Consumer Product Safety Commission ("CPSC") Staff's Statement on Primaira, LLC's Report, "Testing of Ignition Prevention Capabilities of a Pan Temperature Control System in a Gas Cooktop" [1]
September 2015

The following contractor report titled, "Testing of Ignition Prevention Capabilities of a Pan Temperature Control System in a Gas Cooktop," presents the results of testing conducted by Primaira, LLC, under Health and Human Services ("HHS") Contract No. HHSP233201300146A.[2] Primaira performed this research to aid CPSC staff's efforts to develop a supporting rationale for requirements for the voluntary safety standards for gas and electric ranges to reduce surface cooking fire incidents.

Under Contract No. HHSP233201300146A, Primaira conducted a series of tests to establish the ignition characteristics of the test gas range and to evaluate the capabilities of the burner control system that Primaira developed under Contract No. GS11T10BJM6060, as reported in *Pan Temperature-Limiting Control Technology to Reduce Incidence of Unattended Cooking Fires*. Primaira's testing under Contract No. HHSP233201300146A showed that the burner, without any thermostatic control, was able to ignite oil being heated in pans of various materials, depending on the burner flow rate and pan material. Primaira's evaluation of the ignition prevention capabilities of the burner temperature-limiting control system indicated that the control system successfully prevented oil from being heated to ignition.

The burner was modified to integrate the temperature-sensing hardware, without assessing the impact on the performance tests in the *American National Standard for Household Cooking Gas Appliances* - ANSI Z21.1, to which the range had been originally certified. Therefore, the effects of modifications to the burner, *e.g.*, blocking two flame ports to prevent direct impingement on the thermal sensor housing, on the range's overall performance and efficiency were not quantified. Consequently, CPSC staff recognizes that integrating temperature-sensing hardware into existing product designs will require independent engineering development and testing by each of the manufacturers. Additionally, to achieve different levels of performance, a gas range manufacturer may feature more than one burner configuration across its product lines, and this could necessitate independent development projects for each configuration. Although staff believes that these re-design and testing efforts are achievable, more time may be needed before submitting ignition test proposals for ANSI Z21.1. CPSC staff will continue to work with the Association of Home Appliance Manufacturers ("AHAM") and its member companies toward the ultimate goal of developing tests and requirements to address cooking oil ignitions for gas cooktops and ranges, as indicated in AHAM's October 7, 2014 press release.[3]

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[1] This statement was prepared by the CSPC staff, and the attached report was produced by Primaira, LLC, for CPSC staff. The statement and report have not been reviewed or approved by, and do not necessarily represent the views of, the Commission.
[2] The DHHS Program Support Center executed Contract No. HHSP233201300146A on behalf of U.S. Consumer Product Safety Commission (CPSC) staff, in accordance with Modification No. 25 to Interagency Agreement No. CPSC-I-13-0010.
[3] "Home Appliance Industry Announces Plan to Reduce Unattended Cooking Fires"; Association of Home Appliance Manufacturers, https://www.aham.org/index.php?ht=a/GetDocumentAction/i/74829; October 2014.

PRIMAIRA

Testing of Ignition Prevention Capabilities of a Pan Temperature Control System in a Gas Cooktop

Final Report

Period of Performance:

October 2013–February 2014

Report Prepared for:

U.S. Consumer Product Safety Commission

Contract No.: HHSP233201300146A

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Executive Summary

Background, Objectives and Approach

Since 1995, the U.S. Consumer Product Safety Commission (CPSC) has supported work aimed at identifying and mitigating the risks of unattended cooking fires. An estimated annual average of 149,500 cooking equipment-related fires during 2006–2008 accounted for nearly 40 percent of the average annual estimate of total residential fires for the same period. As such, cooking equipment accounted for the largest percentage of residential fires in this time period. Range/oven fires account for approximately 14,600 non-confined incidents per year (*i.e.*, fires that spread beyond their originating item). (D. Miller and R. Chowdhury; 2006-2008 Residential Fire Loss Estimates; U.S. Consumer Product Safety Commission, 2011).

Researchers at several organizations have reviewed a wide variety of potential hazard detection schemes and have tested the efficacy of some of them in practical test environments. This research has demonstrated that pan-bottom temperatures are reliable indicators of pending ignition that can be exploited to initiate automatic corrective actions to prevent food ignition.

In 2010, Primaira LLC, under contract to the CPSC, developed a set of prototype sensor and control systems capable of detecting pre-ignition conditions and then controlling heat input for residential gas, electric coil, and glass ceramic cooktops. The algorithms for the electric coil, gas, and glass ceramic cooktop controls were refined until all cooking processes for all pan types tested provided results that were equivalent to the cooking performance without the controls activated, while at the same time preventing the pan from exceeding 700^{o}F. All boil times with the controls were within the standard deviation of the boil test. Cooking performance for sear, blacken, simmer, and sauté modes with the controls active were all equivalent to non-control-active tests. All cooking and temperature-limiting tests were conducted with aluminum, cast-iron, and stainless steel pans of various configurations. However, control system operation to confirm fire mitigation performance, was not tested at that time

The objective of this subsequent project was to test the ignition-prevention capabilities and other key performance criteria of the pan-temperature-limiting controls implemented into the gas cooktop. Baseline ignition testing was conducted for a test matrix consisting of four different gas heating rates, six different pan types, and two oil amounts. These tests were conducted without the controls activated. Ignition-prevention testing was conducted with the controls activated for 18 tests with the same variables as the baseline tests. Additional performance testing was conducted with warped pans and pans located off-center of the burner.

Fire Test Facility

All testing was conducted in Primaira's cooktop fire test facility. This facility consists of a modified 20-foot ISO Container, with a front area for data acquisition and observation, and a back area with exhaust and fire protection for cooktop fires. The cooktop fire test facility was updated with plumbing, instrumentation, and safety systems to accommodate gas cooktops. The instrumentation added to the facility included a rotameter, a dry gas meter, two manometers, and a pressure transducer. The added safety systems installed were two flame arrestors, a solenoid valve, and a gas sensor alert monitor. The ventilation hood was updated with a large blower to handle the large amounts of smoke generated while testing.

Test Results- Baseline Testing

Baseline testing (no controls) defined the conditions that resulted in fires and the oil and pan temperatures at ignition. Of the 15 independent conditions tested, eight resulted in ignition of the oil.

- Oil did not ignite unless the surface oil temperature exceeded 670°F.
    - For medium-sized pans with 150 ml of oil, ignition occurred at an average oil temperature of 705°F, with the highest oil ignition temperature of 739°F, and the lowest oil ignition temperature of 679°F.
    - For larger pans with 1000 mL of oil, the average oil temperature at ignition was 690°F, with the highest oil ignition temperature of 704°F, and the lowest oil ignition temperature of 672°F.
- Oil in stainless steel pans reached the critical ignition temperature faster than oil in cast iron or aluminum pans.
- Higher burner input rates led to shorter ignition times.
- Oil ignition properties change when oil is maintained at high temperatures (>600°F) for long periods of time, this property change can inhibit ignition.
- Ignitions occurred at gas heating rates from 11,000 Btu/hr. to 18,500 Btu/hr.
- No ignitions occurred at a heating rate of 8,000 Btu/hr. with the combination of pans and oil volume tested.

Test Results—Testing of Controls

The testing of the pan temperature-limiting controls was completed with no ignitions for any of the tests conducted. Comparing the tests with and without pan temperature-limiting controls operating showed little, if any, effect on the initial oil heat up rates. This comparison is important because the comparison indicates that cooking times will not be impacted by the ignition controls. The pan temperature-limiting controls maintained the oil temperature safely below ignition threshold temperatures. The maximum oil temperature reached in tests with 150 mL oil averaged 556°F for each of the pan types tested. This is more than 100°F below the lowest oil ignition temperature seen without the controls operating. The maximum oil temperature reached for 1000 mL oil tests averaged 526°F over each of the pan types tested.

Conclusions and Summary Recommendations

The objectives of the project have been met. The ignition control performance of the pan-bottom temperature-limiting control scheme integrated into a gas cooktop was confirmed. No fires occurred in any of the tests conducted with the control system operating. This included operation at gas heating rates roughly twice the level used to develop the control algorithm. Without the controls in place, oil ignition would occur at more than half of the operating conditions tested. No significant adverse effects of the controls on cooking or operating performance of the cooktop were observed.

We believe that the technology has significant merits as a performance enhancement. The pan temperature limiter will prevent food from "burning" (*i.e.*, overcooking); most foods are not cooked acceptably on the highest input. This control approach can distinguish between water boil and other cooking functions. Therefore, the boiling time will not be increased to provide the desired fire-mitigation performance. It is possible that commercial introduction of the technology would be faster if it were provided not as a "safety" feature, but rather, as a performance feature. This desirable performance feature would bring with it a mitigation of the likelihood of cooktop fires.

1. Introduction

The U.S. Consumer Product Safety Commission (CPSC) initiated a Range Fire Project in 1995, to identify measurable pre-fire conditions and lessen the risk of unattended cooking fires. Over the course of this project, work has been conducted by researchers at the National Institute of Standards and Technology (NIST), the CPSC, Energy International (EI), Arthur D. Little, Inc. (ADL), and Advanced Mechanical Technology Inc. (AMTI), to review a broad range of potential detection systems and to test the efficacy of a few systems in practical test environments. The research demonstrated that food temperatures and pan-bottom temperatures are reliable indicators of pending ignition and that pan-bottom temperatures can be exploited to initiate automatic corrective actions to prevent food ignition.

In 2010, Primaira, LLC, conducted a study under the auspices of the CPSC to refine the temperature sensor design and controls implementation to realize a sufficiently robust and effective solution. (Contract No. GS11T10BJM6060). Sensor and control systems were tested for feasibility in electric coil, glass ceramic, and gas-fired cooktops. The ability of the cooktops with fire mitigation control to function properly (*e.g.*, boil water, sear, sauté, blacken) without loss of performance compared to standard cooktops was tested. In a subsequent project, the ability of the sensor and control systems to mitigate oil fires in electric cooktops was tested. The objective of this program is to confirm that the technology can reduce cooking fires in gas cooktops.

1.1 Cooking Fires

According to the U.S. CPSC report on residential fire loss estimates published in July 2011, cooking equipment accounted for the largest percentage of residential fires in the period from 2006 to 2008. In this period, there was an average of 14,600 range/oven fires annually. These fires were associated with an annual average of 120 deaths, 1,390 injuries, and $267 million in property damage. (D. Miller and R. Chowdhury; 2006−2008 Residential Fire Loss Estimates; U.S. Consumer Product Safety Commission, 2011).

To address the cooking fires issue, a Cooktop Fire Working group was formed in August 2001, at the request of CPSC staff after ADL’s study results were presented to the Underwriters Laboratories Inc. (UL) 858 Standards Technical Panel (STP). The Cooktop Fire Working Group developed the test protocols and common acceptance criteria, referred to as the Technical Feasibility Performance Goals (TFPG). The TFPG were intended to provide guidance to engineers, inventers, entrepreneurs, or others who may be involved with the design of a device intended to reduce cooktop fires by sensing an over-temperature condition. The Cooktop Fire Working Group has stated that the TFPG are available for guidance but are not meant to be final requirements. The TFPG focuses on devices that could be incorporated into a cooktop surface element/burner and that would interface with a cooking utensil (pan) to sense the over-temperature condition.

1.2 Previous Work to Develop Sensors/Algorithms

The pan-temperature control system being tested for ignition-prevention capabilities and other key performance criteria was developed in 2010, under the auspices of the CPSC (Contract No. GS11T10BJM6060). The scope of that project was to design, fabricate, and test prototype sensor and control systems capable of detecting pre-ignition conditions and then controlling heat input in residential gas, electric, glass ceramic, and induction cooktops. The general approach was to use a relatively inexpensive but effective temperature sensor located in the cooktop to measure or infer temperature at the bottom of the pan. In all cases, we used a resistance temperature detector (RTD) sensor in our prototype systems. For gas burner and electric coil cooktops, we developed a rugged pan-bottom temperature sensor that was positioned to contact the bottom of the pan. For the glass ceramic cooktop, we used an RTD sensor positioned beneath and contacting the underside of the glass ceramic.

The pan-bottom temperature sensor and control systems that were implemented in the electric coil, gas, and glass ceramic cooktops all maintained pan temperatures to below the threshold limit of 700°F. This temperature-limiting control was effective on initial heat-up (dry cook) tests, as well as for a boil-dry situation, or a condition in which cooking was completed, food was removed, but the hot empty pan was left on the element/burner.

The algorithms for the electric coil, gas, and ceramic glass cooktop controls were refined until all cooking processes for all pan types tested provided results that were equivalent to the cooking performance without the controls activated, while at the same time preventing the pan from exceeding 700^{o}F. All boil times with the controls were within the standard deviation of the boil test. Cooking performance for sear, blacken, simmer, and sauté modes with the controls active were all equivalent to non-control-active tests. All cooking and temperature-limiting tests were conducted with aluminum, cast-iron, and stainless steel pans of various configurations.

In that testing program, we confirmed that limiting the temperature of the pan bottom to 700°F would not compromise cooking modes, including boiling, searing, sautéing, frying, blackening, or simmering. However, no ignition tests were conducted at that time to evaluate the sufficiency of the 700°F limit to avoid fires when cooking with oil.

1.3 Project Objective

The objective of this project was to test the ignition-prevention capabilities and other key performance criteria of the pan-bottom temperature-limiting controls implemented into the gas cooktop (previously developed and tested for cooking performance under Contract No. GS11T10BJM6060.)

1.4 Implementation Approach

1.4.1 Cooktop

The gas cooktop with the integrated sensor used for testing in this project is shown in Figure 1.

To avoid direct flame impingement on the sensor, we blocked two of the slot-shaped ports in the burner directly adjacent to the sensor. That was the only modification made to the burner itself for the sensor integration.

Figure 1: RTD Sensor Integrated with the Largest Burner of the Gas Cooktop

A calibration was performed on the cooktop's burner control knob to establish repeatability of control settings. This calibration mapped out burner firing rates to burner control knob positions. The gas flow rate of each burner on the cooktop was measured at the "High" setting and compared to the specified output. We measured gas flow in two ways: with a rotameter, which provides an immediate indication of flow rate, and with a dry test meter, which provides a more precise measurement but is not a continuous reading. The two flow readings were consistent and corresponded to the manufacturer-specified burner firing rates. We then characterized the burner firing rate at multiple dial set points for the burner instrumented with the fire mitigation technology. Table 1 shows that our measured heating rates of each burner are consistent with the manufacturer specifications for each burner. Figure 2 shows the dial settings used for testing and the heating rates associated with the dial settings.

Manually locating a burner control knob precisely to a desired setting was not repeatable-variations in firing rate for repeated tests intended to be conducted at the same firing rate were significant. Our approach, therefore, was to leave the burner control knob at one setting for all tests conducted at that firing rate. We turned gas on and off via a control valve upstream of the cooktop. The burner was ignited by turning the control knob of a different burner to “light.” All ignitors issue a spark when one control knob is set to “light.”

Table 1: Burner Heating Rates Tested and Specified

Burner Name	Burner Specified BTU/hr.	Measured BTU/hr.
High Output Burner	11,000	11,100
Precise Simmer Burner	5,000	5,100
All-Purpose Burner	9,500	9,700
Dual-Flame Stacked Burner	18,000	18,500

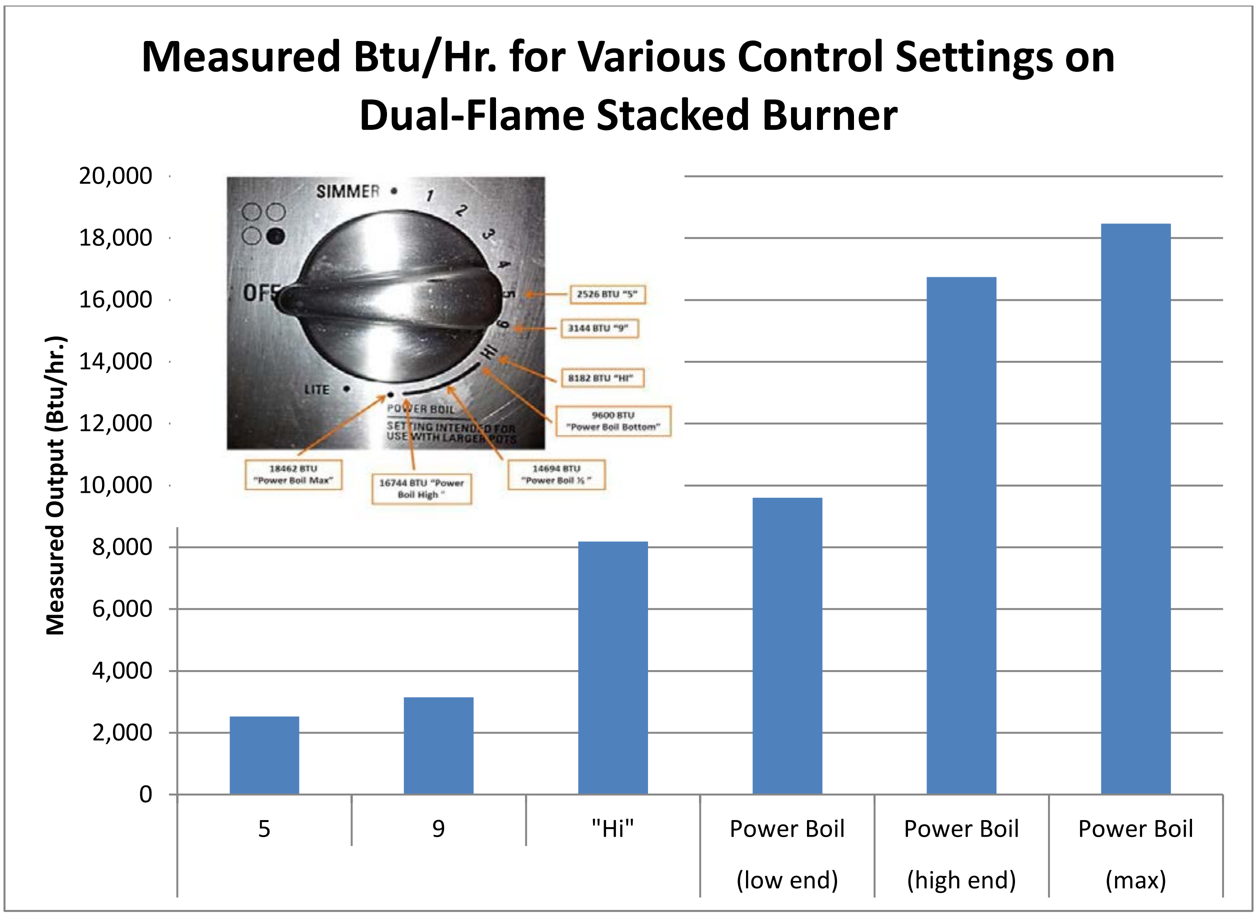


Figure 2: Heat Rate Calibration for the Gas Burner Tested

1.4.2 Sensor/Algorithm

This control algorithm had been developed and implemented to prevent ignition of pan contents without interfering with normal cooking. The control algorithms were based initially on the requirement that the pan temperature must remain below 700°F to avoid ignition. The sensor is a platinum Resistance Temperature Detector (RTD) enclosed in a metal housing (Figure 3 and Figure 4). RTDs are temperature sensors that contain a resistor that changes resistance with temperature. The RTD sensor is spring loaded to ensure direct and constant contact with the cookware. The control algorithm uses a combination of rate of change and threshold monitoring to decide when to decrease the gas flow rate.

Figure 3: RTD Sensor Being Engaged by a Stainless Steel Pan

Figure 4: Pan Bottom Temperature Sensor

The controls continuously monitor the temperature of the cookware as soon as the burner is turned on. The rate of change (Δ) of the temperature of the cookware is calculated every 10 seconds. The controller regulates the flow of gas to the burner using the control logic described in Table 2.

Table 2: Control Logic Summary Table

Condition Statement	Burner Flame
Sensor Temp < 515˚F	Full
Sensor Temp ≥ 550˚F AND Sensor Δ ≥ 1.0	Reduced to 2500 Btu/hr.
Sensor Temp < 550˚F AND Sensor Δ < 1.0	Full
Sensor Temp ≥ 585˚F	Reduced to 2500 Btu/hr.

Once the user turns on the burner, the controls monitor the cookware temperature. If the cookware temperature is less than 515˚F, the input rate to the burner is not impacted. When the sensor detects that the cookware temperature is 550˚F or above, the controls compare the calculated slope to the slope set point of 1.0. If the slope is greater than 1.0, and the sensor measures the temperature to be 550˚F or above, the gas flow is restricted and the flame reduces to 2,500 Btu/hr. The burner will stay at 2,500 Btu/hr. until the sensor detects that the cookware temperature is less than 550˚F and the slope is less than 1.0. Once both of these conditions are met, the burner flame returns to the user's set point. After the initial heat-up of the cookware, the slope of the cookware temperature profile over time tends to level off well below the 1.0 set point, and the controls will only reduce the burner flame if the cookware temperature rises to or above 585˚F. The burner flame returns to the user's set point again as the temperature of the cookware drops below 585˚F.

The algorithm was unchanged from the original throughout the testing.

1.4.3 Pans

The ignition tests were conducted using six different pans. The pans were selected based on readily available materials and sizes. Table 3 describes the material, size, and brand of each of the pans purchased for this program. Three materials were tested: aluminum (AL), stainless steel (SS) and cast iron (CI). Each pan was instrumented with K-type thermocouples at three defined locations on the pan's cooking surface. These locations were chosen to gain a sense of the temperature spread across the pan's cooking surface. These locations are defined as the center of the pan (c), the radius of the pan (r), and half the distance between the center and the radius of the pan (1/2 r). Figure 5 illustrates the placement of pan thermocouples.

Table 3: Pan Index Table

pan index	material	size
SS-AC-10	SS	10"
SS-AC-11	SS	11"
AL-CAL-10	AL	10"
AL-CAL-12	AL	12"
CI-EM-10	CI	10"
CI-EM-12	CI	12"

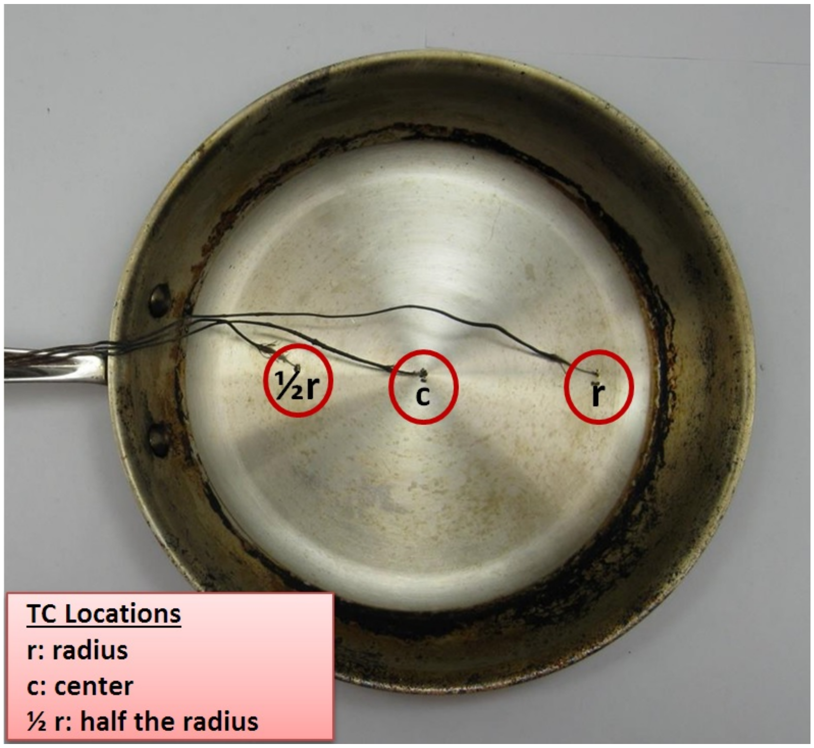


Figure 5: Thermocouple Locations on Pan

1.4.4 Oil

All ignition tests were conducted with a name brand canola oil, purchased in 1.25 (5 quart) gallon jugs at a local retail supermarket. Canola oil was selected because of its prevalence in the market, its low ignition point, and for consistency with oil ignition tests being conducted on electric cooktops. Tests conducted in a 10-inch diameter pan used 150 ml (137 grams) of oil. Tests conducted in 11-inch or 12-inch pans used 1,000 ml (915 grams) of oil. No other type or amounts of oil were used for testing.

2. Test Approach

2.1 Test Facility

Facility

All testing was conducted in Primaira's cooktop fire test facility. This facility consists of a modified 20-foot ISO Container, with a front area for data acquisition and observation, and a back area with exhaust and fire protection for cooktop fires. The cooktop fire test facility was updated with plumbing, instrumentation, and safety systems to accommodate gas cooktops. The facility is shown in Figure 6 and Figure 7. Bottled methane, with heating value of 1,000 Btu per cubic foot, was used as fuel. Commercial grade methane cylinders were used. Methane heating value is within 3 percent to 5 percent of the typical heating value of natural gas; using methane provides the heating value consistency useful for laboratory work.

Figure 6: Outside and Inside Fire Test Facility

Figure 7: Control Room and Ignition Test Room; Gas Cooktop in Ignition Test Room

The instrumentation added to the facility for gas cooktop testing included a rotameter (RM), a dry gas meter (FM), two manometers (PM), and a pressure transducer (PT). The added safety systems installed were two flame arrestors (FA), a solenoid valve (SV), and a gas sensor alert monitor (GS). The ventilation hood was updated with a large blower to handle the large amounts of smoke generated while testing. The process and instrumentation diagram (P&ID) of the fire test facility is shown in Figure 8.

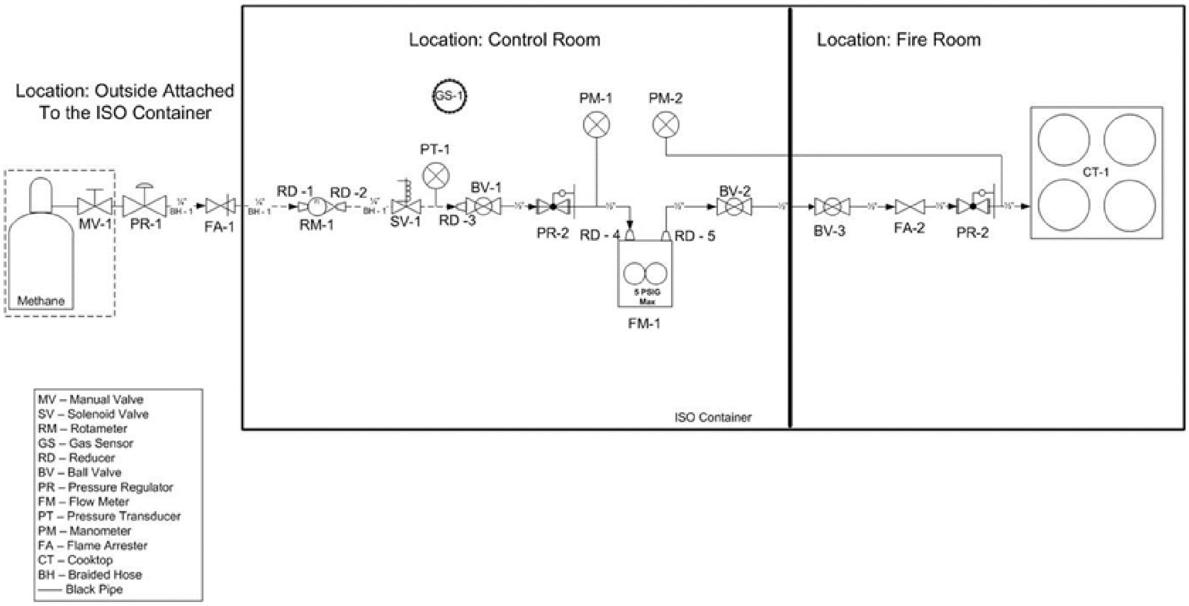


Figure 8: Process and Instrumentation Diagram of Gas System

Test Process:

- Measure pan bottom warpage using feeler gauges in the configuration shown in Figure 9. The left photo illustrates "vertical" warpage measurement, while the right photo illustrates "horizontal" warpage measurement.

Figure 9: Pan Warpage Measurement

- Place spacers of specified thicknesses in pan, under oil thermocouples.

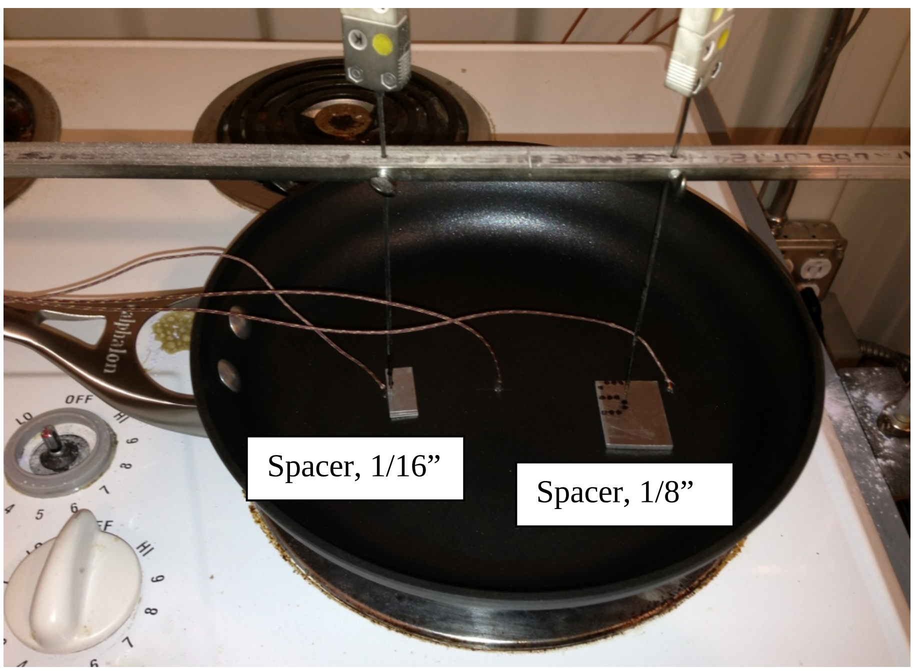


Figure 10: Use of Spacers to Locate Thermocouples in Oil

- Position thermocouples, hold with set screw, and remove spacers.

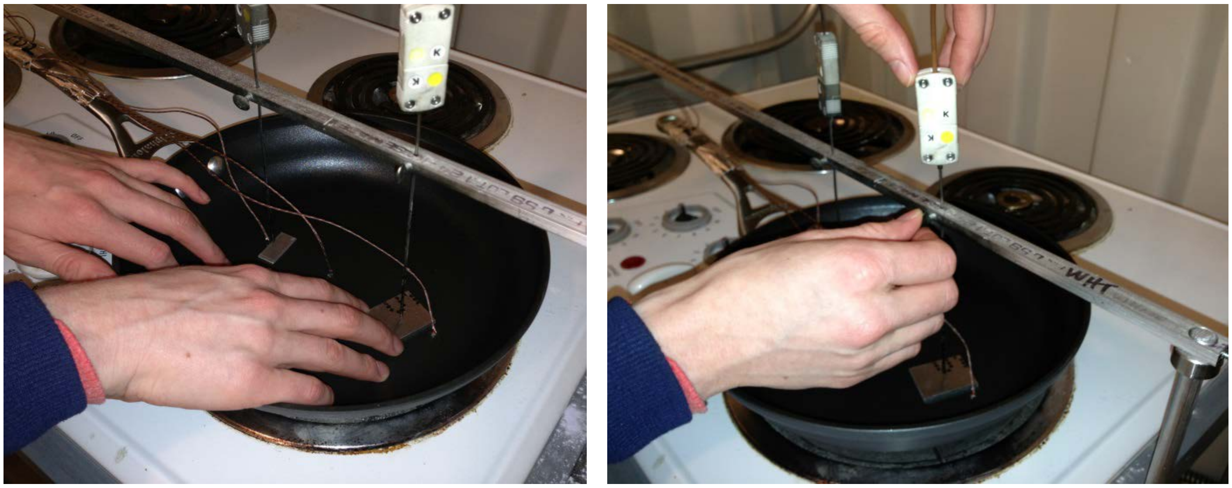


Figure 11: Locating Thermocouples

- Add measured oil to pan, using scraper to get as much oil as possible out of measuring bowl.
- If conducting a baseline fire test, plug ambient temperature RTD into control input to prevent controls from registering temperature increase.

Test Operation

- Watch pan for signs of smoke and ignition on monitor or through door (Figure 12).
- When oil ignites, make Data Acquisition (DAQ) mark with manual switch.
- Shut off gas flow to cooktop using electronic valve.
- Turn fan on high.
- Open door.
- Extinguish fire by pouring scoop of baking soda or Purple K (a dry-chemical fire suppression agent) onto pan.
- Leave burn room.
- Close door until smoke diminishes.

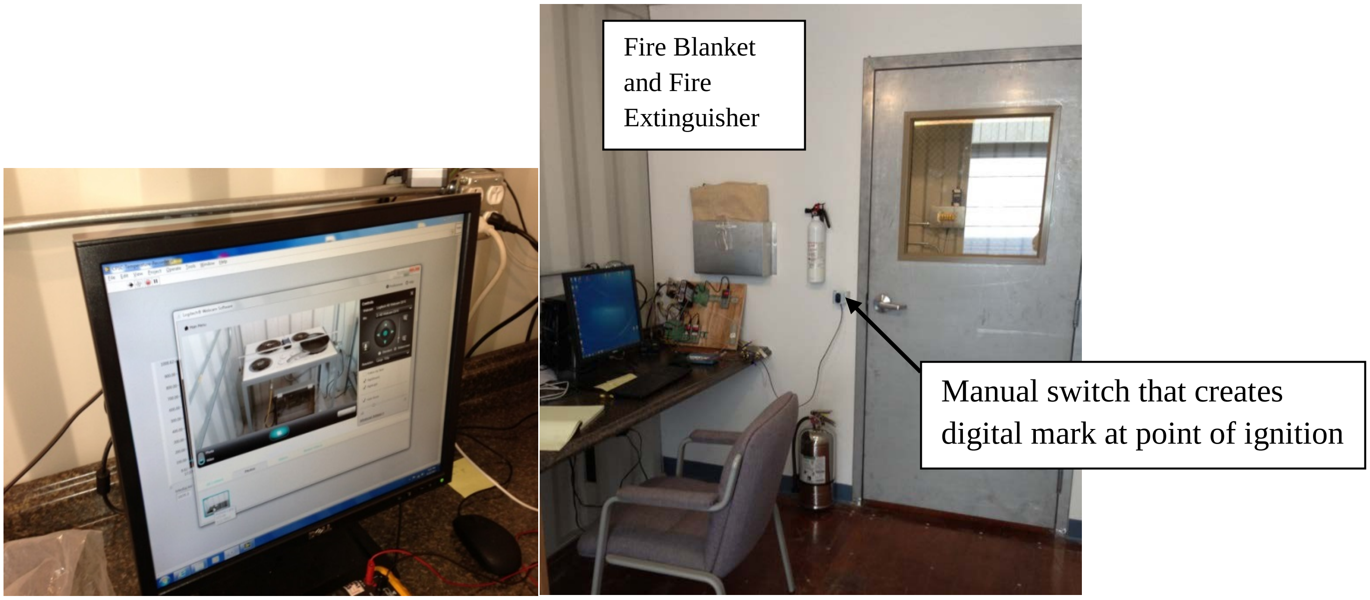


Figure 12: Views of Cooktop: Monitor and Through Door

2.2 Measurements Taken & Sample Data

Pan temperatures, oil temperatures, and gas pressure measurements were logged continuously for all tests. A total of seven temperatures were logged simultaneously: three from thermocouples imbedded in the pan cooking surface, two from thermocouples placed in the oil, the ambient temperature in the fire lab, and one from the RTD sensor (on baseline testing only). Figure 13 illustrates the locations of the pan and oil thermocouples. The gas pressure on the inlet side of the dry gas meter was logged. All measurements were logged every 500 milliseconds using a Measurement Computing data acquisition module (model# USB-2408). The recorded data were saved in a CSV file format. Gas flow through the rotameter was checked visually throughout the test.

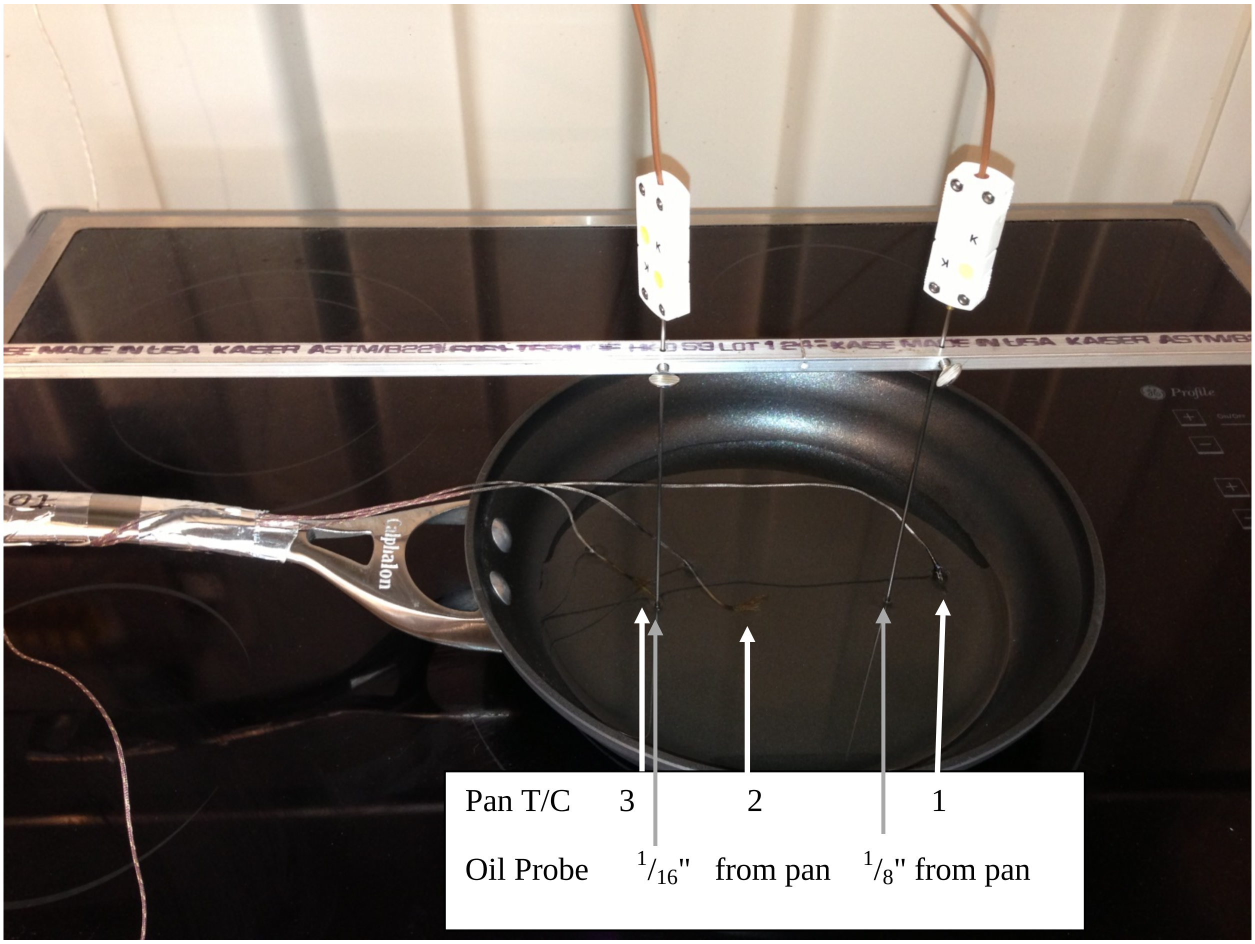


Figure 13: Locations of All Thermocouples in Pans and Oil

2.3 Test Plan

The baseline test matrix is shown in Table 4. The control system test matrix is shown in Table 5. The Test Number is also indicated and is used as an index.

Table 4: Baseline Test Matrix

Oil	Btu/hr.	Pan Type	Pan Diam. (inches)	Test #
150 mL	18,500	AL	10	54
				57
				58
		CI	10	52
		SS	10	53
	15,000	AL	10	59
		CI	10	56
		SS	10	63
	11,000	AL	10	62
		CI	10	60
		SS	10	61
	8,000	AL	10	64
		CI	10	66
		SS	10	65
1,000 mL	18,500	AL	12	68
				69
				70
		CI	12	71
		SS	11	67

Table 5: Control System Test Matrix

Oil	Btu/hr.	Pan Type	Pan Diam. (inches)	Test #
150 mL	18500	AL	10	73
			12	82
		CI	10	74
			12	83
		SS	10	72
			11	90
	15000	AL	10	76
		CI	10	84
		SS	10	77
	11,000	AL	10	81
		CI	10	85
		SS	10	78
1,000 mL	18,500	AL	12	98
		CI	12	91
		SS	11	92
	11,000	AL	12	94
		CI	12	87
		SS	11	86

3. Baseline Test Results

3.1 Summary Table

Baseline testing (no controls) defined the conditions that resulted in fires and what the oil and pan temperatures were at ignition. Table 6 summarizes the test parameters and results for each baseline test conducted.

Table 6: Baseline Ignition Test Summary

Cooktop	Oil Amount	Control Setting	Pan Type	Pan Size (in)	Ignition?	Time to Light (min)	RTD Temp (°F)	Pan Center Temp (°F)	Surface Oil Temp (°F)
Gas Cooktop	150 mL (137g)	18,500 Btu/hr.	AL	10	yes	14.0	814	718	701
					yes	17.9	788	717	695
					yes	17.9	762	718	679
			CI	10	yes	15.6	885	716	694
			SS	10	yes	9.4	801	743	739
		15,000 Btu/hr.	AL	10	no		744	705	648
			CI	10	yes	22.3	728	716	710
			SS	10	yes	9.0	746	730	699
		11,000 Btu/hr.	AL	10	no		656	666	601
			CI	10	no		690	728	707
			SS	10	yes	20.5	701	757	729
		8,000 Btu/hr.	AL	10	no		585	607	541
			CI	10	no		606	646	587
			SS	10	no		613	652	631
	1000 mL (915g)	18,500 Btu/hr.	AL	12	yes	31.5	848	718	703
					yes	33.9	819	714	672
					yes	33.7	848	717	675
			CI	12	yes	32.9	886	728	704
			SS	11	yes	20.8	876	725	697

Shaded red indicates that the oil ignited in this test.

The baseline test results are summarized below:

- Oil did not ignite unless the surface oil temperature exceeded 670°F. Oil temperature greater than 670°F is a necessary but not sufficient requirement for ignition as some long duration tests reached oil temperatures higher than this threshold yet did not ignite.
  - For 10” pans with 150 mL of oil, ignition occurred at an average oil temperature of 705°F, with a high temperature of 739°F, and a low oil ignition temperature of 679°F.
  - For larger pans with 1000mL of oil, the average oil temperature at ignition was 690°F, with the highest oil ignition temperature of 704°F, and the lowest oil ignition temperature of 672°F.
- The 150mL of oil ignited on average in almost 16 minutes.
- The 1,000mL ignition test ignited on average in 30 minutes

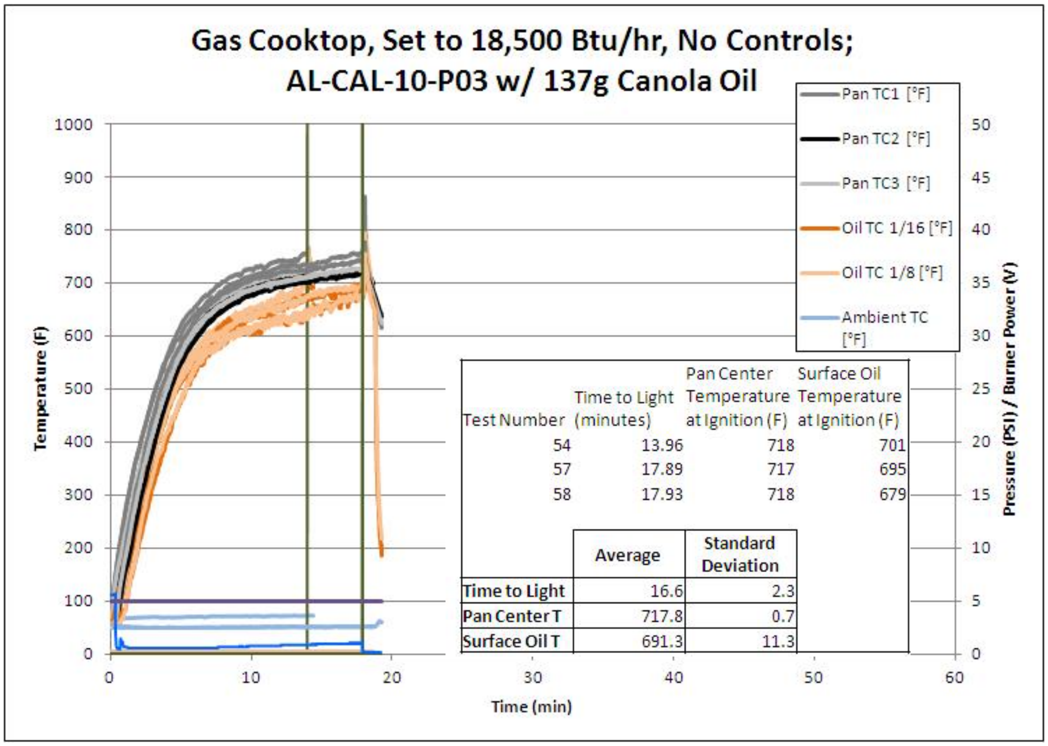
- The stainless steel pan type ignited in the shortest time of all pan types for both quantities of oil (150mL and the 1,000mL) at 18,500, 15,000, and 11,000 Btu/hr.
- Oil in stainless steel pans ignited at three heating rates: 18,500Btu/hr., 15,000Btu/hr., and 11,000Btu/hr, but not a 8,000 Btu/hr.
- Oil in cast iron pans ignited at only two of the four heating rates: 18,500Btu/hr. and 15,000Btu/hr.
- Oil in aluminum pans ignited only at 18,500 Btu/hr. heating rate.
- No ignitions occurred at the 8,000 Btu/hr. heating rate.

3.2 Examples of Temperature Profiles

Three baseline tests were repeated for the aluminum pan at 18,500 Btu/hr. After reviewing the data for the repeatability tests, we realized that there was more variation in the burner rate than expected. The variability had to do with the ability to set the control knob to the same location each time the knob is set. The repeatability data for an aluminum pan at 18,500 Btu/hr. with 150 ml oil are shown in Figure 14. For each of these tests, the control knob was set to Max Power Boil.

We modified our procedure by setting the burner rate with the gas control knob and verifying that the knob was set to the desired firing rate before running a test. We then left the gas control knob in one position for all tests requiring the same firing rate. The gas was controlled by turning the gas on and off using a solenoid valve. To light the burner that was being tested, we would turn on an adjacent burner on the cooktop and, because the igniter spark sparks on all burners, the burner under test was able to be lit. Once the burner that was being tested was lit, the other burner was turned off.

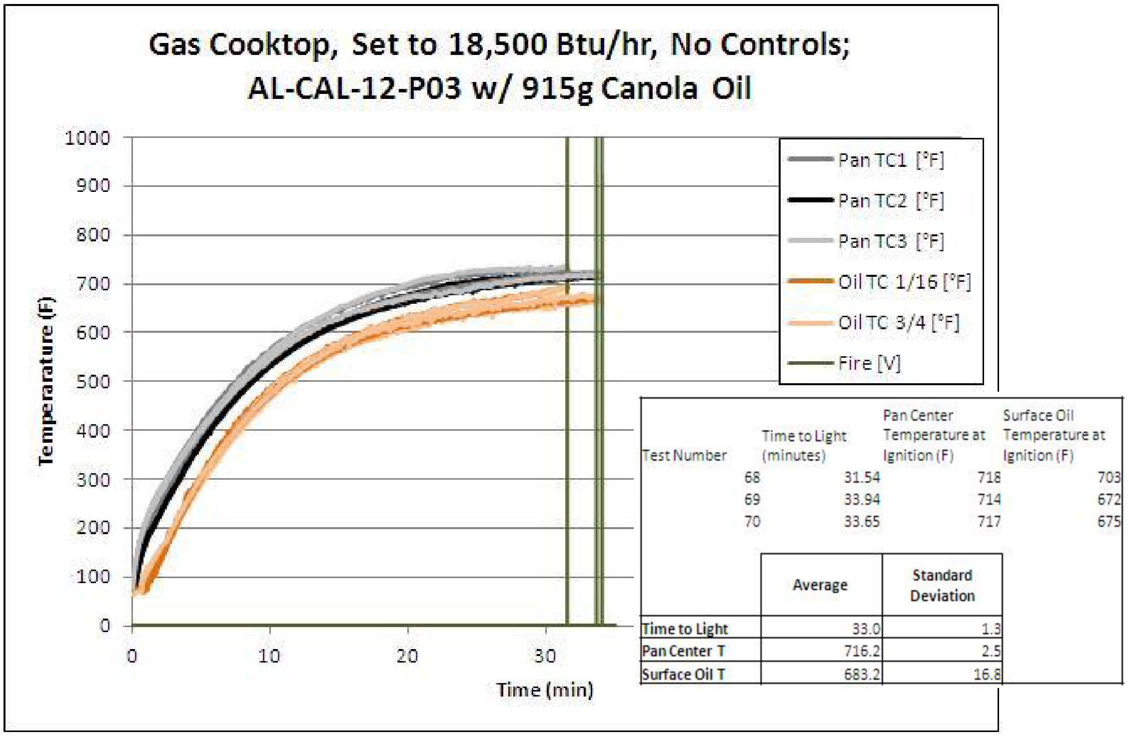
The repeatability data for an aluminum pan at 18,500 Btu/hr. with 1,000 mL oil are shown in Figure 15. For these tests the control knob was set to the Max Power Boil setting once.



Test Number	Time to Light (minutes)	Pan Center Temperature at Ignition (F)	Surface Oil Temperature at Ignition (F)
54	13.96	718	701
57	17.89	717	695
58	17.93	718	679

	Average	Standard Deviation
Time to Light	16.6	2.3
Pan Center T	717.8	0.7
Surface Oil T	691.3	11.3

Figure 14: Aluminum Pan Repeatability Tests: 150mL (137g) of Oil; 10-Inch Pan



Test Number	Time to Light (minutes)	Pan Center Temperature at Ignition (F)	Surface Oil Temperature at Ignition (F)
68	31.54	718	703
69	33.94	714	672
70	33.65	717	675

	Average	Standard Deviation
Time to Light	33.0	1.3
Pan Center T	716.2	2.5
Surface Oil T	683.2	16.8

Figure 15: Aluminum Pan Repeatability Tests: 1,000ml (915g) of Oil, 12-inch Pan

3.3 Oil Ignition Temperature

As illustrated in Figure 16, all ignitions occurred at a surface oil temperature above 670°F. The time to reach ignition temperature also influences the occurrence of an ignition. If the duration to heat up to ignition temperatures was too long, the oil pyrolized. This pyrolized oil has different ignition characteristics than virgin oil. Pyrolysis irreversibly changes the physical properties of the oil, causing the oil to become tar-like and charred. An example of the oil reaching ignition temperatures but not igniting is a 150 mL baseline test conducted at a firing rate of 11,000 Btu/hr. with a 10-inch cast iron pan (baseline test number 60). The oil in this test reached ~707°F in 27 minutes and ignition did not occur. Figure 17 shows the oil's appearance after extended heating without ignition.

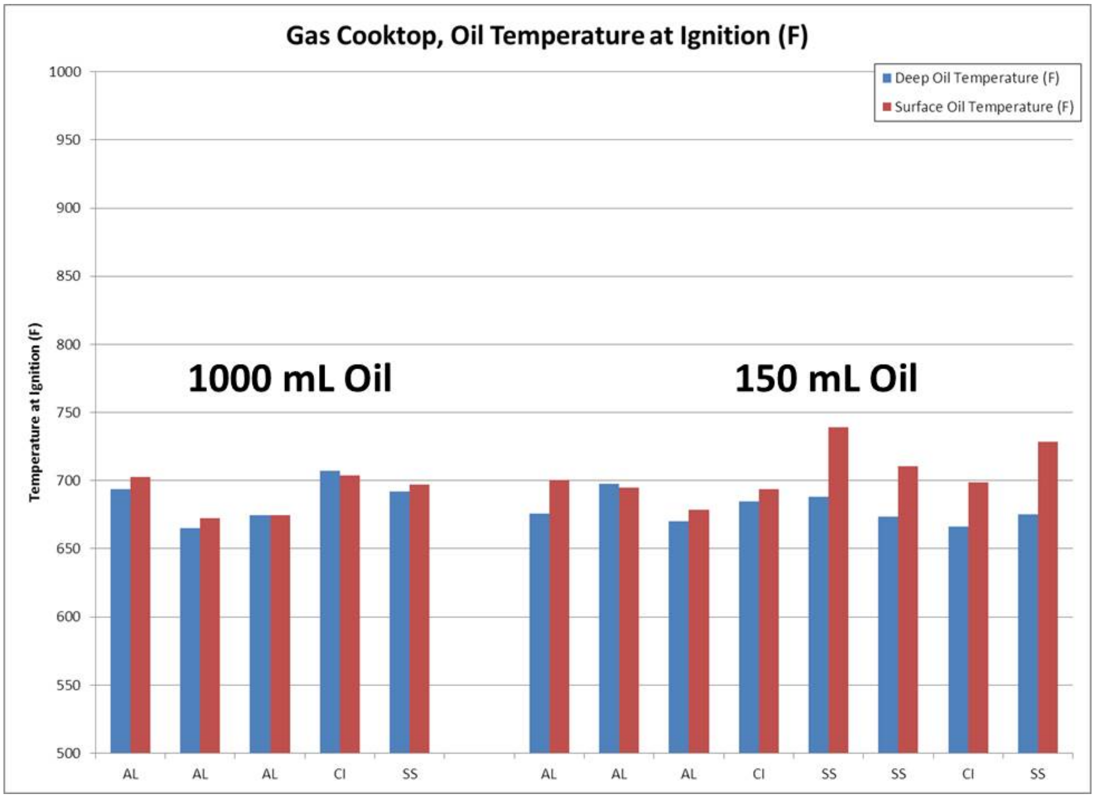


Figure 16: Baseline Testing, Oil Temperatures at Ignition

Figure 17: Pyrolized Oil

Figure 18 illustrates the temperature profiles of all the baseline ignition tests. The red dot at the end of a profile indicates the point of ignition. If there is no red dot, the test did not result in an ignition. The compilation of profiles reveals:

- Ignitions generally occur when the oil temperature exceeds 670°F.
- Oil in stainless steel pans reaches the critical ignition temperature faster than oil in cast iron or aluminum pans.
- Higher firing rates lead to shorter times to ignition.
- Long heat-up times can forestall ignition if the oil transforms before it ignites.

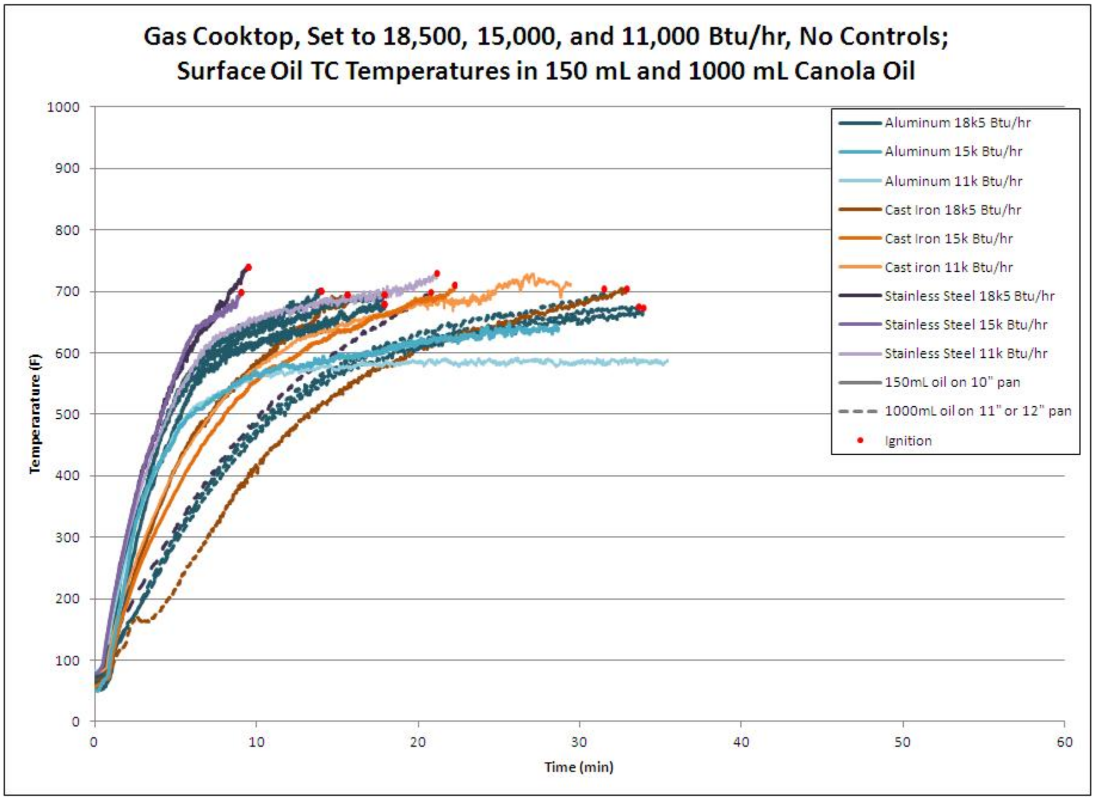


Figure 18: Temperature Profiles of All Baseline Ignition Tests

3.3.1 Impact of Heating Rate

Burner input rate has a significant impact on oil ignition. Oil ignition occurred in all pans at both oil amounts with a burner input rate of 18,500 Btu/hr. As the heating rate was reduced, the oil ignited in fewer pan types/sizes. Table 7 summarizes the maximum surface oil temperatures reached for the baseline testing of 150 mL oil. The red shading in either table indicates that an ignition had occurred.

Table 7: Summary of the Impact of Heat Rate on Maximum (Surface) Oil Temperature for 150mL Baseline Tests

150 mL Oil Test	Burner Set Point (BTU/hr)			
Pan Type	18500	15000	11000	8000
10" Aluminum	701°F, 679°F, 695°F	650°F	601°F	541°F
10" Cast Iron	694°F	710°F	707°F	587°F
10" Stainless Steel	739°F	699°F	729°F	631°F

Red shading indicates ignition; Maximum Surface Oil Temperature Provided

Numbers in Cells are Maximum Oil Temperatures (F) Reached in Test

Table 8 summarizes the maximum surface oil temperatures reached in testing with 1,000 ml of oil at 18,500 Btu/hr. Baseline testing of the larger oil amounts was limited to the highest input rate only.

Table 8: Summary of the Maximum Surface Oil Temperatures for 1,000 mL Baseline Tests

1000 mL Oil Test Pan Type	Burner Set Point (BTU/hr) 18500
12" Aluminum	703°F, 672°F, 675°F
12" Cast Iron	704°F
11" Stainless Steel	697°F

Red shading indicates ignition;
Maximum Surface Oil Temperature Provided

3.3.2 Impact of Pan Type

The temperature data from 150mL and 1,000mL oil tests have been graphed in groups of pan material type. Figure 19 captures the time versus temperature for all baseline tests performed with stainless steel pans. The stainless steel pans had the most ignitions over the four different burner firing rates. The only burner input rate at which ignition did not occur for oil in the stainless steel pans was 8,000 Btu/hr.

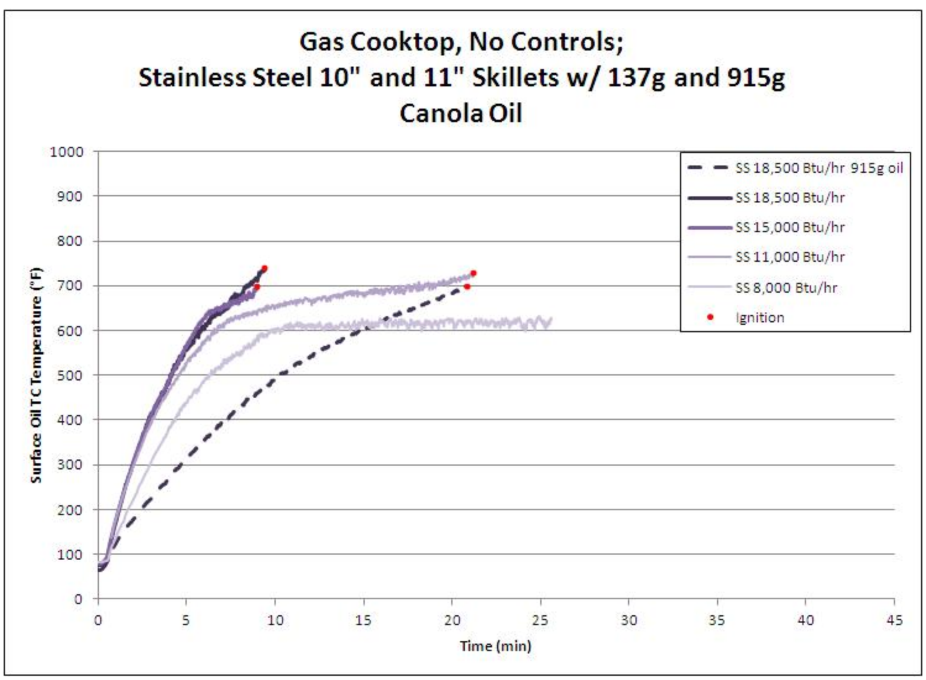


Figure 19: Surface Oil Temperature Profiles for Stainless Steel Pans

Figure 20 captures the temperature data for 150 mL and 1,000 mL oil tests for cast iron. The small volume of oil (150ml) ignited in the cast iron 10-inch pan at 18,500 and 15,000 Btu/hr. heating rates. The time to ignition for the cast iron pans was at least double the time for the stainless steel pans. The cast iron 10-inch pan with 150 mL of oil at a heating rate of 11,000 Btu/hr. led to oil temperatures typical of ignition, but no ignition occurred for this test. Even though the oil reached the temperature of typical ignition, the oil had pyrolized by the time the oil reached typical ignition temperatures.

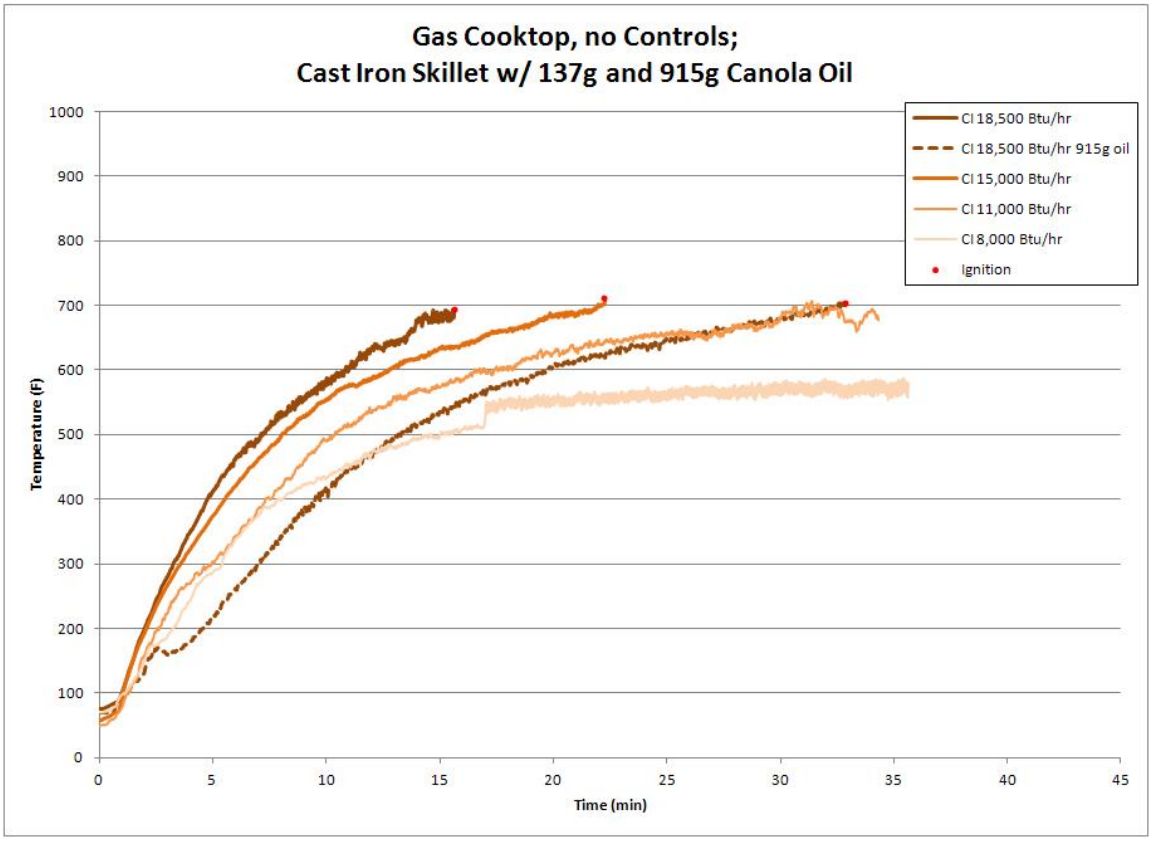


Figure 20: Surface Oil Temperature Profiles for Cast Iron Pans

Figure 21 shows the temperature data for 150mL and 1,000mL of oil in aluminum pans. The aluminum pans had the least incidence of ignition of all the pan types. The oil in aluminum pans ignited only when the burner was set to the maximum firing rate of 18,500 Btu/hr. The time to ignition for 150mL of oil in the 10-inch aluminum pan was around 18 minutes, which was the slowest time to ignition for a 10-inch pan.

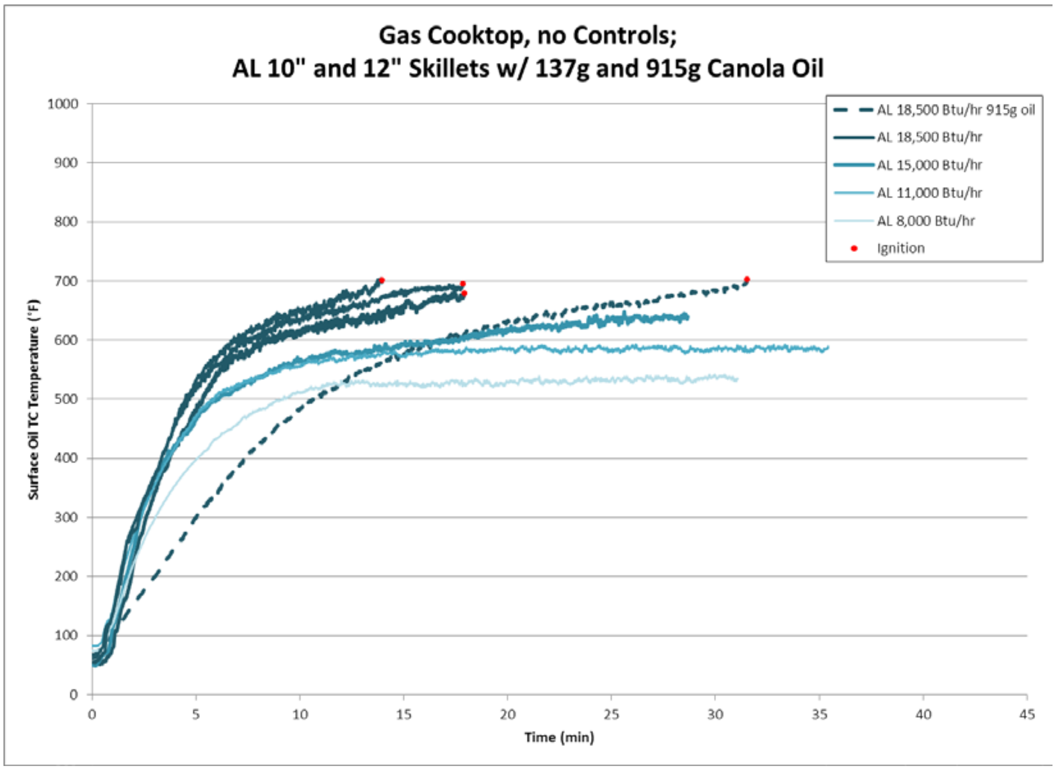


Figure 21: Surface Oil Temperature Profiles for Aluminum Pans

Figure 22 shows a summary of ignition temperature for 150 mL baseline testing by pan type and heating rate. Oil in the stainless steel pan ignited at lower heating rates than the oil in other pans. Oil in aluminum pans ignited only at the highest input rate. The oil in a cast iron pan ignited at heating rates of 18,500 and 15,000 Btu/hr.

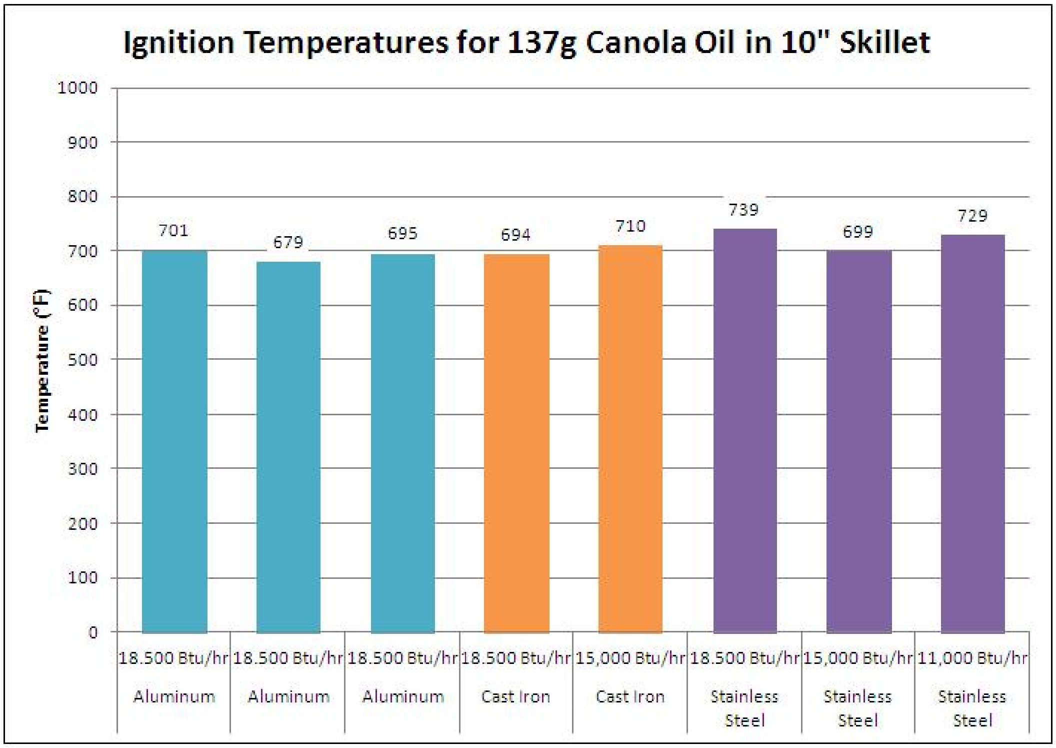


Figure 22: Oil Ignition Temperatures for 150 ml Oil

4. Pan Temperature-Limiting Controls Testing

4.1 Summary Table

The testing of the pan temperature-limiting controls was completed with no ignitions for any of the tests conducted. Comparing the tests with and without pan temperature limiting controls operating showed little, if any, effect on the oil heat-up rates. (This comparison is important because it indicates that cooking times will not be impacted by the ignition controls). The pan temperature-limiting controls maintained the oil temperature safely below ignition threshold temperatures. The maximum oil temperature reached in tests with 150 mL oil averaged 556°F for each of the pan types tested. This is roughly 100°F below the lowest oil ignition temperature seen without the controls operating. The maximum oil temperature reached for 1,000 mL oil tests averaged 526°F each of the pan types tested. Table 9 below summarizes the results of the control system testing.

Table 9: Control System Test Summary

Oil	Pan	Burner Setting (Btu/hr)	Fire?	Max Oil Temp Reached (°F)
150mL	Aluminum 10"	18,500	no	530
150mL	Aluminum 12"	18,500	no	516
150mL	Cast Iron 10"	18,500	no	534
150mL	Cast Iron 12"	18,500	no	531
150mL	Stainless Steel 10"	18,500	no	566
150mL	Stainless Steel 11"	18,500	no	540
150mL	Aluminum 10"	15,000	no	545
150mL	Cast Iron 10"	15,000	no	564
150mL	Stainless Steel 10"	15,000	no	584
150mL	Aluminum 10"	11,000	no	570
150mL	Cast Iron 10"	11,000	no	587
150mL	Stainless Steel 10"	11,000	no	608
1000mL	Aluminum 12"	18,500	no	520
1000mL	Cast Iron 12"	18,500	no	516
1000mL	Stainless Steel 11"	18,500	no	525
1000mL	Aluminum 12"	11,000	no	537
1000mL	Cast Iron 12"	11,000	no	523
1000mL	Stainless Steel 11"	11,000	no	535

A summary of the control system test results follows:

- No fires were experienced in any of the tests conducted.
  - 150 mL oil and 1,000 mL
  - Heating rates (Btu/hr.) of 18,500, 15,000, and 11,000
  - Aluminum, cast iron, and stainless steel (clad) pans
- Comparison of the control system tests to the baseline tests showed that the controls did not affect oil heat up rates.
  - Temperature profiles of the oil for both control system and baseline tests overlap for the first 5 to 10 minutes of cooking.
- Pan temperature-limiting controls maintained a steady temperature of the oil below ignition thresholds.

The temperature data from 150mL and 1,000mL oil tests have been graphed according to burner firing rate. Figure 23 illustrates the effectiveness of the pan limiting controls at a burner firing rate of 18,500 Btu/hr. to mitigate potential pan fires. All pan types with 150mL or 1,000mL of oil being heated with the maximum burner firing rate (18,500Btu/hr.) that were uncontrolled resulted in oil ignition. The same test conditions with the pan limiting temperature control activated resulted in no ignitions.

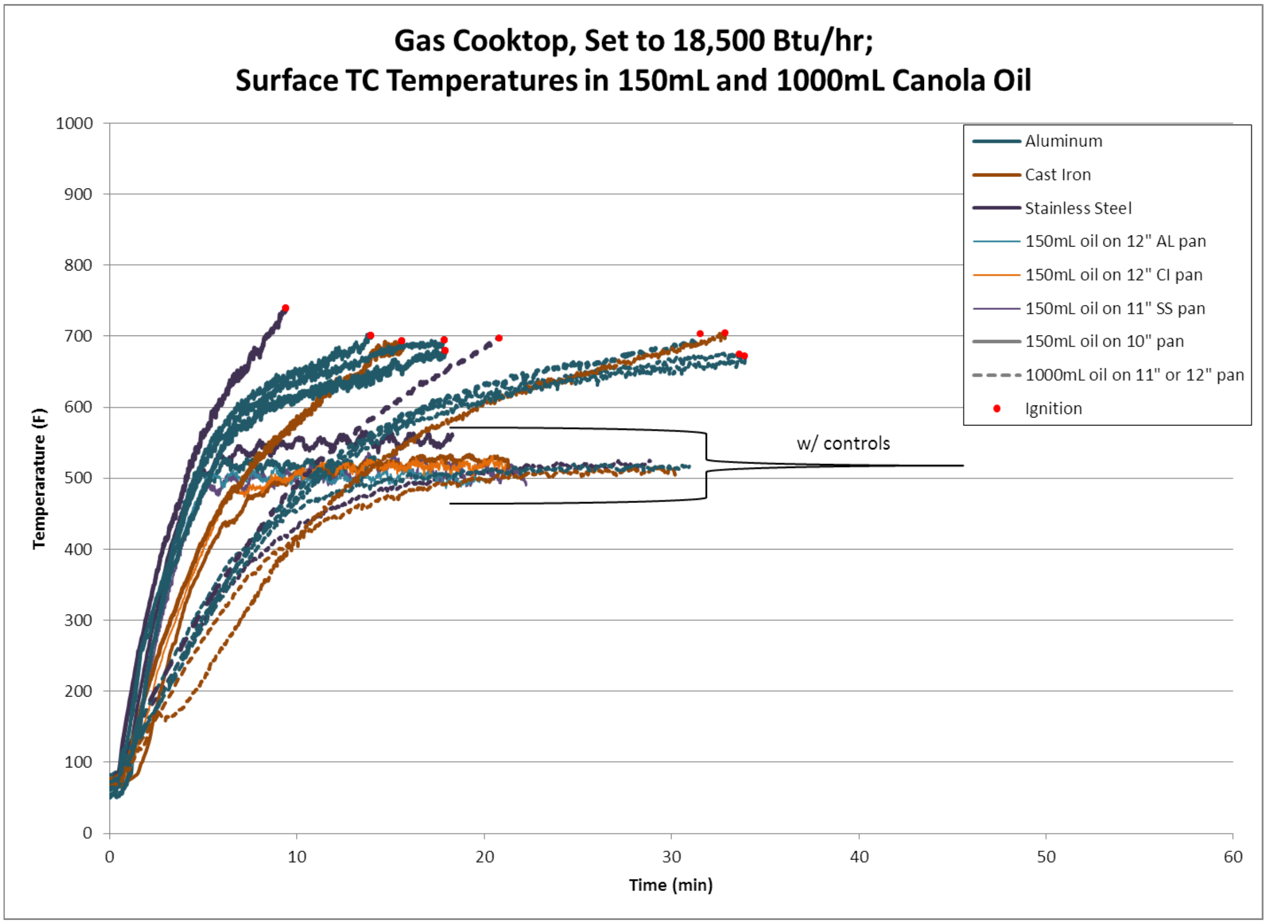


Figure 23: Comparison of Oil Temperature Profiles for Baseline and Control System Tests (18,500 Btu/hr.)

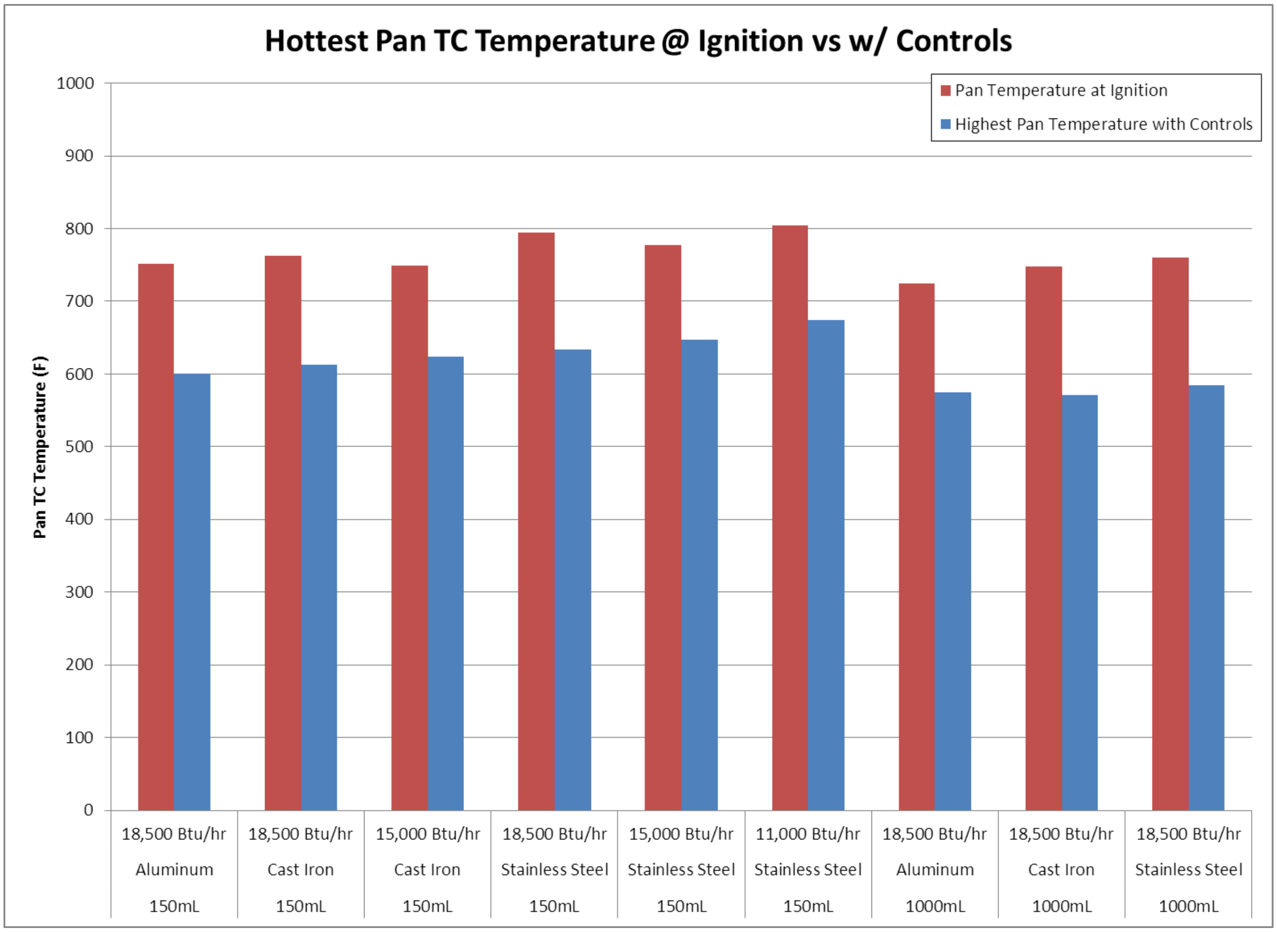


Figure 24: Maximum Pan Temperatures with and without Controls

Figure 24 shows the safety margin in pan temperature provided by the controls is approximately 150°F. This safety margin is shown in the difference between the pan temperature at ignition, shown in red, and the maximum pan temperature reached under the same test condition with controls operating, shown in the adjacent blue bar. This gap is consistently 150°F or greater. Comparisons of pan temperature with and without the controls operating need to be made for the same condition, *i.e.*, for the same pan type, burner heating rate, and oil amount.

Figure 25 and Figure 26 also show the effectiveness of the pan limiting controls at burner firing rates of 15,000Btu/hr. and 11,000Btu/hr., respectively. The surface oil temperature increases slightly as the burner firing rate is reduced, which results from better flame-to-pan contact. This improved contact increases the efficiency of the burner to heat the pan, resulting in higher pan temperatures.

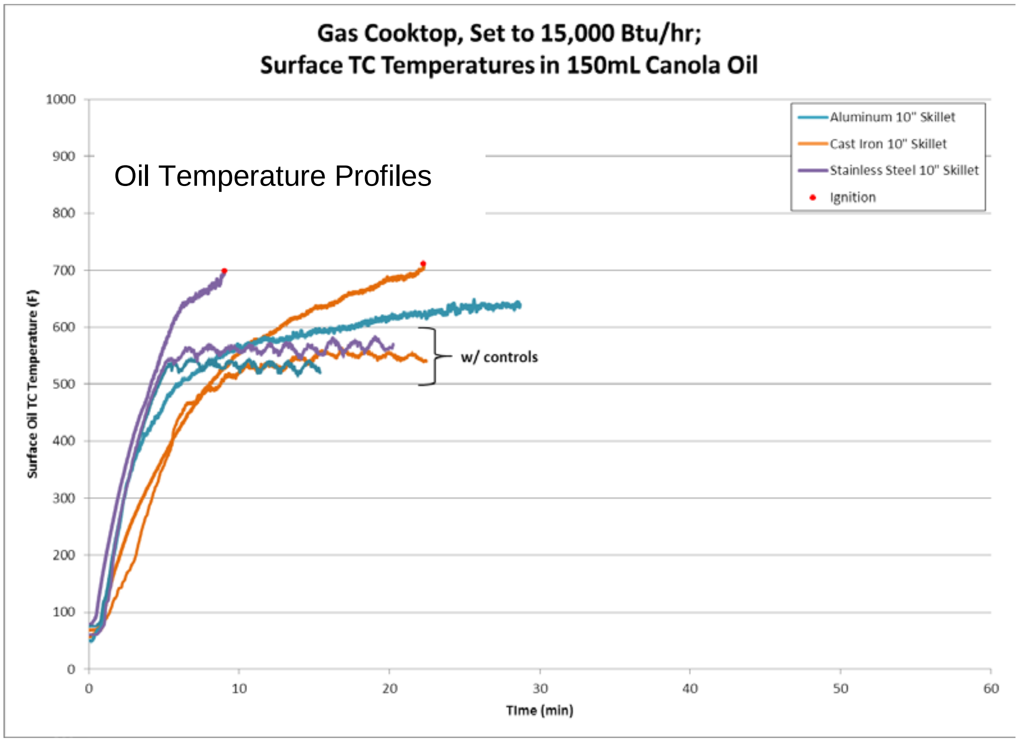


Figure 25: Comparison of Oil Temperature Profiles for Baseline and Control System Tests (15,000 Btu/hr.)

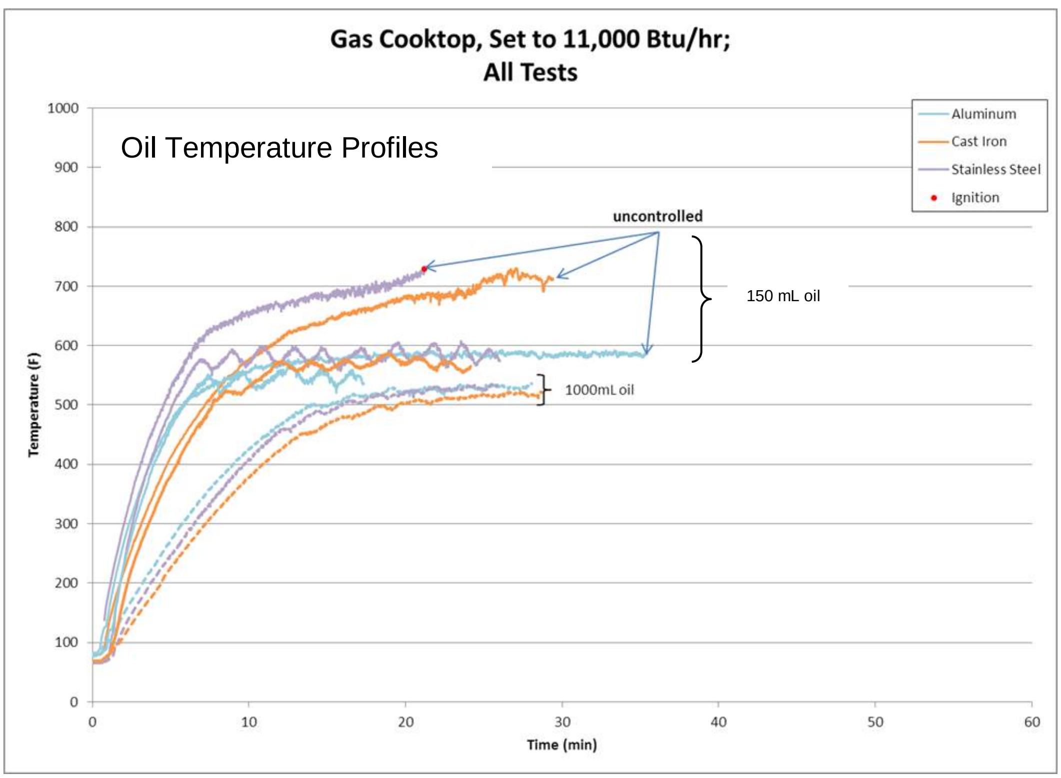


Figure 26: Comparison of Oil Temperature Profiles for Baseline and Control System Tests (11,000 Btu/hr.)

4.2 Impact of Pan Type

Pan type impacted the rate of oil temperature rise, and thus, the time at which the controls engaged. With the stainless steel and aluminum pans, the pan temperature-limiting control engaged sooner than with the cast iron pans. This can be seen in Figure 23. The initial heat up of each pan type was not affected by the pan temperature-limiting controller, however.

5. Warped Pot Water Boil Testing, Pan Warping Data, and Pan Eccentricity Testing

5.1 Warped Pot Water Boil Testing

A series of tests were conducted to determine the impact of pan warpage on the effectiveness of the pan temperature-limiting controls. We conducted a series of water boil tests with pots that were warped in and out by 1/8-inch, as well as a pot that was not intentionally warped. The pots were warped mechanically by applying a force to the center of the pot. The warpage (both convex and concave) was fairly uniformly distributed across the pot (*i.e.*, it was not a small dent or localized deformation, but a distributed curvature of the pan bottom).

All of the water boil tests were completed without the pan temperature-limiting control engaging at any point during the water boil test. The pan temperature-limiting controls were activated for all of the water boil tests labeled “controlled.” Three different stainless steel pots were used for testing. Figure 27 illustrates the time to heat four quarts of water from 100°F to 200°F with the burner firing rate set to 18,500 Btu/hr. The variation in heat-up times for uncontrolled (pan limiting controls deactivated) and controlled (pan limiting controls activated) is no greater than the variation in heat-up times that occurs from natural burner firing-rate variations. The natural burner firing-rate variations come from small day-to-day variations in gas temperature or pressure.

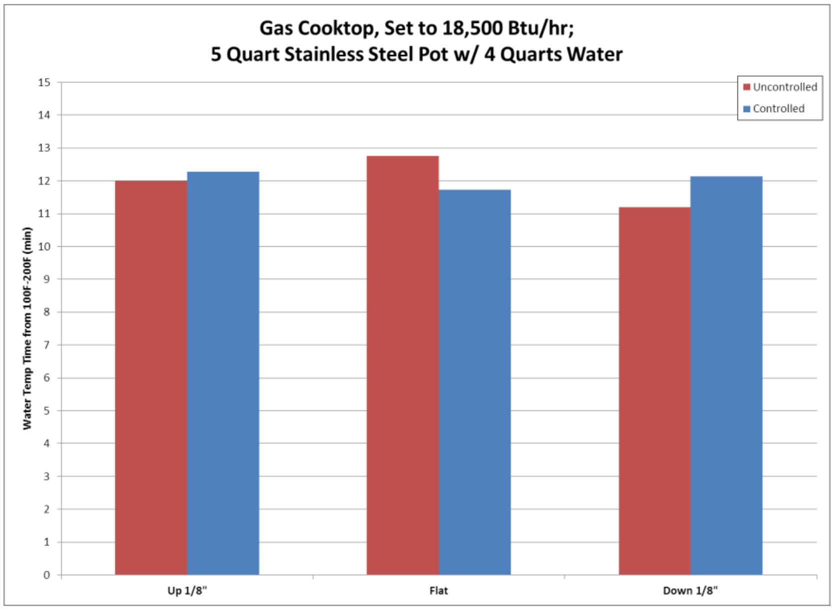


Figure 27: Water Heating Times, with and without Controls

5.2 Pan Warping Data

Periodically, we measured the change in flatness of pans during the tests to gather data on the degree to which pans warp over time (under extreme conditions, given that these were ignition tests). The pans used for the gas cooktop testing had been used in previous ignition tests for electric cooktops. The flatness of the pans had been measured previously over the course of that ignition test program. Figure 28 illustrates the change in pan flatness over tests conducted in both test programs. The greatest curvature measured over all these pans tested was a concave curve in a large stainless steel pan that was 0.09" out of flat. This puts the 0.125-inch curve for the water boil tests in some perspective; the 1/8-inch warp imposed on the water pot was far higher than was observed after multiple extreme tests of over-heated pans.

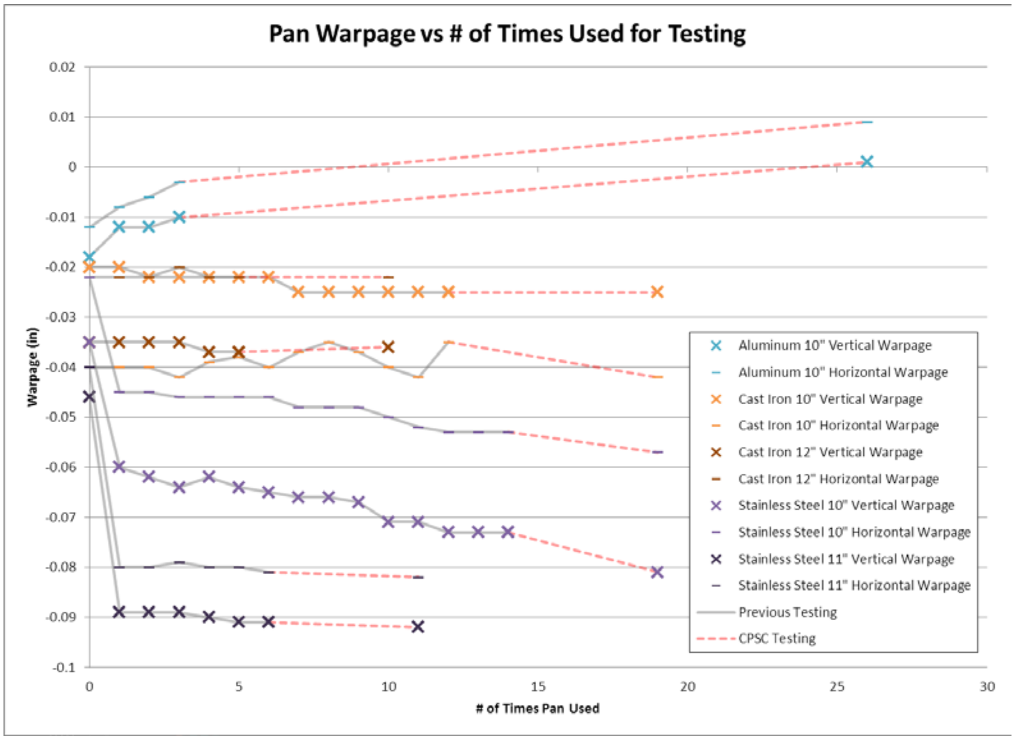


Figure 28: Pan Warpage Versus Pan Usage in Ignition Tests

5.3 Pan Eccentricity (Off-center location on burner)

An additional series of tests were conducted to evaluate the effectiveness of controls with an eccentrically located pan, *i.e.*, one that was not centered on the burner. There were no ignitions in any of the eccentricity tests. These tests were conducted using a 10-inch stainless steel pans heated at 18,500Btu/hr. with 150mL of oil. The testing required the pan to be off-center by 1 inch, 2 inches, and 3 inches. The reference points used were the burner center point and the pan center point. The pan was moved to the left 1 inch, 2 inches, or 3 inches, depending on the test. Figure 29 shows the pan placement for a 3-inch off-center test. Figure 30 shows the oil temperature profile for all eccentricity test performed. The pan temperature limiting controls engaged for each of the eccentricity tests and kept the oil temperature below ignition scenarios. At 3-inch off center, the cycle of the control changed significantly, however.

For these tests, we moved the pan in a direction that would maintain contact with the sensor. The intention of these tests is to ensure that the sensor and control could mitigate a potential fire situation even if the pan bottom temperature itself is non-uniform. Additional tests may be useful in the future to determine the impact of losing contact between the pan and the sensor entirely. One possible implementation approach is to have the sensor as a switch that needs to be engaged for the burner to operate at heating rates high enough to potentially cause ignitions.

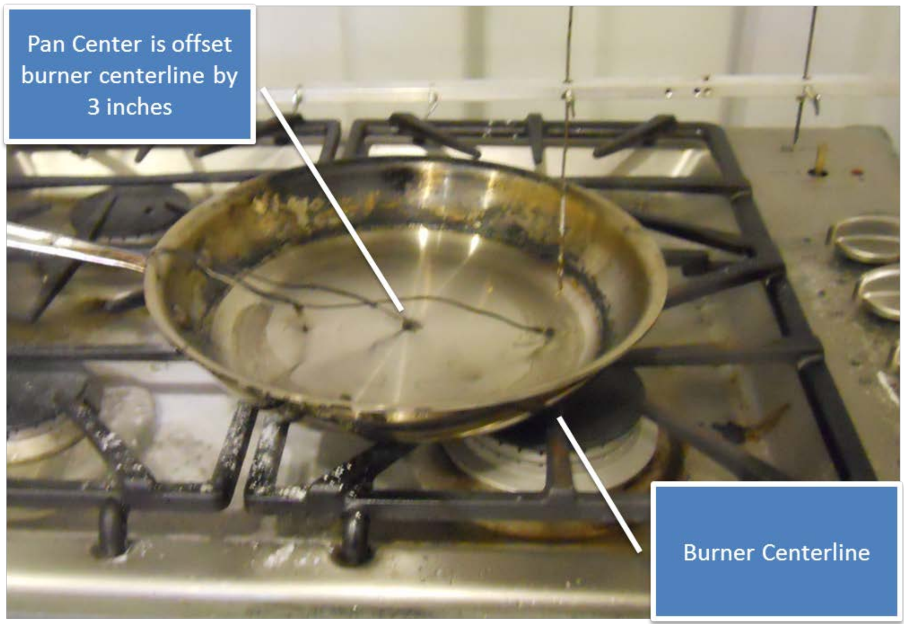


Figure 29: Pan Eccentricity Tests; 3 Inches Off the Burner Center

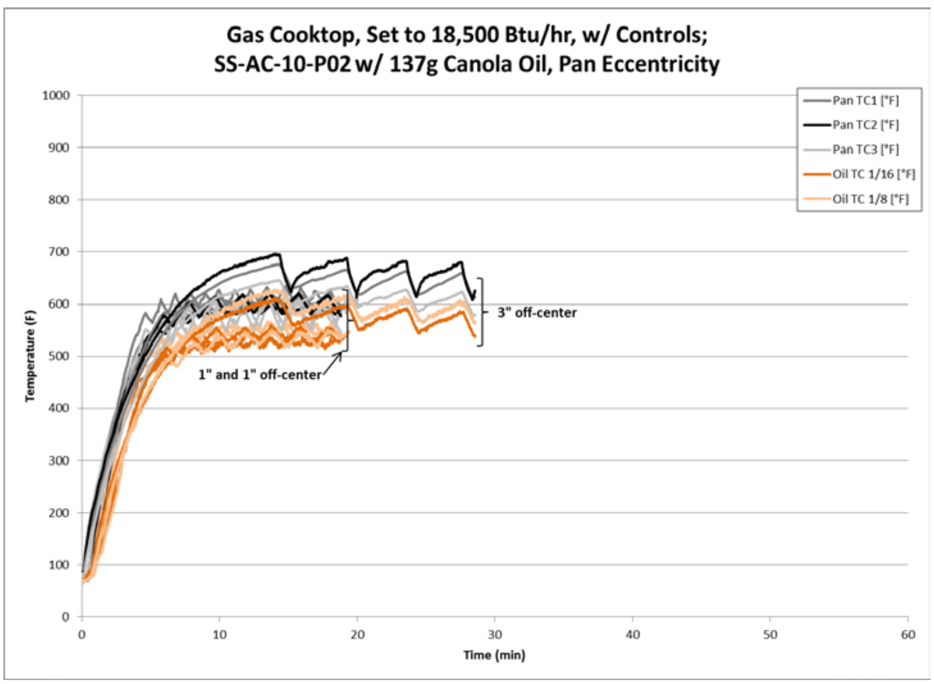


Figure 30: Summary of Oil Temperatures for Pan Eccentricity Tests

6. IR Testing

We conducted a series of pan-temperature profile tests to characterize the impact of the sensor on the temperature distribution in a pan. The pans were instrumented with extra thermocouples and videoed with an infrared camera during heating. Each of the pan types (aluminum, cast iron, and stainless steel) was subjected to a “Dry Cook” test at different burner input rates (18,500 Btu/hr. and 8,000 Btu/hr.). Initially these tests were conducted without the controls activated, so the heat input remained at the initial set point of the burner throughout the test.

The IR camera was very useful in profiling the temperature across the cast iron and aluminum pans due to their relatively high emissivities (because of their dark and rough interior surfaces). The stainless pan, however, was highly reflective and little information was obtained from testing it with the IR camera.

Burner with and without sensor, aluminum pan, 8,000Btu/hr.
In the initial tests, we compared the temperature distribution in an aluminum pan on the burner with the sensor to that for the same pan on a burner without the sensor. In both cases, the burner was set to 8,000 Btu/hr.

Figure 31 shows the IR image for the burner with the sensor. We measured a temperature variation across the bottom of the aluminum pan of about 40°F, with the center (SP1) being about 35°F cooler than the hottest area on the pan (SP3).

The pan section over the sensor (SP 4) is 5°F cooler than the center and 40°F cooler than the hottest point on the pan bottom. The lower pan temperature in the vicinity of the sensor initially appeared to be due to the modification Primaira made to the burner when the RTD sensor was installed. Two of the burner ports were sealed off to prevent the RTD sensor from being heated directly by the impinging gas flame. The pan rim behind the sensor was cooler still (SP 6). This temperature difference did not affect cooking performance, however, as demonstrated in our previous project. We repeated this test for a pan on a standard burner with no sensor and no port modification (see below). The temperature distribution across the pan, and the cold spot were very similar for both tests. So it appears that the sensor and port modifications had a very small impact on pan temperature distribution.

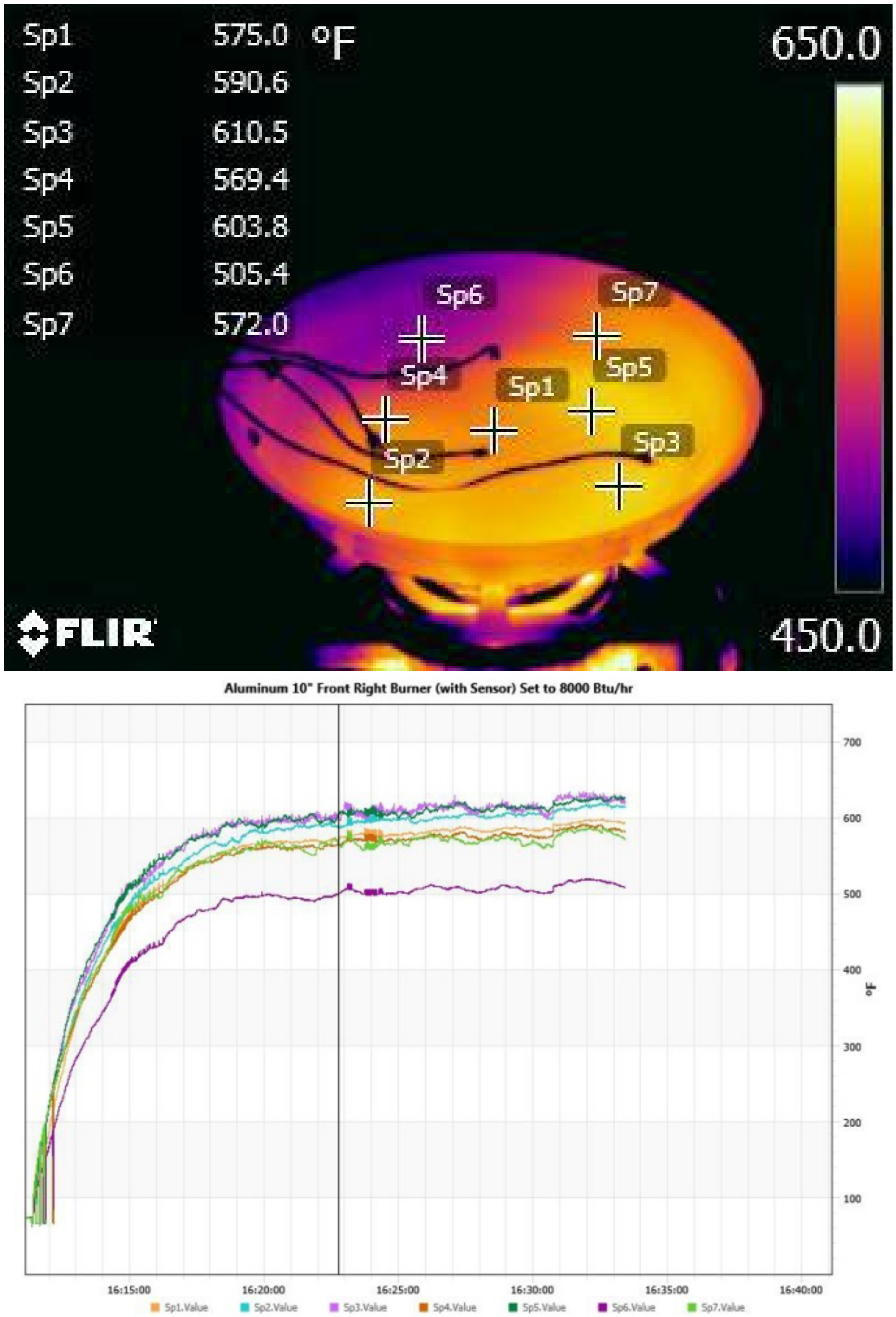


Figure 31: Temperature Profile in Aluminum Pan on High Setting (8,000 Btu/hr.)

The line graph underneath the IR image of the pan shows the temperature profiles over time at each of the seven points marked on the pan as Sp1–Sp7. These data are extracted from the IR image data taken over the duration of the test. The vertical line in the graph shows the point in time of the full IR image above the graph.

We compared the pan temperature distribution on the burner with the sensor, to the same pan on a burner operating at the same heating rate with no sensor. The temperature distribution across an aluminum pan operating on a standard burner at 8,000 Btu/hr. with no sensor is shown in Figure 32. (This standard burner was the front left burner on the cooktop, while the burner with the sensor was on the front right corner of the cooktop.)

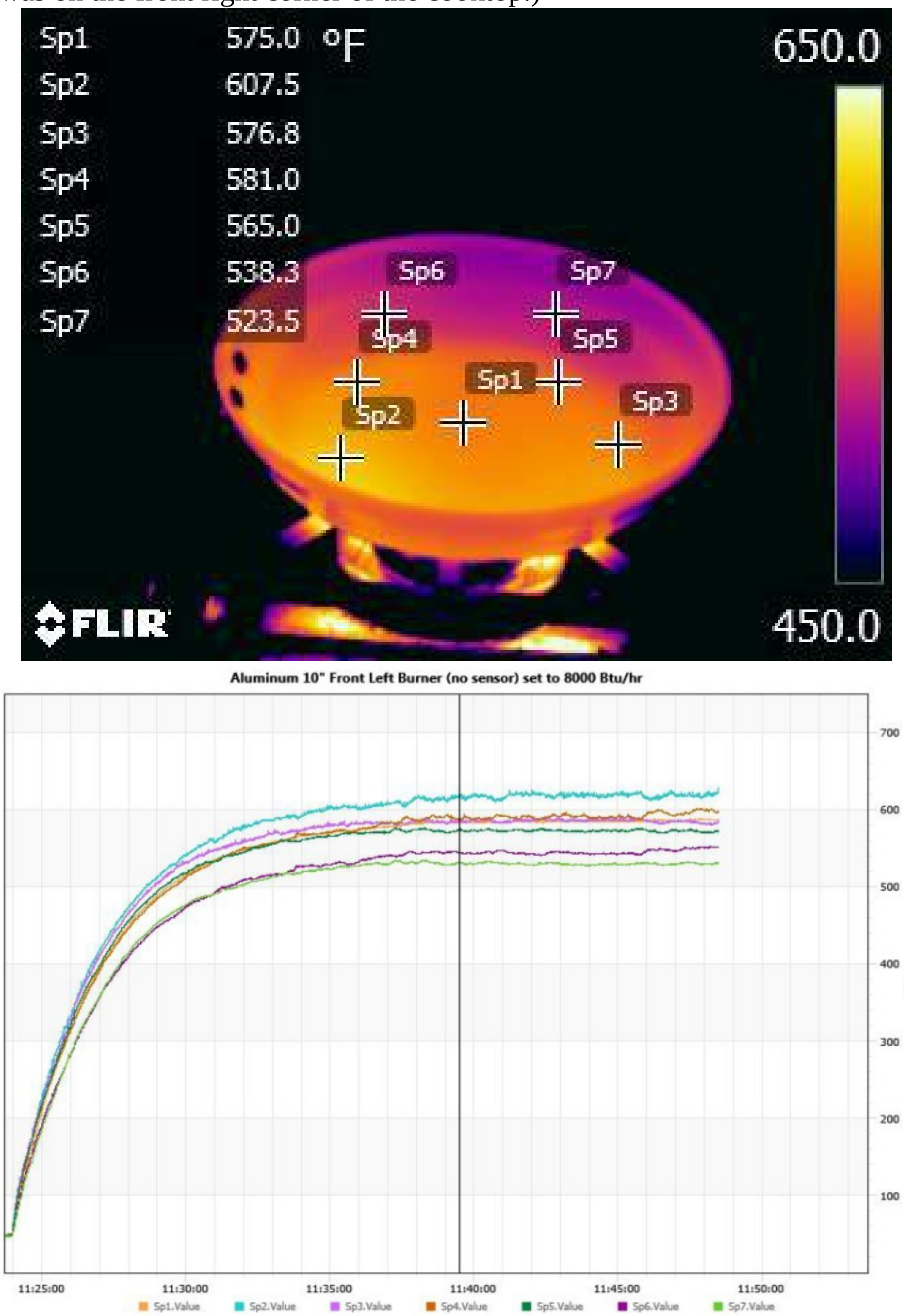


Figure 32: Temperature Distribution Across Aluminum Pan on a Standard Burner

Interestingly, the temperature distribution across the aluminum pan on the standard burner appeared to be very similar to the temperature distribution on the burner with the sensor.

At the same center temperature of 575°F, we observed a difference of 30°F between the center and the hottest point on the pan (SP 2). We also observed a cold spot (SP 6) on the pan bottom that was 37°F cooler than the center temperature, and a cool region of the pan rim (SP 7) that was 50°F cooler than the pan center temperature. Overall, the variation in pan temperatures between the burners with and without the sensors was small.

Burner with Sensor, Aluminum pan, 18,500Btu/hr.
We then examined temperature profile across an aluminum pan on the burner with the sensor at a heating rate of 18,500 Btu/hr. As shown in Figure 33, the higher firing rate on the burner increases the difference between the center temperature and the highest temperature. This difference is now close to 60°F. (This occurs because the higher firing rate results in longer flames that impact the pan farther from the center of the pan). The difference in temperature between the hottest point on the pan and the temperature at the sensor location is around 75°–80°F.

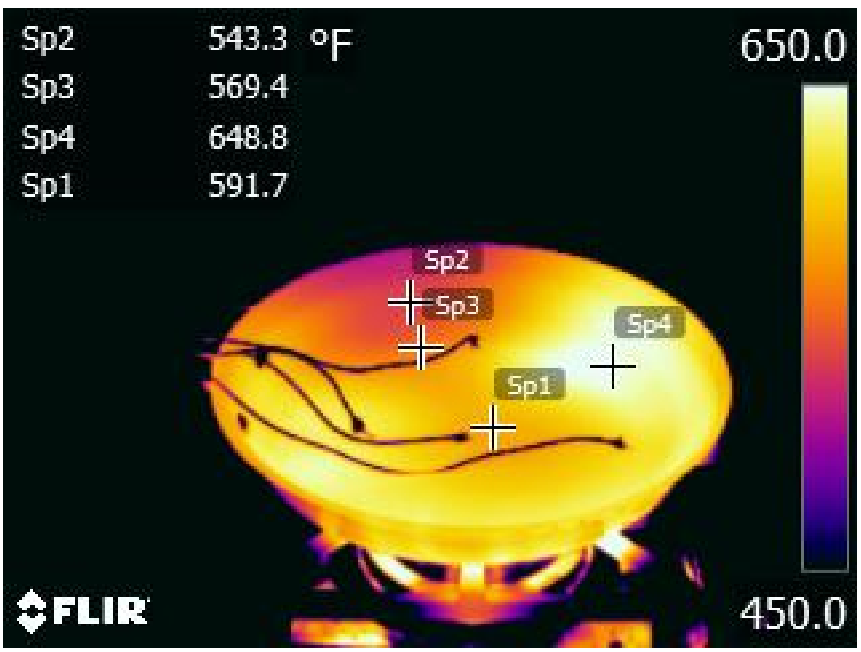


Figure 33: Temperature Profile in Aluminum Pan Power Boil (18,500 Btu/hr.)

The infrared image data is consistent with the thermocouple data collected for this test, shown in Figure 34, below. In this thermocouple temperature profile, we see a temperature difference of approximately 70°F between the sensor location temperature and the hottest pan temperature.

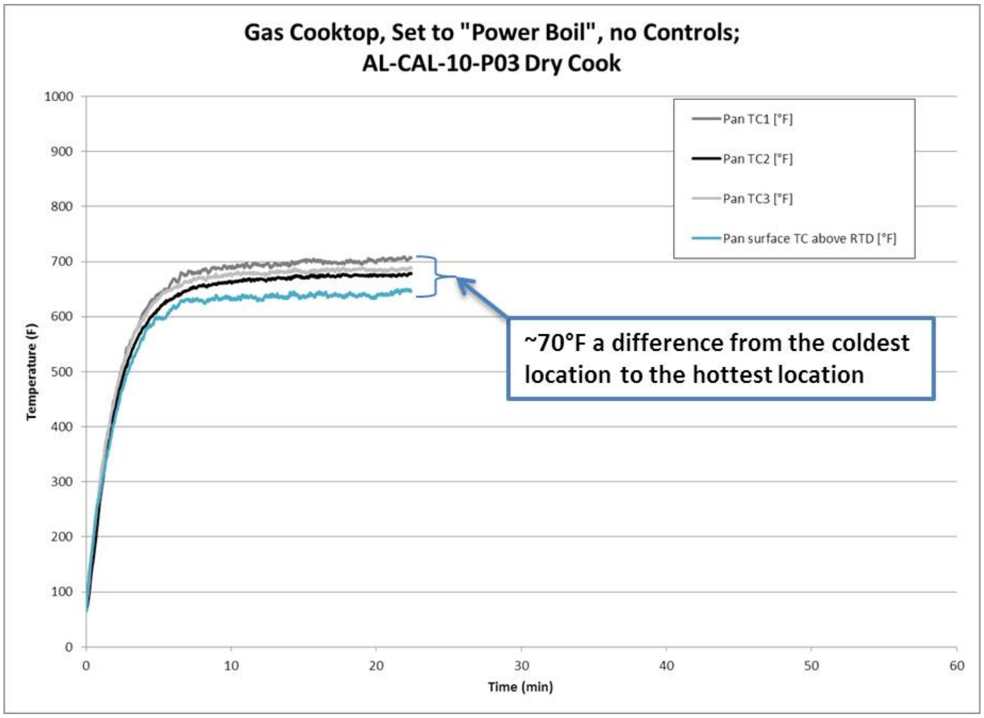


Figure 34: Temperature Profiles from Thermocouples in Aluminum Pan on Power Boil (18,500 Btu/hr)

To determine the impact of the blocked ports on the temperature distribution in the pan, we removed one of the blockages and examined the resulting temperature distribution. A comparison of the left and right images of Figure 35 show the improved uniformity of with one-port-only blocked. It is our expectation that when a more detailed sensor/burner integration task is undertaken, that the sensor will be designed and positioned in a way that minimizes the change in port geometry of the burner.

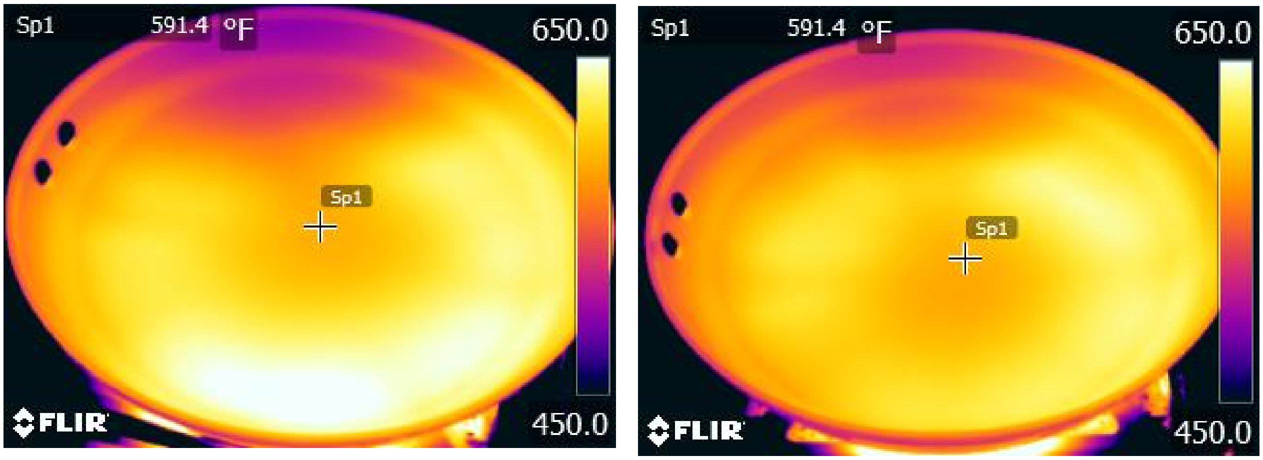


Figure 35: Comparison: Two Burner Ports Blocked (left) versus One Burner Port Blocked (right)

Infrared imaging of a cast iron pan (compared to aluminum pan) revealed that it is difficult to avoid a large temperature distribution with a low conductivity pan material, as shown in Figure 36. In a cast iron pan, the temperature difference from the center (the coldest point) to the hottest point is 180°F. This differential is higher than the differential between the sensor location and other points at that radius on the pan. (Note that in these tests, only one port was blocked rather than two). These data show the value of placing the sensor away from the pan center.

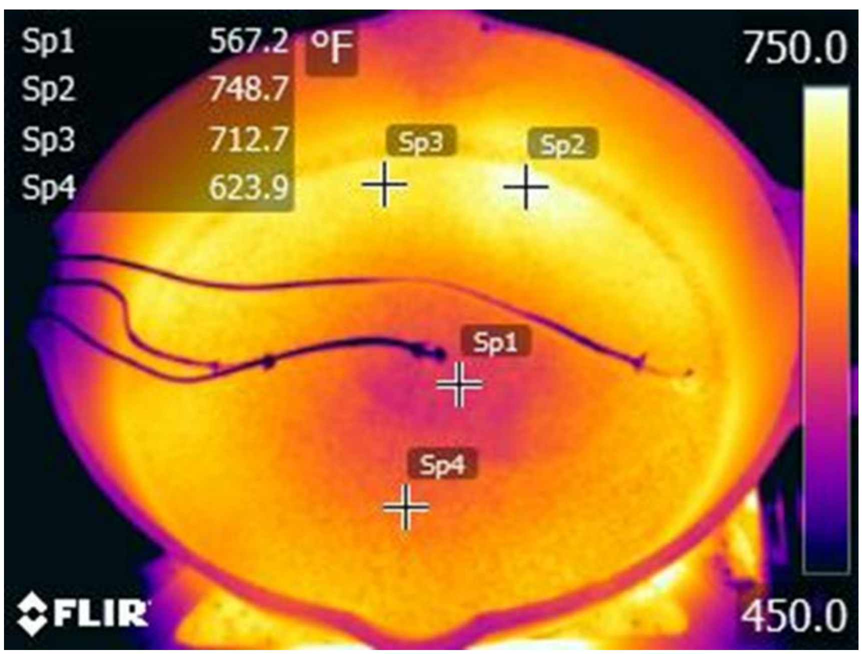


Figure 36: Temperature Profile Across a Cast Iron Pan at Power Boil Setting (18,500 Btu/hr.)

The result from these tests has verified the approach of locating the RTD sensor toward the outside of the burner ring. The data have consistently shown that the outer radius of the pan is hotter than the center of the pan. However, we need to be careful not to create a local cool spot with the sensor by blocking the gas flames near the sensor. The sensor/burner integration needs to avoid direct impingement of the sensor by the flame but also avoid making too large a gap in the flame ring.

Controls operating, with and without oil, aluminum and cast iron pans

A series of tests were conducted with the camera to record the temperature profiles across the aluminum and cast iron pans with the controls operating. We conducted several tests with the controls activated for each pan type (aluminum and cast iron) with and without oil. We compared the temperature distribution in the pan at the upper and lower temperatures of the control cycle.

Figure 37 shows IR images of an aluminum pan temperature profile along with a chart tracking the maximum temperature recorded by the IR camera for the duration of the test. The figure is divided in half; the left side of the figure shows the pan with no oil, the right side of the figure shows the temperature profile with oil in the pan.

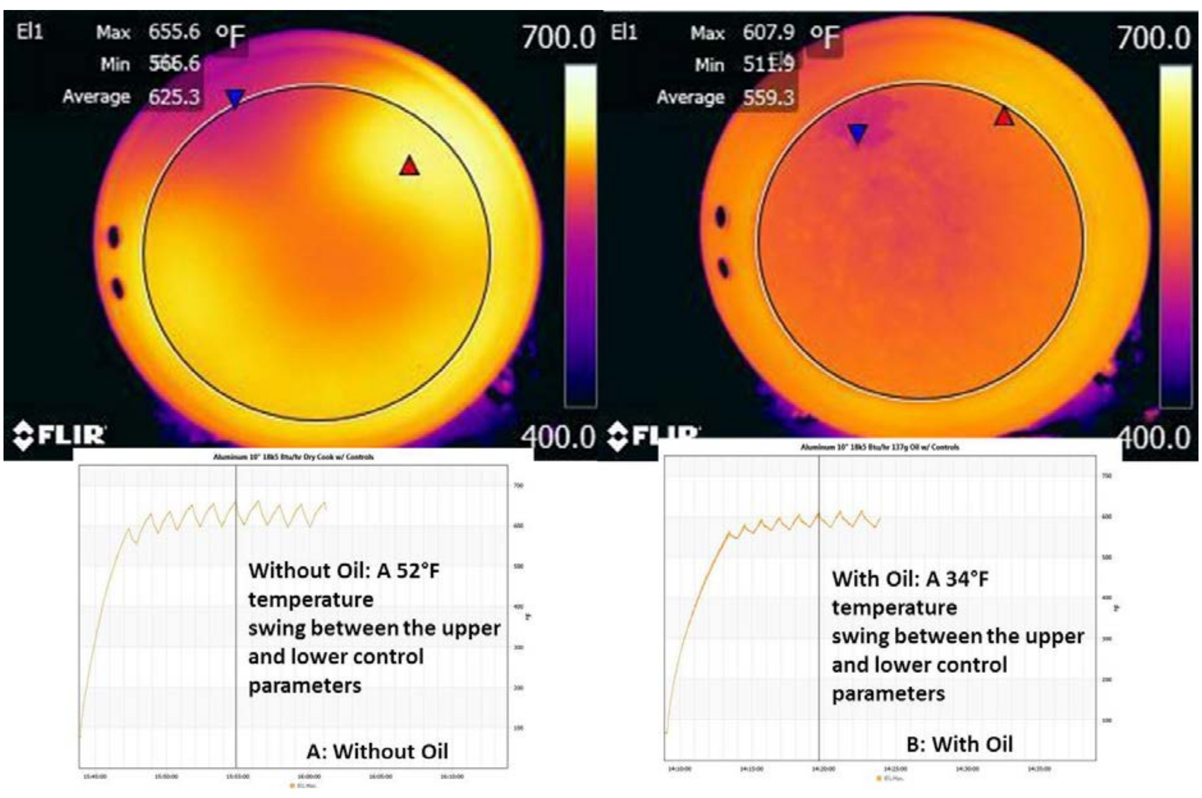


Figure 37: A: Without Oil (Left) and B: With 150 mL Oil (Right), IR Temperature Profile for 10 inch Aluminum Pan; 18,500 Btu/hr. Burner Rate; Controls Active

In comparing the two graphics in Figure 37, the IR images show:

1) Temperatures of the oil are lower than the temperatures of the pan surface without oil.
   This is important because the algorithm was developed with a dry pan. This dry pan case leads to higher temperatures under the same control as an oil case. Therefore, there is a safety factor in the system.
2) The temperature distribution across the oil is more uniform than across the dry pan.
   This is good because it shows that cooking will be uniform across the pan with some oil in it.
3) The temperature swings over time on the pan surface as the controls cycle the burner are less pronounced in the oil than the dry pan.
   This is good because the actual variations over time of the oil temperature are less than about 35°F, which should be insignificant to cooking performance.

The same comparison of temperature distribution (spatial) and temperature swing (over time) was made with the 10-inch cast iron pan without and with oil. Figure 38 shows the comparison of those two tests. The pan with oil had a more uniform temperature distribution across the cast iron pan than the pan without oil. In comparing the temperature swing over time between the two plots in Figure 38, the test conducted with oil had a smaller temperature swing over the control cycle than the test conducted without oil.

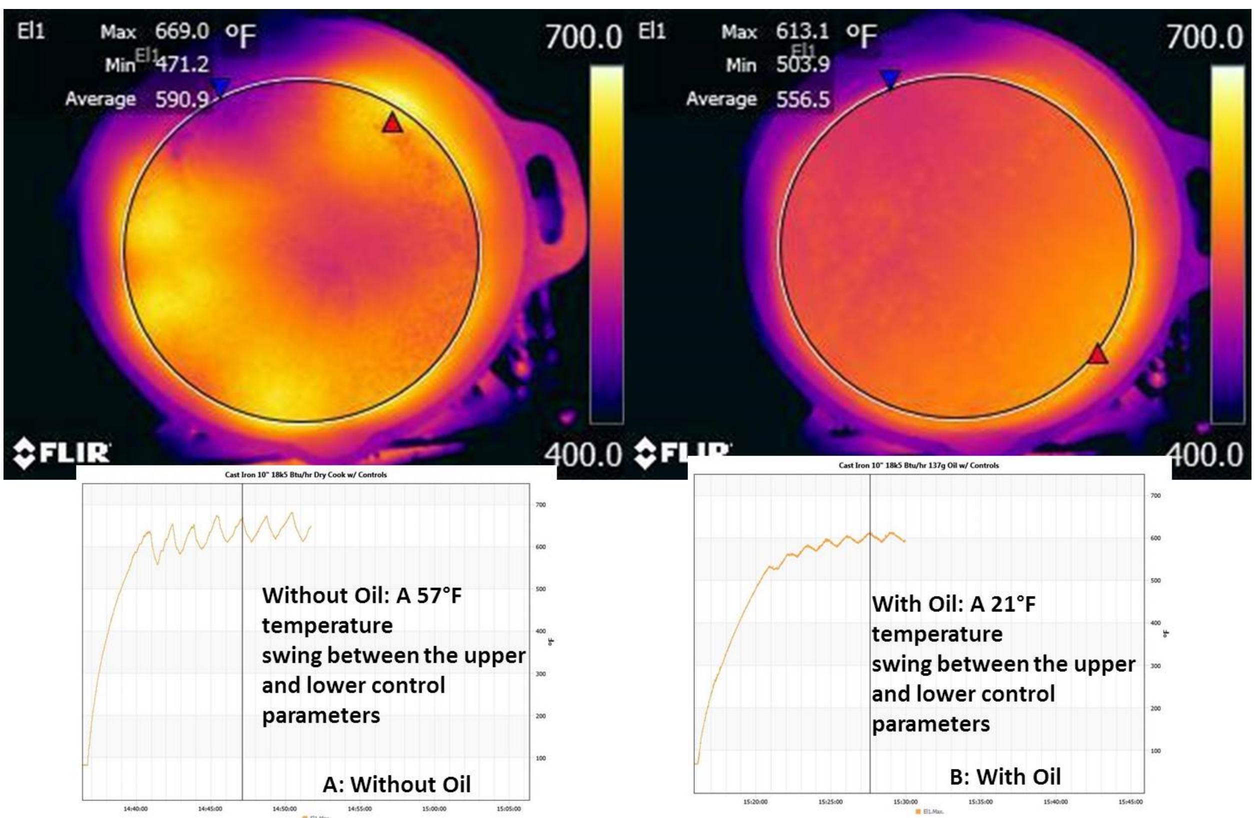


Figure 38: A: Without Oil (Left) and B: With 150 mL Oil (Right), IR Temperature Profile for 10-Inch Cast Iron Pan; 18,500 Btu/hr. Burner Rate; Controls Active

Figure 39 and Figure 40 provide a closer look at the temperature uniformity of the pan at different points in the control cycle. Figure 39 shows an IR image at the maximum temperature reached (left figure) and minimum temperatures reached (right figure) while the controls are cycling the power to the 10-inch aluminum pan. The difference between the upper and lower temperature is 34°F. The spatial temperature variation is slightly less after the burner has been on low than when the pan heats back up on high.

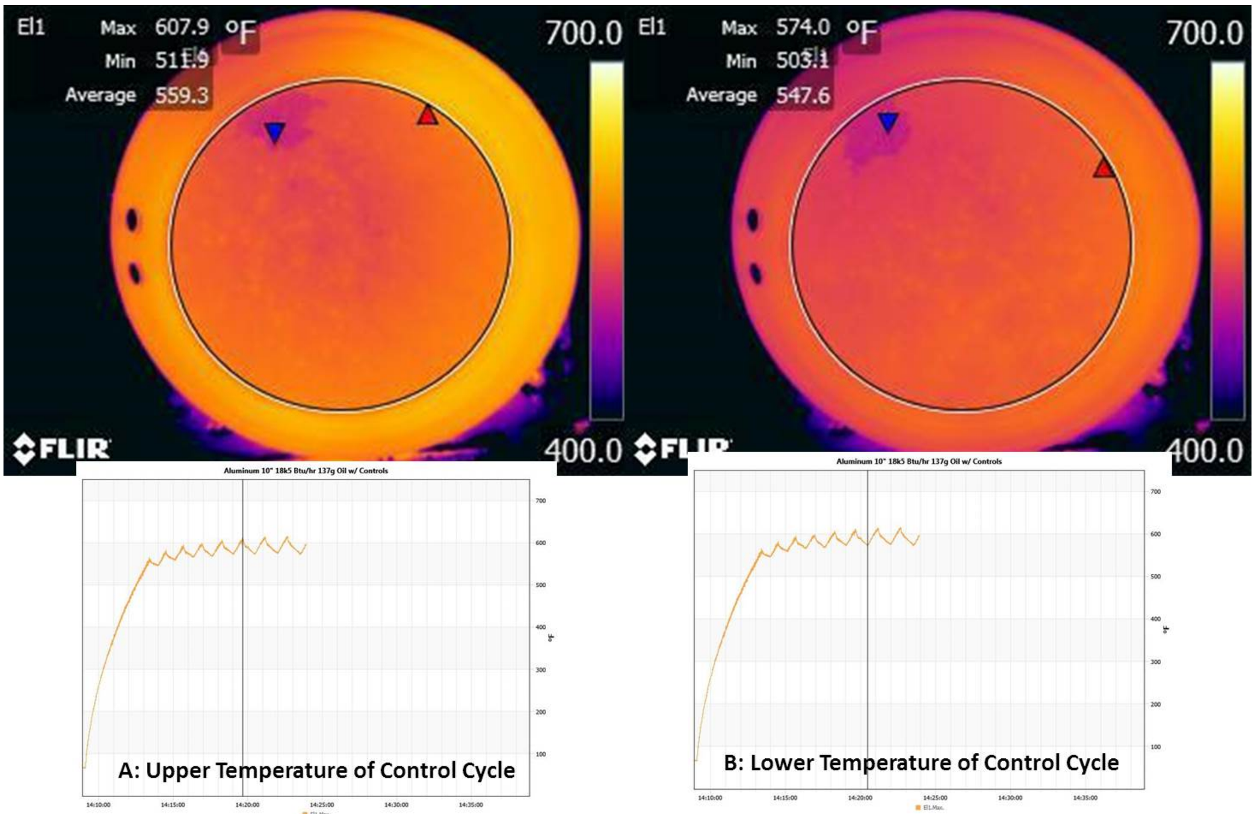


Figure 39: A: Upper Temperature of the Cycle (Left) and B: Low Temperature of the Cycle (Right), IR Temperature Profile for 10-Iinch Aluminum Pan; 18,500 Btu/hr. Burner Rate; Controls Active

Figure 40 shows the same comparison for a cast iron pan. The results are similar; the temperature distribution becomes a bit more uniform after the burner has been on low for a cycle.

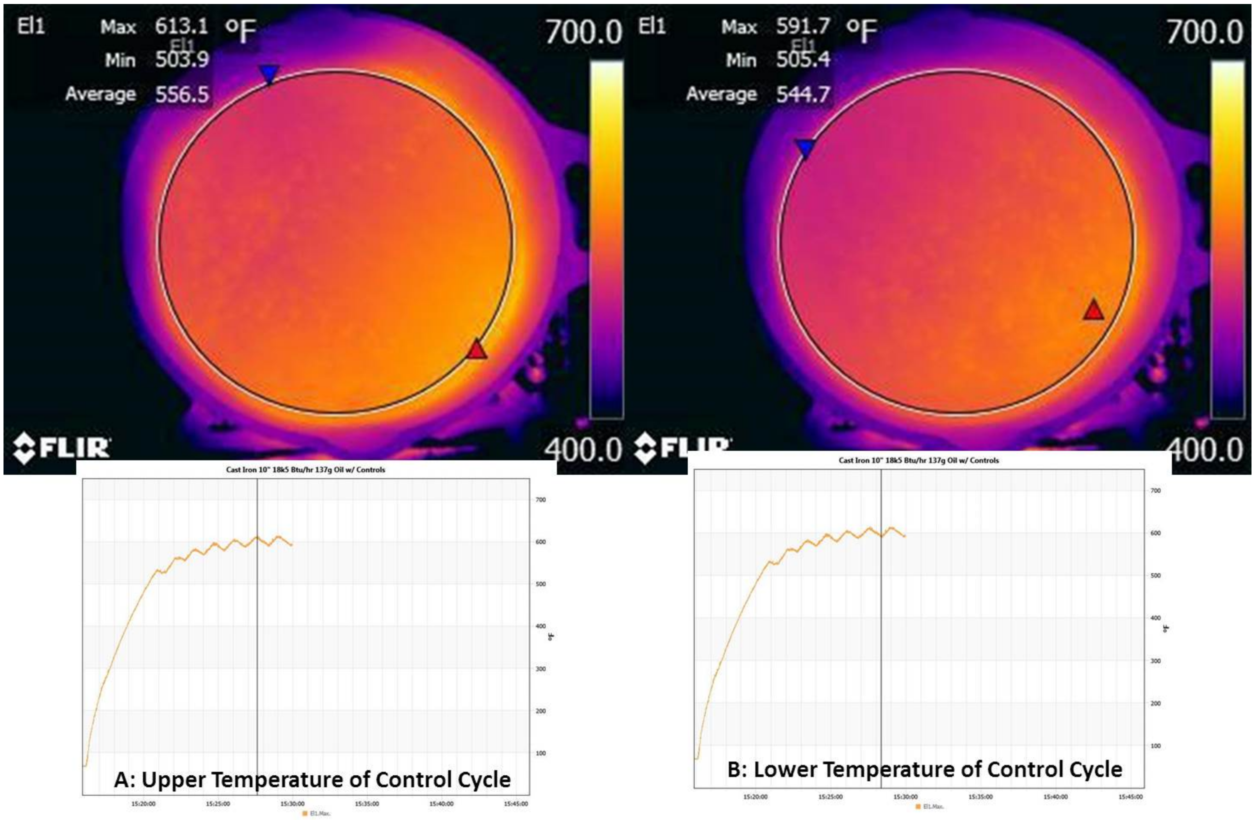


Figure 40: A: Upper Temperature of the Cycle (Left) and B: Low Temperature of the Cycle (Right), IR Temperature Profile for 10 inch Cast Iron Pan; 18,500 Btu/hr. Burner Rate; Controls Active

In summary, the IR testing showed that:

1) The algorithm was developed conservatively;

2) The variation in surface temperature over time due to the cycling of the burner is small; and

3) There is little nonuniformity in pan temperature distribution that is associated with the sensor location.

We could potentially improve uniformity by blocking one port only or by placing the sensor where there already is a disruption of the flame, *i.e.* where the igniter is located.

7. Conclusions

The control system testing has established the effectiveness of the pan-bottom temperature-limiting controls to mitigate cooktop fires.

Appendix A

File Name Key and Test Index

File Name Nomenclature

File Name Key										
_Client	_Case Desc	_Test #	_Pan Type	Pan Brand	Pan Size	Pan Desc	Test Desc	Heating Rate	Controls	_Date
CPSC	GVT	###	a	b	c	d	e	f	g	mmddyy

File Name Key Definitions

_(Pan Type)	
a	AL -Aluminum
	CI - Cast Iron
	SS - Stainless Steel
(Pan Brand)	
b	CAL
	EM
	AC
(Pan Size)	
c	10 - 10 inches
	11 - 11 inches
	12 - 12 inches
	5qt - 5 quarts
(Pan Desc)	
d	P01 - pan 1
	P02 - pan 2
	P03 - pan 3
	Flat Warped
	Up Warped
	Down
(Test Desc)	
e	10FF - 1" off center
	20FF - 2" off center
	30FF - 3" off center
	137g - 150 mL
	915g - 1000 mL
	4 qt - 4 quarts
(Heating Rate)	
f	PB - 18,500 Btu/hr.
	18k5btu - 18,500 Btu/hr.
	15Kbtu - 15,000 Btu/hr.
	11Kbtu - 11,000 Btu/hr.
	8Kbtu - 8,000 Btu/hr.
Controls	
g	- Controls Disabled
	CTRL - Controls Enabled

Example File Name: _CPSC_GVT_054_AL CAL 10 P03 137g PB_010614

Baseline Tests Index

Oil Volume (mL)	Heating Rate (Btu/hr.)	Pan Type	Pan Size (Inches)	Test #	File Name
150	18,500	AL	10	54	_CPSC_GVT_054_AL CAL 10 P03 137g PB_010614
				57	_CPSC_GVT_057_AL CAL 10 P03 137g PB_010714
				58	_CPSC_GVT_058_AL CAL 10 P03 137g PB_010714
		CI	10	52	_CPSC_GVT_052_CI EM 10 P02 137g PB_010614
		SS	10	53	_CPSC_GVT_053_SS AC 10 P02 137g PB_010614
	15,000	AL	10	59	_CPSC_GVT_059_AL CAL 10 P03 137g 15K Btu_010714
		CI	10	56	_CPSC_GVT_056_CI EM 10 P02 137g 15kBTU_010714
		SS	10	63	_CPSC_GVT_063_SS AC 10 P02 137g 15K Btu_010914
	11,000	AL	10	62	_CPSC_GVT_062_AL CAL 10 P03 137g 11K Btu_010914
		CI	10	60	_CPSC_GVT_060_CI EM 10 P02 137g 11K Btu_010714
		SS	10	61	_CPSC_GVT_061_SS AC 10 P02 137g 11K Btu_010814
	8,000	AL	10	64	_CPSC_GVT_064_AL CAL 10 P03 137g 8K Btu_011014
		CI	10	66	_CPSC_GVT_066_CI EM 10 P02 137g 8K Btu_011014
		SS	10	65	_CPSC_GVT_065_SS AC 10 P02 137g 8K Btu_011014
1000	18,500	AL	12	68	_CPSC_GVT_068_AL CAL 12 P03 915g 18k5Btu_011314
				69	_CPSC_GVT_069_AL CAL 12 P03 915g 18k5Btu_011514
				70	_CPSC_GVT_070_AL CAL 12 P03 915g 18k5Btu_011514
		CI	12	71	_CPSC_GVT_071_CI EM 12 P02 915g 18k5Btu_011514
		SS	11	67	_CPSC_GVT_067_SS AC 11 P01 915g 18k5Btu_011314

Control System Tests Index

Oil Volume (mL)	Heating Rate (Btu/hr.)	Pan Type	Pan Size (Inches)	Test #	File Name
150	18,500	AL	10	73	_CPSC_GVT_073_AL CAL 10 P03 137g 18k5BtuCTRL_011714
			12	82	_CPSC_GVT_082_AL CAL 12 P03 137g 18K5BtuCTRL_013014
		CI	10	74	_CPSC_GVT_074_CI EM 10 P02 137g 18k5BtuCTRL_011714
			12	83	_CPSC_GVT_083_CI EM 12 P01 137g 18K5BtuCTRL_013114
		SS	10	72	_CPSC_GVT_072_SS AC 10 P02 137g 18k5BtuCTRL_011714
			11	90	_CPSC_GVT_090_SS CAL 11 P01 137g 18k5 BtuCTRL_020514
	15,000	AL	10	76	_CPSC_GVT_076_AL CAL 10 P03 137g 15kBtuCTRL_012014
		CI	10	84	_CPSC_GVT_084_CI EM 10 P02 137g 15k BtuCTRL_020314
		SS	10	77	_CPSC_GVT_077_SS AC 10 P02 137g 15kBtuCTRL_012014
	11,000	AL	10	81	_CPSC_GVT_081_AL CAL 10 p03 137G 11BtuCTRL_013014
		CI	10	85	_CPSC_GVT_085_CI EM 10 P02 137g 11k BtuCTRL_020314
		SS	10	78	_CPSC_GVT_078_SS AC 10 P02 137g 11kBtuCTRL_012114
1000	18,500	AL	12	98	_CPSC_GVT_098_AL CAL 12 P03 915g 18k5 BtuCTRL_020714
		CI	12	91	_CPSC_GVT_091_CI EM 12 P01 915g 18k5 BtuCTRL_020514
		SS	11	92	_CPSC_GVT_092_SS AC 11 P01 915g 18k5 BtuCTRL_020514
	11,000	AL	12	94	_CPSC_GVT_094_AL CAL 12 P03 915g 11k BtuCTRL_020614
		CI	12	87	_CPSC_GVT_087_CI EM 12 P01 915g 11k BtuCTRL_020314
		SS	11	86	_CPSC_GVT_086_SS AC 11 P01 915g 11k BtuCTRL_020314

Water Boil Testing With Out-Of-Flat Pot Test Index

Water Volume (quarts)	Heating Rate (Btu/hr.)	Pot Type	Pot Size (quarts)	Pot Warpage	Controls	Test #	File Name
4	18,500	SS	5	FLAT	off	97	_CPSC_GVT_097_SS CAL 5QT FLAT 4QT 18k5 Btu_020714
					on	96	_CPSC_GVT_096_SS CAL 5QT FLAT 4QT 18k5 BtuCTRL_020714
				1/8" UP	off	89	_CPSC_GVT_089_SS CAL 5QT WARP UP 4QT 18k5 Btu_020414
					on	88	_CPSC_GVT_088_SS CAL 5QT WARP UP 4QT 18k5 BtuCTRL_020414
				1/8" DOWN	off	95	_CPSC_GVT_095_SS CAL 5QT WARP DOWN 4QT 18k5 Btu_020714
					on	93	_CPSC_GVT_093_SS CAL 5QT WARP DOWN 4QT 18k5 BtuCTRL_020614

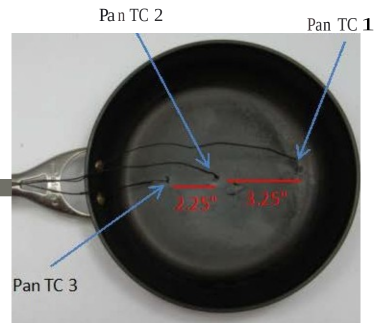
Eccentricity of Pan off Burner Center Test Index

Oil Volume (mL)	Heating Rate (Btu/hr.)	Pan Type	Pan Size (inches)	Pan Location	Test #	File Name
150	18,500	SS	10	1" off-center	100	_CPSC_GVT_100_SS AC 10 P02 1INCHOFF 137g 18k5 BtuCTRL_021314
				2" off-center	101	_CPSC_GVT_101_SS AC 10 P02 2INCHOFF 137g 18k5 BtuCTRL_021314
				3" off-center	102	_CPSC_GVT_102_SS AC 10 P02 3INCHOFF 137g 18k5 BtuCTRL_021414

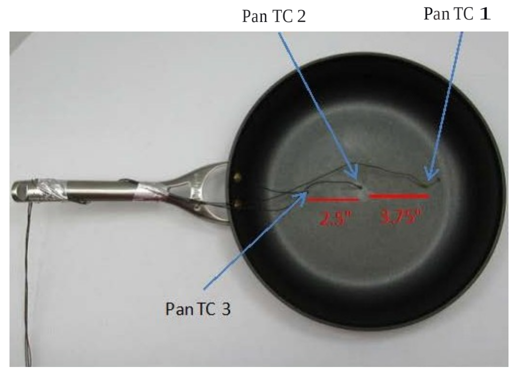
Pan Thermocouple Placement Key:

Aluminum

10" skillet

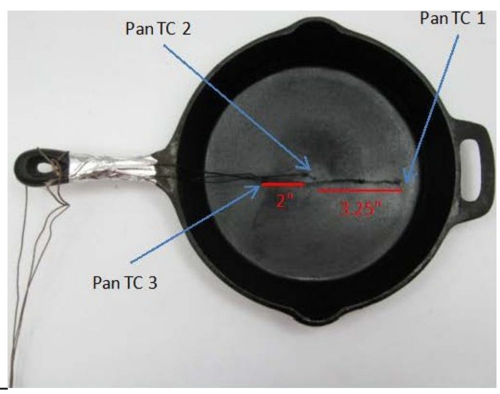


:12" skillet

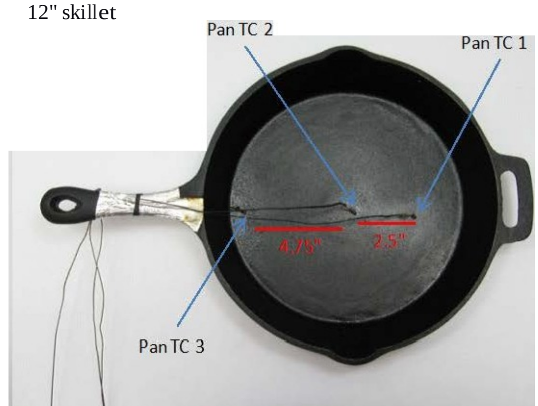


Cast Iron

10" skillet

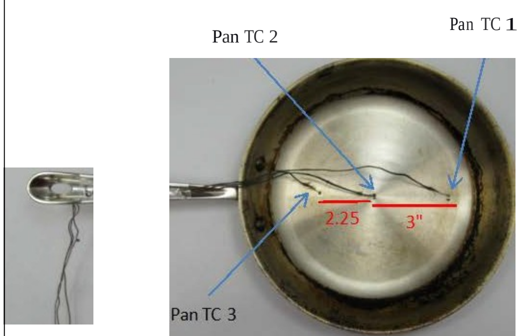


12" skillet

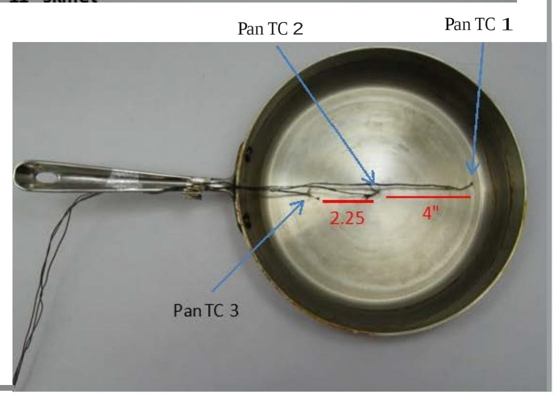


Stainless Steel

10" skillet

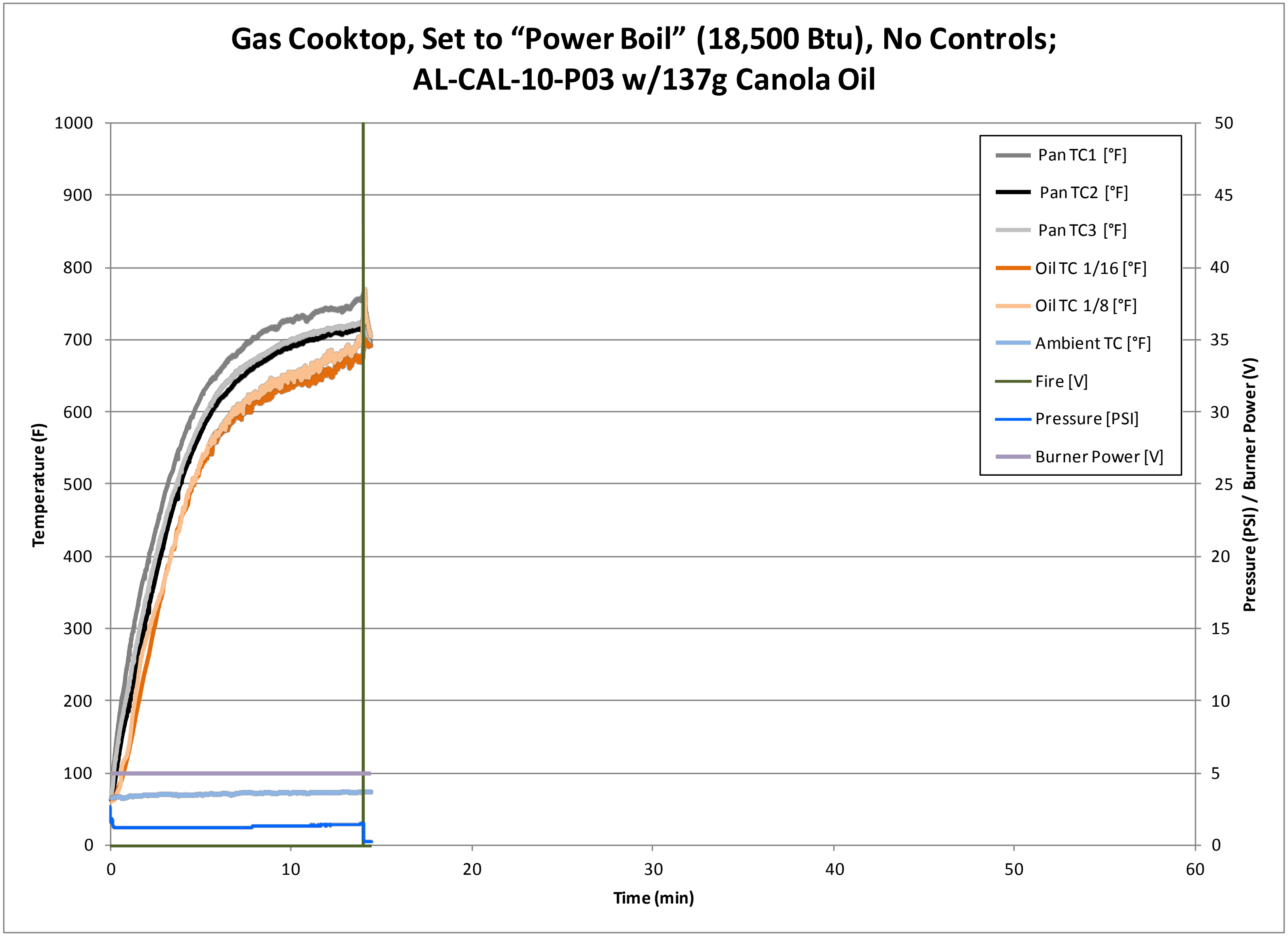


11" skillet

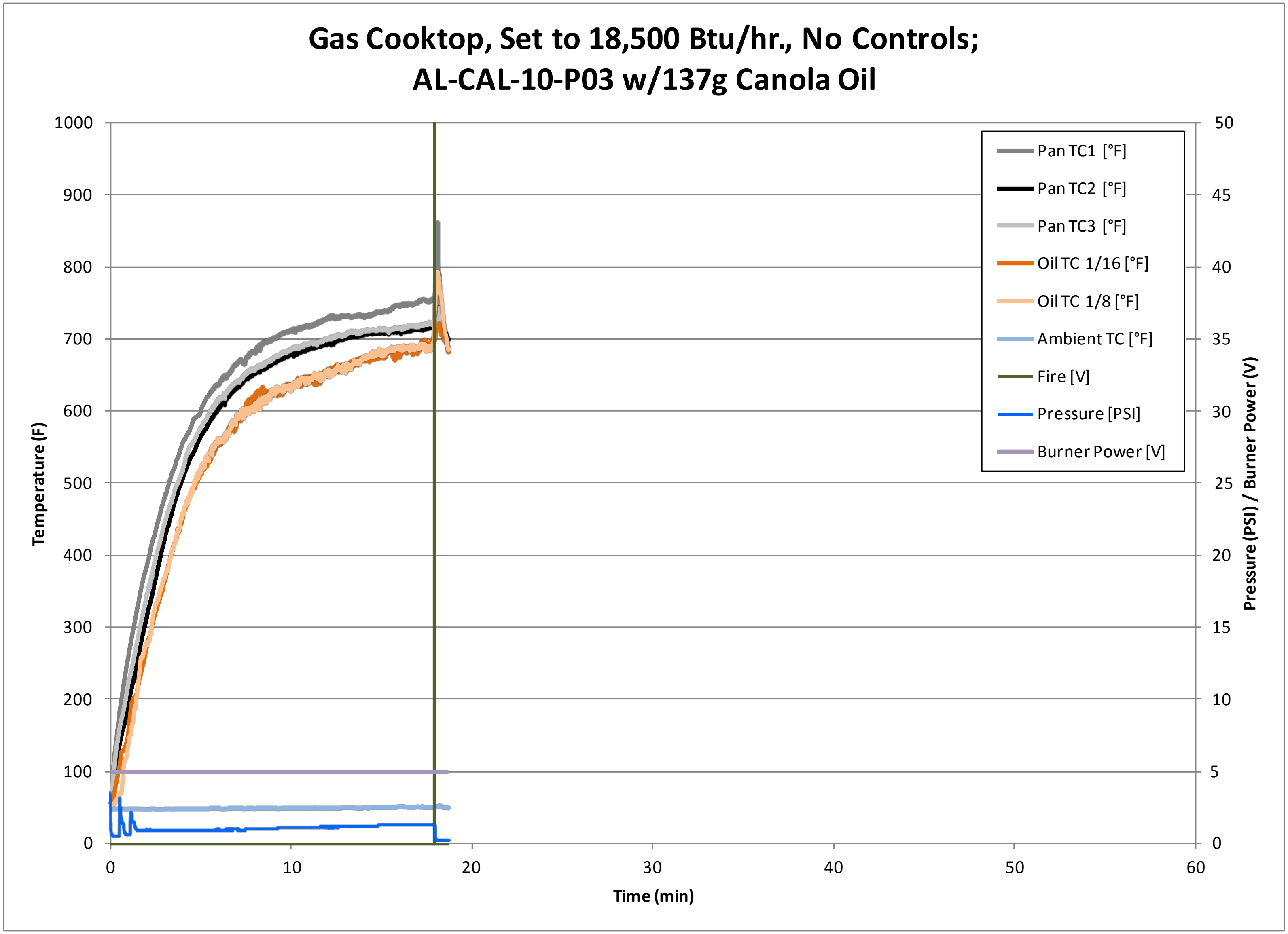


Appendix B

Baseline Testing – No Controls



_CPSC_GVT_054_AL CAL 10 P03 137g PB_010614



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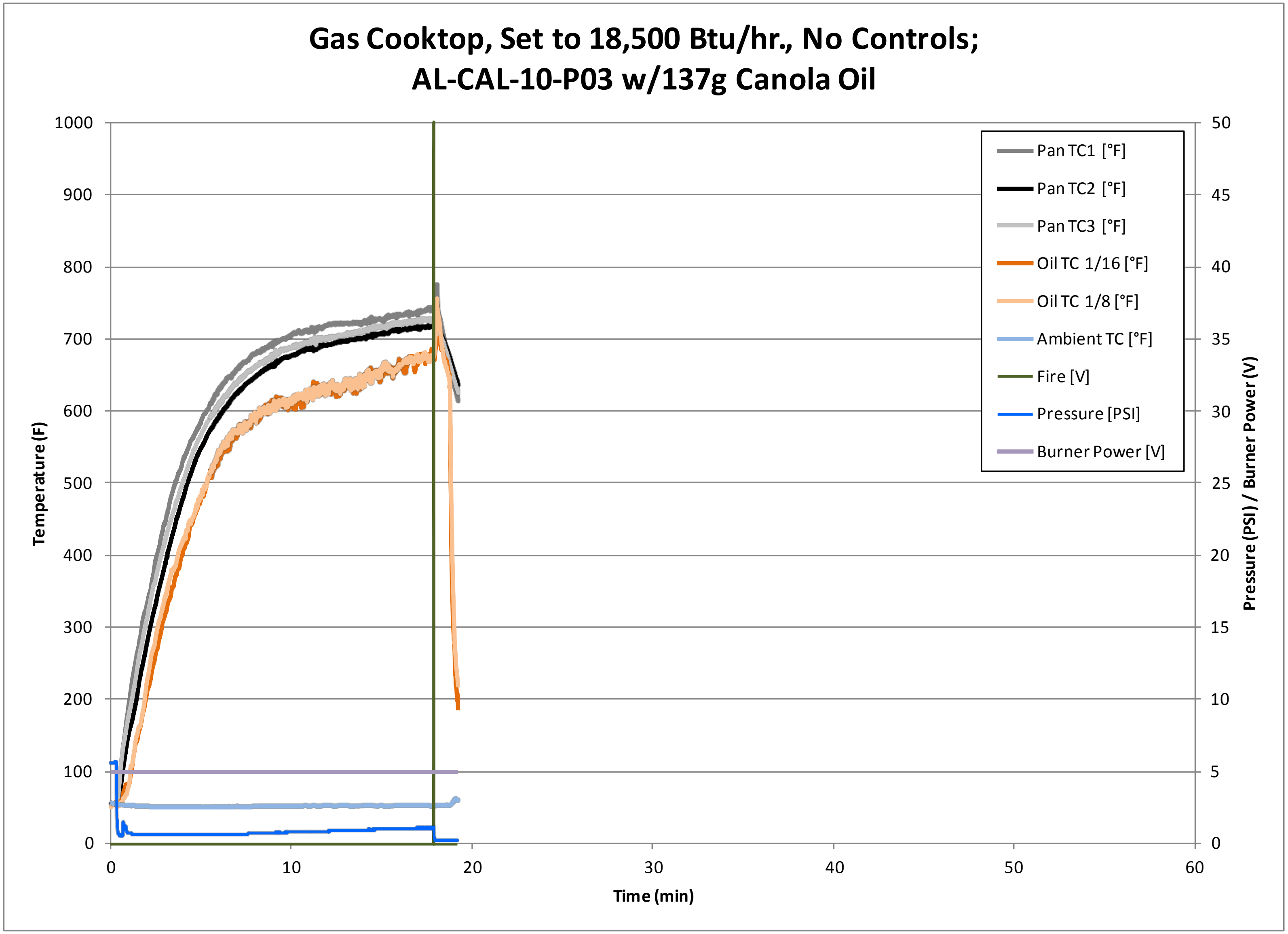

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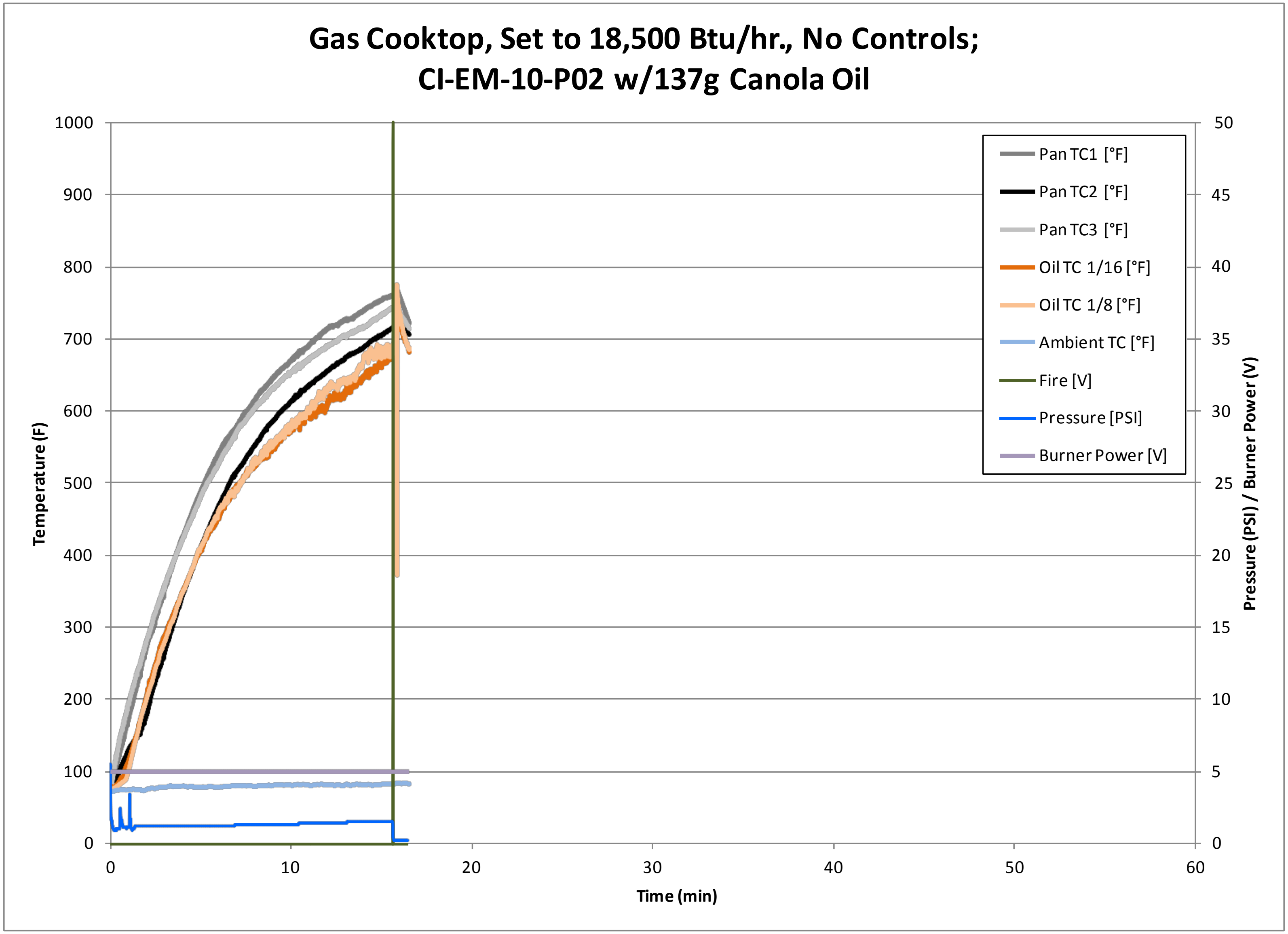

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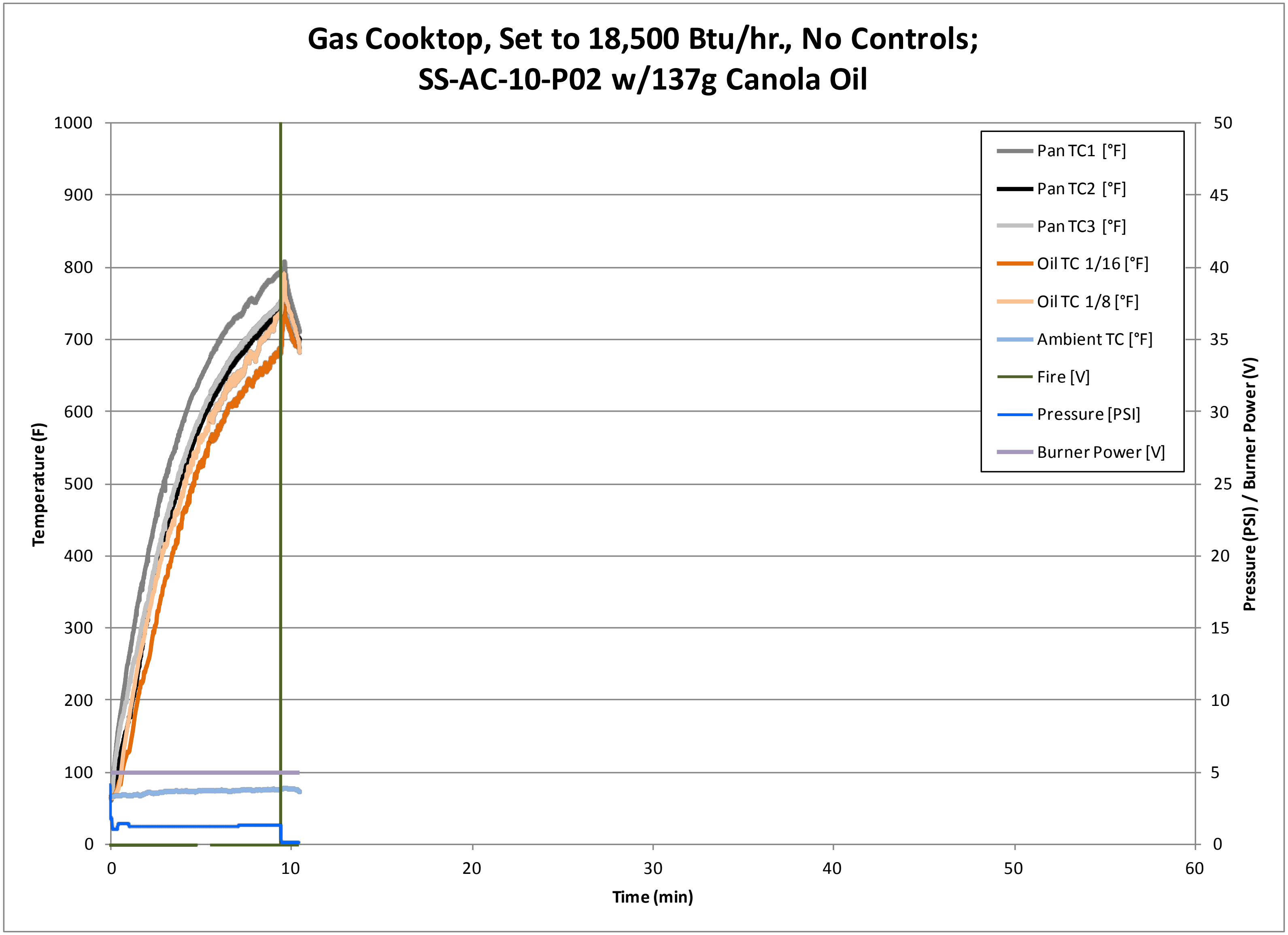
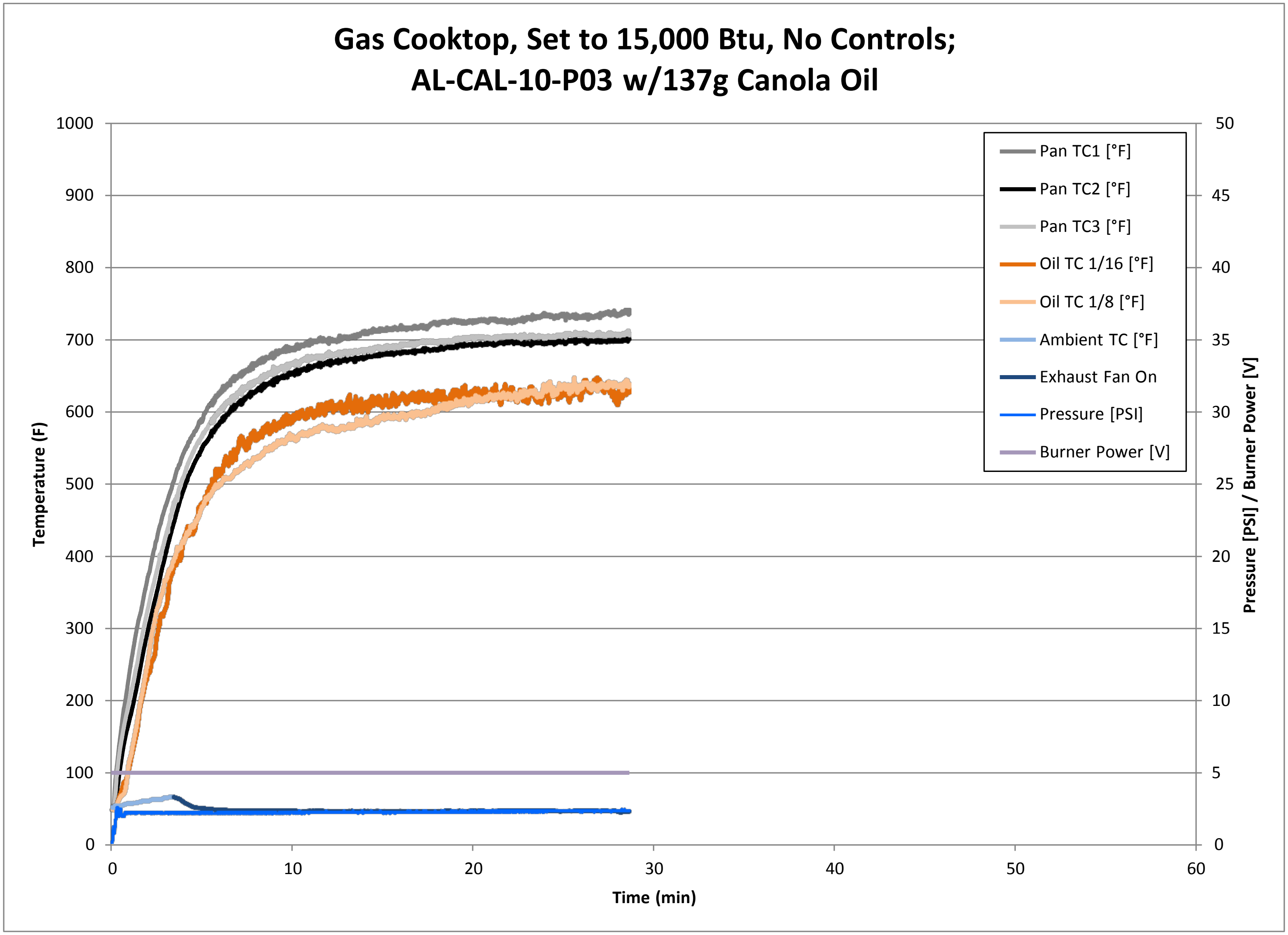


_CPSC_GVT_053_SS AC 10 P02 137g PB_010614



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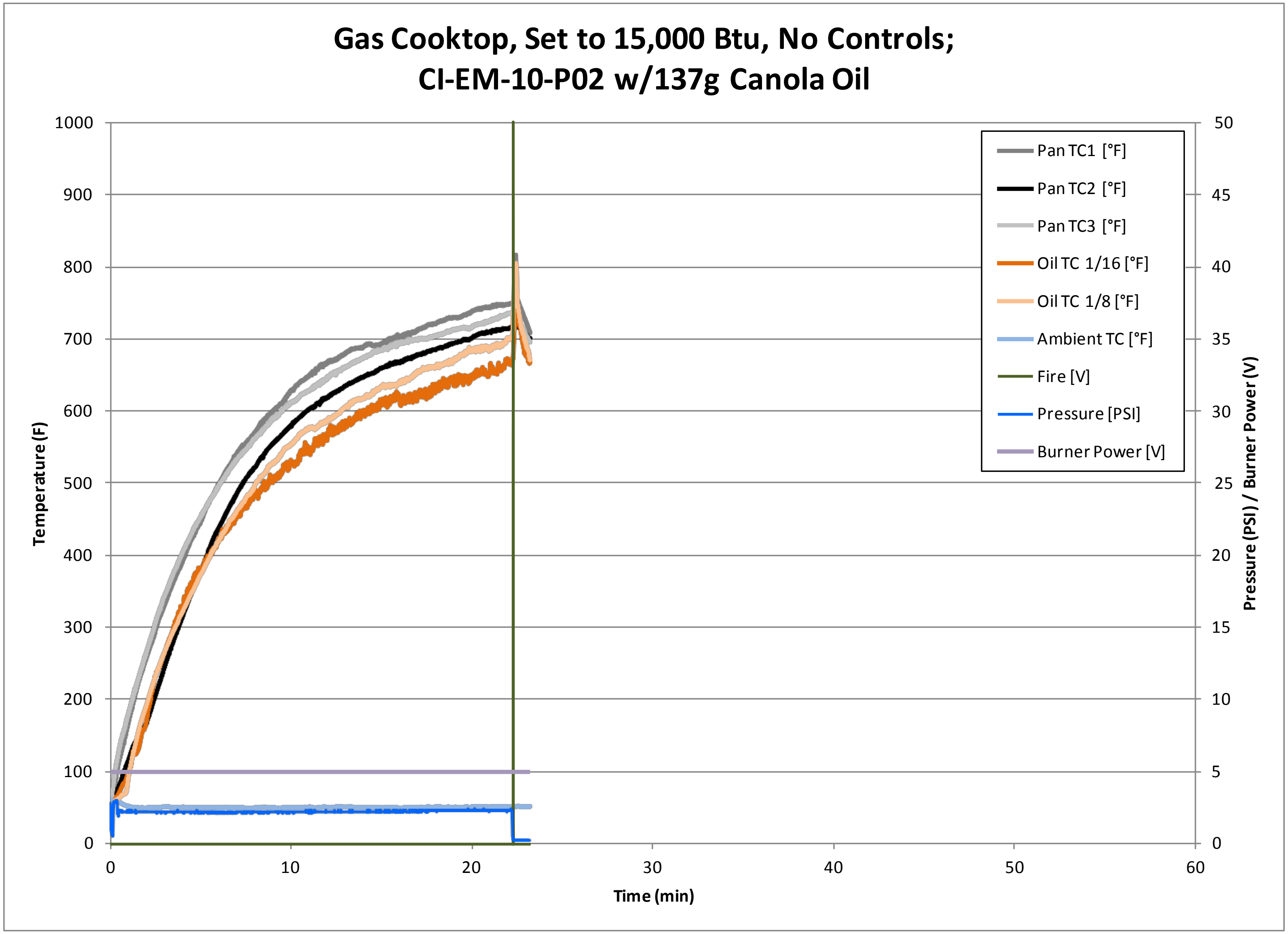

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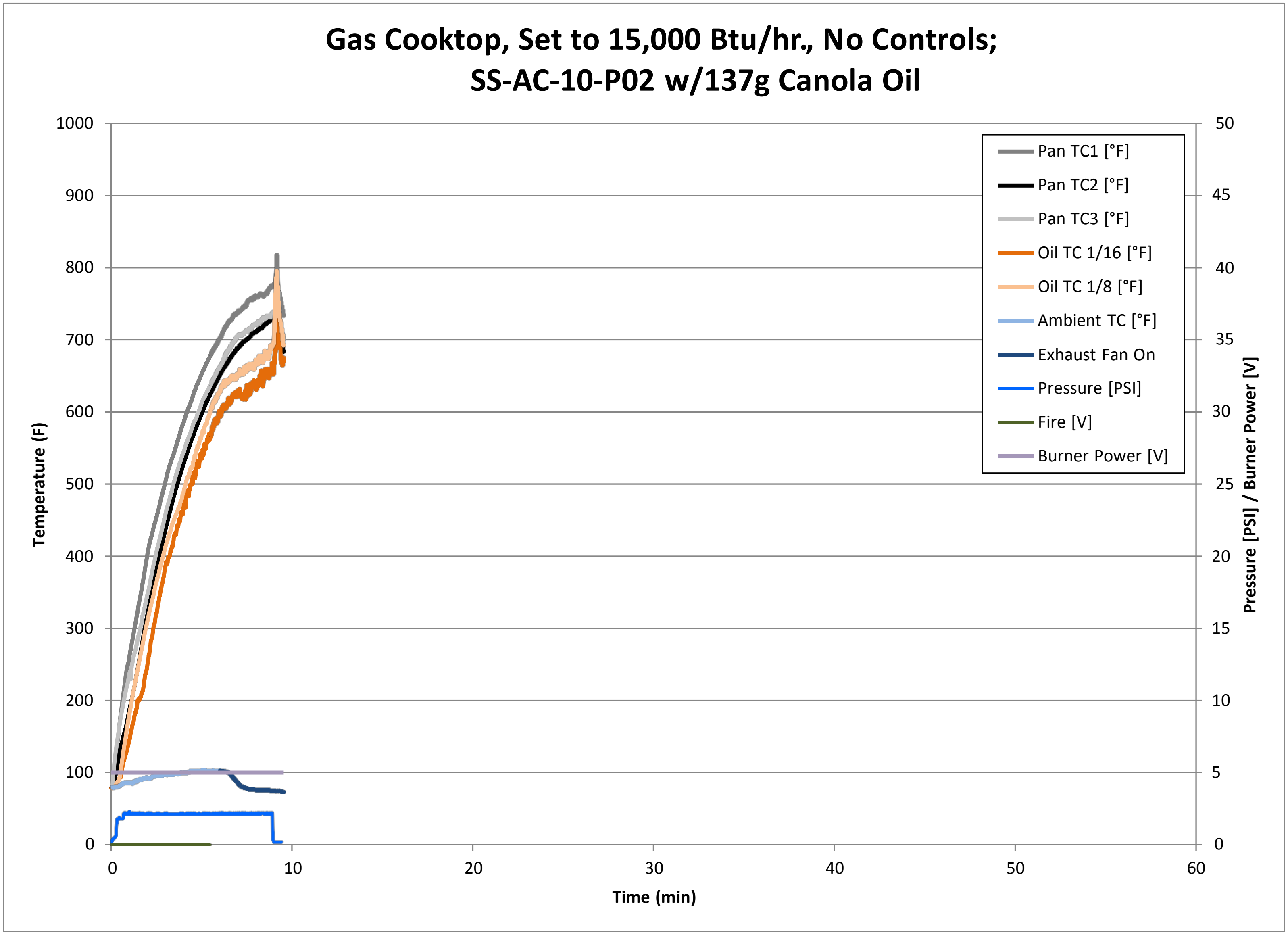

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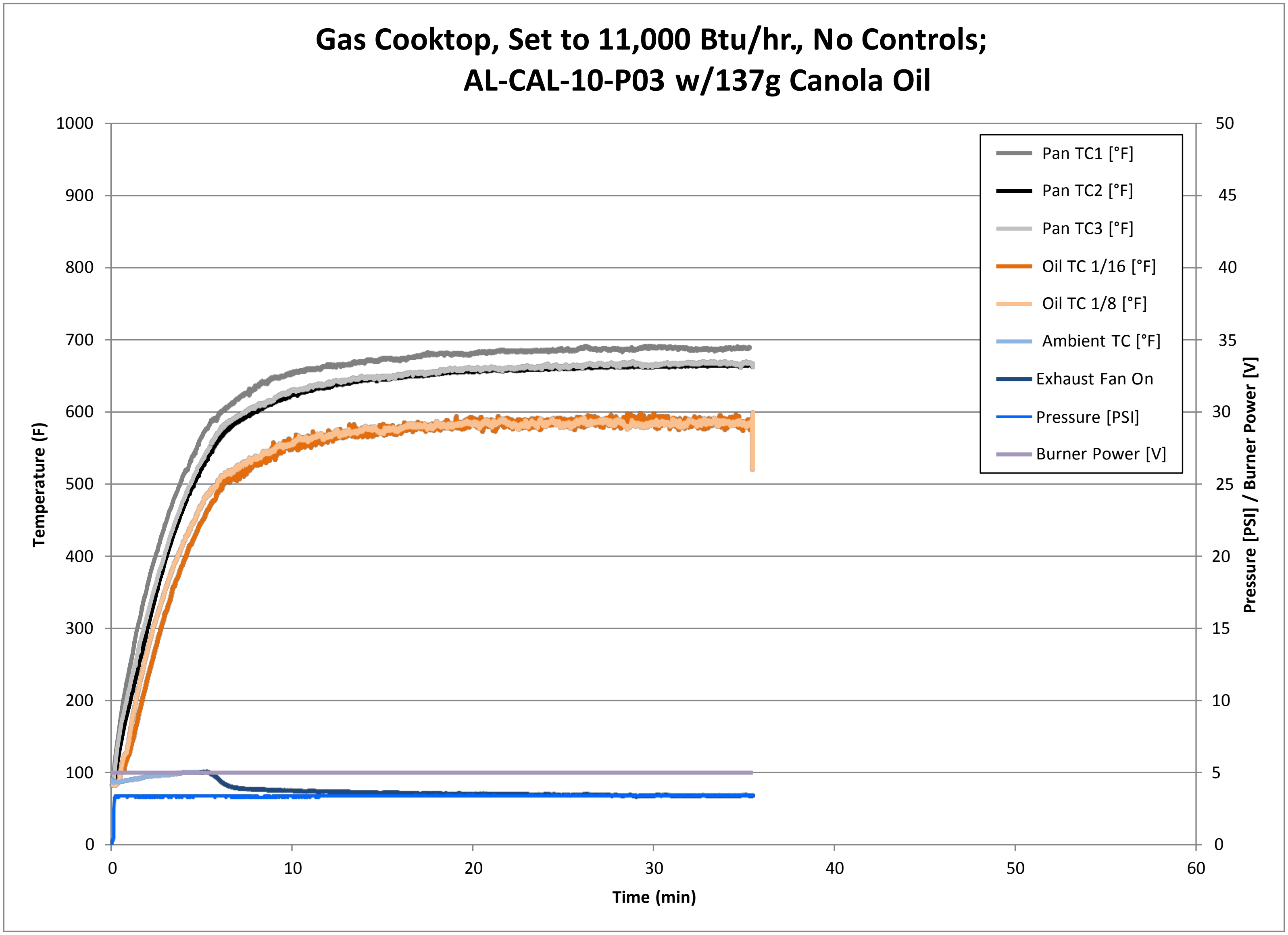
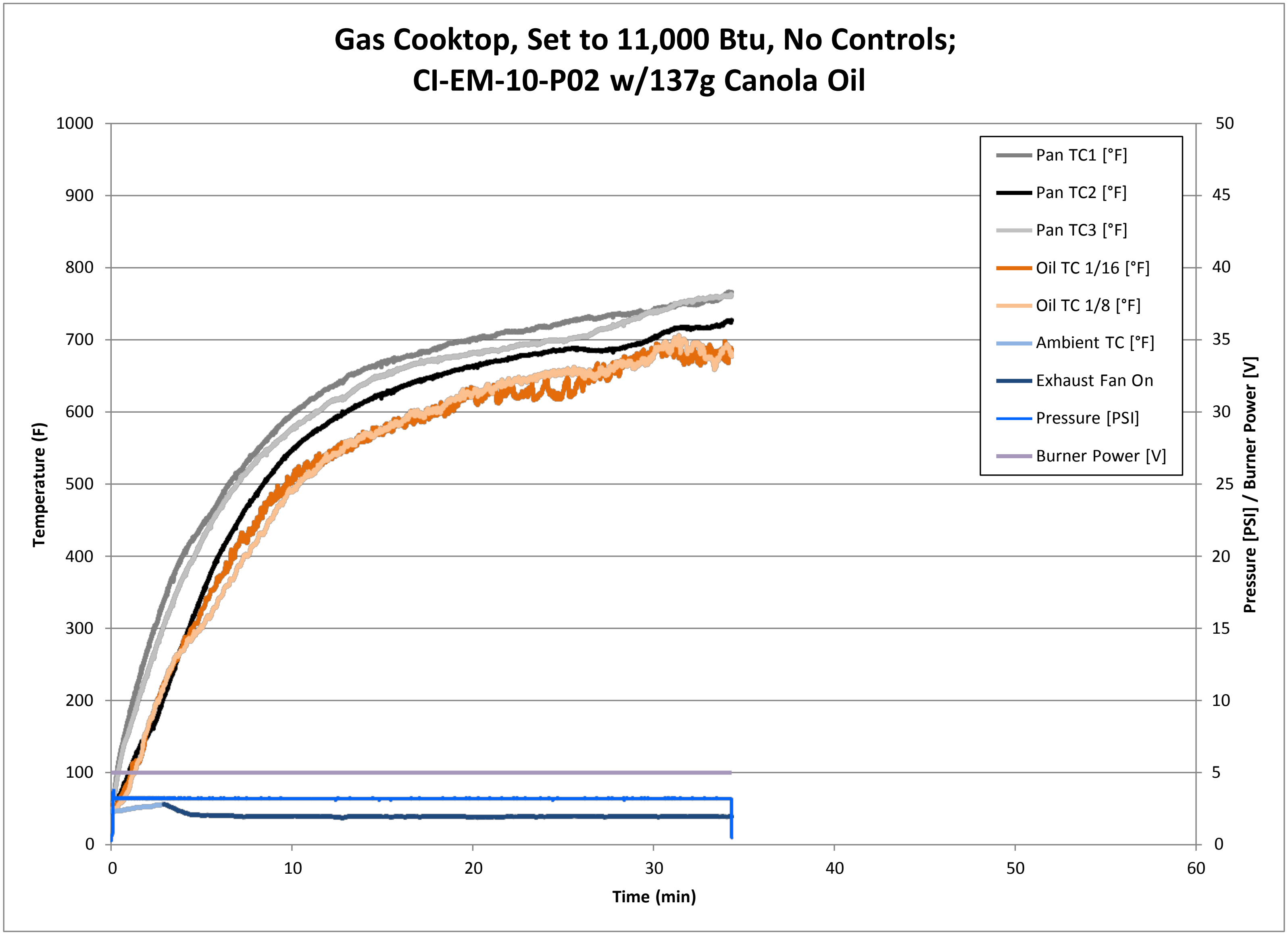


_CPSC_GVT_062_AL CAL 10 P03 137g 11K Btu_010914



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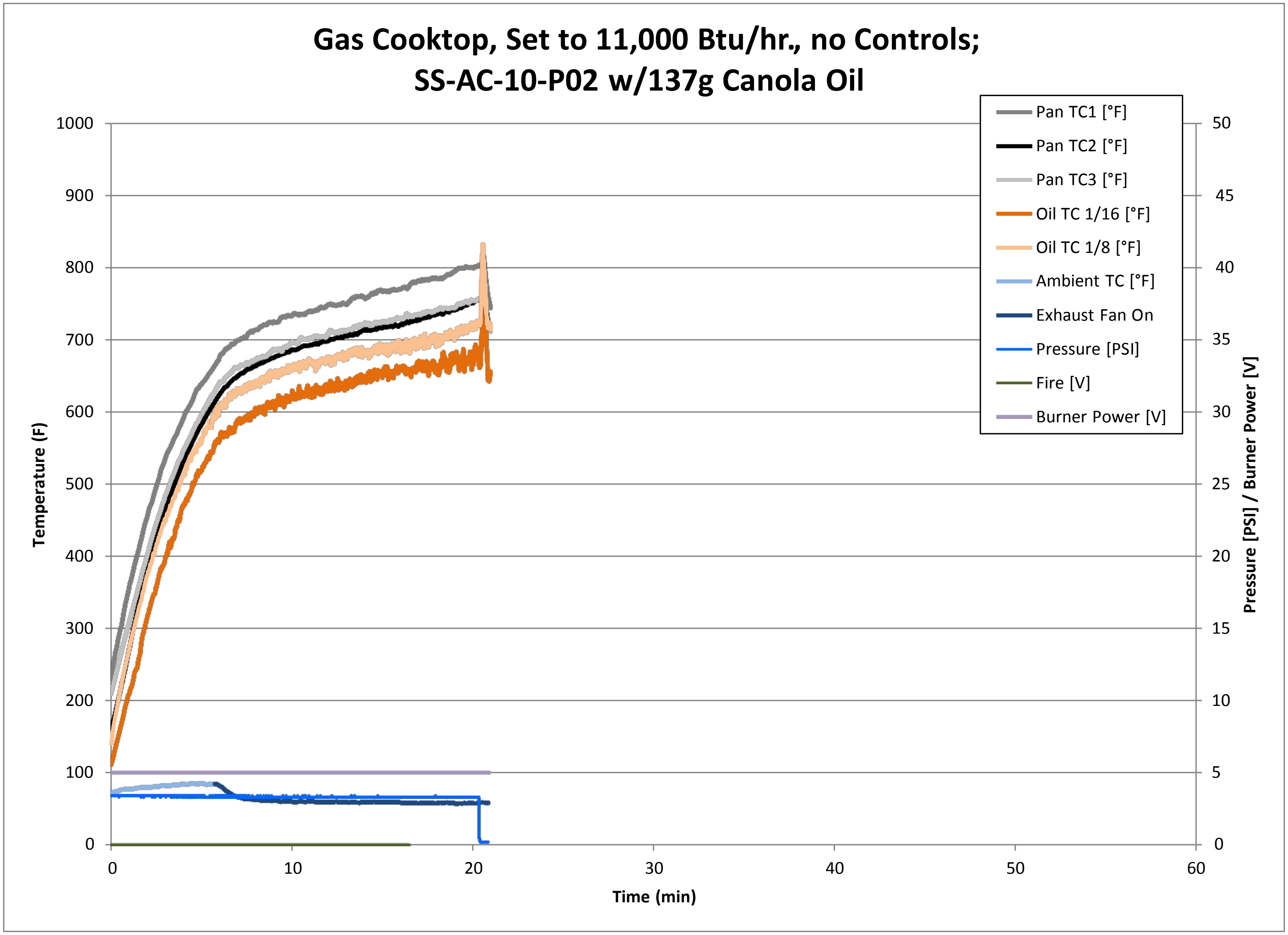

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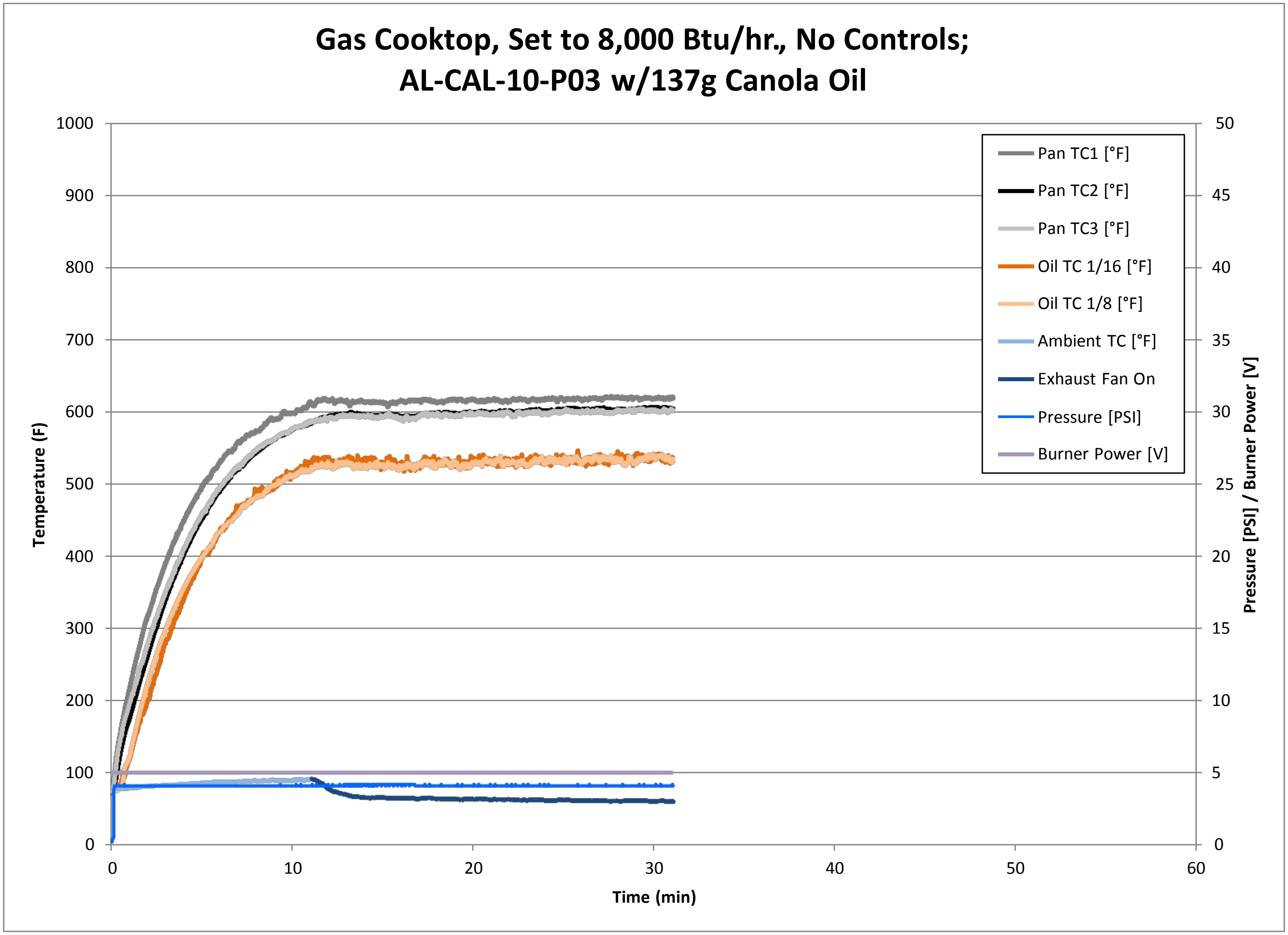

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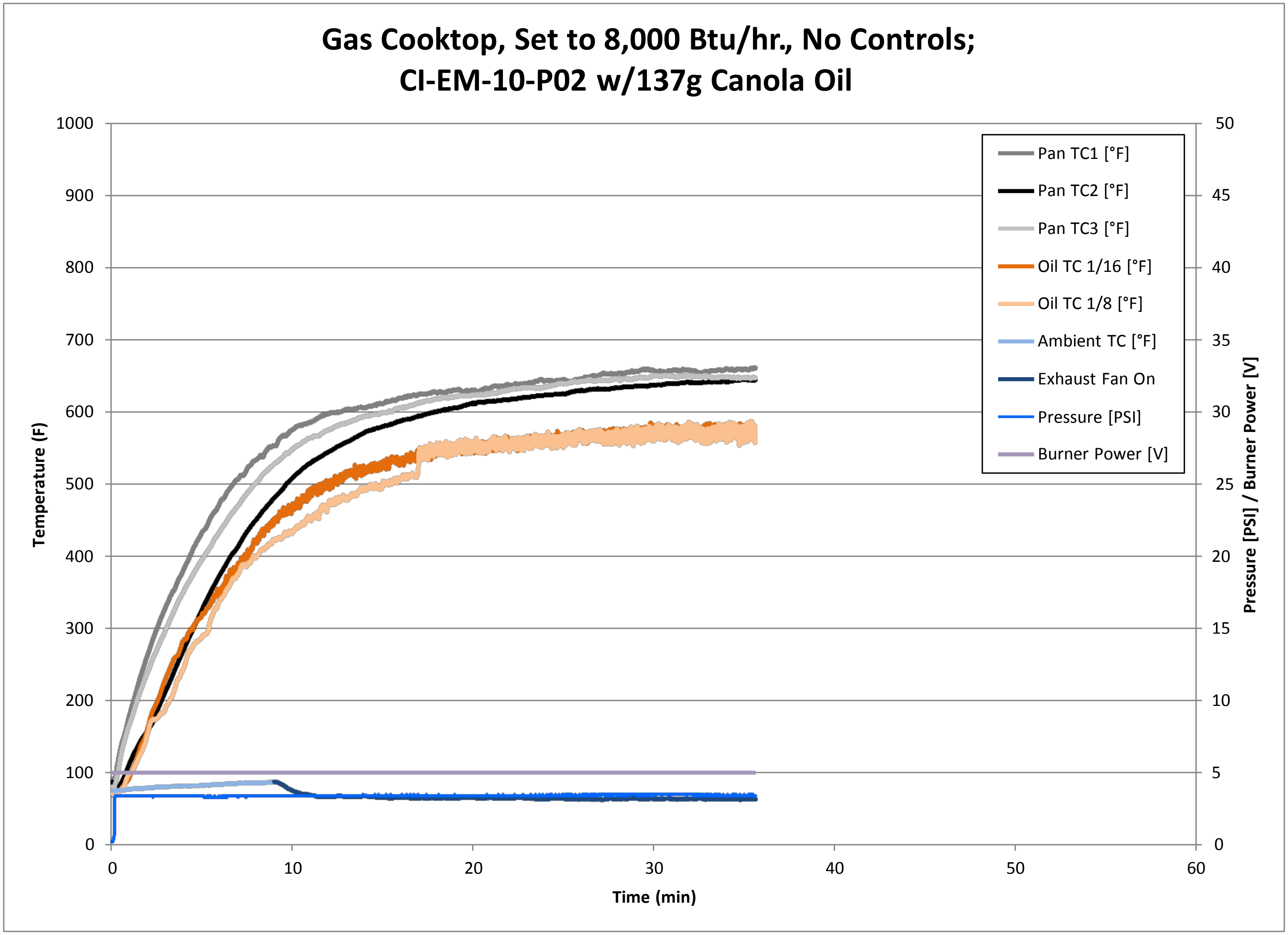

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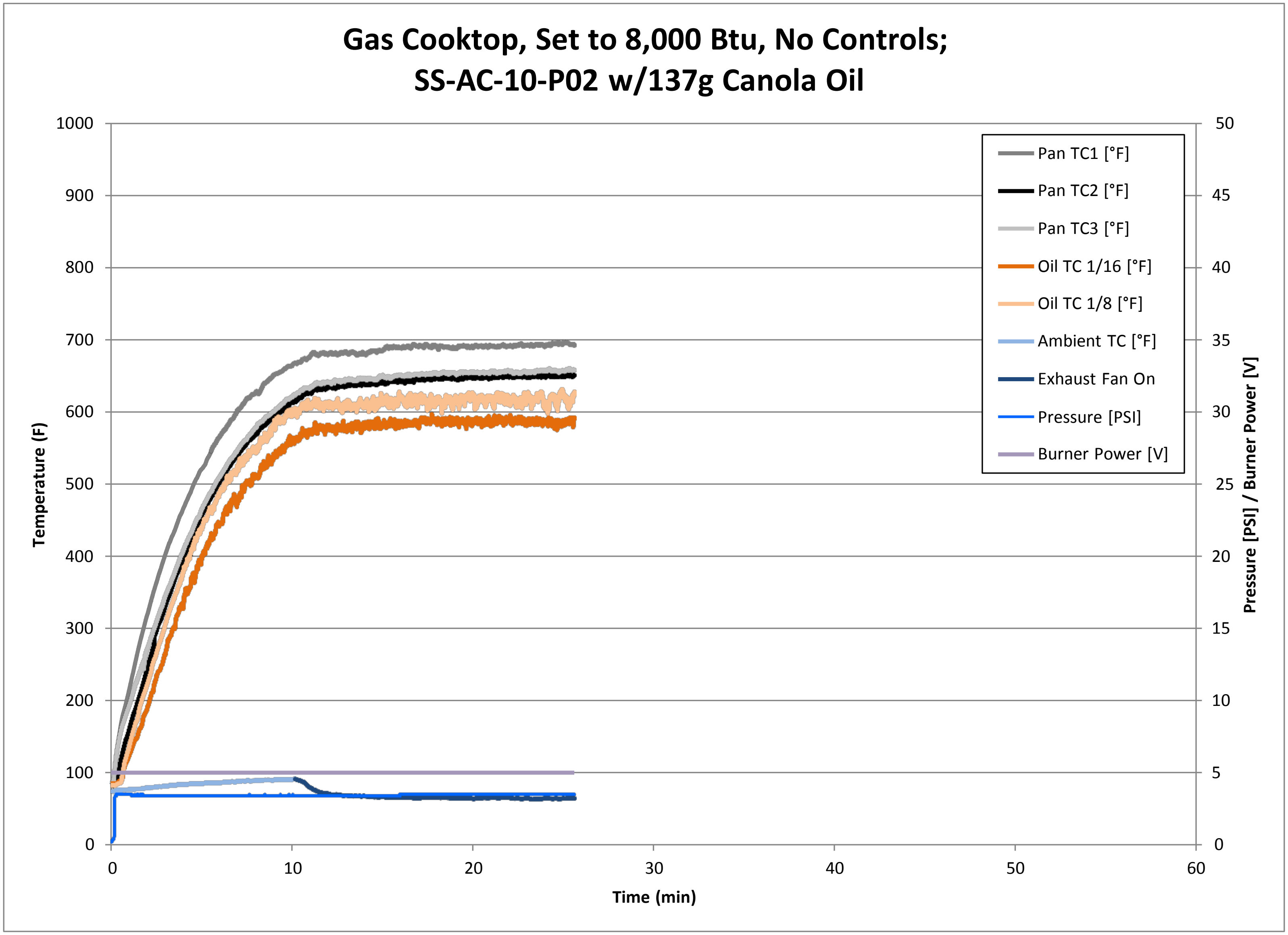

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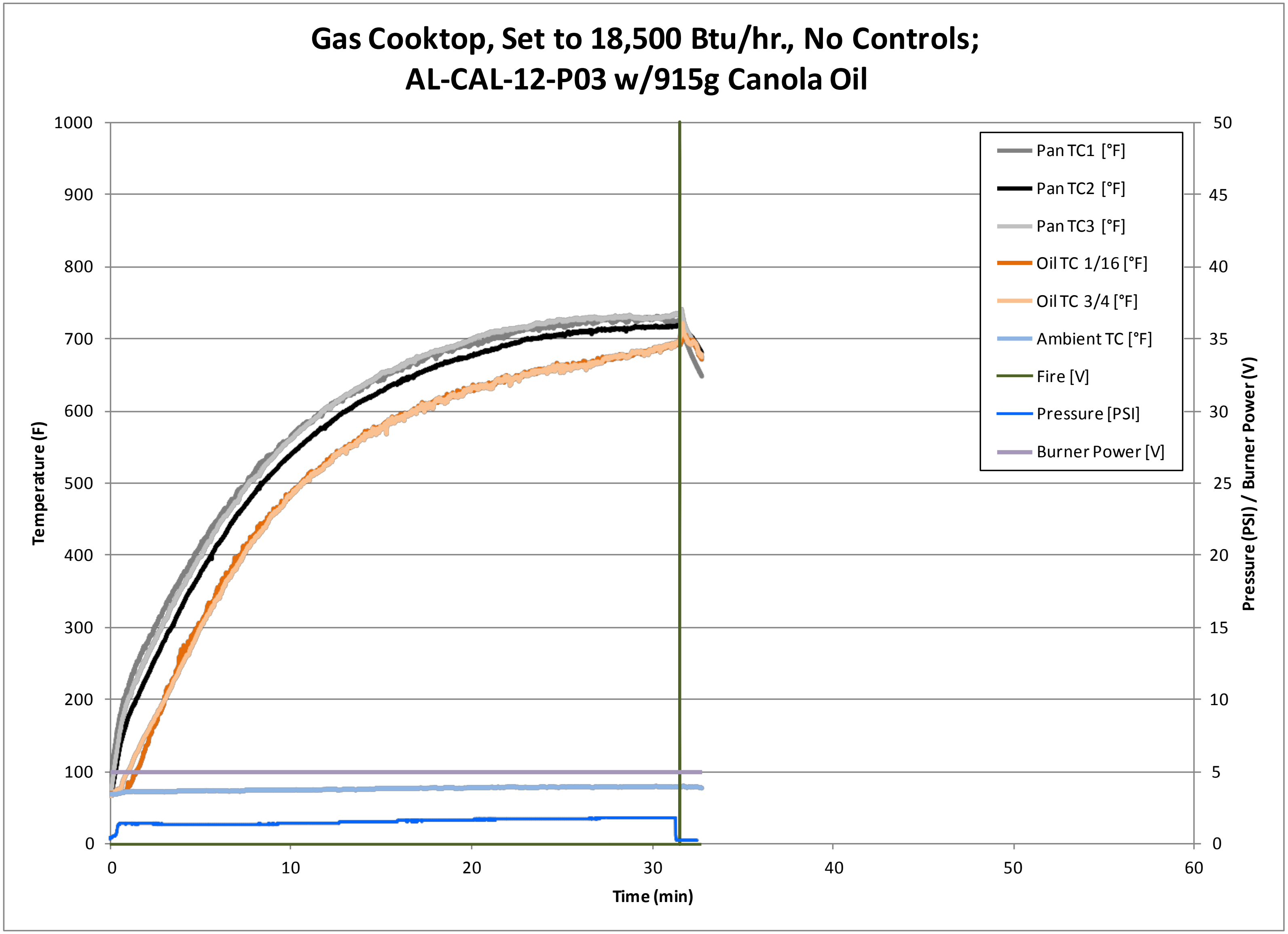

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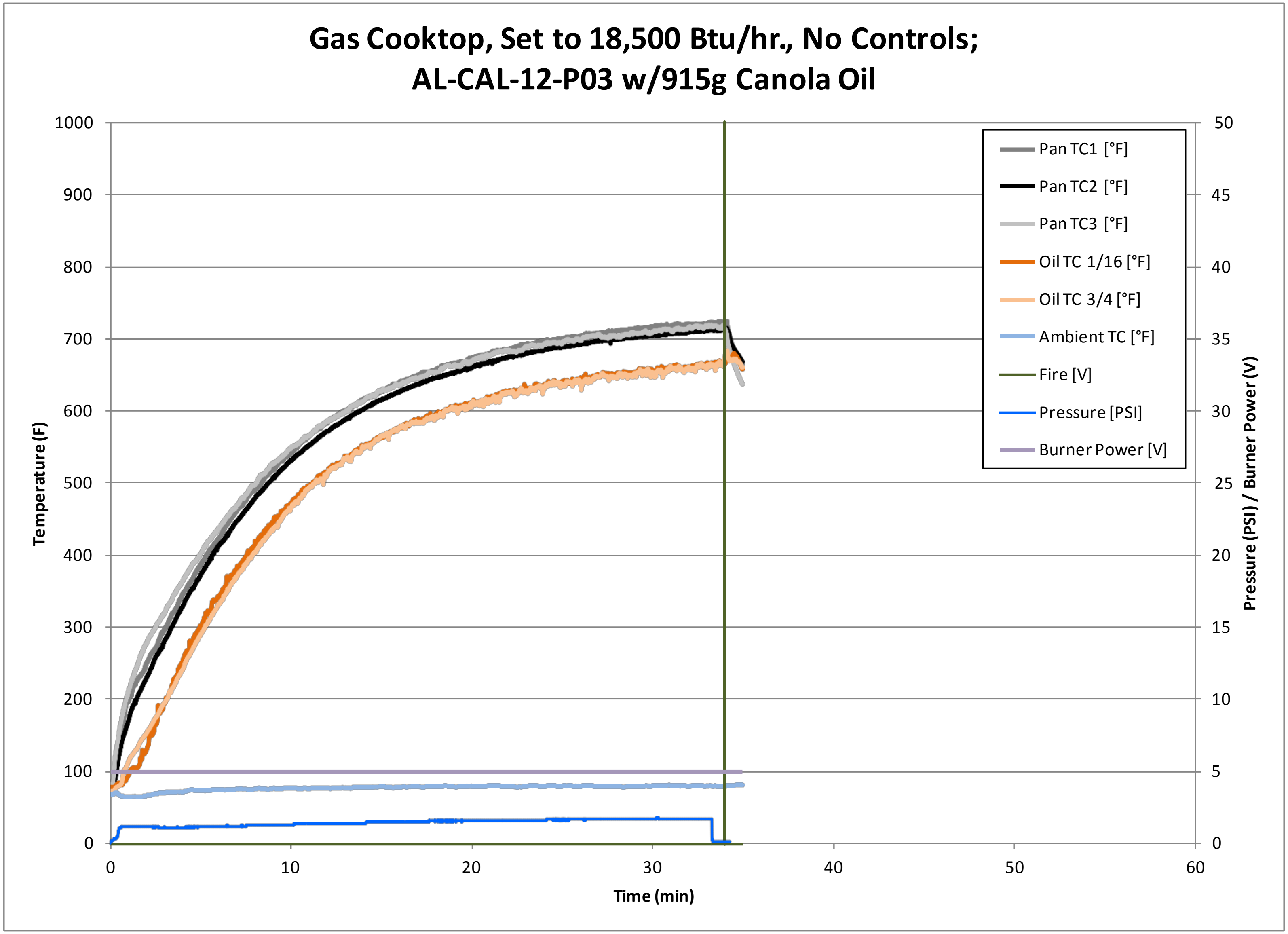

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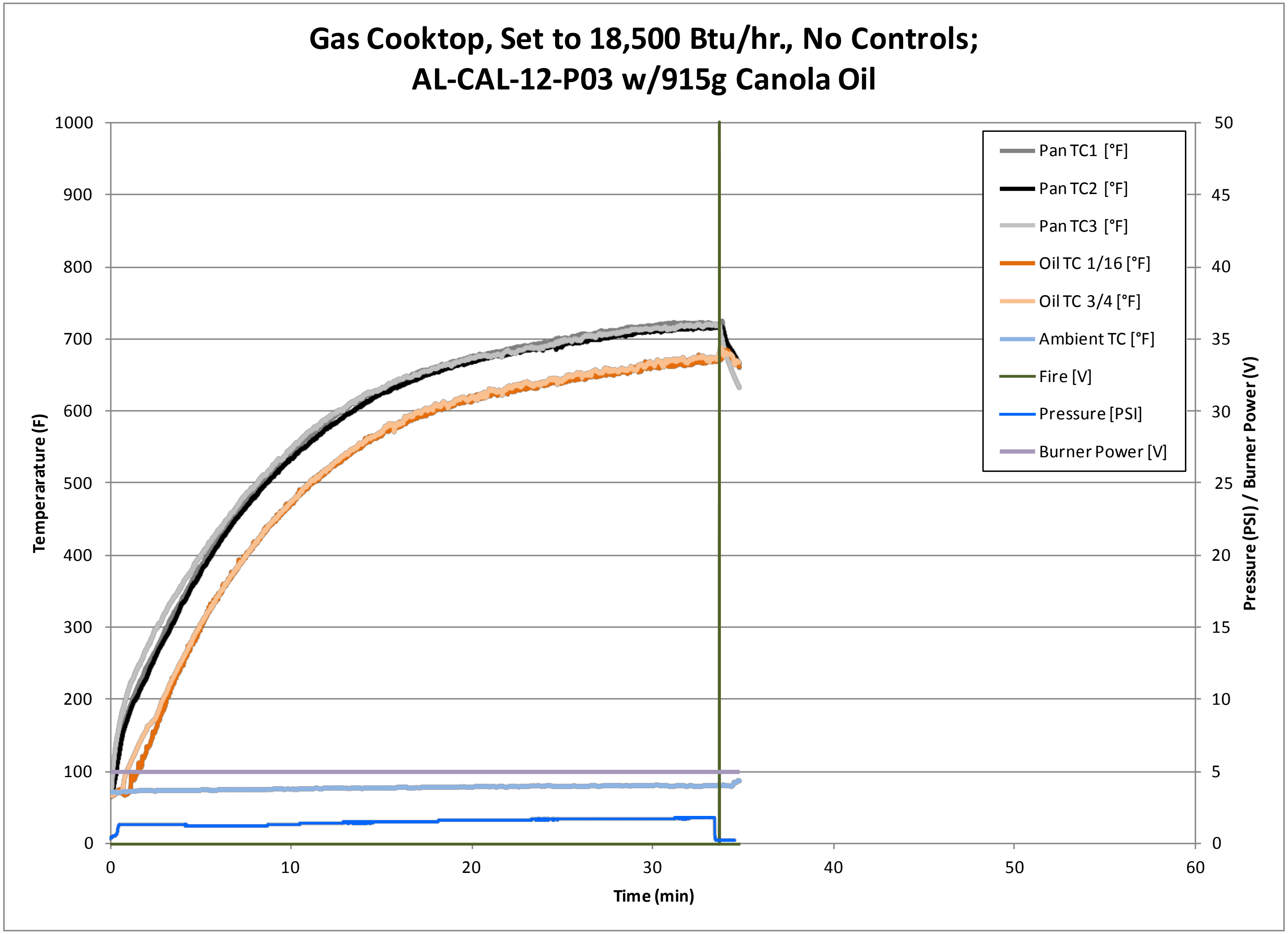

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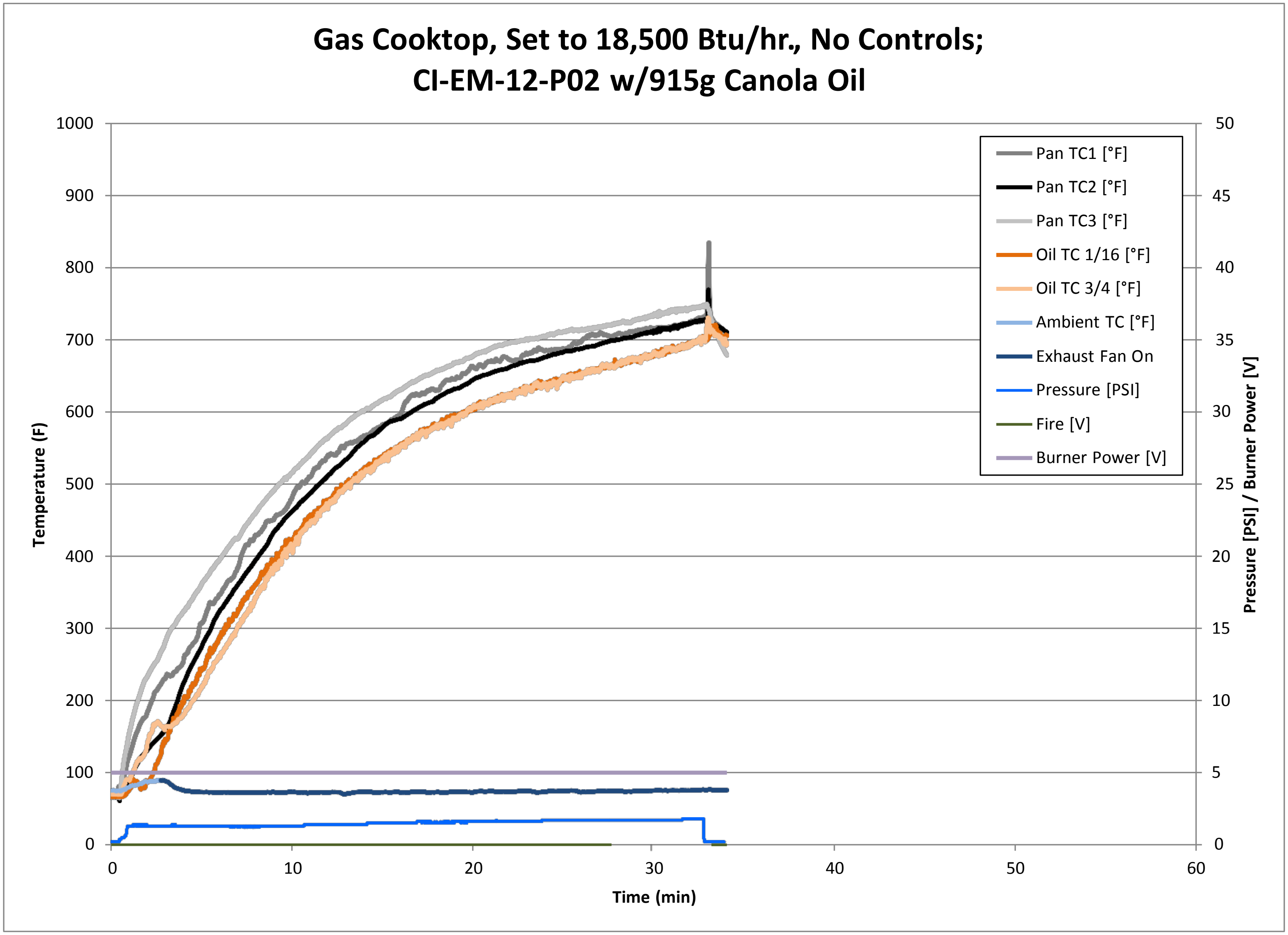

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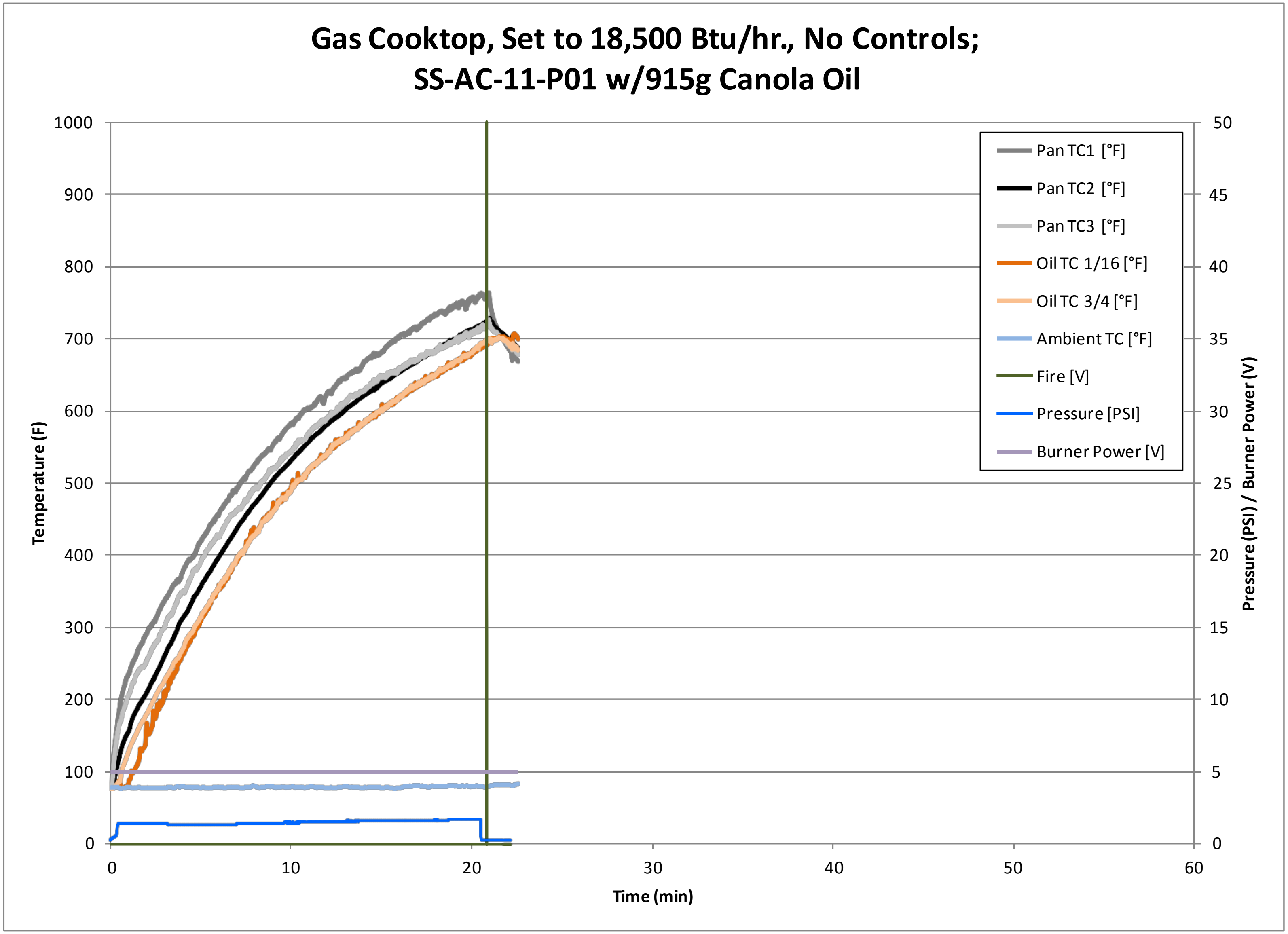
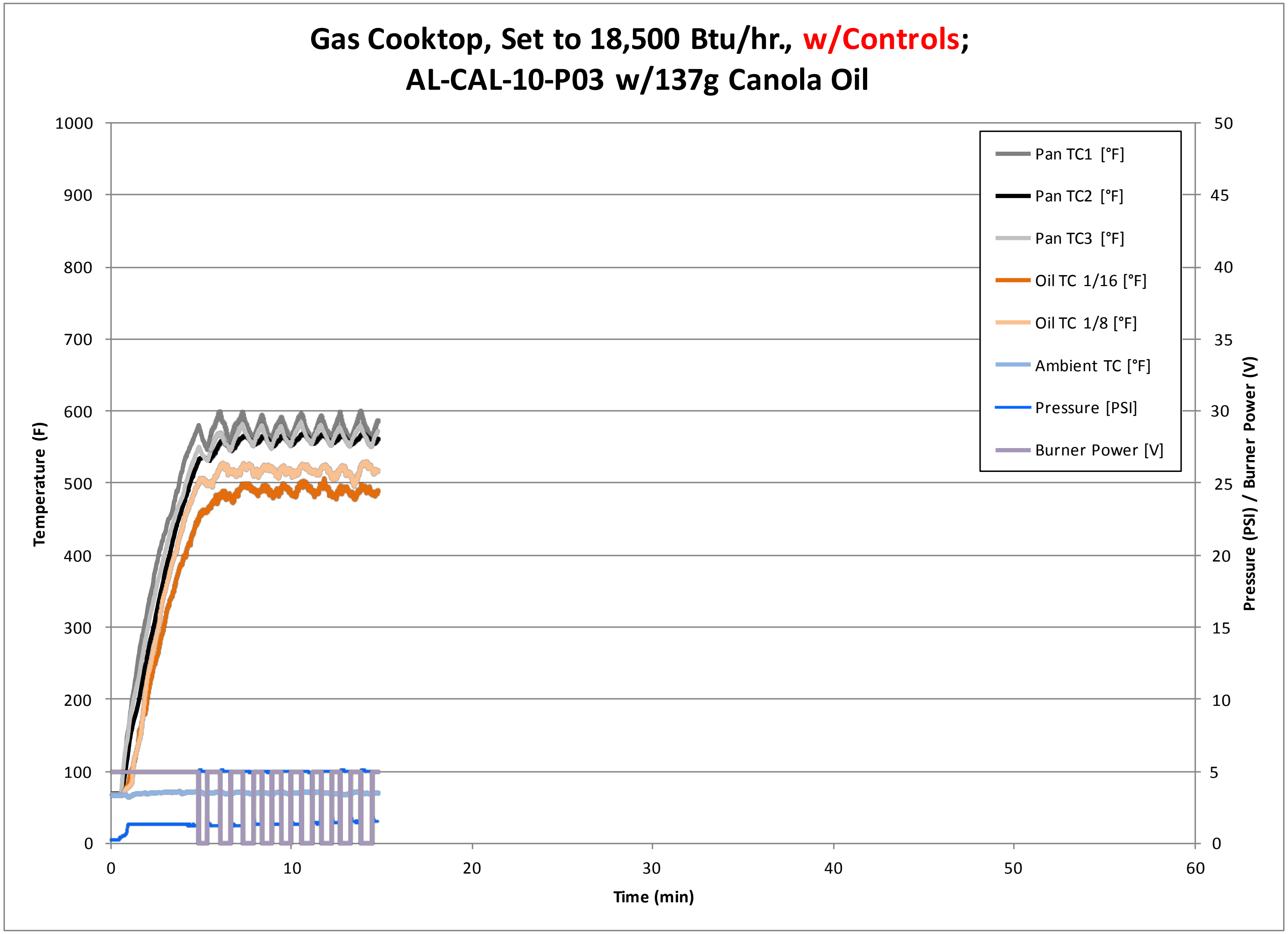


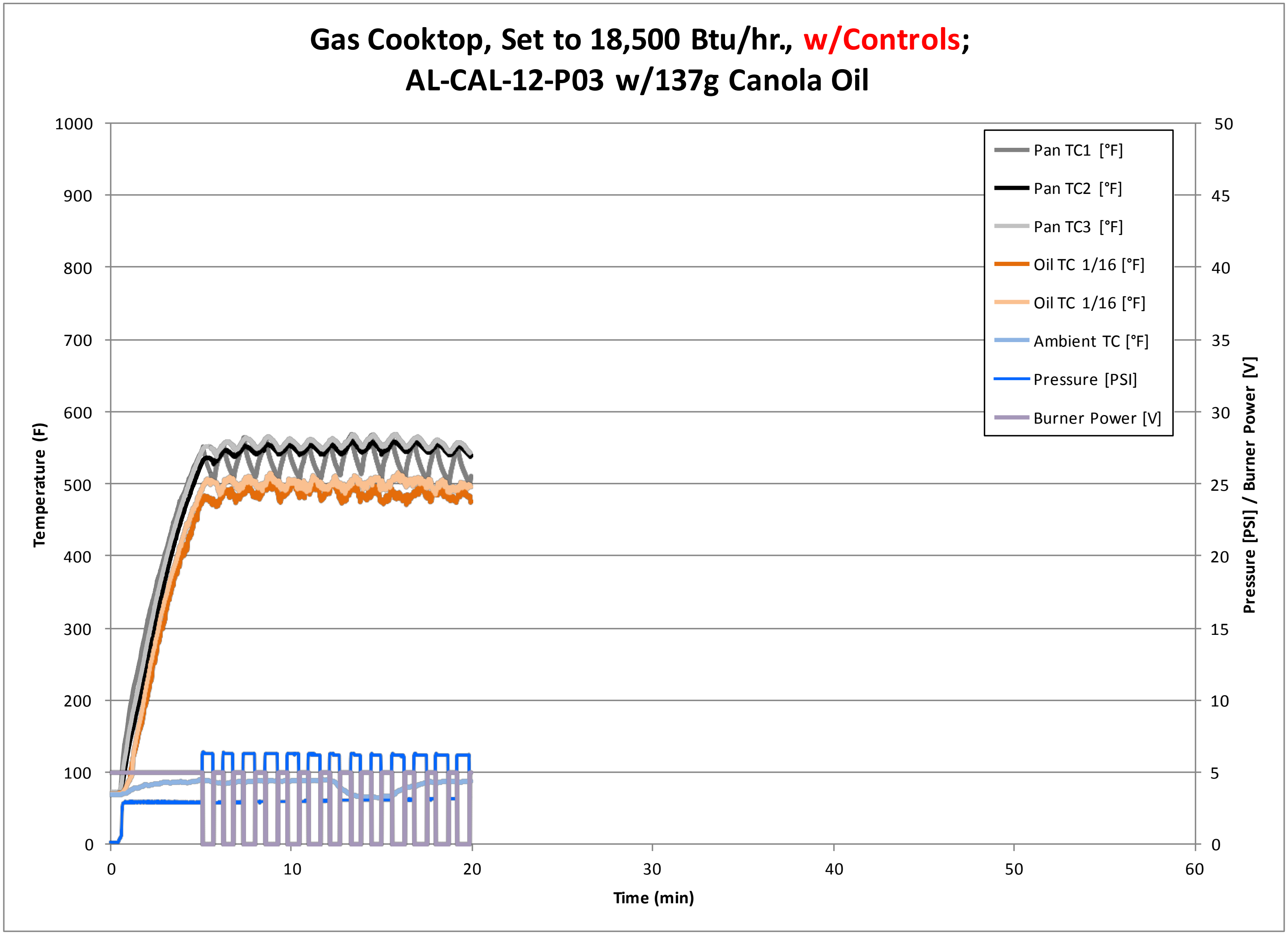
_CPSC_GVT_067_SS AC 11 P01 915g 18k5Btu_011314

Appendix C

Testing – With Controls



_CPSC_GVT_073_AL CAL 10 P03 137g 18k5BtuCTRL_011714



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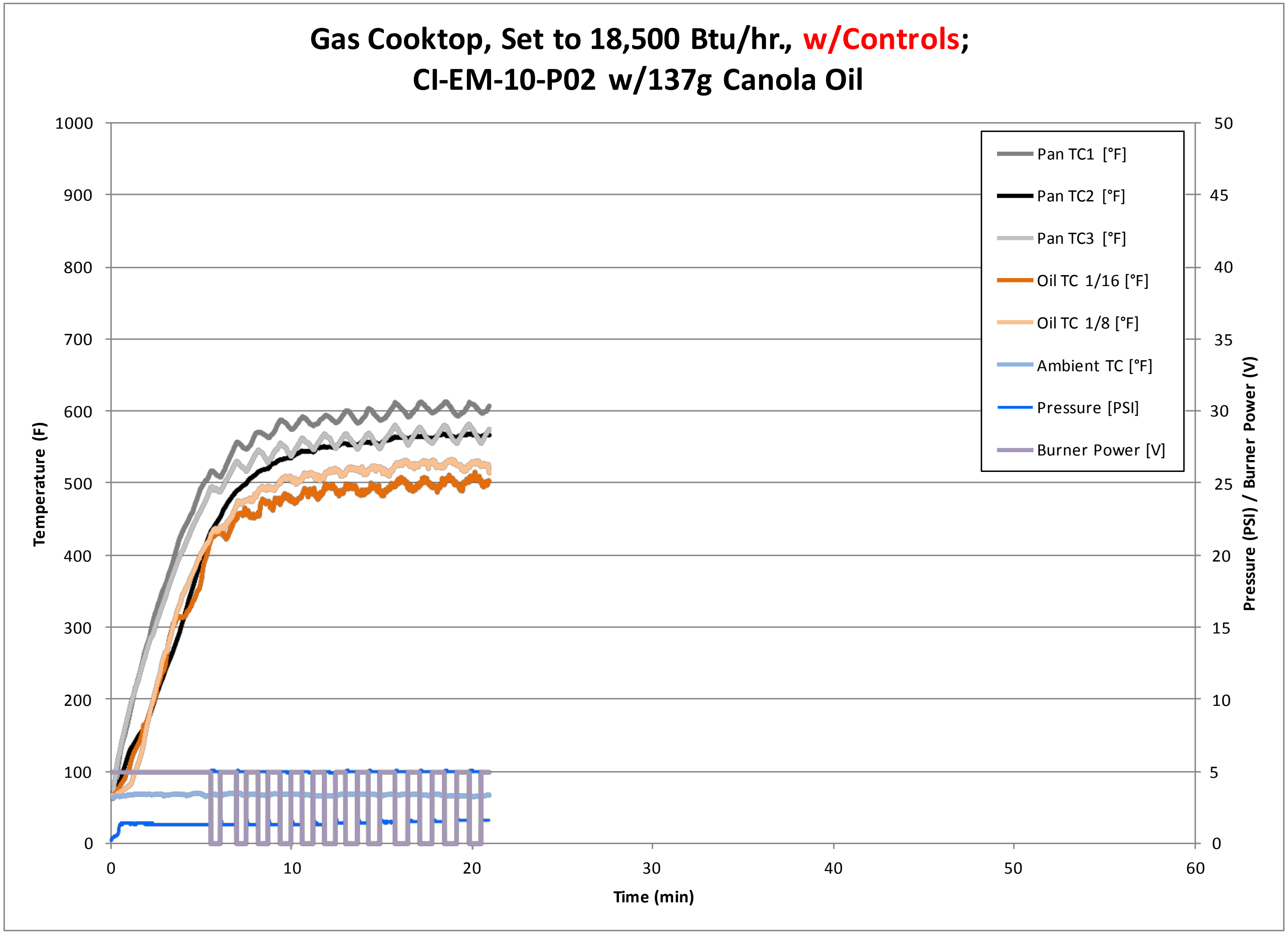

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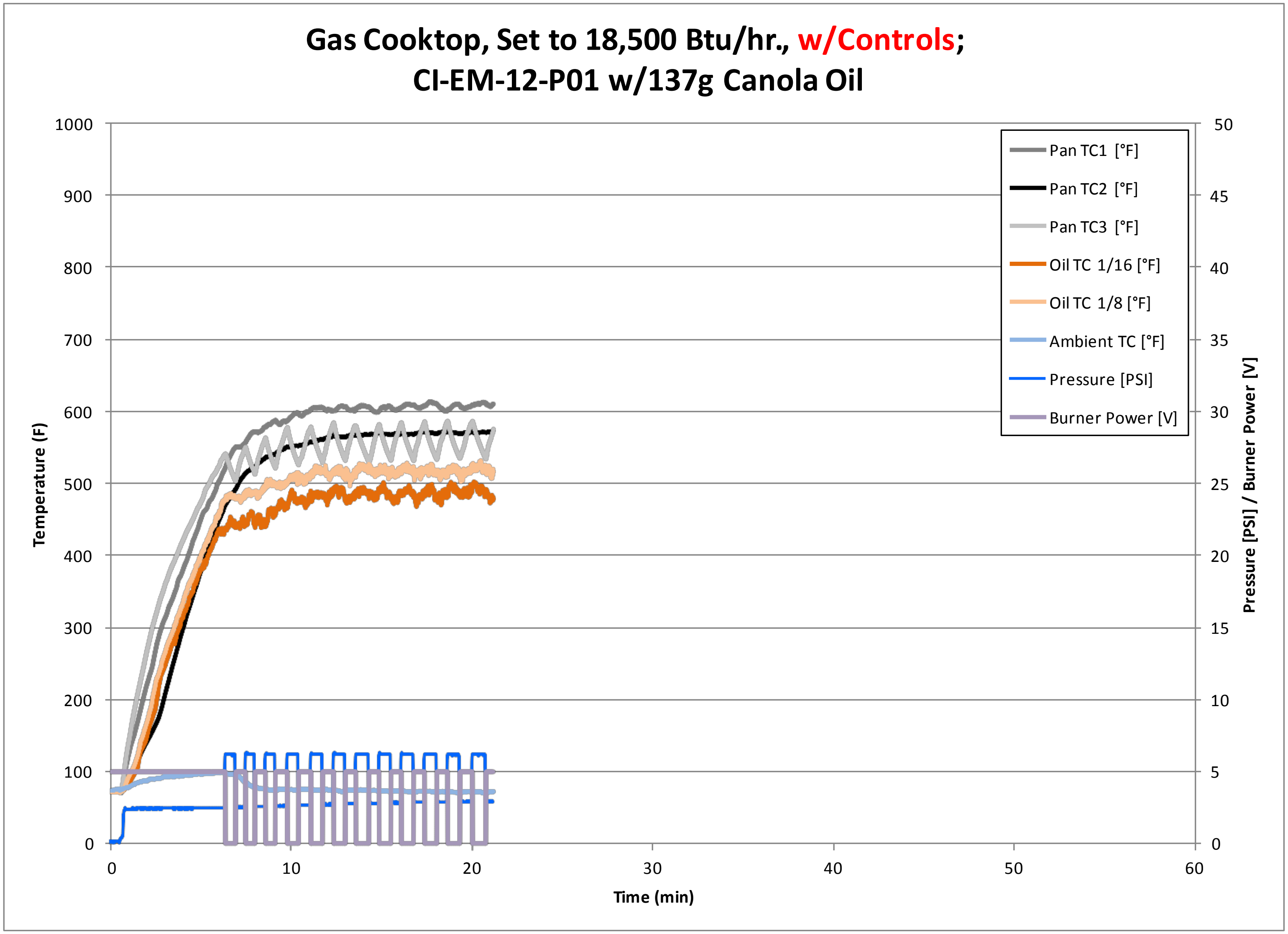

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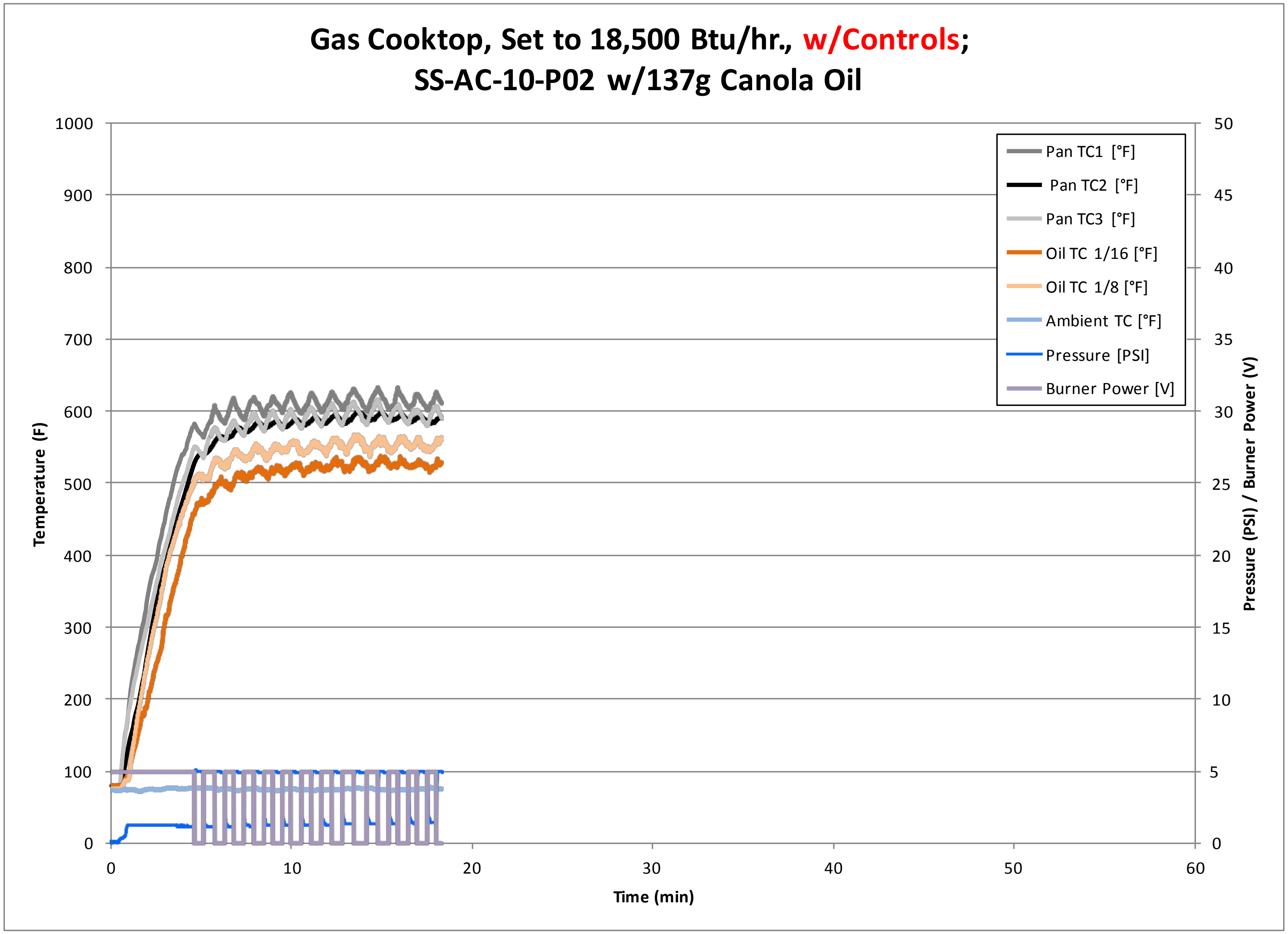

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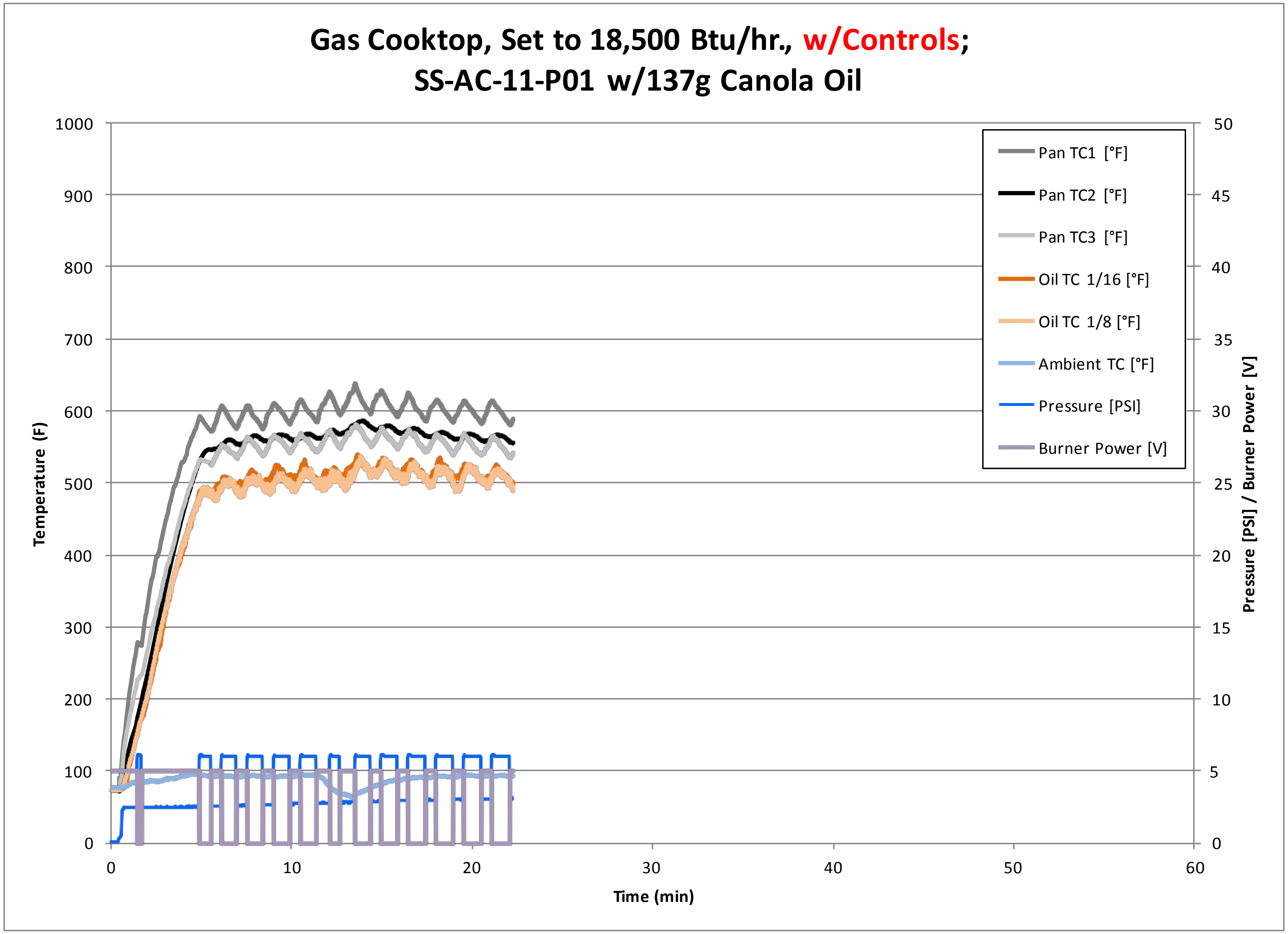
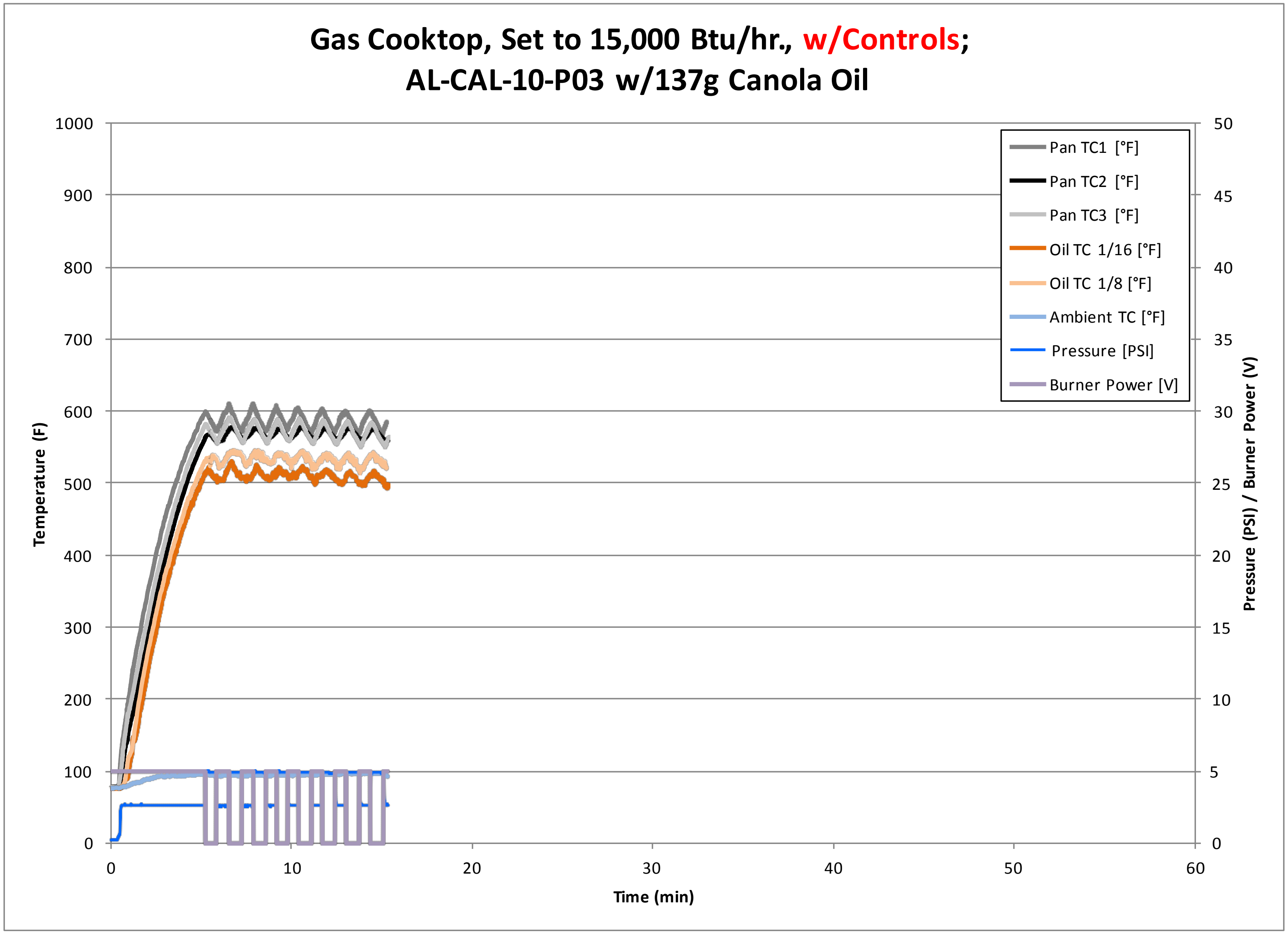
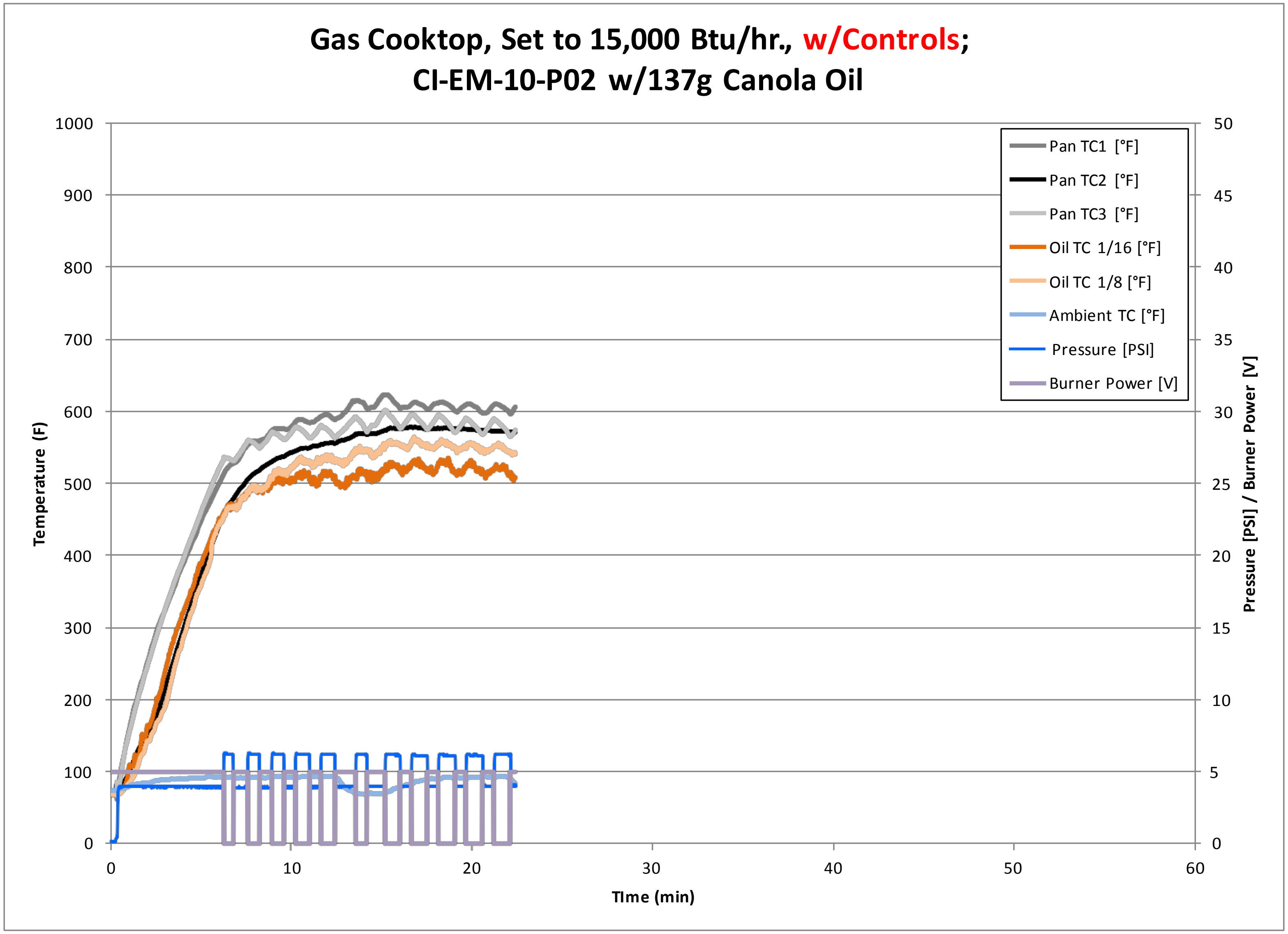


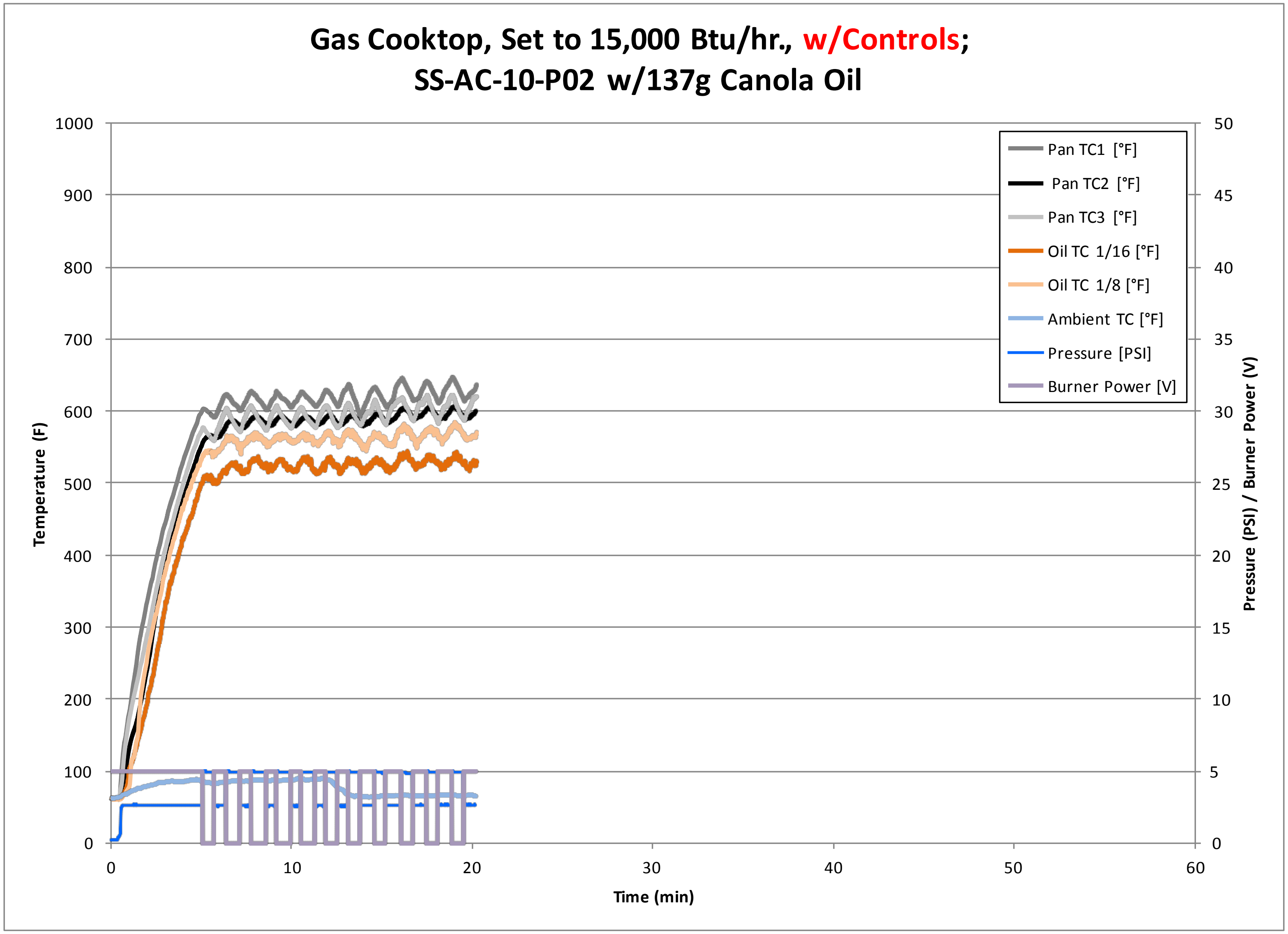
_CPSC_GVT_090_SS CAL 11 P01 137g 18k5 BtuCTRL_020514



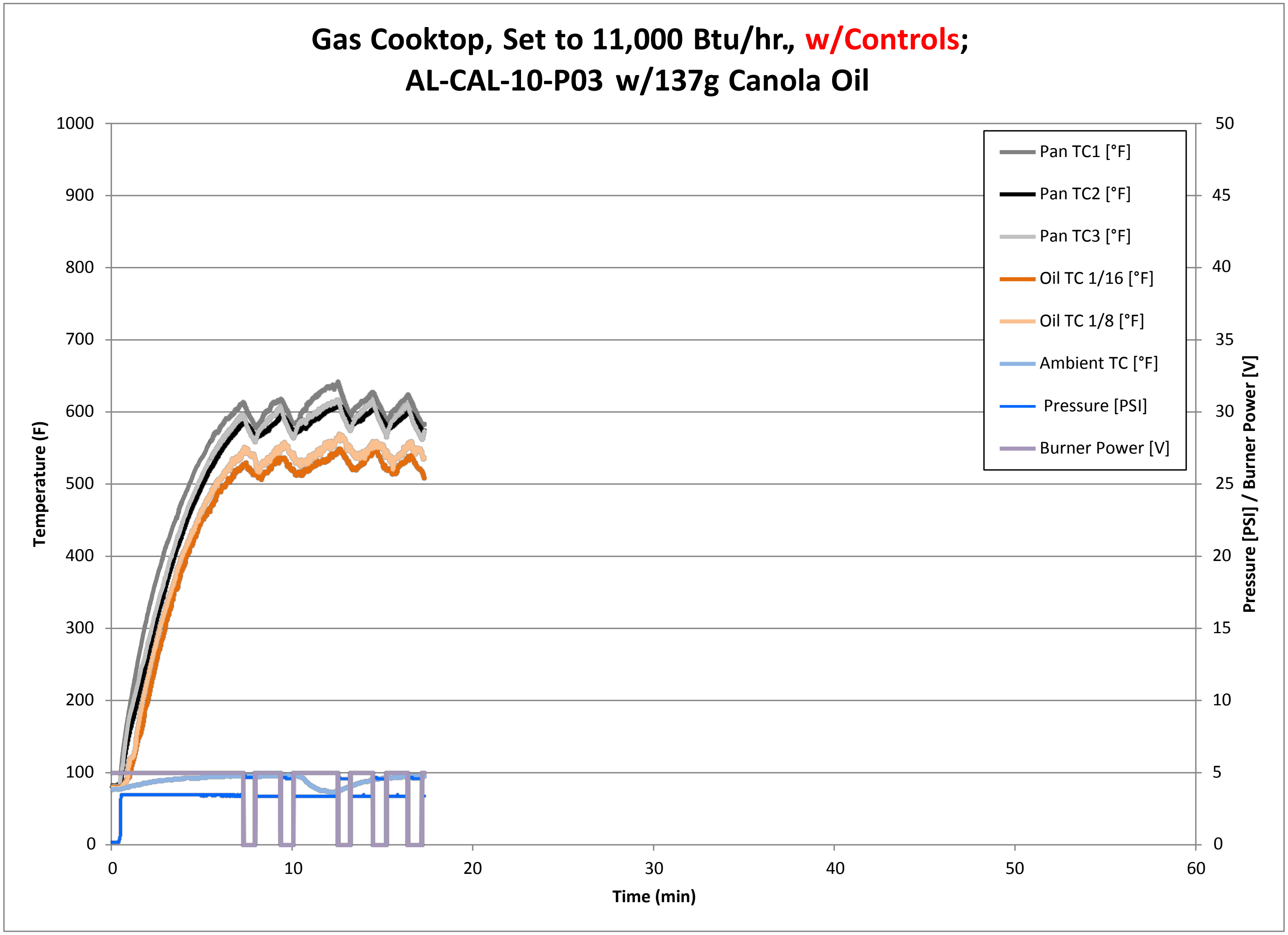
_CPSC_GVT_076_AL CAL 10 P03 137g 15kBtuCTRL_012014



_CPSC_GVT_084_CI EM 10 P02 137g 15k BtuCTRL_020314



_CPSC_GVT_077_SS AC 10 P02 137g 15kBtuCTRL_012014



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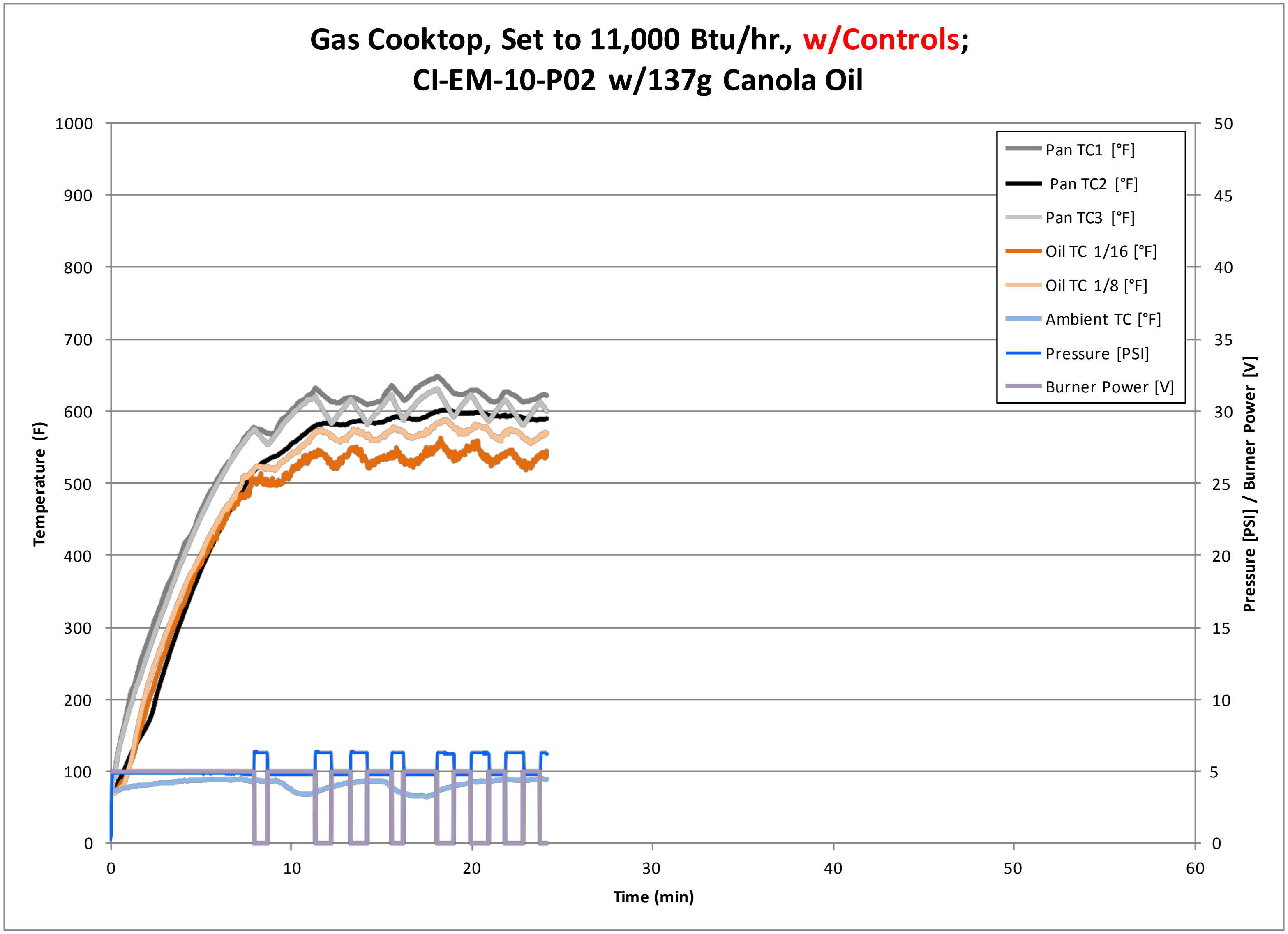

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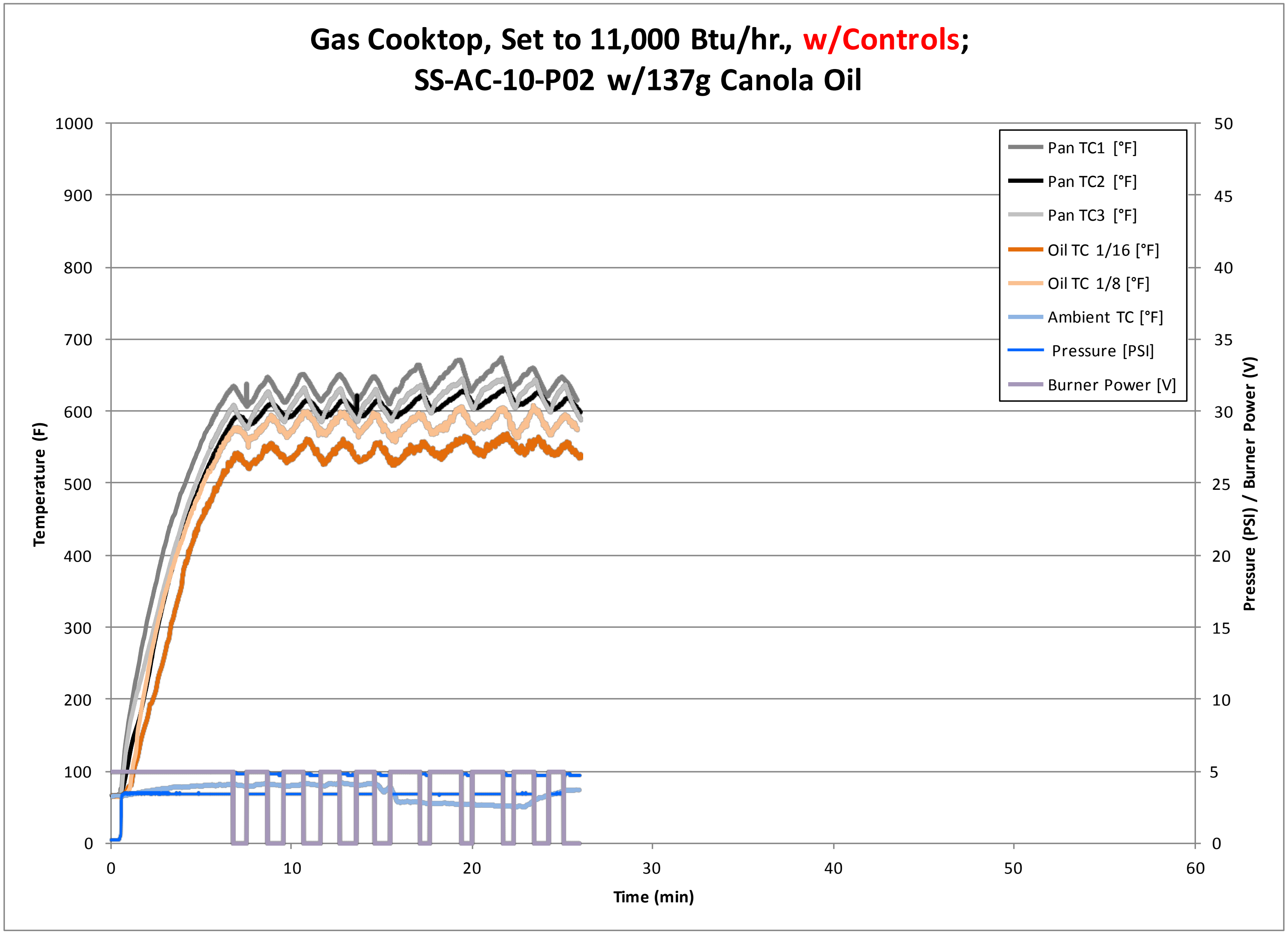

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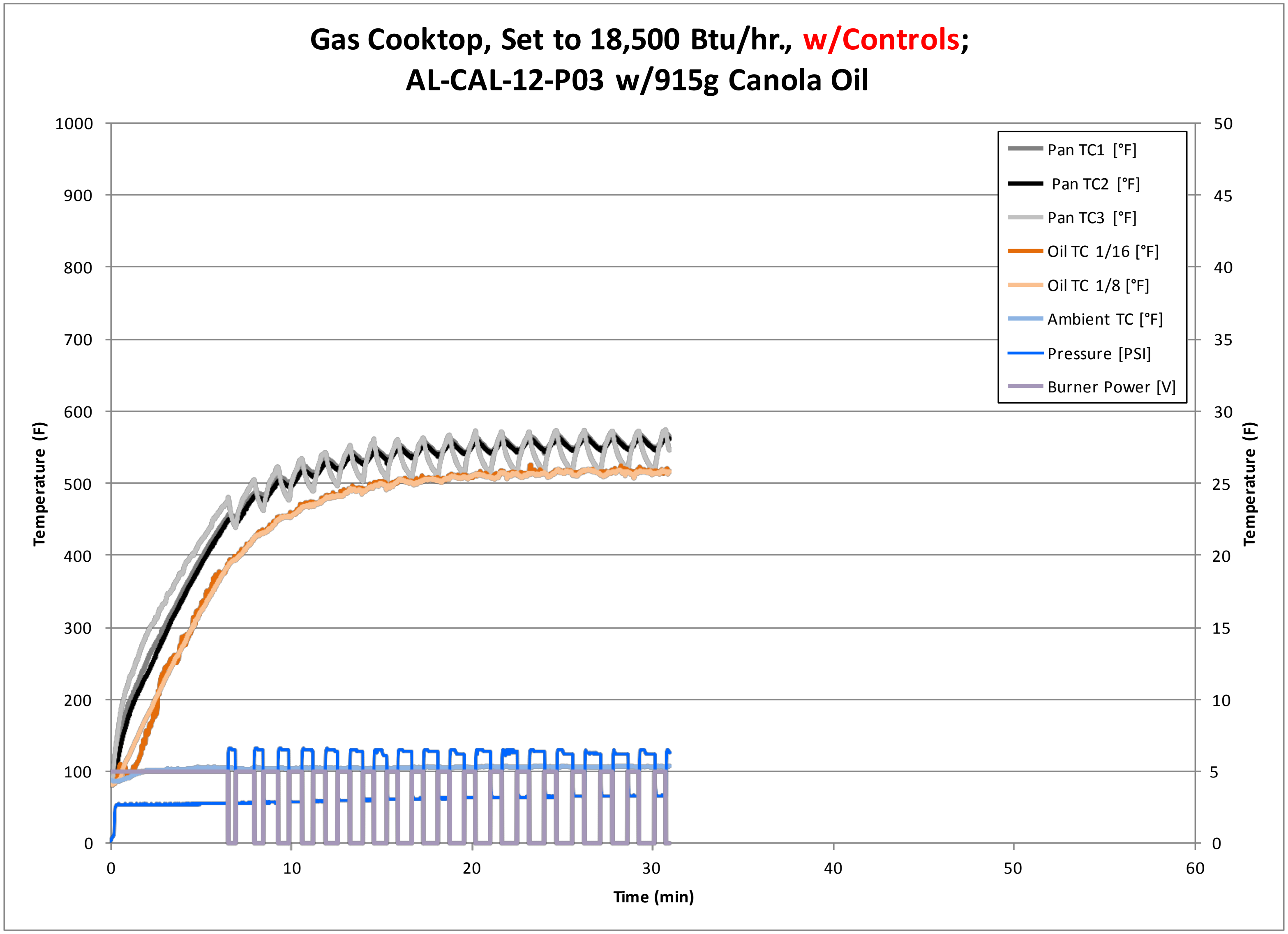

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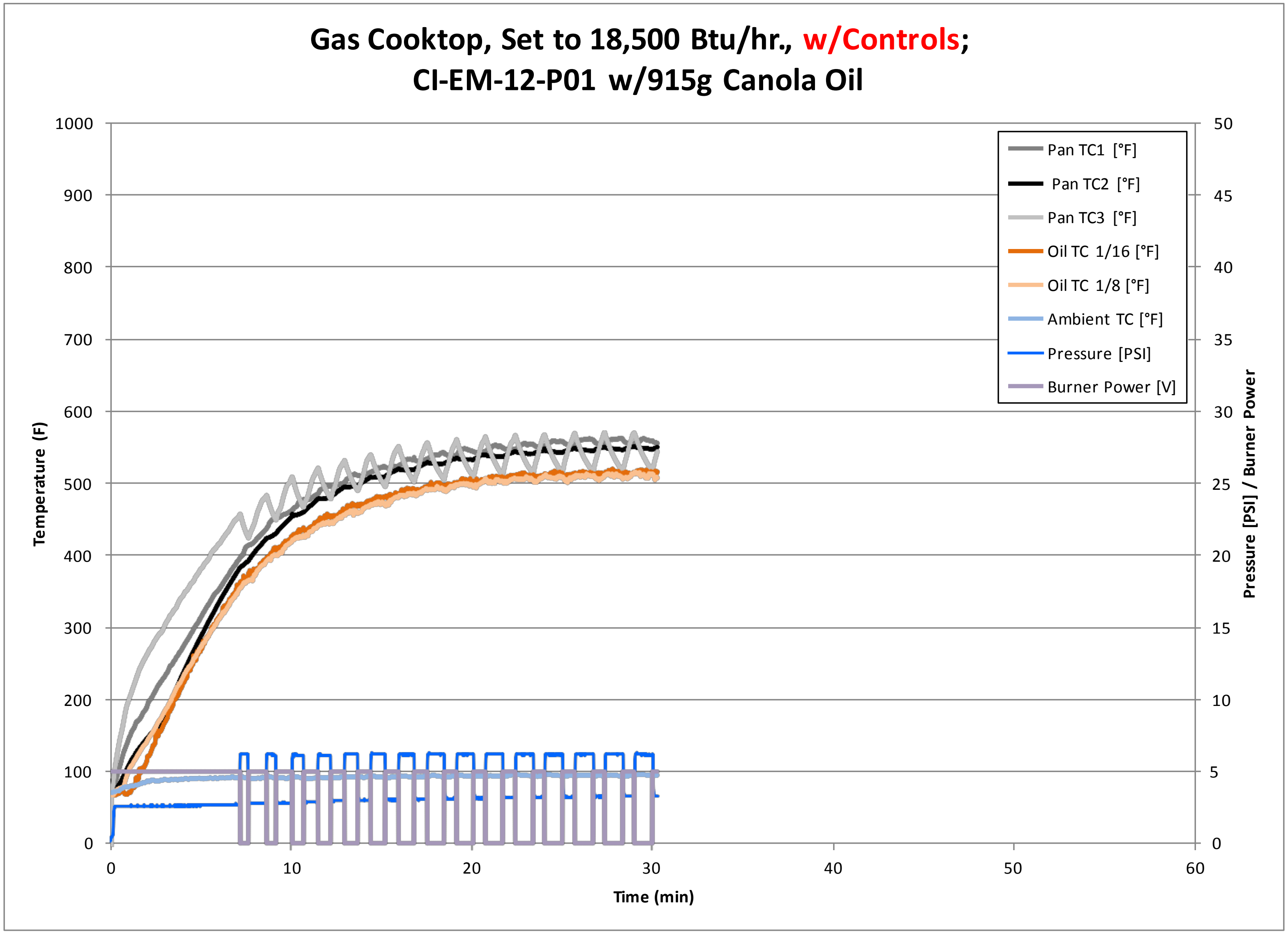

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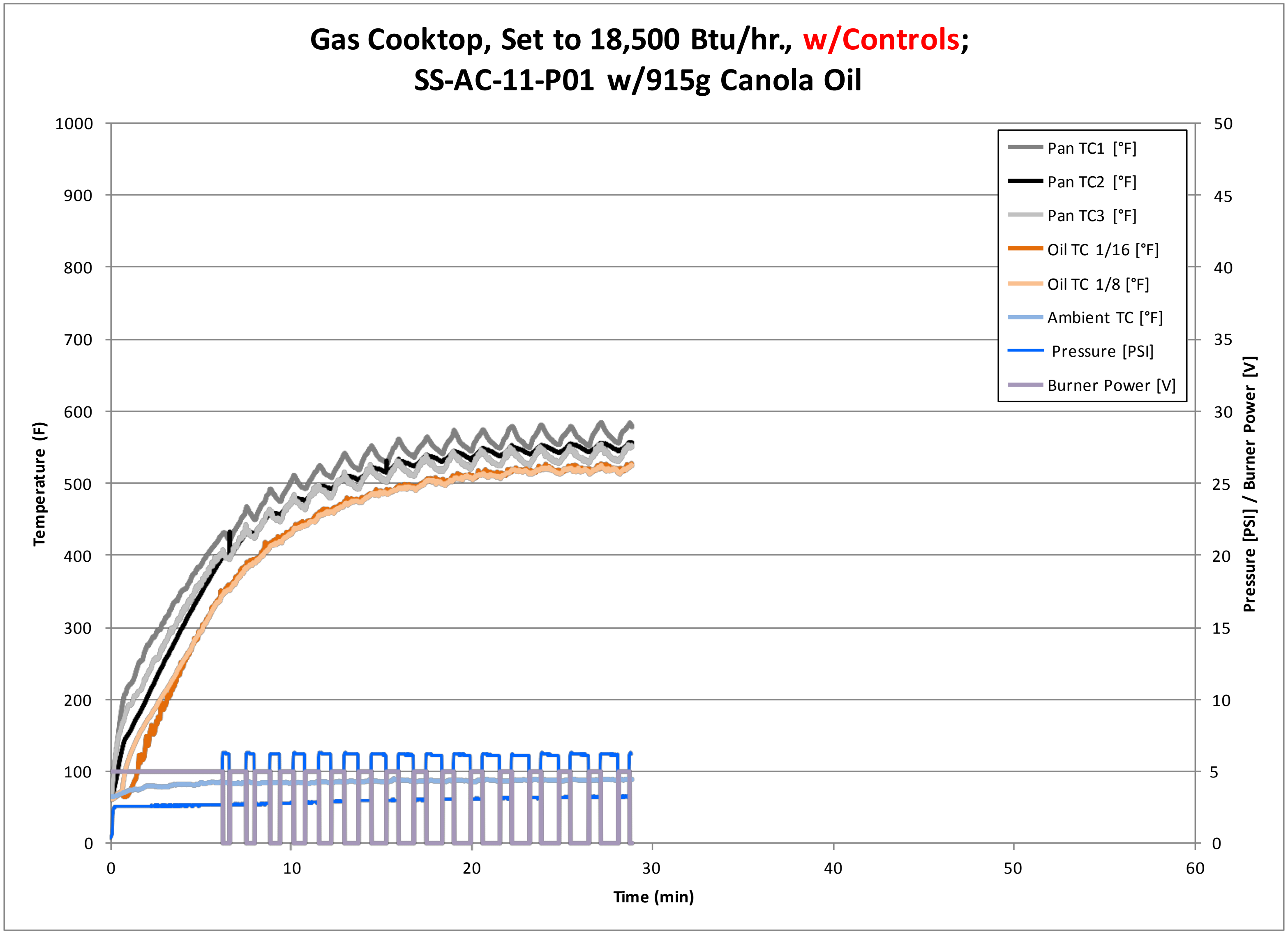

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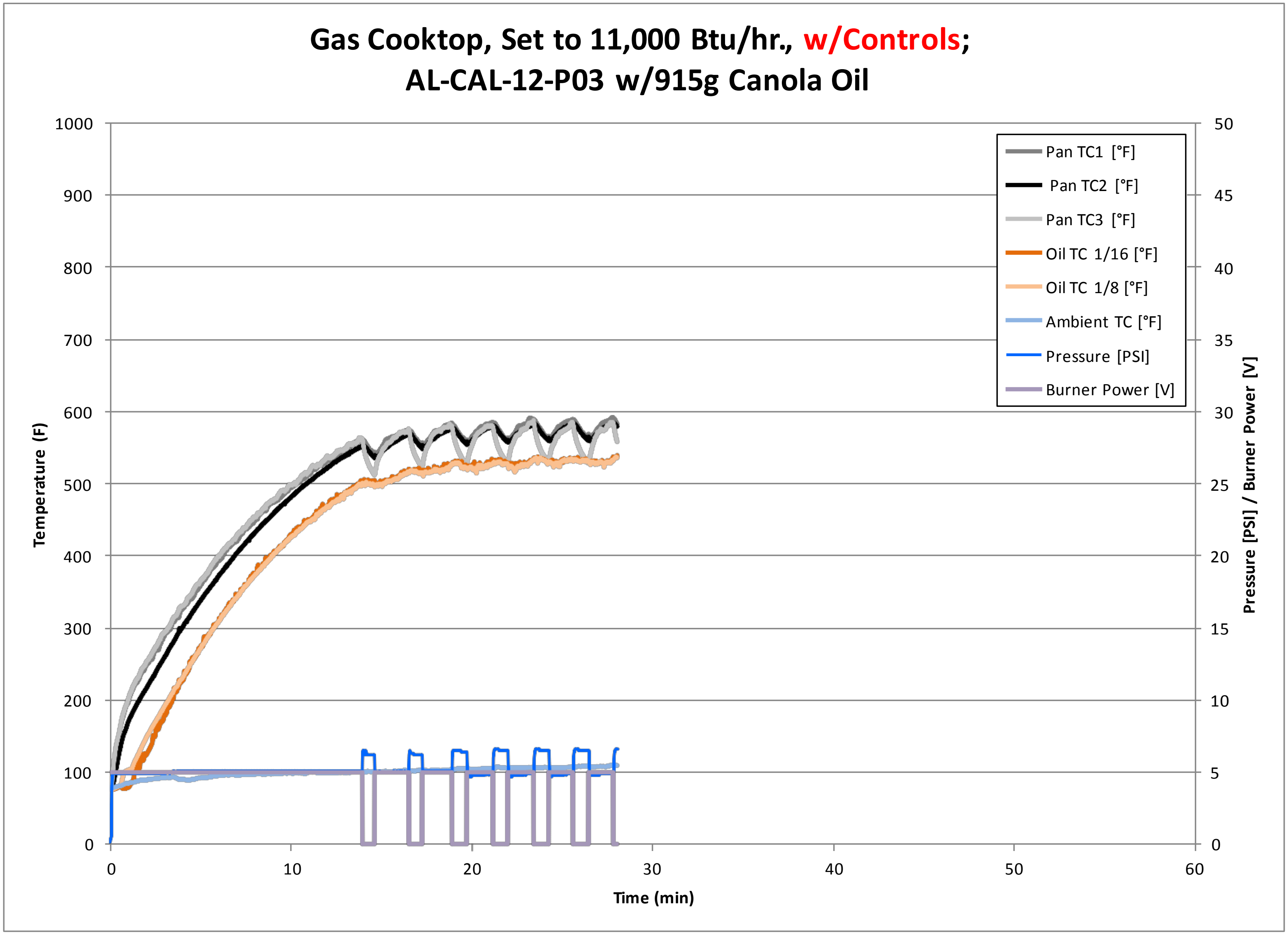

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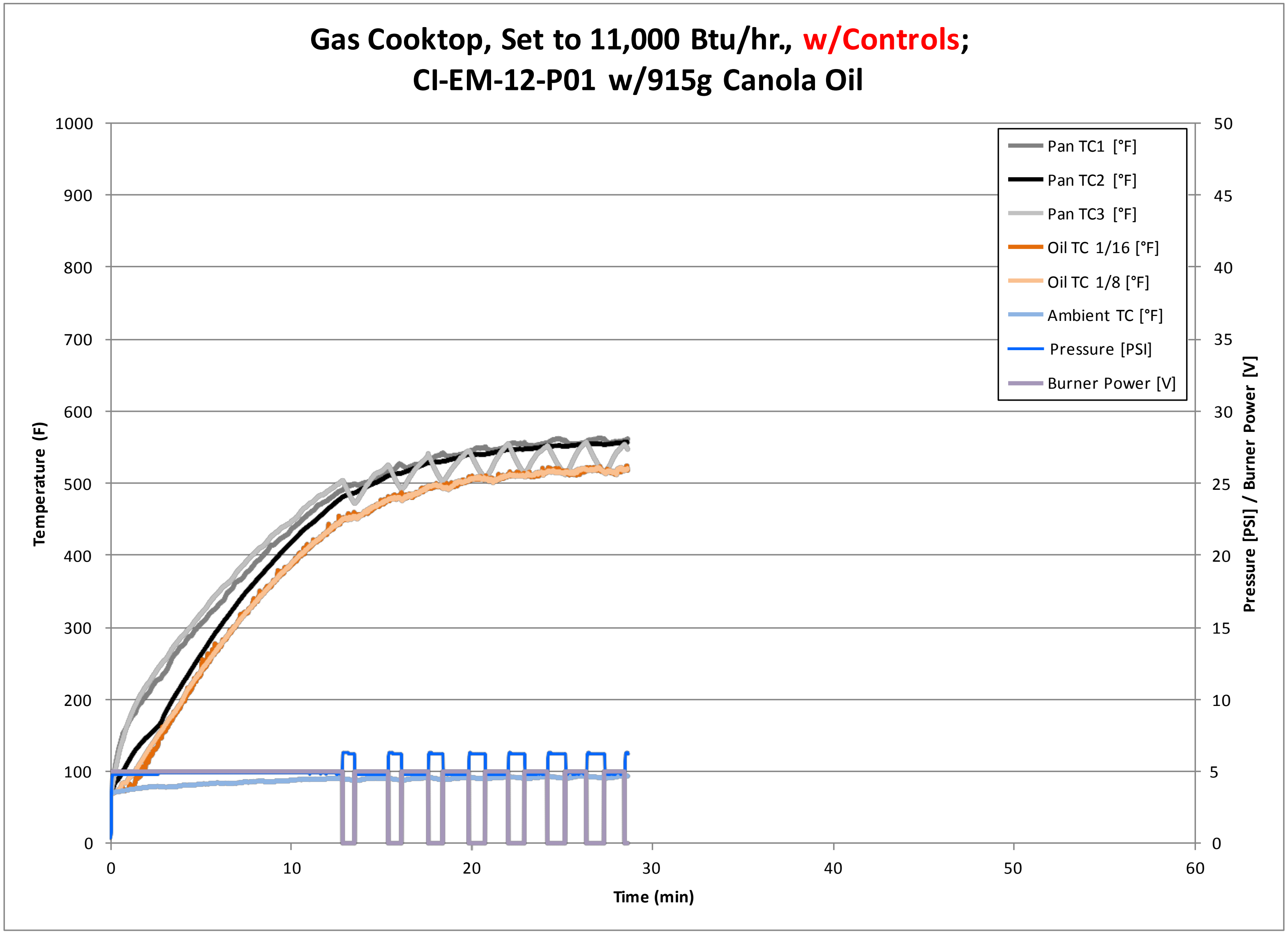

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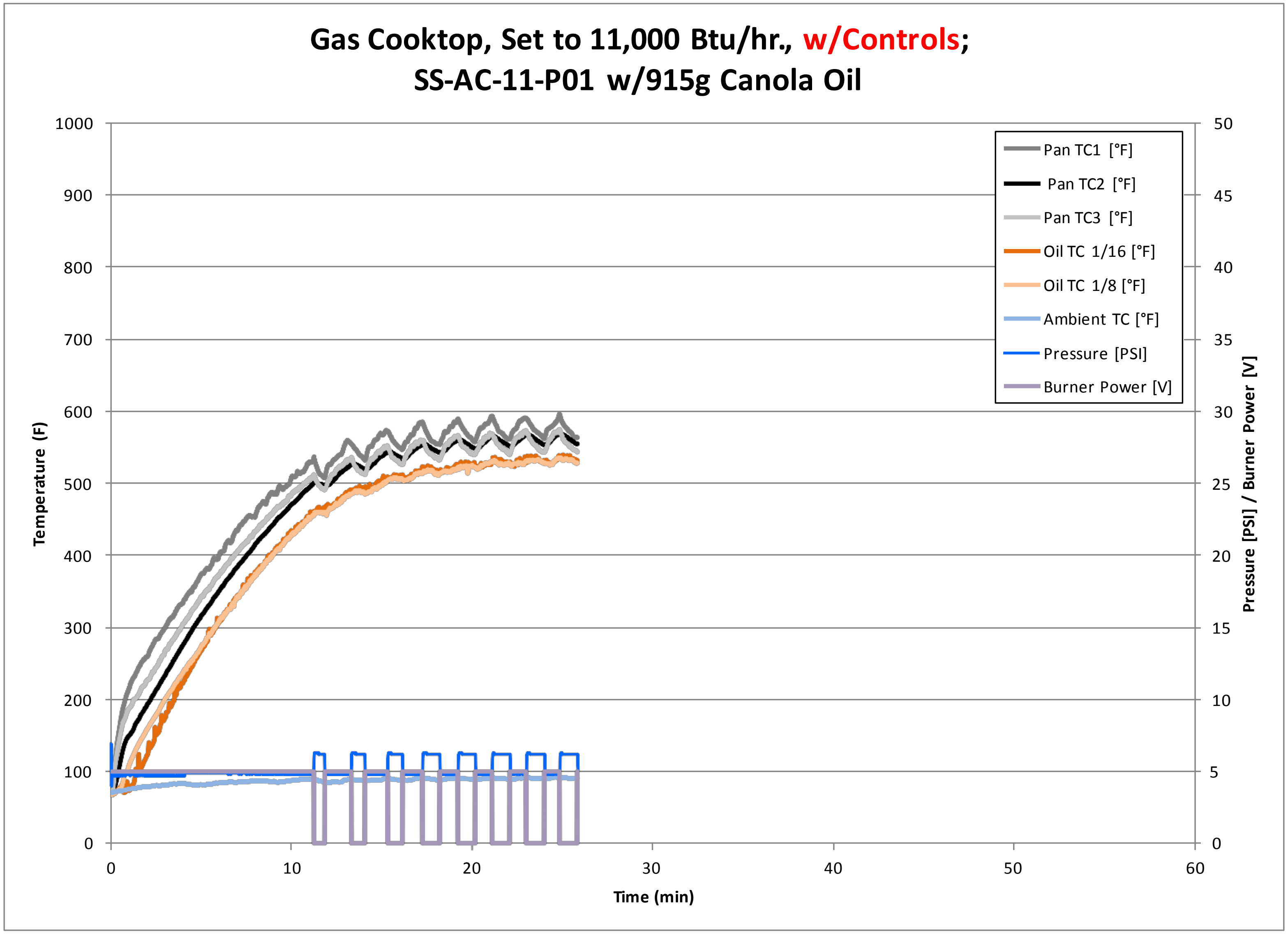
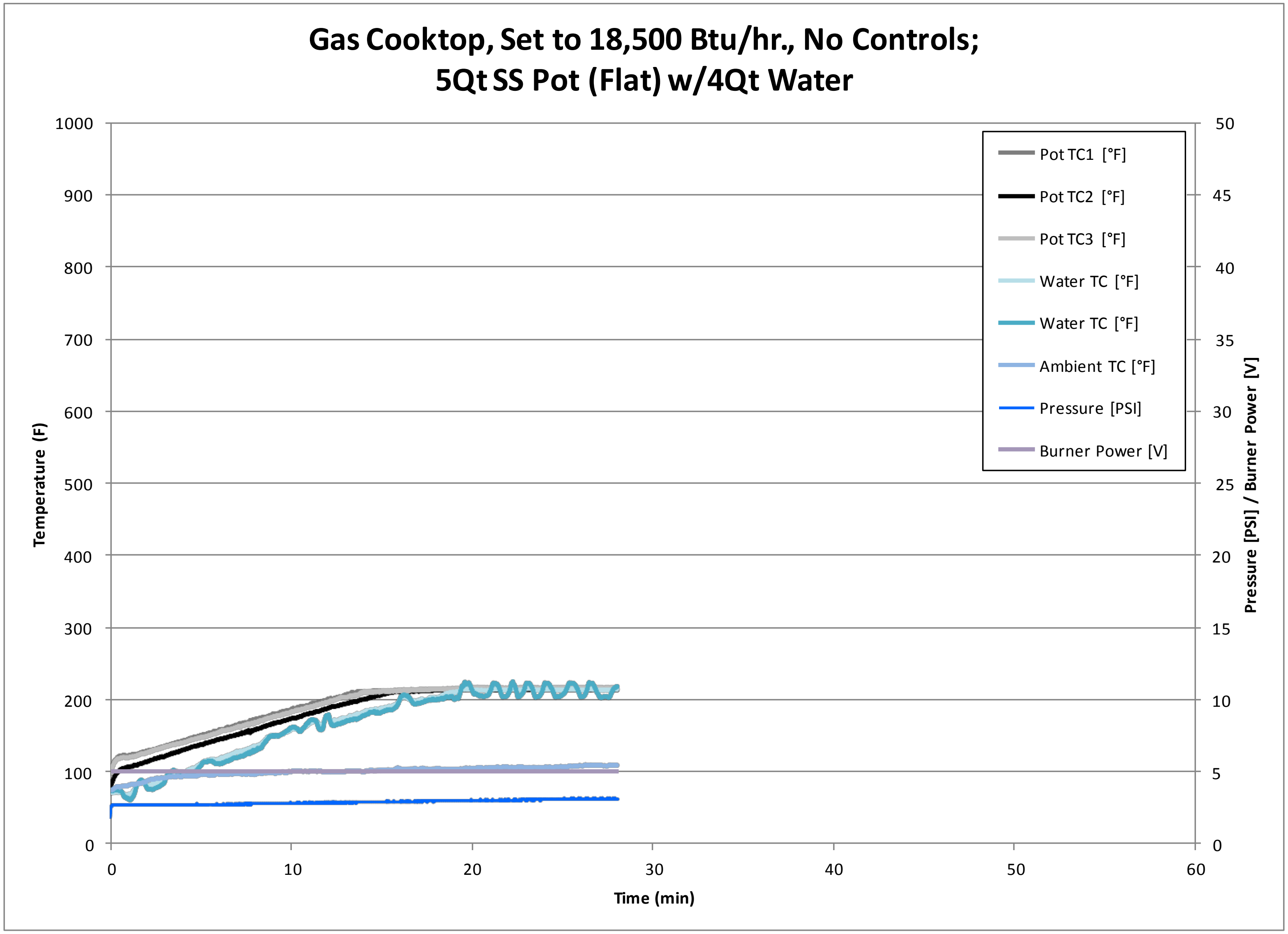


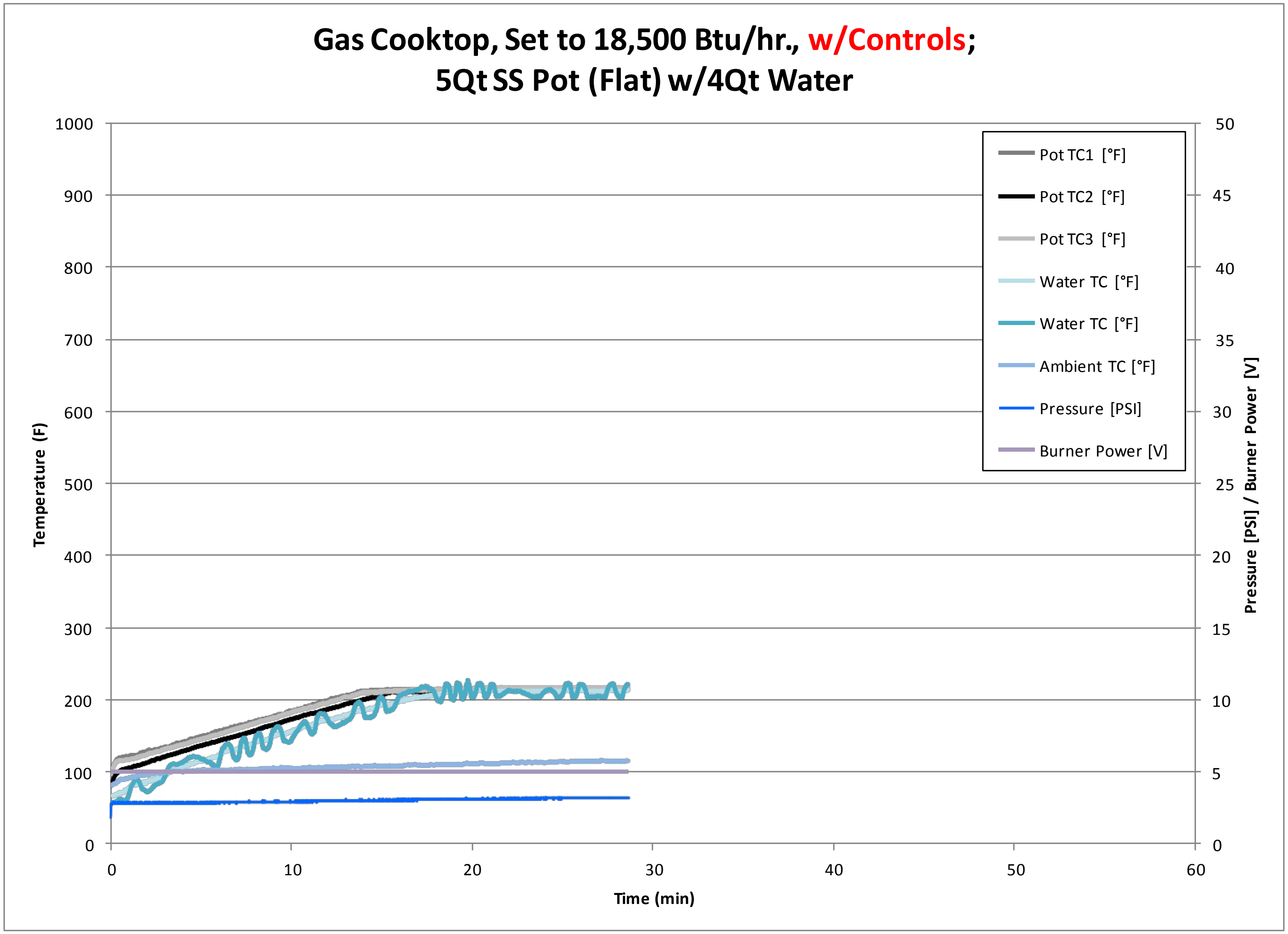
_CPSC_GVT_086_SS AC 11 P01 915g 11k BtuCTRL_020314

Appendix D

Water Boil – Out-of-Flat Stainless Steel Pots



_CPSC_GVT_097_SS CAL 5QT FLAT 4QT 18k5 Btu_020714



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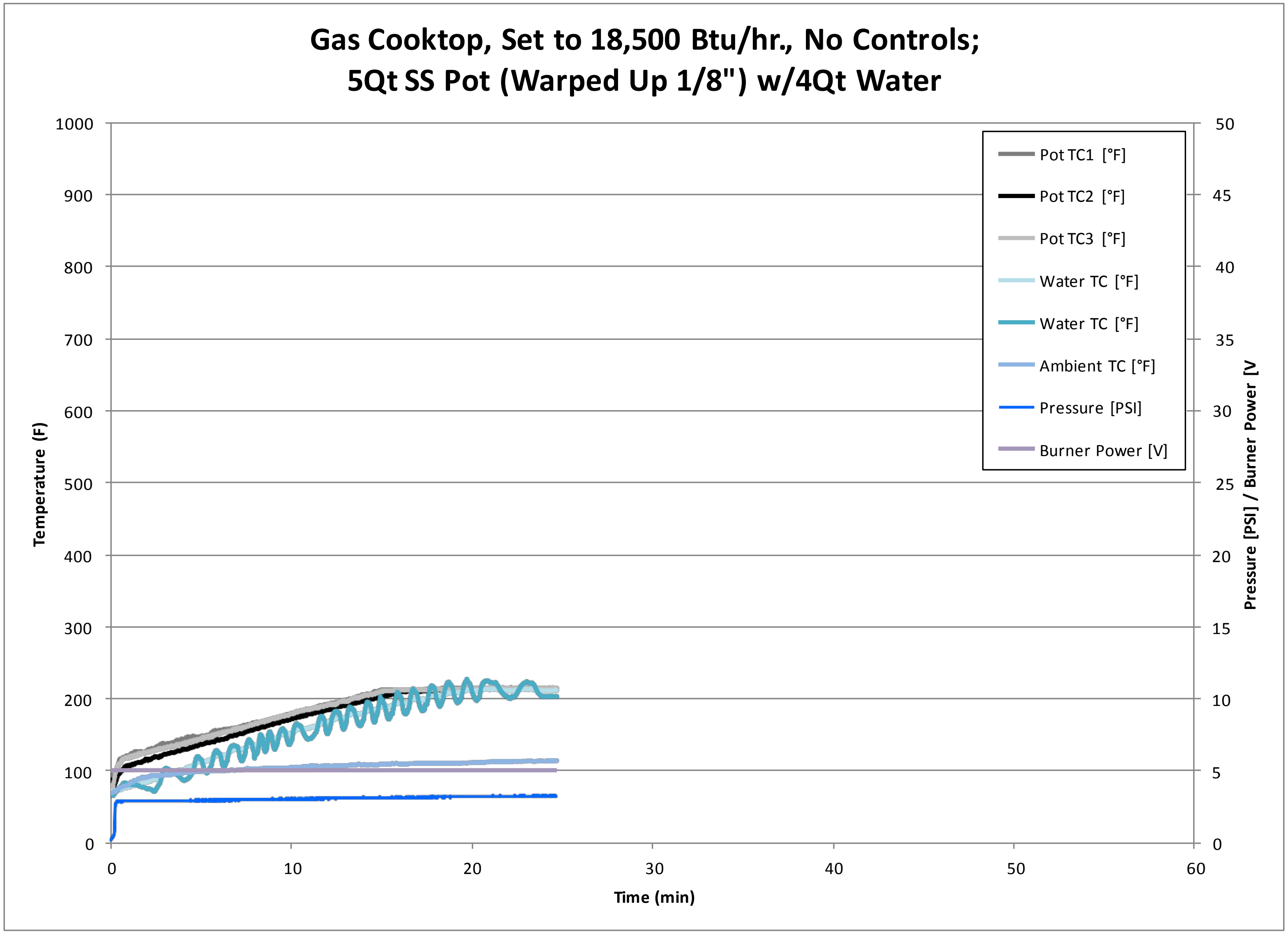

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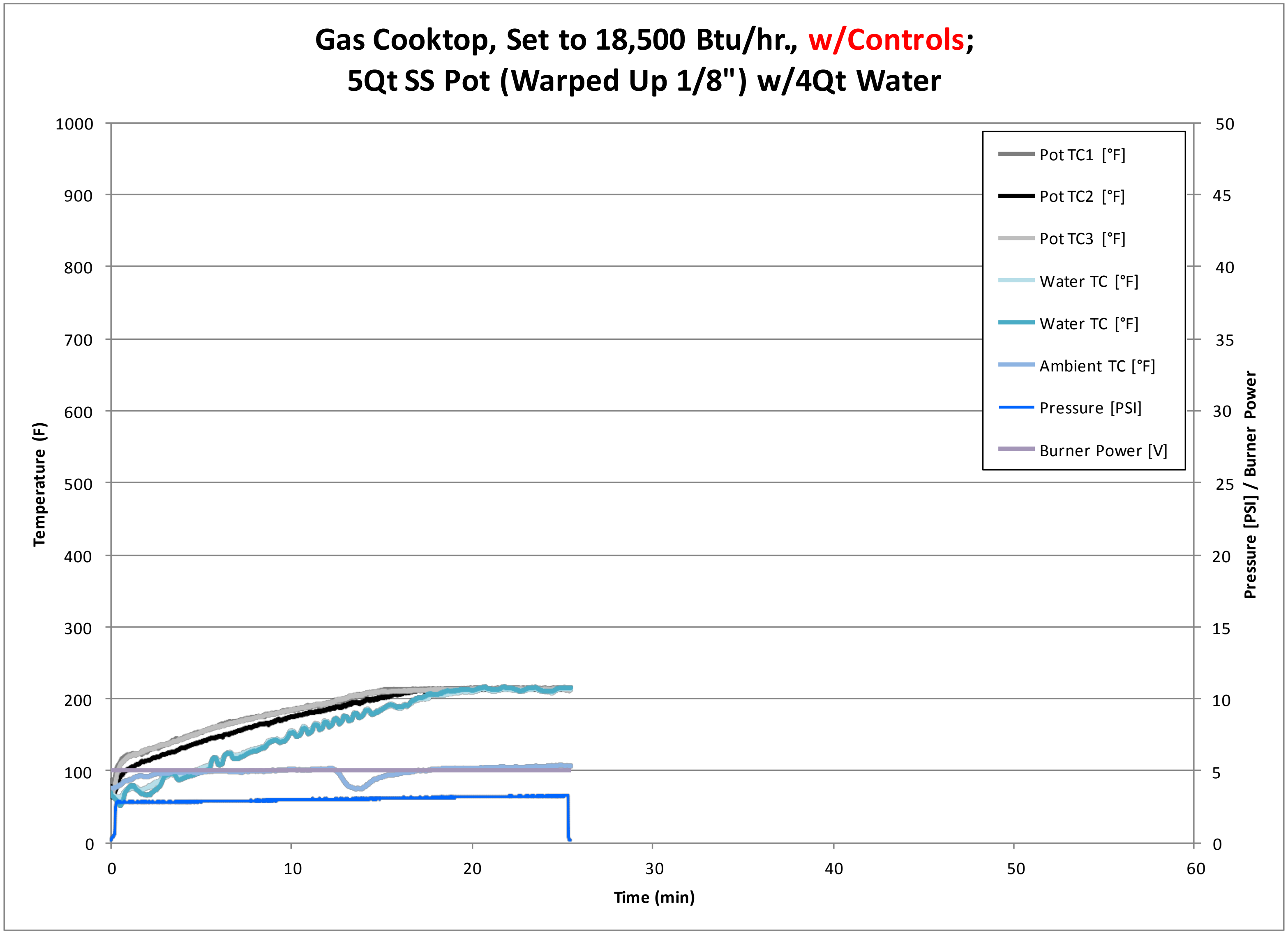

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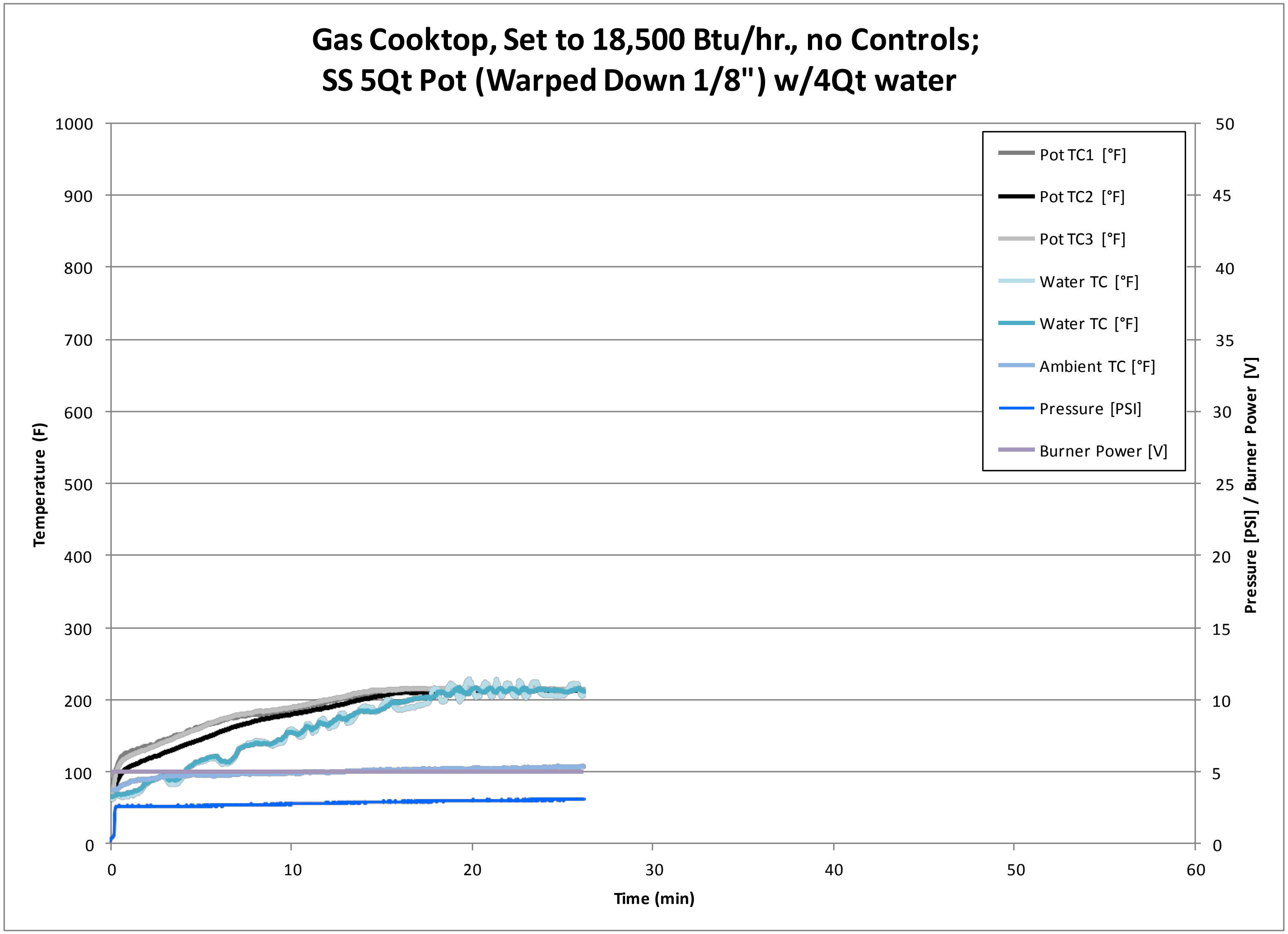
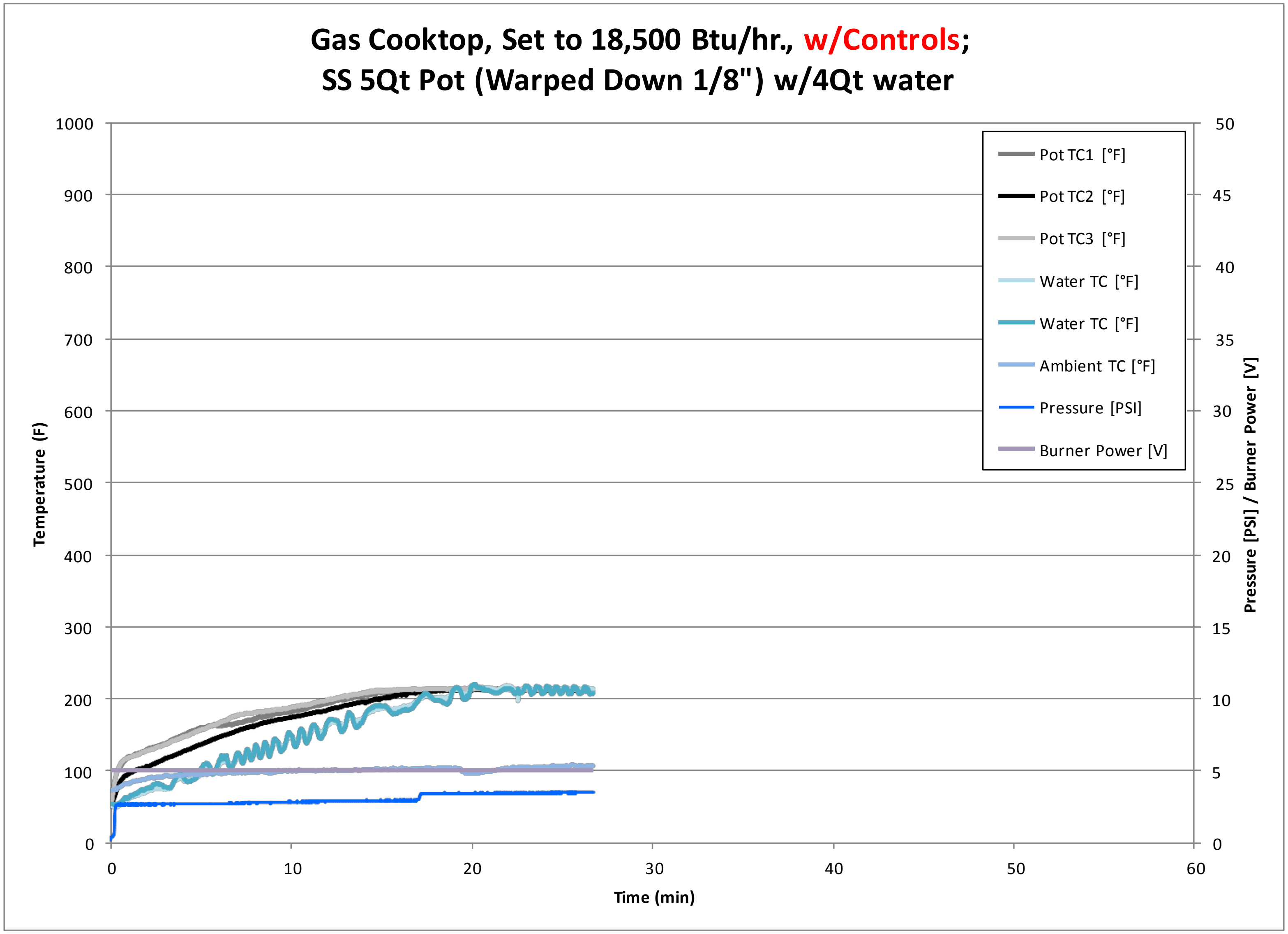


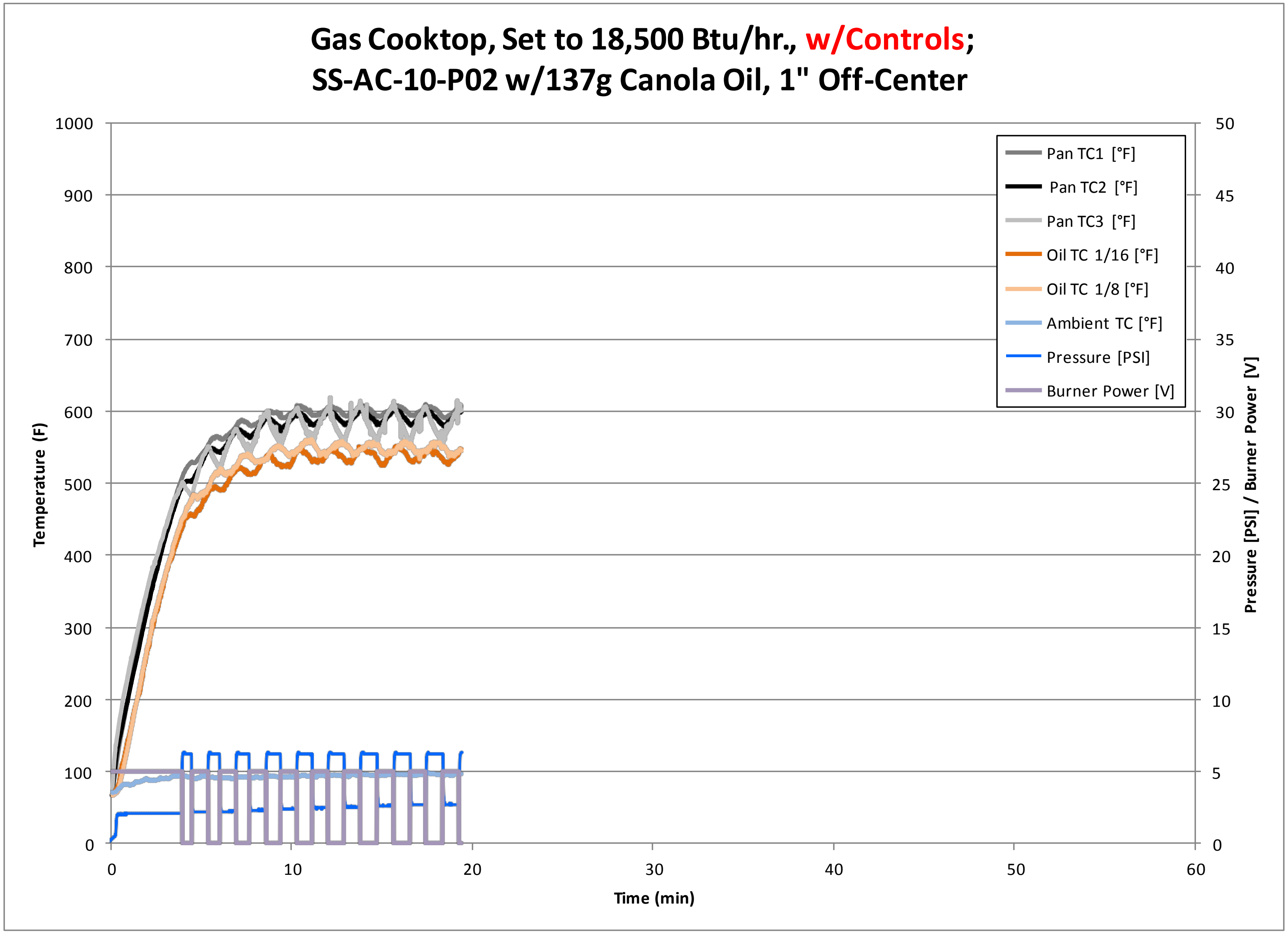
_CPSC_GVT_095_SS CAL 5QT WARP DOWN 4QT 18k5 Btu_020714



_CPSC_GVT_093_SS CAL 5QT WARP DOWN 4QT 18k5 BtuCTRL_020614

Appendix E

Pan Eccentricity – Stainless Steel 10" Skillet



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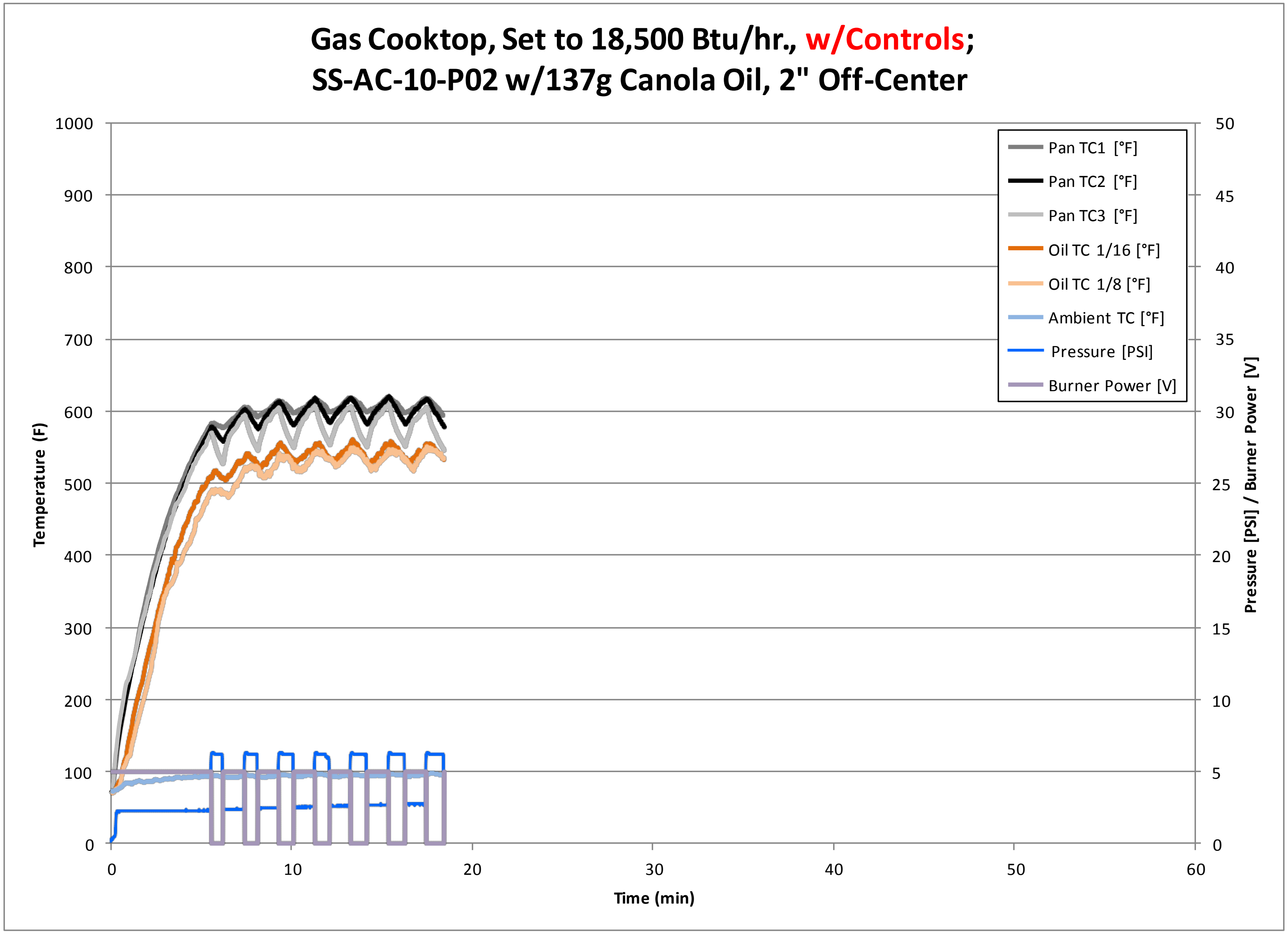

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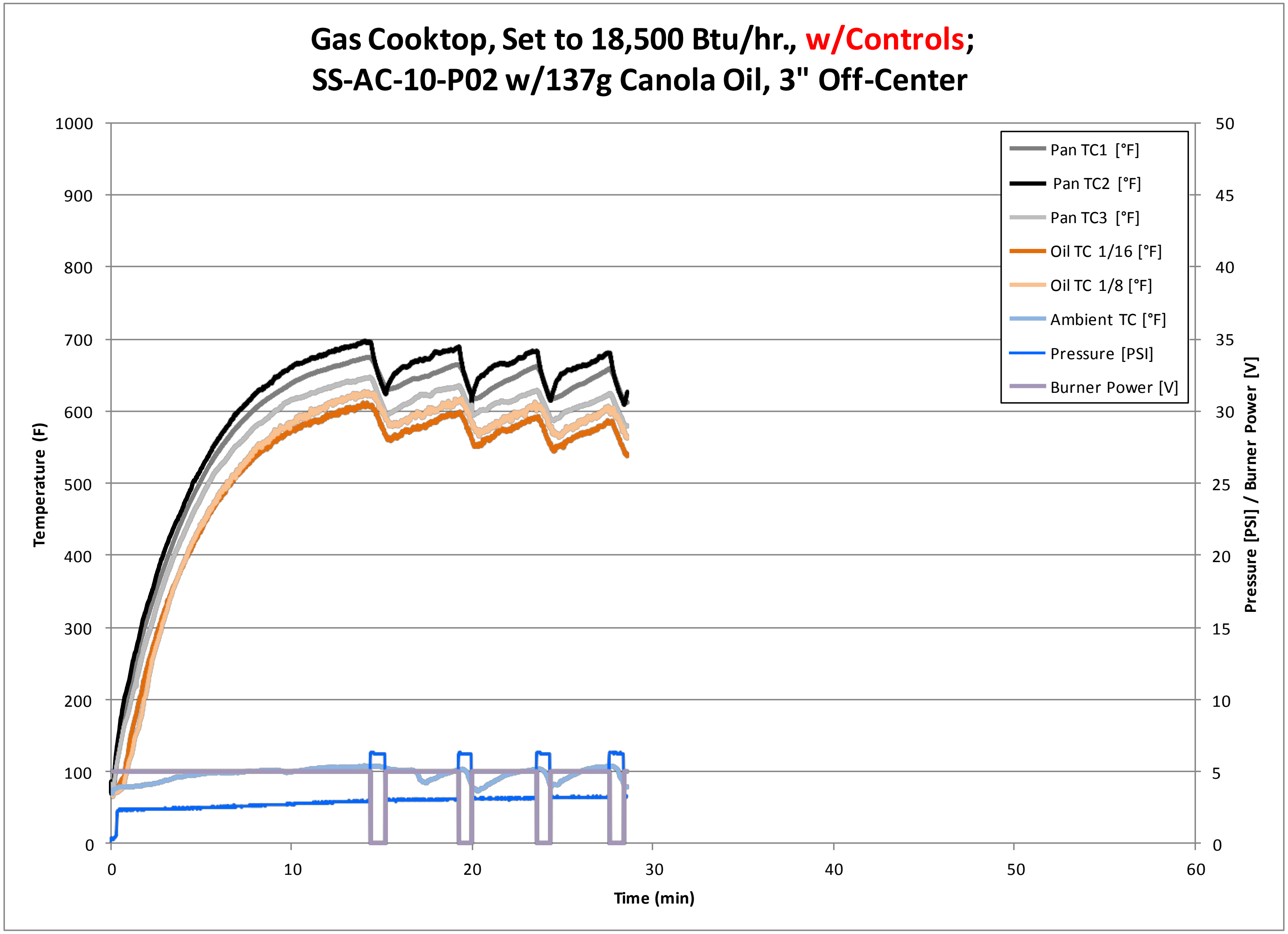

_CPSC_GVT_102_SS AC 10 P02 3OFF 137g 18k5 BtuCTRL_021414