UNITED STATES
Consumer Product Safety Commission

Washington, D.C. 20207

GAS RANGE DELAYED IGNITIONS
Tests and Examinations of Ranges

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July 15, 2002

EXECUTIVE SUMMARY

Consumer complaints and incident investigations of gas ovens in the late 1990's appear to indicate that unburned fuel gas can accumulate within ovens and ignite, producing hazardous flare-ups or explosions. Reported injuries have included facial burns from flare-ups, and bruises and falls from explosions. Causes were not determined although associations to incident factors and conditions were made. The primary factors theorized in the causes of incidents were the "self-proving" ignition systems that are used in most gas ovens and "suction draft" interference from house or exhaust fans.

A Directorate for Engineering Sciences (ES) project activity was started in 1999 to analyze the oven igniters used in the self-proving systems. These systems lack true feedback on gas ignition, and rely on electrically heated igniters to control gas flow. Reported incidents led staff to consider that possibly a failure in timing between the heating of the igniter and the release of gas could cause a potentially hazardous delay in ignition of accumulated gas. Due to the scope and magnitude of testing required, the project was transferred to the Directorate for Laboratory Sciences (LS) in early 2001. Project scope grew to include suction draft effects after an incident investigation by CPSC Field staff identified an over-the-range exhaust hood as the likely cause of a delayed ignition. It was also theorized at the time that an exhaust hood could possibly overwhelm the relatively weak natural convection created from and necessary for gas combustion within the oven.

The test program at LS evaluated gas ranges, oven igniters, and a downdraft range hood for ignition and suction draft problems. The appliances were installed in a mock kitchen to model the reported conditions in the incidents. Instrumented data was collected on operational factors, including igniter temperature, gas flow, and flue gas velocity. Tests covered parametrical variations in voltage, gas pressure, igniter age, and fan operation. Igniter system test results indicated that gas explosions are possible with very low gas supply pressures. Cyclic aging of igniters and voltage variations were not shown to adversely affect oven combustion. The suction draft tests indicated that a specific combination of a downdraft-type range hood with a gas oven could halt normal broiler combustion, resulting in ignition of accumulated gas either internally or when the oven door was opened. In tests recreating incident conditions, potentially hazardous gas flare ups occurred after opening the oven door.

The project results support the need to correct a potential hazard in the installation of specific gas ranges and downdraft range hoods. A general compatibility problem between these types of appliances may exist. Industry awareness is encouraged and will be pursued by staff with a letter to the appropriate standards organizations and trade associations alerting them to the findings in this report.

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By Mark G. Eilbert, LSM

Background

From January 1990 to March 2002, the U. S. Consumer Product Safety Commission (CPSC) received reports from hospitals, reporting under the National Electronic Injury Surveillance System (NEISS), and directly through consumer complaints, of gas range and oven explosions and flare-ups attributable to delayed ignition of gas. Thirty-two in-depth investigations reported "delay" of "ignition" or oven "explosion"[1]. In addition, two cases reported that house fans, a range hood and an attic fan, were implicated in delayed ignition within an oven. A majority of these 34 incidents resulted in injuries or property damage. Several incidents resulted in facial burns, singed hair, and injury to limbs and digits.

Self-proving ignition systems, those that operate without flame detection, are associated with many of the incidents. One contributing factor in some incidents has been air draft effects from air moving appliances within or exhausting from the home. A market report on oven igniters, prepared by the Directorate for Economic Analysis (EC)[2], reports that since 1990 hot surface igniters (HSI) associated with self-proving systems have predominated in the residential gas range/oven market. From that report, an estimated 15 million gas ranges/ovens in use have HSIs, which represents about one-half of all gas ranges/ovens.

CPSC Product Safety Assessments (PSAs) have been conducted on ranges or components involved in delayed combustion within the oven. In three PSAs laboratory tests were conducted on self-proving ignition ranges. Additional exploratory work was also performed on one of the sample ranges reported herein. None of the work produced conclusive results. The Directorate for Engineering Sciences (ES) initiated a project in FY1999 entitled "Self-Proving Electronic Ignitions Systems." The project focus was on oven ignition with ignition timing as the critical factor. The project was transferred to the Directorate for Laboratory Sciences (LS) in FY2001. The project focus at LS was on two fronts: the ignition system and the effects of overhead range hoods on oven combustion.

[1] From an INDP Multi-field data search for CY 1990 through CY 1998, Directorate for Epidemiology, submitted December 23, 1998.
[2] Market Information Regarding Hot Surface Igniters and Their Use in Gas Ovens, Robert Franklin, Directorate for Economic Analysis, June 27, 2000.

Objectives

The primary objectives of this LS project were to:

1. Generate scientific data that define the conditions that led to delayed ignition and/or explosions within a gas range; and

2. Support practical recommendations for new standards provisions to reduce or preclude fire and explosion (delayed ignition) hazards associated with the gas oven ignition systems.

Scope

Investigation of the self-proving ignition system focused on an incident range with an established ignition problem. Factors possibly affecting ignition performance, e.g. voltage and gas pressure, were varied. In a parallel study, the effects of age on igniters were analyzed over a life-cycle test approximating 3-years usage.

Similar in scope, an investigation into the suction effects of residential air-moving equipment on oven combustion concentrated on a specific case. In 2001, a CPSC incident investigation identified a gas range and range hood combination with a combustion problem. That combination was set up for test and evaluation at the CPSC Testing Laboratory.

This report provides general gas range and hood fan descriptions so that it can be made publicly available under Section 6b of the Consumer Product Safety Act.

Introduction

The gas oven is an enclosed cooking appliance available in two forms: the wall oven and the freestanding range. The range has the addition of open top burners and is freestanding, while the wall oven is built into and supported by the house structure. Either type may have multiple burners and igniters. In this description of ranges, the term “oven” will be used to indicate the enclosed cooking box, and “range” the appliance itself. Often, a range hood will be installed over a freestanding range to draw, collect, filter, and discharge cooking fumes from the range.

A. Ranges

Figure 1 shows schematics of typical ranges and range hood installations. In a two-burner oven (Figure 1a), a broiler burner is located near the top of the main oven box and a bake burner at the bottom. In a one-burner oven (Figure 1b), the burner is located at the bottom of the oven box, which is suitable for baking, and a smaller compartment below the one burner allows broiling. Each burner has its own associated igniter. Methods of oven burner ignition include pilot, electronic spark, and self-proving with the latter being the most common. In a self-proving ignition system, an electric current in the ignition circuit causes the hot surface igniter (HSI) to heat as well as the gas valve to open after a time delay. Products of combustion exit by natural convection through the flue, which spills out above the oven box into the room. Incoming combustion air is drawn from the bottom of the range through many gaps in the range structure. Typically, ranges can be configured to burn either propane or natural gas.

Range hoods are often installed over ranges as depicted in Figure 1a. The hood fan removes cooking odors and smoke in two ways. Typically for new home installations, the fan discharges through ductwork to the outside. The range hood can also remove

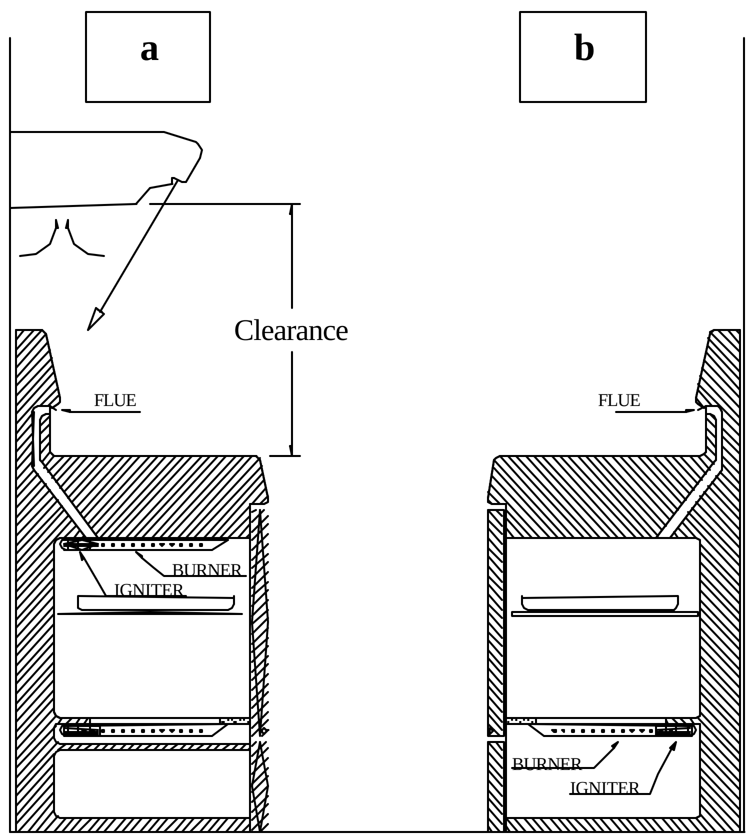


Figure 1. Sectional Views through (a) Two-burner Range with Range Hood and (b) One-burner Range.

odors and smoke by filtering through, typically, a charcoal filter. In that case, the fan air can be returned to the room by direct discharge from the hood. In Figure 1a, the hood both draws air from and discharges air to the space above the range top. A safety concern is the proximity of the oven flue to this space and the possibly disruptive effect the "suction draft" of the hood may have on the necessary flow of combustion products from the oven.

B. Self-Proving Ignition System

The hot surface igniter (HSI) functions both as an ignition source and as an effective timing switch for the gas valve. As an ignition source, the HSI reaches a maximum temperature of over 2000 °F (1100 °C), greater than the ignition temperature for natural gas (1300 °F, 700 °C) or for propane (920-1125 °F, 500-600 °C). As a switch, the HSI limits the current through itself and through the gas valve, which itself requires internal heating to open. The term "self-proving" refers to a requirement in ANSI Z 21.20 that an ignition source be established or proven before the gas valve opens. A failed HSI igniter will not pass current or, presumably for a degraded igniter, enough current to heat the gas valve actuator. The circuit is thus self-proving and requires no active feedback to the thermostat.

Figure 2 shows the self-proving circuit comprising the igniter and valve and typical details of the valve. In a properly functioning system, the heating of the igniter and the opening of the valve are matched so that the igniter will have reached combustion temperature before the valve opens. The valve seat opens as depicted in Figure 2(b) after the "heater wires" sufficiently warm the bi-metal arms. The electric current to cause that heating is restricted by the electrical properties of the igniter. To achieve the desired current rise, the composition of the silicon carbide igniter is "doped" with special chemicals.

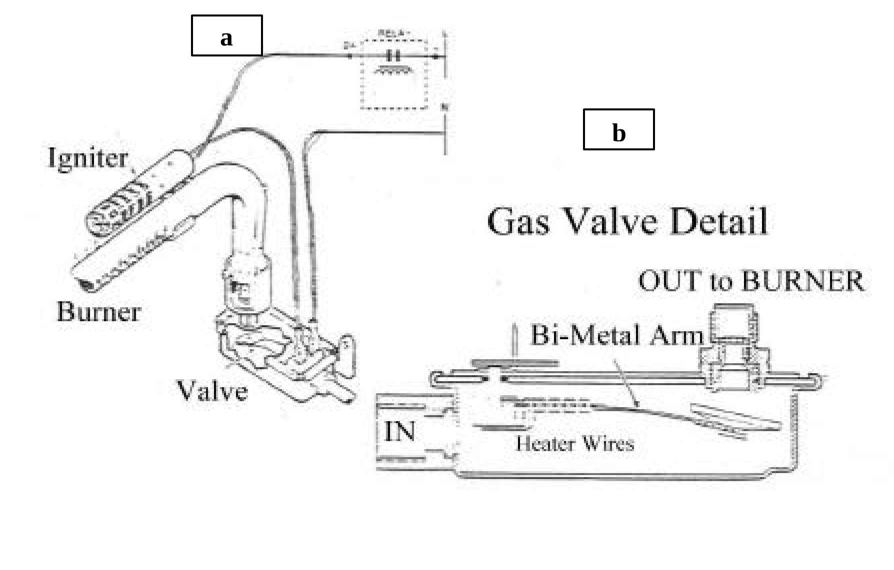


Figure 2. Self-Proving Ignition System: Assembly (a) and Gas Valve (b)

Applicable Standards

The following standards include safety requirements for gas ranges and components and range exhaust hoods:

- ANSI Z21.1, Household Cooking Gas Appliances
- ANSI Z21.21, Standard for Automatic Valves for Gas Appliances
- ANSI 21.20, Standard for Automatic Gas Ignition Systems and Components
- NFPA 54-ANSI Z223.1, National Fuel Gas Code
- UL 507, Standard for Safety for Electric Fans

LS staff is not aware of any standards or building codes that address the compatibility of gas ranges or wall ovens with range hoods.

Investigations

Laboratory testing was designed to investigate two hazardous gas ignition scenarios, represented by two specific incidents:

(1) A delayed-ignition case in which accumulated gas auto-ignited within the oven.

(2) A re-ignition case in which accumulated gas ignited once the oven door was opened.

Neither case directly implicates the self-proving ignition system or suction draft as factors. For example, the igniter must have functioned to have caused those ignitions. Rather, investigations focus on the conditions in which gas can accumulate without ignition.

The incident case selected to investigate a possible failure of the self-proving ignition system (IDI 000607HAA2591) will be called the Delayed-ignition incident. That case reported a delayed explosion within minutes after the bake burner was turned on. The oven door was shut prior to the explosion that threw the door open. The use of air-moving appliances, such as a range hood or kitchen exhaust fan, was not reported.

The incident case selected to investigate a re-ignition of gas with a probable link to fan suction (IDI 010418HCC2409) will be called the Suction-Draft incident. That case reported a flare-up with the broiler burner and directly associated an overhead range hood with the incident. The oven door was shut at start-up and the hood was turned on. Then, after an unspecified time period, the victim opened the door and the flare-up occurred.

Instrumentation

Instruments were selected to monitor characteristics of components and processes in the oven combustion and heating cycle. In the Delayed-ignition ignition tests, it was important to show the (reduced) time delay between the igniter reaching the combustion temperature of natural gas and the flow of gas. In igniter aging, focus was on the change in igniter temperature and current flow over time. In the Suction-Draft tests, a loss of flame and diminished flue velocity would indicate a cessation of combustion. Data collection was through a data acquisition module by Data Translation and software by LabTech.

Table 1 lists instruments for the range tests. The Infrared Thermometer (IR) required a water-cooled jacket with an 8-14 μm-transmittance glass viewing port and a laser sight to locate the focal centerline. The jacket and laser sight were designed and fabricated at Laboratory Sciences. A mount was also developed to support the IR and maintain precise aim on the igniter target. A low (about 30 degrees) viewing angle was selected to avoid "seeing-through" the igniter. For Suction-Draft tests, a pitot tube to measure flue velocity was placed approximately 1 in (25 mm) down into the flue, parallel to the flow.

Table 1
Instrumentation

Test*			Parameter	Instrument	Range of Interest
D	I	S			
•		•	Gas Pressure	Pressure Gage	1.5-8.5 in w.g.(370-2100 Pa)
•	•	•	Igniter Temperature	Infrared Thermometer	1000-2500 °F (540-1370 °C)
•	•		Igniter Current	AC/DC transducer	0-5 Amp
•		•	Natural Gas Flow	Gas Mass Flow Meter	0-15 LPM (32 ft^3/h)
•			Oven Temperature	Type K thermocouple	100-500 °F (38-260 °C)
•		•	Flame Detection	Type K thermocouple	100-1500 °F (38-815 °C)
		•	Flue Temperature	Type K thermocouple	500-1500 °R (280-830 °K)
		•	Flue Velocity	Low-Pressure Transducer	±0.05 in w.g.(±12 Pa)
		•	Fan Speed of Hood	AC/DC transducer	Amp Level at 3 Speeds

*Key: Delayed-ignition Tests; Igniter-aging Tests; Suction-draft Tests

Installations

A kitchen mockup was constructed with a back wall, side cabinets, and a floor (Figure 3). The sample ranges and range hood were installed according to the clearances reported in the incident investigations. The gas hose, IR cooling tubes, and instrument wires were routed through an access door in the rear wall. The access door and all gaps in the mockup surfaces were sealed.

Figure 3. Kitchen Mockup

Investigation of Delayed-Ignition Range and Igniter Aging

These tests monitored the ignition performance of a range with a presumed delayed ignition problem. The specimen used for testing was a gas range with a single burner. This range (Delayed-ignition range) was involved in a reported incident (IDI 000607HAA2591) of a gas explosion in which the oven door blew open on the initial oven cycle, nearly striking the victim. The range had a history of delayed ignition of the bake burner. Important external factors including voltage and gas pressure were not reported. Those factors were chosen as test parameters. Another factor, suction draft, was not selected as a test parameter for this range because there was no exhaust fan in the kitchen and no other possible sources of draft were reported.

The objective of the igniter cycling tests was to support the Delayed-ignition investigation by determining the effect that age might have on the heating and current flow characteristics of the igniters at rated voltage. A change in the rate of temperature rise or in the maximum temperature could affect the timing of ignition or whether ignition were possible, respectively. As described previously, the igniter and gas valve are electrically connected in series and have the same current flow. A change in igniter current characteristics could affect the gas valve operation and the timing of ignition. Those igniters with significant changes in temperature or current characteristics were then mounted in a gas oven, appropriate for that igniter, and tested under normal oven usage.

Sample Selection

The Delayed-ignition range (Figure 4) was collected during an investigation. The range has a single oven burner, with a configuration similar to Figure 1b. The oven has a spiral-type igniter.

Figure 4. Gas Range used in Delayed-Ignition Tests

Eight hot surface igniters were selected for long-term aging tests: six spiral- and two flat-type igniters, similar to those in Figure 5. Those tested are listed in Table 2. The spiral-type igniters are similar to the igniter in the Delayed-ignition range.

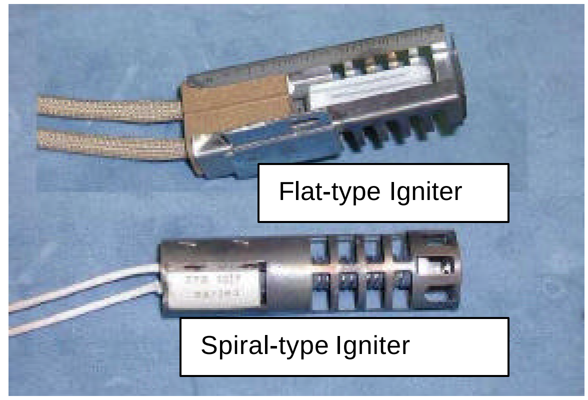


Figure 5. Typical Hot Surface Igniters

Table 2
Igniters Used in Cycling Tests

Specimen ID	Sample Number	Type
1	98-793-0362-02	Spiral
2	98-793-0362-05	Spiral
3	98-793-0362-04	Spiral
4	98-793-0362-03	Spiral
5	98-793-0362-06	Spiral
6	98-830-3655	Flat
7	98-490-1104	Flat
8	98-793-0362 -01	Spiral

For the bench tests of igniter aging, the IR and current transducer were used to collect data at discrete intervals in the on-going cycling. The IR was mounted on a common structure with the igniter to achieve a stable and reproducible measurement of the hot igniter surface. The viewing angle was set to about 30 degrees.

Setup

The Delayed-ignition range was installed in the mock kitchen with similar clearances as reported in the investigation: 3-inch side clearances from the cabinetry and 3.5-inch rear clearance to the wall. There was no range hood or upper cabinet.

Delayed-Ignition Test Results

The Delayed-ignition range was tested in the kitchen mockup. Testing progressed from baseline tests of the bake burner at nominal conditions, through parametric tests with igniter, voltage, gas pressure, and other factors. The oven door was kept closed throughout all tests.

Baseline Tests

Figure 6 shows a typical baseline test of the Delayed-ignition range with various parameters plotted and identified in the graph and caption. The initial start cycle is shown. At the start (5 sec), the current rises rapidly, and then stabilizes at 2.67 amps. The igniter temperature rises more slowly, reaches the nominal gas combustion temperature of 1300 °F (T_{min}) at 14 sec, and later levels at 2149 °F (T_{max}). The gas valve opens fully after 25 sec, 11 sec after T_{min}. Combustion is evident as the Flame Detect graph begins to rise after the gas valve opens. Note that Flame Detect is intended to show presence of flame and is not an accurate measure for rate or temperature, as the thermocouple data depended on its exact placement near the flame.

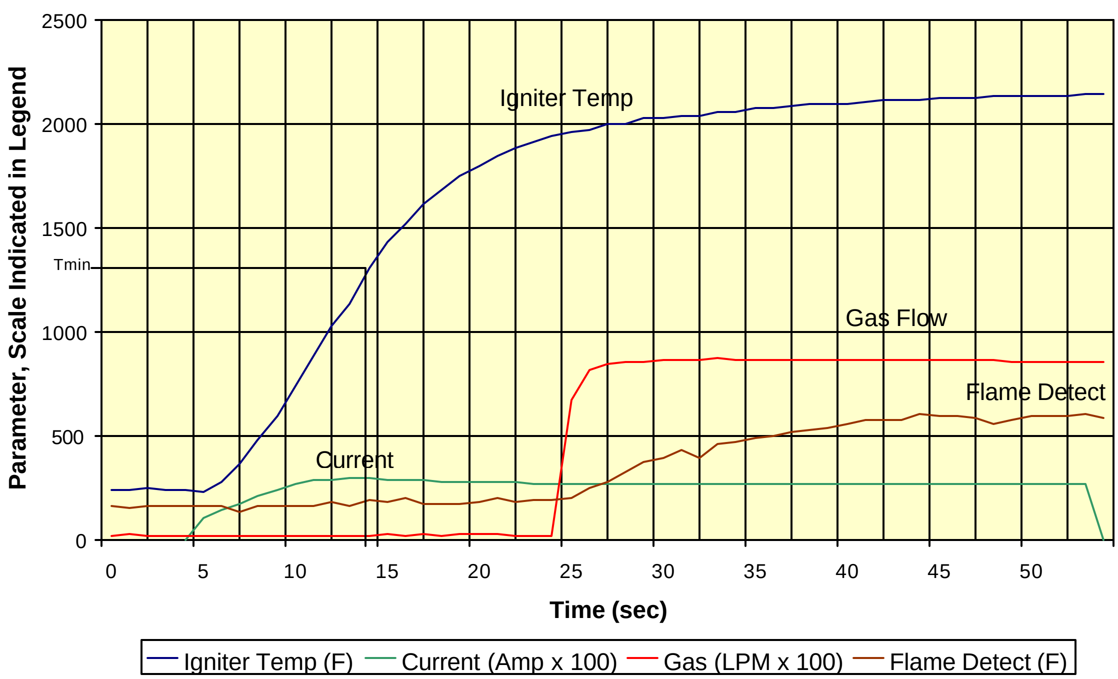


Figure 6. Baseline Test of Delayed-Ignition Range

Later in the test, during oven cycling, the oven thermostat turned the igniter/gas valve circuit on and off to maintain the selected oven bake setting of about 350 °F. The average cycle time was 108 sec with a 127-sec maximum and a 91-sec minimum time (108/127/91). The time for the igniter to reach T_{min} averaged 5 sec with a 7-sec maximum and a 3-sec minimum time (5/7/3). The gas valve opened an average 9 sec after T_{min} (9/11/8). The average T_{max} for the igniter was 2192 °F (2192/2205/2175). This baseline test of the incident oven indicates that the ignition system functions. The expected sequence of igniter heating and gas valve operation is evident.

Test Parameter: Igniter

In Figure 7, the graph shows a comparison between the original incident igniter and a new, factory replacement igniter for the Delayed-ignition range. In this bench test, the replacement igniter displays a somewhat faster rise in temperature and current, although the steady-state current is lower than the incident igniter. This limited comparison does not itself indicate that age is an underlying factor. In contrast, it does show that both igniters significantly exceed the gas combustion temperature (reaching maximums exceeding 2000 °F, 1100 °C). Further investigations into igniter aging are presented in the Igniter-aging Bench Test results.

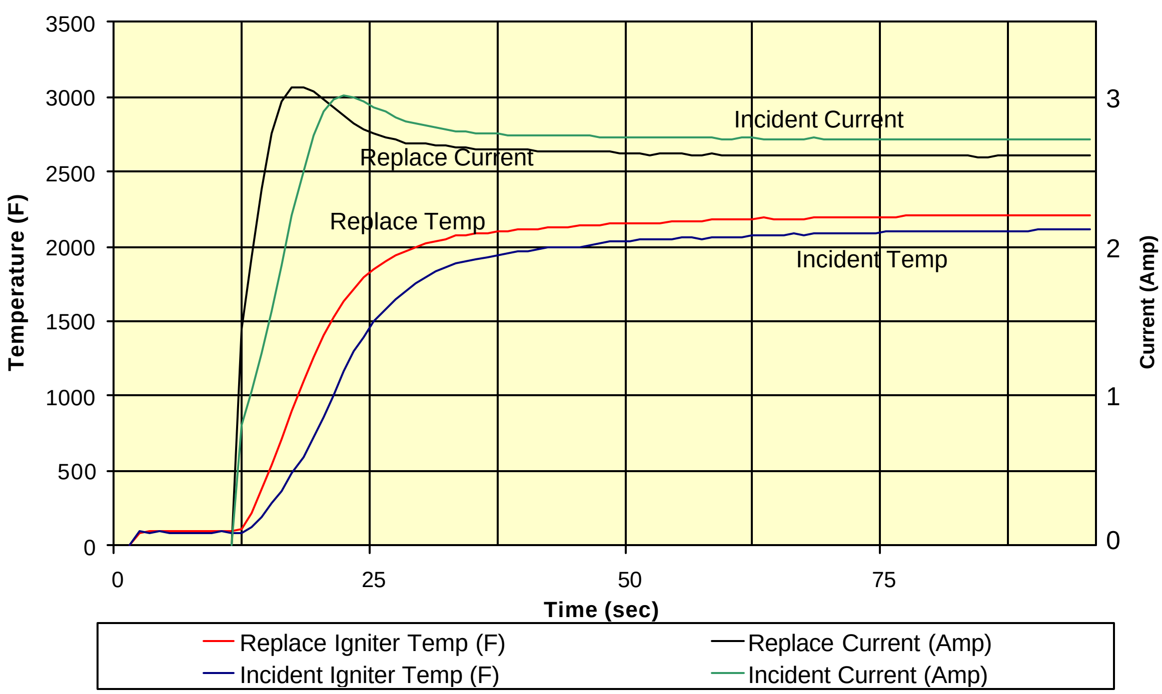


Figure 7. Igniter Comparison, Incident and New

Test Parameter: Voltage

Figure 8 shows, for the initial combustion cycle, the effect of voltage on the igniter temperature and the time delay of the gas valve. In the figure, each arrow indicates a separate test at a selected voltage. Arrow length indicates the gas valve time delay, which is the time to open after the igniter reaches T_{min}. Two lines of constant temperature are included: T_{min} =1300 °F and T=1800 °F. The latter was selected for convenience of comparison. For example, at 130 V, the igniter reached T_{min} at 9 sec and then the gas valve opened at 18 sec: the delay is 9 sec. Times to reach T_{min} increased with decreasing voltage, as expected. Delay times for gas valve operation also increased with decreasing voltage, from 9 sec at 130 V to 22 sec at 100 V (39 sec minus 17 sec). The effect was less pronounced for the steady-state cycles (not shown) where the range was from 8 sec at 130 V to 15 sec at 100 V. The gas valve did not open at all at voltages below the range of 79 to 85 V. These oven tests indicate that, while voltage affected ignition sequence, the opening of the gas valve always followed the igniter preheating to T_{min}.

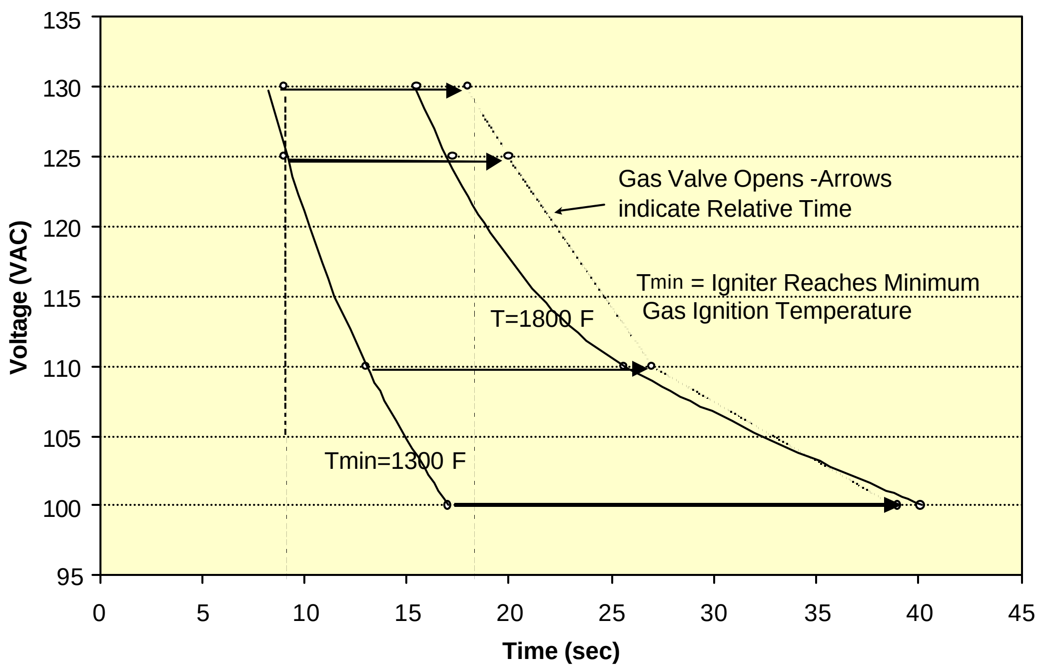


Figure 8. Affect of Voltage on Ignition Sequence

Test Parameter: Gas Pressure

Figure 9 shows the effect that gas line pressure has on ignition timing. The oven's gas regulator input and output ratings were 0.5 psi (3400 Pa) and 4 in w.g. (water gauge[3]) (1000 Pa), respectively. From the normal gas line pressure at the test facility, 8.5 in w.g. (2100 Pa), down to about 2.0 in w.g. (500 Pa) combustion within the oven is normal. Between 1.5 and 2.0 in w.g. (370-500 Pa), delays in ignition of about 60 sec resulted in small explosions within the oven. Below 1.5 in w.g. (370 Pa), no explosions were noted although gas continued to flow throughout the remaining 4 minutes of testing. The oven is capable of operation at low gas pressures; those below the 4 in w.g. (1000 Pa) output rating. Lower pressures will not compress an internal spring and will not force the regulator closed. Lower gas line pressures should not affect the operation of the oven gas valve, which operates through electrical heating. These tests demonstrate a possible source for gas escaping without combustion. The scenario requires a nominal gas supply pressure that is not normally found in homes.

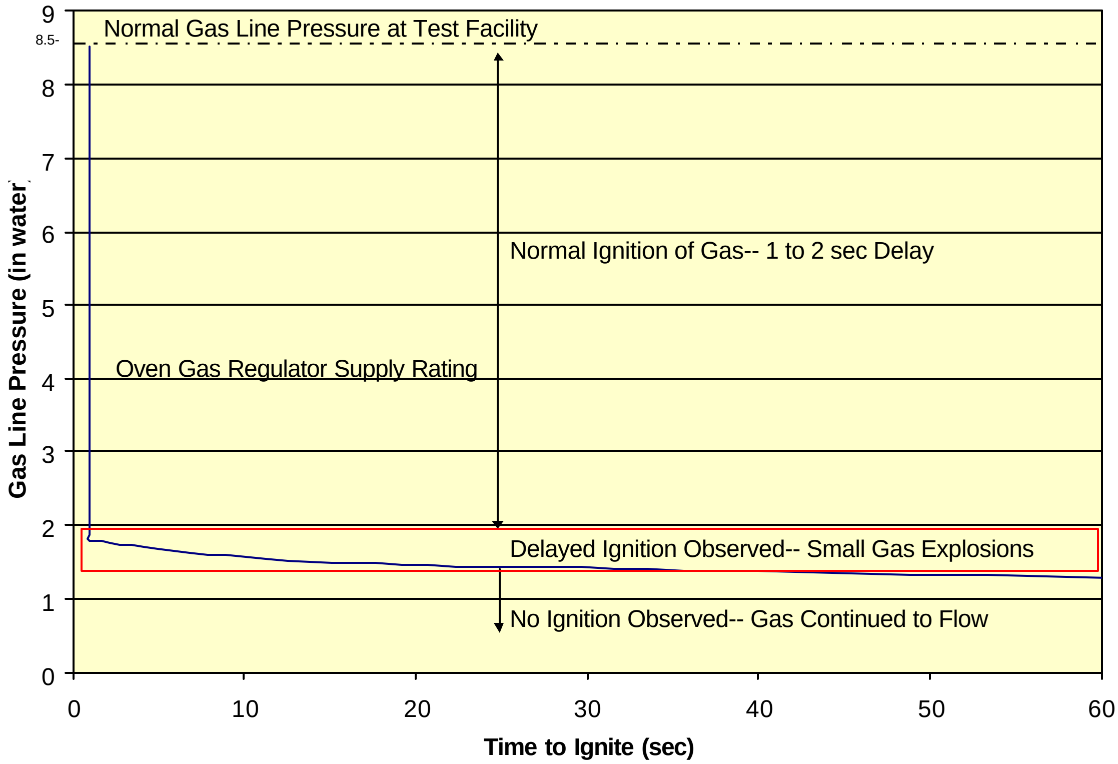


Figure 9. Affect of Gas Pressure on Ignition

Test Parameter: Power Interruption

Tests involving power interruptions were conducted. Since both the igniter and gas valve function through internal electric heating, power interruptions could cause irregular heating and cooling of each component, affecting the ignition sequence. In none of the tests did the gas valve open before the igniter reached T_{min}.

[3] Pressure: 1.0 psi (pound per square inch) equals 27.7 in w.g. (inches of water gauge).

Igniter-aging Bench Tests

Igniters were cycled over a symmetric 86-sec (43 sec ON, 43 sec OFF) heating cycle at 120 V for 61,000 cycles. This represents approximately 2- to 3-years of usage based on 1- to 2-hour-usage per day. The 86-sec interval was selected as a typical cycle time for a gas oven. Igniter surface temperature and current data were collected in bench tests on individual igniters at discrete cycle intervals.

Figure 10 shows that the maximum current decreases approximately 2-4 % for the six spiral-type igniters and about 8 % for the two flat-type igniters over the 61,000 cycles[4].

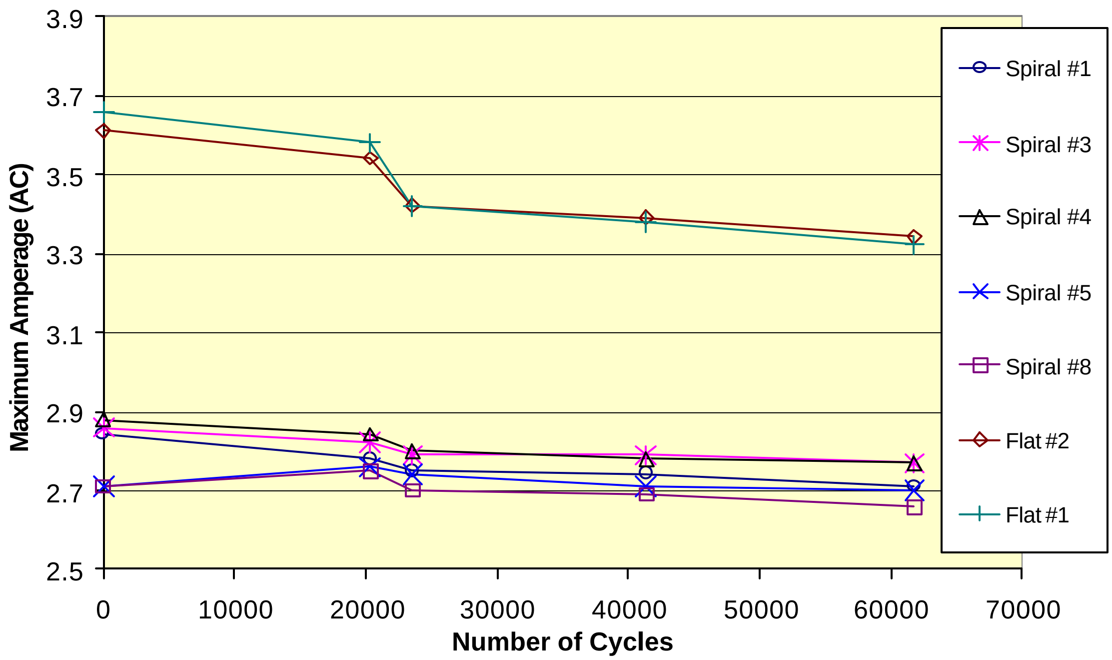


Figure 10. Effect of Igniter Cycling on Current Capacity

[4] Bench testing was delayed for one year at 20,000 cycles. The abrupt change of slope at 20,000 is due, in part, to a change of instrumentation.

Figure 11 shows that the maximum temperature decreases approximately 150 to 350 °F (65-176 °C) for the six spiral-type igniters and about 100 to 150 °F (38-65 °C) for the two flat-type igniters over the 61,000 cycles[5].

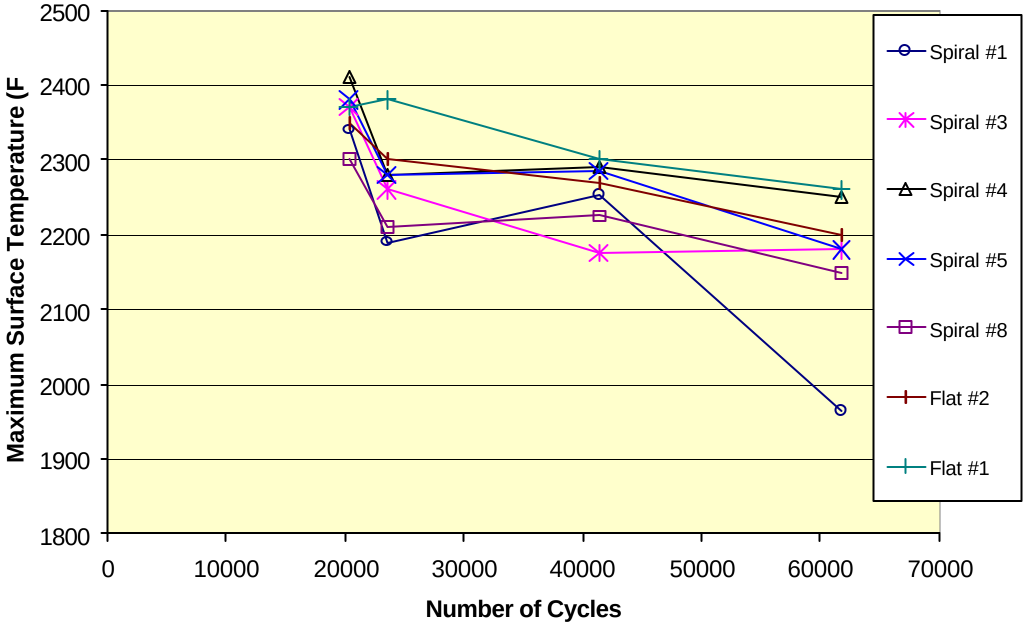


Figure 11. Effect of Igniter Cycling on Temperature

Another important measure for igniter aging is the rate of temperature rise, most significantly the time to reach the minimum ignition temperature, T_{min}. Table 3 shows that spiral-type igniter #3 has the longest delay. That igniter was tested in the Delayed-ignition oven to determine the practical effect of aging. Spiral-type igniter #3 and the incident igniter (Delayed-ignition) were similar models. In the Delayed-ignition oven, spiral-type igniter #3 took 34 sec to reach T_{min} and the gas valve took 11 sec to open after $t = T_{min}$ in the initial oven cycle. This compares to 9 sec to T_{min} and 11 sec for the gas valve to open in the baseline test with the incident igniter.

Table 3
Time to Reach Ignition Temperature* At 61,000 Cycles

	Spiral #1	Spiral #3	Spiral #4	Spiral #5	Flat #6	Flat #7	Spiral #8
Time to T_{min} (sec)	13	**32**	7	15	16	15	10

* Natural Gas

[5] Bench testing was delayed for one year at 20,000 cycles. The abrupt change of slope at 20,000 is due, in part, to a change of instrumentation.

Investigation of Suction-Draft Range

The objective of this investigation was to monitor the ignition performance of an oven burner that presumably is affected by the suction draft of a range hood. The sample used for testing was a gas range with two oven burners. This range was involved in a reported incident (IDI 010418HCC2409) in which the oven broiler ignited accumulated gas within the oven as the door was opened, burning the victim's face. The incident occurred on startup, the initial oven cycle. The on-site CPSC investigator was able to recreate the conditions of the incident, short of the resulting flare-up. When used with the oven broiler, the range hood was implicated in stopping normal combustion.

Sample Selection

A gas range was purchased (Figure-12). This is the range model described in the Suction-draft incident. The oven has two burners with spiral-type igniters.

A range hood was purchased (Figure 12). This is the incident model range hood of the Suction-draft incident described above. The hood has three speeds with a top or back discharge but can be configured for re-circulation as a downdraft hood. The sample was configured as a downdraft, as in the incident hood. In the investigated incident, the range hood's discharged air was directed back towards the range top, similar to Figure 1a.

Figure 12. Gas Range and Range Hood used in Suction-Draft Tests

Setup

The Suction-draft test range and range hood were installed in the mock kitchen with similar clearances to those in the investigation report: Range had zero side clearances from the cabinetry and zero rear clearance to the wall; range hood was installed 23.5 in (600 mm) above the range top.

Suction-Draft Test Results

Testing progressed from baseline tests at nominal conditions, through parametric tests with the range hood, varying fan speed, vertical clearance, and sequencing of oven/fan operation. The CPSC field investigator detailed the conditions in which the range hood reportedly caused combustion problems in the oven. That set of conditions appears in the test matrix as test run 10.

Baseline Tests

Figure 13 shows a typical baseline test of the broiler burner of the Suction-draft range, without the range hood in operation. The gas valve opens at 40 sec, 12 sec after the igniter temperature reaches the nominal gas ignition temperature of T_{min} =1300 °F (700 °C). Combustion is evident as the Flame Detect graph rises after the gas valve opens. [Note that Flame Detect is intended to show presence of flame and is not an accurate measure for rate or temperature.] The flue gas velocity immediately rises to 3 ft/sec (1.0 m/s) and continues to rise to 4 ft/sec (1.2 m/s) as the flue temperature also rises. Note that the flue velocity and temperature reach steady state at about 6 ft/sec (1.8 m/s) and 1200 °R (670 °K), respectively. This baseline test indicates that the products of gas combustion are sensed (Flue Temperature and Velocity) immediately following ignition (Flame) and that the flue gases continuously exit the flue.

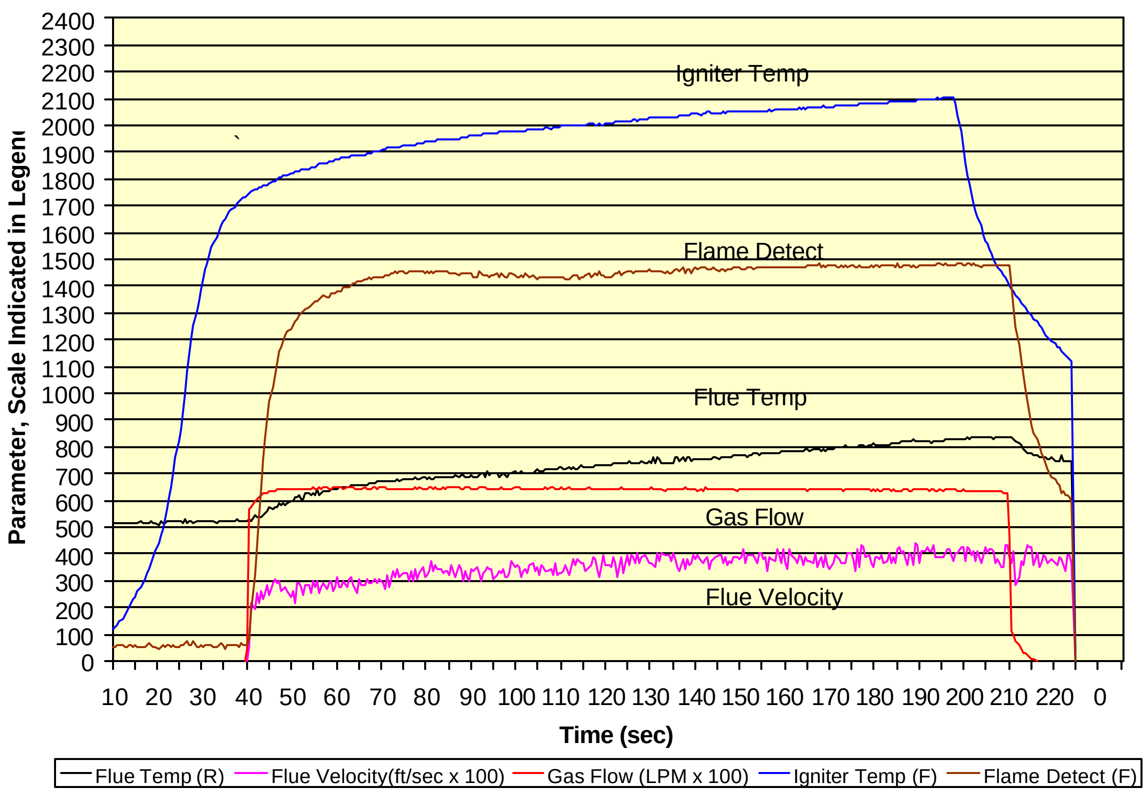


Figure 13. Baseline Test of Suction-Draft Oven

Range Hood Air Discharge

The range hood draws air upwards into the filter area and discharges out from the front edge of the hood, down and towards the back of the range top, at an approximate 30- to 35-degree angle from the vertical. This angular discharge is depicted in Figure 1a. The discharge is directed to the vicinity of the oven exhaust flue. Recorded discharge velocities at high speed were approximately 4 to 10 ft/s (1.2 to 3.0 m/s) at 18 in (0.5 m) from the range hood vents, or about 2/3 the distance to the Suction-draft flue. These discharge velocities are comparable, and are opposed in direction, to those recorded for the flue gases in the baseline tests.

Parametrical Tests

The following parameters were varied in tests with the Suction-draft range and range hood:

1. Fan Speed
2. Fan Clearance above range
3. Operation Sequence (which appliance was first energized)
4. Warm-up (oven warmed, then fan turned on; oven not warmed, then fan on)

Table 4 shows the main test matrix: a four factor, two level, full factorial test plan and additional tests conducted at Medium fan speed and at other clearances. The range hood had 3 speeds. The Sequence factor is the operational sequence of the oven and range hood. For example, "HO" describes a sequence where the range hood is energized first followed by the oven broiler. The Warm-up factor is whether or not the oven has been pre-heated prior to operating the range hood. Clearance is the vertical distance from the range top surface to the underside of the range hood.

Table 4
Test Matrix for Suction-Draft Range and Range Hood

	Speed	Sequence	Warm-up	Clearance		Speed	Clearance
RUN	1(-), 3(+)	HO(-), OH(+)	No(-), yes(+)	19"(-), 23.5"(+)	RUN[b]	2(-), 3(+)	21"(-), 27"(+)
1	-	-	-	-	17	-	-
2	+	-	-	-	18	+	-
3	-	+	-	-	19	-	+
4	+	+	-	-	20	+	+
5	-	-	+	-			
6	+	-	+	-			
7	-	+	+	-			
8	+	+	+	-			
9	-	-	-	+			
10[a]	+	-	-	+			
11	-	+	-	+			
12	+	+	-	+			
13	-	-	+	+			
14	+	-	+	+			
15	-	+	+	+			
16	+	+	+	+			

a. Run 10 recreates the incident with this model range.
b. Runs 17 through 20 were all conducted with a hood-oven sequence (HO) and without Warm-up.

Incident Scenario, Run 10

Figure 14 shows Run 10 of the test matrix, the reported conditions present in the investigated incident. The range hood fan speed is high and the oven starts cold. The igniter heats up normally and a flame is detected after the gas valve opens at 48 sec. However, there is no flue temperature rise or flue gas flow. At about 68 sec (20 sec later), the Flame Detection weakens and drops rapidly. At about 100 sec, the fan is turned off. Ignition then re-establishes and normal combustion resumes. Calculated from the graph, approximately 4 to 5 liters (0.14 to 0.18 ft^3) of non-combusted natural gas are discharged into the oven box in this 52-sec period. These tests, incident and baseline, confirm that the range hood fan interrupted normal combustion. This incident scenario test indicated a potential hazard in the collection of natural gas within the oven. In the reported incident, the victim opened the oven door and then gas suddenly combusted - indicating a collection of gas, as demonstrated in this test.

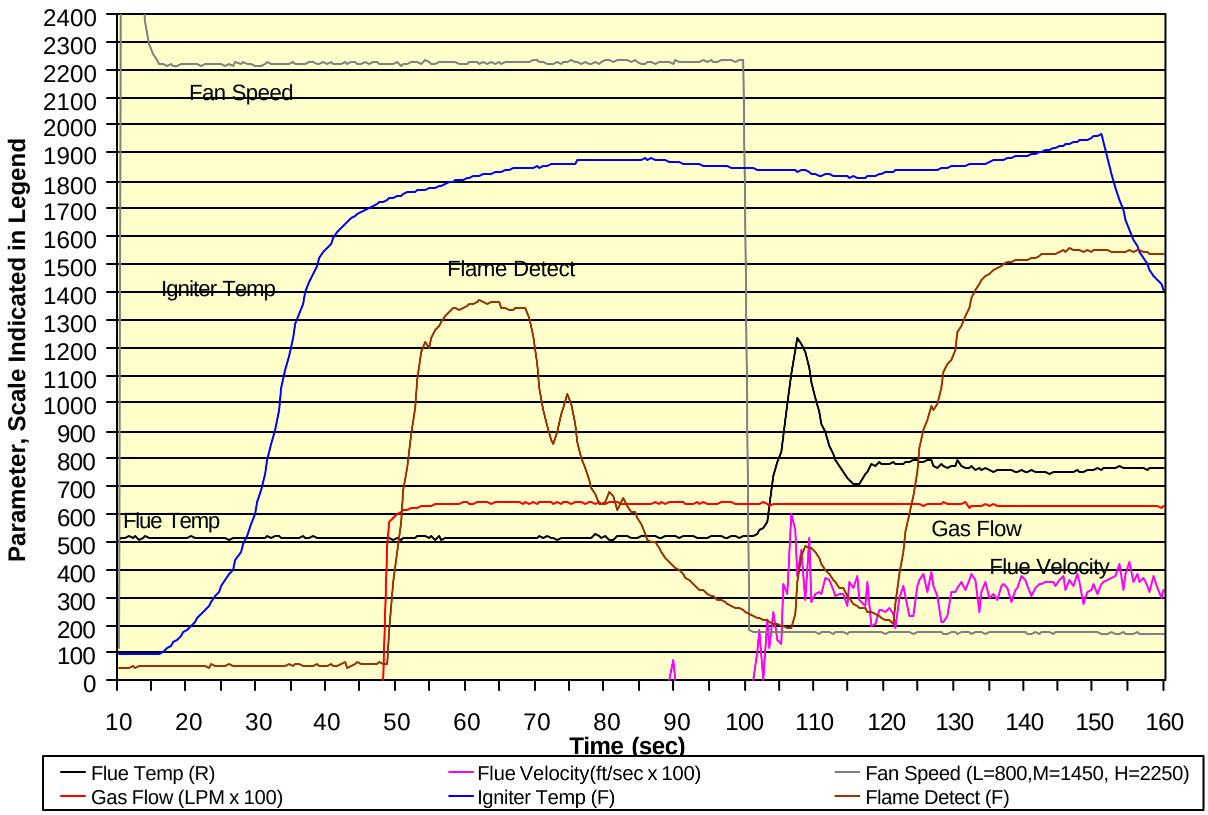


Figure 14. Test of Suction-Draft Range and Range Hood at High Fan Speed

Similar Test at Medium Fan Speed

Additional tests were run at different speeds and clearances. Figure 15 is a test conducted at a medium (number 2) fan speed, but is otherwise similar to Run 10. The effect of the range hood fan on ignition at medium speed begins as in Run 10. However, in a 40-sec transition to stability, the faltering flame recovers and the flue gas velocity (flow) rises to normal combustion levels. Diminished flue gas velocity indicates incomplete or halted combustion since the flue is the one exit for the gas products of combustion.

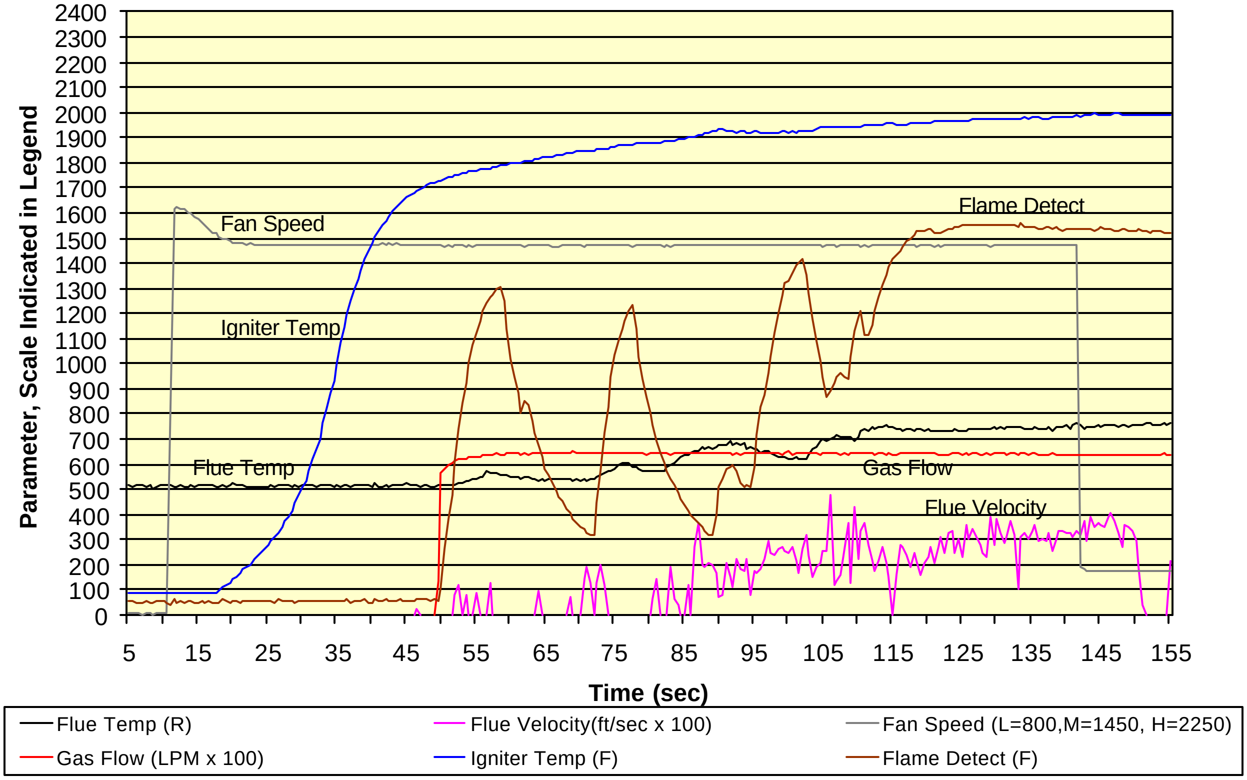
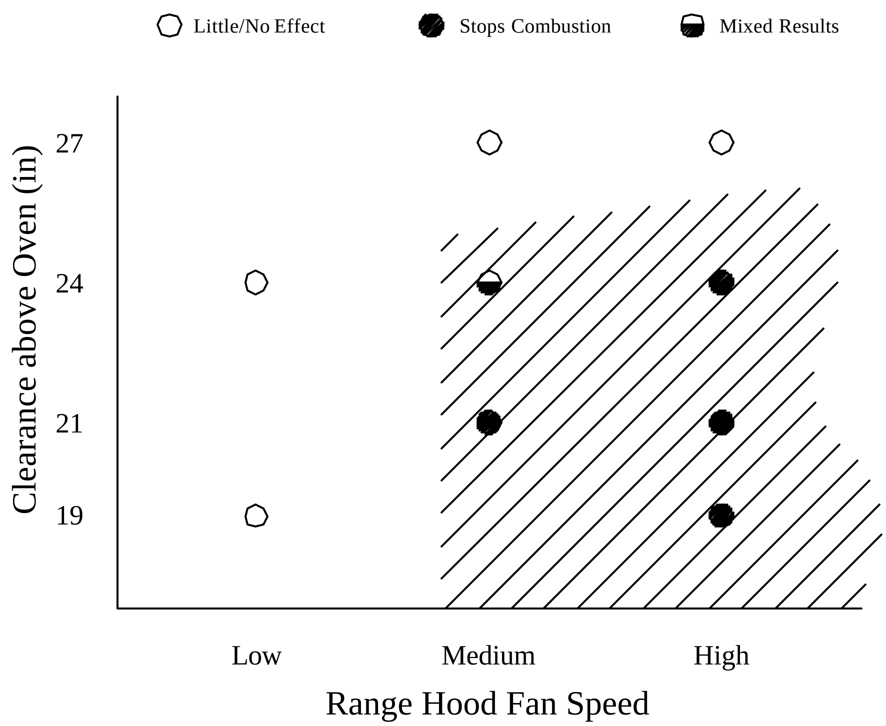


Figure 15. Test of Suction-Draft Range and Range Hood at Medium Fan Speed

Affect of Hood Clearance and Fan Speed

The results of all Suction-draft tests are summarized in the effects chart of Figure 16. Clearance is plotted against fan speed. The other two factors were fixed at a hood-oven sequence and with no warm-up (cold oven). The chart shows that ignition/combustion problems were not present at the lowest fan speed or at a clearance of 27-in (690-mm). The medium speed test run of Figure 15 is the transitional case and is represented as a half-filled circle in Figure 16. The shaded area signifies conditions in which combustion problems resulting in gas accumulation were documented.

The sequence factor (Table 4), which appliance was turned on first, did not affect the outcome. Because of the approximate 30-second time-delay for the gas valve to open, the order of fan-oven activation was not important. The Warm-up factor, however, had a substantial effect on combustion. All suction-draft effects on oven combustion were associated with starting the oven cold (room temperature). When warmed, the heated mass of the oven itself generates some convective flow up the flue. Smaller in magnitude than that flow produced by the combustion from the burner, the flow still registers as a positive velocity up the flue. In tests involving a warmed-up oven, combustion proceeded successfully at all fan speeds and at all installed clearances.



Shaded area indicates gas accumulation.

Figure 16. Clearance and Fan Speed Effect on Combustion

Video Images of Range Hood Affect on Oven Broiler Combustion

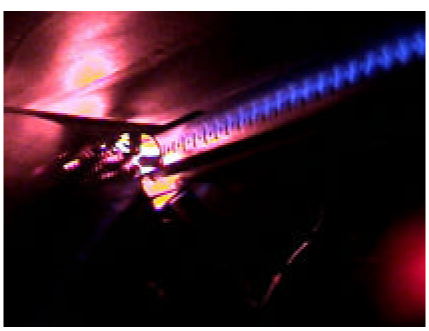
Figure 17 is a view inside the range with normal lighting. Figures 18 and 19 document the typical effect of the range hood on the Suction-draft range when the broiler and range hood are on at the same time. The test conditions are similar to those in the incident (IDI 010418HCC2409) and test run 10: High fan speed with the hood mounted 23.5 in (600 mm) above the range.

Figure 17. View inside Suction-Draft Range

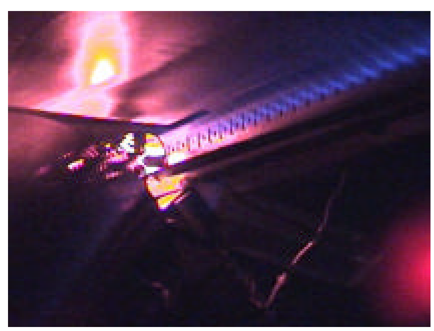
Showing Broiler Igniter and Burner

In Figure 18, the gas starts with somewhat normal combustion (a), but within 1.5 sec the flame is pulled horizontally (b). After 3 sec, the flame is nearly out (c). The flame is out at 6 sec but gas continues to flow (d). Moisture condenses and clouds the oven window.

a) T=0, Gas Valve Opens



b) T=1.5 seconds



c) T=3 seconds

d) T=6 seconds

Figure 18. Start Sequence of Suction-Draft Broiler with Fan On

Tests Opening the Oven Door

A series of tests was conducted in which the oven door was opened after failed combustion. The tests simulated the known conditions in the incident (Table 4, run 10) in which the victim opened the door after starting the fan and oven broiler. In conducting these tests, the delay time in opening the door was varied, beginning at 30 sec after the gas valve opened at $t_{gas} = 0$. Figures 19a through 19c show a sequence in a test with a large flare-up. In this test, Figure 19(a) occurs 88 sec after the broiler is turned on ($\Delta t_{start} = 88$ sec) and 56 sec after the gas valve opens ($\Delta t_{gas} = 56$ sec). The flare-up in Figure 19(a) is internal and was fueled by the accumulation of gas over that 56-sec period. The oven door is opened slowly ($\Delta t_{gas} = 78$ sec) using a long rope. [The diagonal lines in the images are restraint ropes]. Figure 19(b) shows a flare-up outside the oven box about 1.0 sec later. The column of flame reaches upward in Figure 19(c). The series of images in Figure 19 model the incident scenario as reported.

a) Flare-up before opening. b) T=1.0 sec after Door Opened. c) t=1.2 sec

Figure 19. Opening Oven Door of Suction-Draft Range after Failed Combustion

Internal flare-ups first occurred in the range 25 sec < Δt_{gas} < 60 sec. Repeated tests with varying delays in opening the door indicated that successive internal flare-ups occurred at quickening intervals and that they, along with the delay time, established a time window for a successful external flare-up. Based on test results, this time window was 54 sec < Δt_{gas} < 78 sec after the gas valve opened. Below this range, the initial ignition (e.g. Figure 14 at 60 sec) consumed some gas and there was less time for gas accumulation. Outside that range, the internal flare-ups consumed gas, which then slowly warmed the flue. The combustion within the oven then stabilized. Typically, to create an external flare-up, the door was opened before or immediately after the first internal flare-up.

Discussion

Laboratory tests were conducted on two gas ranges. One oven test of the original incident range investigated a report of a delayed gas ignition and explosion using the bake burner. The other range was analyzed for failed combustion of the broiler burner when used with a range hood, as reported in an investigation. Tests were also conducted on eight hot surface igniters. Oven igniters were subjected to long-term cycling to determine the effect of age on performance.

A recreation of the incident was sought for the Delayed-ignition range by varying the operating conditions. Exact conditions during the incident are not known. A broad investigation was made into the effects of voltage, gas pressure, igniter age, and availability of power. In contrast, the incident conditions are documented for the Suction-draft range because the CPSC investigator recreated the conditions on-site. For that range, subtle variations in range hood performance, clearance, and fan speed were investigated.

Delayed-Ignition Range

Tests were conducted to determine if ignition timing varied with varied conditions. In fact, all the parameters had some effect on the timing. The voltage tests show that the overall combustion time schedule increases for lower voltages and decreases for higher voltages. In decreasing, the gas valve opens sooner. In the worst case at 130 V, the gas valve opened 8 sec after the igniter reached combustion temperature, T_{min} (Figure 8). To compare, in the normal 110-125 V operating range, the time is 11 sec to 14 sec. For gas to escape without combustion, the valve should open *before* the igniter reaches T_{min}. The graph in Figure 8 does not suggest any convergence of the delay times in any reasonable voltage range. Evidence does not support voltage variation as a factor that would adversely affect ignition timing.

A change in the temperature-current characteristics of the igniter could result in the igniter drawing a current that actuates the gas valve before the igniter heats to T_{min}. The characteristics of the Delayed-ignition igniter can be compared to the replacement igniter (Figure 7) and the aged spiral-type igniter #3 from the cycle tests (Table 3). The incident igniter heats up more slowly than the replacement igniter does-- perhaps a sign of the age of the incident igniter. Spiral igniter #3 exhibited the most change in temperature characteristics of the aged igniters. Indeed, spiral igniter #3 took 34 sec to reach T_{min}, compared to 9 sec for the incident igniter, when installed in the Delayed-ignition range. However, the more important gas valve delay was 11 sec after T_{min} for spiral igniter #3 compared to 11 sec for the incident igniter. This indicates that the two igniters have comparable gas valve delays and hence margins of safety. The rate of temperature rise of the igniter does not appear to diminish the key timing characteristic between the gas valve and the igniter.

A marked decline in maximum temperature and current capacity was evident for the eight cycled igniters. All the igniters declined from above 2300 °F (1260 °C) (one dropping to 1950 °F (1070 °C)) after 61,000 cycles. These temperatures are still significantly above the ignition temperatures of natural gas (1300 °F, 700 °C) or propane (920-1125 °F, 500-600 °C). Operating spiral igniter #3 in the Delayed-ignition range demonstrated that the degraded properties of an aged igniter do not compromise the margin of safety of the self-proving ignition circuit.

The range's gas regulator acts to buffer higher line pressures and supplies gas to the burner at no greater than the rating of 4 in w.g. (1000 Pa). Lower gas line pressures were investigated since they do affect regulator output pressures to the oven burner. Testing on the Delayed-ignition range indicated that gas line pressures below the regulator rating would result in low-pressure flows to the burner. Line pressures down to about 2 in w.g. (500 Pa) resulted in normal ignition timing and combustion for the broiler burner. Below that pressure, however, gas would not ignite consistently and either ignition was delayed or no ignition occurred. The flow of non-combusted gas into the oven box caused intermittent explosions in the 1.5 to 2.0 in w.g. (370-500 Pa) range. Below that range, no combustion occurred in the 4-minute tests but gas continued to flow. Because the oven has a self-proving ignition system, gas flow continued as long as the oven thermostat called for heating. Without combustion, the thermostat continuously energized the ignition circuit, heating the igniter and keeping the gas valve opened. These low gas line pressures would not be normal, and would be expected to trigger a service call. However, low supply pressures to the oven are conceivable with the possibilities of intermittent service and constricted or long runs of gas piping leading to the range. These factors were possible, but were not reported for this incident range.

Suction-Draft Range

Determining the cause of the incident associated with this gas range/range hood combination was the main goal of this investigation. Additional tests were conducted by varying certain factors that were selectable by the installer (installed clearance) or the user (fan speed, order appliances are turned on, preheating, time delay in opening oven door). Clearance and fan speed had the greatest affect on the combustion performance of the Suction-draft range, although the timing of the door opening was the critical factor in creating an external flare-up.

In the incident, the victim turned the range hood on high speed, then turned on the oven broiler. He then opened the oven door a short time later and a fireball from the oven burned his face. Comparison of baseline tests with no fan and tests recreating the incident conditions (run 10, Table 4) indicate that the fan caused the improper ignition within the oven. Figure 14 showed that although gas is initially ignited, combustion is not maintained. Also revealing is that there is no flue velocity – no flow, which would normally rise abruptly after ignition (Figure 13). Outward flow from the flue indicates that combustion of the natural gas is occurring. Inspection of the range hood indicated that the air is discharged towards the oven flue. This suggests that the range hood fan is pressurizing the flue, effectively blocking the exit of flue gases. With combustion stopped, the thermostat continued to call for heat and supplied current through the self-proving ignition circuit. This maintained the igniter above combustion temperatures and kept the gas valve open. There is no other feedback to the ignition system and the gas valve remained open and poured gas into the oven box, which later ignited.

Videotaped images demonstrate the hazard to the user of the range. Figure 18 showed the burner flame extinguishing during the incident test. The flame is pulled away from the burner over a 3-sec period. When the flame is extinguished, the natural gas accumulates in the oven. Figure 19 showed the eruption of flame after the door is opened 78 sec after the gas first flows. A mixture of non-combusted gas within the oven and outside air comes into contact with the still-hot igniter, causing a sudden flare up. The victim's facial injuries in the incident are consistent with his position in front of the door.

Other tests at differing parameters indicate that a combination of fan speeds and clearances exists in which oven combustion fails. This zone comprises medium and high fan speeds and clearances of 23.5 in (600 mm) and below. Additionally, the hazardous external flare-up is sensitive to the timing in opening the oven door. Tests indicate that external flare-ups occur when the door is opened at approximately one minute after the gas valve opens. After about one minute, normal combustion slowly establishes following a warming of the flue by the consumption of accumulated gas by internal flare-ups. Apparently, the warmed flue creates enough convection to counter the pressurization by the range hood fan.

The incident conditions and possibility of hazard were confirmed in the on-site investigation. The incident oven flare-up was also recreated at the engineering laboratory. The effect that the fan has on the oven combustion is robust and has been shown to exist over a wide range of fan speeds and clearances. The external flare-up was shown to occur over a narrow time frame in opening the oven door.

Conclusions

This project focused on self-proving ignition systems, which represent the dominant ignition type for residential gas ranges and ovens on the market. Any ignition system must be designed to prove the existence of the ignition source. These tests demonstrated that while the hot surface igniters and gas valves coordinated operation through a shared circuit, the system is not failsafe and the presence of gas at the burner was not proved. When stressed with low gas line pressure or suction drafts, the resulting incomplete combustion and accumulation of gas can result in delayed combustion and hazardous combustion outside the range itself.

In the course of this investigation, the following conclusions were reached:

1. The broil burner of the Suction-draft gas range releases potentially explosive amounts of natural gas when operated with the downdraft exhaust of the selected range hood at medium and high speeds for installed clearances of 23.5 in (600 mm) and below.

2. The bake burner of the Delayed-ignition gas range releases non-combusted natural gas when operated at line pressures below 2.0 in w.g. (500 Pa) and small internal explosions occur when operated in the range 1.5 to 2.0 in w.g. (370-500 Pa).

3. The two gas ranges tested have no means to detect and react to the release or accumulation of non-combusted gases.

4. The self-proving ignition systems of the ranges maintain ignition temperatures irrespective of the status of gas flow.

5. Igniter aging does not appear to adversely affect the function of the self-proving ignition system.

Recommendations

1. The clearances for compatible installation of specific combinations of gas ranges and downdraft range hoods should be stated in their respective installation instructions.

2. Industry standards groups should be encouraged to add requirements that installation instructions specify minimum acceptable clearances between range tops and range hoods.

3. Industry awareness should be pursued by staff with a letter to the appropriate standards organizations and trade associations alerting them to the findings in this report.

4. CPSC staff should continue to monitor reports of range or oven explosions with emphasis on range hood compatibility and the possibility of low gas line pressures.