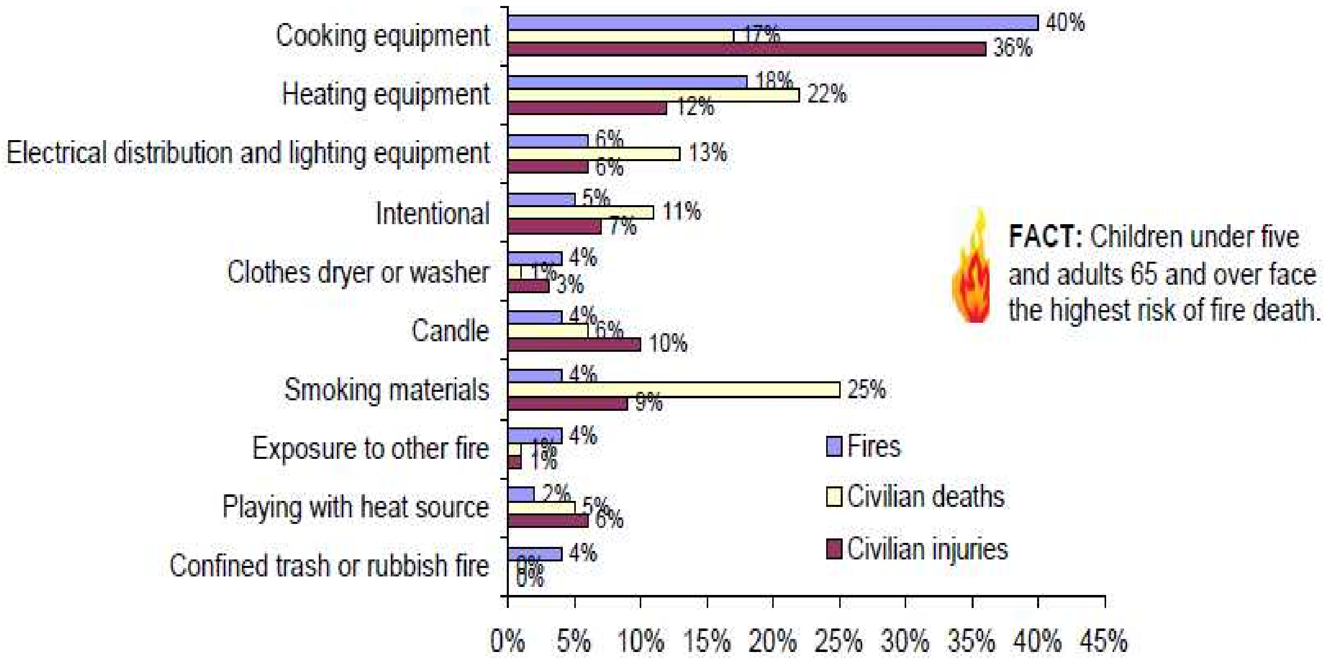


Figure 2 *(NFPA2009)*

Figure 2 *(NFPA2009)* shows that kitchen fire due to cooking equipment is the major cause of deaths and injuries. Also the no. of deaths occurring due to smoking materials is very alarming.

Table 1 shows in detail the number of fire incidents and their losses every year.

Home Fires Involving Cooking Equipment, by Year
Structure Fires Reported to U.S. Fire Departments

Year	Fires		Civilian Deaths		Civilian Injuries		Direct Property Damage (in Millions) as Reported		Direct Property Damage (in Millions) In 2006 Dollars
1980	148,300		500		5,030		$245		$600
1981	153,500		530		5,090		$766		$1,696
1982	136,500		500		5,540		$422		$881
1983	125,200		470		5,610		$343		$694
1984	124,100		480		4,910		$372		$721
1985	127,500		450		4,870		$350		$655
1986	127,700		510		5,010		$398		$733
1987	125,100		410		5,500		$397		$704
1988	126,700		470		5,870		$461		$786
1989	119,800		480		5,480		$451		$734
1990	120,500		440		6,050		$476		$735
1991	122,100		360		6,060		$621*		$919*
1992	130,300		350		6,010		$451		$648
1993	128,400		430		6,530		$548		$765
1994	118,200		370		5,500		$618		$841
1995	111,700		370		5,390		$446		$590
1996	115,200		470		5,490		$519		$668
1997	117,500		380		5,760		$565		$710
1998	109,100		500		5,380		$527		$652
1999	85,800	(37,200)	310	(310)	2,620	(1,670)	$504	($475)	$610
2000	95,700	(34,600)	240	(240)	3,750	(2,470)	$517	($475)	$606
2001	120,900	(38,600)	510	(510)	4,490	(2,960)	$534	($511)	$608
2002	128,500	(38,000)	150	(150)	4,300	(2,910)	$673	($645)	$754
2003	143,800	(35,900)	540	(530)	4,510	(3,060)	$771	($739)	$846
2004	151,500	(36,500)	630	(620)	4,820	(3,290)	$732	($706)	$782
2005	147,300	(38,000)	500	(480)	4,740	(3,300)	$869	($836)	$897
2006	160,100	(40,700)	360	(360)	4,600	(3,150)	$698	($676)	$698

[3]

Table 1: *(Home Fires involving cooking equipment- Marty Ahrens)*

[3] Home structure fires, Marty Ahrens ,march 2010
home fires involving cooking equipment, November 2009

Home Fires Involving Cooking Equipment, by Human Factor Contributing to Ignition
Annual Average of 2003-2006 Structure Fires Reported to U.S. Fire Departments
(Excluding Fires Reported as Confined Fires)

Human Factor	Fires		Civilian Deaths		Civilian Injuries		Direct Property Damage (in Millions)	
Unattended or unsupervised person	7,000	(19%)	100	(21%)	650	(20%)	$164	(23%)
Asleep	2,300	(6%)	110	(23%)	290	(9%)	$61	(8%)
Age was a factor	900	(2%)	90	(19%)	140	(4%)	$23	(3%)
Possibly impaired by alcohol or drugs	600	(2%)	60	(13%)	140	(4%)	$21	(3%)
Possibly mentally disabled	300	(1%)	20	(4%)	50	(2%)	$6	(1%)
Multiple persons involved	200	(1%)	20	(4%)	20	(1%)	$9	(1%)
Physically disabled	200	(0%)	20	(4%)	30	(1%)	$3	(0%)
None	26,600	(71%)	170	(34%)	2,030	(64%)	$474	(65%)
Total	37,200	(100%)	490	(100%)	3,190	(100%)	$728	(100%)
Total entries	38,200	(102%)	590	(121%)	3,350	(105%)	$761	(105%)

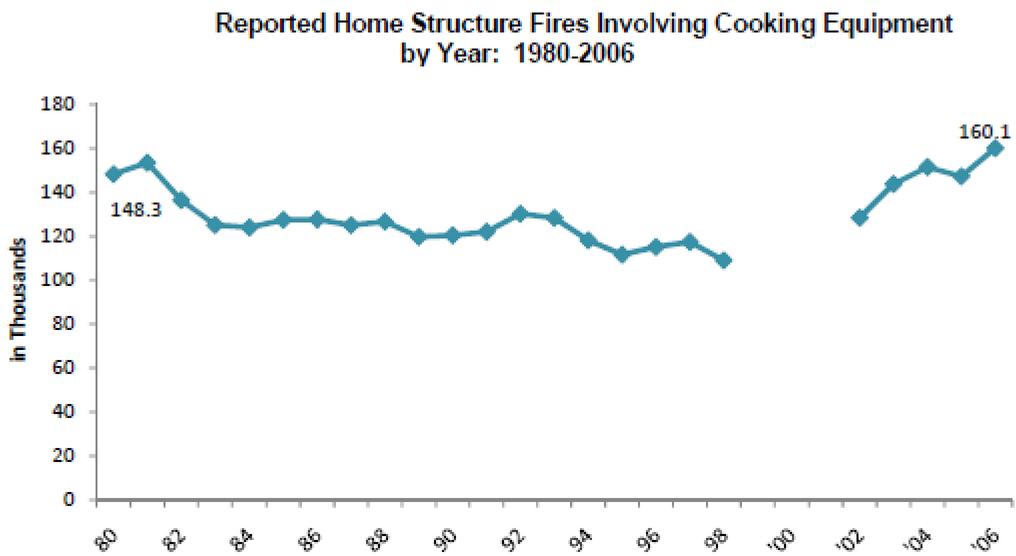
Note: Multiple entries are allowed, resulting in more factor entries than fires. Sums may not equal totals due to rounding errors. Unknowns have been allocated proportionally.

[4]

Table 2: *(unattended fire / human cause) NFIRS Version 5.0 and NFPA*

[4] Home structure fires, Marty Ahrens ,march 2010
home fires involving cooking equipment, November 2009

- **Cooking Equipment Fire plays a major part in Residential Fire :**



[5]

Figure 3 *(Home Fires involving cooking equipment- Marty Ahrens)*

The data depicted in Figure 3 *(Home Fires involving cooking equipment- Marty Ahrens)* was obtained from NFIRS and NFPA Survey. Estimates for 1999-2006 are based on NFIRS 5.0 data and include all fires with the confined cooking fire incident type. Marty Aherns mentioned this graph in her November 2009 report of home fires involving cooking equipment which she did for NFPA.

From ***Figure 3 (Home Fires involving cooking*** equipment- ***Marty*** *Ahrens)* we observe that Fires due to cooking equipment were somewhat stable up to 1998, but from 2002 they are constantly on rise.

- **Deaths due to Cooking Equipment Fire :**

[5] Home structure fires, Marty Ahrens ,march 2010
home fires involving cooking equipment, November 2009

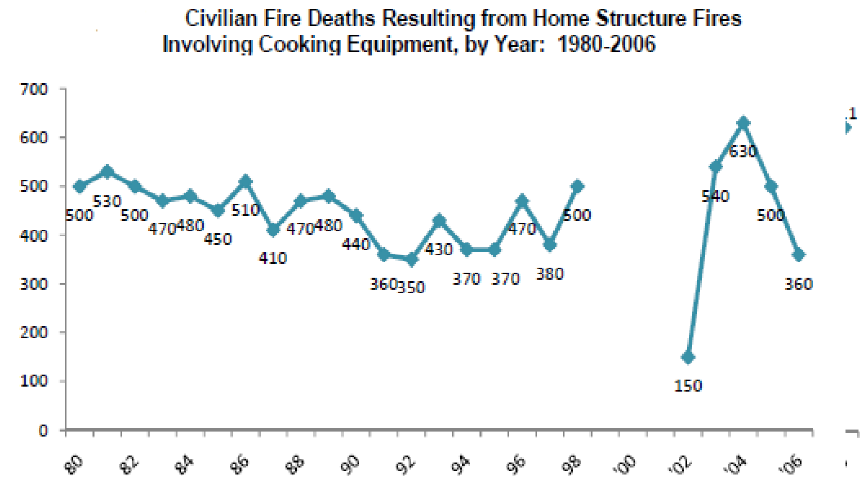


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Figure 4 *(Home Fires involving cooking equipment- Marty Ahrens)*

From Figure 4 *(Home Fires involving cooking equipment- Marty Ahrens)*Figure 4 *(Home Fires involving cooking equipment- Marty Ahrens)* it can be observed that the deaths due to cooking fire were almost stable by 1998, however in the next decade they touched their all- time high..

- **Injuries due to Cooking Equipment Fire :**

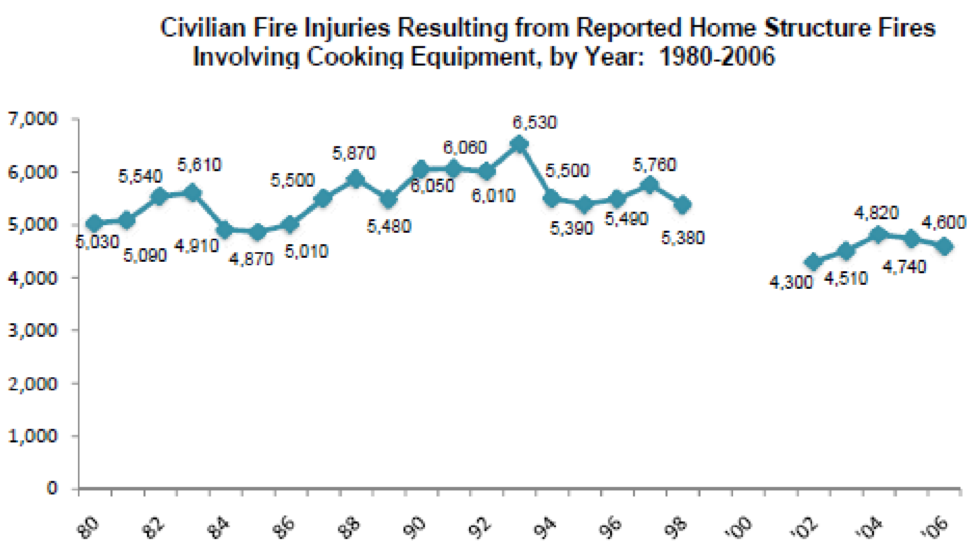

Figure 5 *(Home Fires involving cooking equipment- Marty Ahrens)*

[6] [6] Home structure fires, Marty Ahrens ,march 2010
home fires involving cooking equipment, November 2009

From Figure 5 *(Home Fires involving cooking equipment- Marty Ahrens)* it can be observed that the injuries due to cooking fires have always been almost same throughout the years with a slight reduction from 2002.

[7]

Logistics behind Kitchen Fire

Kitchen Fire is always dangerous if not detected at an early stage. There are two major factors contributing to the magnitude of the Kitchen Fire :

- Presence of continuous supply of Fuel
- Presence of combustible material

Oxygen has not been mentioned since it is already available during cooking, t cannot be used as a factor for detecting.

Again, this needs to be repeated that in most of the cases it is the unwanted Fire or in simple terms, the unattended Fire that leads to damage. The amount of Property and Life damage caused by such breakout of Fire in a household can only be imagined. (*Refer to the stats above*)

The fire event during cooking is anticipated due to elevation of cooking oil temperature beyond the “Ignition Temperature”. It is also anticipated that the “Amount of Smoke” may increase significantly as the oil temperature is increased.

Henceforth, this experiment and its analysis will focus on monitoring these factors contributing to the detection of Kitchen Fire, understanding their behavior at the Ignition Point and discussing possible indication methods before the Ignition Point is reached.

[7] Home structure fires, Marty Ahrens ,march 2010
home fires involving cooking equipment, November 2009

Previous Research

[8]

In the mid-1990's, the CPSC began investigated cooking related fires associated with electric and gas range. Over the next several years various cooking fire projects were initiated by CPSC, with some of work conducted by the National Institute of Standards and Technology (NIST). The work was divided into three phases, with NIST performing the first two phases, and CPSC the third. The first phase consisted of 22 experiments using electric (both open coil and smooth top) and gas ranges. The 22 experiments consisted of ignition test with following food groups: soybean oil, bacon and table sugar. Cooking utensils also were studied, including differences between pot and pan materials. Throughout the tests it was found that the best parameters for determining pre ignition were temperature, smoke particulates and hydrocarbon gases. Another aspect of this phase of NIST's work included was a literature and patent search on existing and potential devices, and systems or methods capable of detecting the previously determined pre-ignition conditions. Thermocouples were deemed the most promising technology for determining pre-ignition temperature. For detecting smoke particles, scattering or attenuation types of photoelectric devices were considered the best. Tin oxide and narrow-band infrared absorption sensors were found to be the best form of technology for detecting hydrocarbon gases.

During the next phases a lot of emphasis was laid on studying pan contact temperatures to develop it as an effective means of detecting fire prone conditions. Also cooktop sensors were designed and experiments were conducted on cooktops with these sensors, findings showed them as a reliable method of dealing with unattended cooking fires.

Despite the six years of work performed by CPSC on researching and developing technology that will mitigate cooking fires, the US appliance manufacturers were still deeply concerned about the potential impact on cooking performance, operability, reliability, durability, safety and manufacturability. For industry, reliability is a significant issue. A safety device needs to address all fire incidents that it is intended to address throughout the life of the appliance. Also, the device would need to shut off when it is unable to perform its safety task. In response to these claims by the US appliance manufacturers, CPSC and AHAM contracted with A. D. Little, Inc. (now tiax,Inc.) to conduct a study to evaluate the technical, practical and manufacturing feasibility of range cooktops modifications intended to address the mitigation of cooking fires. This study focused on surface cooking fires and surface cooking fire mitigation technologies.

[8] Sources report of research on cooking fires and pan contact sensor technology, August 13, 2003,UL Inc.

Importance of this Research

From the data that has been surveyed and shown below, a large loss of Residential Fire results from Kitchen Fire. They have been discussed briefly in the 'Introduction' section. Here, are some excerpts from a few reports highlighting the losses that have occurred due to kitchen fire hence proving how important it is to find out solutions to curb these losses.

SCOPE AND LIMITATIONS

The research paper is meant to suggest ideas for a detection system that can detect the possibility of a fire, so that the fire itself can be avoided from occurring. It is obvious that it is a very vast and detailed topic to be covered in a very short time interval of three weeks, therefore the focus has been only on covering some of the aspects of the cooking fires problem so that effective measures can be implemented for those aspects tackled and provide a platform for further research in the subject.

Keeping in mind the above constraints the research paper and the experiments will only deal with cooking fires resulting from the electric operated cooking appliance. Moreover, because of lack of time only boiling oil was used in the experiments. The experimental procedure may be considered as one of the cases of unattended cooking, however such an experiment is very different from a normal cooking procedure but it will help to realize the physical quantities that might be helpful in designing a detection system for kitchen fires.

The variables that can be sighted as an effective means to detect kitchen fires may be temperature and smoke detectors, hence using these two basic detection systems the research attempts to come up with a feasible solution for an early detection of kitchen fire.

Though the above experimental procedure is a lot useful in understanding the problem of kitchen fire, however have its own limitations:

- Only three types of oils are used in the experimental analysis, the nature of results are not known for other types of oils

- The oil used in experiments was left to heating till it completely burnt off, in actual practice oil is used to cook food items, such a setup might yield different results as from the one used above
- Only electric heating equipment was used throughout the experiments, again the results will vary for gas operated cooking appliance which have a greater heat release rate as compared to the electric operated cooking equipment.
- All the tests were performed in open laboratory conditions, which are very different from the physical conditions present in a normal kitchen.

OBJECTIVE

Identify cooking conditions that have the potential to lead to a fire event.

TEST PLAN

The Test Plan included the following elements:

1. Design of the Experiment and Instrumentation.
2. Selection of Cooking Oils.
3. Development of Data.
4. Analysis of Data and Discussions.
5. Conclusions and Recommendations.

DESIGN of EXPERIMENT and INSTRUMENTATION

From the knowledge of basic sciences it is known that a fire is preceded by an increase in temperature, in addition to this oil(test sample) first starts to develop smoke(at the smoke point).the instruments used in testing, keeping in mind these two facts the instruments were chosen for the experiment

Firstly there were 5 thermocouples used to measure changes in temperature throughout the experiment, the positions of the thermocouples are clearly marked in the following figure.

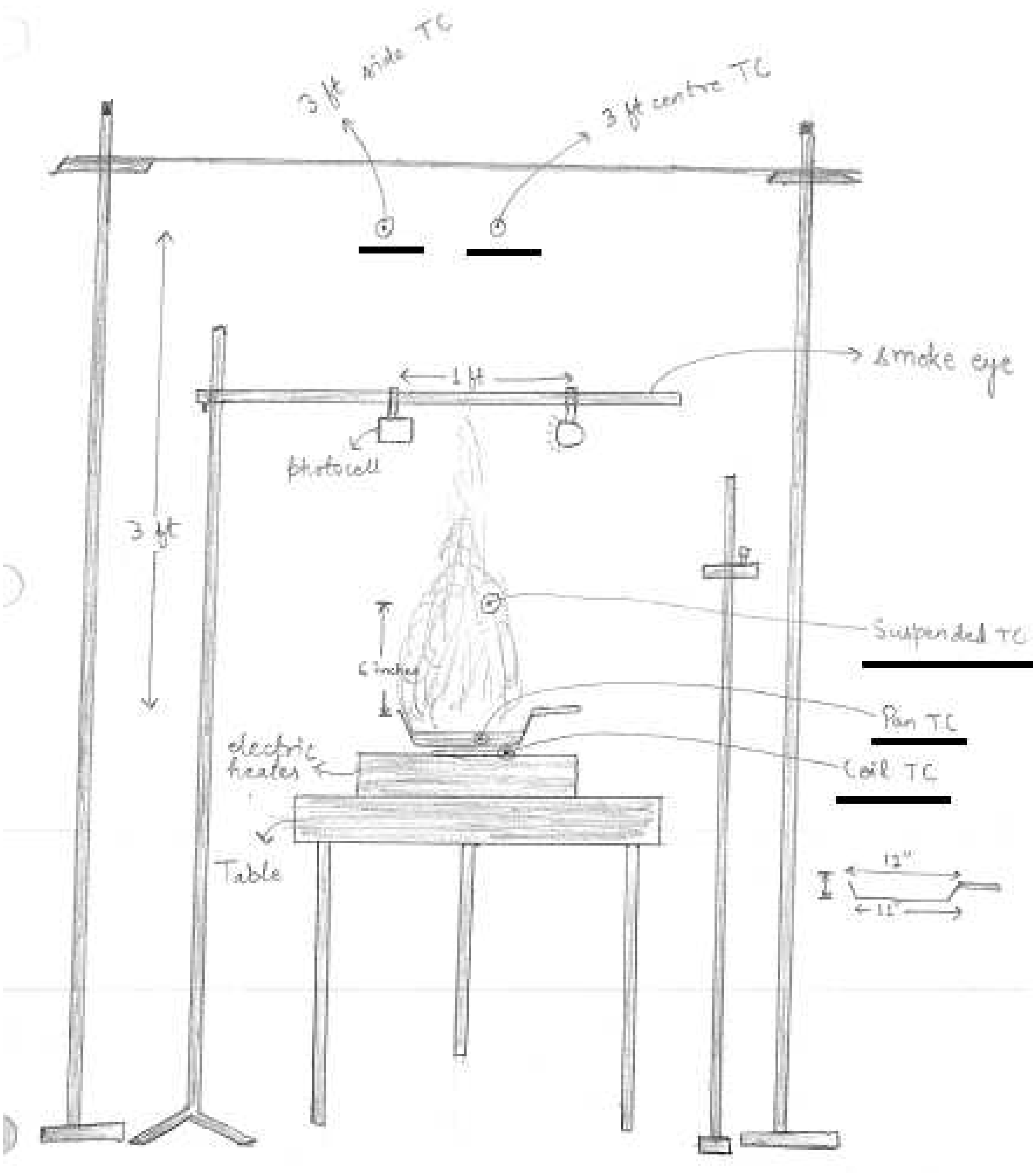

Figure 6 : Position of Thermocouples

In Figure 6 : , K - type thermocouples of 1.5mm diameter are used in the experiment. These thermocouples were connected to the data acquisition system of Cell D lab of Underwriters' laboratories Inc. In addition to this a smoke detector was placed over the cooking appliance at a height of 0.59 meter. The objective was to analyze the amount of smoke at different times during the experiment.

Apart from these the instruments such as smoke analyzer, CO_2 and CO analyzer, HRR measuring instrument, duct pressure gauge which were already installed in the data acquisition system were also used.

All the data obtained from these instruments as well as from the thermocouples and smoke detector at 0.59 meter, was fed into the data acquisition system of Cell D, NEBS.

The complete experiment was recorded using two fixed cameras and one moving camera in some instances.

SELECTION OF OILS

Table 1: Oil Types and Properties

Oil Type	Smoke Point (*Celsius*)	Flash Point (*Celsius*)
Canola Oil	242	290 - 330
Corn Oil	236	310 - 339
Peanut Oil	231	282 - 320

DEVELPOMENT OF DATA

As stated the main objective of this study is to design an effective fire detection system for the households of United States of America. Therefore, it was necessary while carrying out experiments to keep in mind the feasible implementation of all the techniques that are used to detect a kitchen fire

The experimental setup is shown in the Figure 7: Sketch of the Experimental Setup:

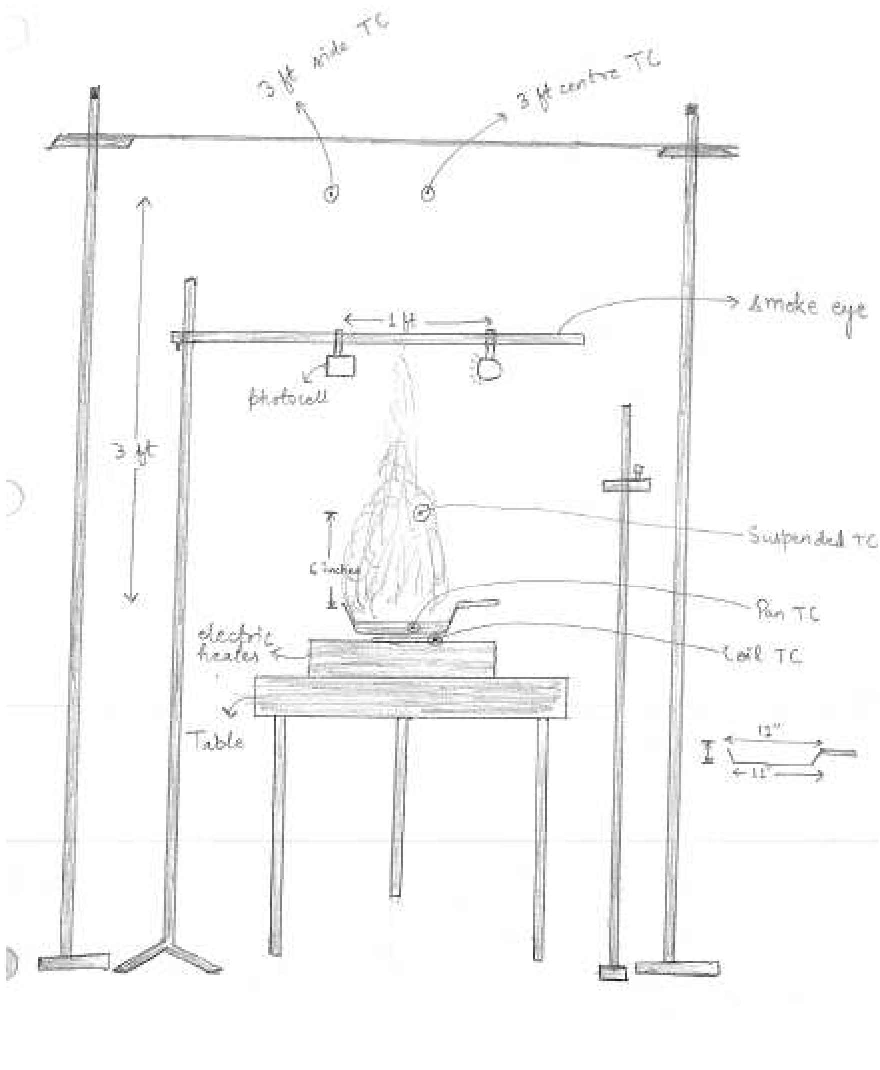

Figure 7: Sketch of the Experimental Setup

In Figure 7: Sketch of the Experimental Setup, a pan made out of cast iron of dimensions (lower diameter = 11”, outer diameter = 12” and depth = 2.5”) was filled with different quantities of oil(1",0.5",0.25") as well as different types of oil(canola, corn and peanut) and was heated with an electric operated cooking appliance of rating() up to its maximum power. The oil was heated till all the oil in the pan was completely burnt off.

The duct of the calorimeter was operated at 8m/s speed and used so as to capture all the combustible products once ignition occurred. This is quite high as compared to the exhaust ducts used over cooktops in USA households. The scan rate for analyzing the data by the data acquisition system was 1 second.

Figure 8: Photograph of the Experimental Setup

The observations included visible changes on the oil surface (appearance of smoke, boiling and occurrence of flash).

The above experimental procedure is very basic in its approach and implementation; however it is very important too considering that most of the kitchen fires happen due to unattended cooking (leading to prolonged heating of food items).

Safety Measures

While doing the experiments these precautionary measures were implemented for safety of personnel working in the laboratory and the apparatus used:

- The personnel working in the laboratory at all times wore safety glasses and shoes with a sealed toe. This should be put to practice without any exception
- Once the surface of oil ignites, it can cause melting of any plastic or soft parts present in the vicinity of the apparatus; therefore all such parts (such as the knob of cooking equipment) were covered with a heat resistant tape before the start of the experiment.
- The thermocouples used in the experiment were carefully placed and checked before the start of the experiment, if they are fixed by a tape, it were done by a heat resistant tape.
- The amount of oil used in the experiment was according to the depth of the cooking equipment used, or else the oil might start spilling over once it ignites.
- While resetting the experiment setup, experimental care was taken while handling the 'extremely hot' pan and it was not touched without putting on insulating gloves.

Figure 9: Safety Helmets

Figure 10: Safety Glasses

Figure 11: Safety Gloves

Figure 12: Cell D Laboratory

DATA ACQUISITION

Experimental Matrix

The measurements taken from the Experiments were:

Table 2

Oil	Quantity	Ignition Point	Coil TC	OD / length	Smoke Eye	Smoke Visibility	Experiment #
		Minutes	*Celsius*	*1/m*	*mV*	*Minutes*	*Cell D Database*
Canola	1.00"						
Canola	0.50"						
Canola	0.50"						
Canola	0.50"						
Corn	0.25"						
Corn	0.50"						
Corn	0.50"						
Corn	0.50"						
Peanut	0.25"						
Peanut	0.25"						
Peanut	0.50"						
Peanut	0.50"						

- Electronic Data Acquisition, using “Edge Computer Program”.
- The data was recorded at a rate of per second time basis using an electronic database machine.

Stages of Fire Growth: Pictorial Representation

Figure 13: Initiation of Smoke

Figure 14: Increase in Smoke with time

Figure 15: Smoke before Ignition

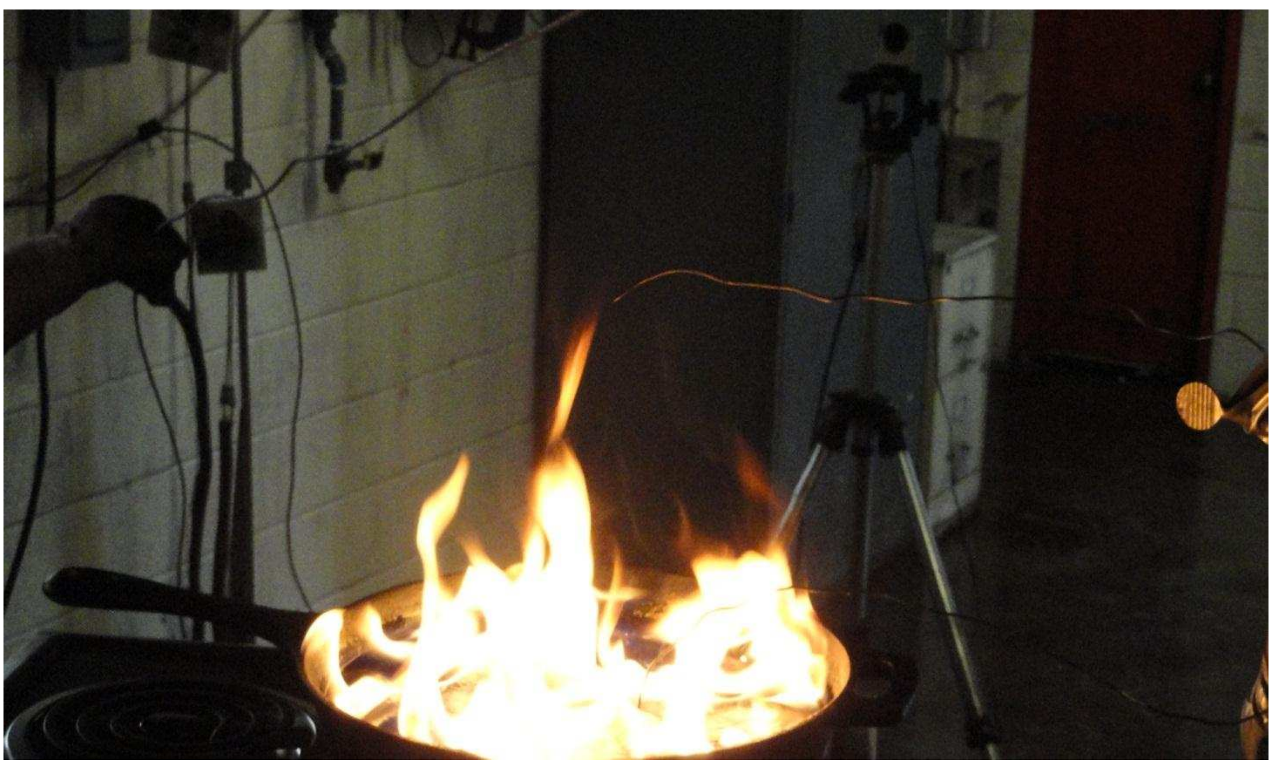

Figure 16: Initiation of Fire

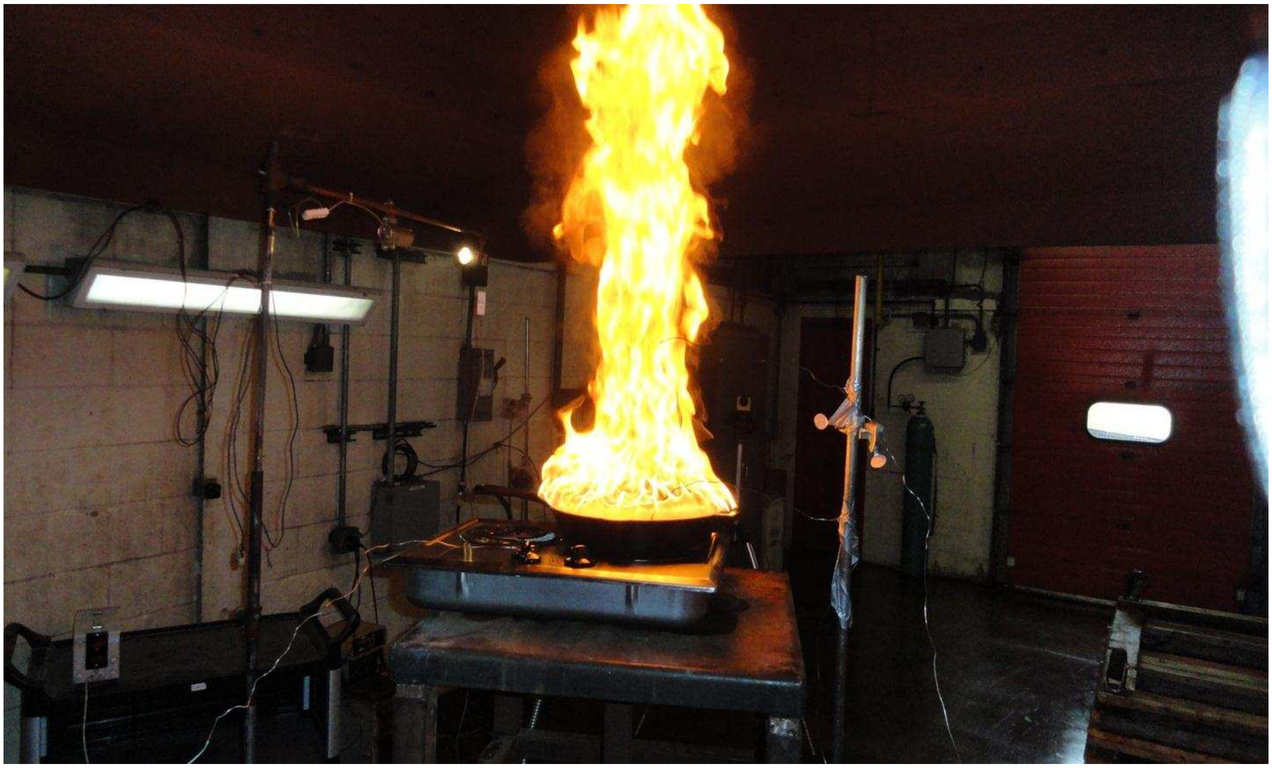

Figure 17: Full Fire Flame

Figure 18: Burnt out Pan

DATA ANALYSIS

Observation Matrix

Table 3: Observaton Matrix

Oil	Quantity	Ignition Point	Coil TC	OD / length	Smoke Eye	Smoke Visibility	Experiment #
		Minutes	*Celsius*	*1/m*	*mV*	*Minutes*	*UL Database*
Canola	1.00"	56:54:00	371	-2.26E-02	7.60E-02	15:48	#06231006
Canola	0.50"	34:42:00	357	0.226712	41.36177	11:44	#06241003
Canola	0.50"	36:28:00	355	0.315437	37.71059	11:40	#06241004
Canola	0.50"	38:40:00	332	0.119781	27.9341	11:32	#07021003
Corn	0.25"	24:05:00	339	0.041195	28.87313	6:04	#07011002
Corn	0.50"	35:54:00	354	0.128274	39.73438	11:31	#06251001
Corn	0.50"	39:31:00	352	0.093324	28.33612	11:40	#06251002
Corn	0.50"	36:54:00	323	0.244037	25.96899	10:20	#07011003
Peanut	0.25"	25:09:00	313	0.058164	28.90889	8:30	#07011005
Peanut	0.25"	24:02:00	342	0.043369	29.0383	8:18	#07021002
Peanut	0.50"	36:35:00	334	0.089553	27.18988	9:28	#07011004
Peanut	0.50"	38:04:00	325	0.348265	23.47298	9:46	#07021001

Graphical Analysis

Here graphs have been plotted for three different parameters:

1. Coil Temperature
2. Instantaneous smoke - Duct Smoke (the NEBS Cell D lab)
3. Smoke Eye – Instantaneous smoke measurement (additional Photocell used) – 15 second moving average graph
4. Optical Density per unit length (additional Photocell used)

In addition, same parameters for different oils have also been drawn for a comparative study.

Canola Oil

Legend				
Ignition Time ::	38:40:00	36:28:00	34:42:00	56:54:00

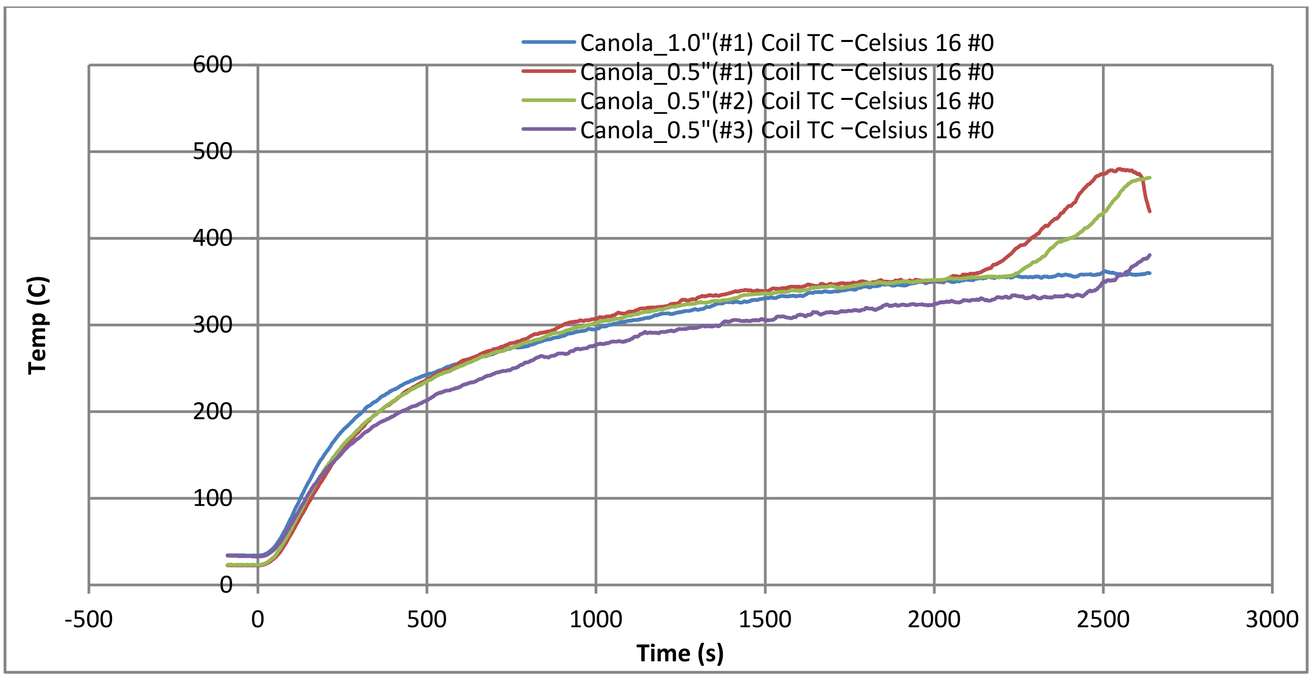

Figure 19: Graph 1.1

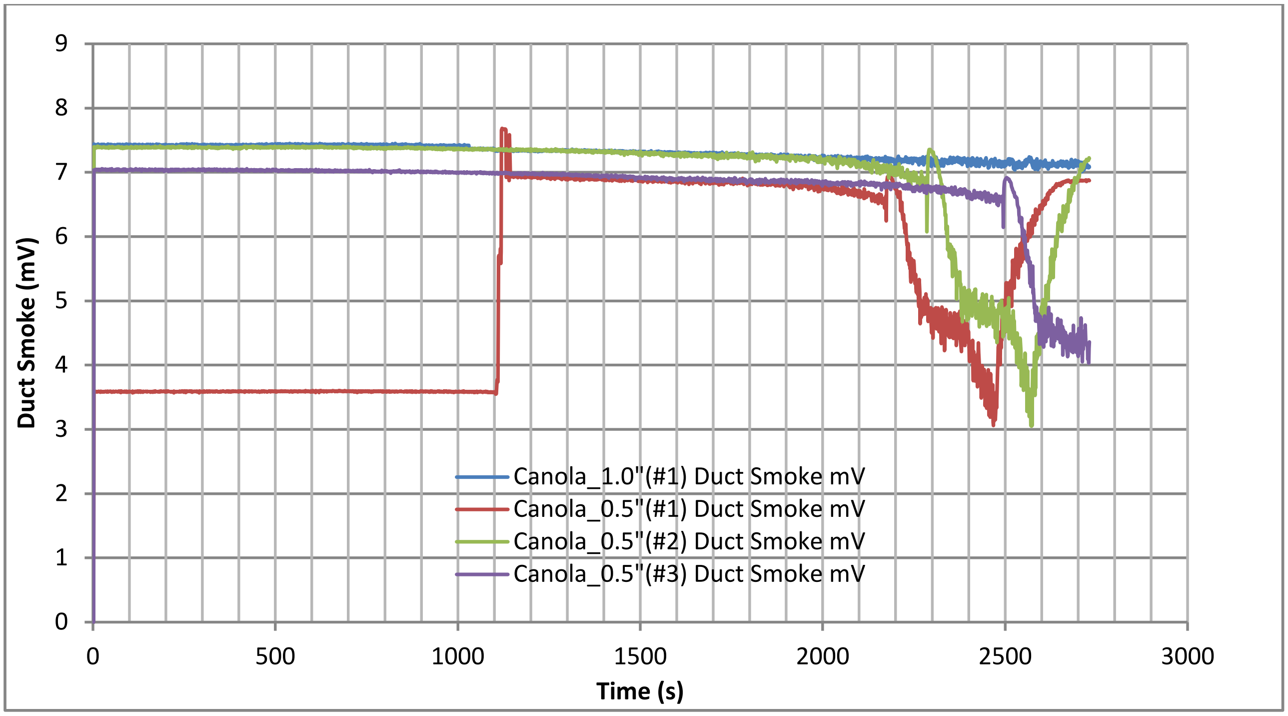

Figure 20: Graph 1.2

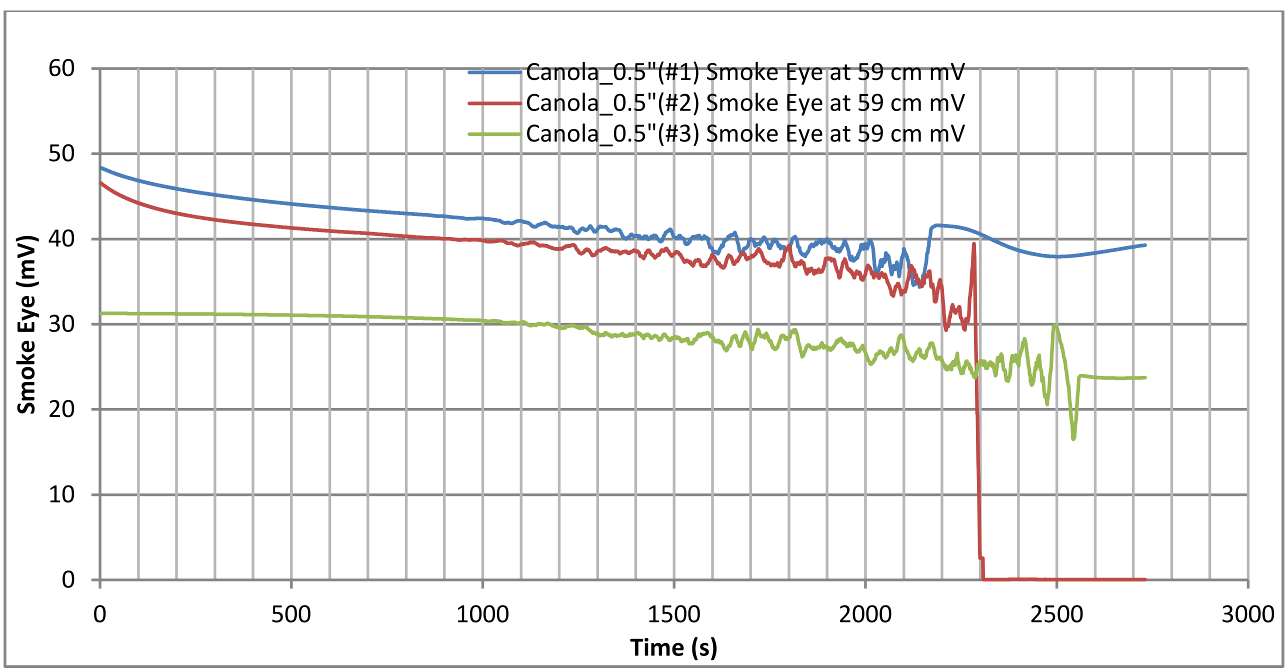

Figure 21: Graph 1.3

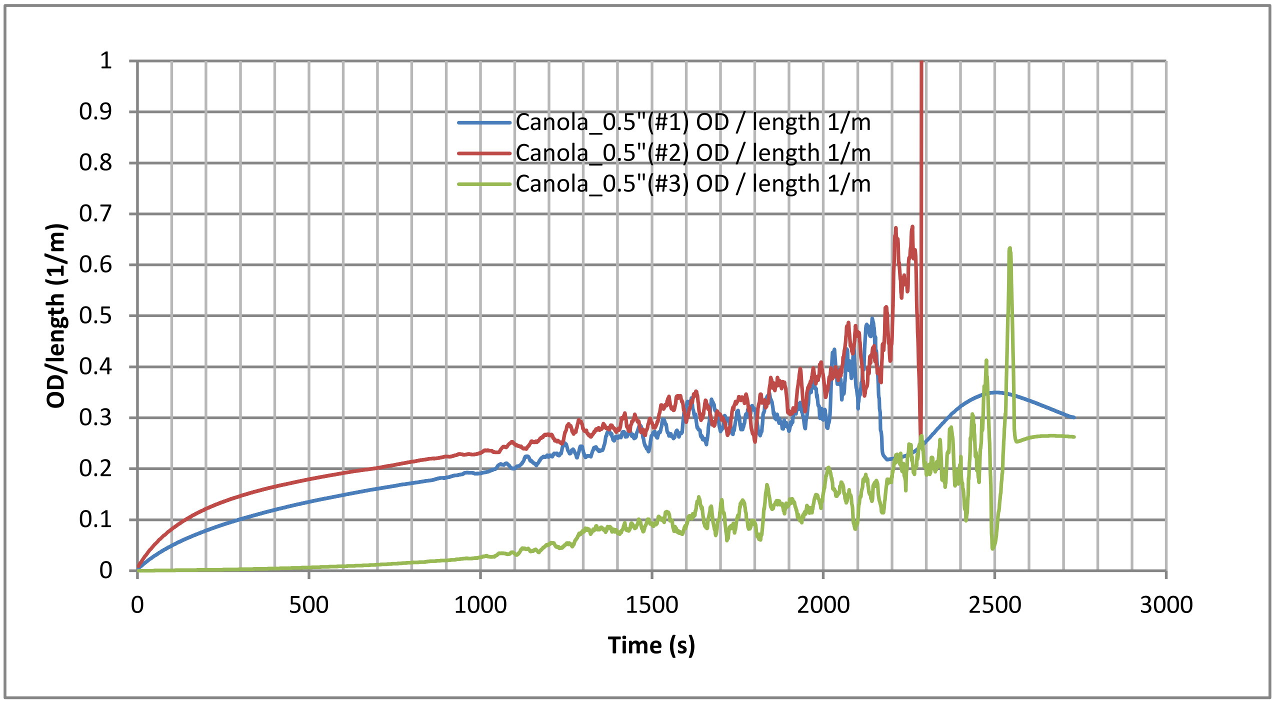

Figure 22: Graph 1.4

<u>Corn Oil</u>

Legend ::	purple	green	red	blue
Ignition Time ::	24:05:00	36:54:00	39:31:00	35:54:00

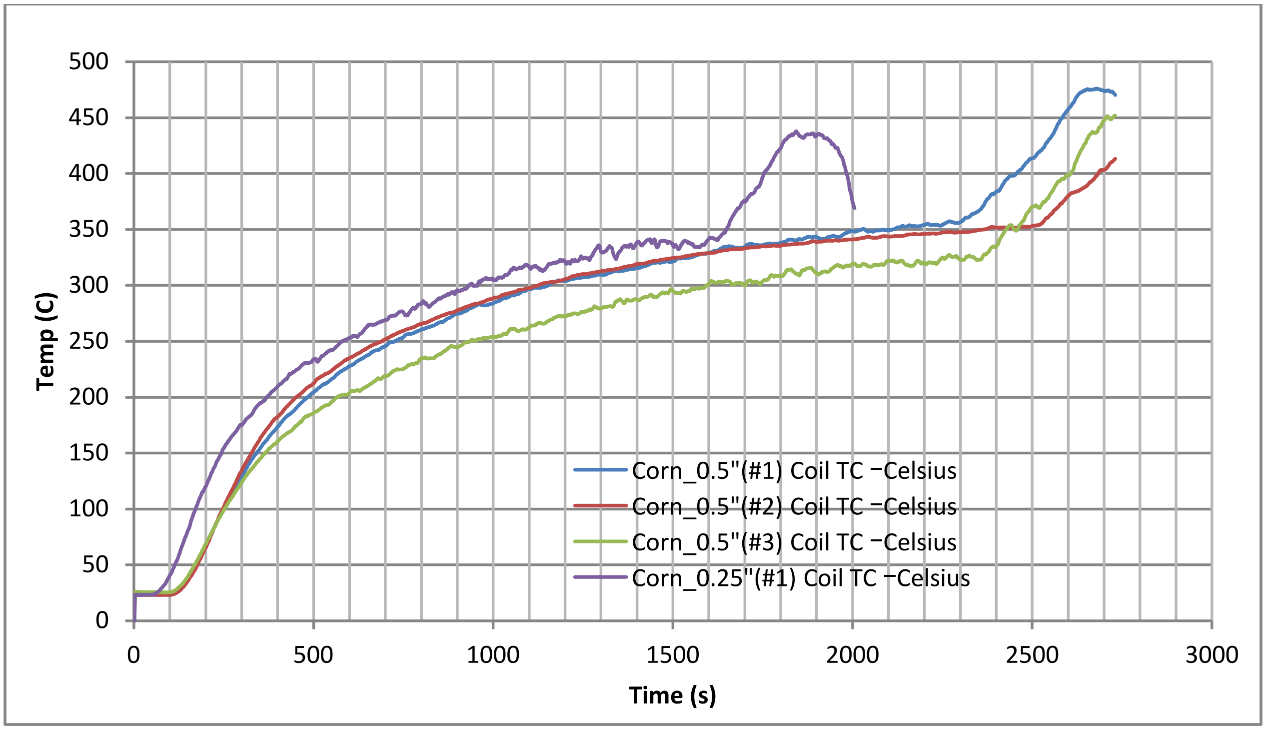

Figure 23: Graph 2.1

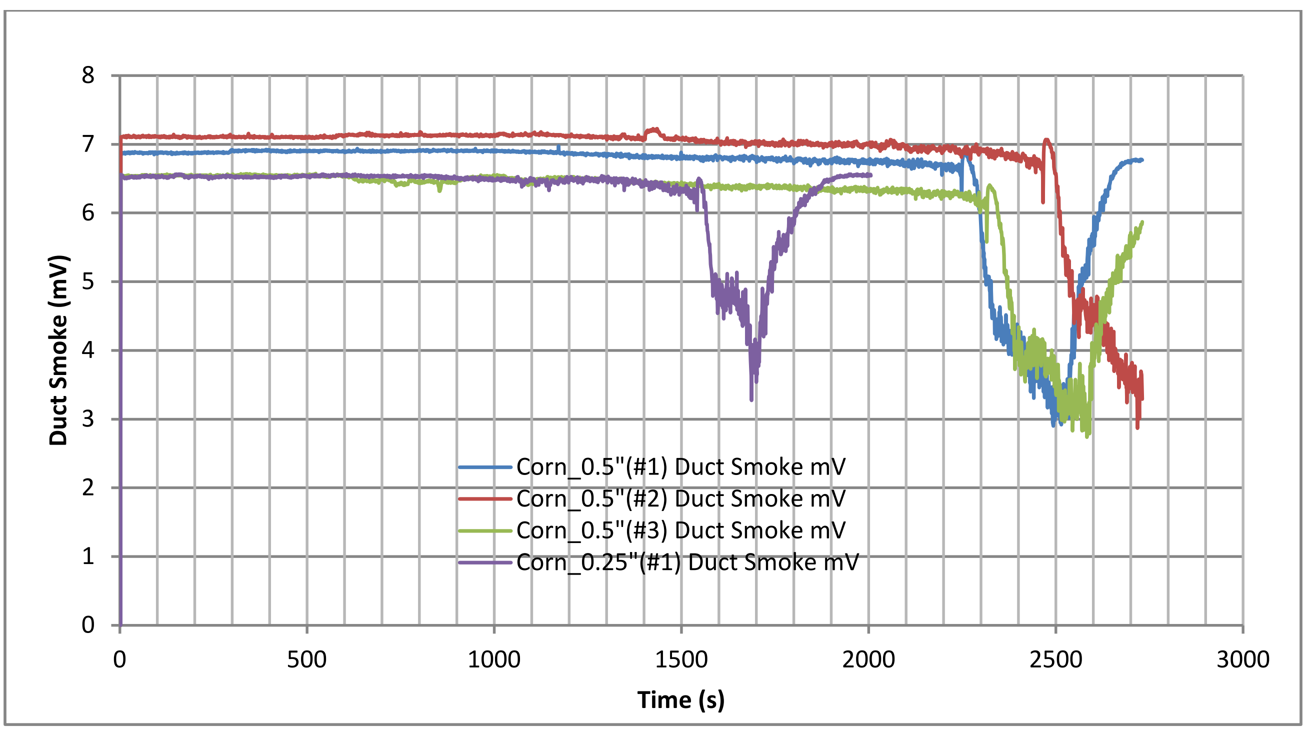

Figure 24: Graph 2.2

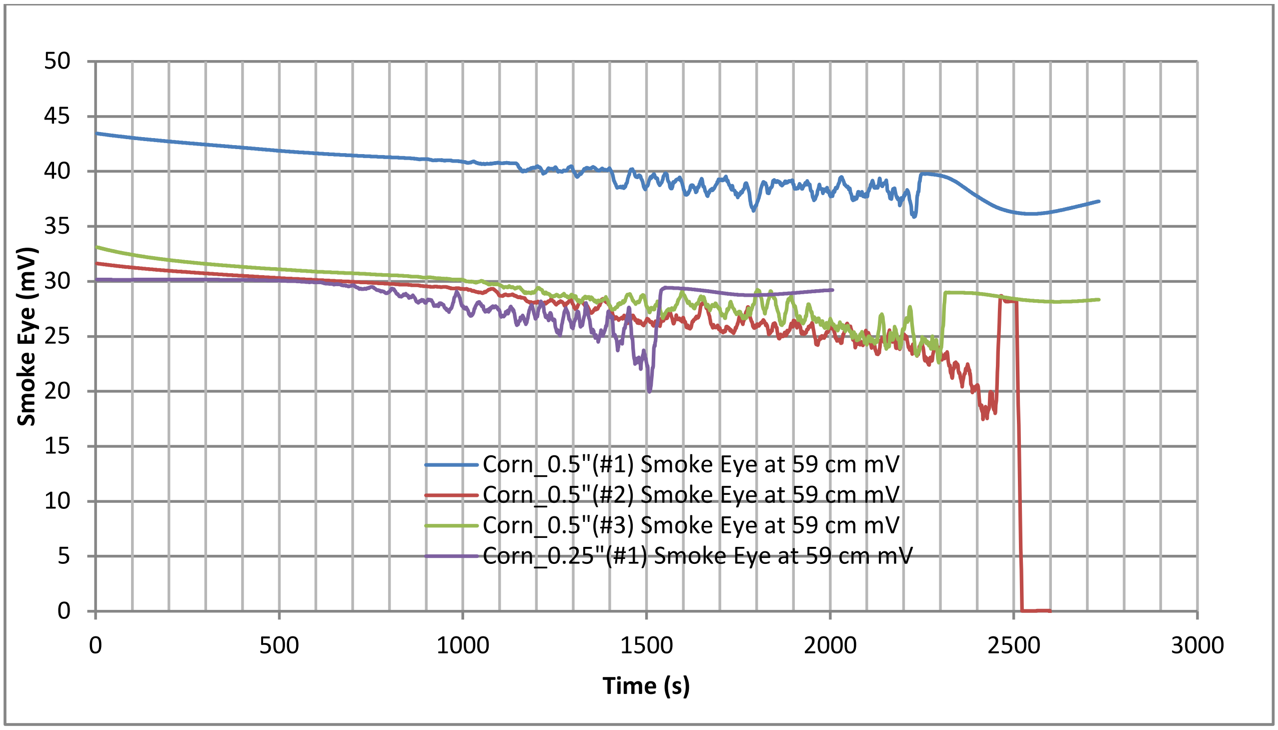

Figure 25: Graph 2.3

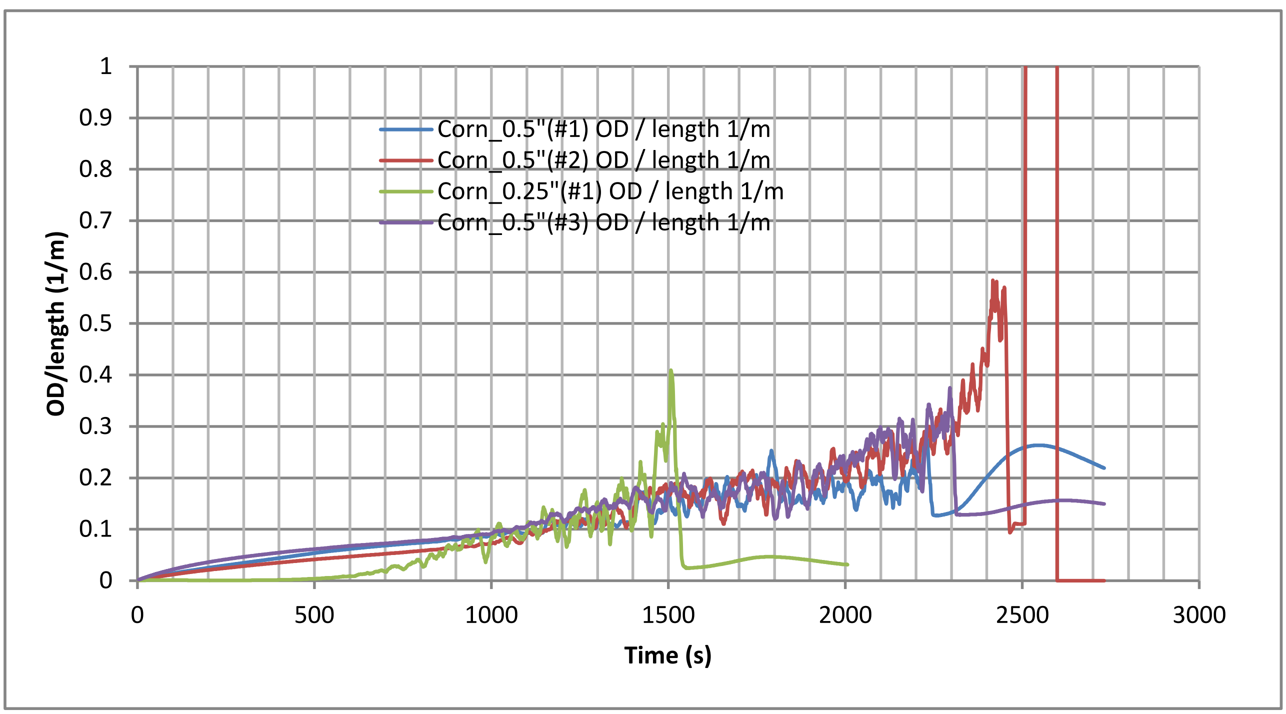

Figure 26: Graph 2.4

Peanut Oil

Legend ::

Ignition Time ::	24:02:00	25:09:00	38:04:00	36:35:00

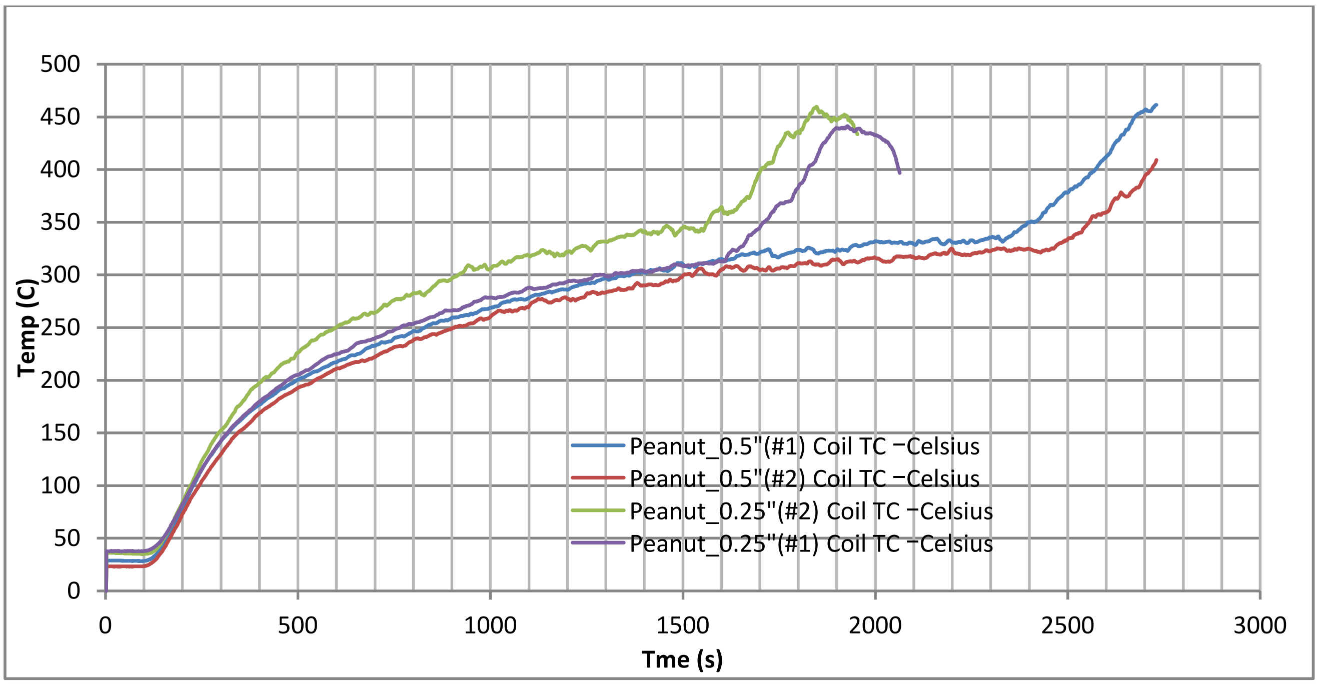

Figure 27: Graph 3.1

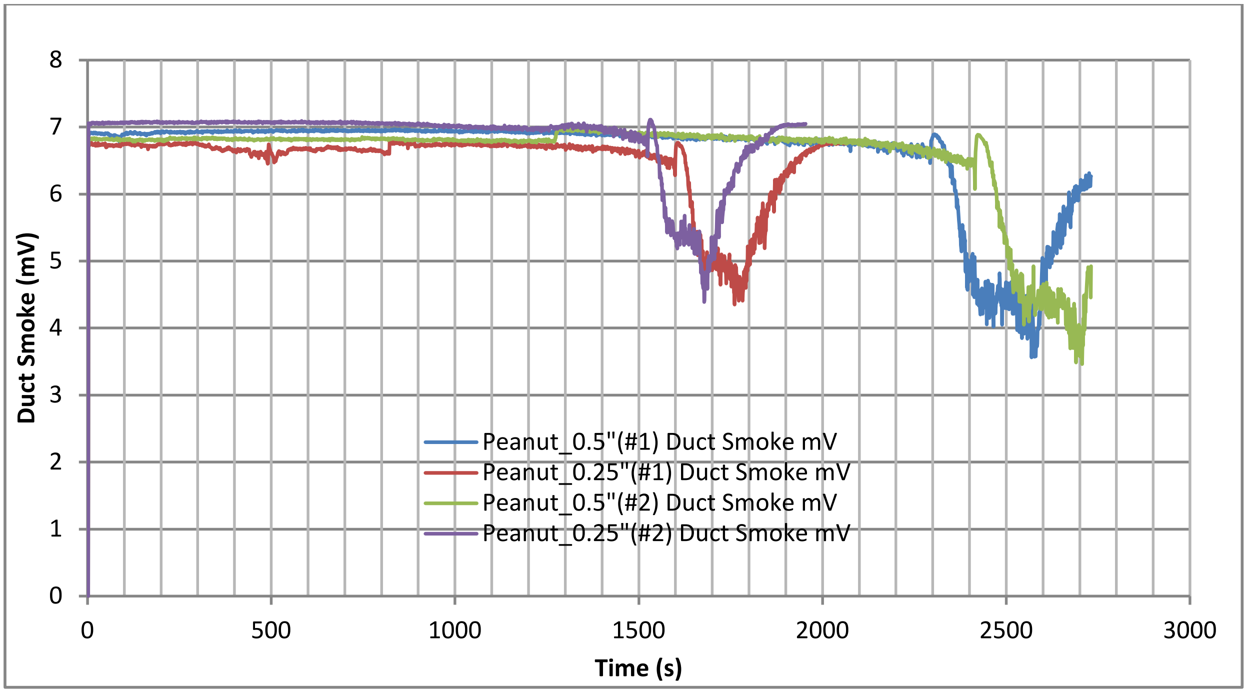

Figure 28: Graph 3.2

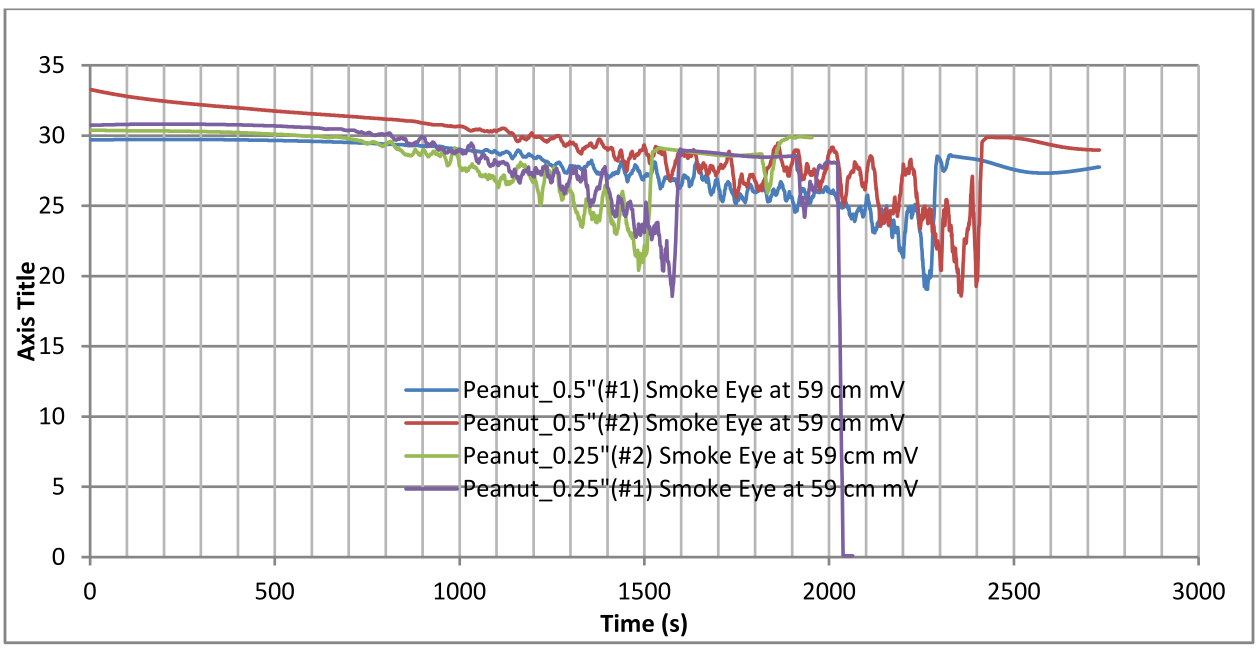

Figure 29: Graph 3.3

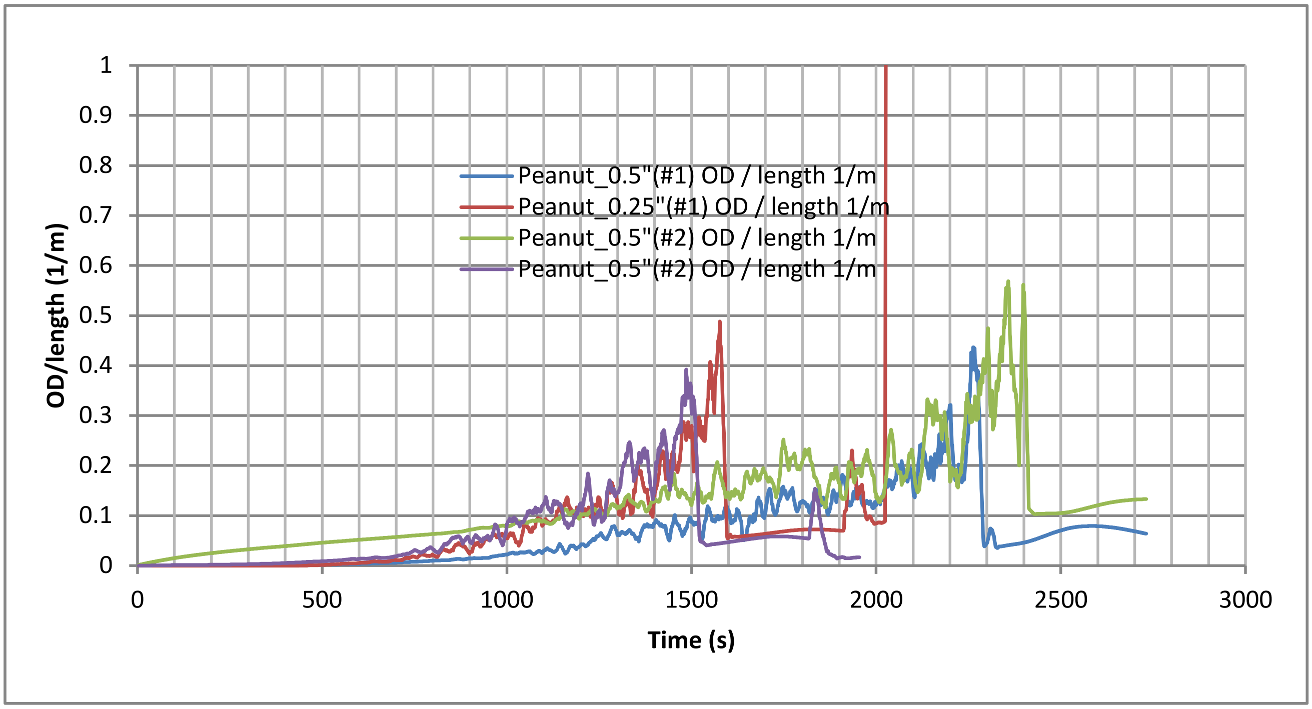

Figure 30: Graph 3.4

Same Volume of Different Oils

Legend ::			
Ignition Time ::	35:54:00	38:40:00	36:35:00e

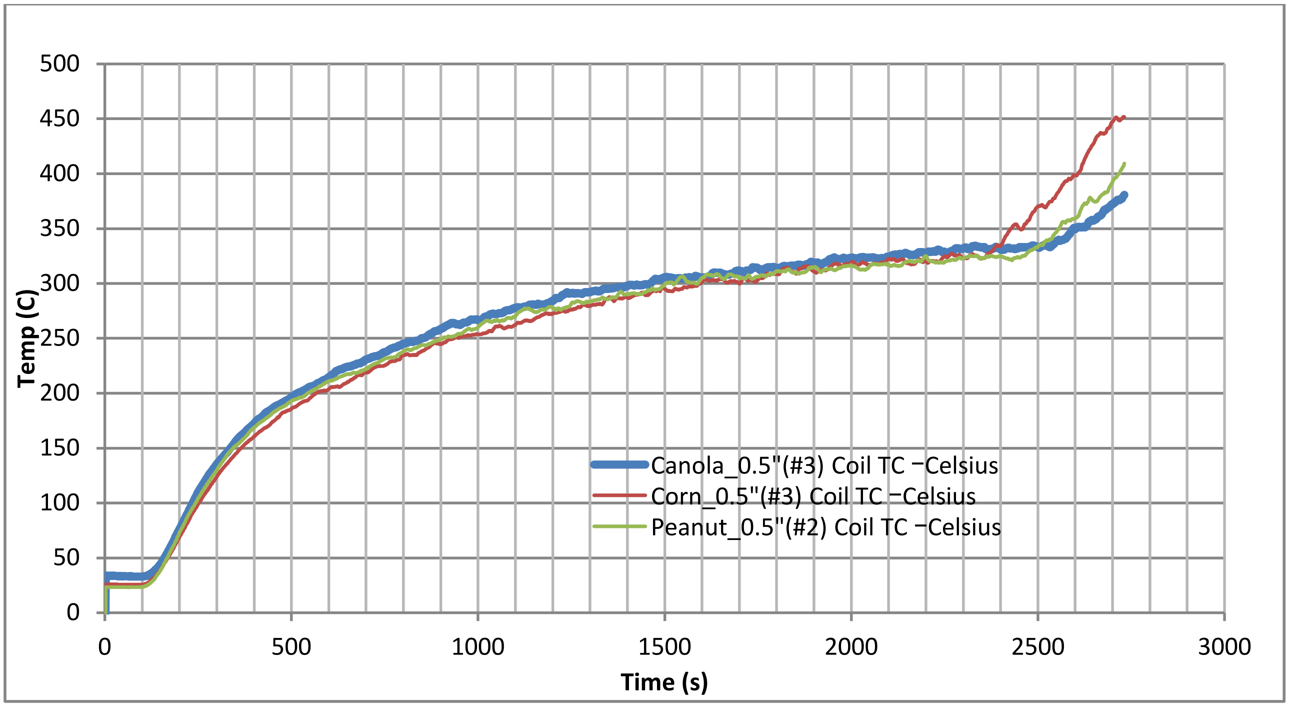

Figure 31: Graph 4.1

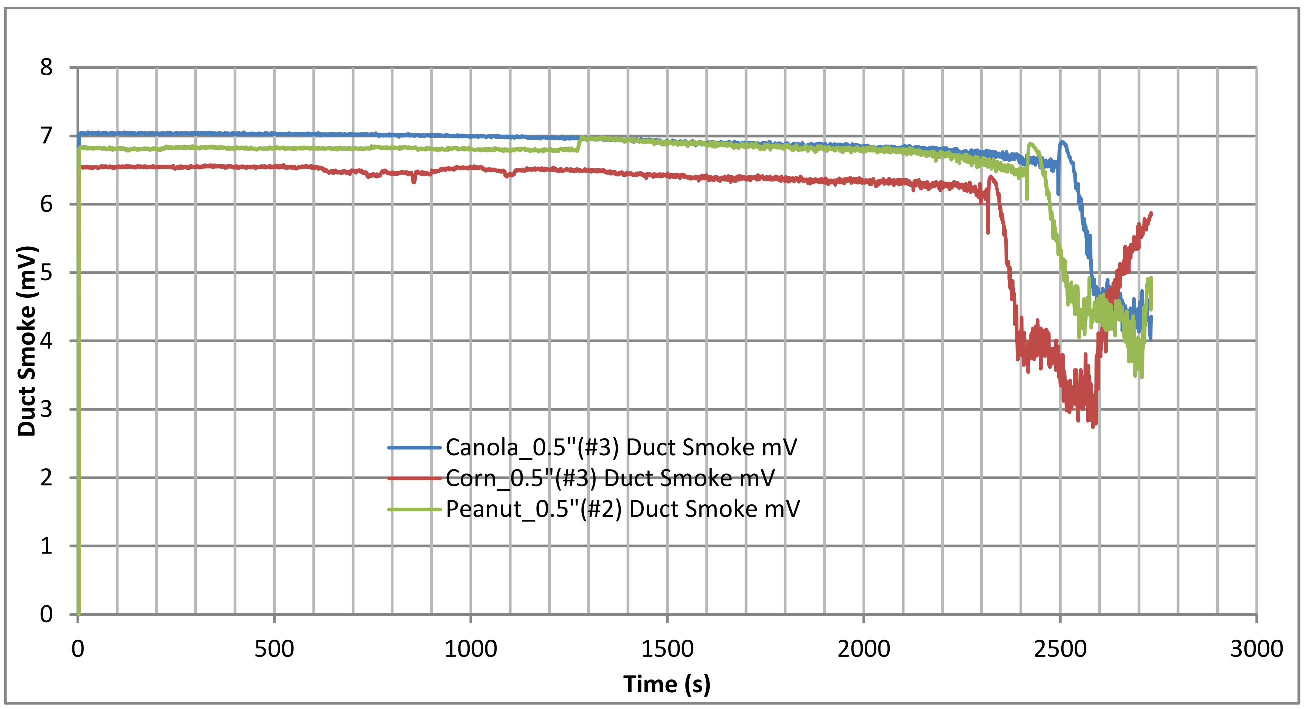

Figure 32: Graph 4.2

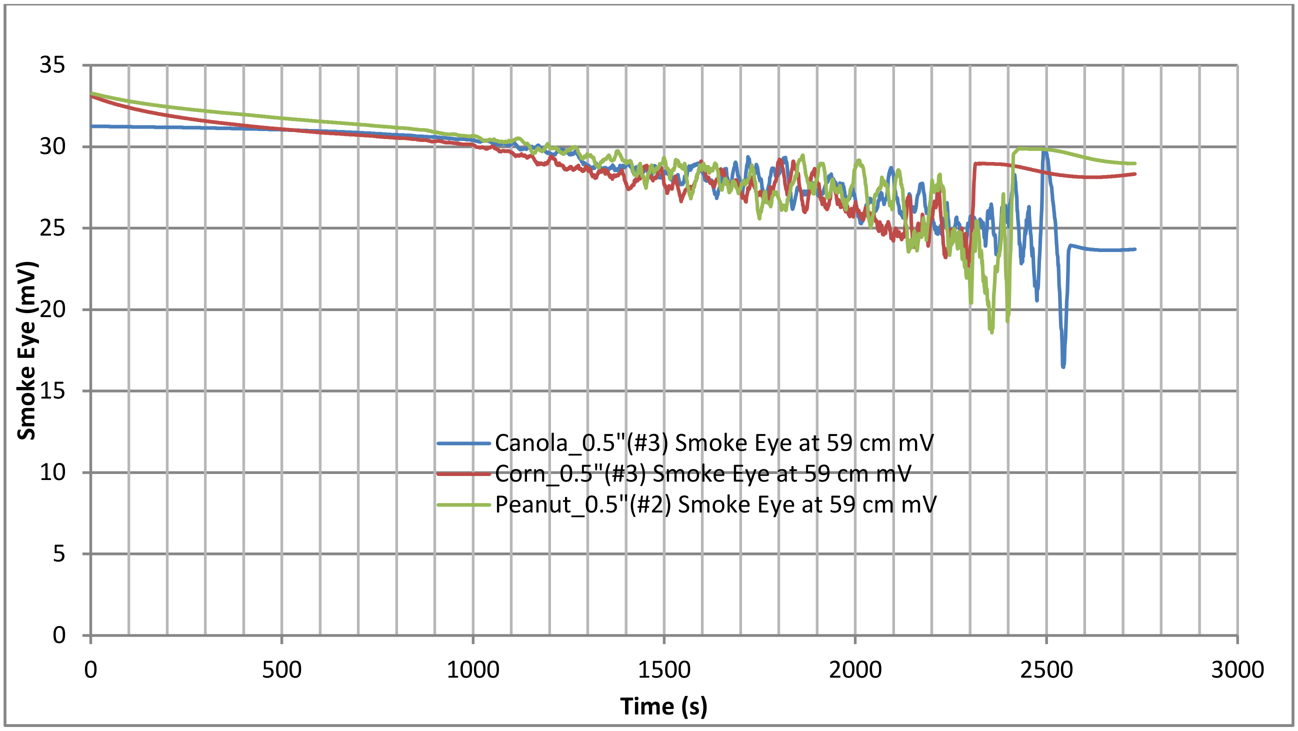

Figure 33: Graph 4.3

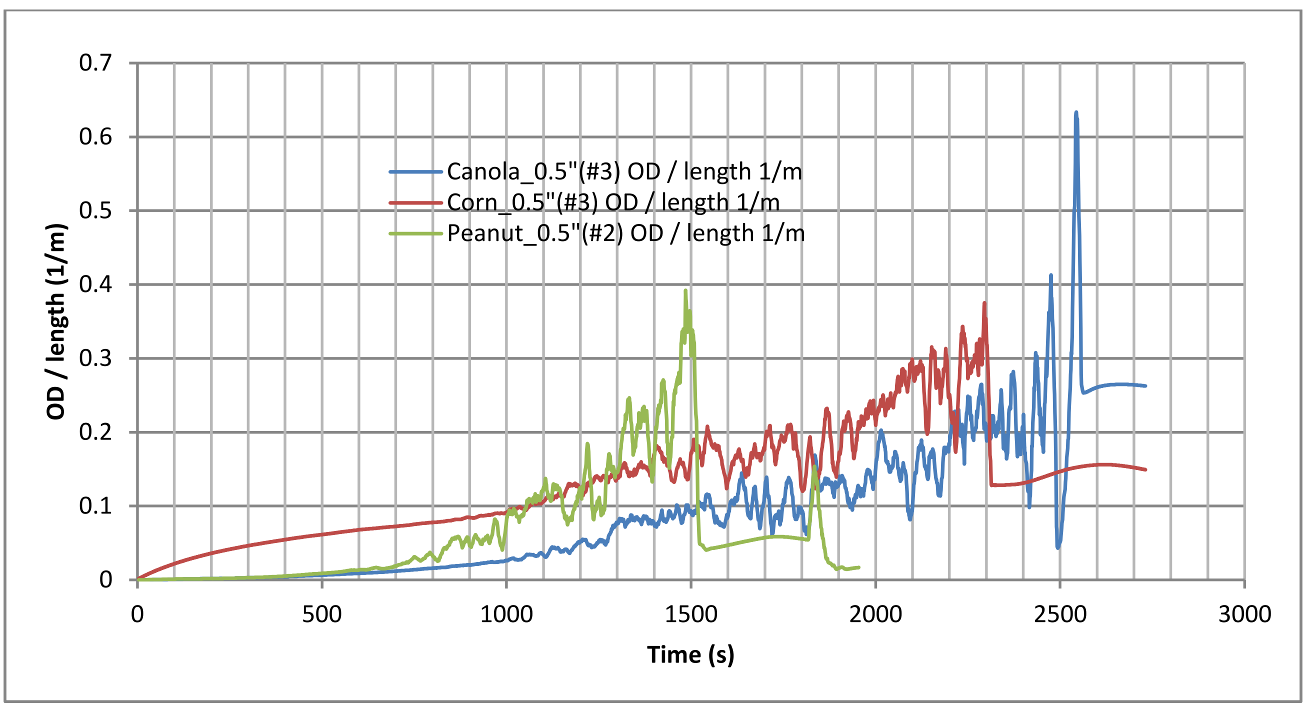

Figure 34: Graph 4.4

The Table 3: Observaton Matrix, given at the start of data observation summarizes some important test results such as the temperature of coil when ignition occurs and the value of duct OD at the point of ignition.

The graphs given after the Table 3: Observaton Matrix, give an idea of the flow of the experiment. Each of the variables of interest has been analyzed and the changes occurring in them are represented graphically.

Figure 31: Graph 4.1, Figure 32: Graph 4.2, Figure 33: Graph 4.3 and Figure 34: Graph 4.4 deals with the study of those variables with respect to different types of oil of same volume.

The graphs for Smoke Eye and Optical Density are not for the actual data obtained from the experiments, however to eliminate the large amount of noise in data a moving average at 15 seconds has been taken into account.

The following graph shows the actual variation of amount of Optical Density / length and also the variation after taking the 15 second Moving Average of Optical Density / length.

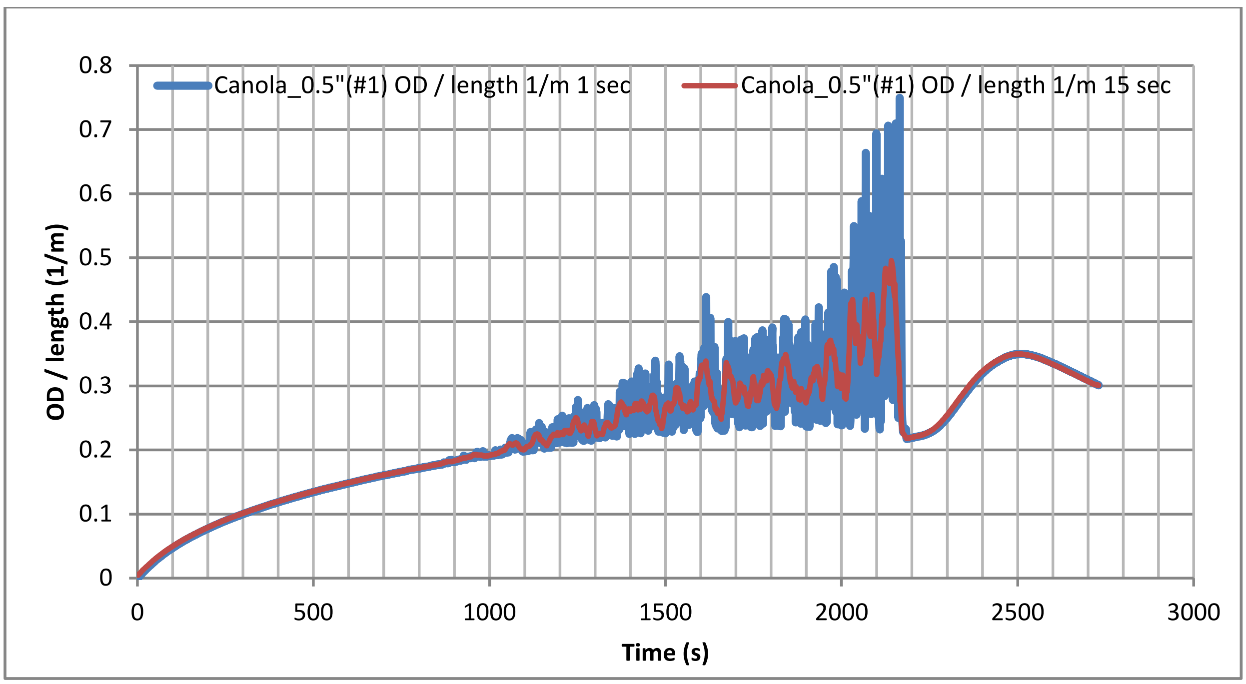

Figure 35: Graph 5

Legend ::

Data :: 1 sec Actual Data 15 sec Moving Average Data

Here is a graph of the Heat Release Rate of the Experiment n kW. The size of the full-fledged fire was approximately 4 feet high (Figure 17: Full Fire Flame).

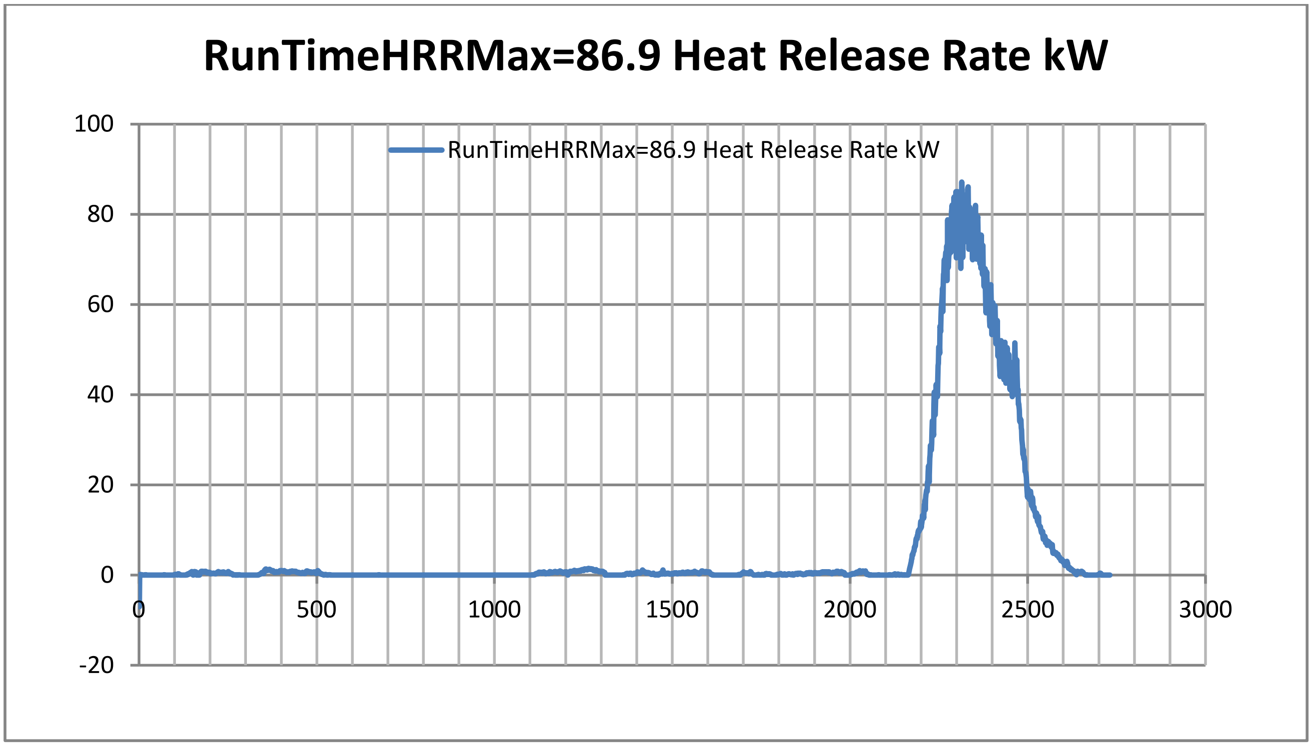

Figure 36: Graph _ HRR

Analysis

The experiments carried out revealed a lot of interesting results however the results will narrow down our analysis to only those data which can be useful in implementing a better and reliable detection system. Hence in our further results and analysis, focus will be primarily upon two of the major instruments used in the experiment i.e. Optical Density per unit length and Thermocouples on the heating coil of the cooking appliance. The reason for choosing these three out of all the instruments are:

- Easy application
- Cost efficiency
- Feasibility
- Precise results
- Better accuracy

The findings of thermocouples used at a 3' height were more suitable and apt for a suppression system rather than a detection system. The thermocouples used in the pan were more of an indication of flash and smoke point than to be used in detection. Other instruments such as CO analyzer and CO_2 analyzer are much expensive to implement and moreover yielded a noisy data.

Firstly, looking at the graphs of the Coil TC for all the different oils of same volume it was found that the flash occurs at the surface of oils when the temperature of the coil TC exceeds 320 degrees Celsius. However, this data may vary depending upon the test conditions and the power rating of cooking equipment used.

More so over, while manufacturing cooking equipment; its safe rating can easily be analyzed and marked. i.e. for the cooking equipment used by us a safe rating would fall somewhere between 320-340 degrees Celsius, it must be noted that a suitable value must be chosen for this safe range, so that it does not cause a nuisance as well as is reliable.

On analyzing the data retrieved by the smoke eye installed in the duct of Cell D lab and the additional Photocell used, it was observed that just when ignition was about to occur a lot of smoke is given off by the oil surface, mostly due to incomplete combustion of oil and more importantly due to boiling, occurring at the surface of oil, the result of all these phenomenon results in a considerable decrease in the Duct OD. During the last set of experiments we tried to predict the value of Duct OD and Duct Smoke at the point of ignition depending upon the existing data and the value at the start of the experiment, the prediction was ‘spot on’. Hence, this can be a very effective means of designing a detection system.

Yet to be mentioned is that the amount of smoke generated during cooking will vary upon the food that is being cooked, and many other such parameters. Therefore, for the detection system to be reliable enough; all such parameters need to be taken into account.

The Prediction Matrix provided analyzed here uses an AND logic gate for the two primary parameters taken into account, namely OD/ length and Coil Temperature. This matrix tries to predict a safe range of values that can be fed into a microprocessor for an effective and nuisance-free detection system. Indeed, this Matrix is not exhaustive and more research on the topic is invited for a safe and fire-accident free US kitchens.

Prediction Matrix

Test #	Threshold Temp.	Threshold optical density per unit length	Predicted Time	Actual Time
UL database	*Celsius*	*1/m*	*Minutes*	*Minutes*
#6231006	333	0.35 - 0.40	***	56.54
#6241003	333	0.35 - 0.40	32:31	34.42
#6241004	333	0.35 - 0.40	31:36	36.28
#7021003	333	0.35 - 0.40	***	38.4
#7011002	333	0.35 - 0.40	23:35	24.05
#6251001	333	0.35 - 0.40	***	35.54
#6251002	333	0.35 - 0.40	38:11	39.31
#7011003	333	0.35 - 0.40	36:42	36.54
#7011005	333	0.35 - 0.40	24:44	25.09
#7021002	333	0.35 - 0.40	23:12	24.02
#7011004	333	0.35 - 0.40	36:22	36.35
#7021001	333	0.35 - 0.40	36:36	38.34

*** Smoke Eye not working properly

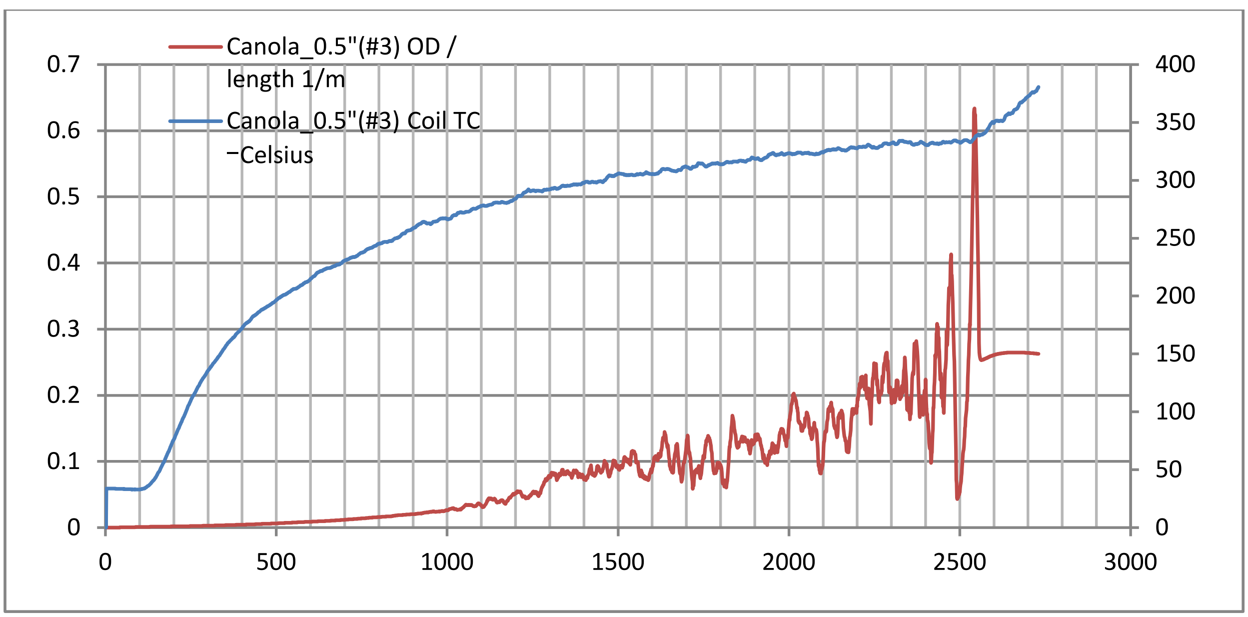

Figure 37 graph of the variation of coil temperature and optical density per unit length

Discussions

Figure 37 graph of the variation of coil temperature and optical density per unit length reveals that there is a lot of smoke at the point of ignition and the coil TC has reached above the value of safe rating of the instrument. Hence the data is very much coincident with our prediction. However on analyzing the prediction results it is found that it is better to use as large path length as possible, and also use it at as near to the pan possible so as to grab all the smoke in its path.

CONCLUSIONS AND RECOMMENDATIONS

The 2010 report of Home structure fires by Marty Aherns stated that one of every 22 households of United States of America had a cooking fire and cooking equipment was involved in two thirds of such incidents, hence the findings of this report will be very helpful in laying the foundations of a better and more efficient system of detection system for USA households

Based upon the findings of this research a detection system can be designed that takes into account both the temperature of the heating coil of the cooking equipment as well as the smoke detector that calculates the amount of smoke and hence, optical density per unit length. The alarm system of such a detection system should take into account the safety limit of both the instruments. The detection device should first sound a warning alert when the safety rating of the device is approaching and finally resulting in switching off the heating coil when that limit is exceeded.

Further Research

More and more research needs to be carried out on detecting and developing more factors that can be included in such an alarm system, to make it more efficient, robust and nuisance free. This research paper deals only with electricity operated cooking equipment. What it fails to incorporate is how to detect fires occurring from gas operated cooking device. Therefore, more research is needed to be carried out on how to extend such a detection system to gas operated cooking device.

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