

DOT/FAA/AR-05/3

Office of Aviation Research
Washington, D.C. 20591

Uncontained Engine Debris Fire Mitigation Test—Fuselage- Mounted Engines

February 2005

Final Report

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U.S. Department of Transportation
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1. Report No. DOT/FAA/AR-05/3		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle UNCONTAINED ENGINE DEBRIS FIRE MITIGATION TEST—FUSELAGE-MOUNTED ENGINES				5. Report Date February 2005	
				6. Performing Organization Code NAWCWD 418300D	
7. Author(s) Steven J. Lundin, Charles E. Frankenberger, and Richard B. Mueller				8. Performing Organization Report No.	
9. Performing Organization Name and Address Commander Naval Air Warfare Center Weapons Division 1 Administration Way China Lake, CA 93555-6001				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Office of Aviation Research Washington, DC 20591				13. Type of Report and Period Covered Final Report	
				14. Sponsoring Agency Code ANM-100	
15. Supplementary Notes The FAA William J. Hughes Technical Center monitor was William Emmerling.					
16. Abstract Uncontained engine failures can liberate fragments that can penetrate the fuselage. In a few cases, fragments severed pressurized fuel lines in aft engine airplane configurations. The Federal Aviation Administration sponsored this effort, to test commercially available technologies that could improve aircraft safety. These tests investigated the viability of suppressing aircraft fires induced by uncontained engine failures, specifically in fuselage-mounted engine configurations. Six contractors participated in the tests, providing detectors and suppressors for evaluation. A total of 55 tests were conducted with 7 suppression and 5 detection technologies. Some tests were conducted in airflow and some with actual blade fragment impacts. This report documents the results of tests conducted during July and August 2002 at the Naval Air Warfare Center, China Lake, California.					
17. Key Words Fire testing, Uncontained engine debris, Fuselage fire			18. Distribution Statement This document is available to the public through the National Technical Information Service (NTIS), Springfield, Virginia 22161.		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 269	22. Price

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LIST OF ACRONYMS

FAA	Federal Aviation Administration
GD-OTS	General Dynamics-Ordnance and Typical Systems
NAWC	Naval Air Warfare Center
OFD	Optical Fire Detectors
TIM	Thermal Initiation Material
UEDMP	Uncontained Engine Damage Mitigation Program
WSL	Weapons Survivability Laboratory

EXECUTIVE SUMMARY

This work was conducted under the sponsorship and oversight of the Federal Aviation Administration (FAA) Transport Airplane Directorate. The Uncontained Engine Debris Mitigation Program falls under the Aircraft Catastrophic Failure Prevention Program, which is managed by the FAA William J. Hughes Technical Center. The accident history for uncontained engine failures leading to hull loss had several events where pressurized fuel lines were severed by engine debris, resulting in a hull loss. One nonfatal event was the 1995 Atlanta rejected takeoff.

A series of tests were conducted during the summer of 2002, investigating the applicability of military and commercial technologies to the specific fires associated with uncontained turbine engine events with fuselage-mounted engines. These fires can be fed by severed main fuel lines with leak rates over 1 gallon per second. These tests were a cooperative effort between the FAA, United States Navy, and all the manufacturers that participated. The government funded the fabrication and testing, while the participating manufacturers provided their devices and support personnel. The government provided two types of optical fire detectors. They were fielded detectors used on three military platforms.

The objective was to create repeatable fire environments similar to actual aircraft fires and provide manufacturers with the opportunity to install and operate their devices to evaluate effectiveness. The tests included fire detection and suppression devices. These tests are technology demonstrations and not specific mitigation system development.

A steel aircraft structure simulator was fabricated to resemble a commercial or business aircraft with fuselage-mounted engines. This facility was cost-shared between the FAA and Naval Air Systems Command. Additional tests, beyond that reported here, were performed in support of military system development. An announcement inviting manufacturers to participate was placed in the Commerce Business Daily in July 2001. A total of seven manufacturers of sensors and/or suppressors participated.

All the technologies tested proved capable of suppressing the fires. The potassium aerosols were capable of extinguishing fires in less than 5 seconds. The detection methods varied from highly successful to only somewhat successful. The performance of the heat-initiated systems was heavily dependent on their location relative to the fire. If the fire retreated behind a rib or plate, the thermal detector might not initiate for many minutes. Advanced powder panels showed promise as a passive fire suppression system.

1. INTRODUCTION.

1.1 PURPOSE.

The purpose of these tests was to evaluate technologies that might be applied in detection and suppression for fires induced by uncontained engine debris impacting a fuselage and associated fuel lines. There is a minimal amount of volume above and below the cabin floor in which to place detectors and suppressors. The fires that result from these impacts can be very severe and spread rapidly. In June 1995, this type of event destroyed a DC-9. The plane was stopped on the runway prior to takeoff for an emergency evacuation, then the plane was destroyed by fire, as shown in figure 1. There were no fatalities.



FIGURE 1. ENGINE FAILURE FRAGMENTS SEVER ENGINE FUEL LINE
RESULTING IN HULL LOSS FIRE

1.2 BACKGROUND.

The Federal Aviation Administration (FAA) commissioned a program, the Uncontained Engine Damage Mitigation Program (UEDMP), to investigate and determine methods to mitigate the damage caused by uncontained engine debris. Damage from such an event is often considerable, but need not necessarily be catastrophic as long as structural integrity is maintained, fires are not sustained, and redundant critical systems do not become inoperable. The UEDMP, operated through the FAA Aircraft Catastrophic Failure Prevention Program (ACFPP), works with industry and government to determine possible engineering solutions to reduce injuries and critical damage resulting from uncontained engine events. This UEDMP-funded effort was performed at the Naval Air Warfare Center Weapons Survivability Laboratory (WSL) at China Lake, California.

A publication in the Commerce Business Daily was used to announce the test program to industry, and subsequently seven industry teams responded. Each company provided sensors and/or suppressors with manpower to direct the installation and use of their technologies. The WSL fabricated an all-steel test chamber resembling a typical mid-sized commercial aircraft with fuselage-mounted engines. This allowed repeatable tests with controlled fires. The fires were designed to simulate an actual uncontained engine event.

The industry participants and their applied technologies are listed in table 1. The industry participants provided, at their costs, the detectors and suppressors used in the tests. The exception was Kidde, their detectors were military purchases.

TABLE 1. TEST PARTICIPANTS AND TECHNOLOGIES

Company	Technologies Applied
Fire Combat	Suppressor: Aerosol SPFE* Patented Aerosol Potassium Nitrate compound - KNO ₃
General Dynamics-OTS	Suppressors: Aerosol SPFE Proprietary and Hybrid (H ₂ O)
Goodrich Sensors	Optical Detector: Prototype model
International Aero-Pyrogen	Thermal Detector: Fire Chord ® Suppressor: Aerosol SPFE Patented Aerosol Potassium Nitrate compound - KNO ₃
Kidde	In-Service Optical Fire Detectors
Plastic Fabricating Co.	Aluminum Oxide Powder Panels
Tally Defense Systems	Thermal Detector: Proprietary Thermal Initiation Material Suppressor: Aerosol SPFE Patented Aerosol Potassium Nitrate compound - KNO ₃

*SPFE – Solid Propellant Fire Extinguisher

1.3 THREAT.

The ballistic threat was due to liberated turbine engine parts. Impacting a 4- by 8-inch titanium fan blade segment into skin and interior material created fuselage damage. The same damaged panel was used for all tests.

To characterize the ignition source for persistent fires occurring as a result of an uncontained engine event, high-speed films from previous China Lake engine tests were studied to determine the timing of real events, as shown in figures 2 through 4. Two of these events were propagated from ballistic impact, and the third event was an intentional blade release.



FIGURE 2. UNCONTAINED FAN BLADE TEST AT CHINA LAKE
SHOWING TYPICAL DAMAGE



FIGURE 3. UNCONTAINED TURBINE BLADE TEST AT CHINA LAKE
SHOWING TYPICAL DAMAGE



FIGURE 4. UNCONTAINED DISK FAILURE TEST AT CHINA LAKE
SHOWING TYPICAL EFFECT

In all cases, very high-energy (hot, high-velocity fragments) engine debris was ejected from the engine followed by a fireball propagated by the high-pressure internal engine gasses expanding through the ruptured case wall. The engine debris was not traveling fast enough to cause pyrophoric flash on impact to create a fuel ignition source, but the metal sparks from the engine failure were hot enough to ignite fuel. Either the hot-engine debris or the hot gasses could cause the ignition of the fuel under the right conditions.

2. TEST OBJECTIVE.

The objective of this test was to demonstrate the potential effectiveness of off-the-shelf fire detection and suppression devices in mitigating the fires caused by uncontained turbine engine failures. The specific type of fire tested here was an internal cabin fire caused by a piece of debris cutting through a main fuel line, and the resulting fuel spray was ignited by the sparks released by the uncontained engine event.

3. APPROACH.

This test was designed to allow fire detection and suppression manufacturers to demonstrate off-the-shelf capabilities of their devices in a realistic aircraft uncontained engine debris fire environment. An all-steel fire simulator was fabricated to resemble a section of a commercial or business turbine engine-powered aircraft with the engines mounted on the aft fuselage. The scenario simulated was that an uncontained engine event had liberated an engine fragment and damaged the main fuel line to the engine. This led to a fire and high-flow fuel leak into the fire area. Two events could be simulated, one of damage above the cabin floor and one with damage below the floor. The cabin had simulated interior wall panels and actual aircraft insulation blankets. In the lower bay or baggage compartment area there was a substantial volume between the aircraft skin and the compartment wall where the lower fires were most predominant. This region had a simulated air-conditioning duct, hydraulic lines, and wiring. See figures 5 and 6.

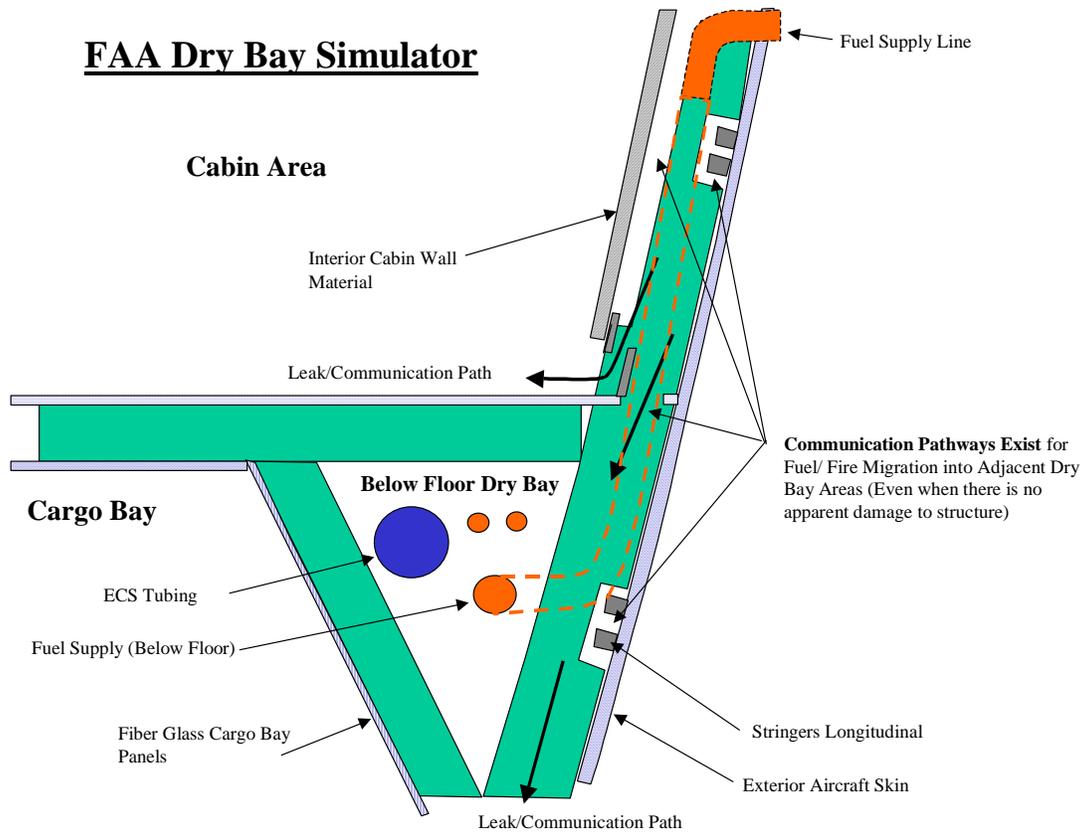


FIGURE 5. DRY-BAY SIMULATOR SECTION VIEW SHOWING TEST AREAS AND MODELED FLOW PATHS

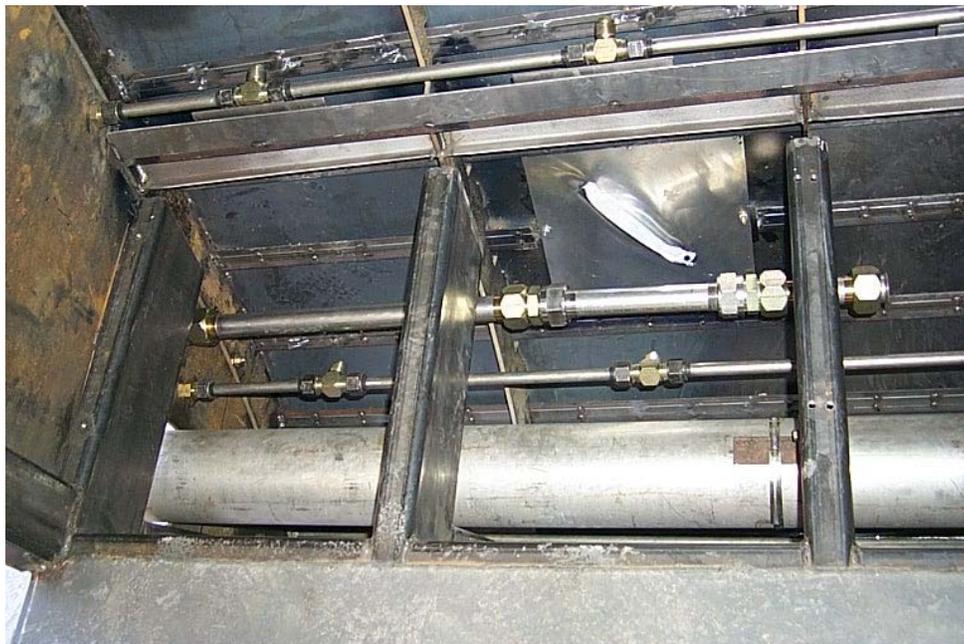


FIGURE 6. LOWER TEST VOLUME WITH COMPARTMENT WALL REMOVED

Test objectives did not include replication of the ignition mechanism but did ensure that ignition occurred (i.e., it was assumed that the fire was ignited by the uncontained event in some fashion). An ignition source was provided independent of the fragment, which provided a consistent interior cabin fire. Figure 7 shows the igniter in operation. The igniter is operated by mixing oxygen and acetylene in a chamber and lighting it with a spark of 0.5-sec duration. The duration of the igniter was chosen to match the duration of the explosive event associated with the beginning of the uncontained event. Motion picture data from an uncontained engine test show the duration of the ignition source to be 0.5 sec on the average.

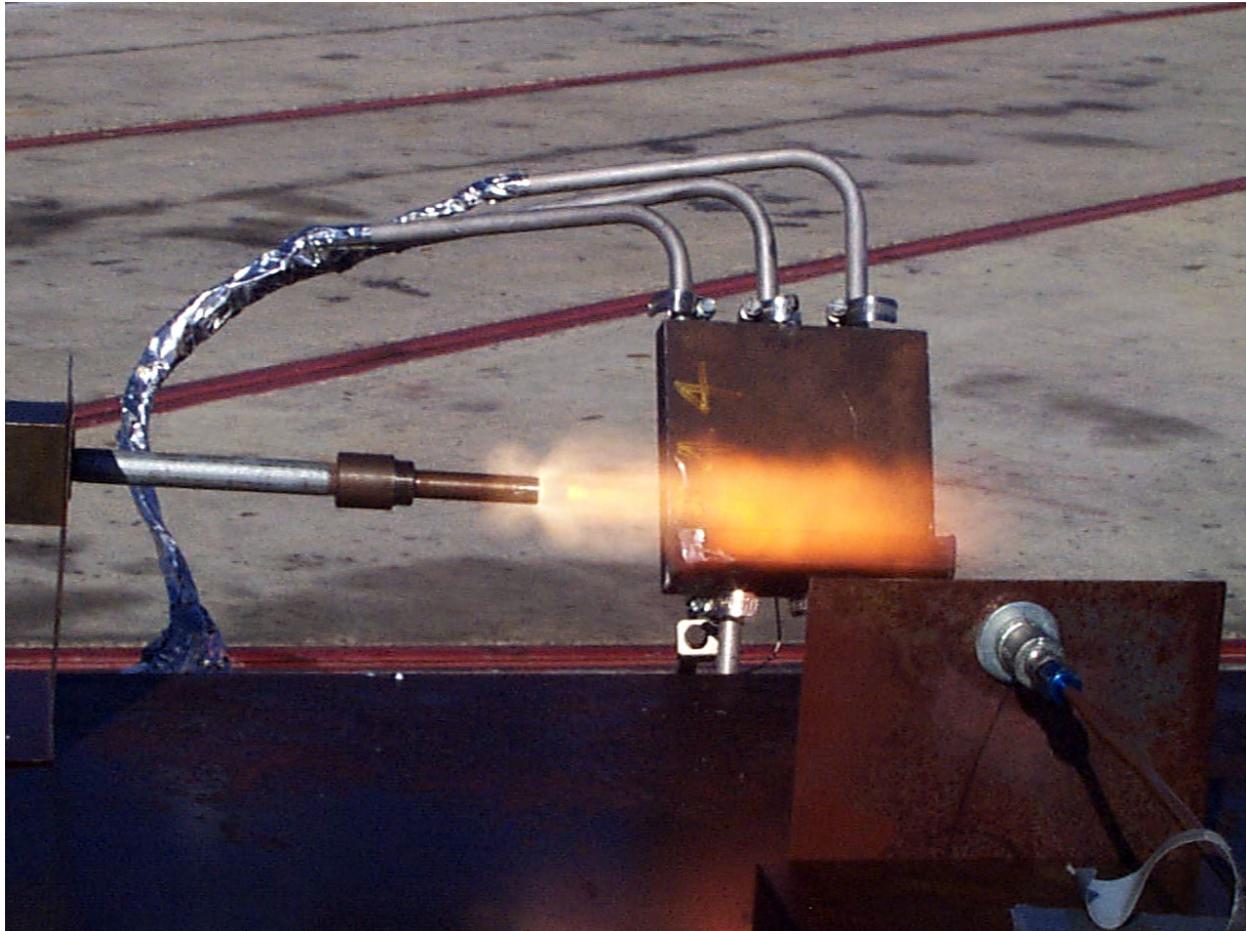


FIGURE 7. IGNITER TO BE USED FOR FIRE INITIATION

3.1 TEST OVERVIEW.

Tests were performed at the Naval Air Warfare Center (NAWC) WSL, China Lake, CA. All tests were performed on the C-2 section of the main test pad from 15 July through 6 August 2002. Both standard and high-speed video were used to document the fires.

A total of 55 tests were conducted, and investigating technologies are listed in table 2.

TABLE 2. DETECTOR AND SUPPRESSOR TECHNOLOGIES

Technology	Description
Suppressor Concepts	Four aerosols with potassium compound active agents One hybrid solid propellant: H ₂ O Two passive powder panels using aluminum oxide
Optical Fire Detectors	In service on military aircraft, Kidde In service on ground vehicles, Kidde Prototype, Goodrich
Thermal Initiation	Fire Chord [®] , International Aero Thermal initiation material, Talley

All tests had the optical fire detector installed on the exterior to provide positive indication of the igniter being triggered. The tests were set up in two categories: the upper or cabin area and the lower or baggage area. For the nonimpact tests, the igniter was positioned to fire into the test volume through a 12-inch-square replaceable damage simulator. This damage simulator was made prior to the tests by impacting a fan blade fragment into the steel plate with a large gas gun. This produced an impact hole that was of the type caused by uncontained engine debris. An igniter was made to simulate the explosive ignition caused by the uncontained engine event. A single fuel line leak was simulated with a 0.25-inch orifice for the upper bay tests and a 0.5-inch hole in the main fuel feed line for the lower bay tests, corresponding to an 11- and 27-gpm leak rate respectively.

The aircraft simulator is shown with access doors open in figure 8. The two impact locations are visible, one has typical impact damage and the one above and to the left is covered. At the time of the photograph, no instrumentation wires were installed.



FIGURE 8. AIRCRAFT SIMULATOR ON TEST PAD PRIOR TO TESTING

The airflow tests were done in cooperation, both financially and technically, with a military development program. They needed a technology that could suppress a high-airflow fire in a confined space. For this test, a venturi evacuator was used and powered by a turbine engine start cart known as a huffer. In this manner, the air was sucked through the test section and the evacuate flow was measured with a manometer. The evacuator hose is visible, and the intake hole is covered.

The intake is a roughly triangular plate on the near face and allowed air to flow through the space that simulates the volume between the baggage compartment and the skin.

The below floor dry bay is shown in figure 9, which provides the estimated bay volumes in the aircraft fire simulator. For the upper volume tests, suppressors were placed in both the outer wall area and in the cabin area.

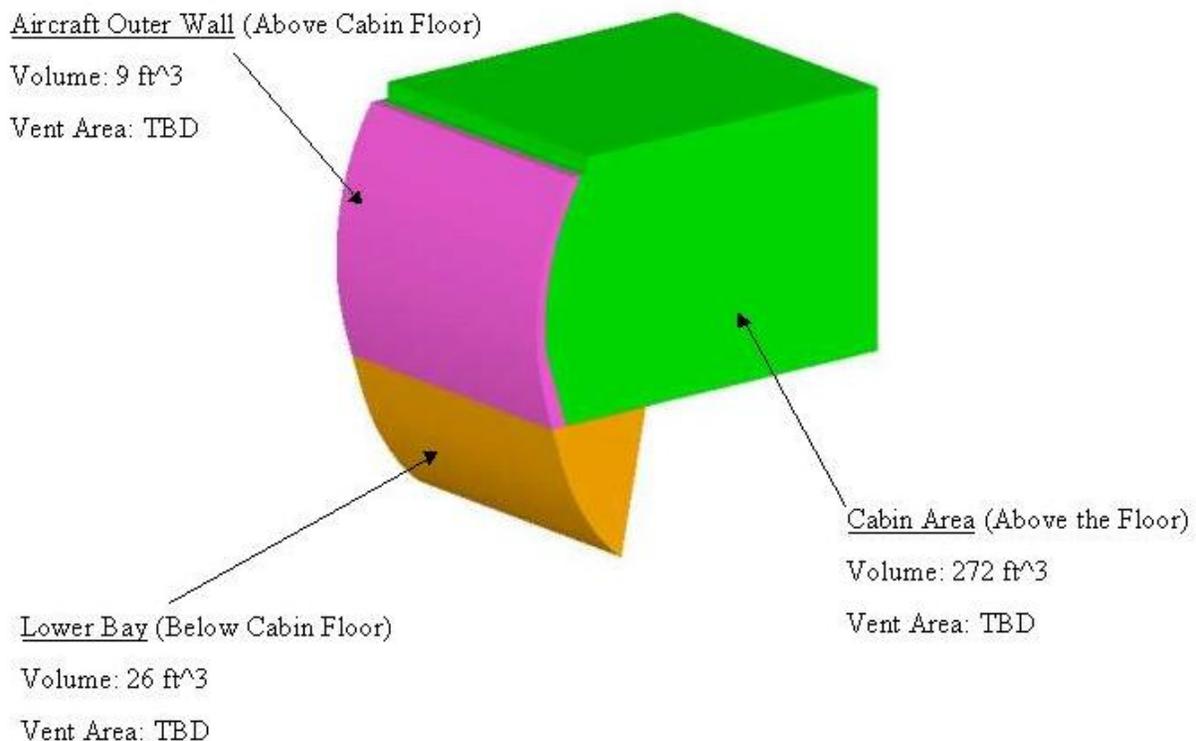


FIGURE 9. ESTIMATED SIMULATOR VOLUMES

For the impact tests, a 6-inch, nitrogen-powered gas gun was used to propel the debris fragment into the test panel. Through pretest calibration, the impact was timed and the igniter fired as the debris fragment impacted the simulator. If the igniter fired too early or too late, the test would fail or produce false indications. For that reason, care was taken to ensure positive indication of igniter firing and a high-speed video camera was set up to monitor the impact and ignition. The igniter was basically an oxy-acetylene cannon and produced a substantial fireball that persisted significantly longer than the impact duration. The igniter never failed to produce a fire in any pretest or actual test.

Each test was conducted in a manner to ensure that the fires were repeatable and as similar as possible. The following scenario describes the test procedure for each test:

- Fuel switch activated at $t - 3$ sec (full fuel flow by $t = 0$ s, upper 0.5 gal/sec and lower 1 gal/sec)
- Igniter fired at $t = 0$ sec
- Suppressors activated by electrical or thermal means after ignition
- Fuel off at $t = 30$ sec
- Simulator observed for 2 minutes after apparent fire suppression for reignition

Each participant determined the location and quantity of suppressors used in a test. For tests where the suppressors were initiated electrically, the timing was specified by the participant and based on the igniter firing pulse. A minimum of 15 ms was maintained as the processing time that would be required for a detector-suppressor system. This time is typical for the military units tested.

3.2 TEST SETUP.

Some of the setup was common to all tests. The thermocouple and optical fire detectors (OFD) placement stayed constant. There were six thermocouples arranged around each of the impact holes: six around the upper impact area and six around the lower impact area. The locations of the thermocouples are shown in figure 10. The frames or ribs are shown as vertical lines and the cabin floor is horizontal in the middle. The thermocouple data for each test are presented in appendix A.

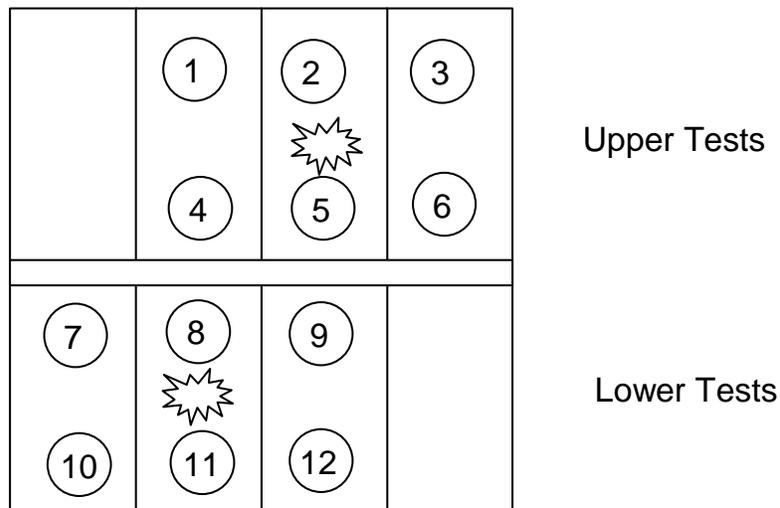


FIGURE 10. THERMOCOUPLE LOCATIONS VIEWED FROM INSIDE SIMULATOR
(View looking outboard from interior bays)

OFDs were installed in the upper and lower areas. One OFD was mounted on the external side of the skin to monitor the igniter. Figure 11 shows the locations of the OFDs. In tests 13-27, the lower PM-34C OFD was inoperable. There were water-cooled video cameras located in the three major test areas.



FIGURE 11. DRY-BAY SIMULATOR FIRE DETECTOR LOCATIONS

4. RESULTS.

All the technologies tested proved capable of suppressing the fires. The potassium aerosols were capable of extinguishing fires in less than 5 seconds. The detection methods varied from highly successful to only somewhat successful. The heat-initiated systems were heavily dependent on their location relative to the fire. If the fire retreated behind a rib or plate, the thermal detector might not initiate for many minutes.

The following paragraphs summarize the tests, with complete plots of the data collected presented in appendix A.

The simulator was divided into several test sections. There was a large upper section that represented the cabin area. In the upper section, there was an interwall dry bay that was between the interior wall panel and the exterior skin. This area had aircraft insulation blankets installed and in some tests had suppressors installed. The second major section was the lower area that represented the baggage compartment. Adjacent to this was the lower dry bay, which had a fairly large amount of space between the compartment wall and the outer skin that was roughly triangular in cross section. This outer lower bay had clutter simulating wire bundles, fuel lines, and an air duct. Suppressors placed in the upper interwall space were specified as part of the upper section.

The results presented used the following nomenclature.

- Location—either upper (cabin) or lower (baggage) section
- Suppressors Upper—number and size of suppressors in the upper section
- Suppressors Lower—number and size of suppressors in the lower section
- Suppressors Outer Lower—number and size of suppressors in the outer lower section

For all the tests, there were production OFDs installed in the upper and lower outer compartments. Plots of all the OFD data are presented in appendix A.

The tests were declared a “no test” due to malfunctions of either the instrumentation system, support equipment, or firing system. Several times unseen wiring fire damage from a previous test interfered with suppressor firing signals. Those tests were discounted. Of the 55 tests run, 13 were declared no test for a success rate of 76%.

4.1 BASELINE FIRES.

Baseline tests were conducted to verify that the igniter would start fires in a repeatable manner. The timing of the fuel spray, 3 seconds prior to firing the igniter, provided very consistent fires for the test participants. Figure 12 shows an example of typical fires in the upper and lower bays. Table 3 is a summary of the baseline tests.

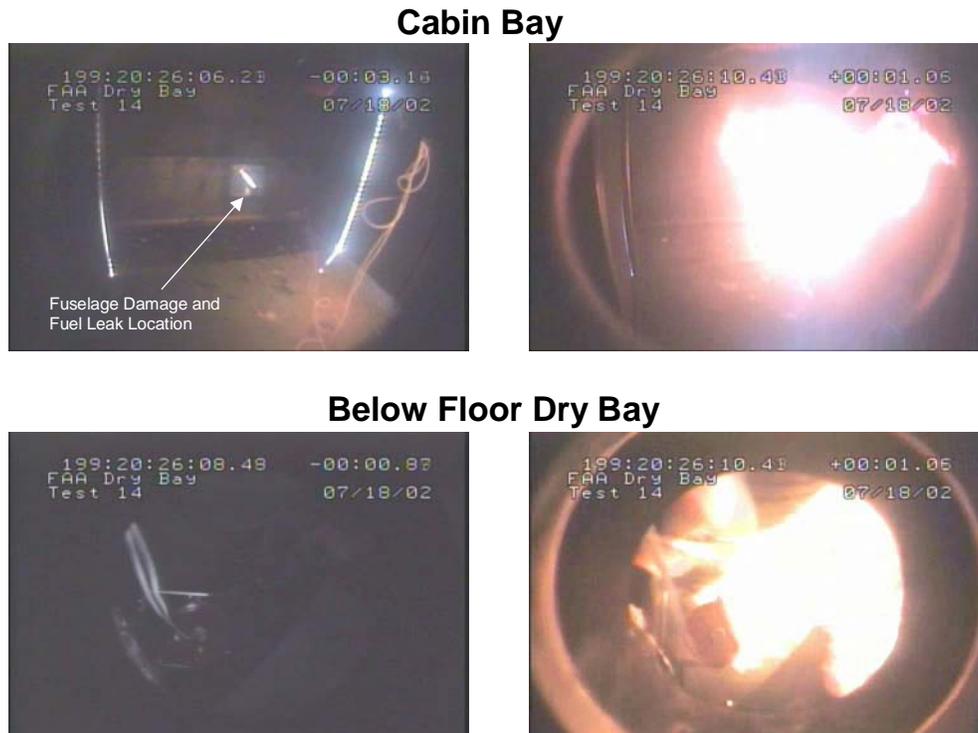


FIGURE 12. TYPICAL DRY-BAY FIRE

TABLE 3. BASELINE TEST RESULTS SUMMARY

Test	Section	Devices Upper Size and Timing	Devices Lower Size and Timing	Devices Outer Lower Size and Timing	Results
1					No test
2	Lower	none	none	none	Fire
3	Lower	none	none	none	Fire
4	Lower	none	none	none	Fire
5	Upper	none	none	none	Fire
6	Upper	none	none	none	Fire
7					No test

4.2 FIRE COMBAT.

Sensor Electronics Corporation, Fire Combat participated in ten tests. They provided Aero-K[®] solid propellant aerosol fire extinguishers. Fire Combat was successful in extinguishing the fires in most cases. In the lower bay, the fires were suppressed and extinguished within 20 seconds in most cases. Agent distribution was achieved via a low-pressure generator that burns at a slow rate, which takes some time to achieve proper bay concentration levels. To address a bay with airflow, a large 1000 g extinguisher was used. Despite the larger size, this agent was ineffective due to the slow distribution rate and entrainment of the agent with the airflow, thus rendering the agent ineffective for this case. In the upper bay fire test, Fire Combat was successful in each test. The affect of distribution/extinguisher location and agent quantity can be seen from the time required to extinguish the fires. Figure 13 shows the Fire Combat installation, table 4 summarizes the results, and figure 14 shows the results of test 14.



FIGURE 13. FIRE COMBAT OUTER LOWER BAY INSTALLATION

TABLE 4. RESULTS SUMMARY FOR FIRE COMBAT

Test	Section	Devices Upper Size and Timing	Devices Lower Size and Timing	Devices Outer Lower Size and Timing	Results
8	Lower	none	250 g 0.1 sec	100 g 0.6 sec	Fire persisted until end of test at 2 minutes
9	Lower	none	250 g 0.1 sec	250 g 0.6 sec	Fire suppressed in less than 20 sec
10	Lower	none	none	100 g 100 g 0.1 sec	Fire suppressed in less than 20 sec
11	Lower	none	none	2x 100 g 0.1 sec	Fire suppressed in less than 20 sec
12	Lower with airflow	none	none	1000 g 0.1sec	No effect on fire
13	Lower with airflow	none	500 g -0.5	1000 g -0.5	No effect on fire Devices were preignited to simulate a faster propellant
14	Upper	1000 g 0.1 sec 100 g* 0.1 sec	500 g 0.1 sec	250 g 0.1 sec	Fire suppressed in less than 5 sec
15	Upper	500 g 0.1 sec	500 g 0.1 s	100 g 0.1 s	Fire suppressed in less than 10 sec
16	Upper	1000 g 0.1 sec	500 g 0.1 sec	100 g 0.1 sec	Fire initially suppressed in less than 15 sec, relight at 90 sec but suppressed by remaining aerosol within 30 sec
35	Upper	1000 g 0.1 sec	250 g 100 g 0.1 sec	100 g 0.1 sec	Fire suppressed in less than 2 sec

The timing data shown is from the fire pulse to the igniter.

*Installed in insulation blanket area between skin and interior wall panel.

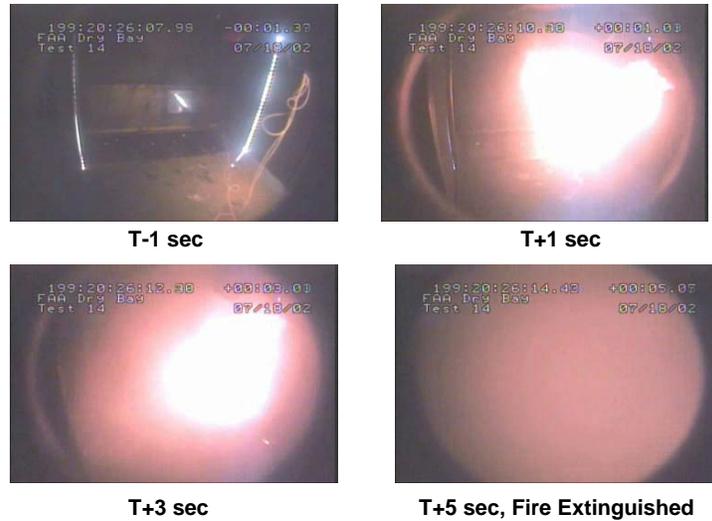


FIGURE 14. FIRE COMBAT, TEST 14

4.3 INTERNATIONAL AERO-PYROGEN.

Test results showed the Pyrogen devices to be successful in extinguishing fires. This series of tests show the typical developmental process of optimizing agent concentration to achieve the desired robustness to extinguish the fire. Initially, the system was undersized, allowing the fire to persist. Additional extinguishers were added, which resulted in putting the fire out. Later tests explored the sensitivity to initiation timing. Changing the extinguisher initiation time from 0.1 second to 2 or 5 seconds had a significant effect on the systems ability to extinguish the fire. By increasing the initiation time, the fire became well established, making it more difficult to extinguish. This series of tests show the importance of early extinguisher initiation. Figure 15 shows the International Aero-Pyrogen installation, table 5 summarizes the results, and figure 16 shows the results of test 19.



FIGURE 15. PYROGEN AEROSOL CAN INSTALLATION, OUTER LOWER BAY

The Pyrogen devices are categorized as:

- Mag 3—200 g aerosol
- Mag 4—1,000 g aerosol
- Mag 5—500 g aerosol
- Fire Chord is a thermally activated fuse

TABLE 5. RESULTS SUMMARY FOR PYROGEN

Test	Section	Devices Upper Size and Timing	Devices Lower Size and Timing	Devices Outer Lower Size and Timing	Results
17	Upper	Mag 4 0.1 sec	Mag 3 0.1 sec	Mag 3	Fire suppressed in less than 5 sec - relight at 90 sec, and continued to burn until end of test
18	Upper	Mag 5 0.1 sec	Mag 3 0.1 sec	Mag 3 Fire Chord	Outer lower initiated by fire, others manually fired at 18 sec, fire suppressed at 29 sec
19	Upper	2x Mag 3	Mag 3	Mag 3	Fire suppressed in less than 20 sec
20	Lower with airflow	2x Mag 3	Mag 3	Mag 3	Fire not suppressed timing: 3.0 sec 1 upper and 1 lower 5.0 sec 1 upper and 1 lower
21	Lower with airflow	none	none	4x Mag 3 2.0 sec	Fire not suppressed
22	Lower with airflow			2x Mag 3	No test
33	Lower	none	none	2x Mag 3 0.1 sec	Fire suppressed in less than 10 sec
34	Lower	none	none	Mag 3 0.1 sec	Fire suppressed in less than 35 sec



FIGURE 16. AERO-PYROGEN, TEST 19

4.4 TALLEY DEFENSE SYSTEMS.

Results for the Talley extinguishing system were mixed. When the extinguisher was initiated electrically, the agent was successful in extinguishing the fire. When the initiation was reliant on the thermal initiation material (TIM), located on the extinguisher unit, the extinguisher was not activated due to the 450° temperature requirement to initiate the device. Unless the device was directly in the fire, the initiation material did not activate. In most cases with the TIM, the dry-bay fires moved around the bay, so the TIM was not directly in the fire; thus, it did not activate. Figure 17 shows the Talley Defense Systems installation, table 6 summarizes the results, and figure 18 shows the results of test 27.



FIGURE 17. TALLEY EXTINGUISHER CAN INSTALLATION, OUTER LOWER BAY

TABLE 6. RESULTS SUMMARY FOR TALLEY DEFENSE SYSTEMS

Test	Section	Devices Upper Size and Timing	Devices Lower Size and Timing	Devices Outer Lower Size and Timing	Results
23	Lower	none	none	500 g 0.1 sec	No test
24	Lower	none	none	500 g 0.1 sec	No test
25	Lower	none	none	500 g 0.1 sec	Fire extinguished in less than 45 sec
26	Lower	none	none	500 g 0.1 sec	Fire suppressed in less than 5 sec
27	Lower	none	500 g 0.1 sec	500 g 0.1 sec	Fire suppressed in less than 5 sec
28	Lower	none	none	500 g TIM	No extinguisher initiation, fire did not reach TIM.
29	Lower	none	none	500 g TIM	Fire was not hot enough at TIM. Large external fire.
30	Lower	none	none	500 g TIM	No test/no fire, facility wire damage due to previous test fire fighting
31	Lower	none	none	500 g TIM	No extinguisher initiation, fire did not reach TIM limit. Added fuel twice in an attempt to increase fire.
32	Upper	4x 500 g 0.1 sec	none	500 g 0.1 sec	Fire suppressed in less than 5 sec

TIM - Thermal Initiation Material; fused by heat



FIGURE 18. TALLEY DEFENSE SYSTEMS, TEST 27 (LOWER BAY FIRE)

4.5 GENERAL DYNAMICS-ORDNANCE AND TACTICAL SYSTEMS.

Gas generators are being successfully used to address dry-bay fire issues in a number of military applications. Typically, to be successful, a series of development tests are needed to properly size the extinguishing system for the specific bay and airflow conditions. This is an engineering activity for most fire conditions. Two factors that affect the success of the system are the quantity and distribution of the agent. As indicated in table 7, General Dynamics Ordnance and Tactical Systems (GD-OTS) was unsuccessful, extinguishing the fire using a single 210 g extinguisher. The hybrid water mist extinguisher, in combination with the gas generator in the lower bay, was successful, extinguishing the fire. This hybrid technology may be more attractive to commercial use since it reduces the amount of active agent needed in the dry bay, using the water system to cover the larger volume in the cabin area. Tests 39-41 were conducted with airflow through the bay. Airflow in the bay significantly increases the difficulty extinguishing a fire, since the agent is entrained in the airflow lowering the agent concentration in the bay and reducing its effectiveness. Figure 19 shows the GD-OTS installation. Figure 20 shows the results of test 40 with airflow.

TABLE 7. RESULTS SUMMARY FOR GENERAL DYNAMICS-OTS

Test	Section	Devices Upper Size and Timing	Devices Lower Size and Timing	Devices Outer Lower Size and Timing	Results
36	Lower	none	none	210 g 0.02 sec	Initially suppressed, relight at 30 sec, fire not suppressed
37	Lower	none	none	210 g 0.75 sec	Fire not suppressed
38	Lower	4.3 lb H ₂ O	none	210 g 0.75 sec	Fire suppressed
39	Lower with airflow	none	none	420 g 0.75	Fire not suppressed
40	Lower with airflow	none	none	2x 420 g 0.01	Fire suppressed in less than 2 sec
41	Lower with airflow	none	none	2x 420 g 0.04	Fire not suppressed

Test 38 used a hybrid suppressor that created a water mist in the upper cabin area.



FIGURE 19. GENERAL DYNAMICS-OTS LINEAR FIRE EXTINGUISHER INSTALLATION

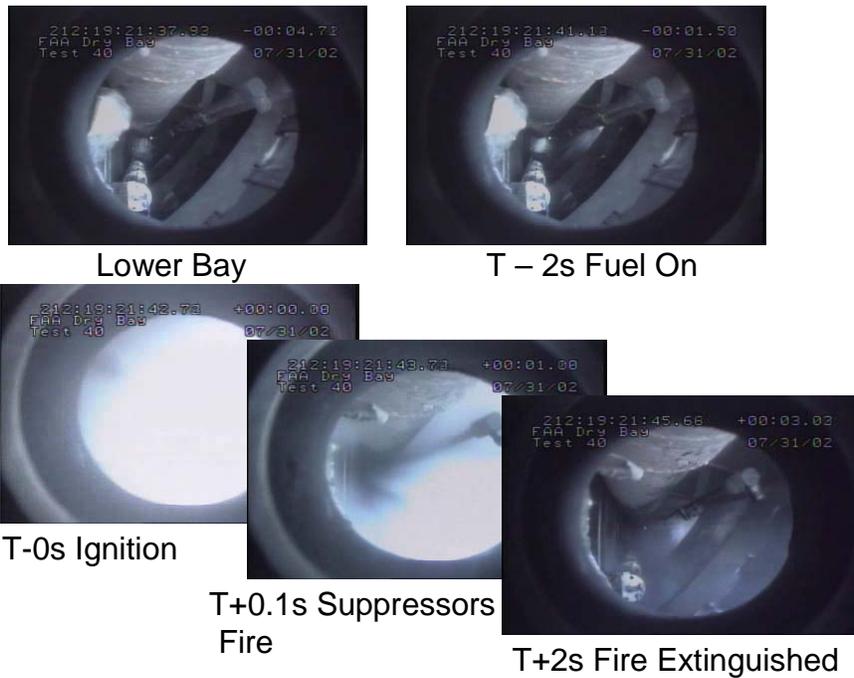


FIGURE 20. GENERAL DYNAMICS-OTS, TEST 40 WITH AIRFLOW

4.6 GOODRICH SENSORS.

Goodrich Sensors tested a prototype dual spectrum, ultraviolet infrared (UV) and infrared (IR) optical fire detector. Placement of the detectors in the upper bay is shown in figure 21. A fire alarm signal was sent if both sensors detected a fire at the same time. In these tests, two detector pairs were mounted in the upper bay, looking in the general direction of the fire. A summary of the test results is provided in table 8. A sample of the Goodrich sensor data is provided in figure 22.



FIGURE 21. GOODRICH SENSORS LOCATED IN THE UPPER BAY

TABLE 8. RESULTS SUMMARY FOR GOODRICH SENSORS

Test	Section	Devices Upper	Devices Lower	Devices Outer Lower	Results
42					No test; gas gun firing check
43	Upper	prototype	none*	none	Both UV sensors detected fire, no IR sensor detection
44	Upper	prototype	none	none	Both UV sensors detected fire, no IR sensor detection
45	Upper	prototype	none	none	Both UV and IR sensors detected fires and fire alarms set
46	Upper	prototype	none	none	Both UV and IR sensors detected fires and fire alarms set
47	Upper	prototype	none	none	Both UV sensors detected fire, no IR detection

none* - means no other Goodrich Sensors devices were installed, the baseline set was in place.

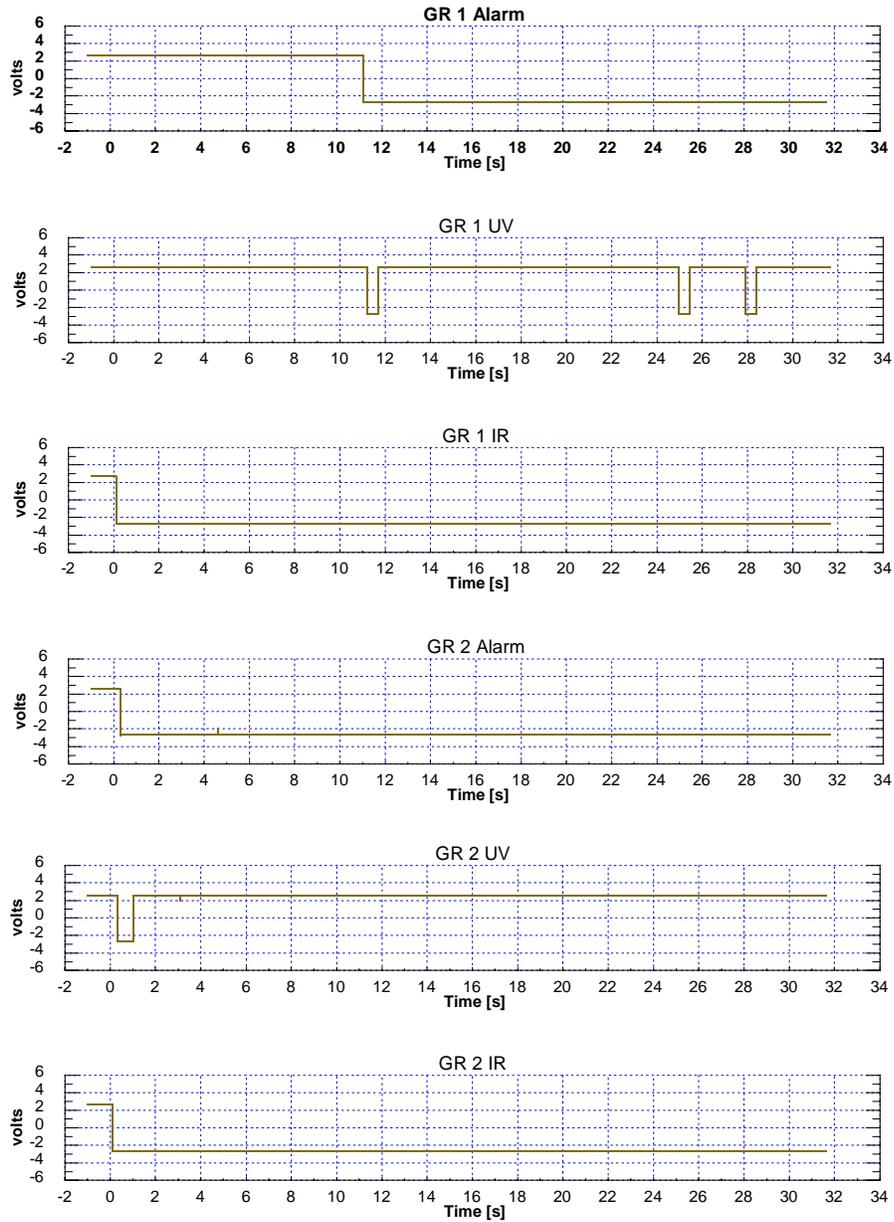


FIGURE 22. GOODRICH FIRE DETECTOR SENSOR DATA, TEST 46

4.7 POWDER PANELS.

These tests are not conclusive, but indicate some suppression capability exists for powder panels and warrants further study. Specifically, the Skyward Ltd. advanced powder panel was very impressive in terms of distribution of the agent and fire suppression after impact. This technology offers a passive approach that does not need a fire detection and control system. The benefit of a passive system for protecting remote aircraft structure is desirable. Additional tests and some long-term panel durability tests are needed in this area. Table 9 summarizes the results of the powder panel tests.

TABLE 9. RESULTS SUMMARY FOR POWDER PANELS

Test	Panel Type	Fragment Mass (g)	Impact Velocity (ft/s)	Results
48		380	400	Igniter Timing
49		380	525	Igniter Timing
50		380	525	Igniter Timing
51		380	525	Igniter Timing
52	Military Panel	380	525	Fire not suppressed
53	Military Panel	380	525	Fire not suppressed
54	Skyward Ltd. prototype	380	400	Fire suppressed
55				No test

5. CONCLUSION.

The hazard of a fuel-fed fire in a confined space has been demonstrated by a few very rare events. The tests performed here demonstrates that it is possible to defeat fires caused by uncontained engine debris impacting fuel lines. Additional research is needed to understand the limitations and durability of the systems so that benefits can be assessed.

A few general conclusions may be made from these test results.

This test series has demonstrated that fire extinguishing technology, in terms of fire detection and suppression/extinguishing, is available to protect commercial aircraft dry bays.

These tests demonstrate the need for early fire detection and quick acting extinguishers. The time frames are within the realm of current optical fire detector technologies. These data show that these technologies will detect and suppress fires caused by uncontained engine events.

Fires initiated in the upper bay quickly migrated to the lower bay through plumbing and electrical routing channels. A fire protection system for an aft fuselage-mounted engine configuration should address the migration of the fire from the upper bay to the lower bay.

The wall space with insulation blankets was a difficult area to detect and suppress fires. The detection of the event could take place from the cabin area. It was unclear if placing suppressors in the insulation space provided an advantage in suppression. The tests show that the suppressors can eliminate the fire if placed in the cabin area. However, there are human factor issues with agent discharge in the cabin.

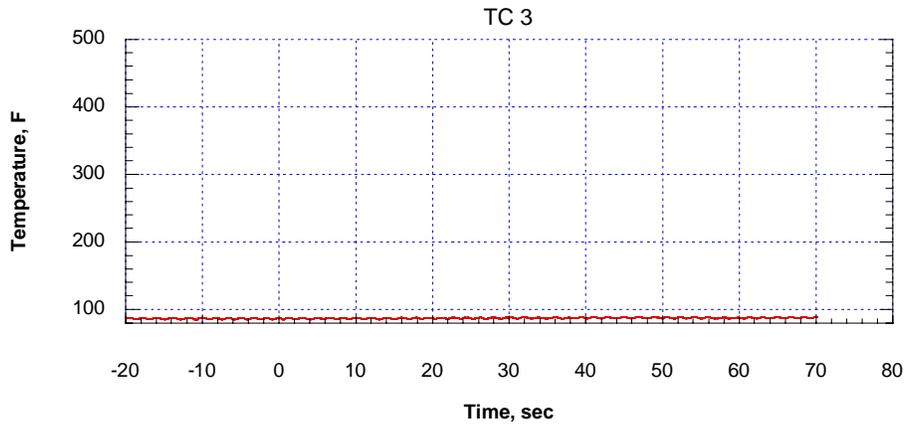
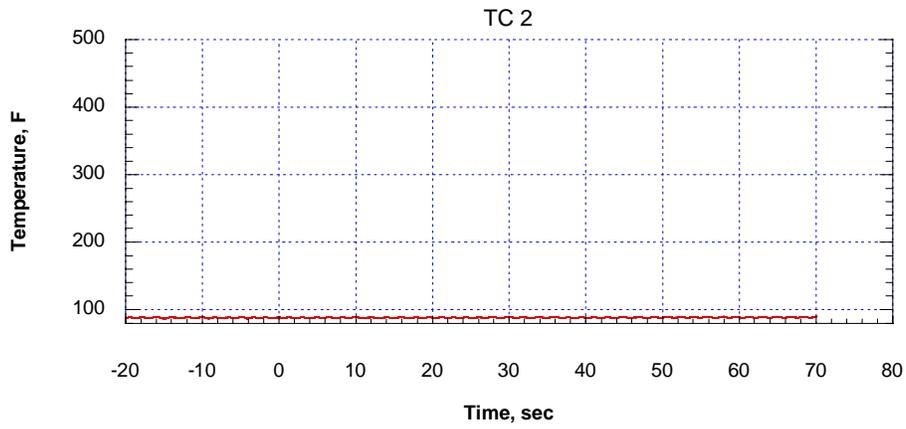
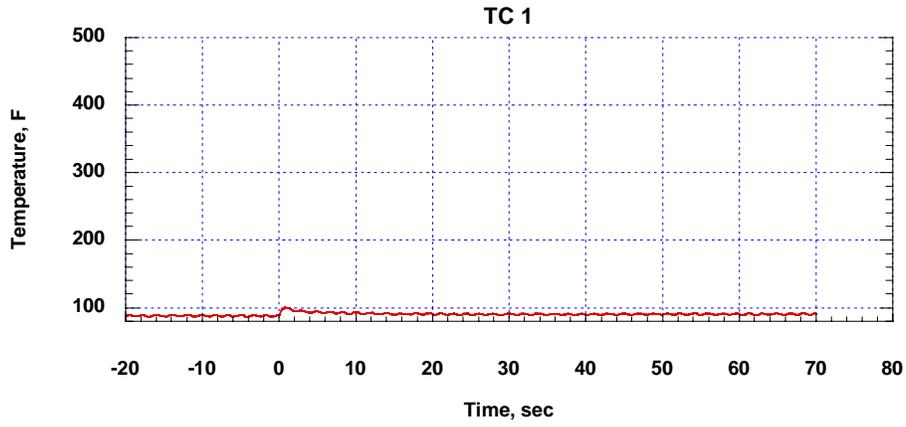
The airflow tests showed that a high-airflow environment fire is difficult to extinguish. To suppress fires under these conditions, detection must be quick and the extinguishers aggressive in terms of agent performance and distribution in these adverse conditions. The suppression

systems tested would be most effective in aircraft ground fire scenarios, i.e., low airflow around the affected bay.

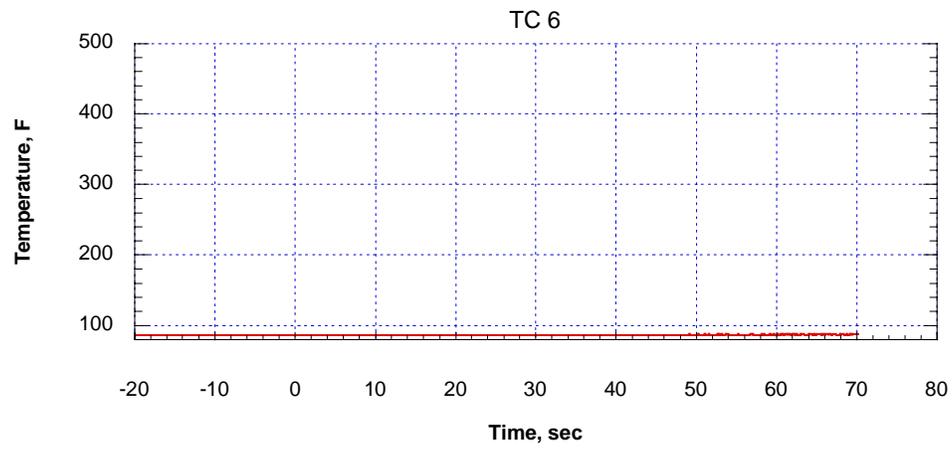
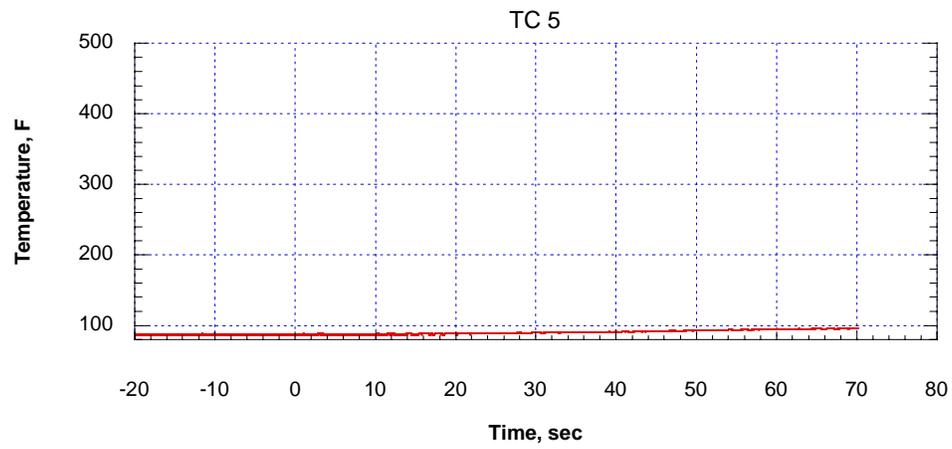
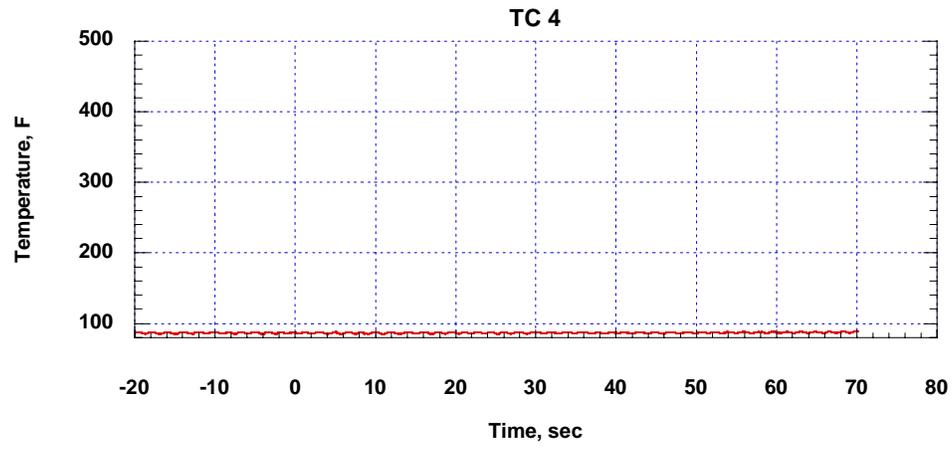
There are other issues that are not addressed by these tests regarding the operational suitability of the technologies for a commercial aircraft application.

APPENDIX A—TEST DATA

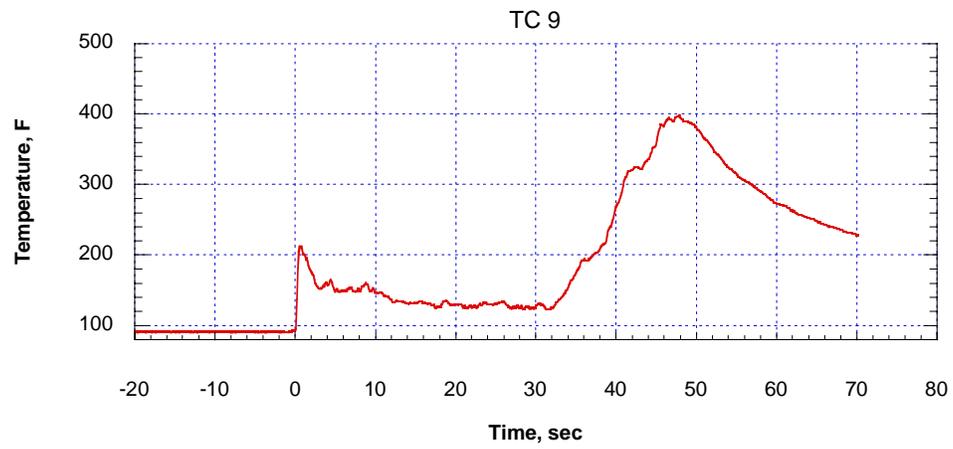
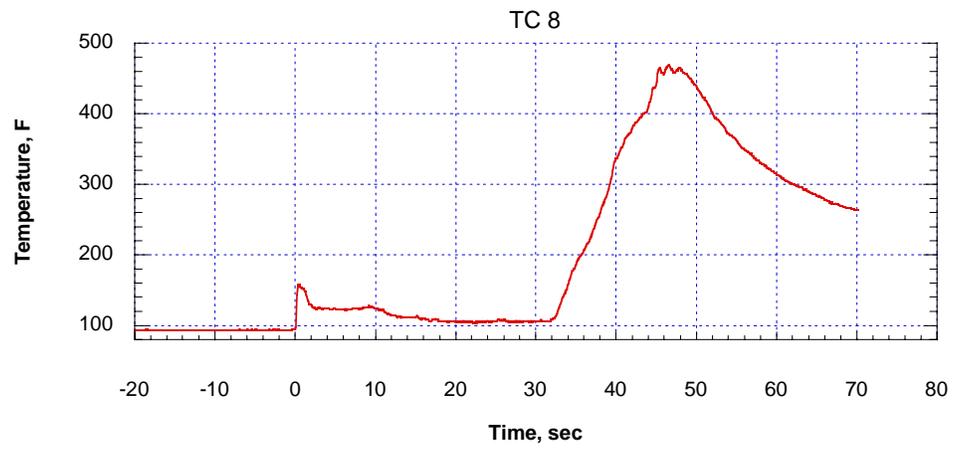
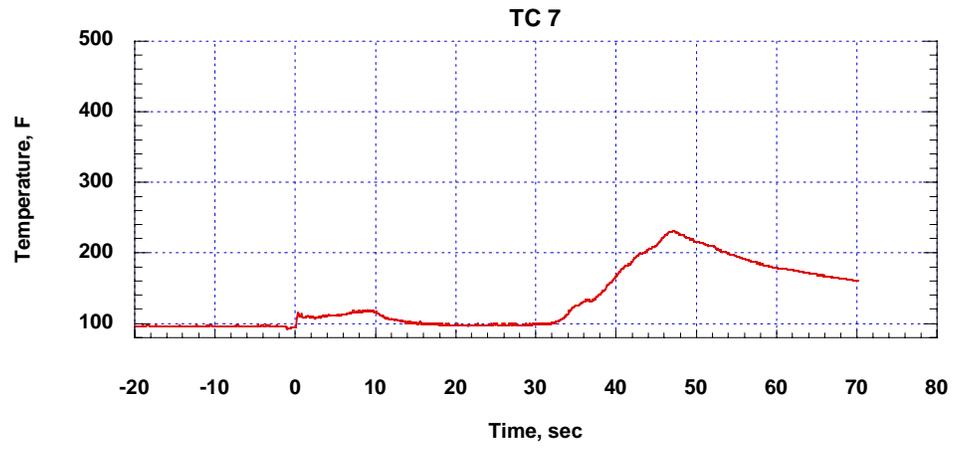
Test 03 Temperature vs Time



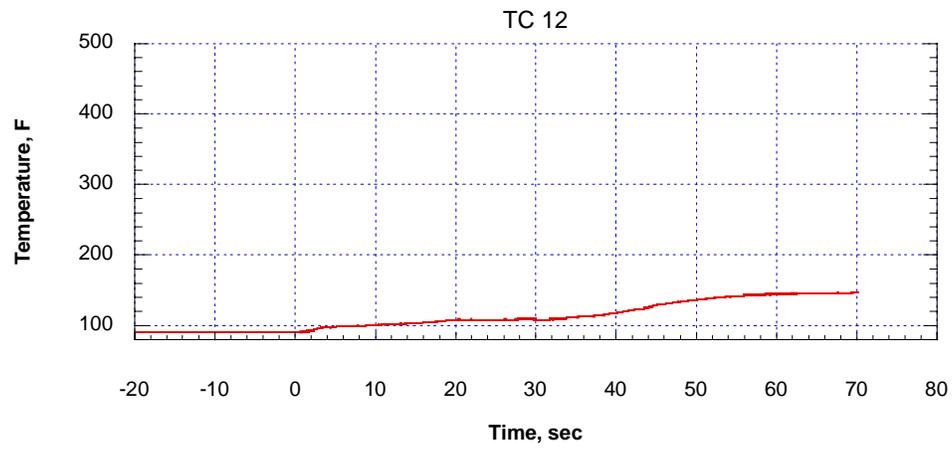
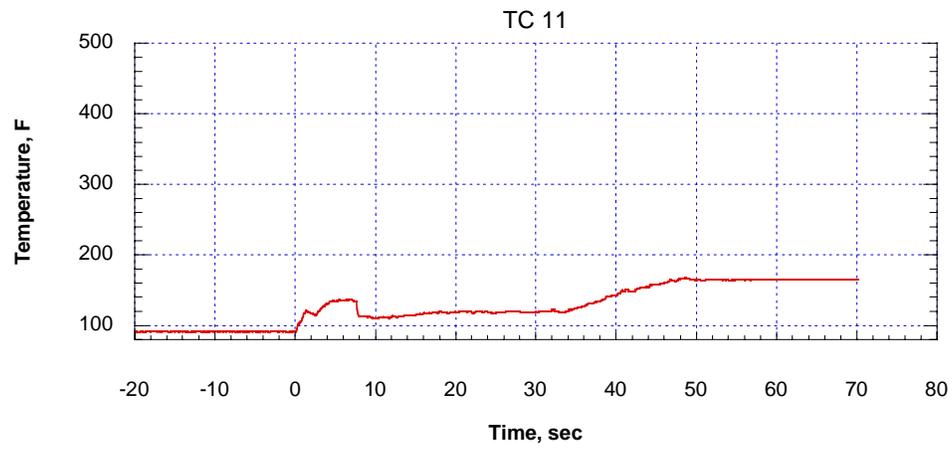
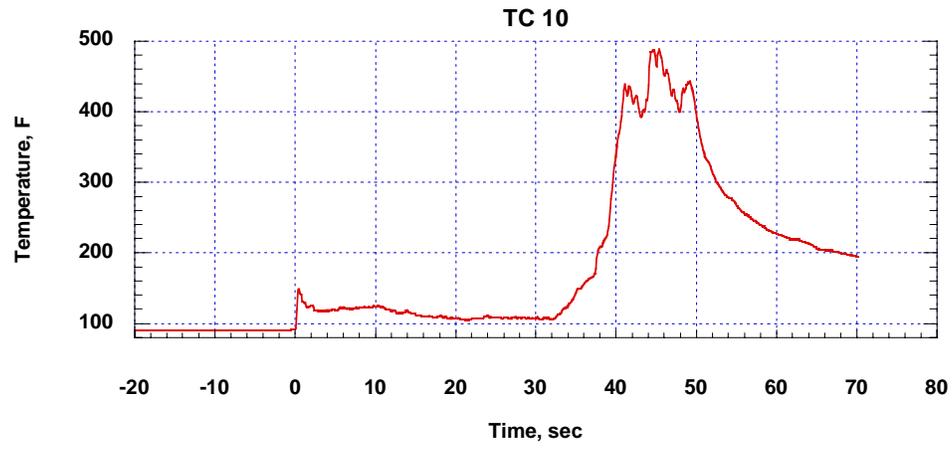
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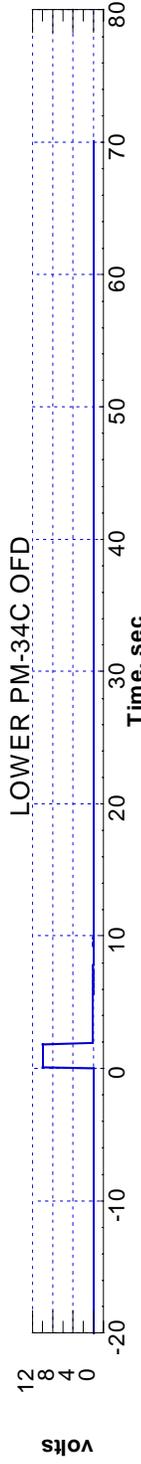
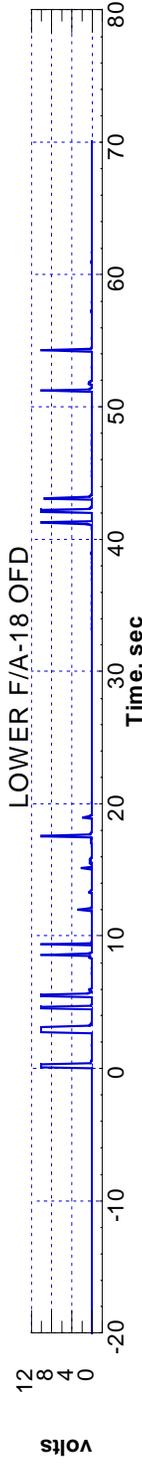
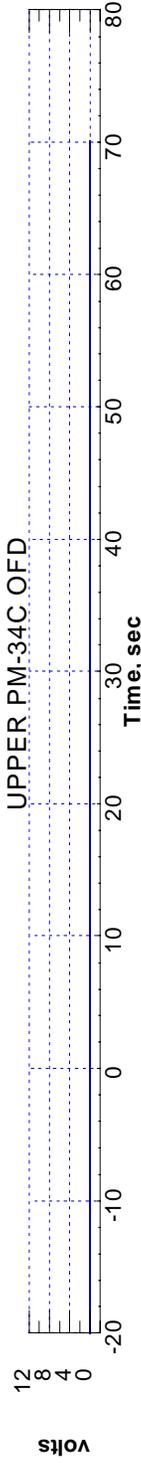
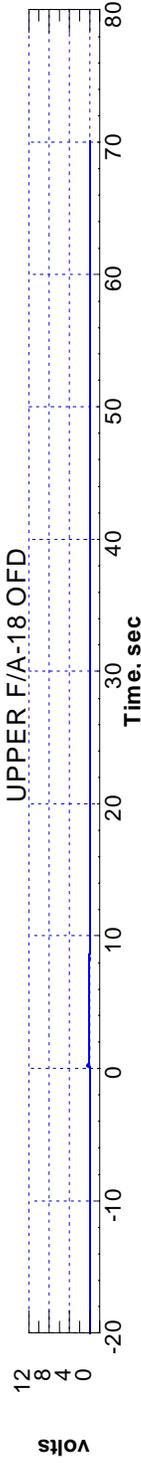
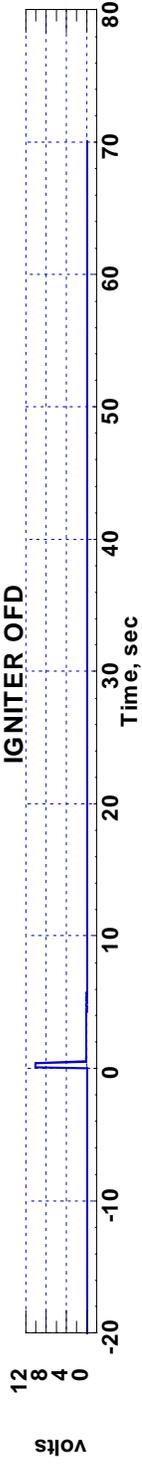
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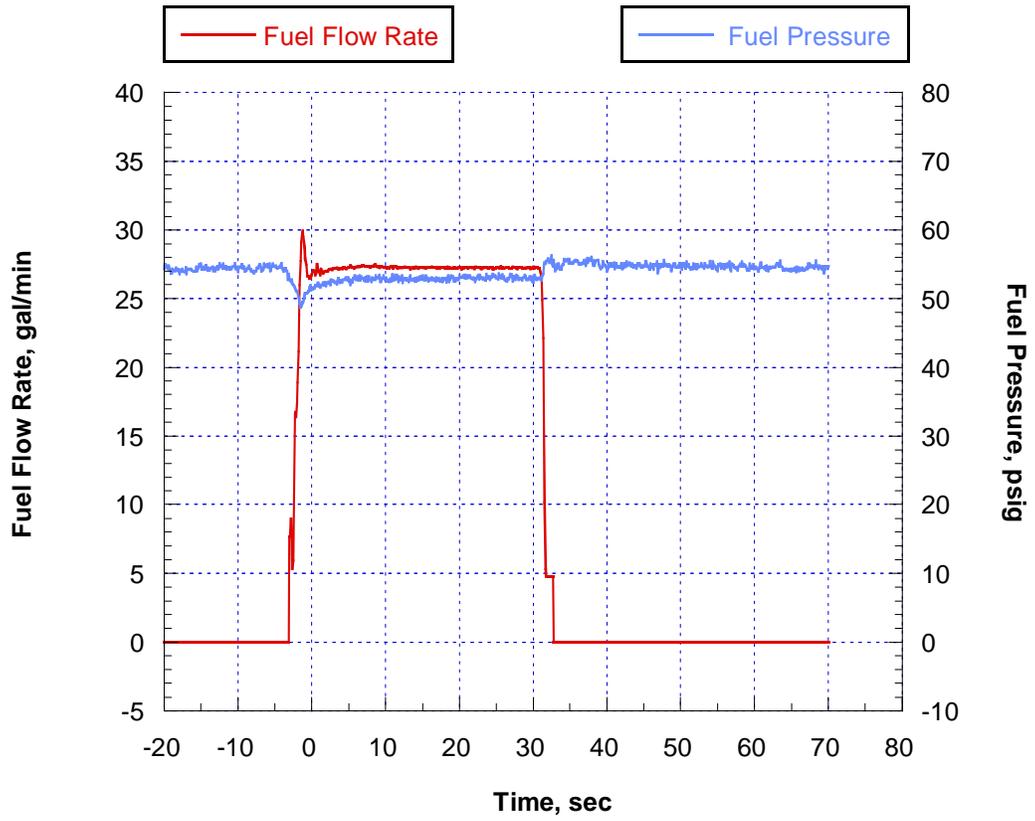
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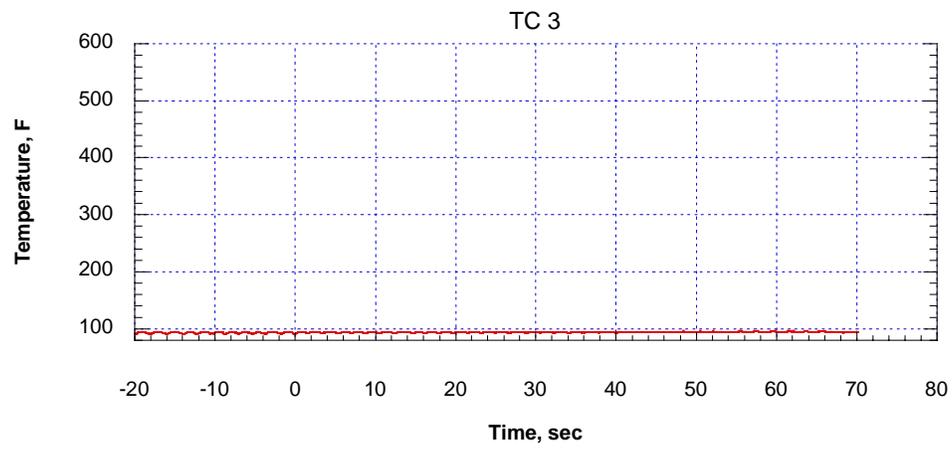
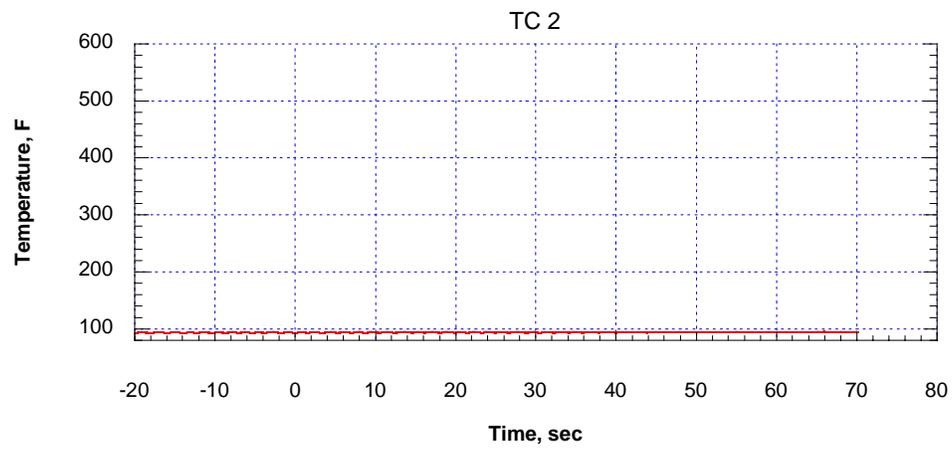
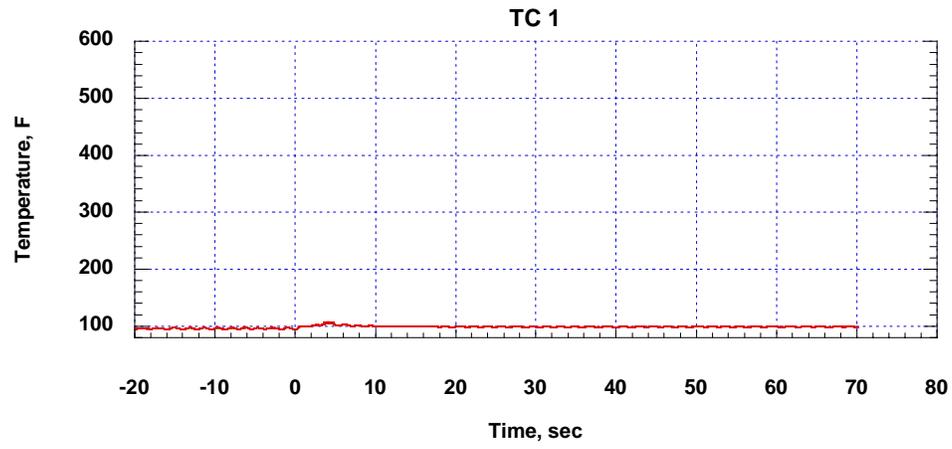
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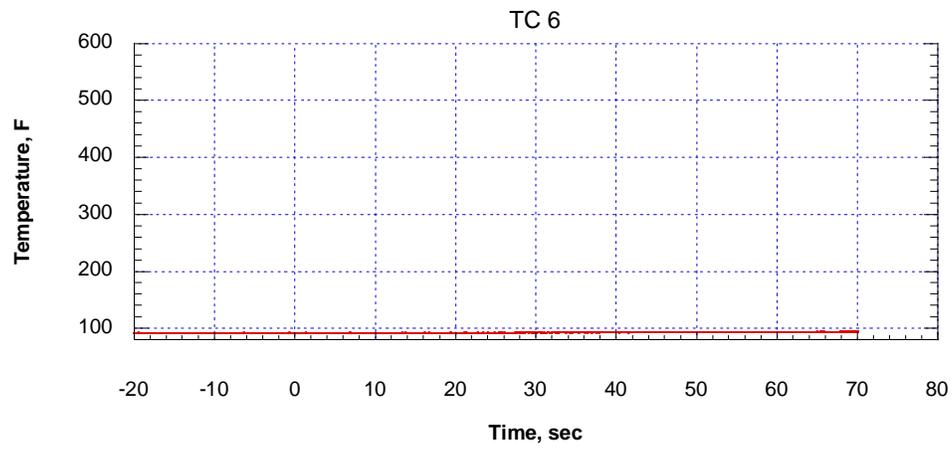
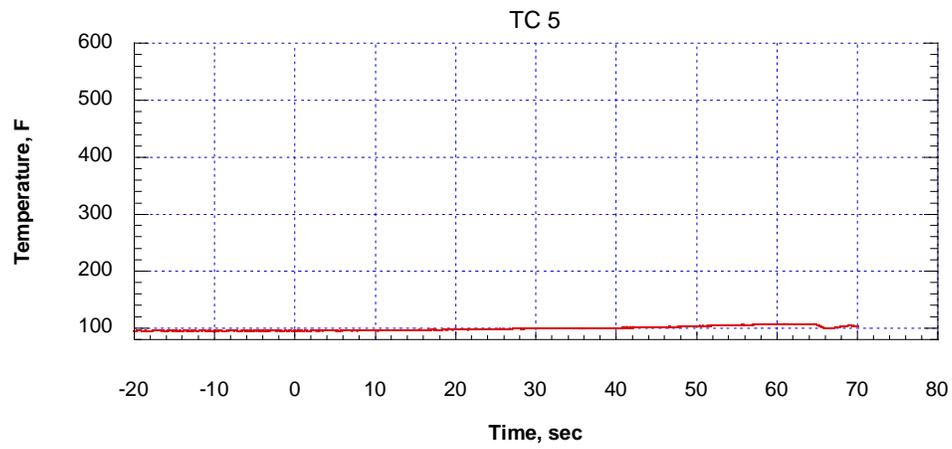
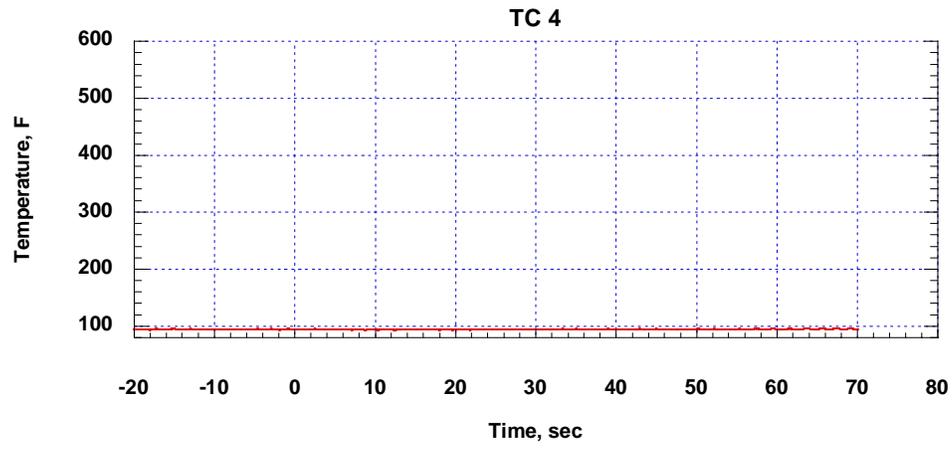
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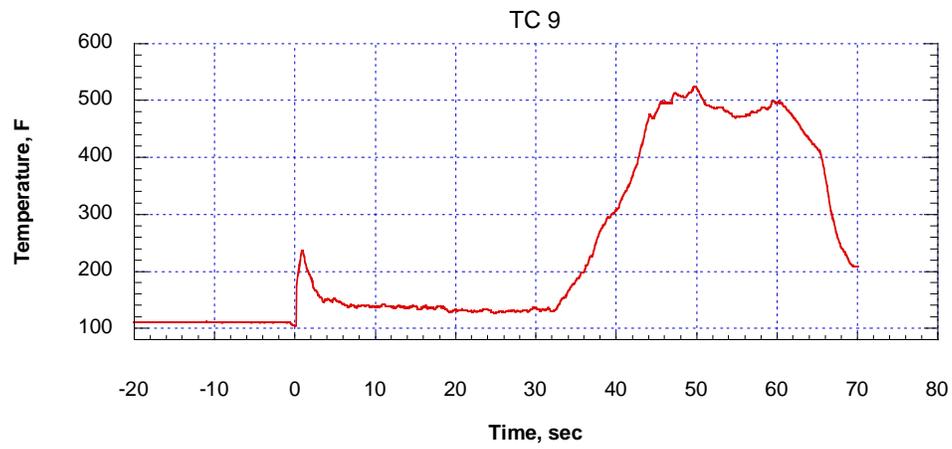
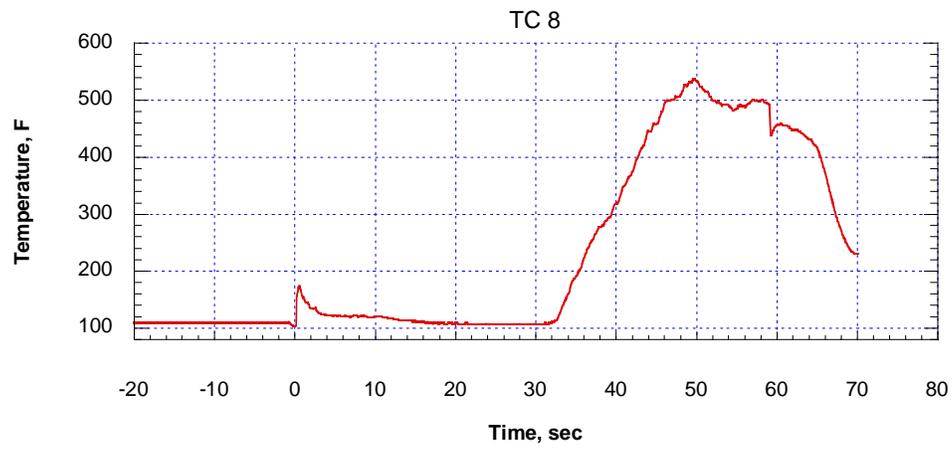
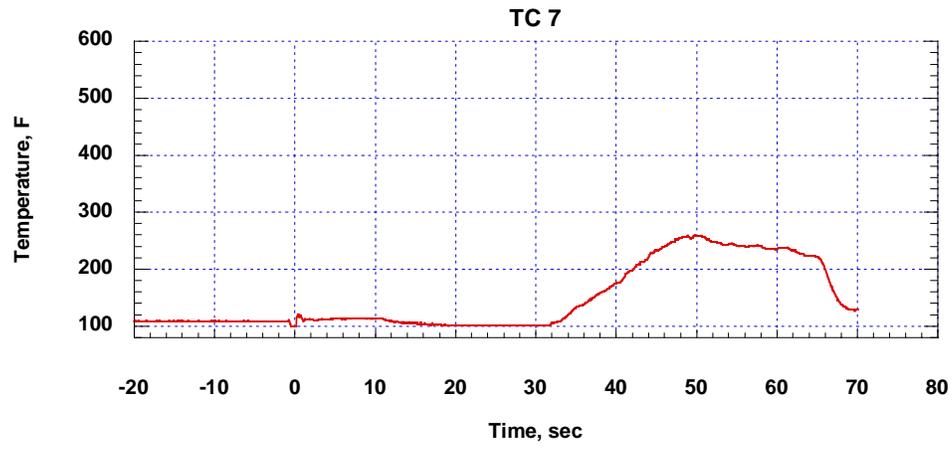
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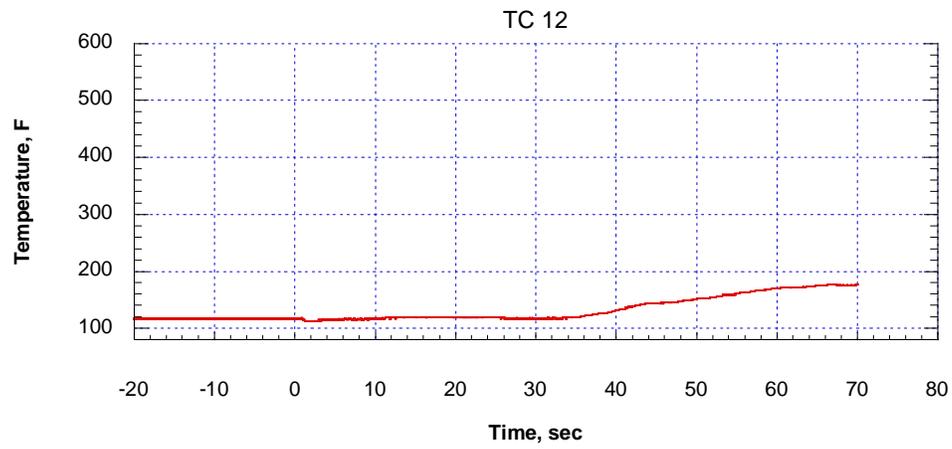
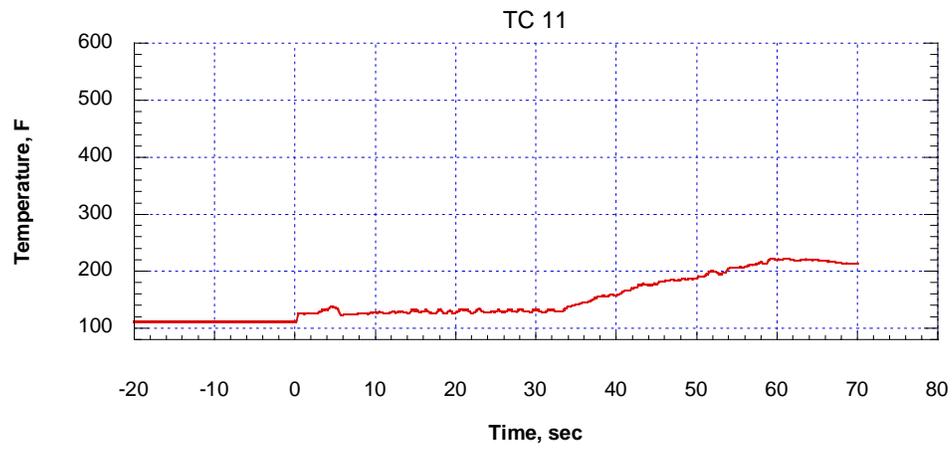
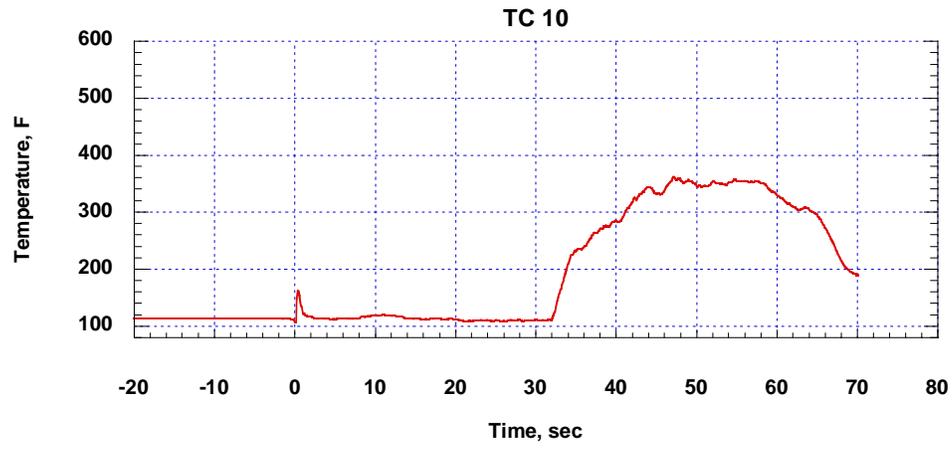
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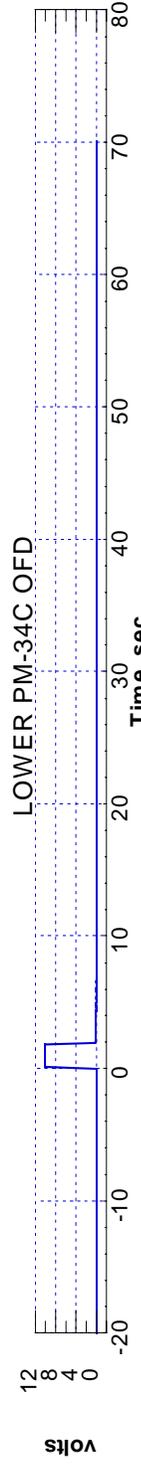
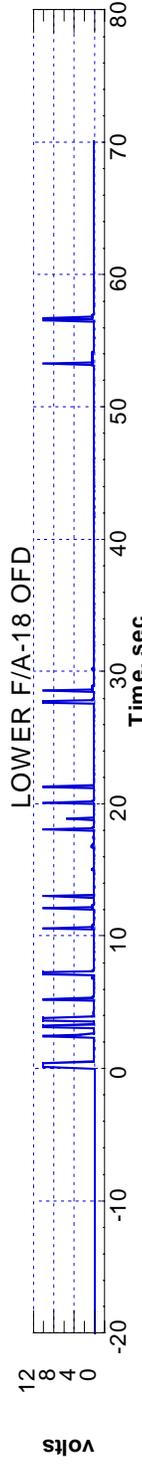
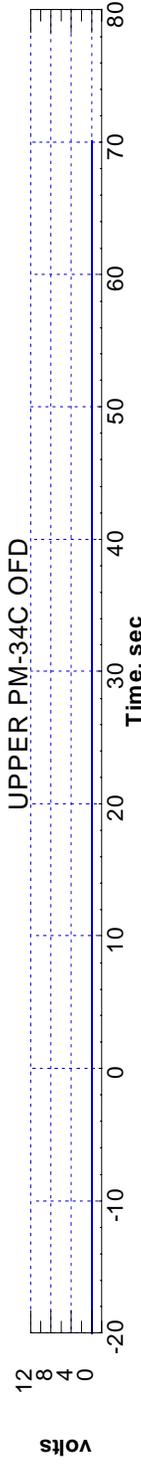
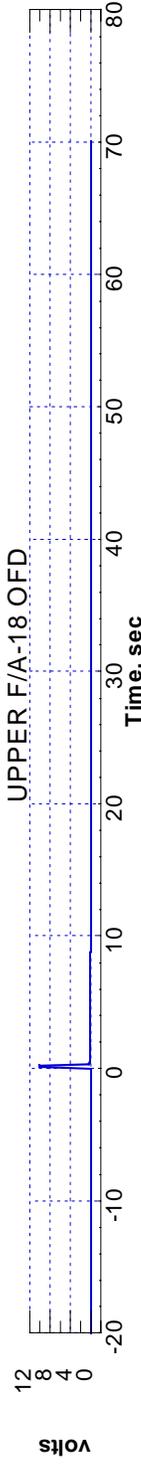
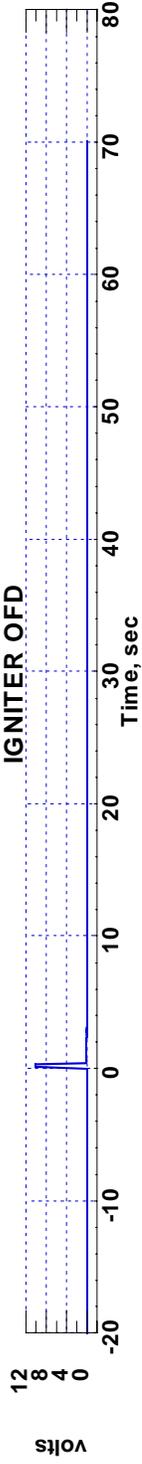
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Temperature vs Time



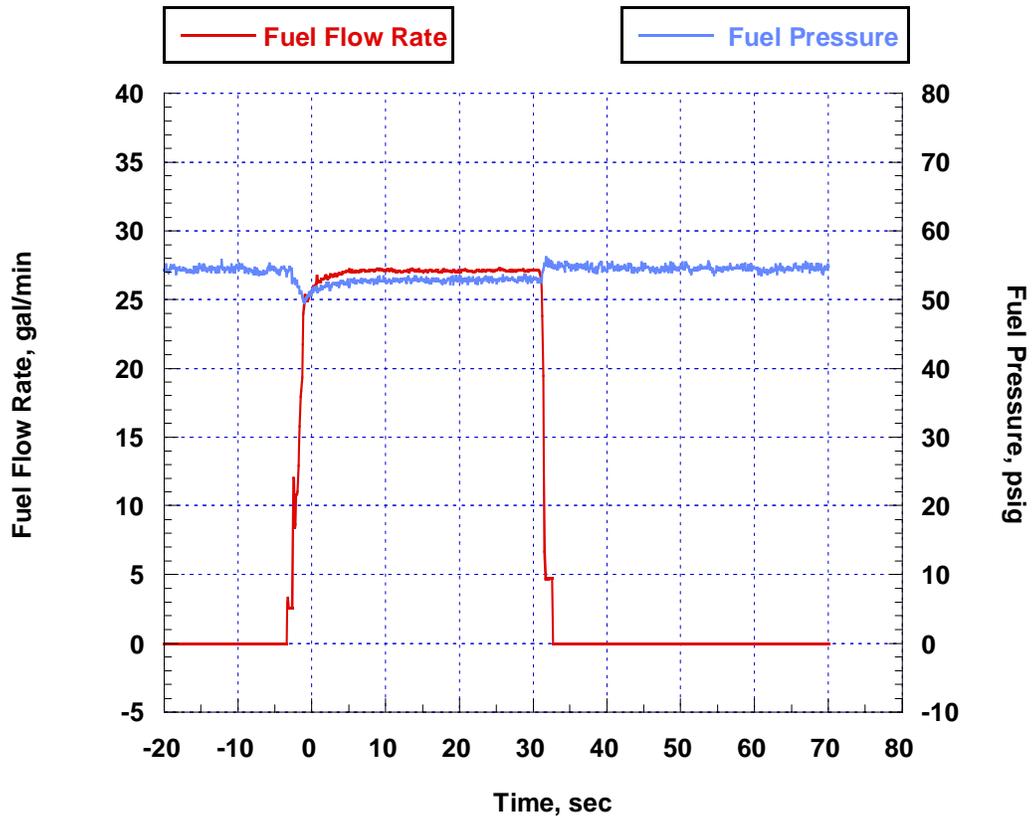
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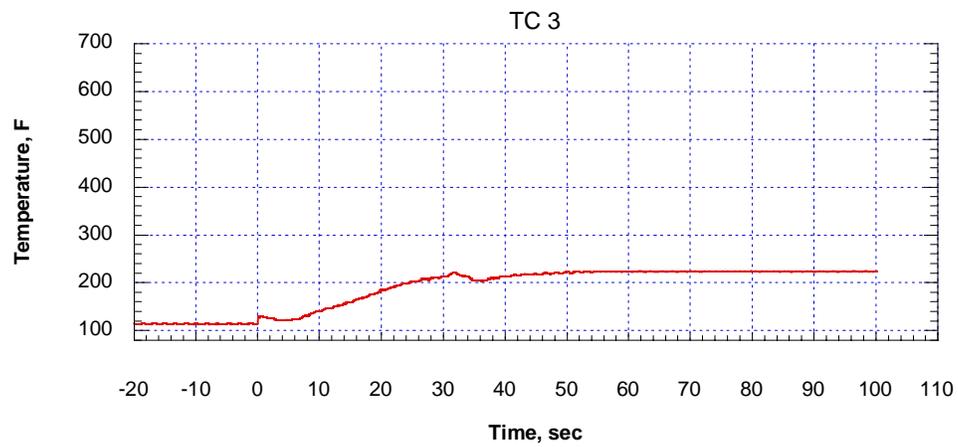
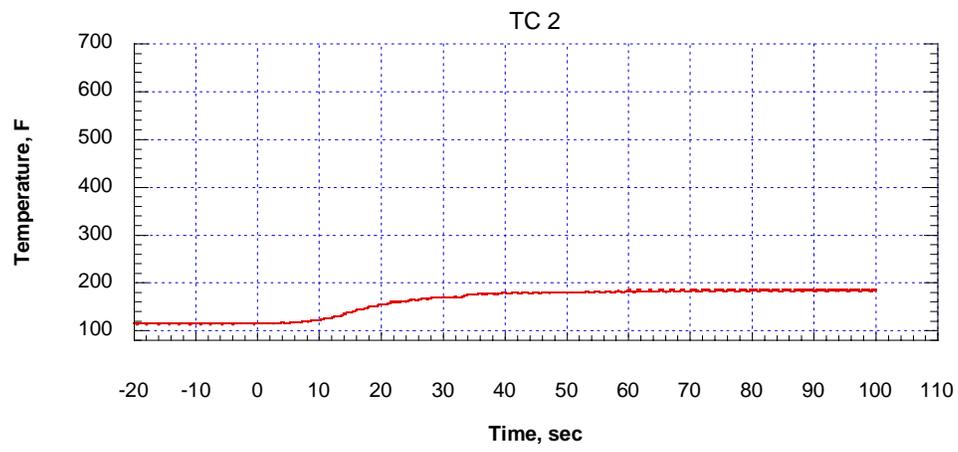
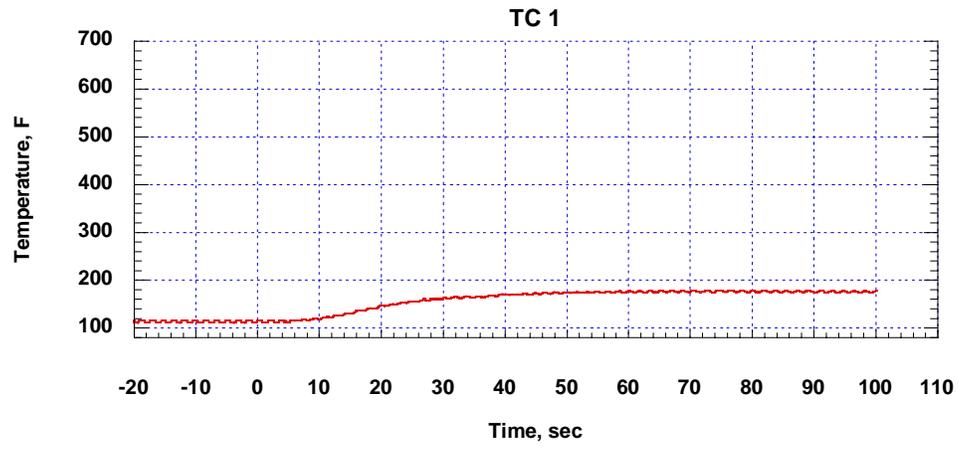
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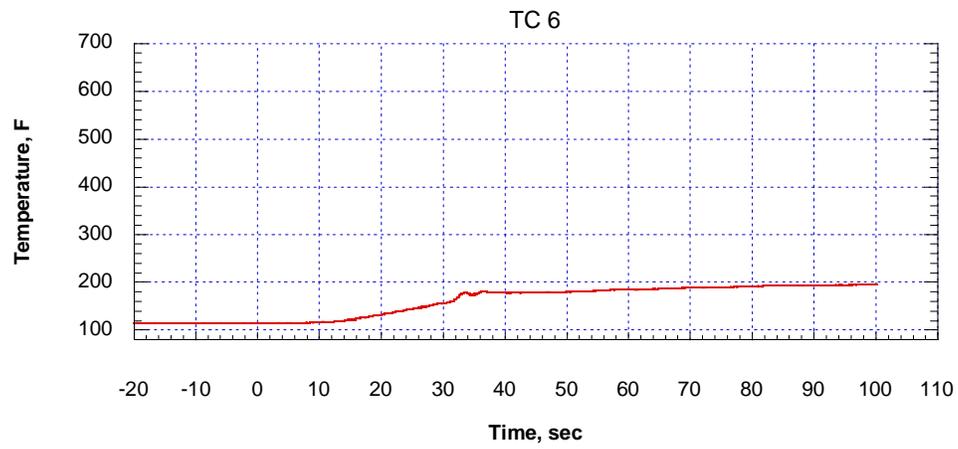
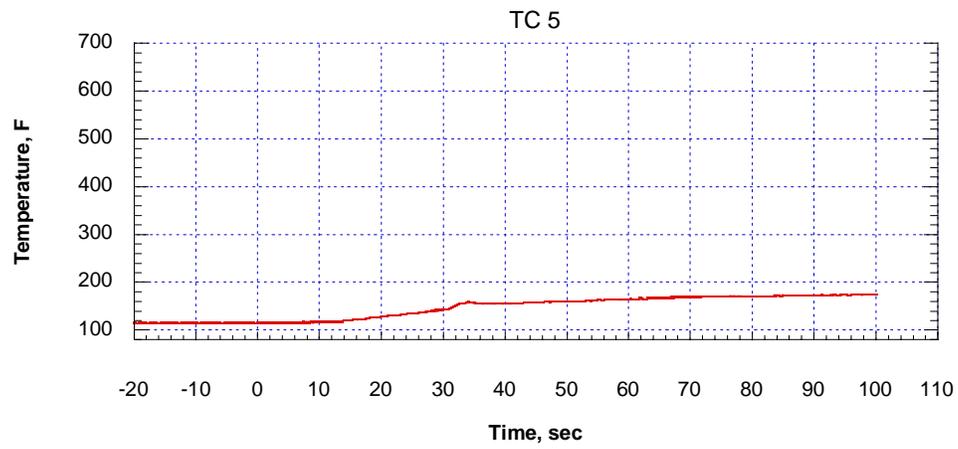
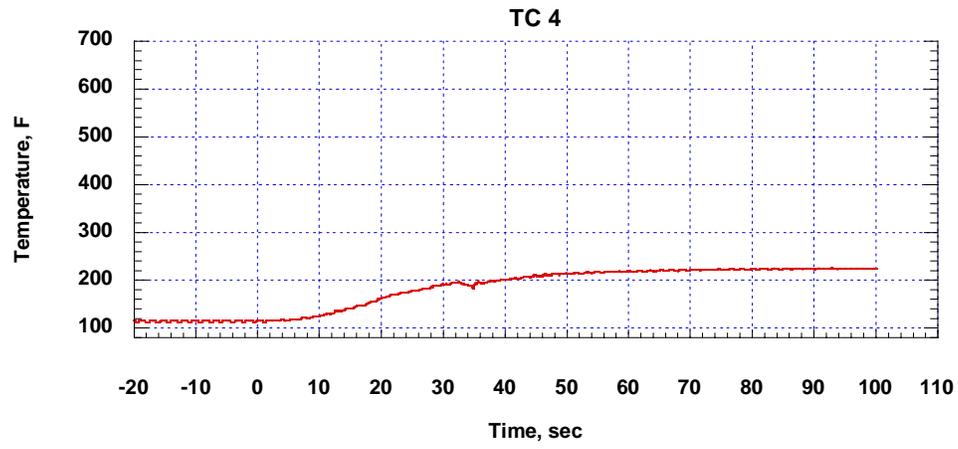
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Fuel Pressure and Flow Rate vs Time



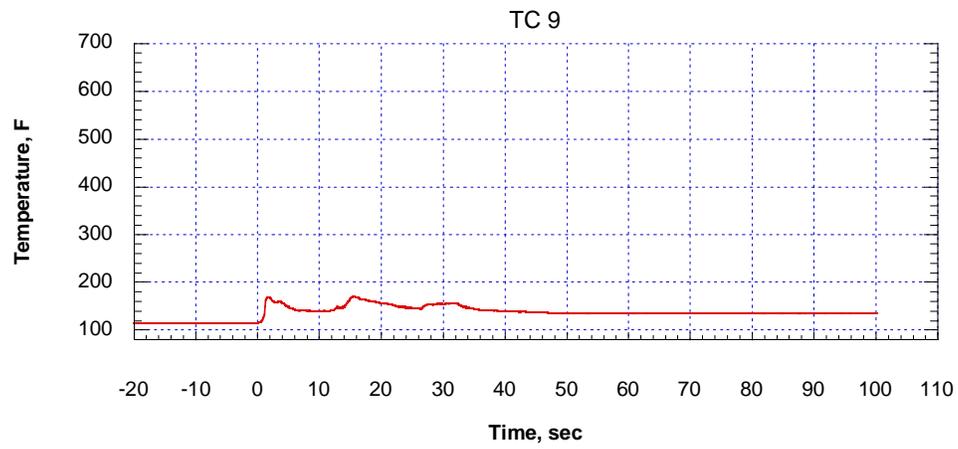
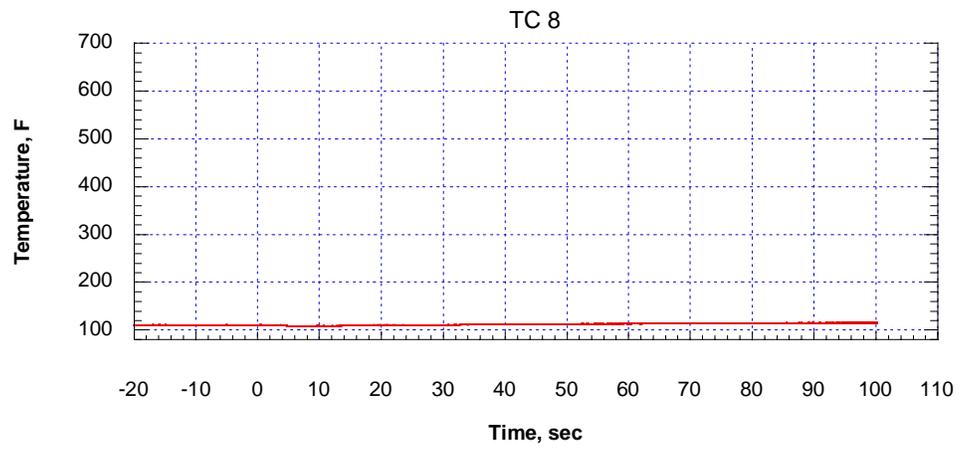
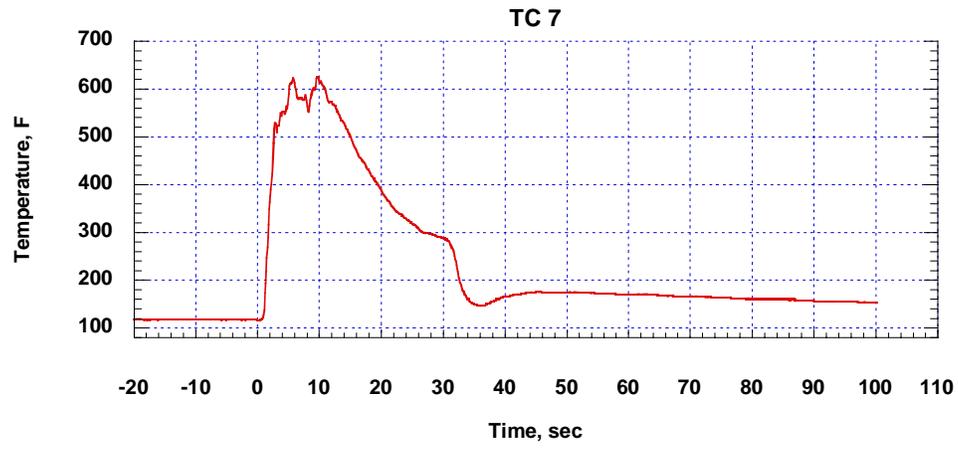
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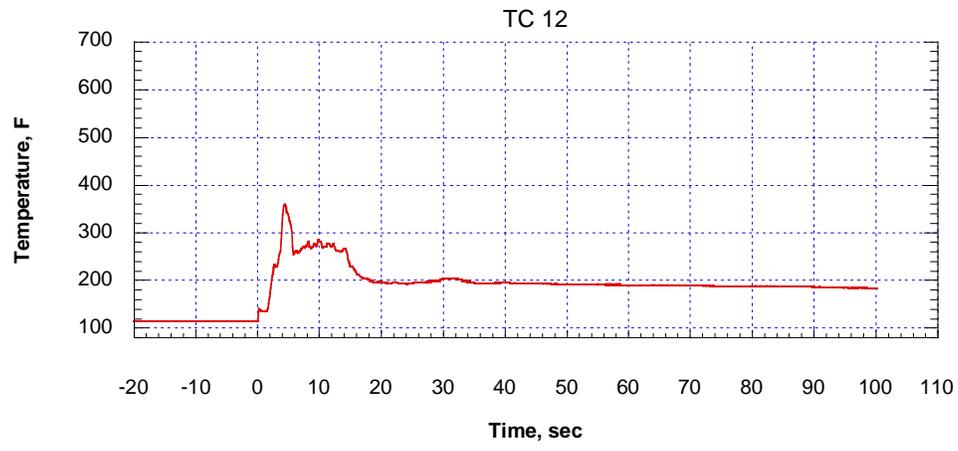
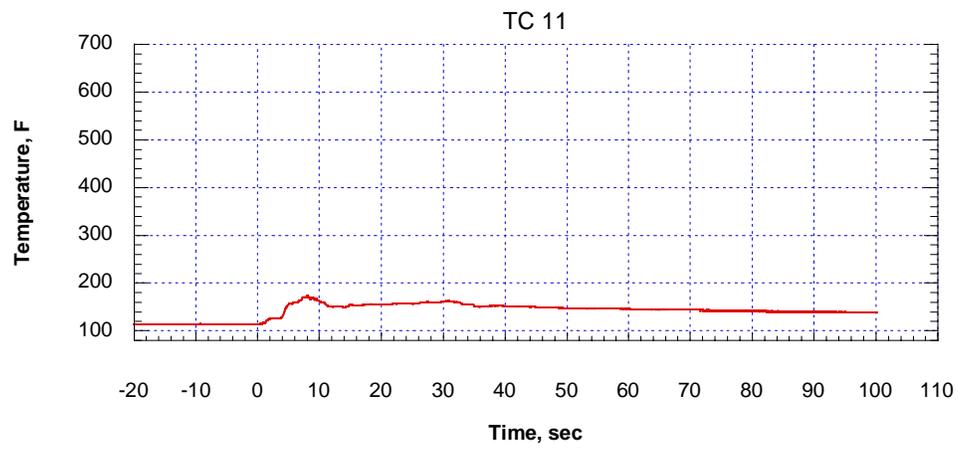
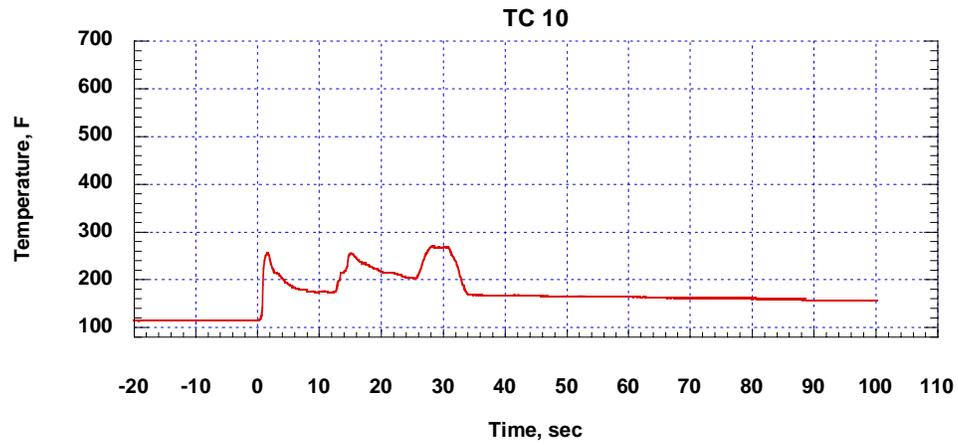
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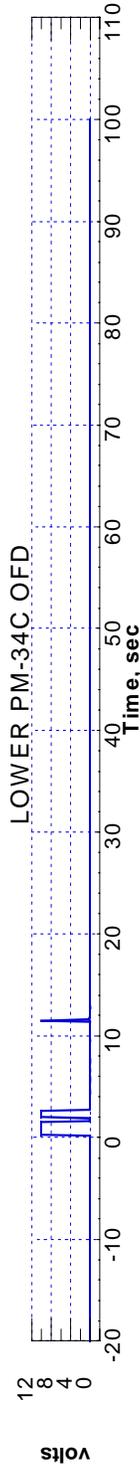
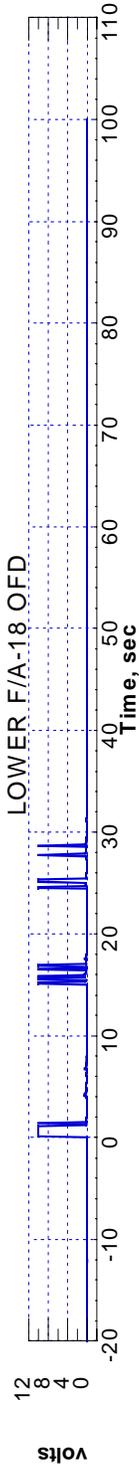
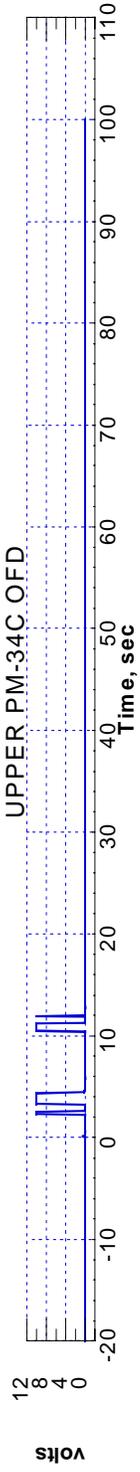
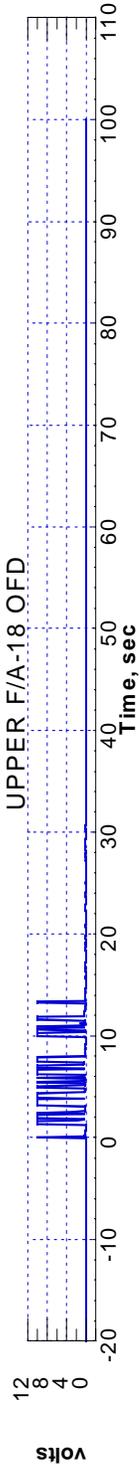
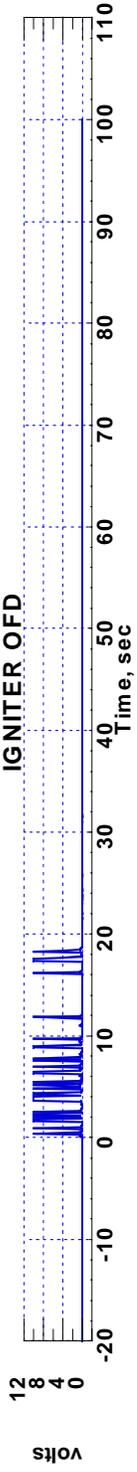
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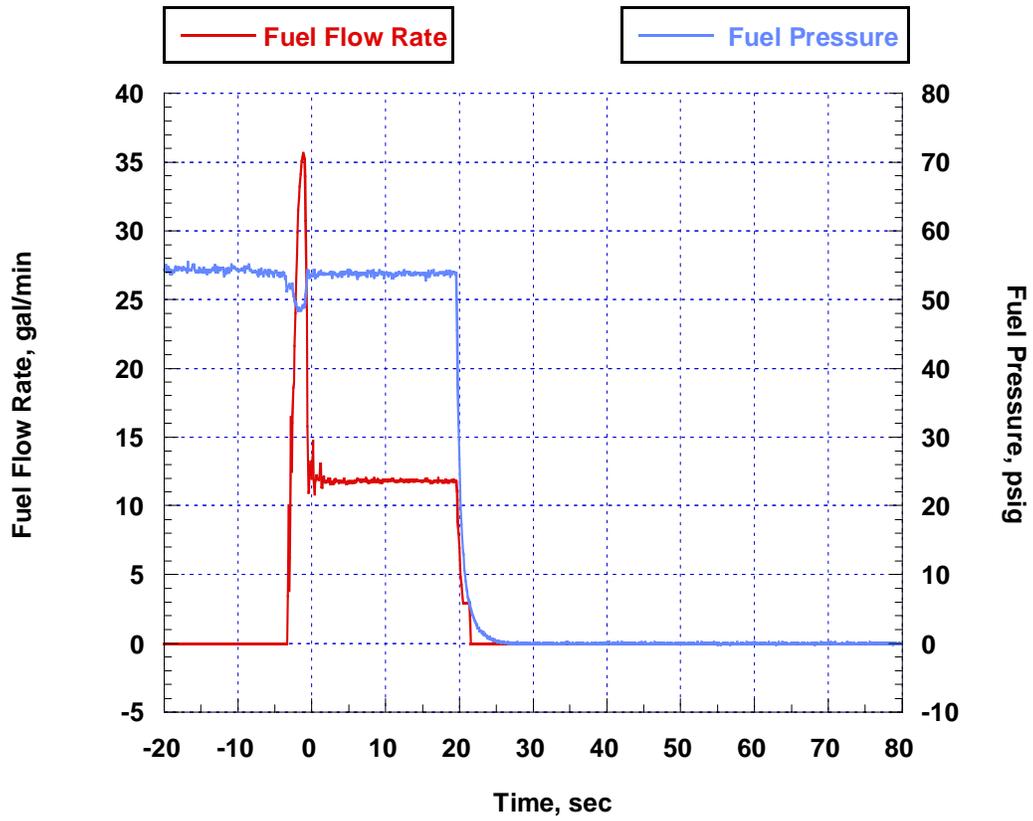
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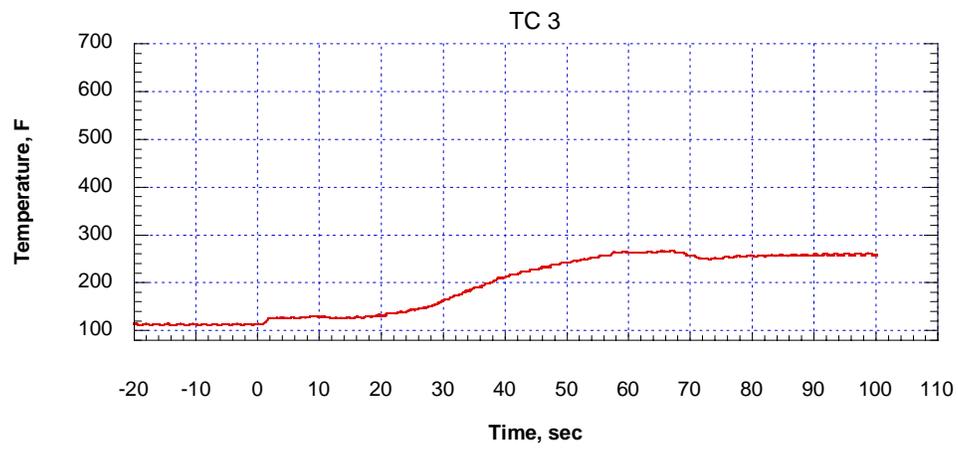
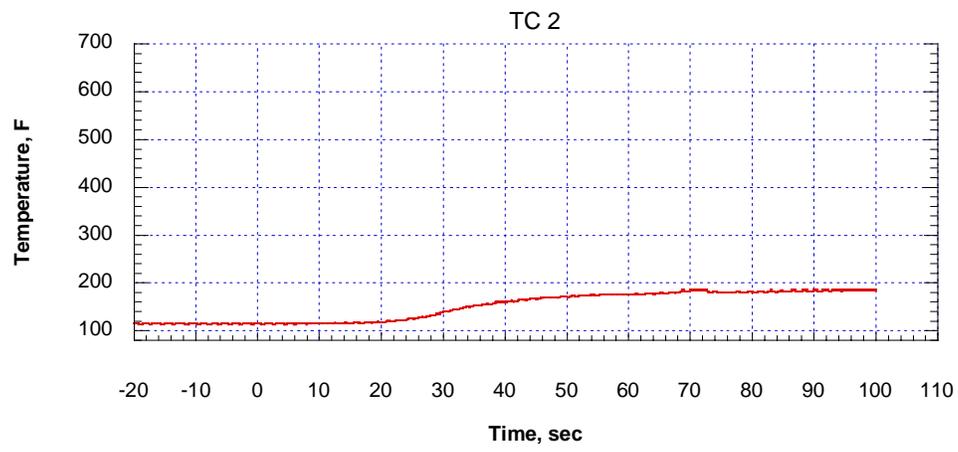
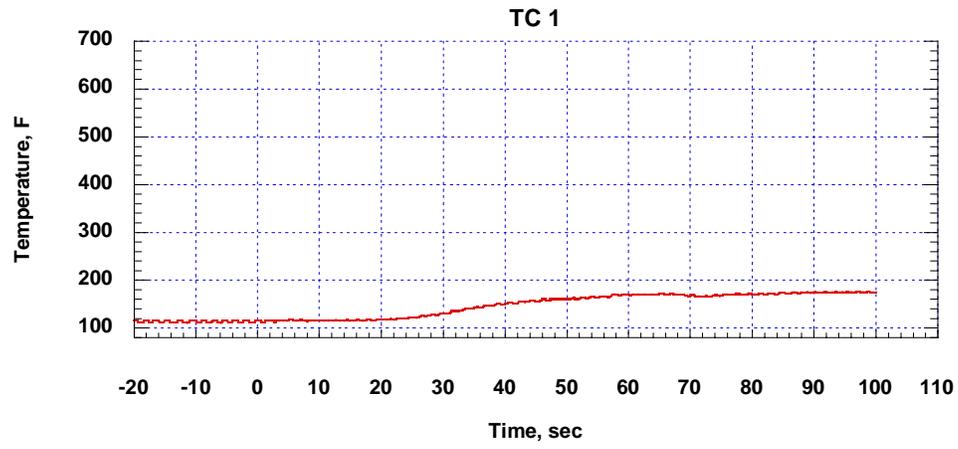
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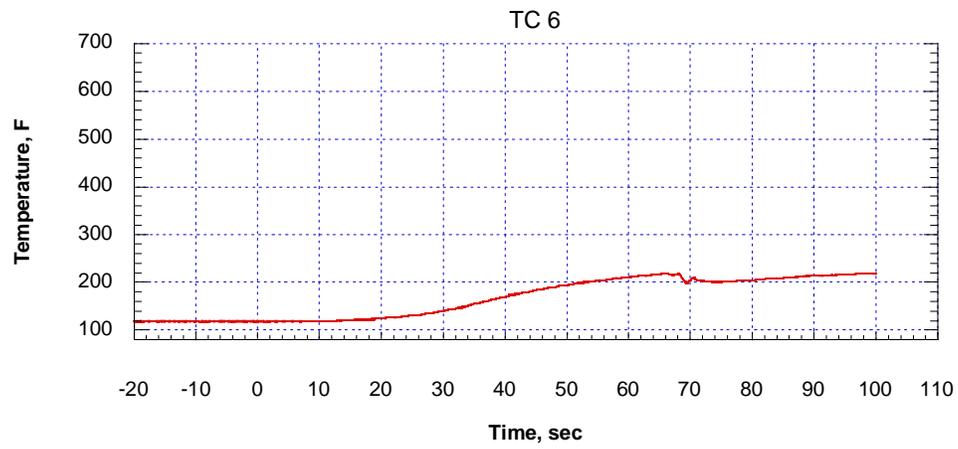
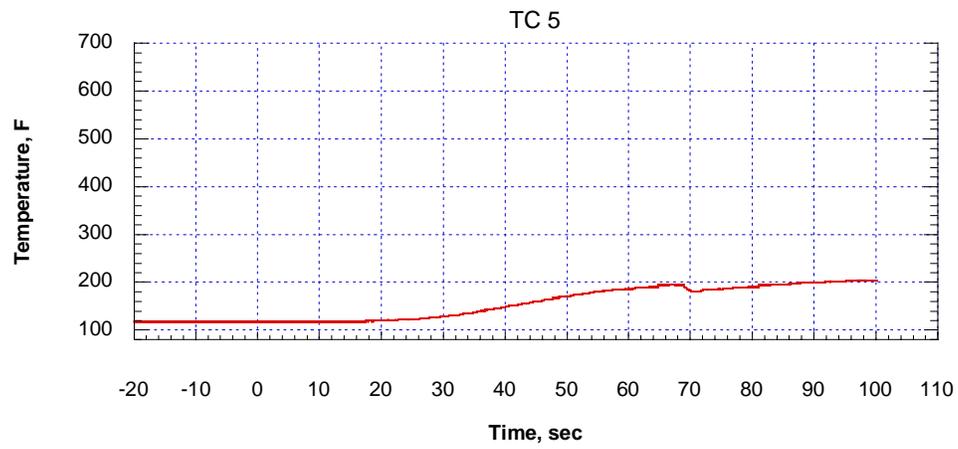
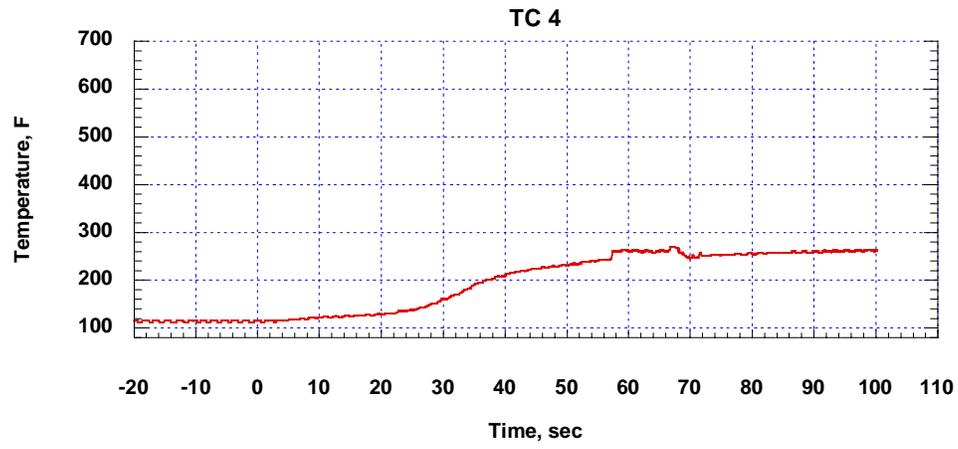
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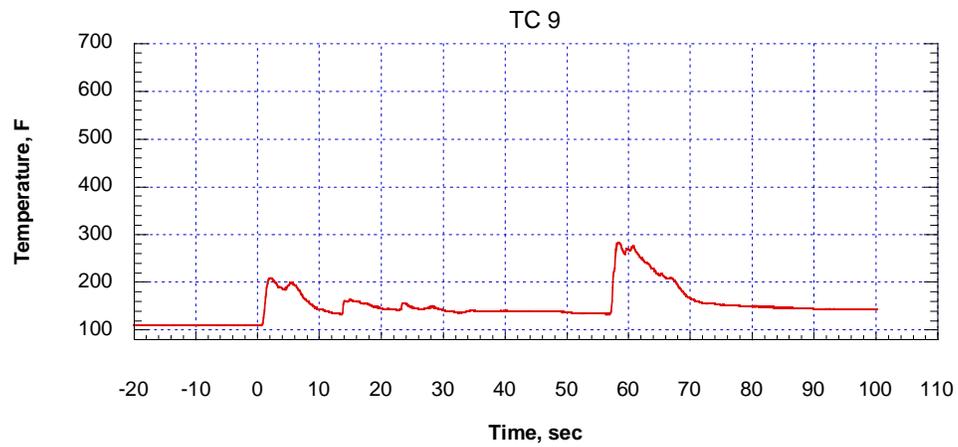
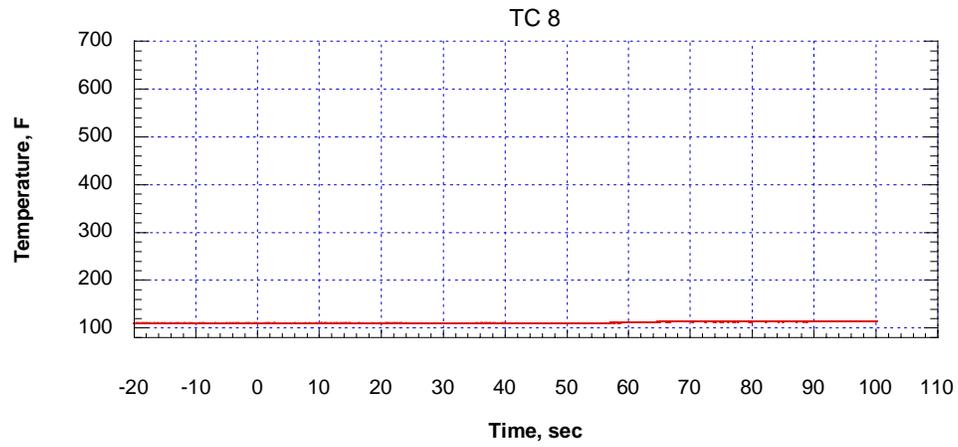
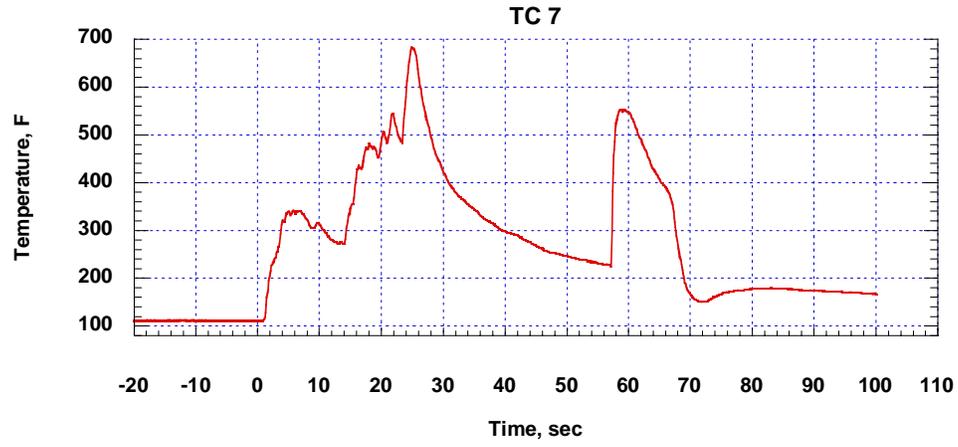
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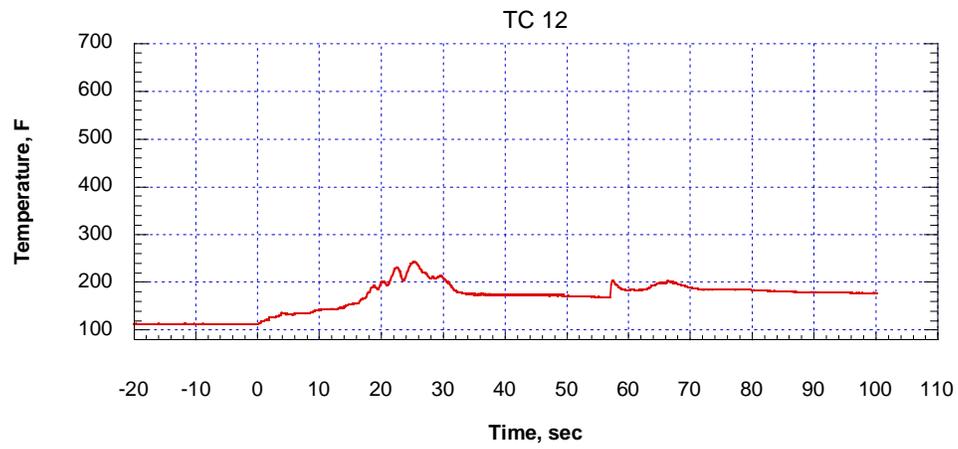
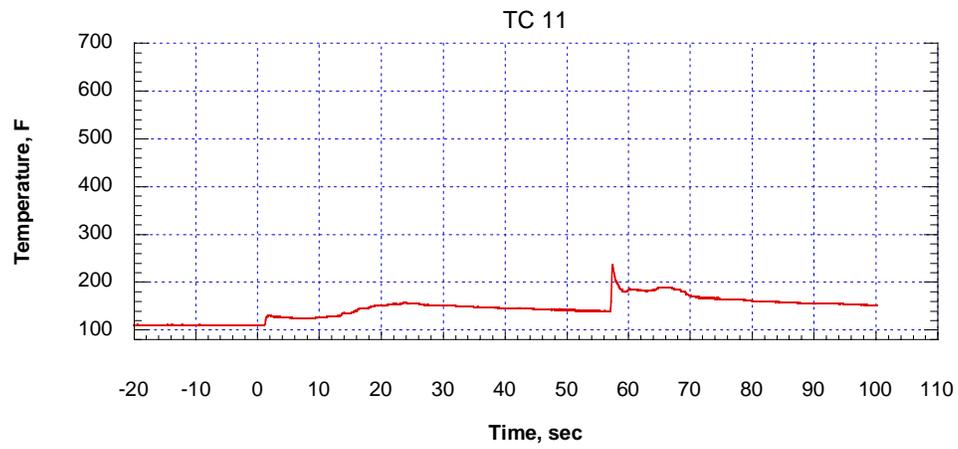
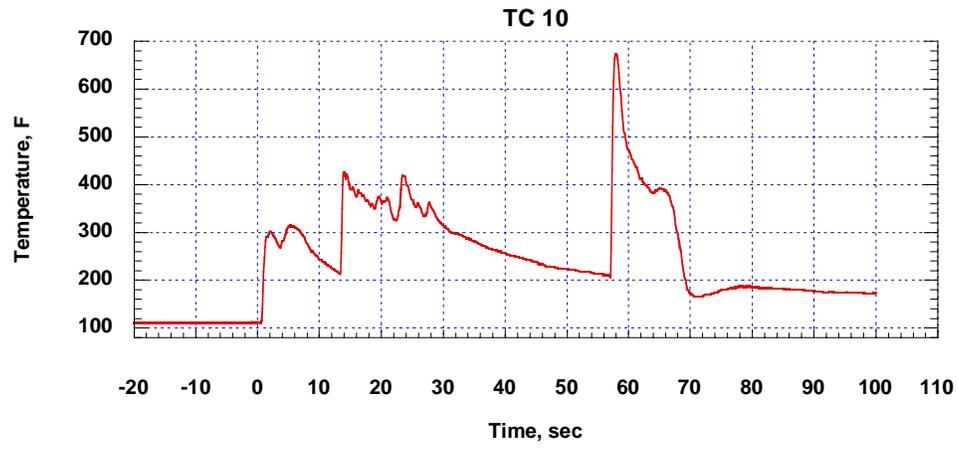
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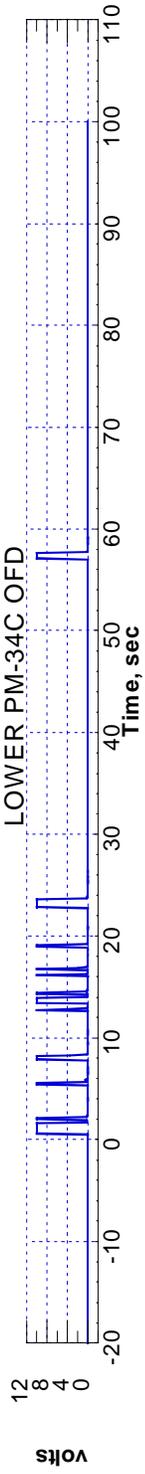
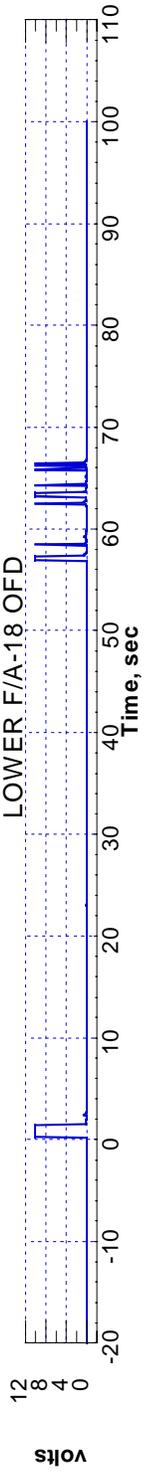
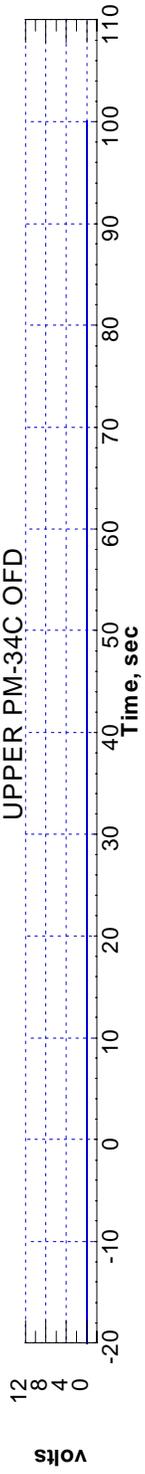
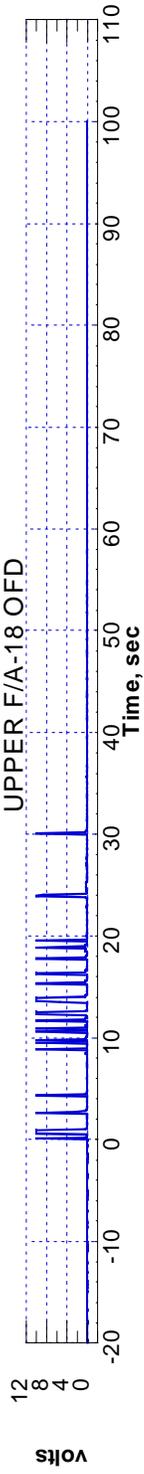
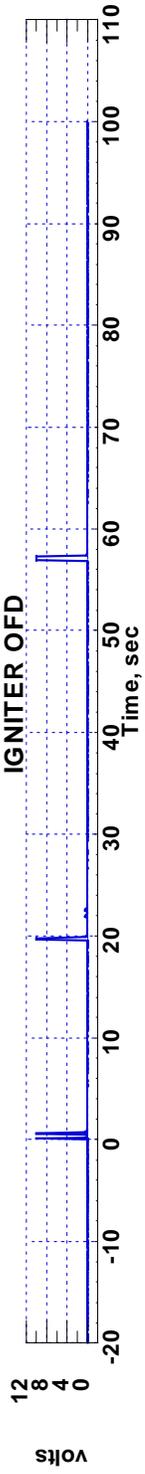
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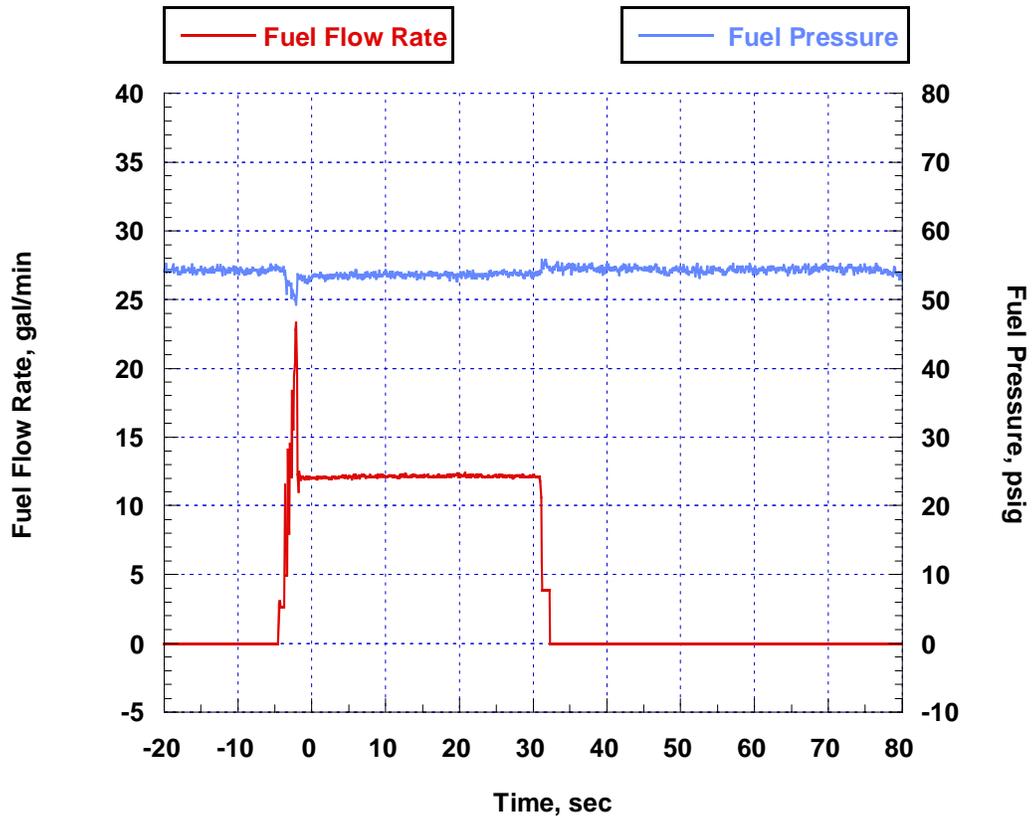
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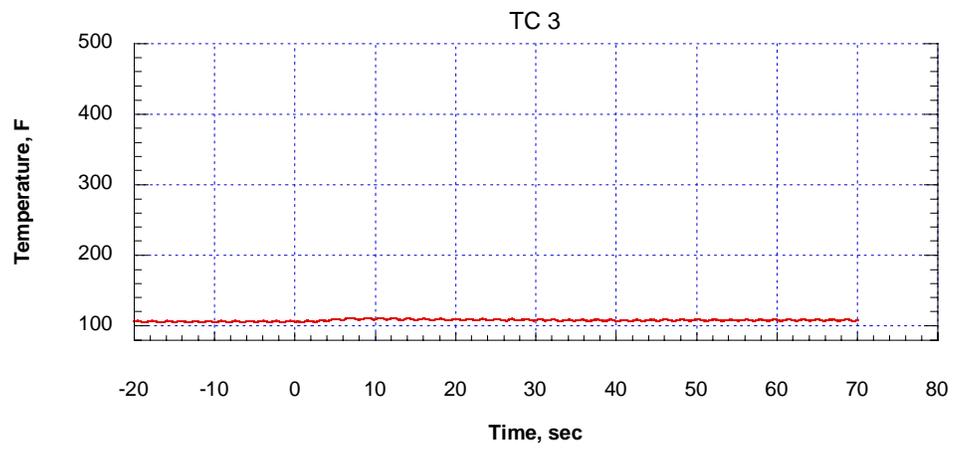
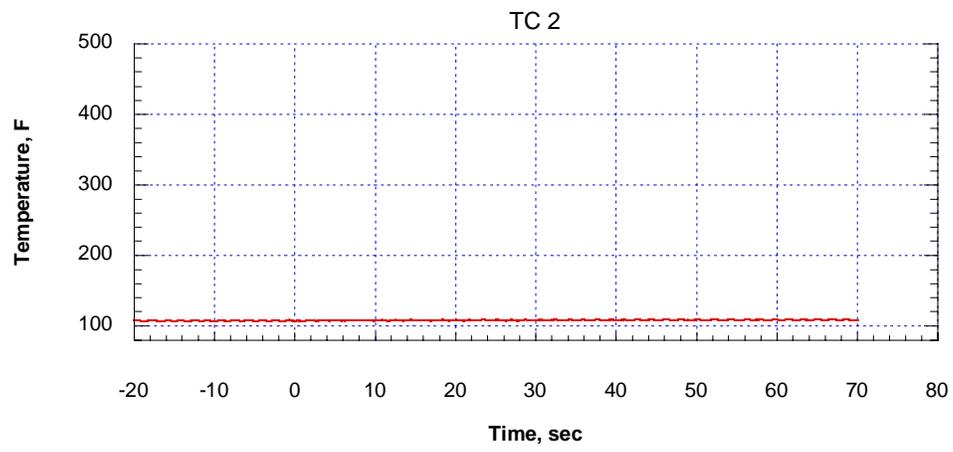
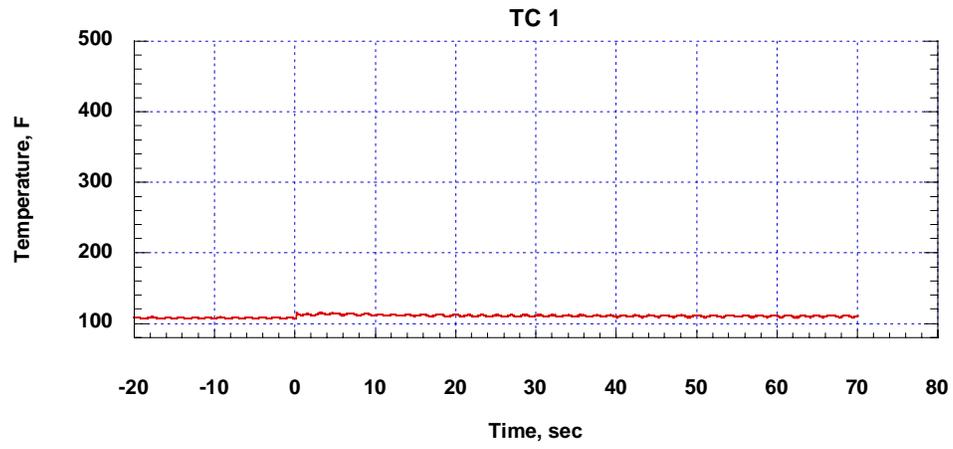
Test 06
Optical Fire Detector Signal vs Time



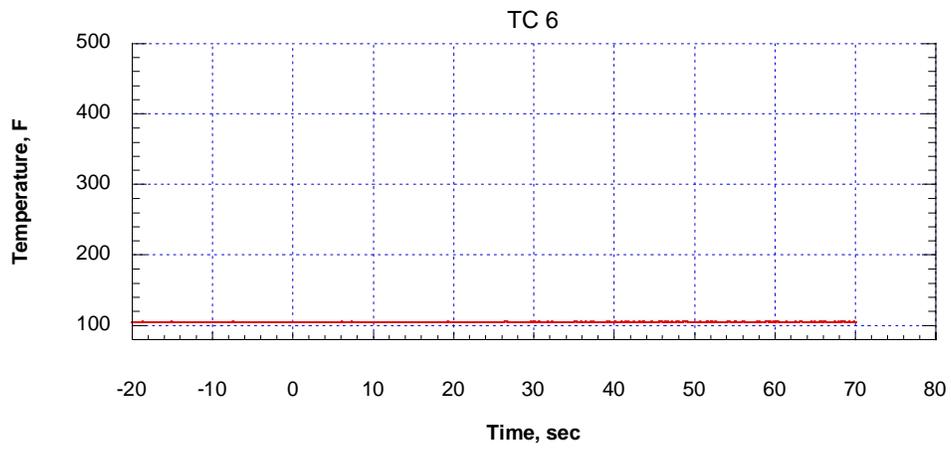
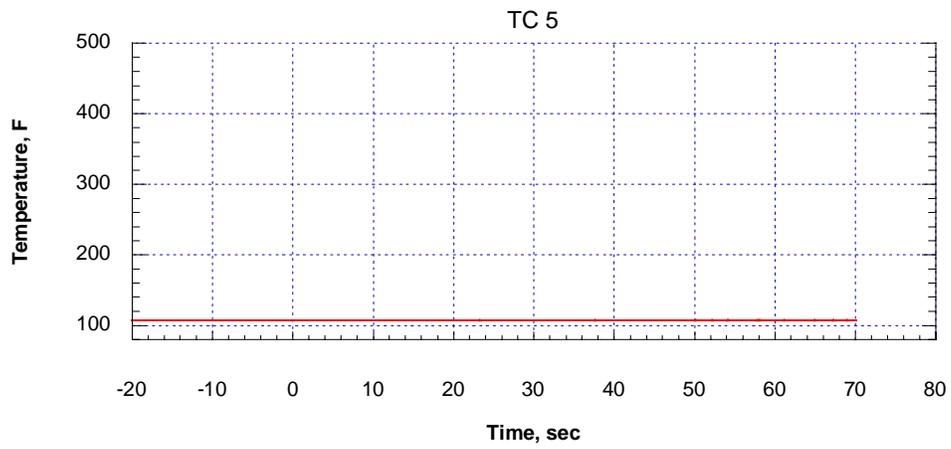
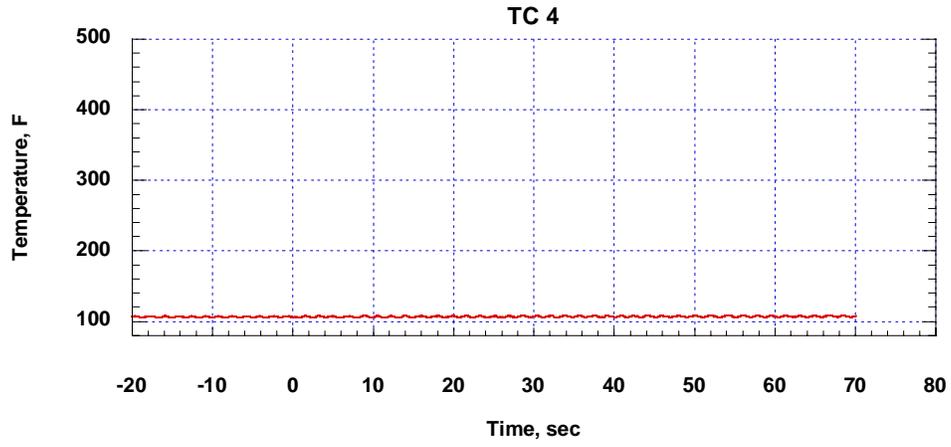
Test 06
Fuel Pressure and Flow Rate vs Time



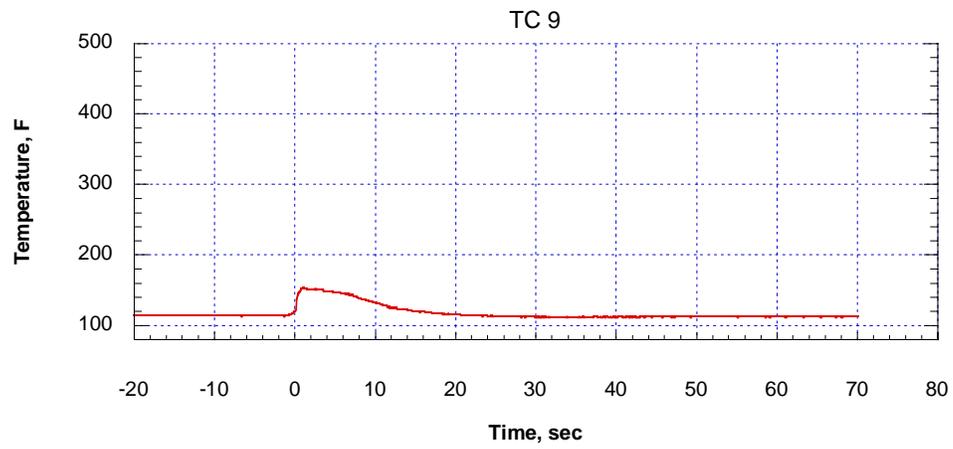
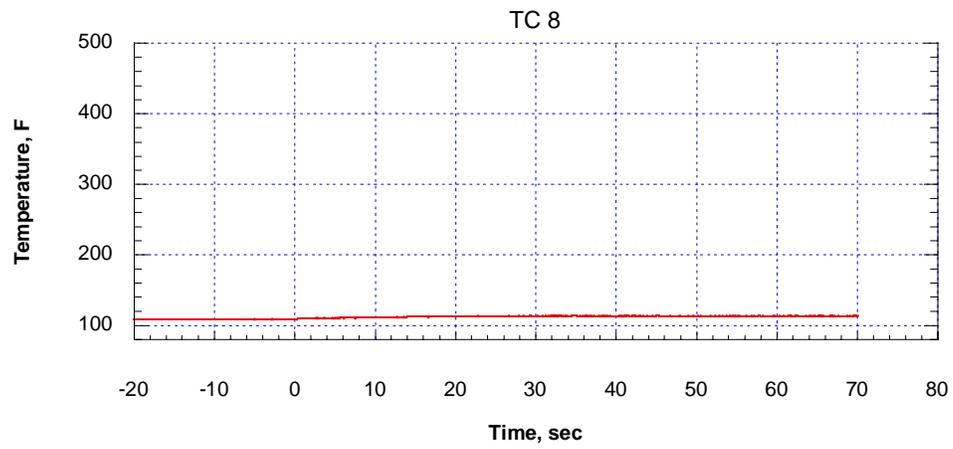
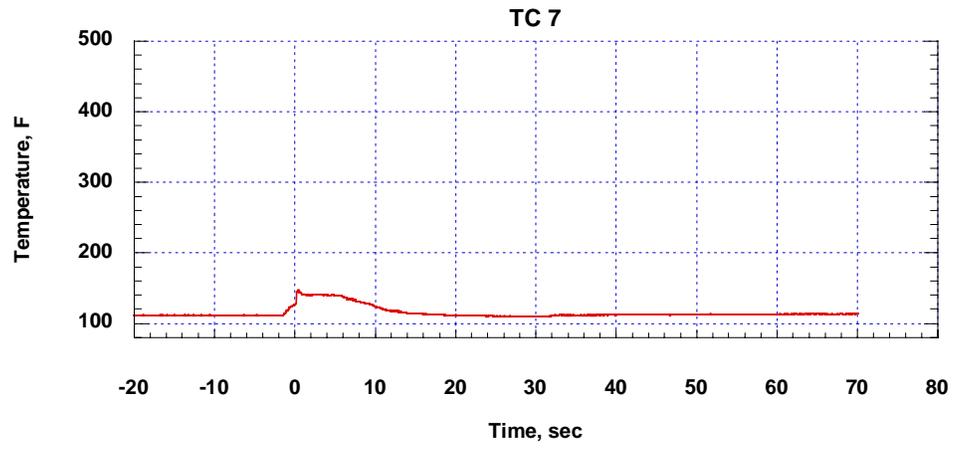
Test 08
Temperature vs Time



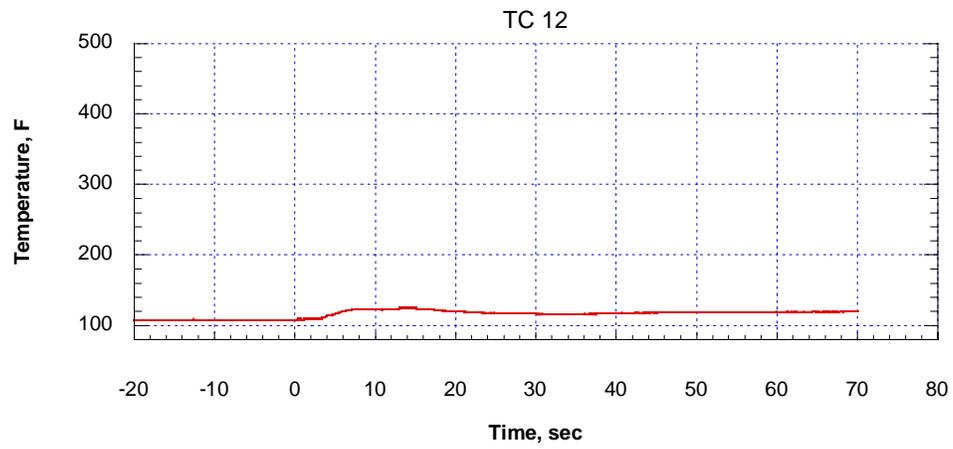
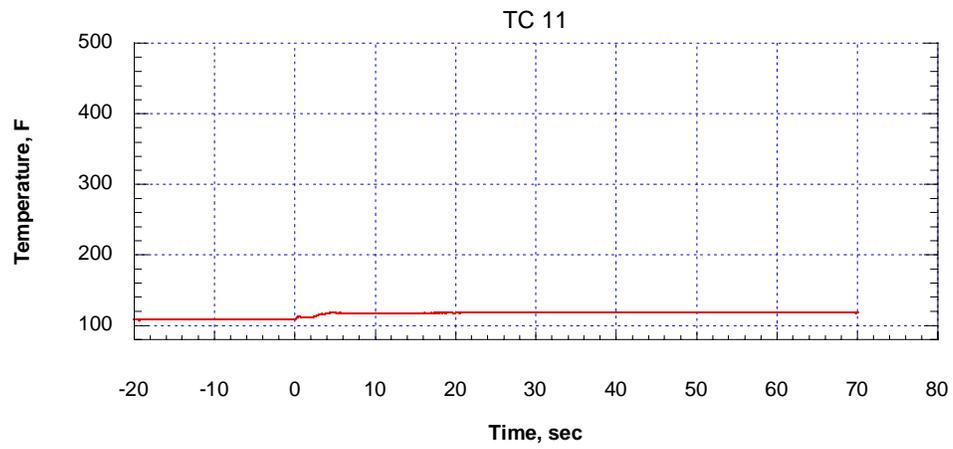
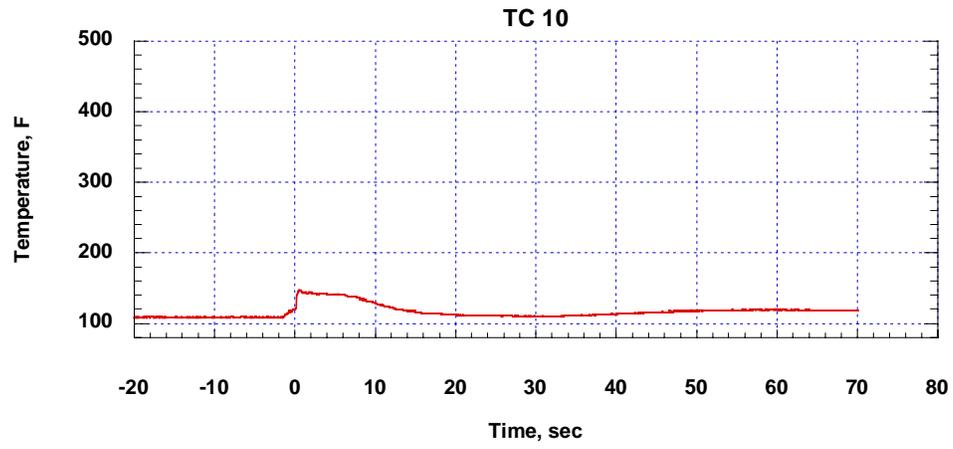
Test 08
Temperature vs Time



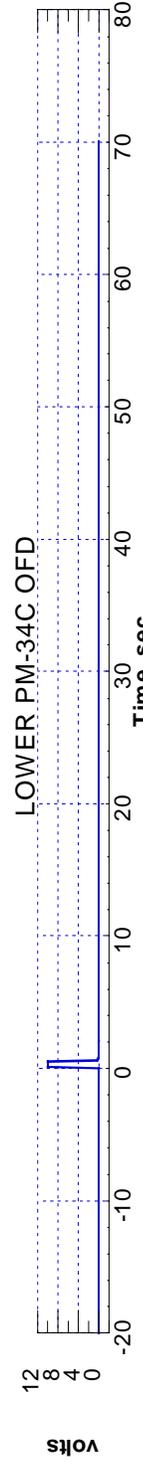
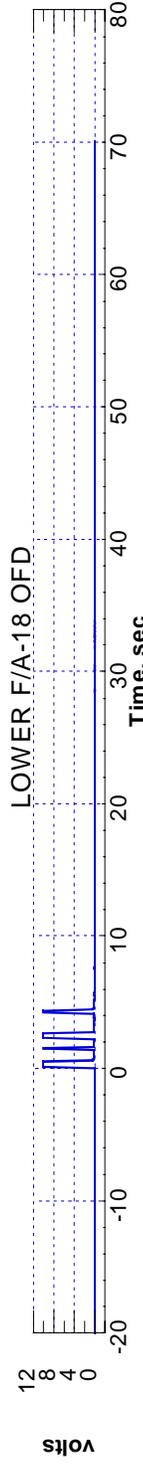
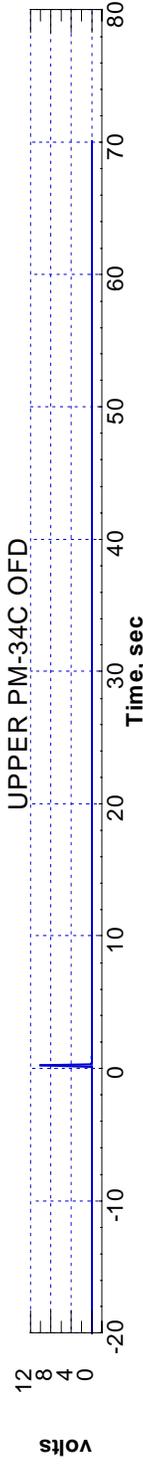
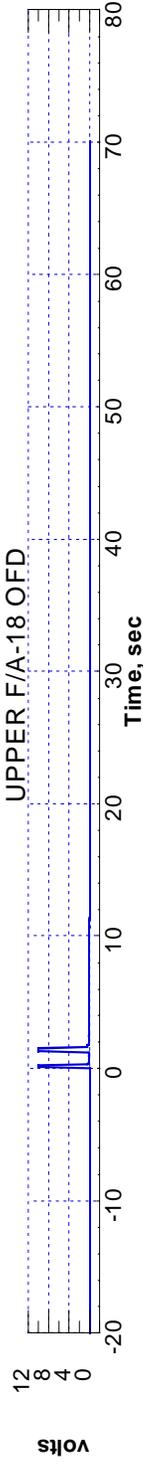
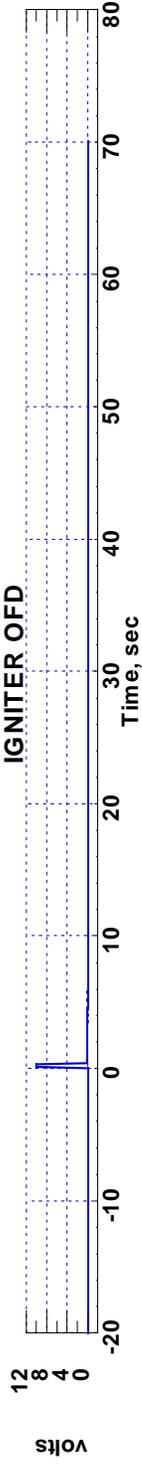
Test 08
Temperature vs Time



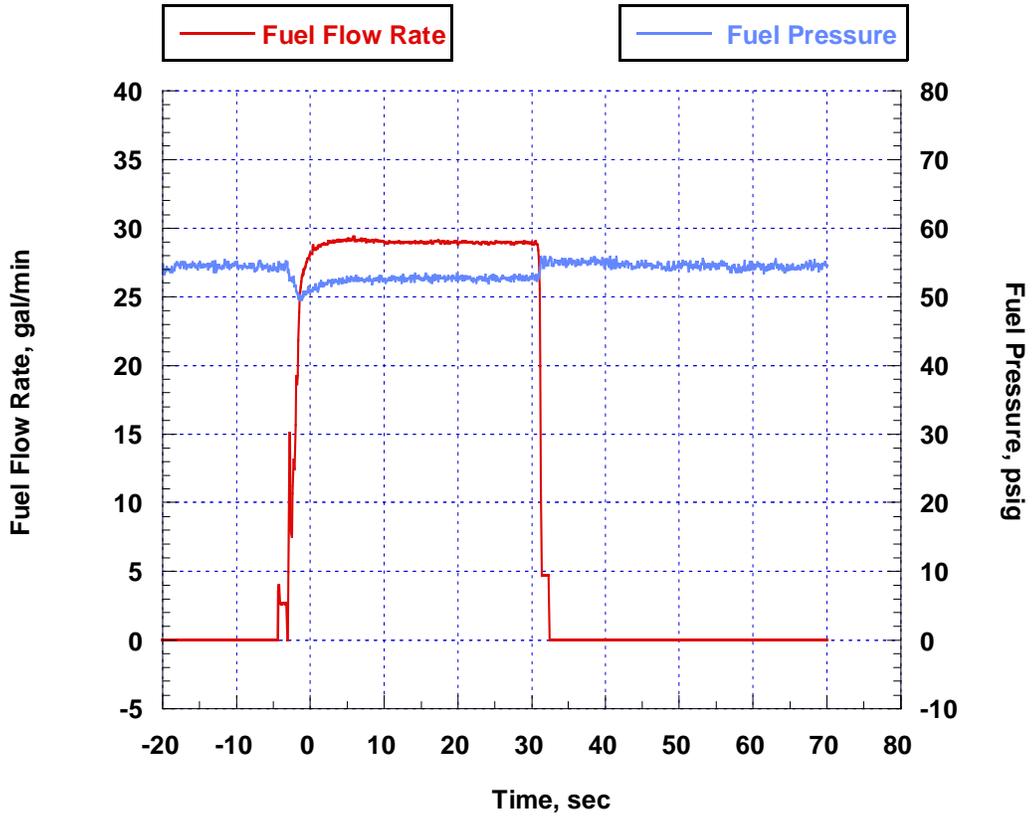
Test 08
Temperature vs Time



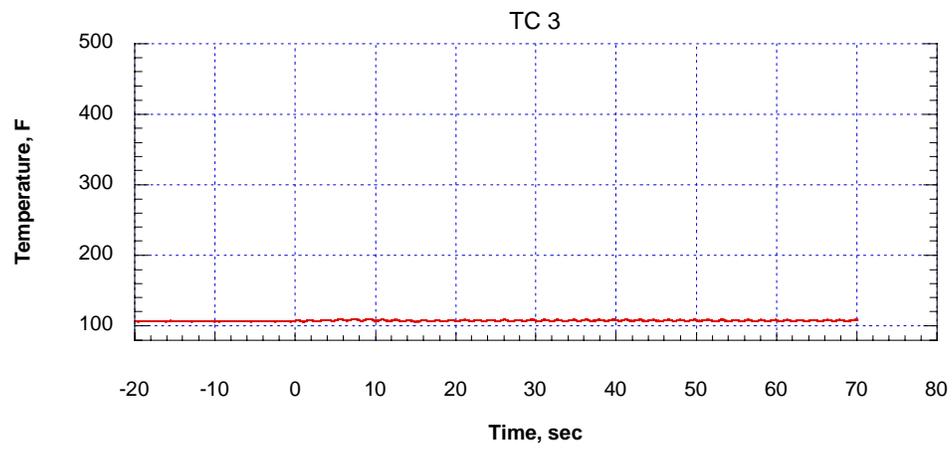
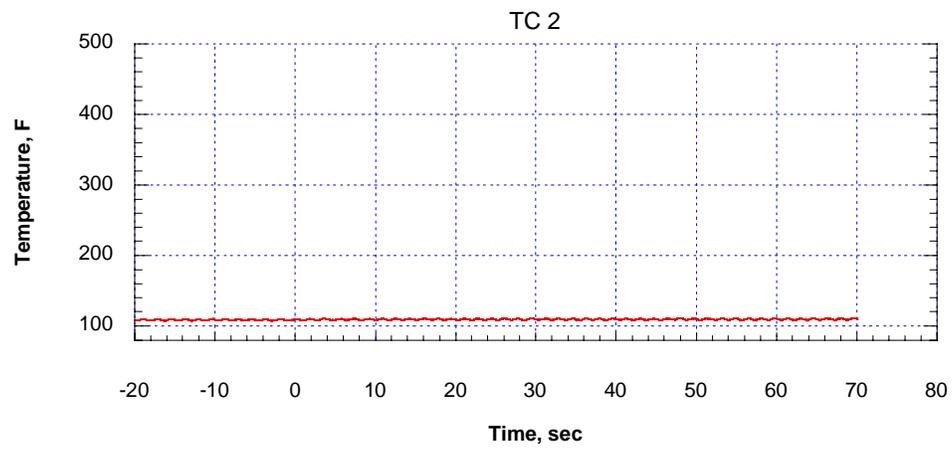
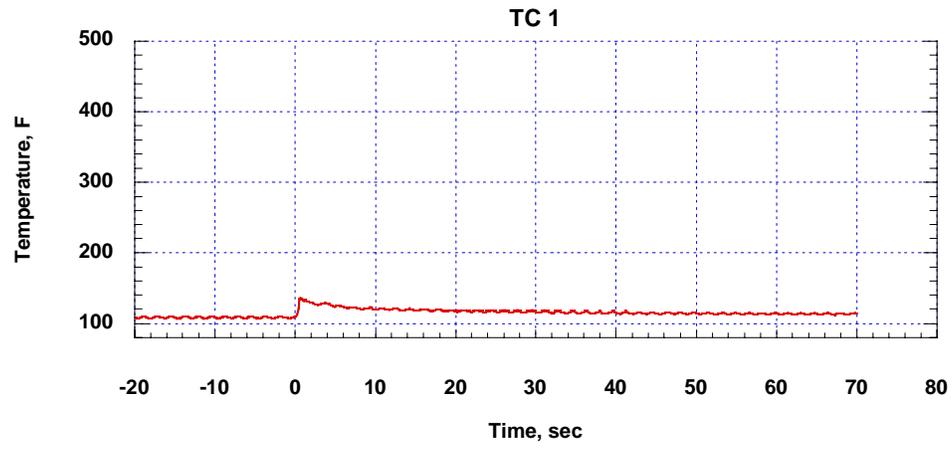
Test 08
Optical Fire Detector Signal vs Time



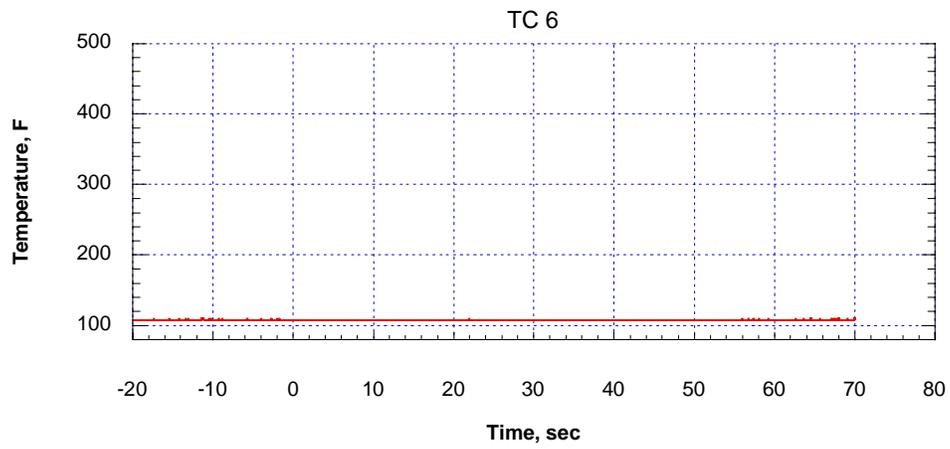
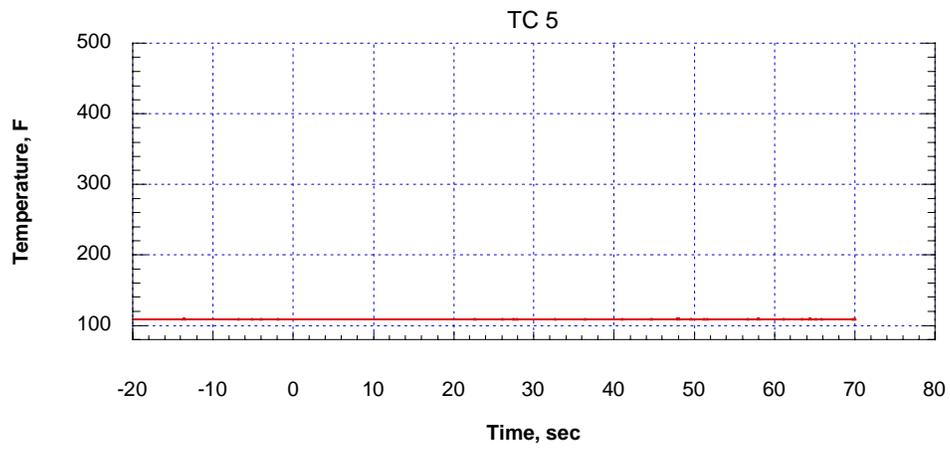
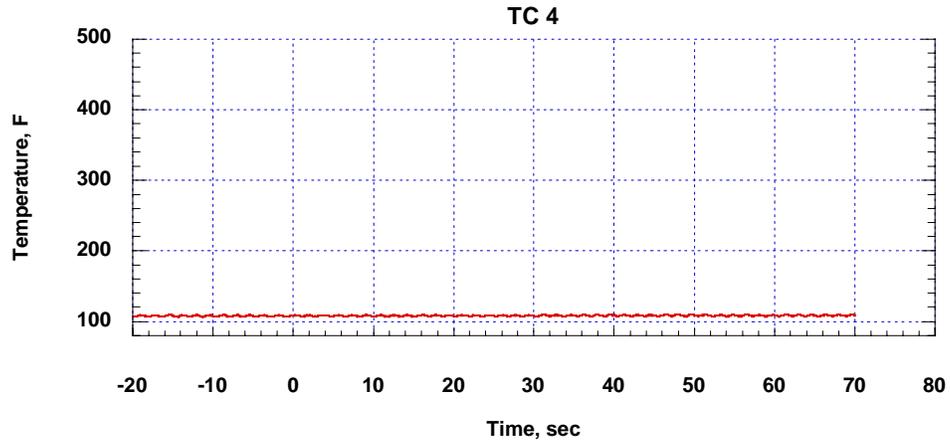
Test 08
Fuel Pressure and Flow Rate vs Time



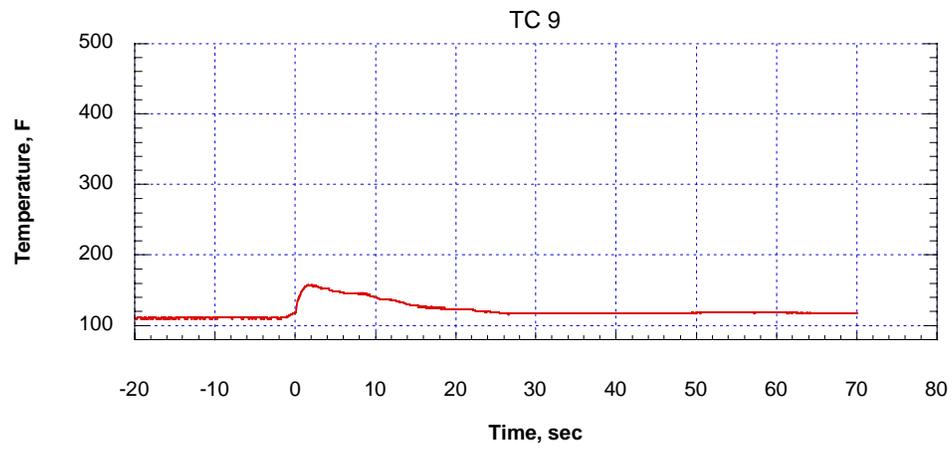
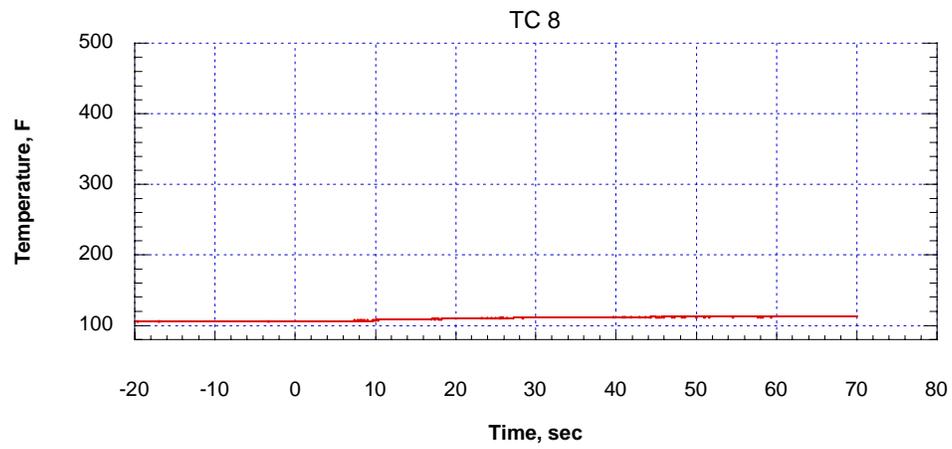
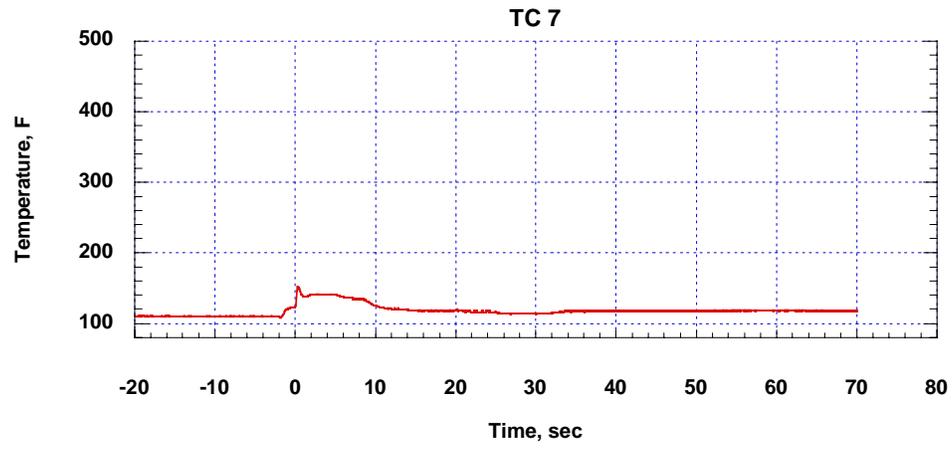
Test 09
Temperature vs Time



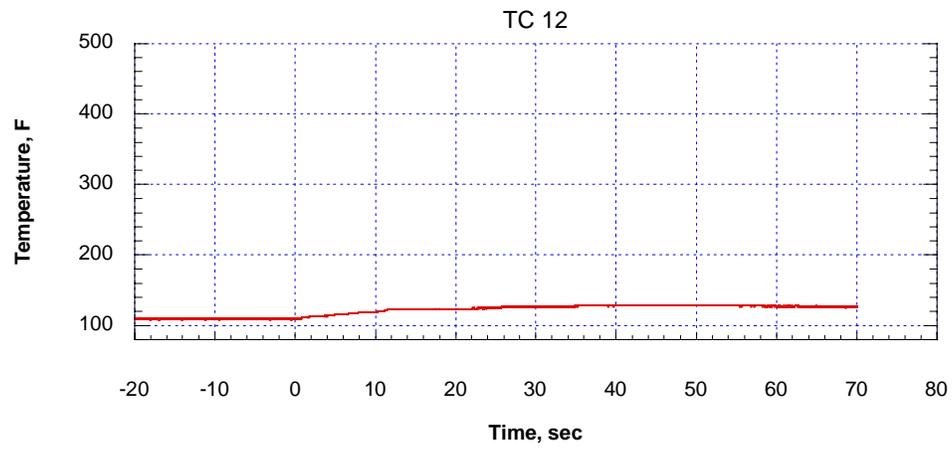
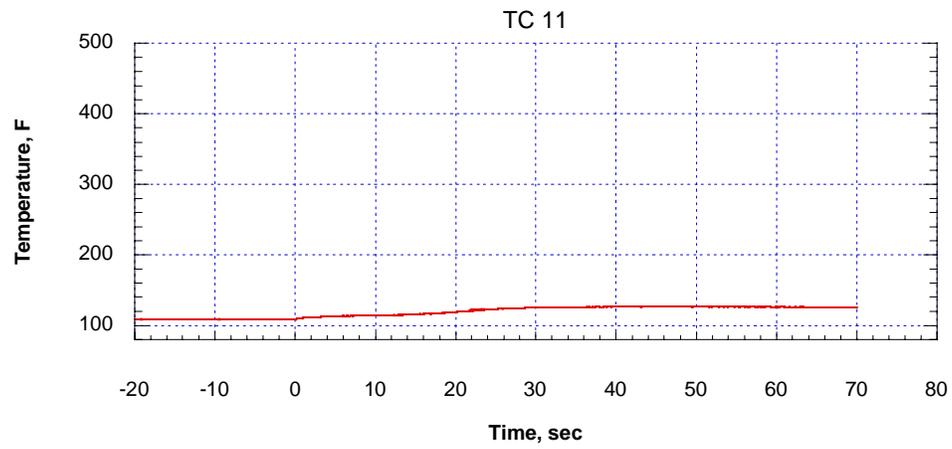
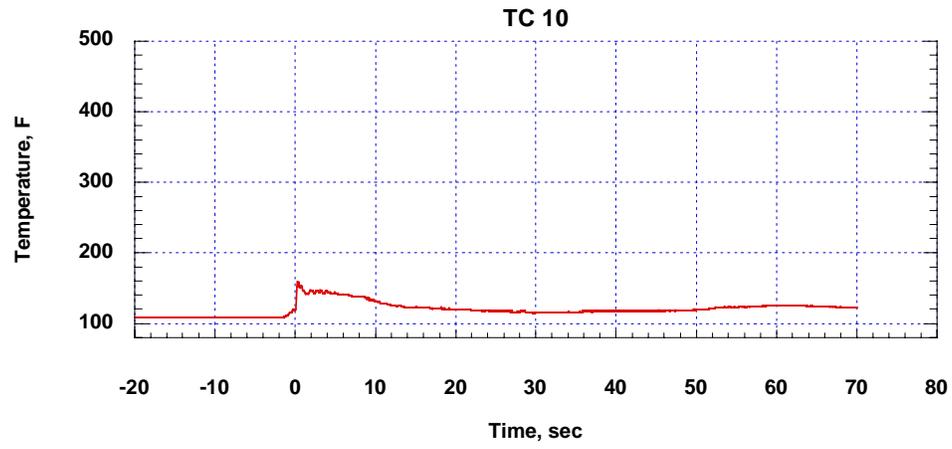
Test 09
Temperature vs Time



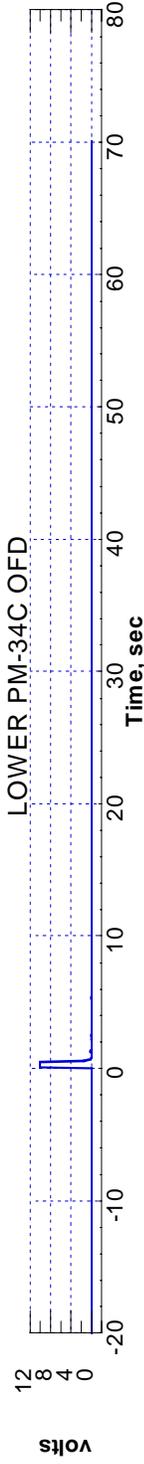
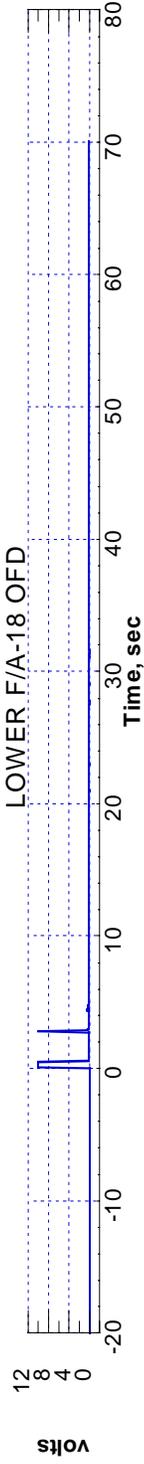
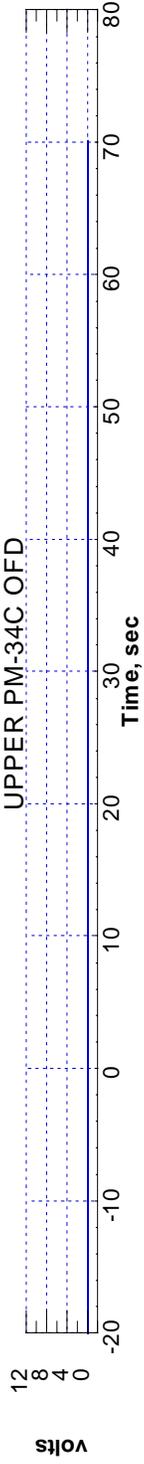
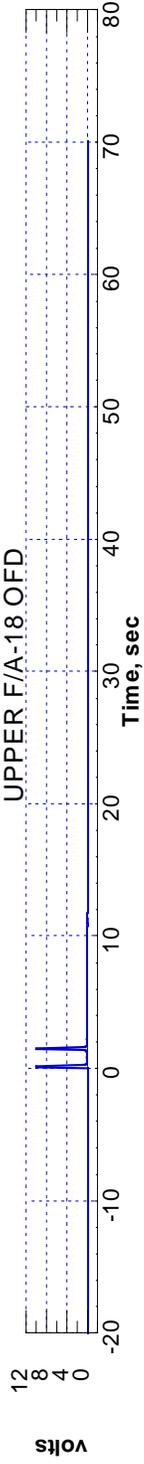
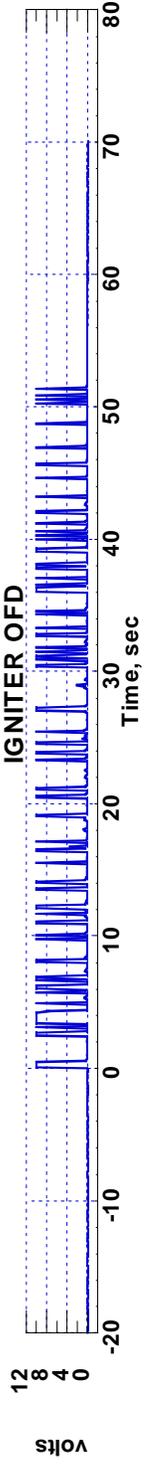
Test 09
Temperature vs Time



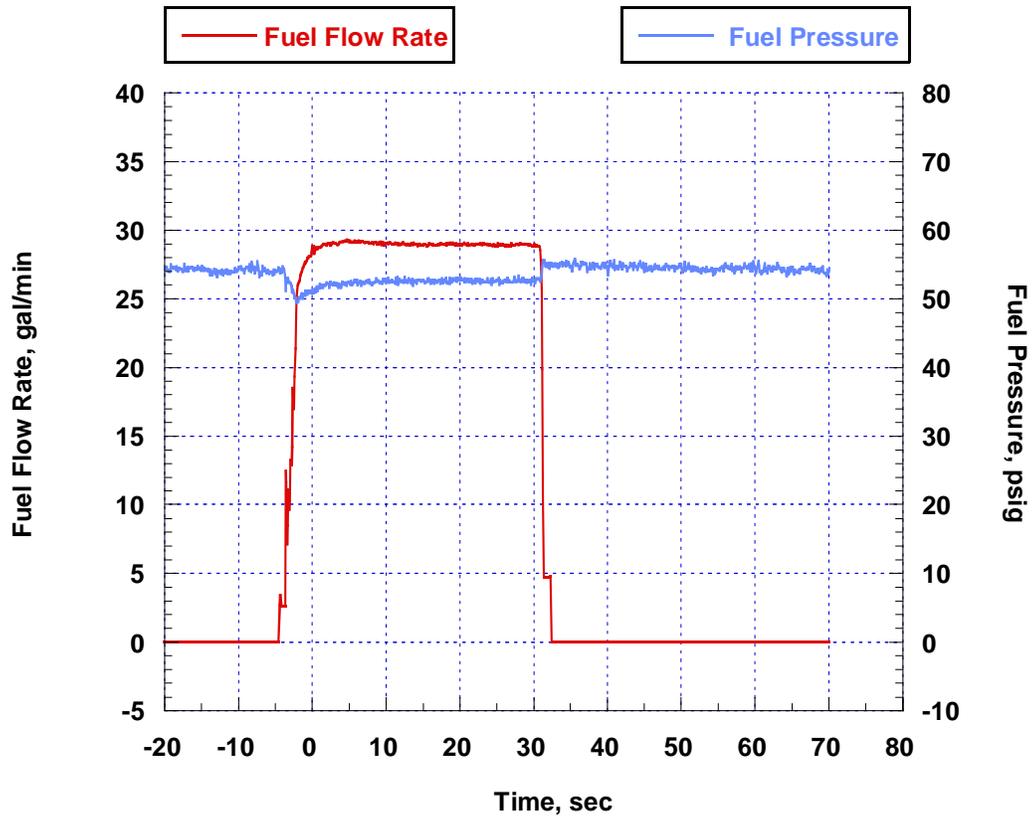
Test 09
Temperature vs Time



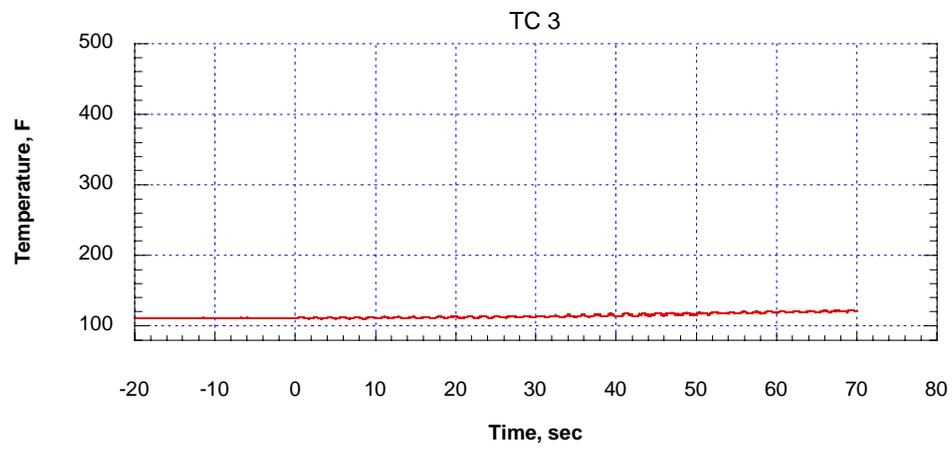
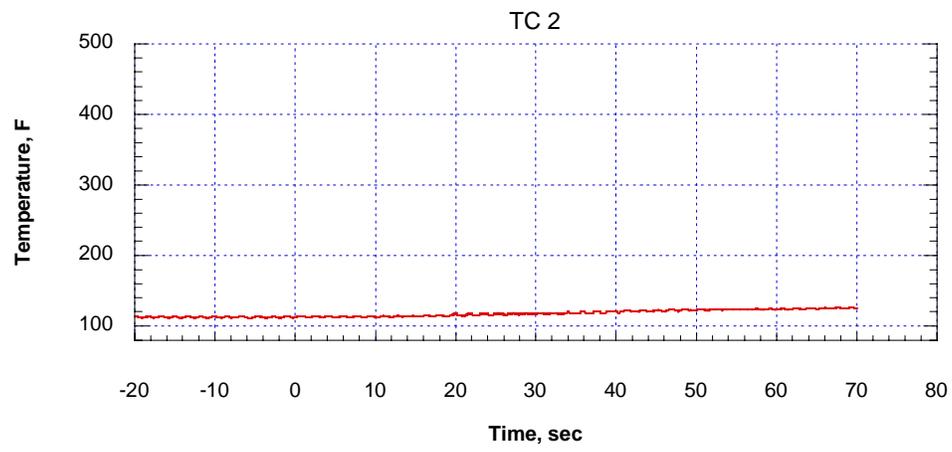
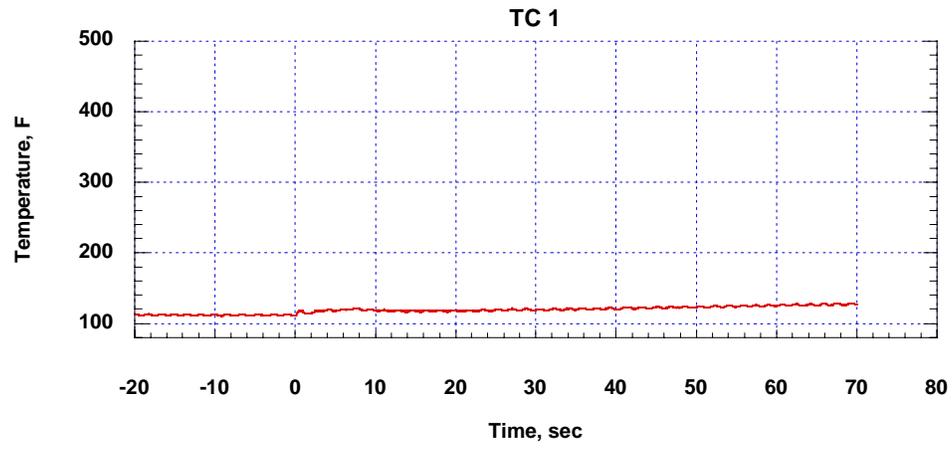
Test 09
Optical Fire Detector Signal vs Time



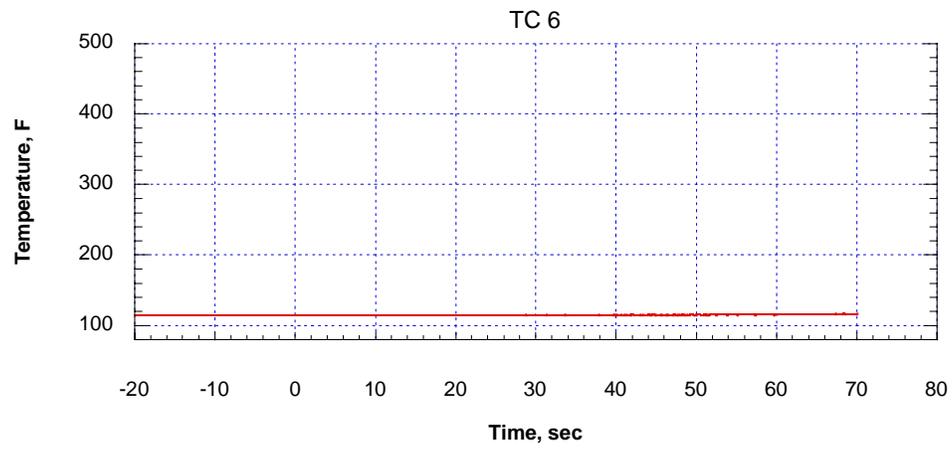
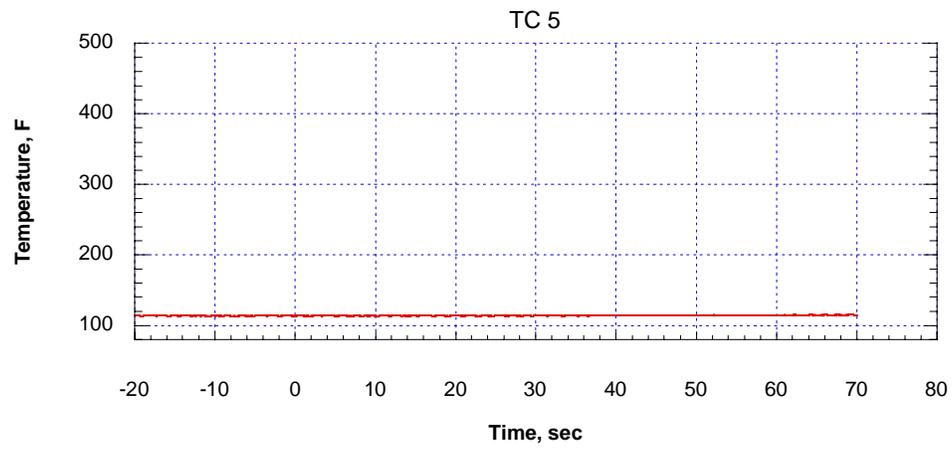
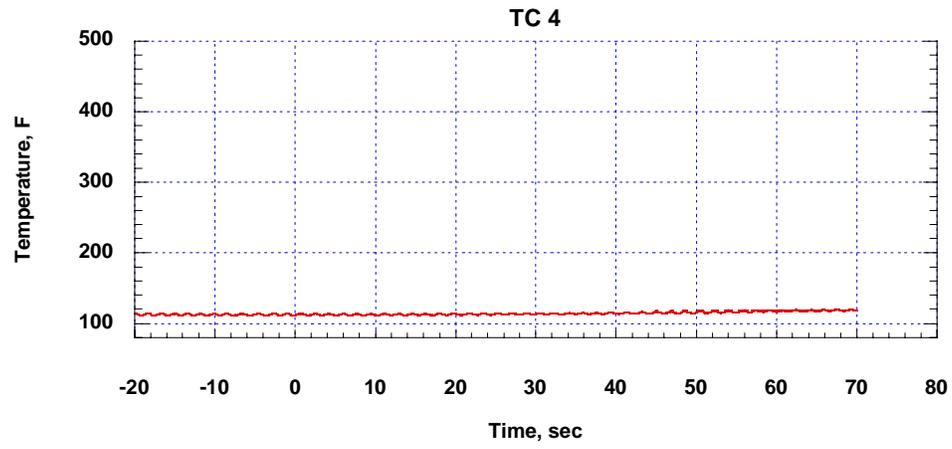
Test 09
Fuel Pressure and Flow Rate vs Time



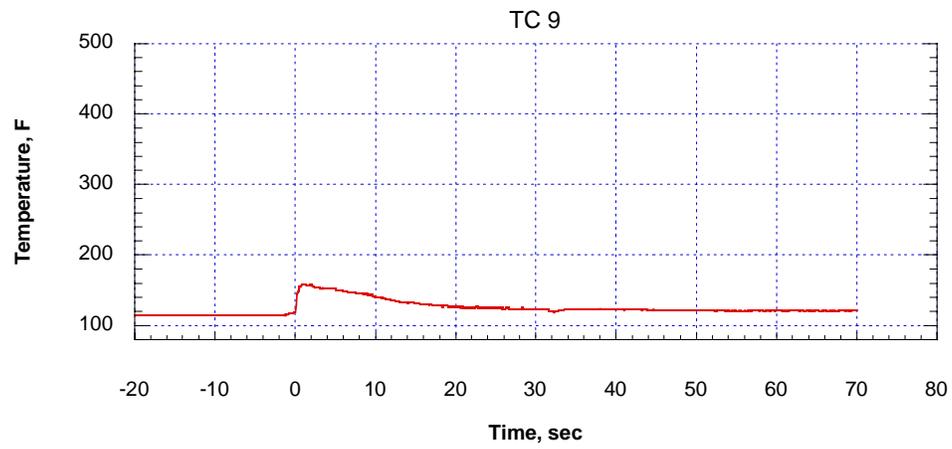
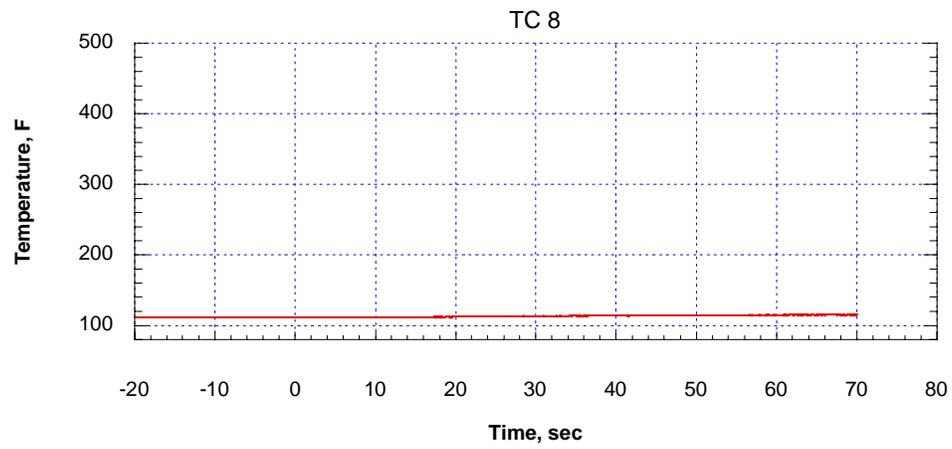
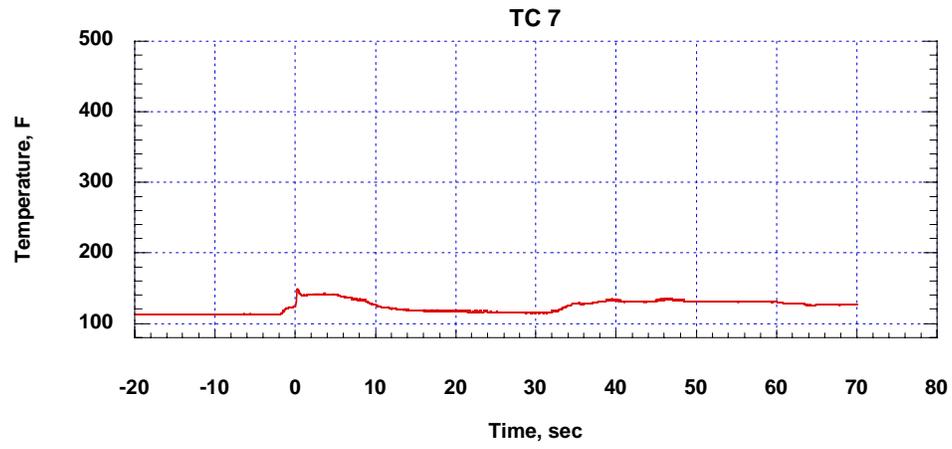
Test 10
Temperature vs Time



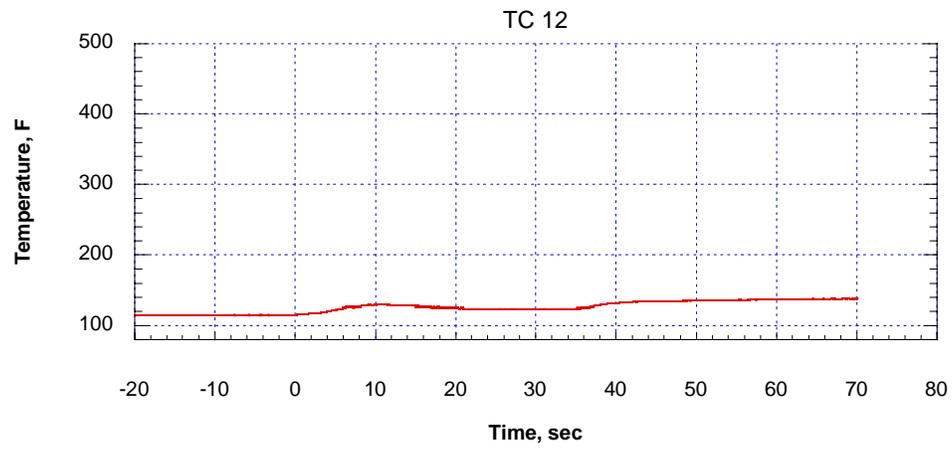
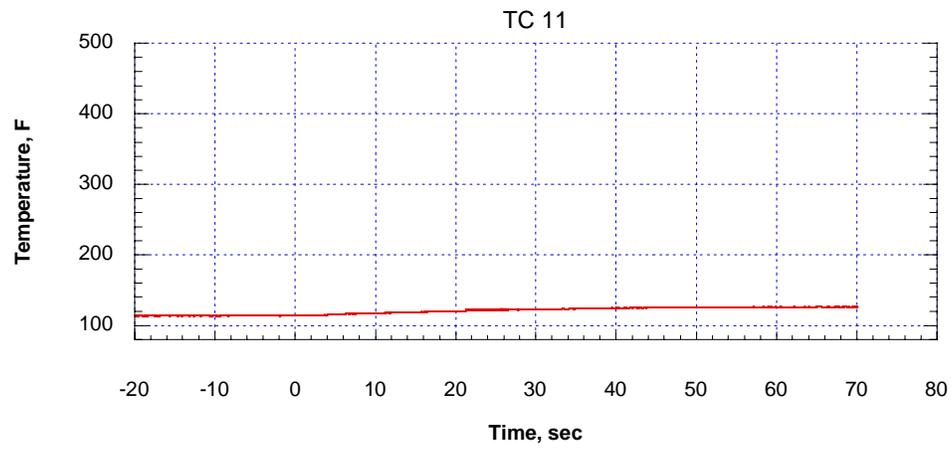
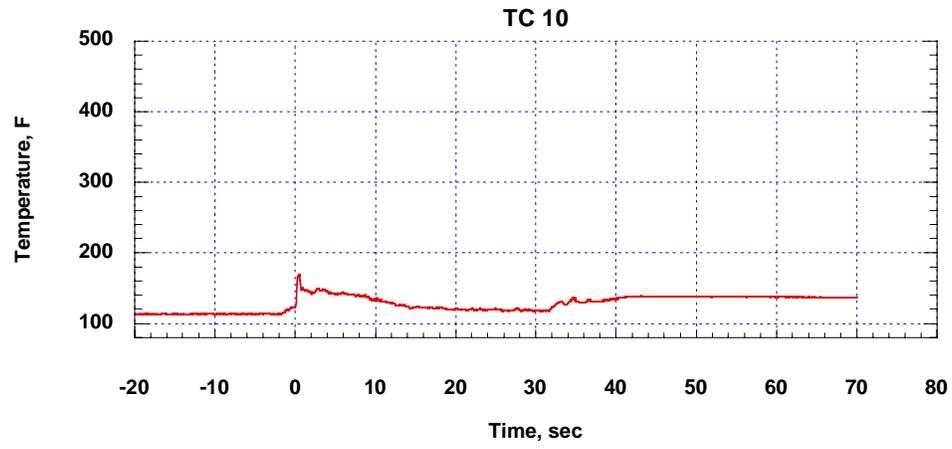
Test 10
Temperature vs Time



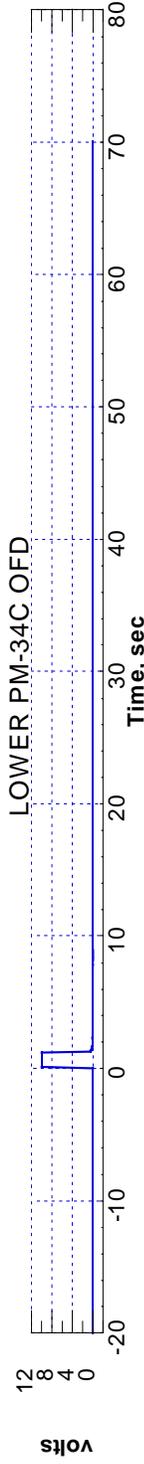
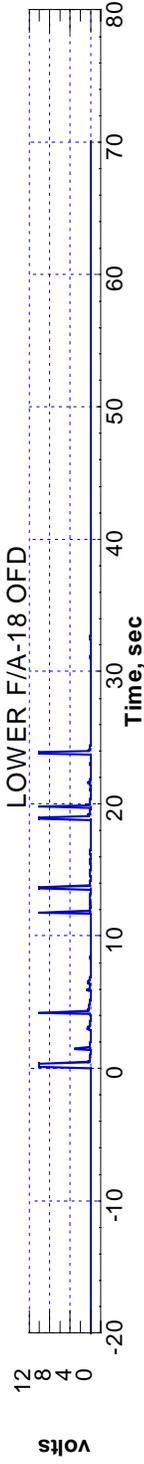
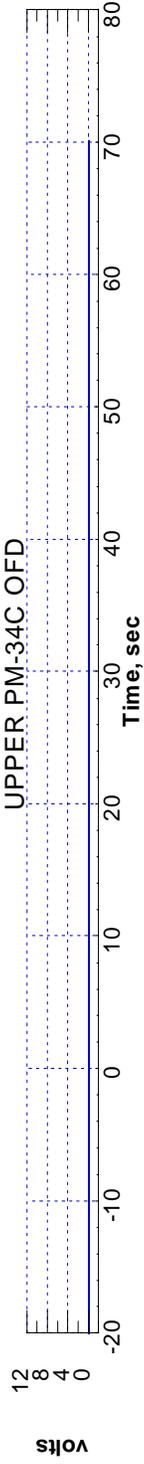
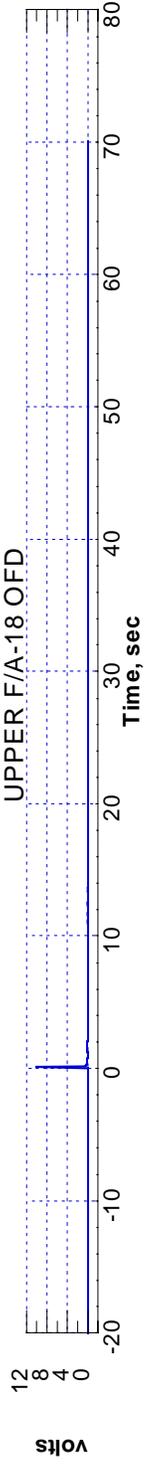
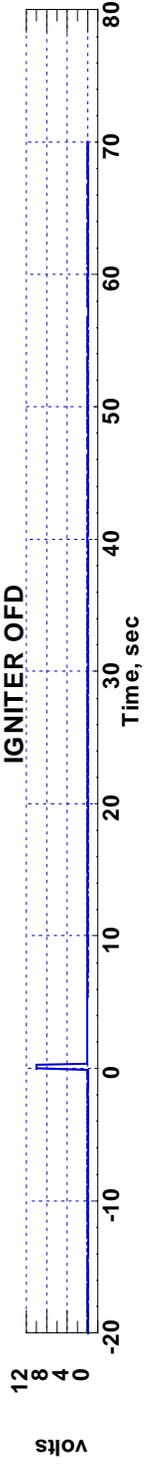
Test 10
Temperature vs Time



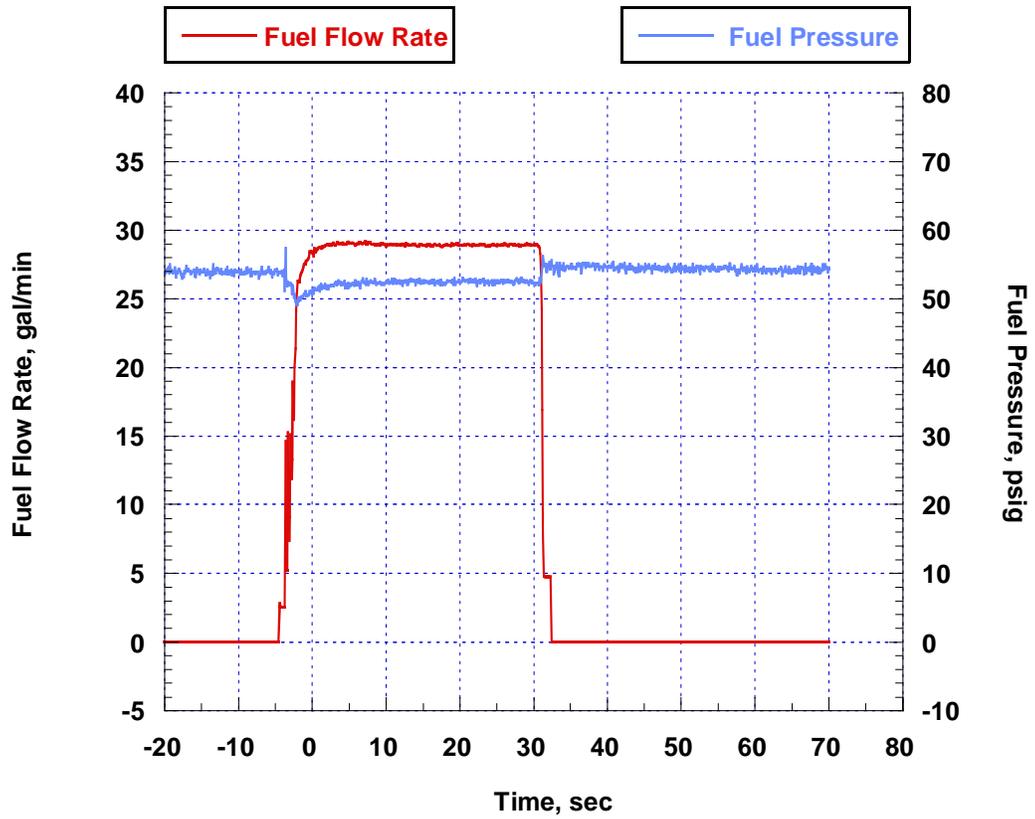
Test 10
Temperature vs Time



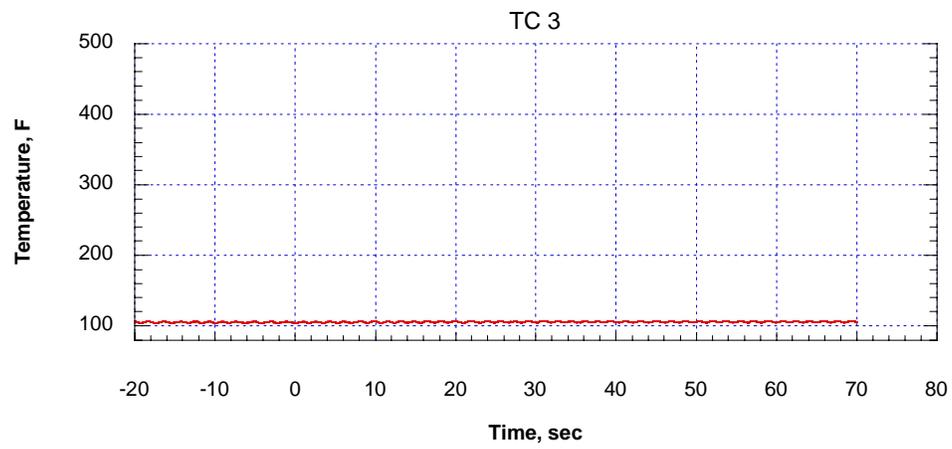
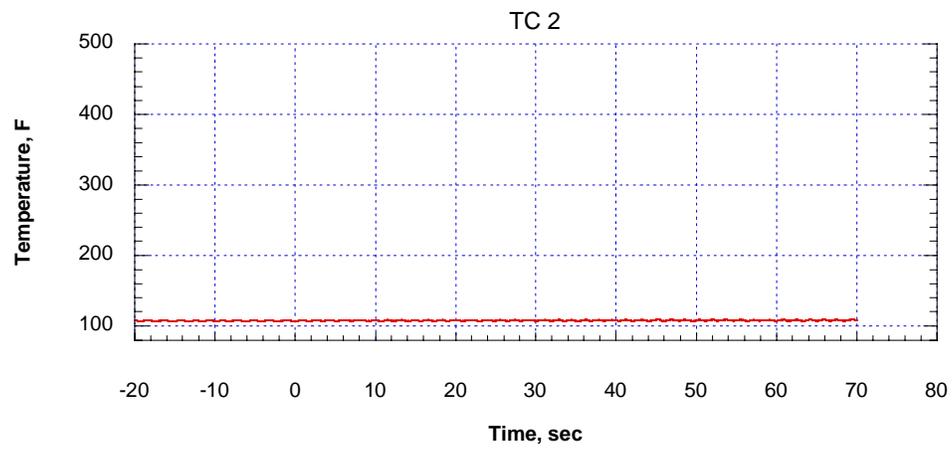
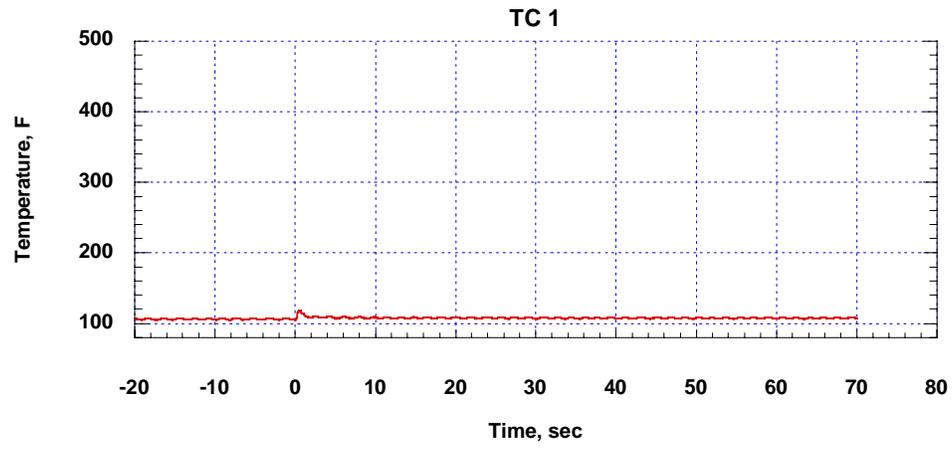
Test 10
Optical Fire Detector Signal vs Time



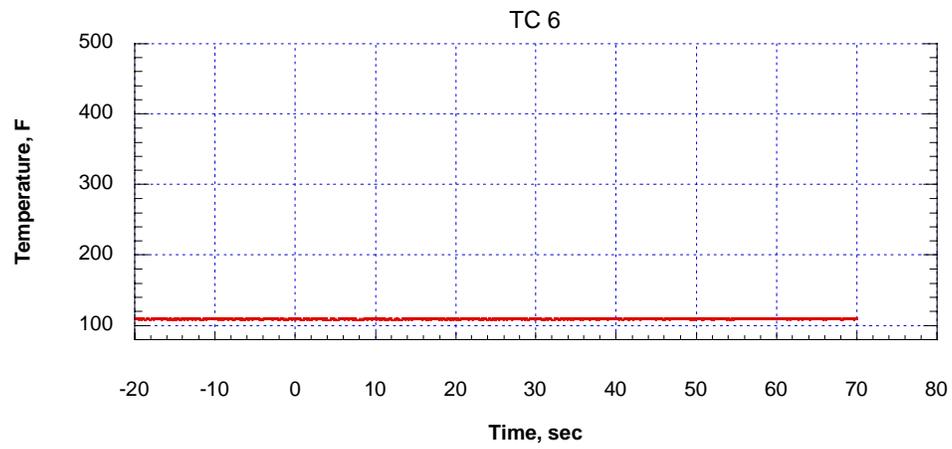
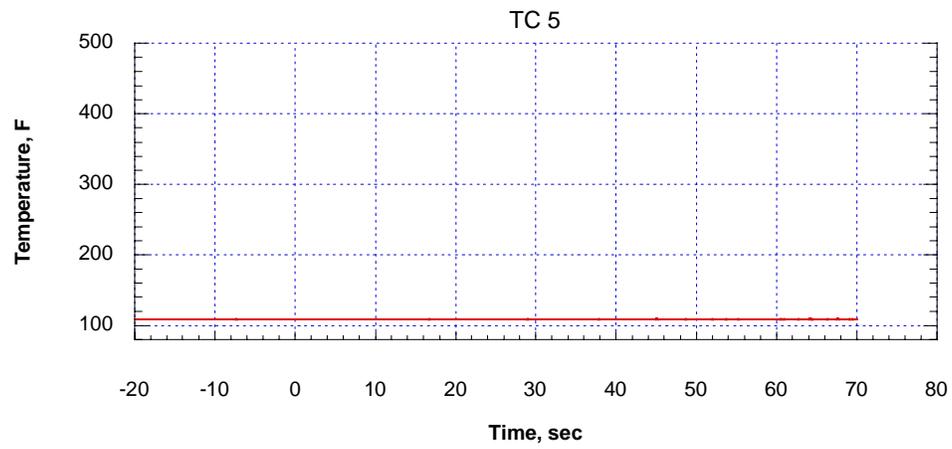
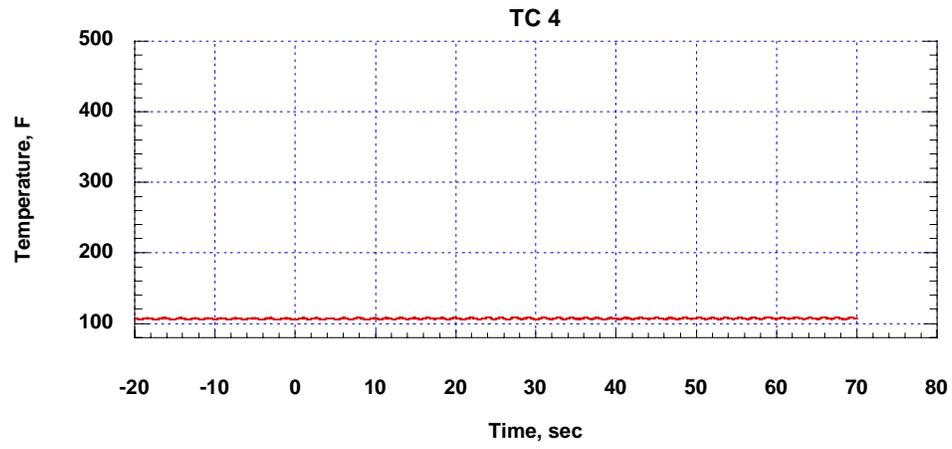
Test 10
Fuel Pressure and Flow Rate vs Time



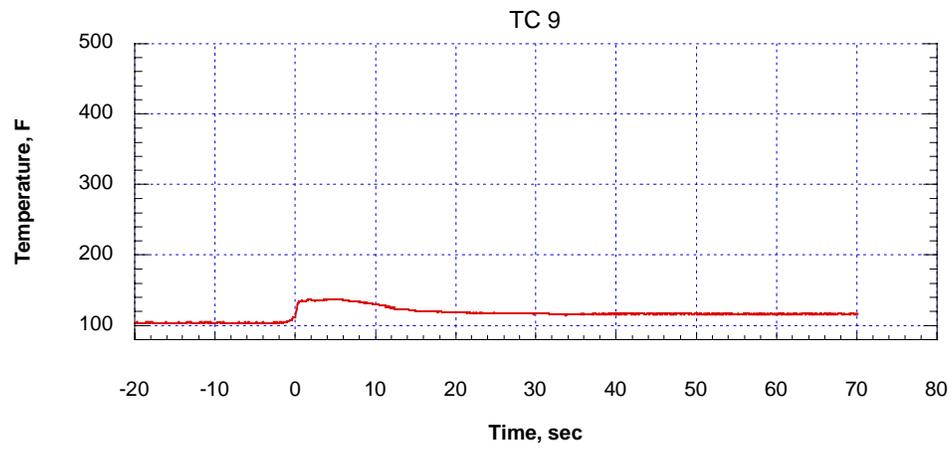
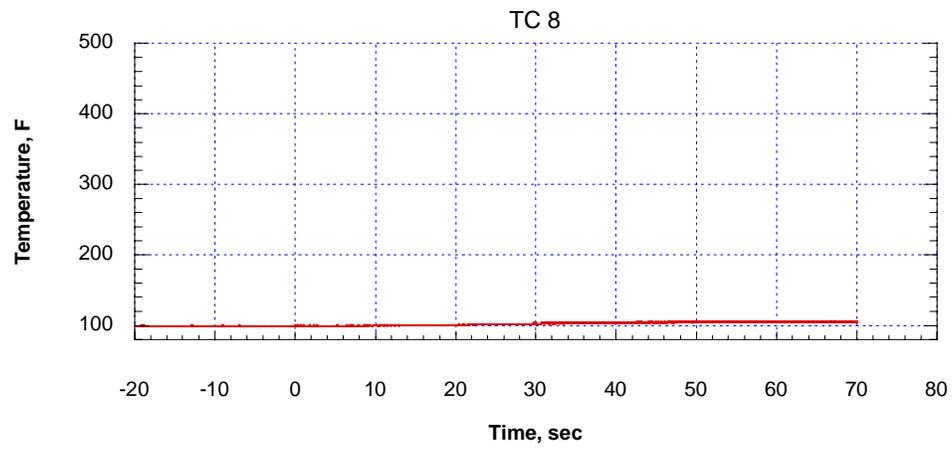
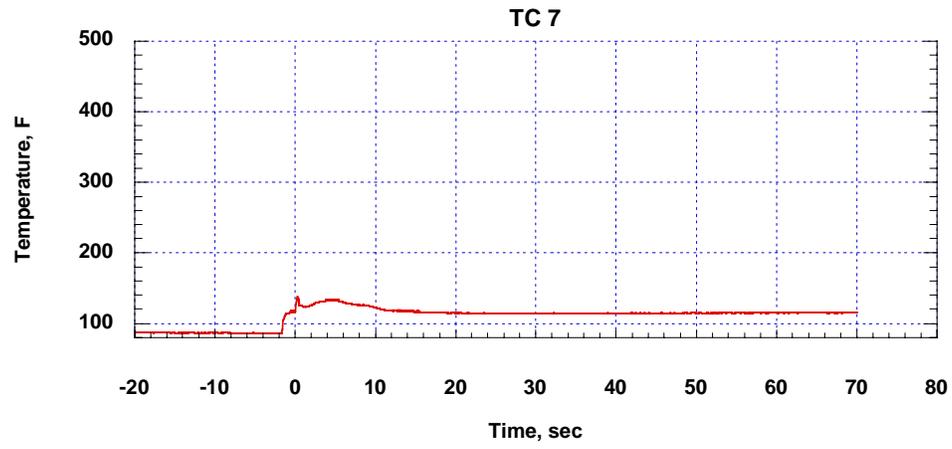
Test 11
Temperature vs Time



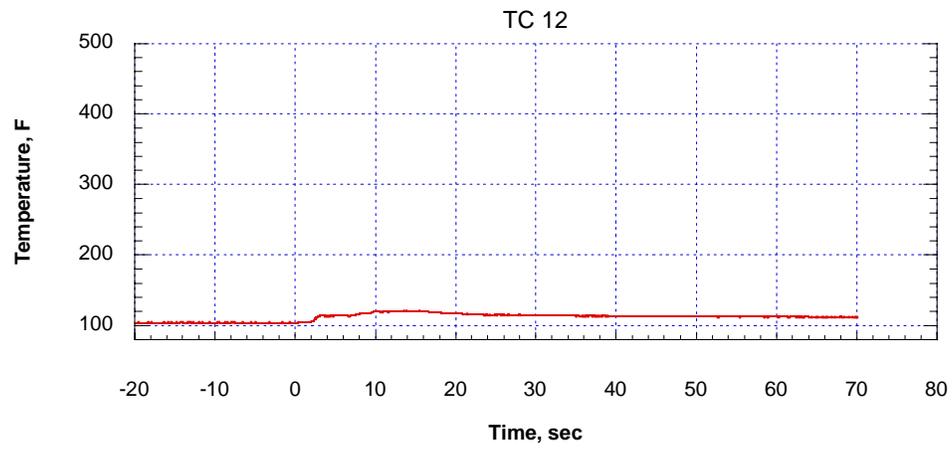
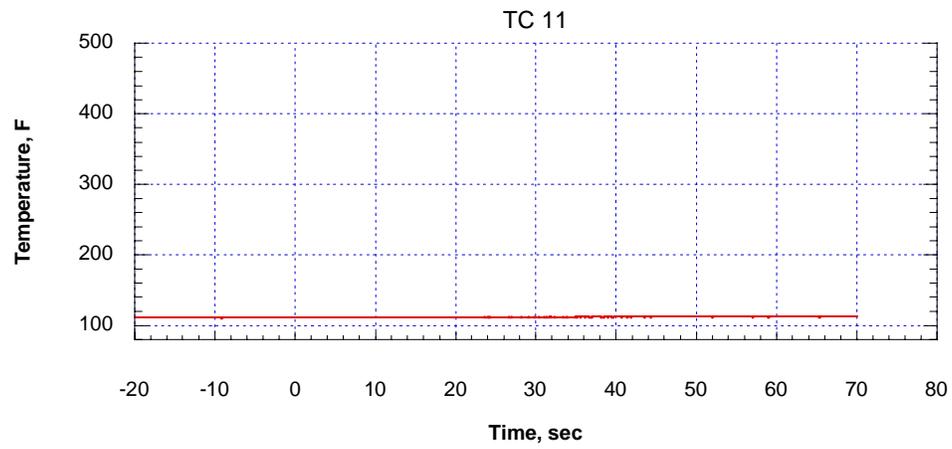
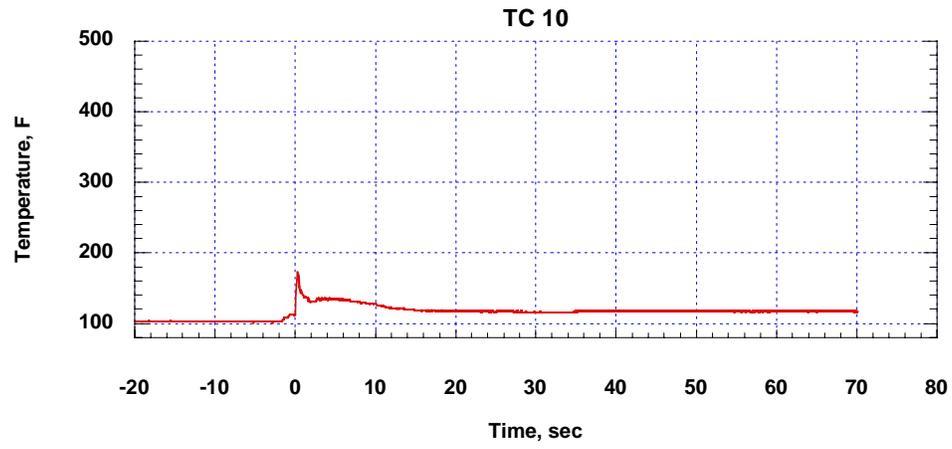
Test 11
Temperature vs Time



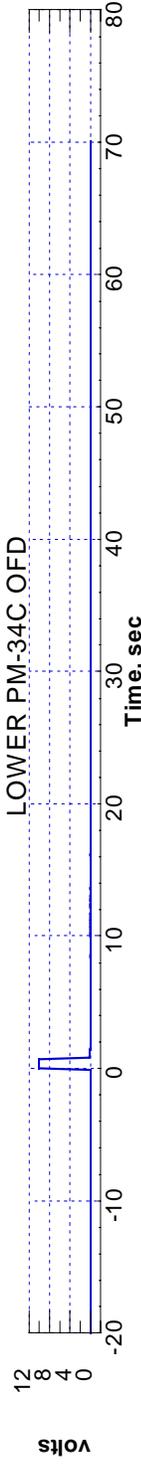
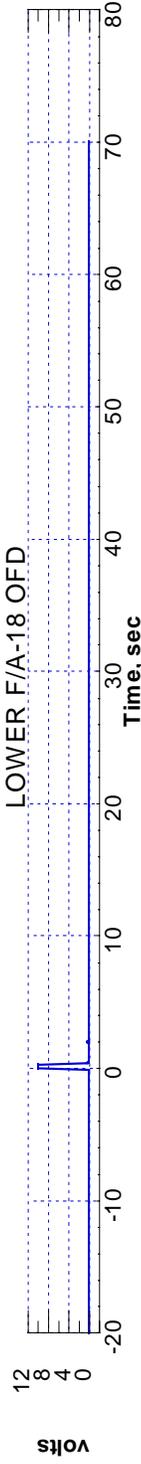
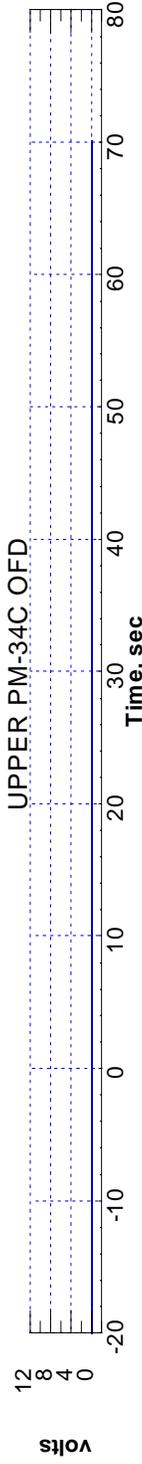
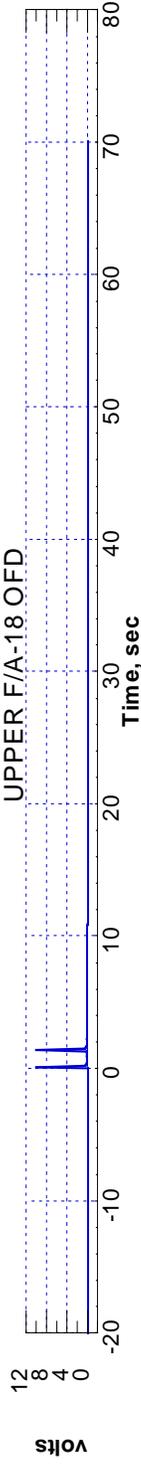
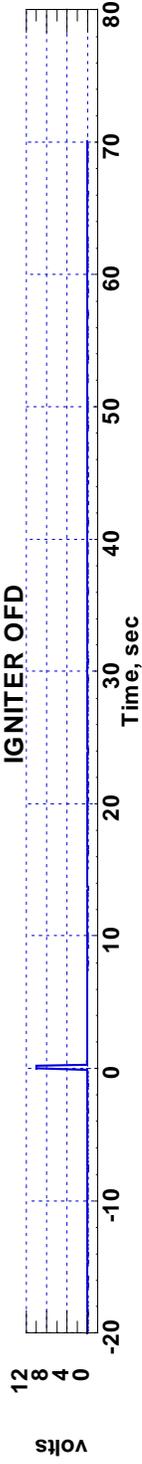
Test 11
Temperature vs Time



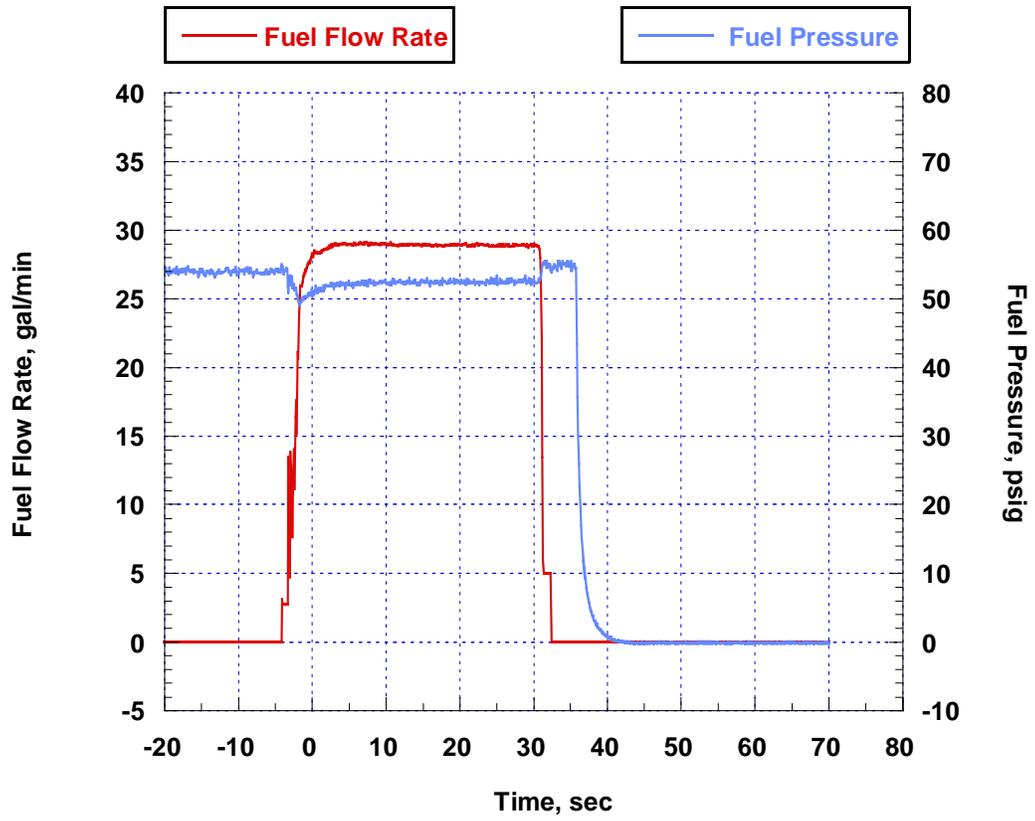
Test 11
Temperature vs Time



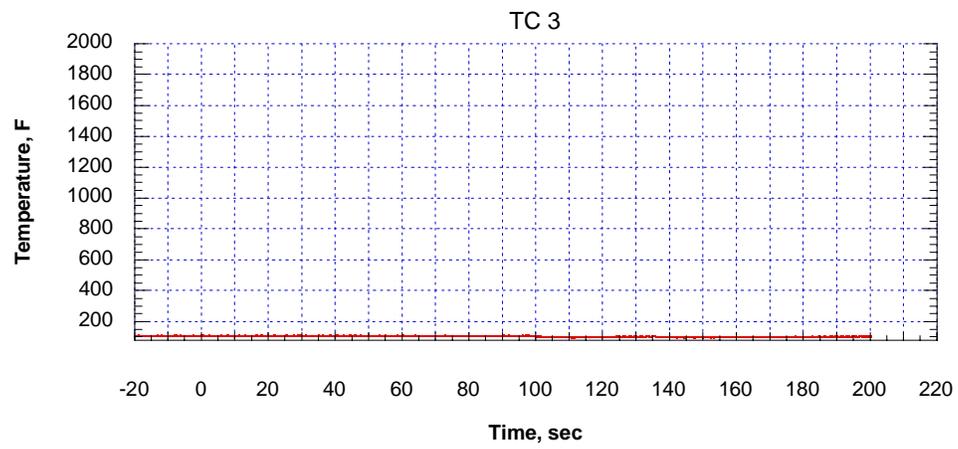
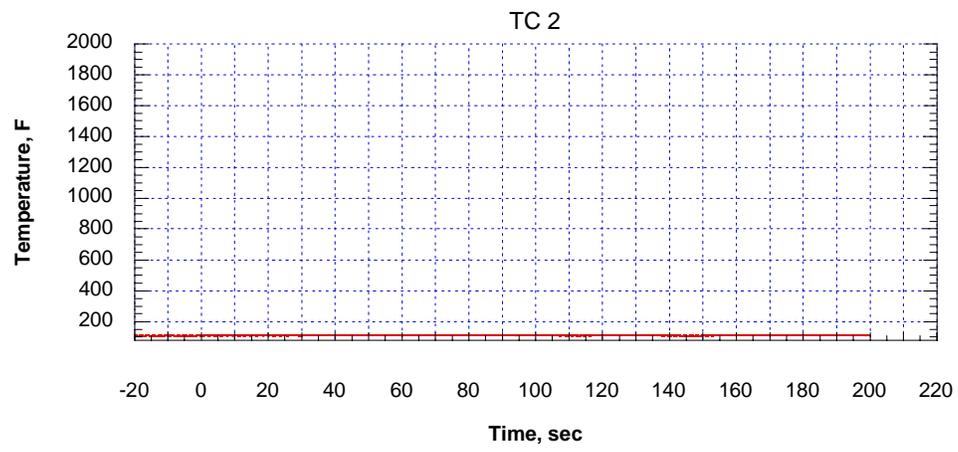
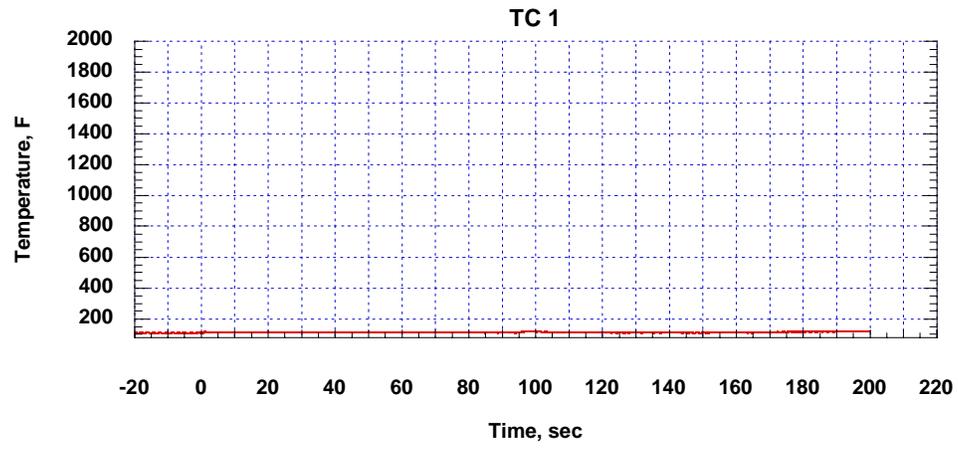
Test 11
Optical Fire Detector Signal vs Time



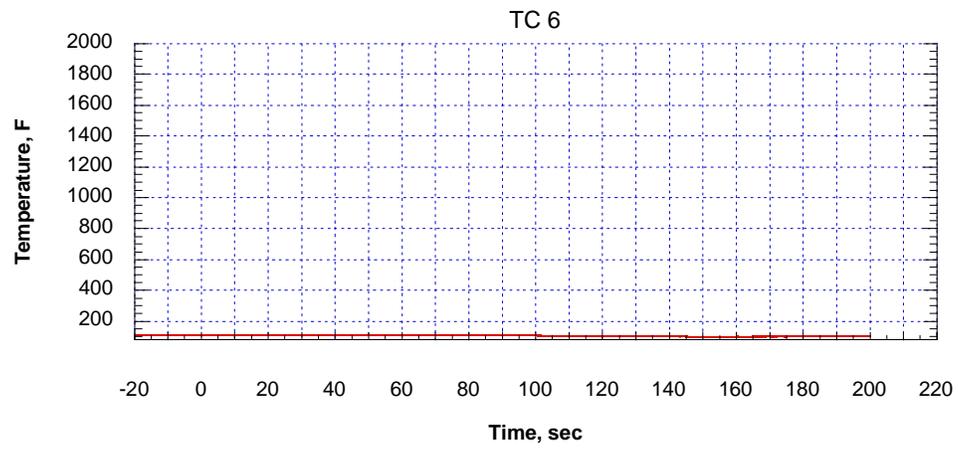
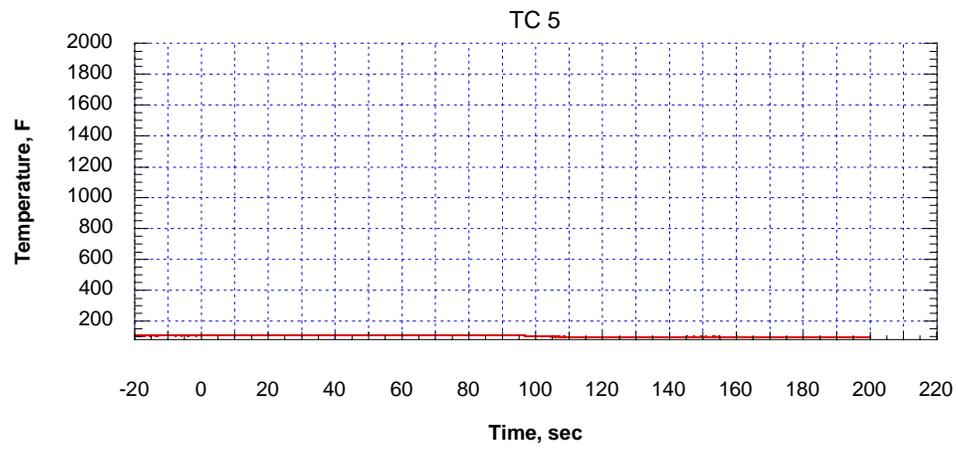
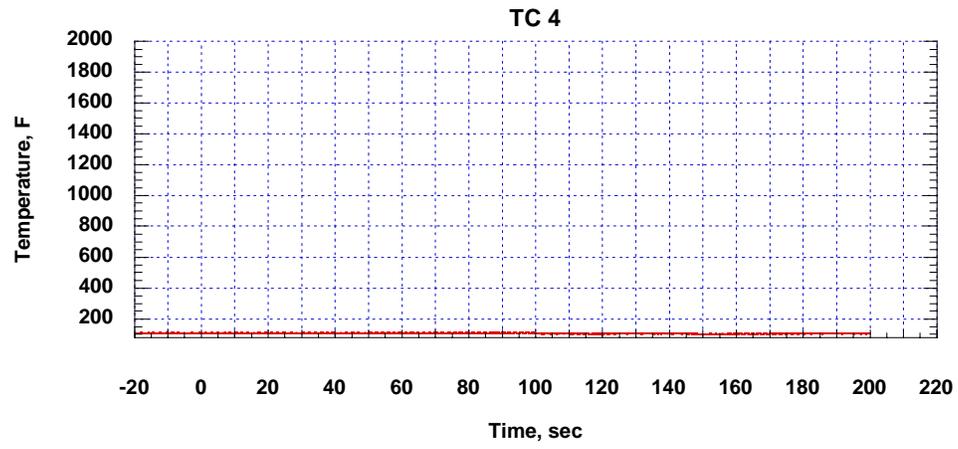
Test 11
Fuel Pressure and Flow Rate vs Time



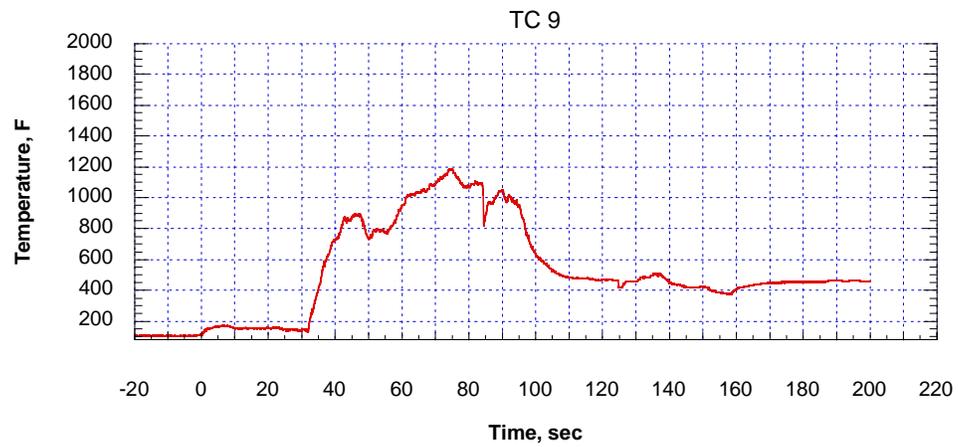
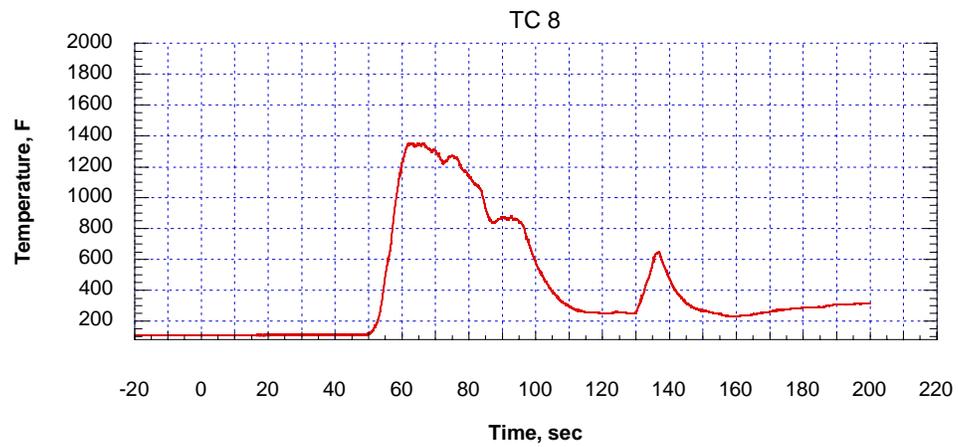
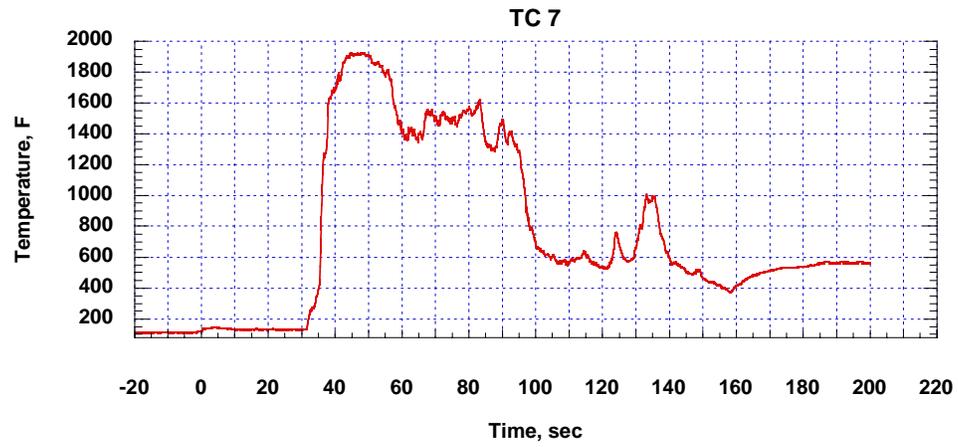
Test 12
Temperature vs Time



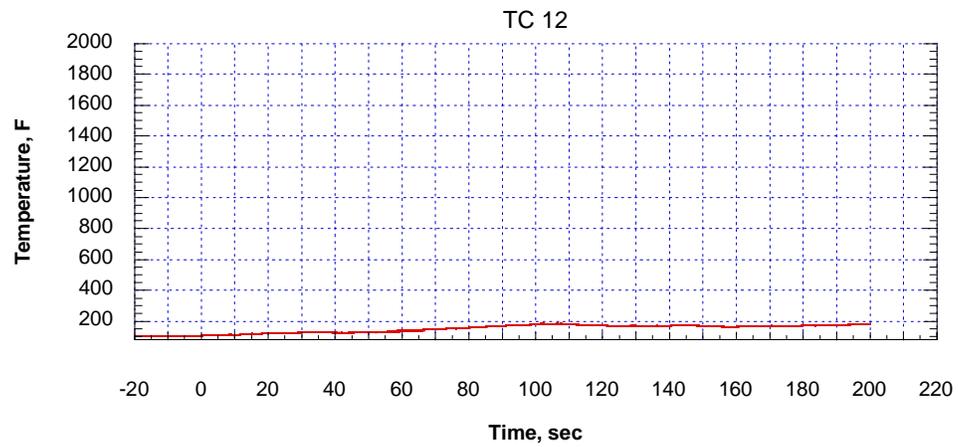
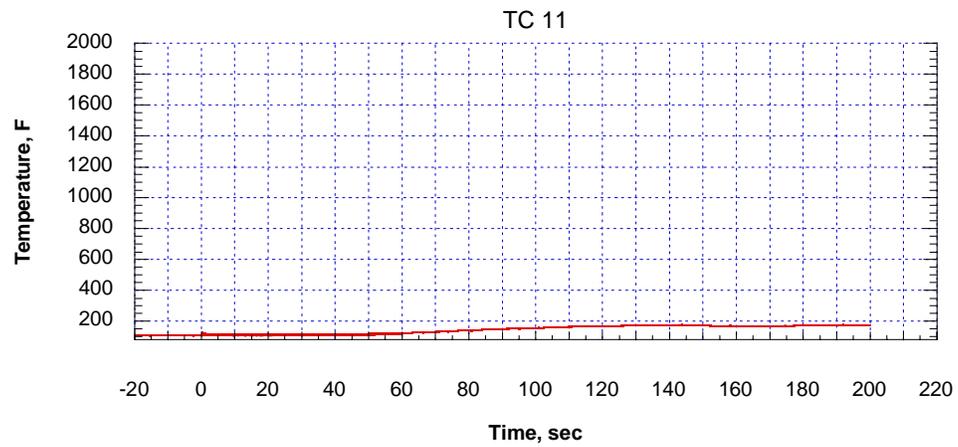
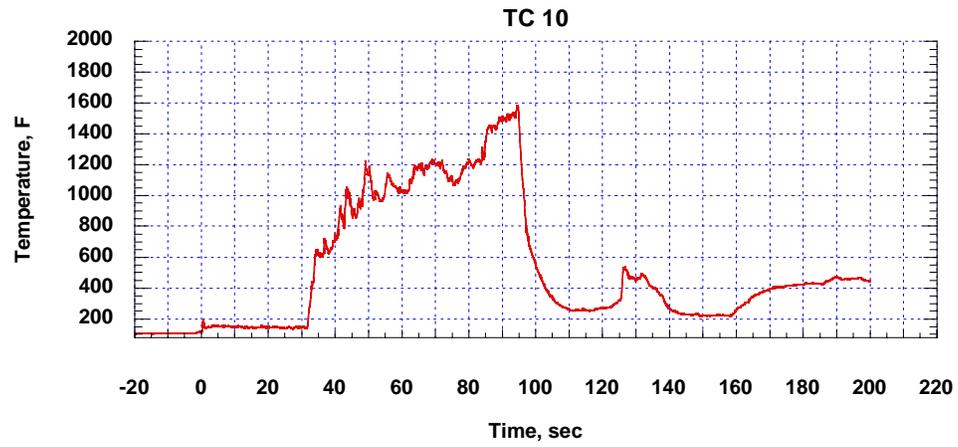
Test 12
Temperature vs Time



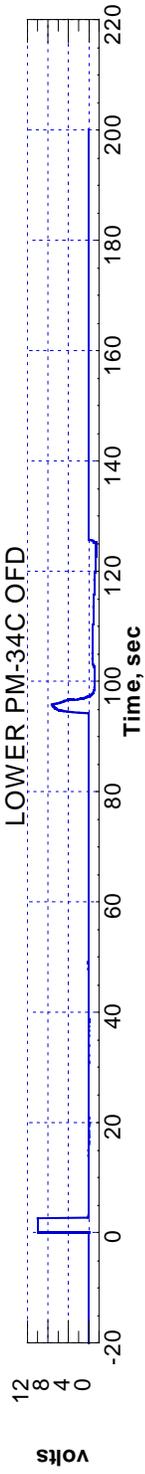
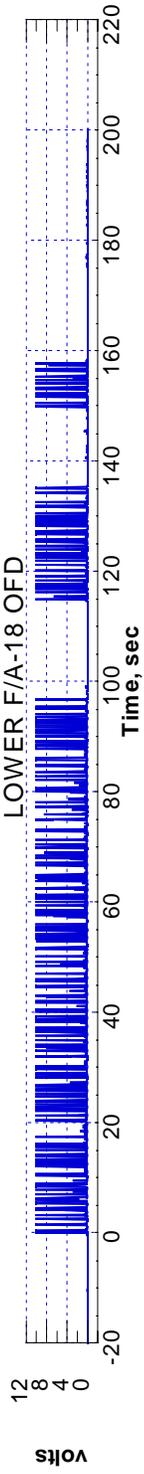
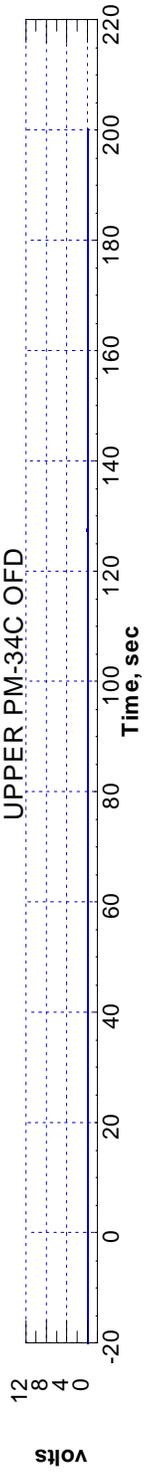
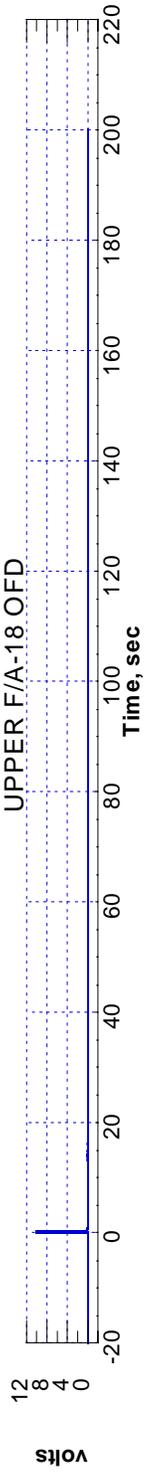
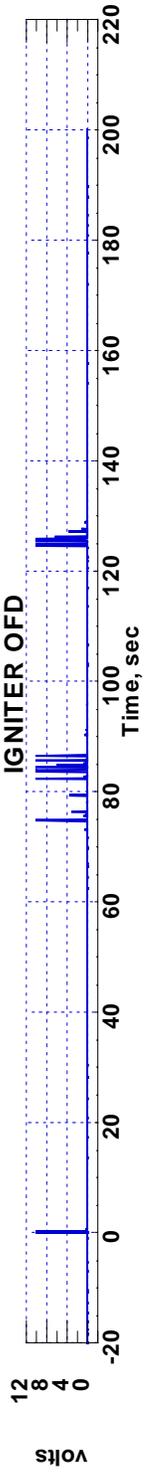
Test 12
Temperature vs Time



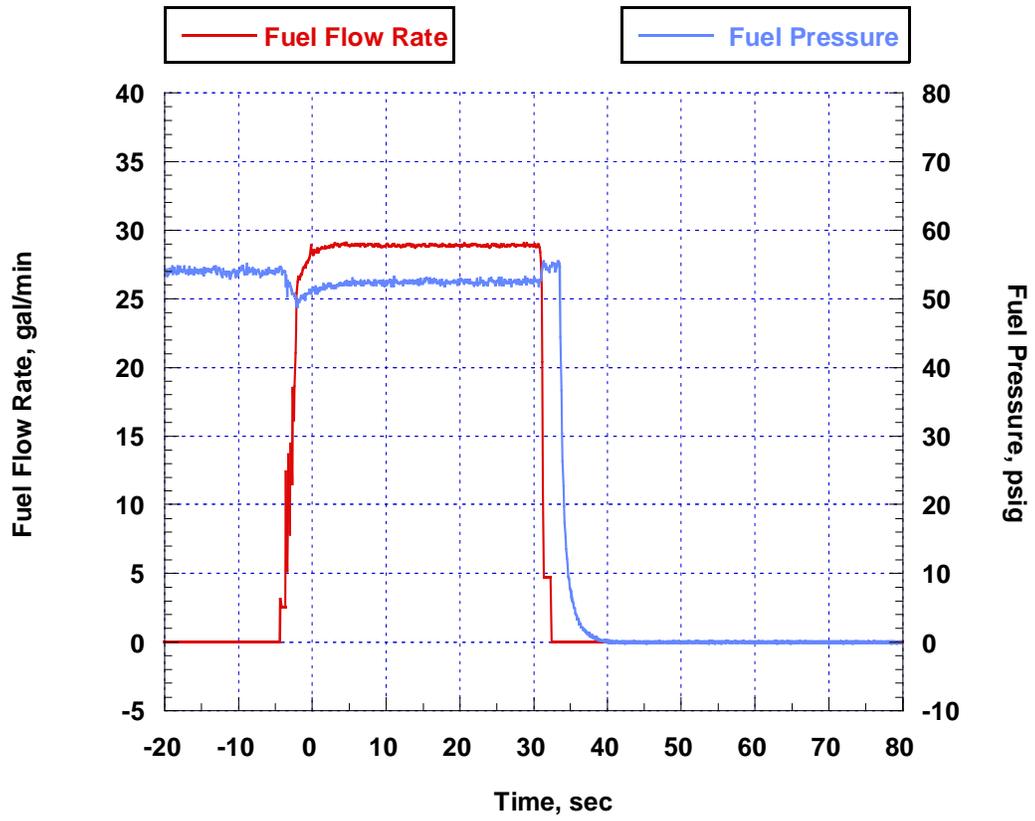
Test 12
Temperature vs Time



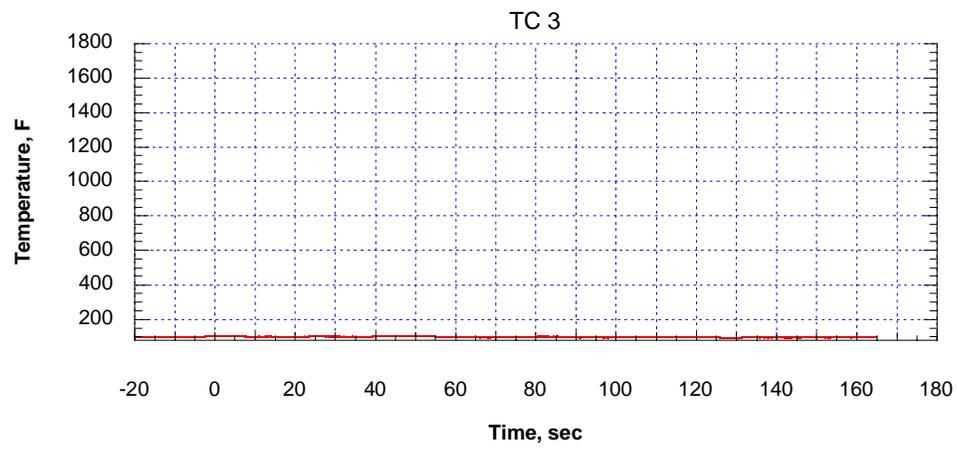
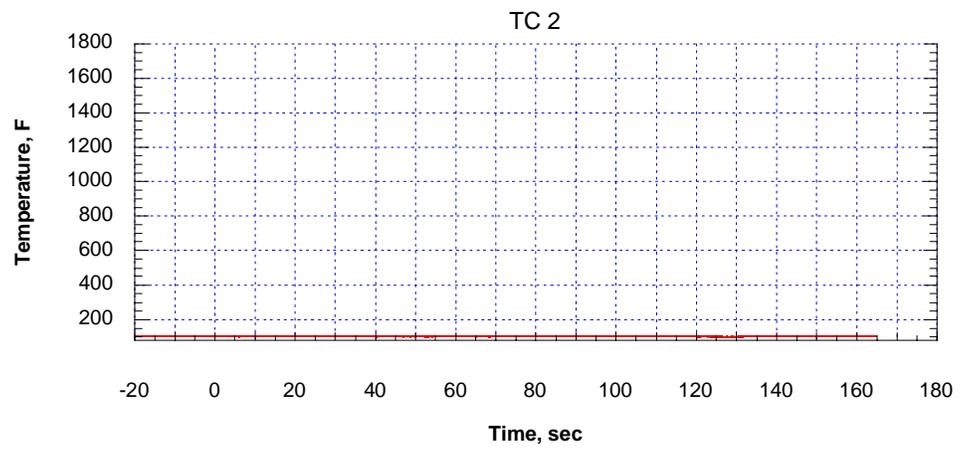
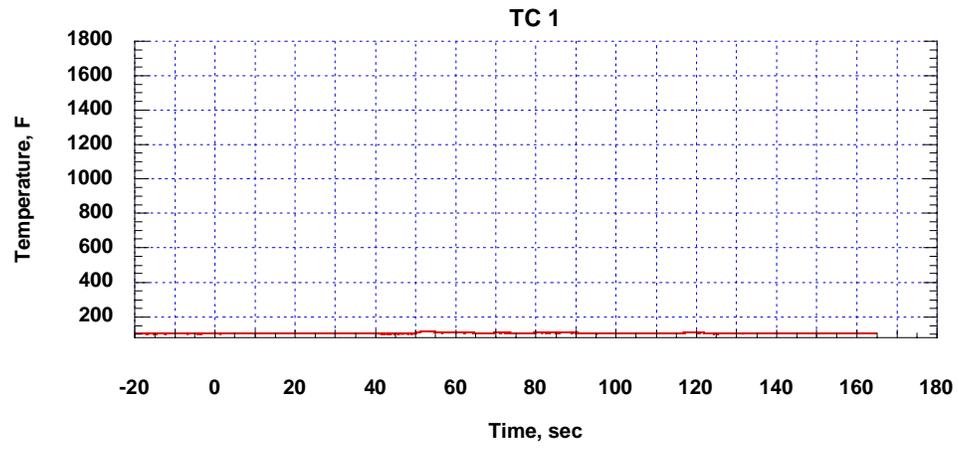
Test 12
Optical Fire Detector Signal vs Time



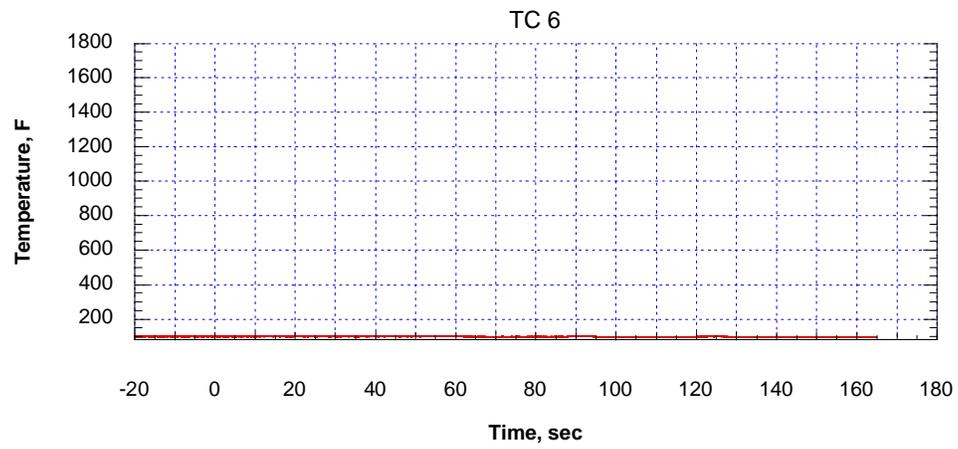
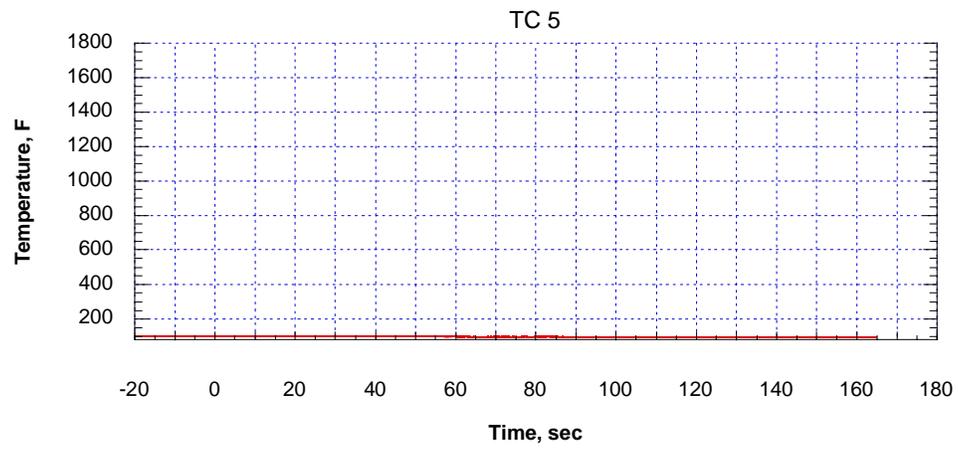
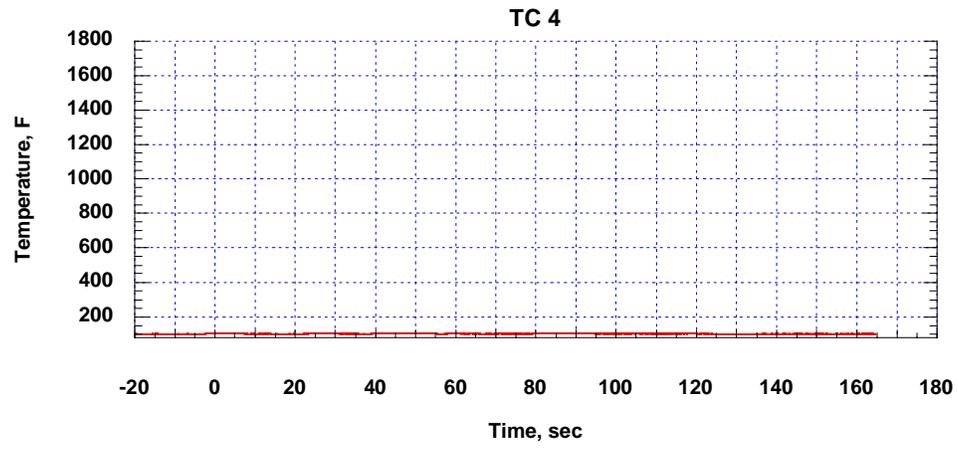
Test 12
Fuel Pressure and Flow Rate vs Time



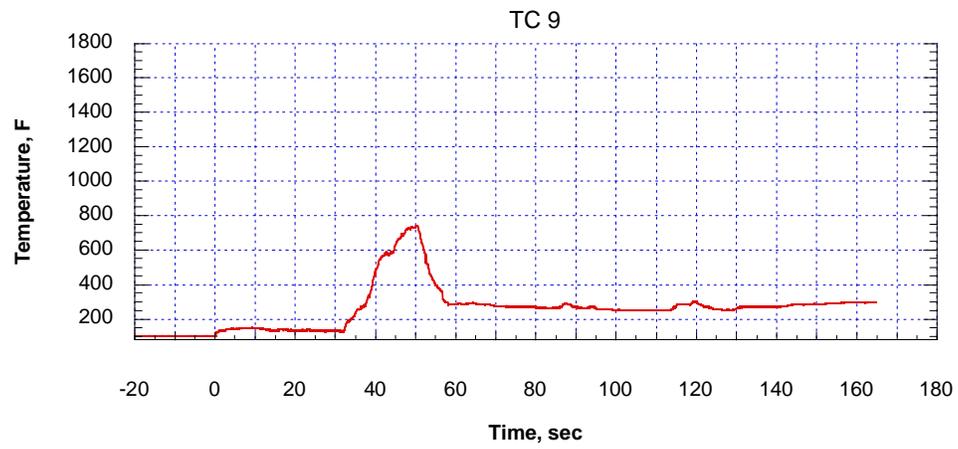
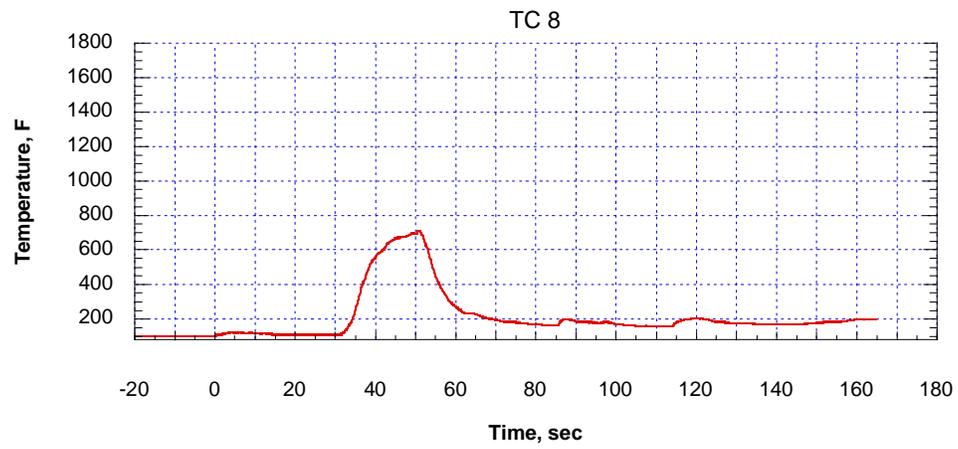
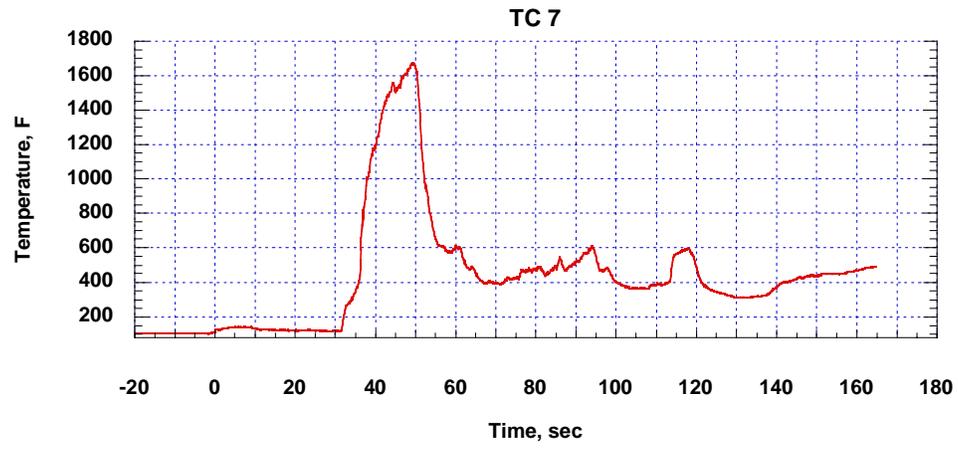
Test 13
Temperature vs Time



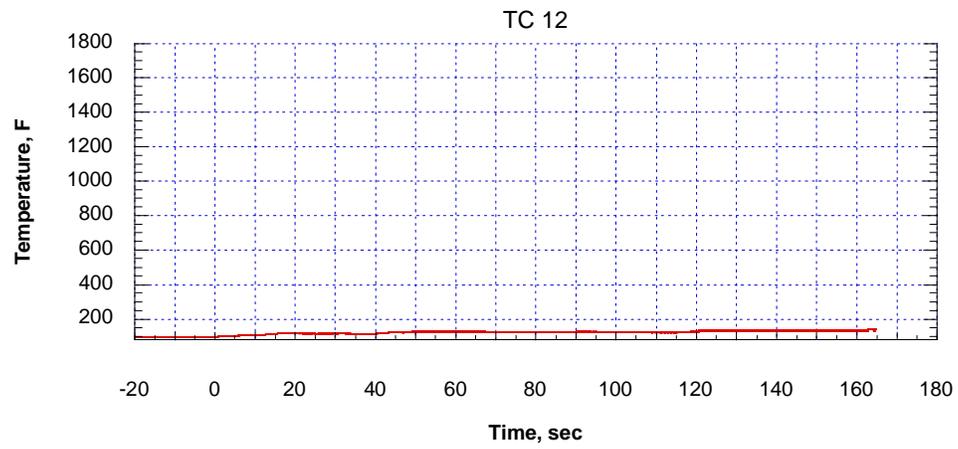
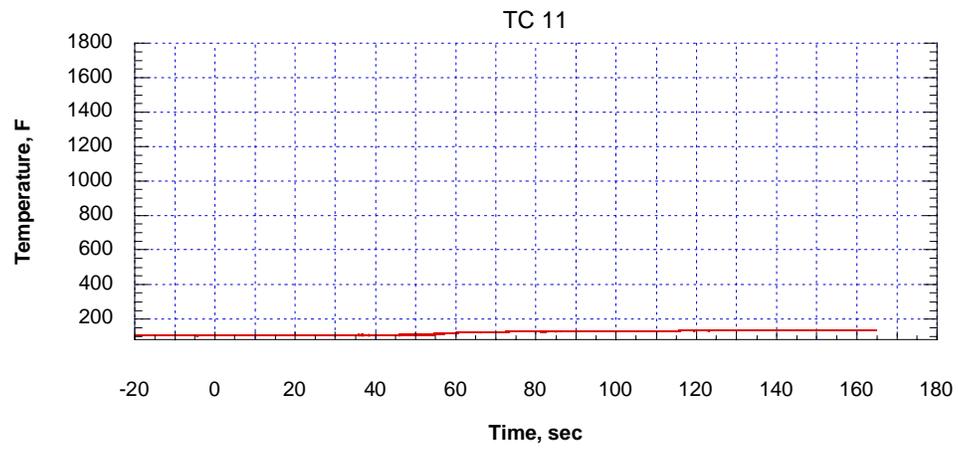
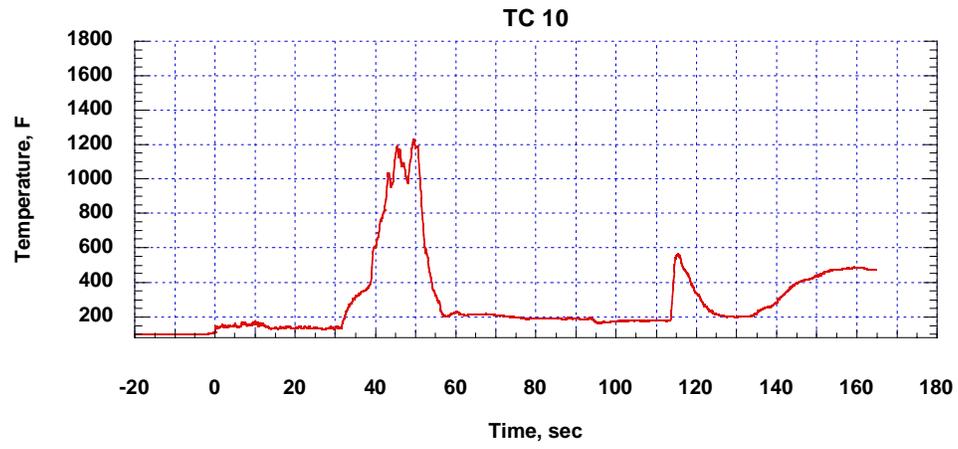
Test 13
Temperature vs Time



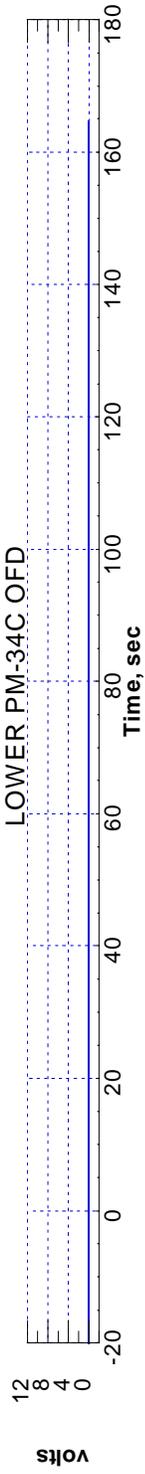
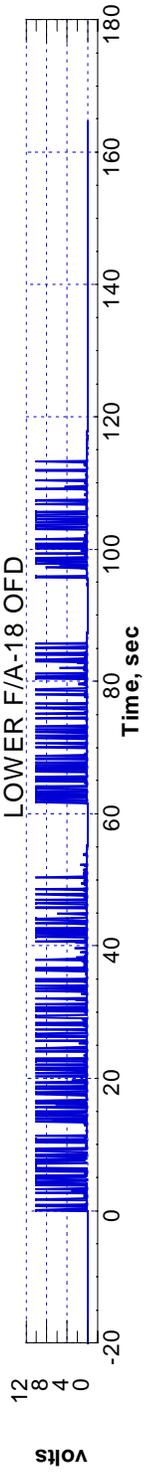
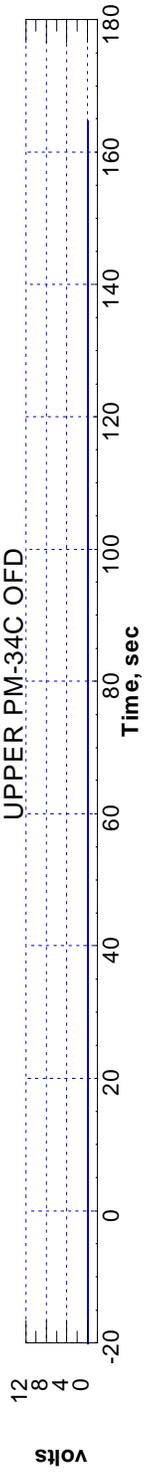
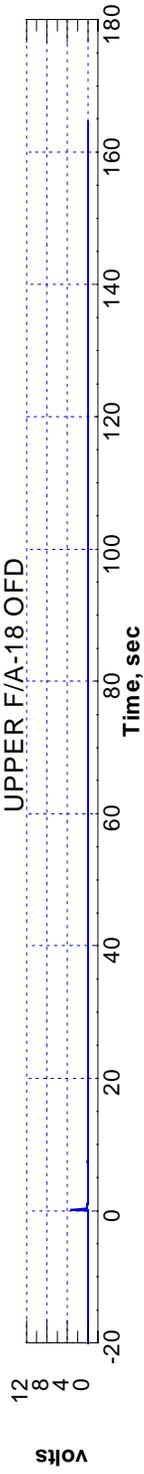
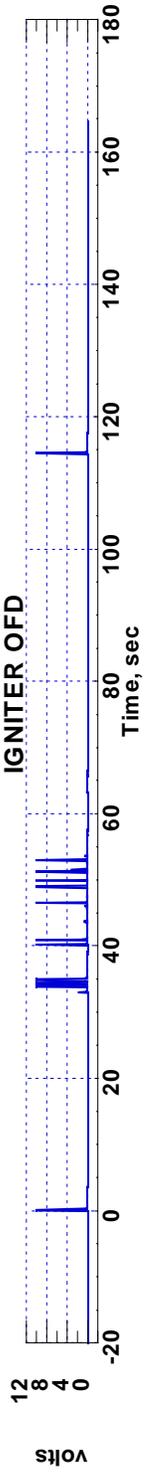
Test 13
Temperature vs Time



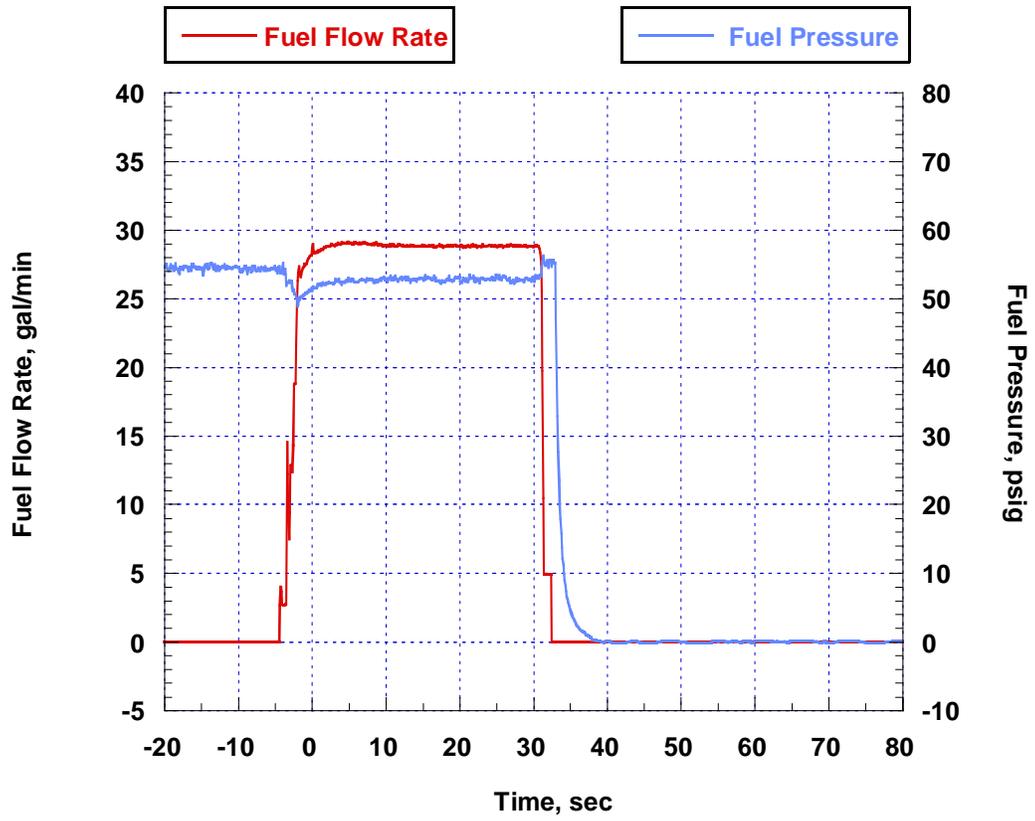
Test 13
Temperature vs Time



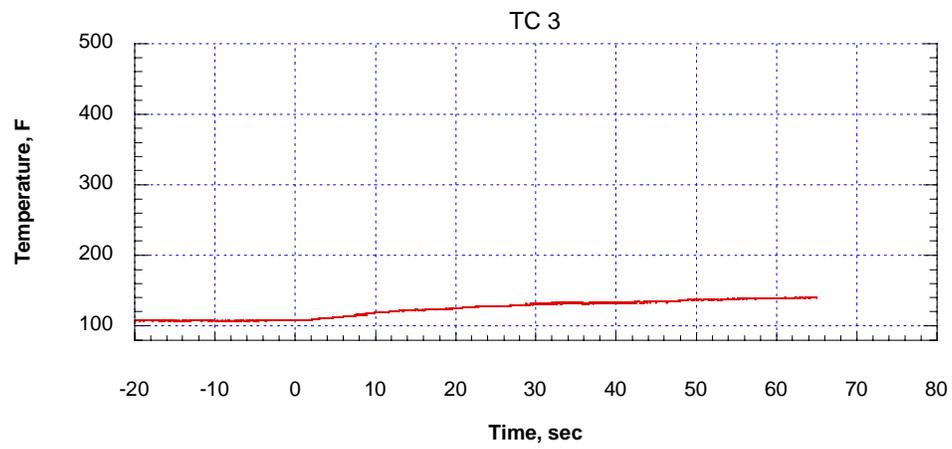
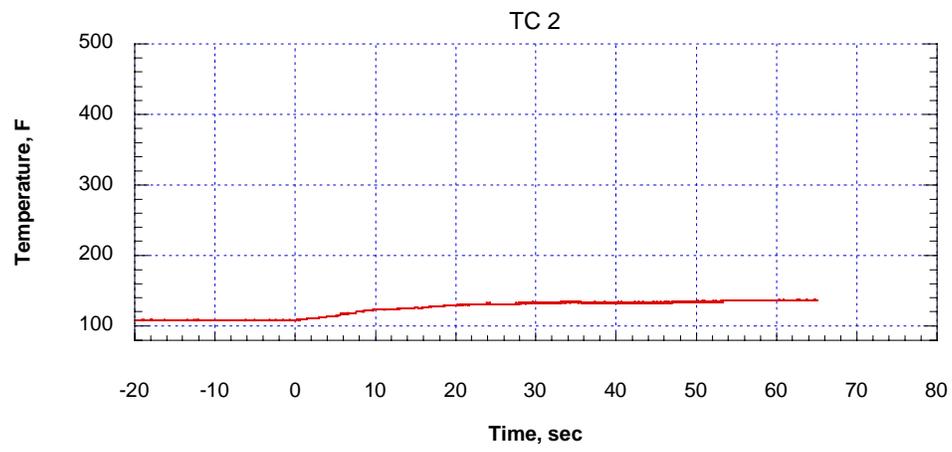
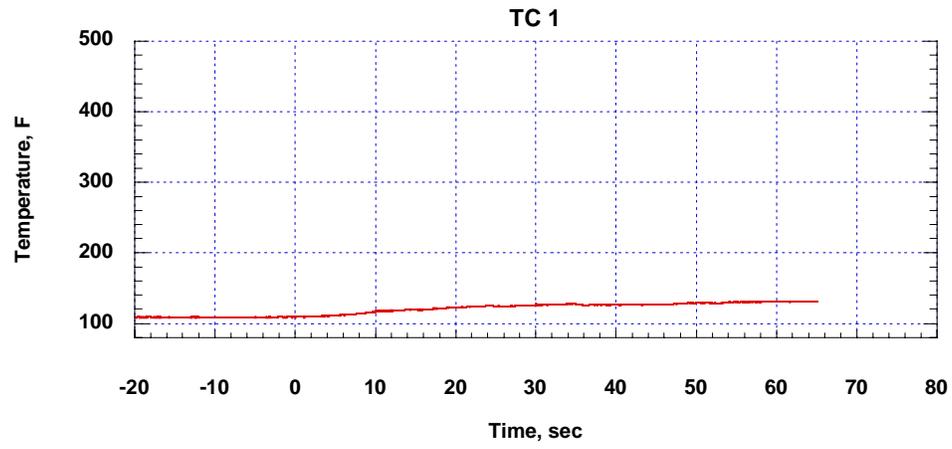
Test 13
Optical Fire Detector Signal vs Time



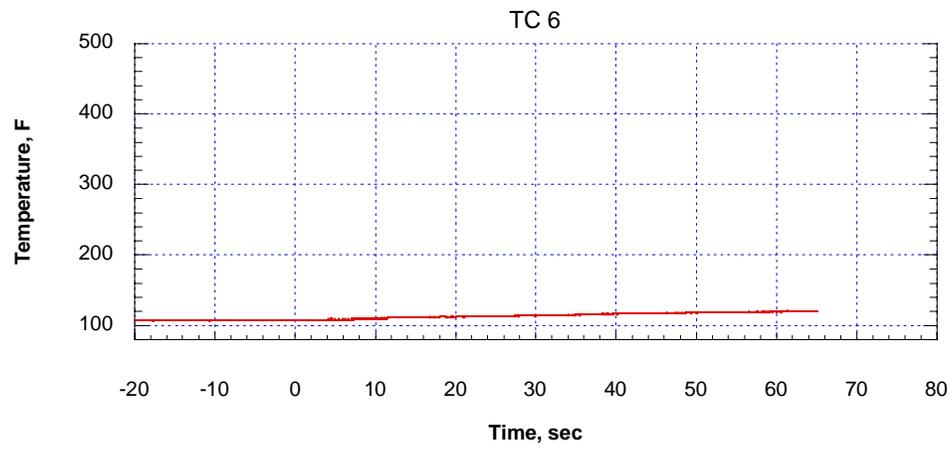
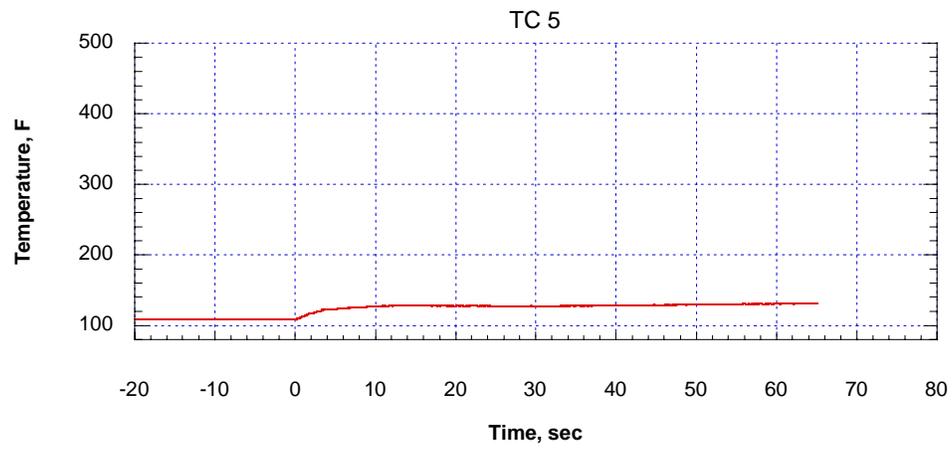
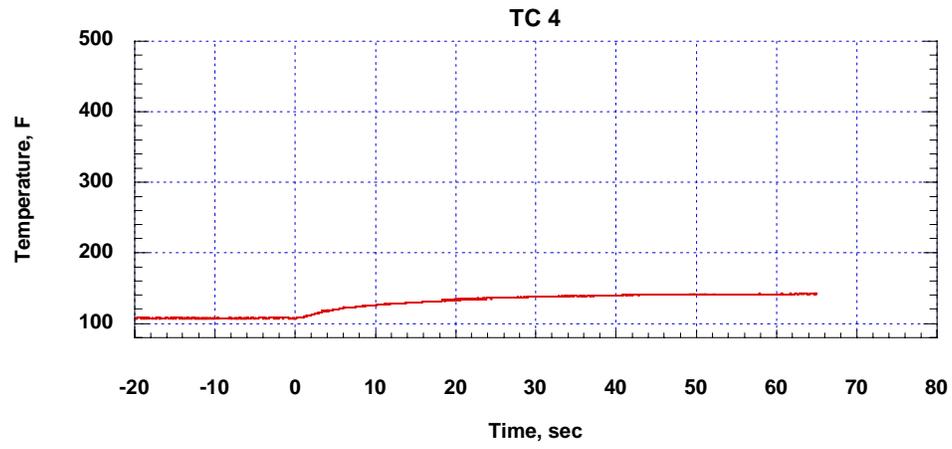
Test 13
Fuel Pressure and Flow Rate vs Time



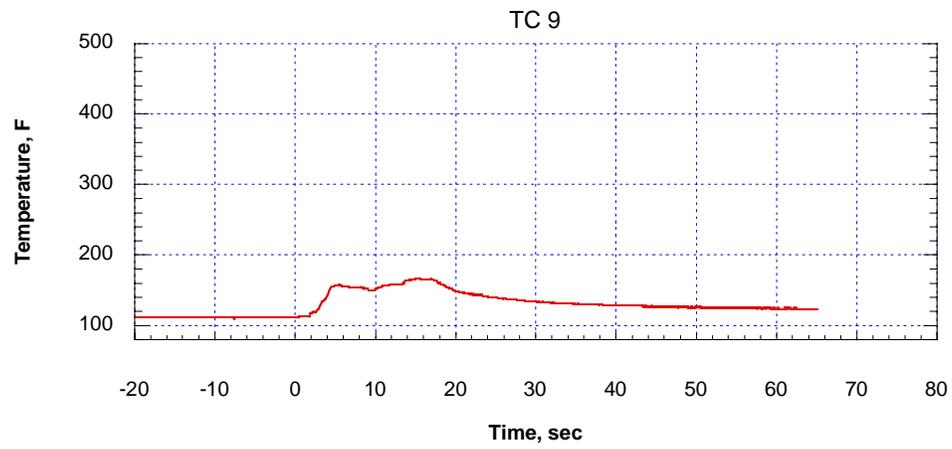
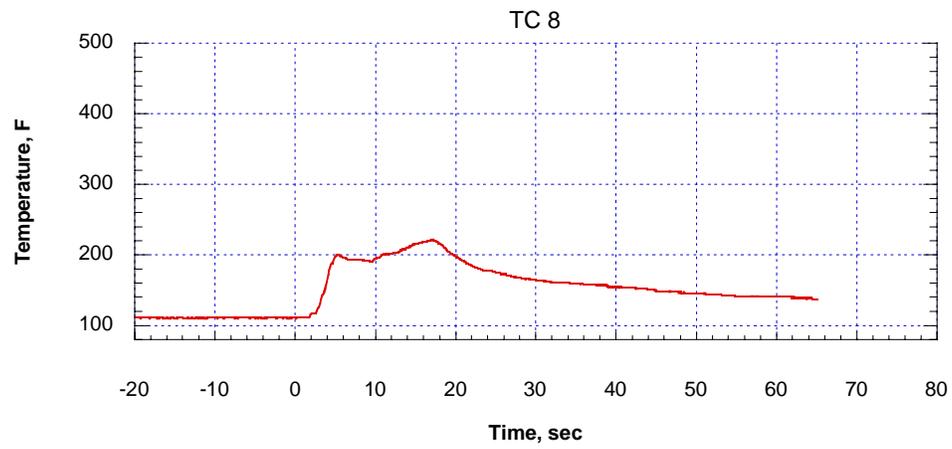
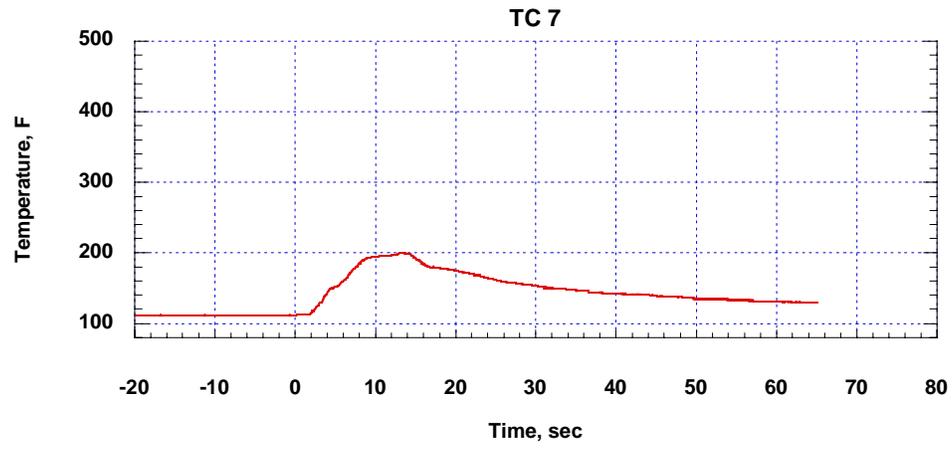
Test 14
Temperature vs Time



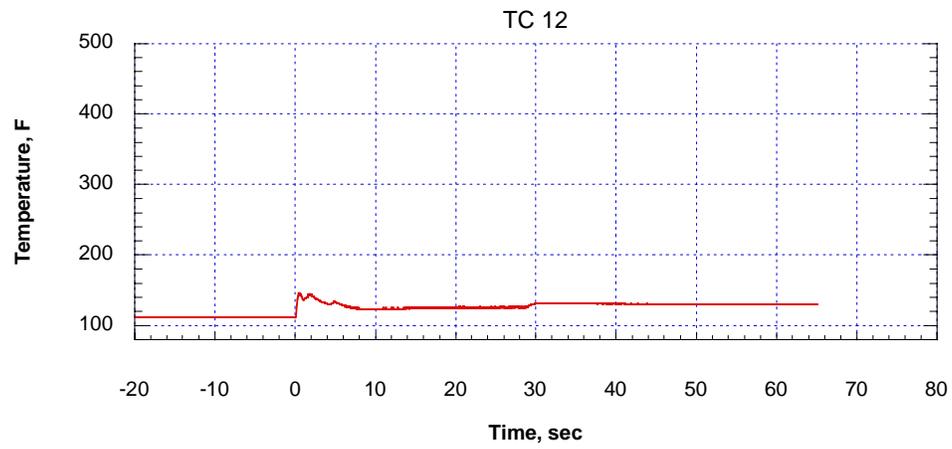
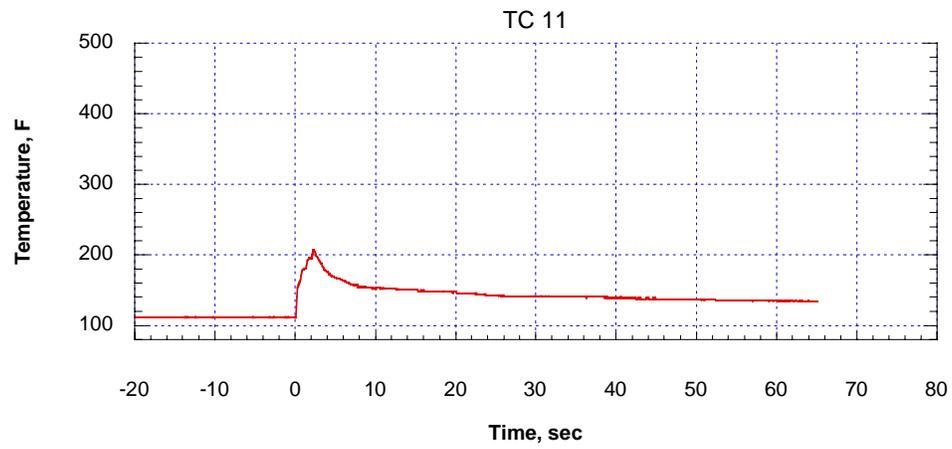
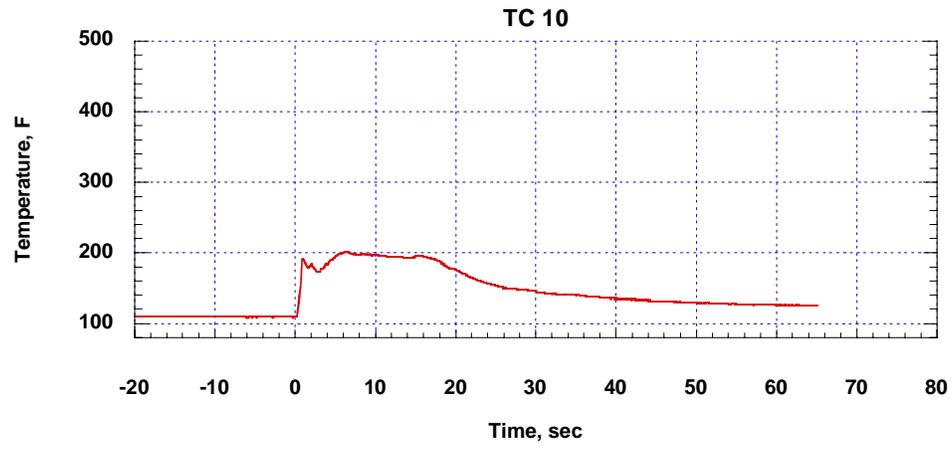
Test 14
Temperature vs Time



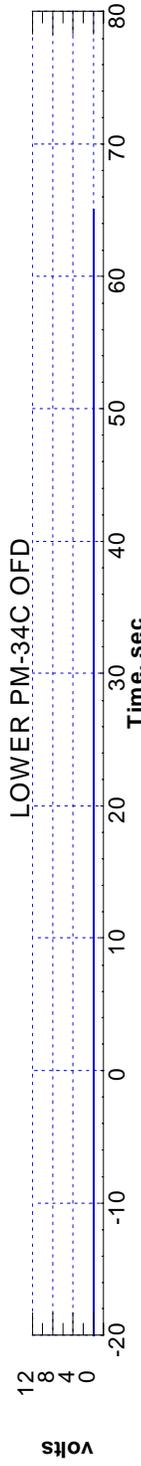
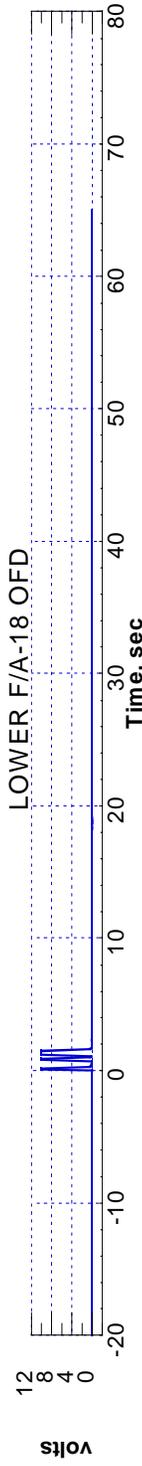
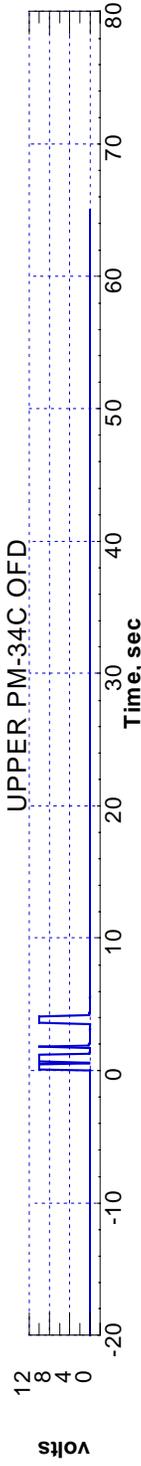
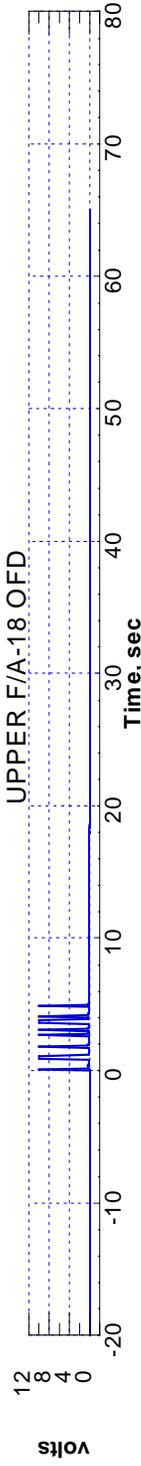
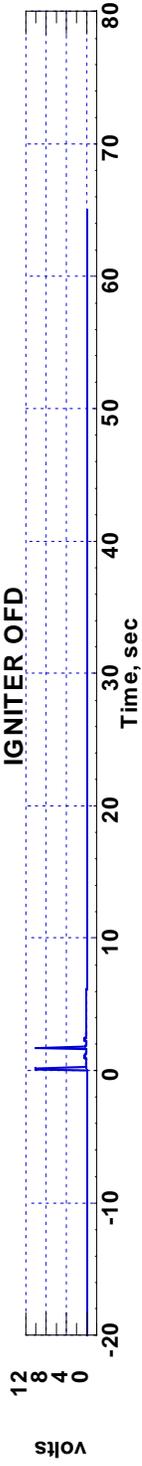
Test 14
Temperature vs Time



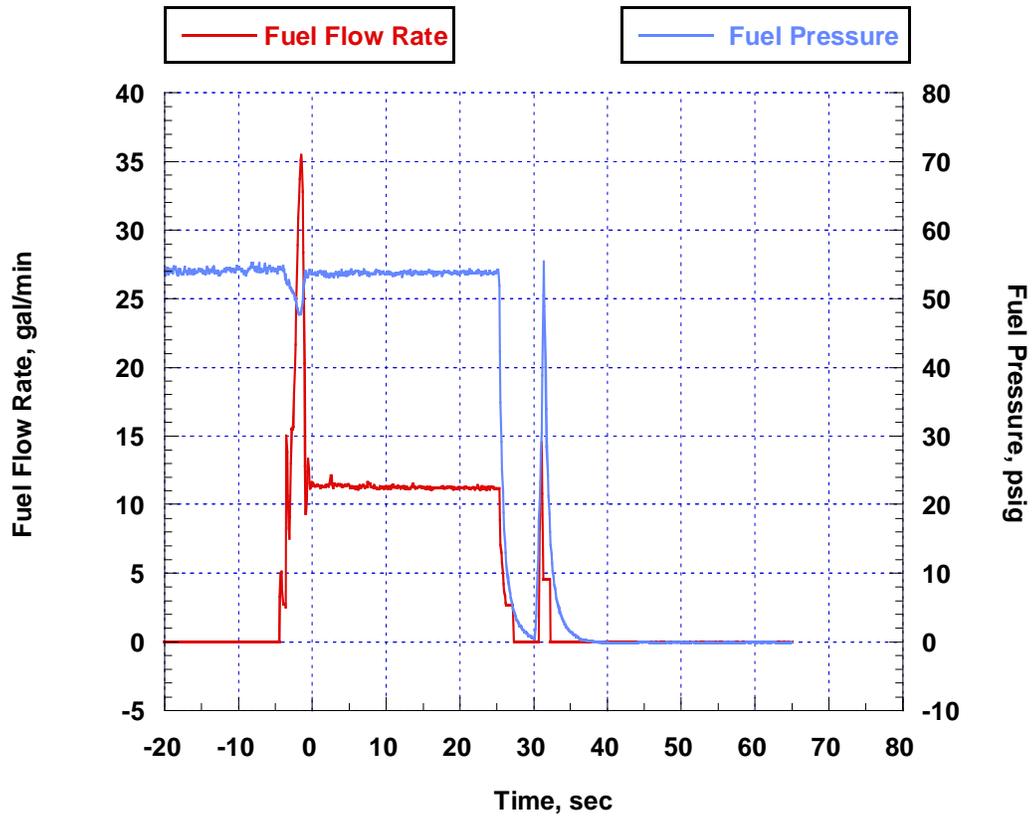
Test 14
Temperature vs Time



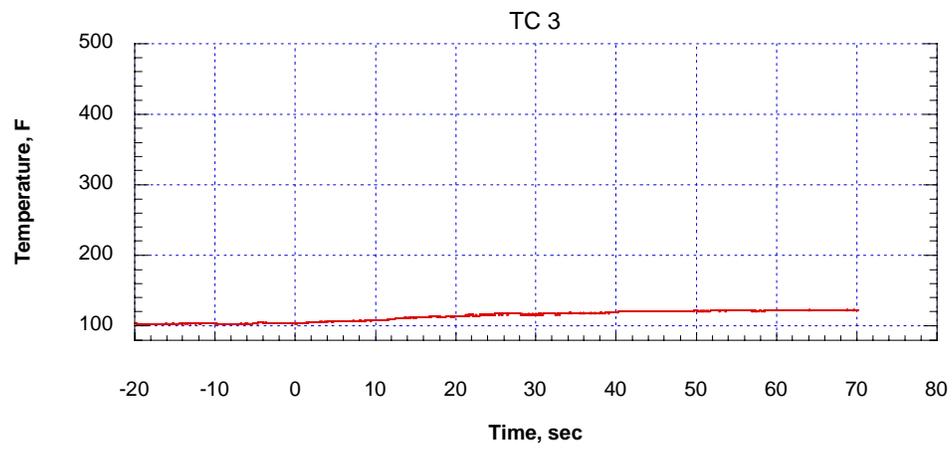
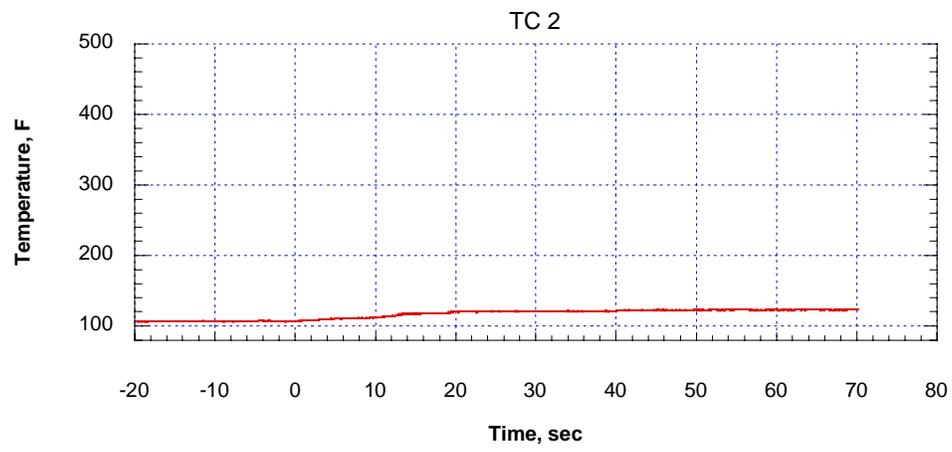
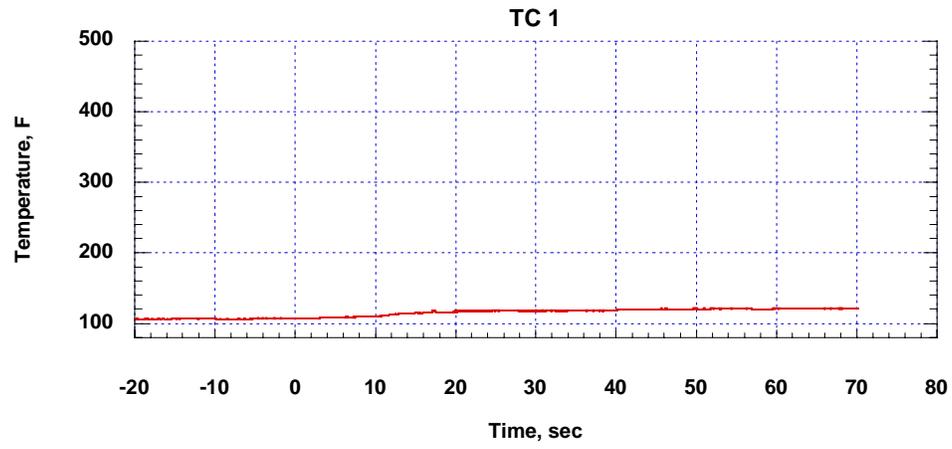
Test 14
Optical Fire Detector Signal vs Time



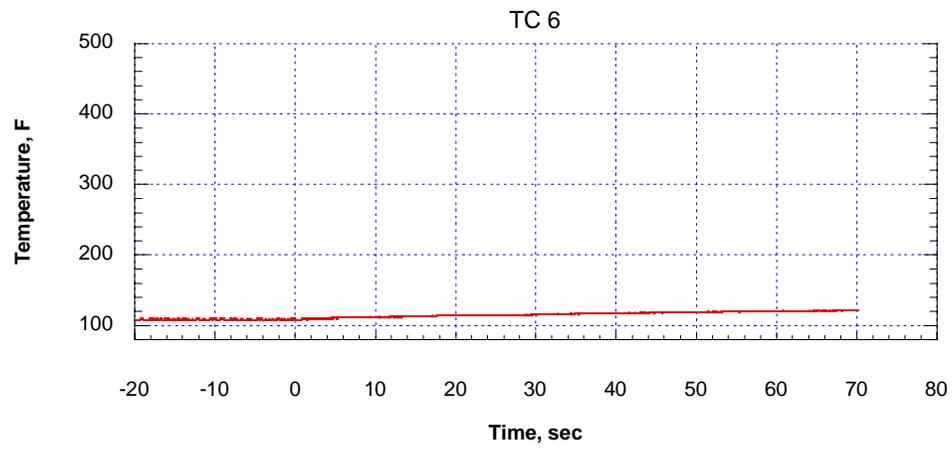
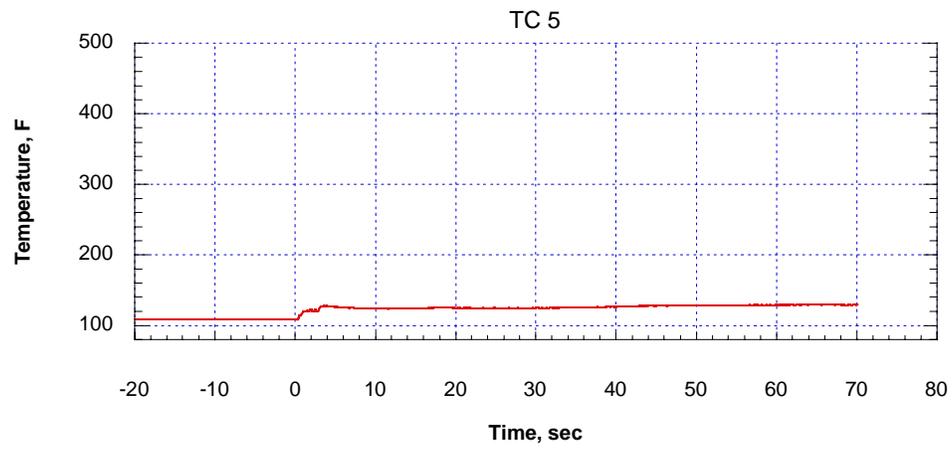
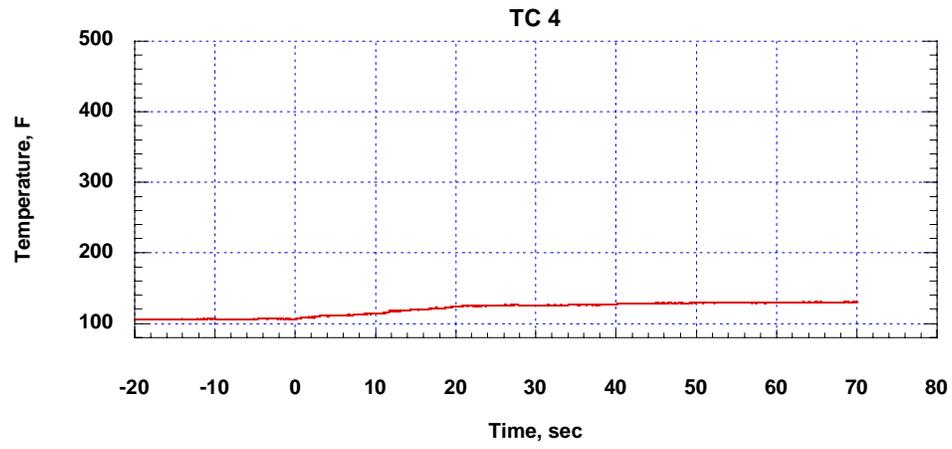
Test 14
Fuel Pressure and Flow Rate vs Time



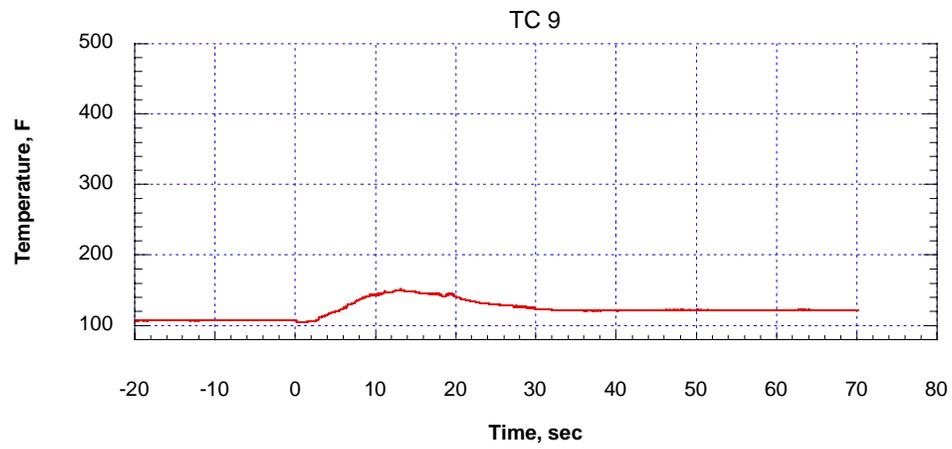
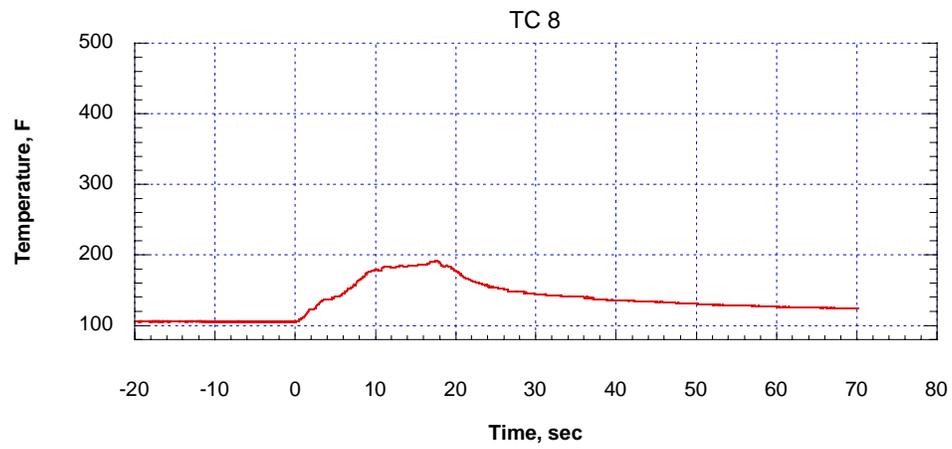
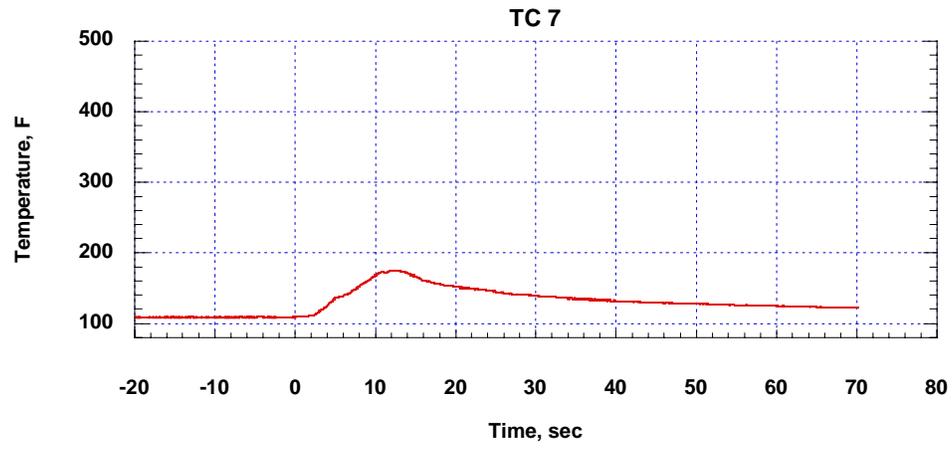
Test 15
Temperature vs Time



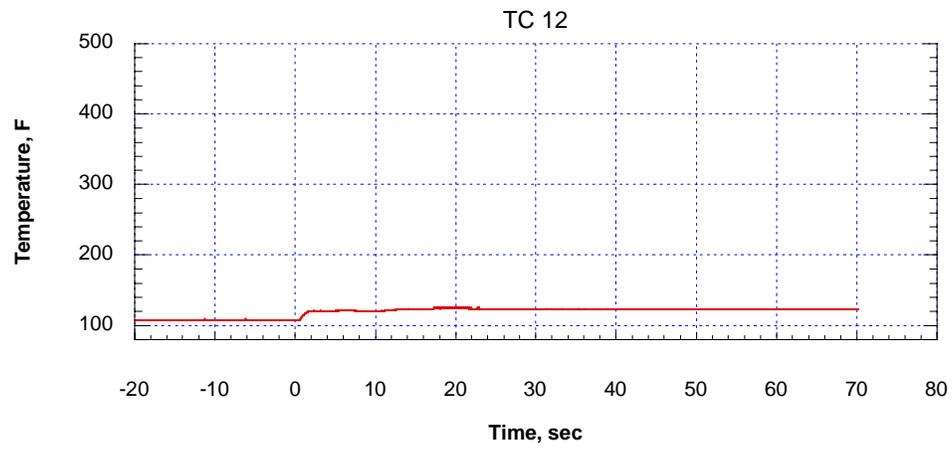
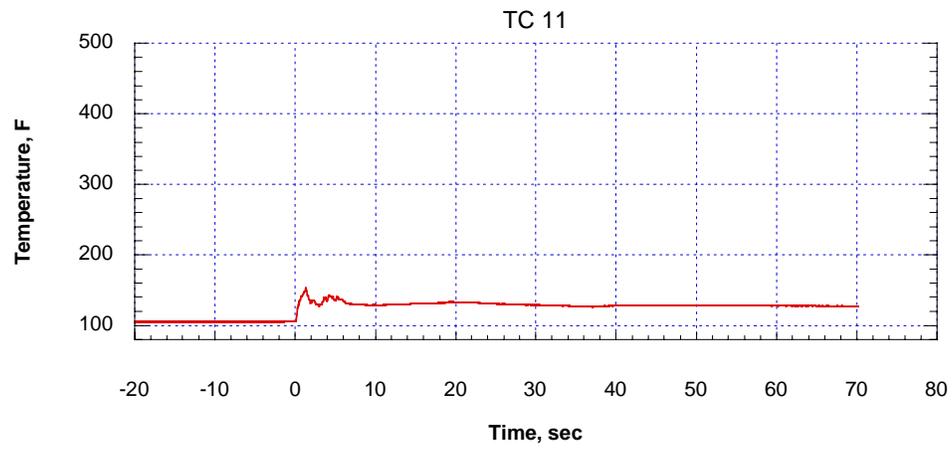
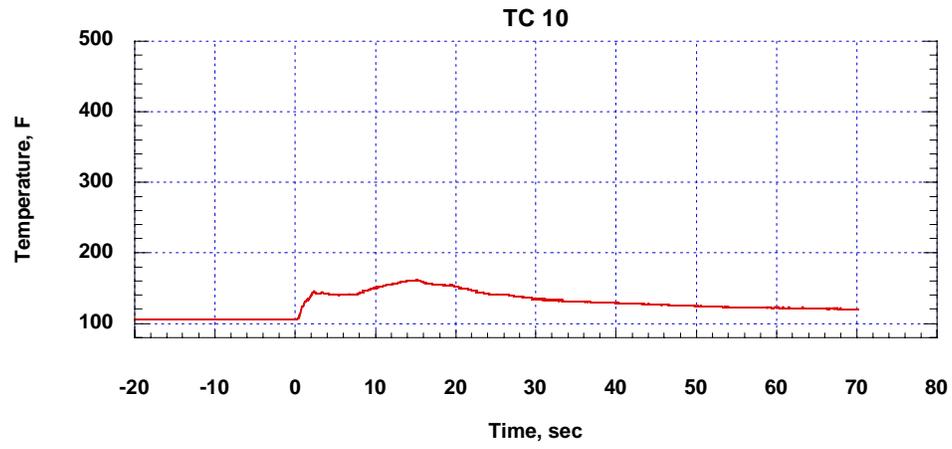
Test 15
Temperature vs Time



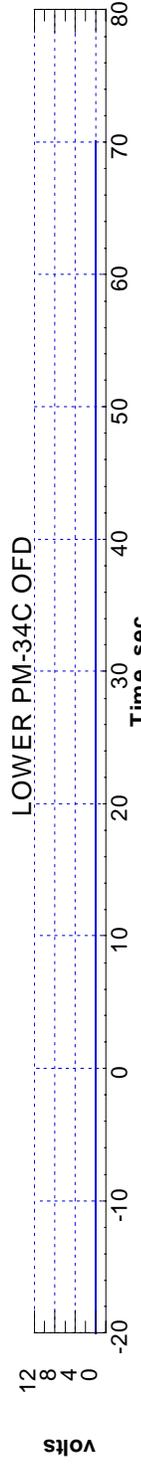
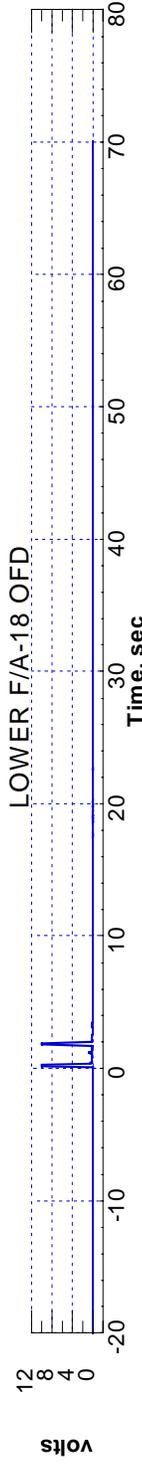
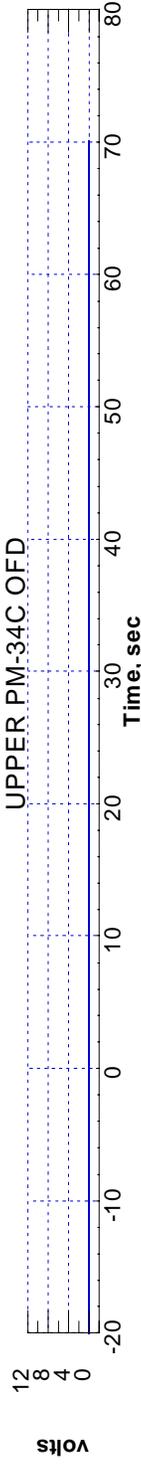
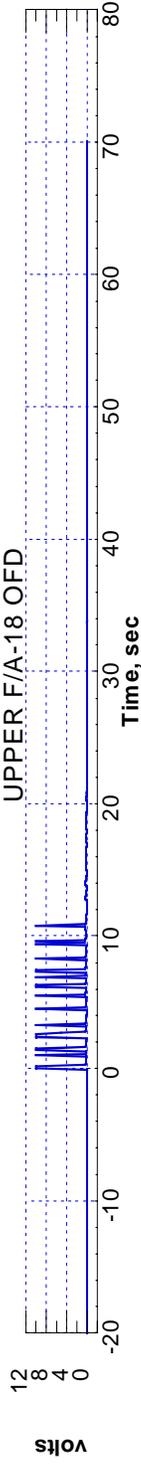
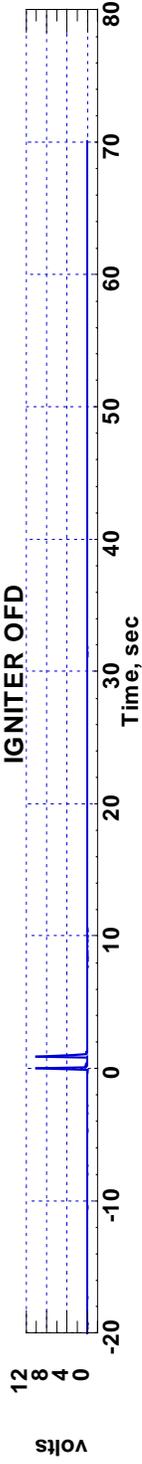
Test 15
Temperature vs Time



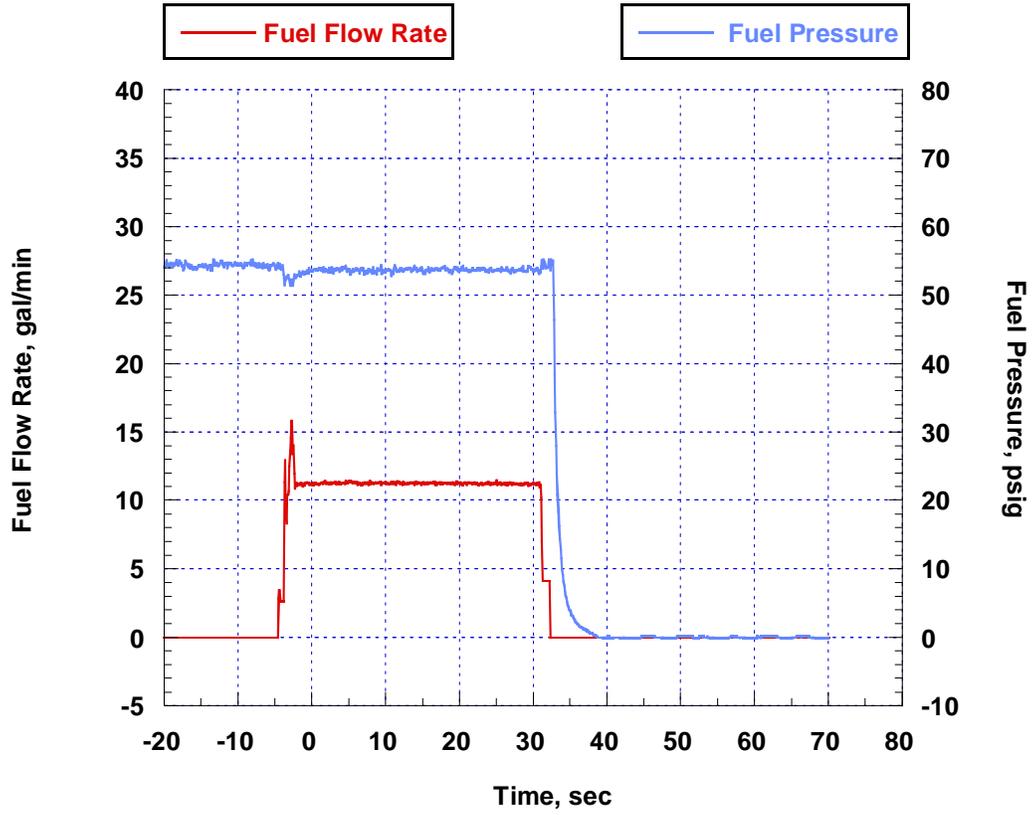
Test 15
Temperature vs Time



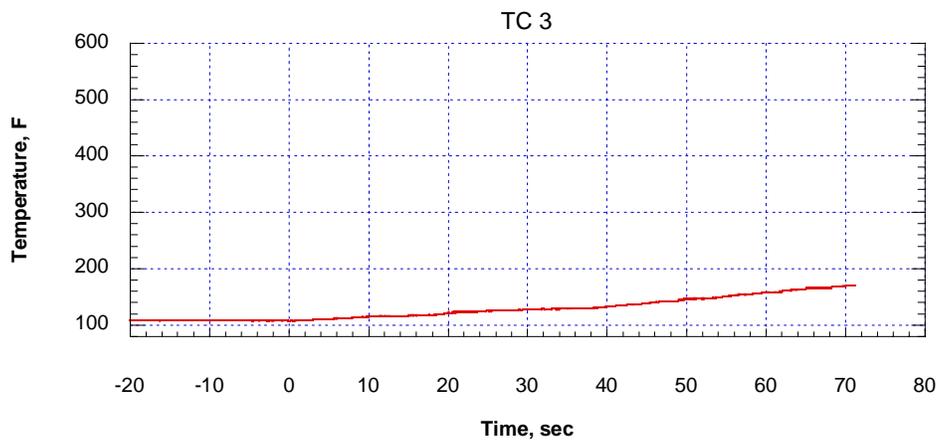
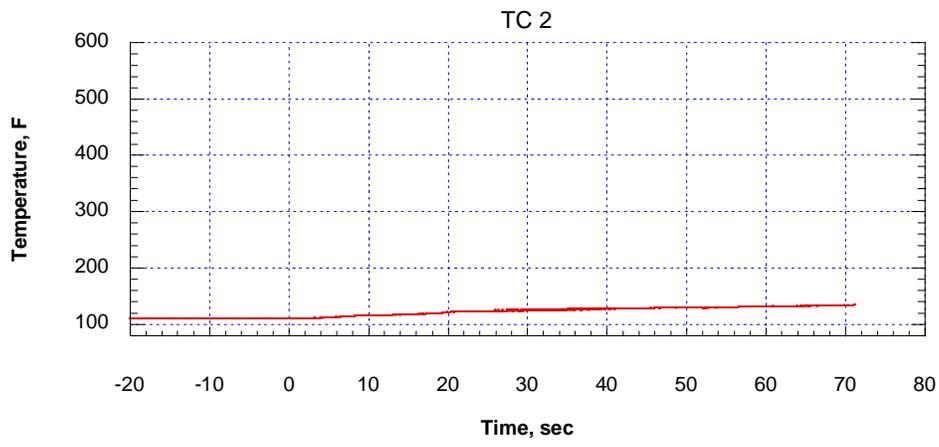
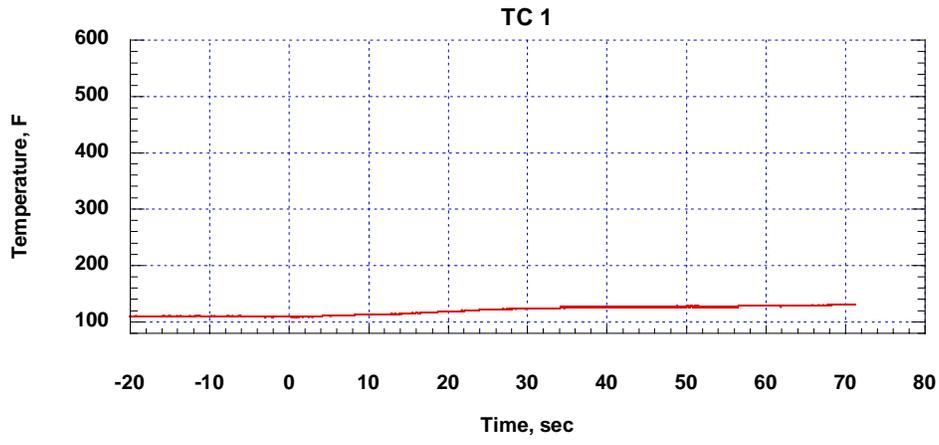
Test 15
Optical Fire Detector Signal vs Time



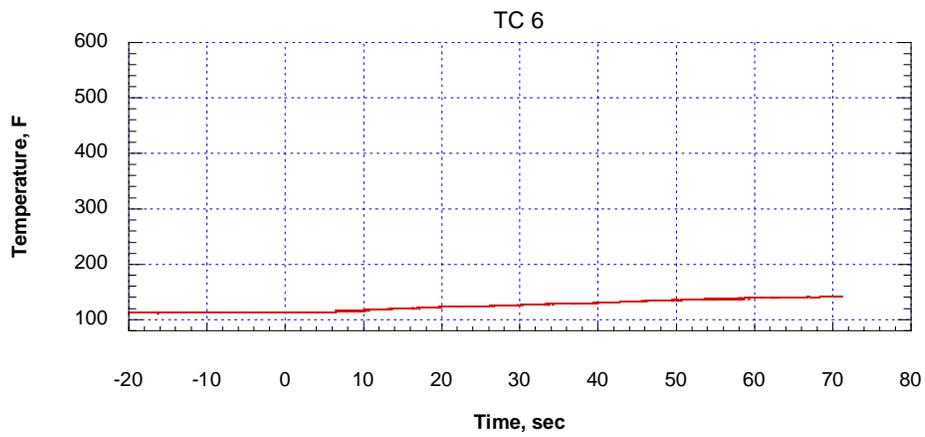
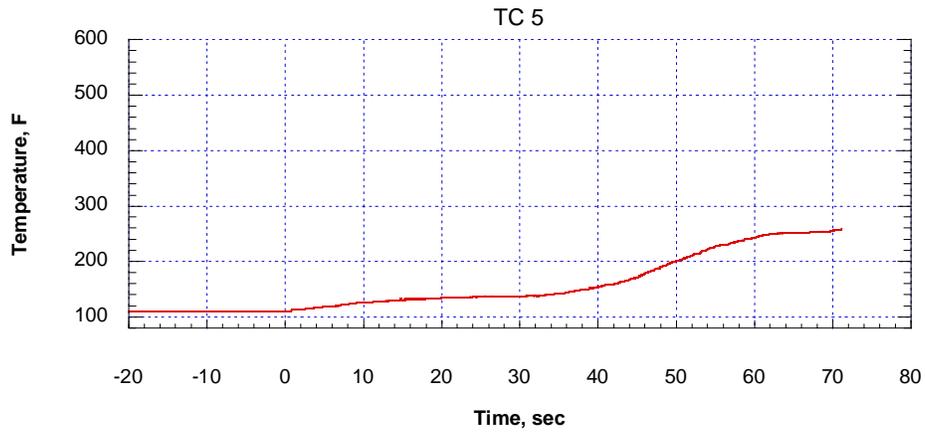
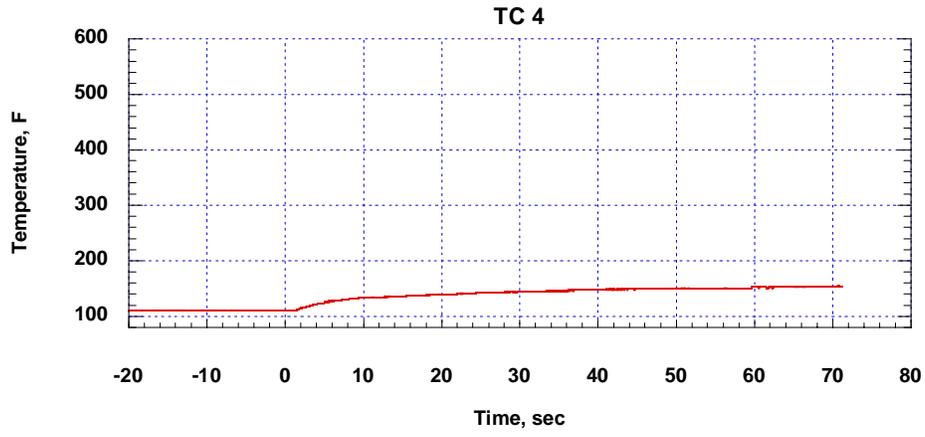
Test 15
Fuel Pressure and Flow Rate vs Time



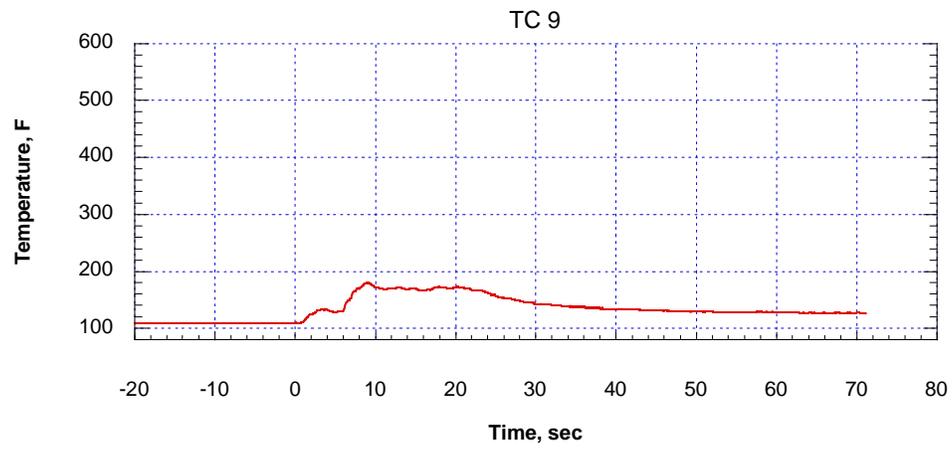
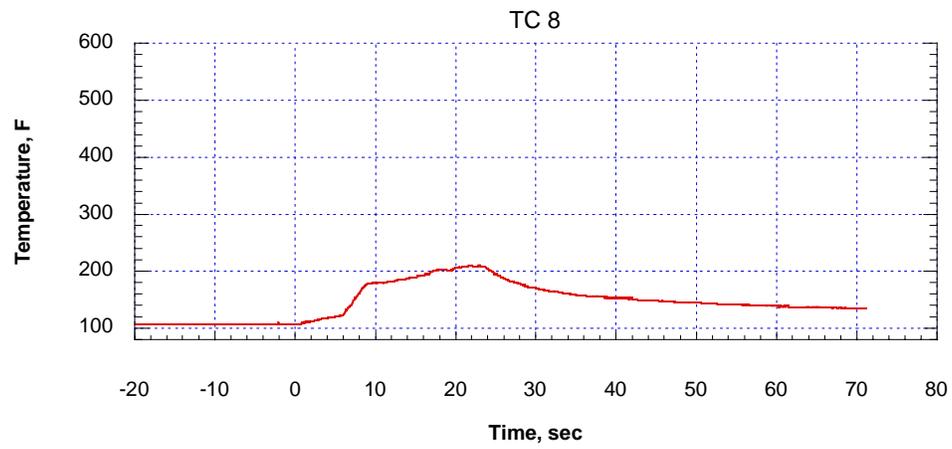
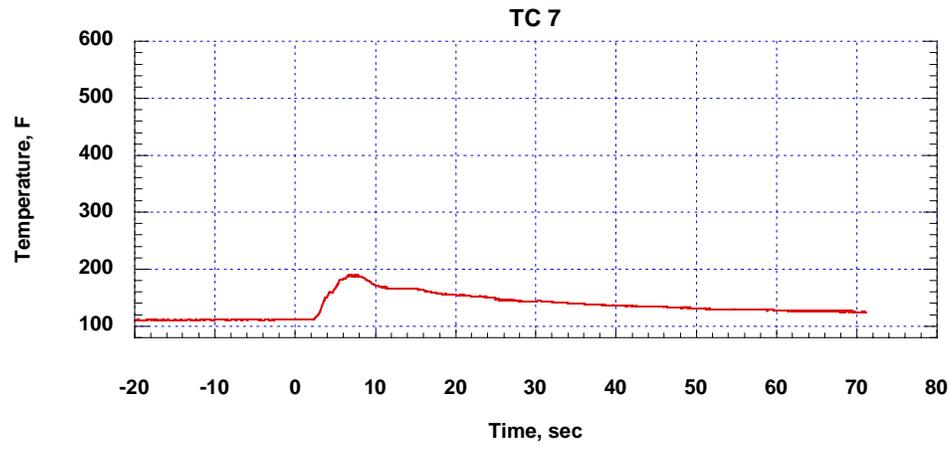
Test 16
Temperature vs Time



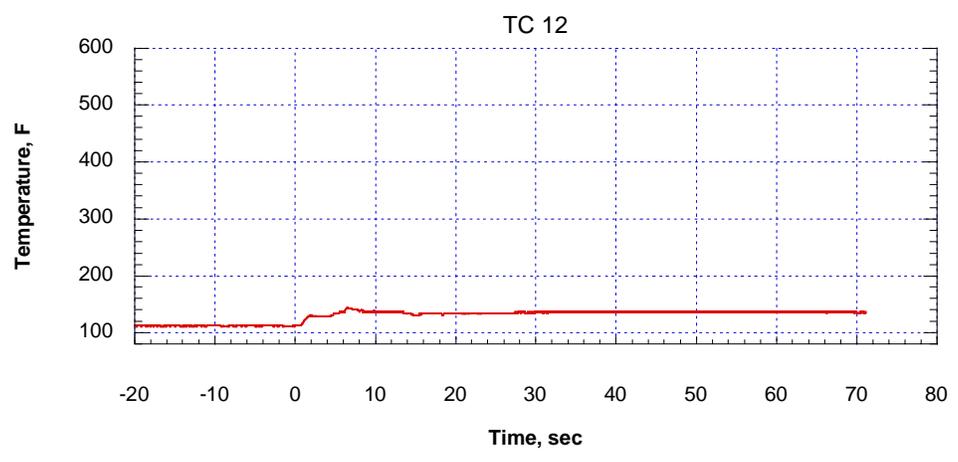
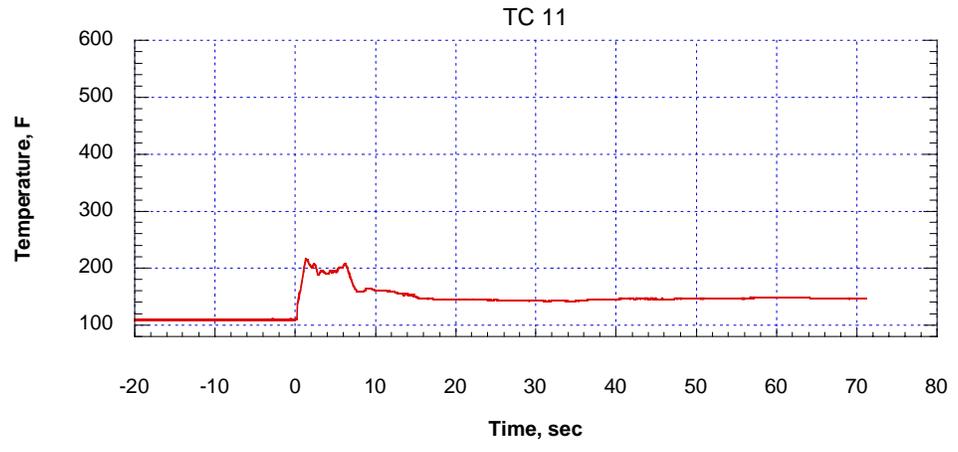
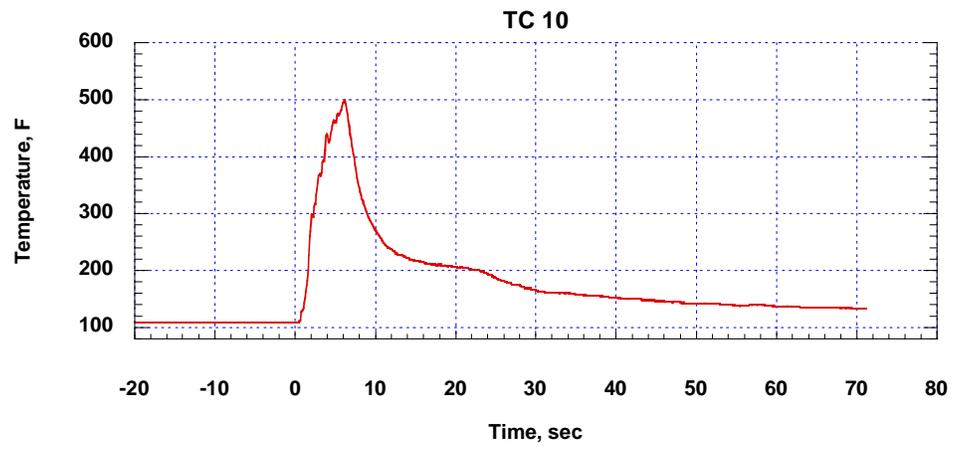
Test 16
Temperature vs Time



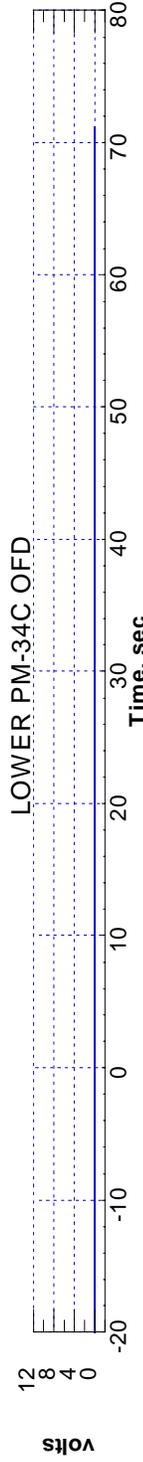
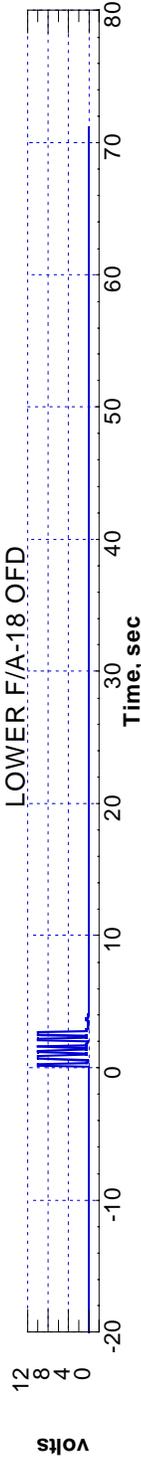
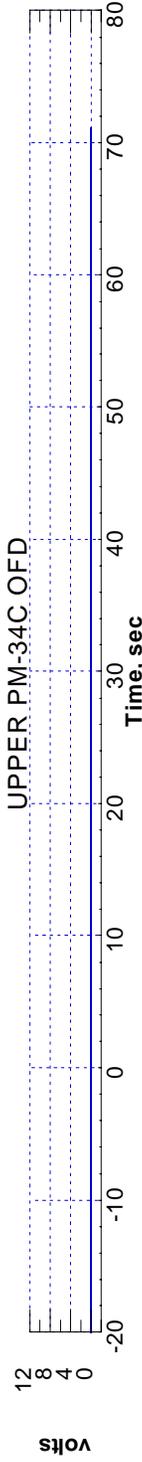
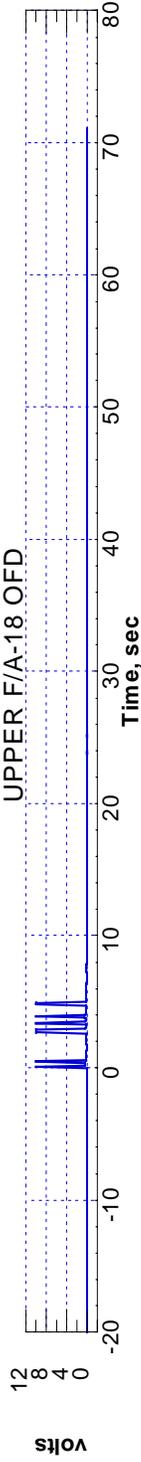
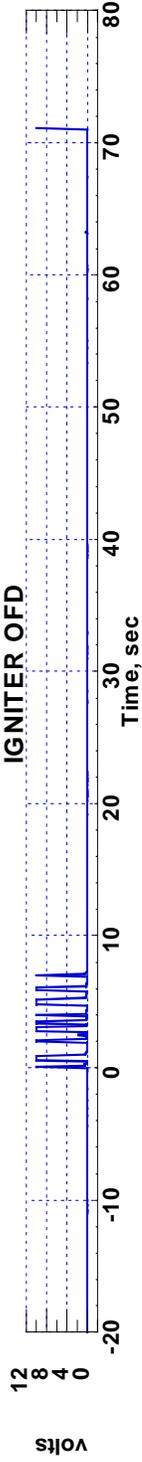
Test 16
Temperature vs Time



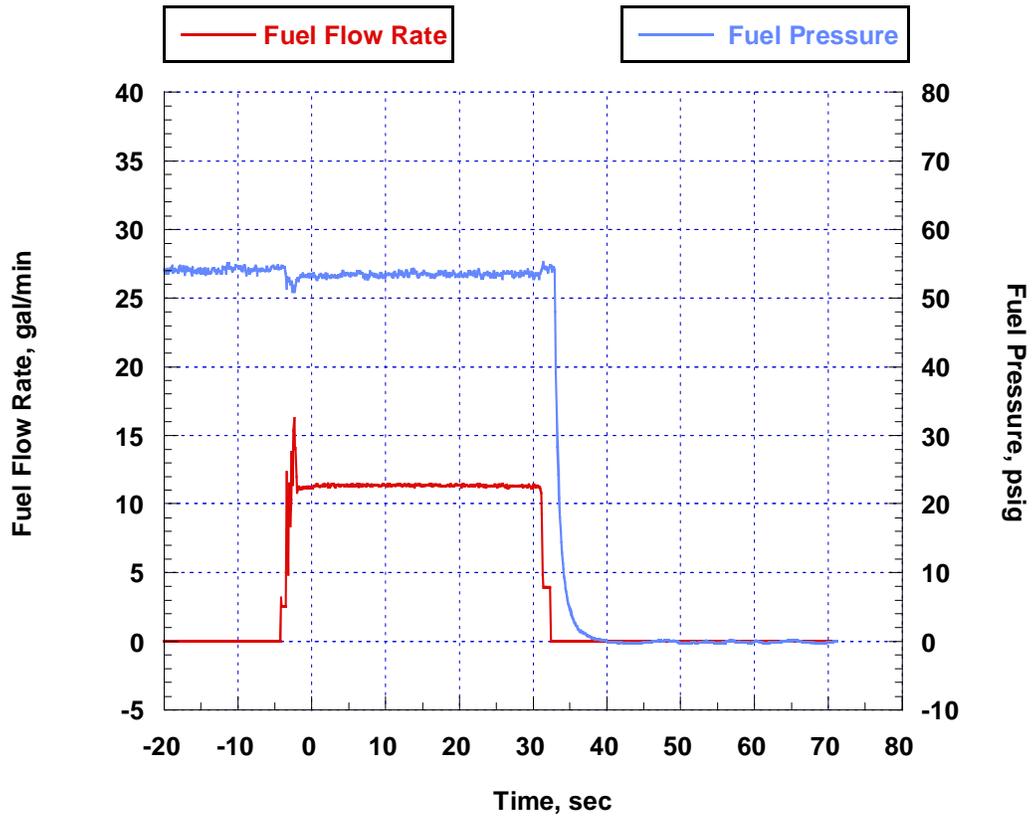
Test 16
Temperature vs Time



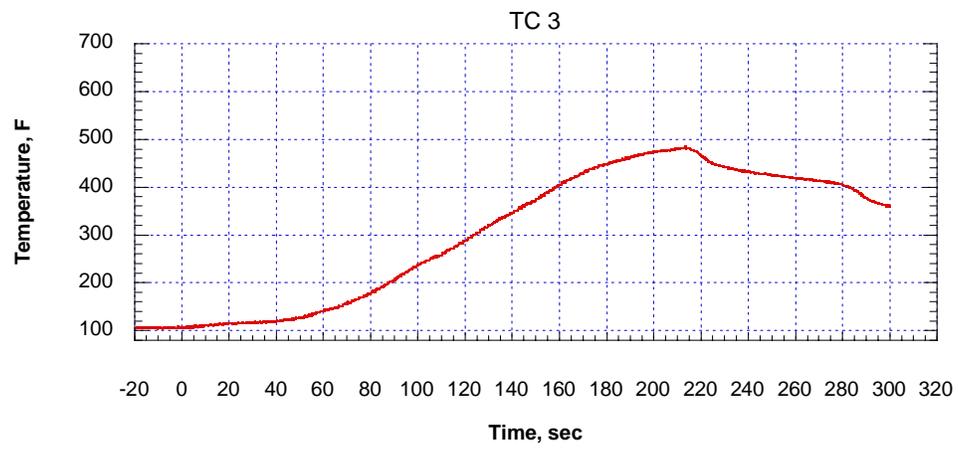
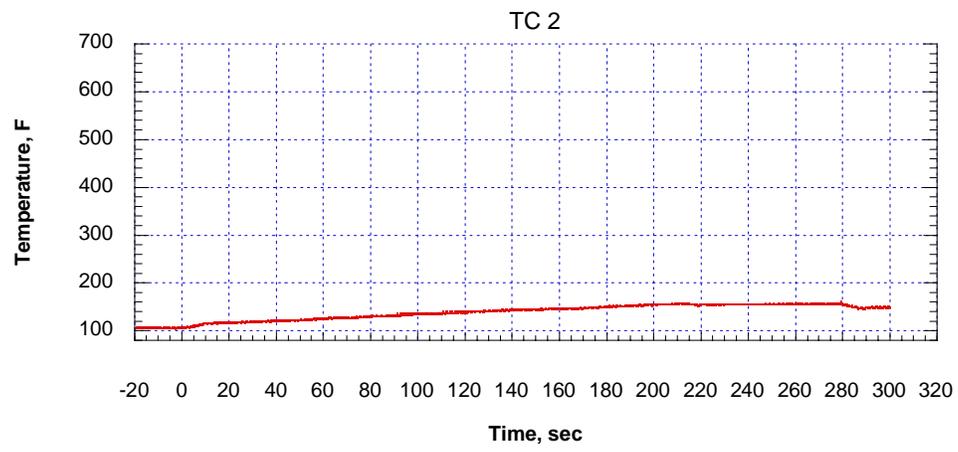
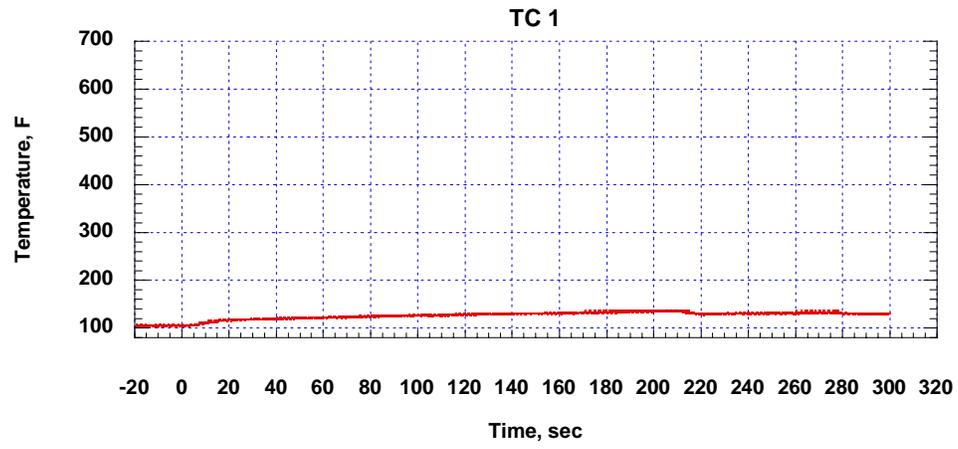
Test 16
Optical Fire Detector Signal vs Time



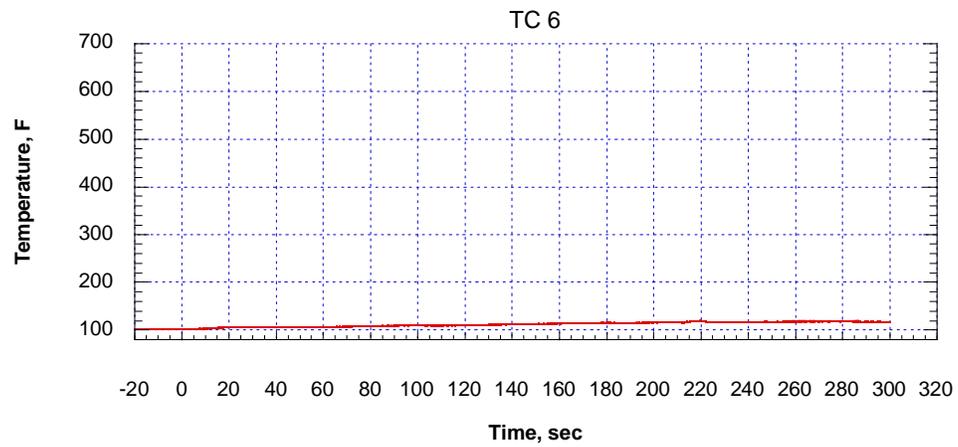
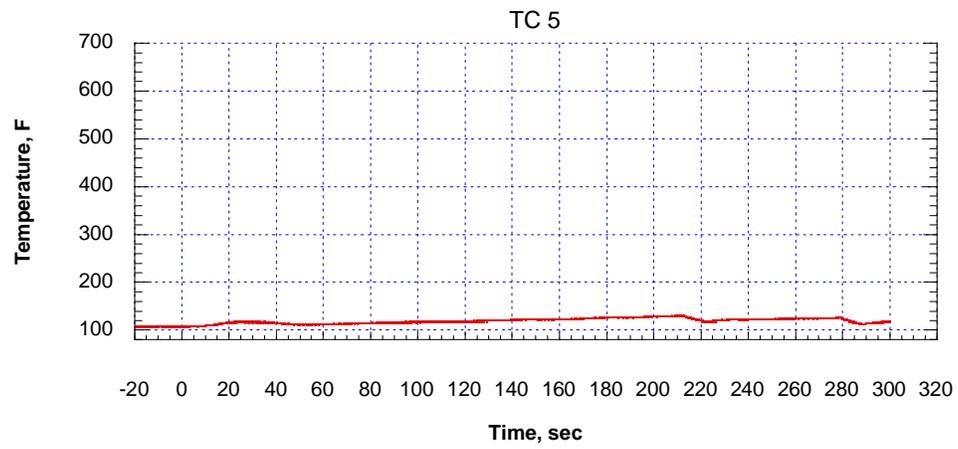
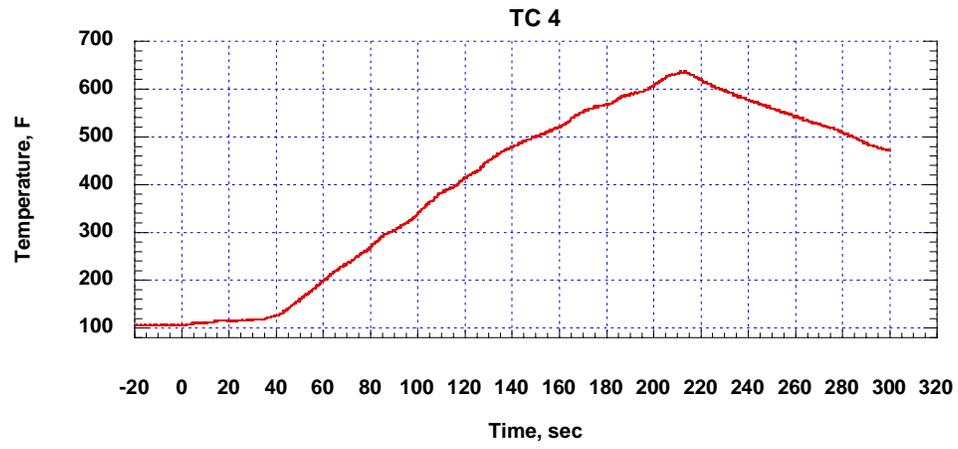
Test 16
Fuel Pressure and Flow Rate vs Time



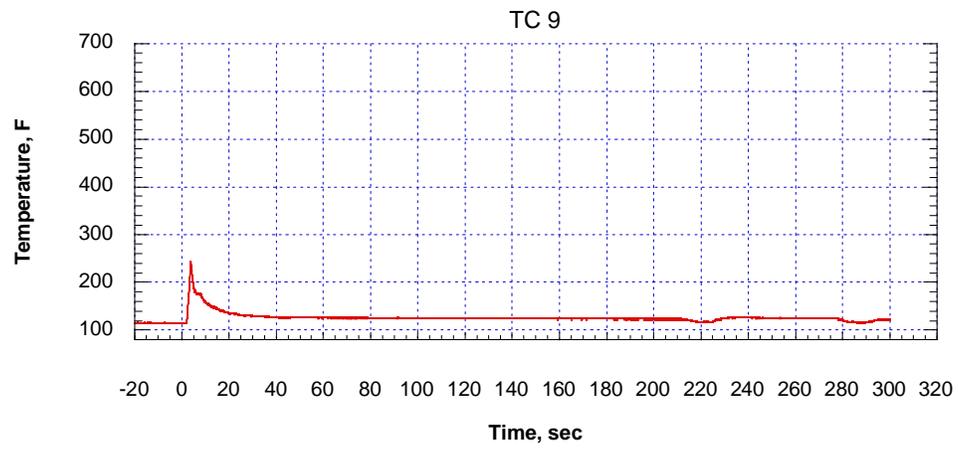
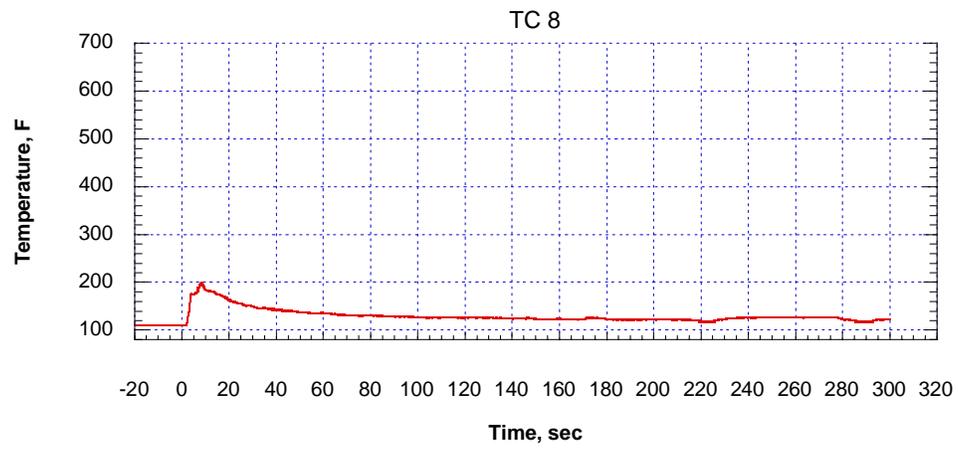
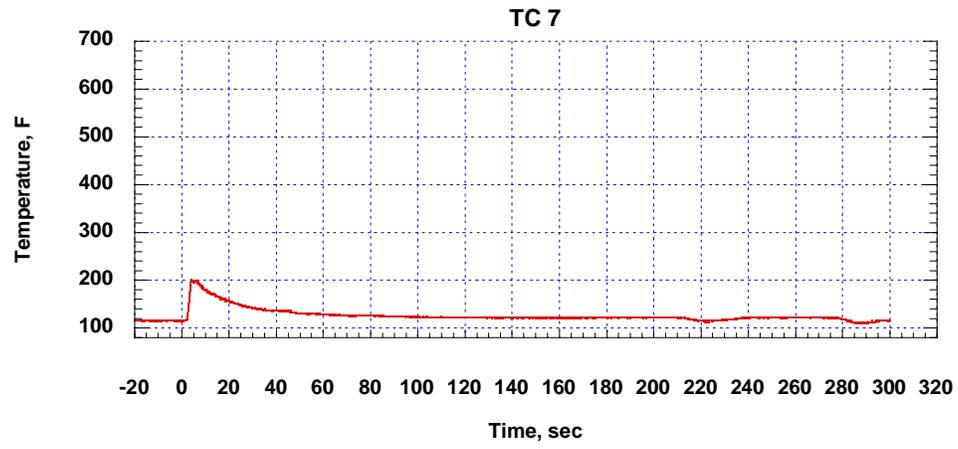
Test 17
Temperature vs Time



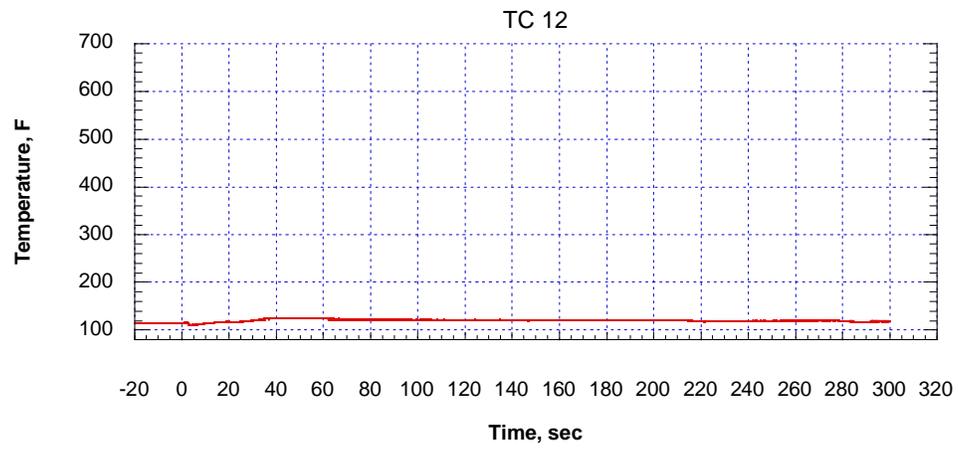
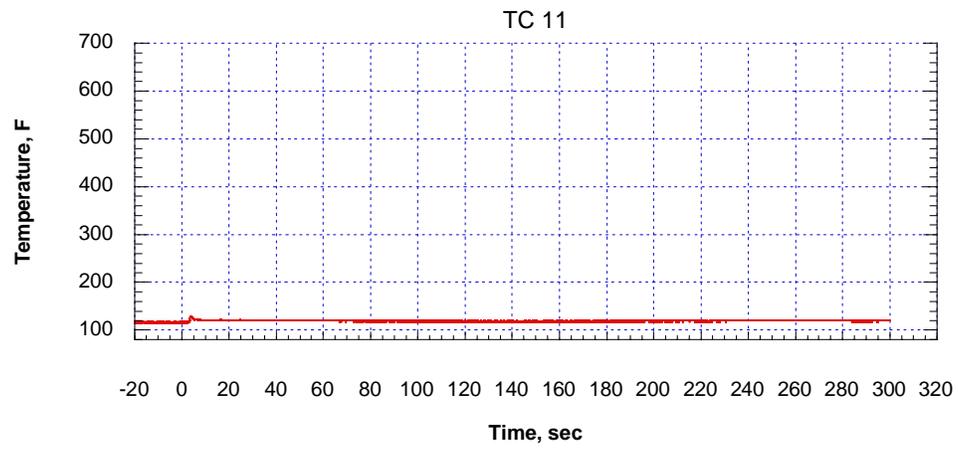
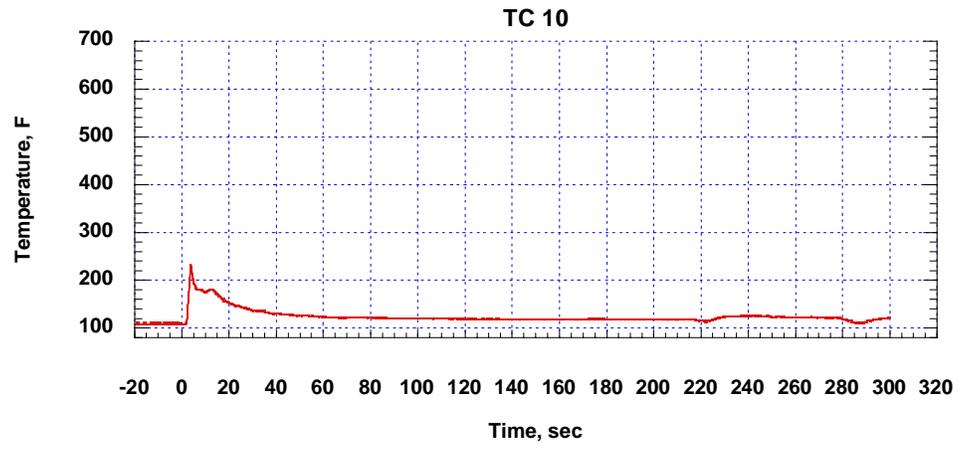
Test 17
Temperature vs Time



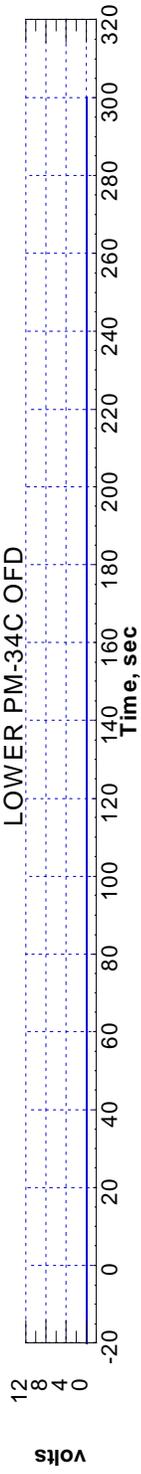
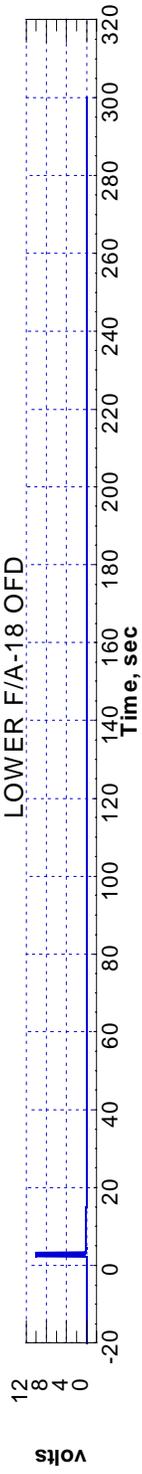
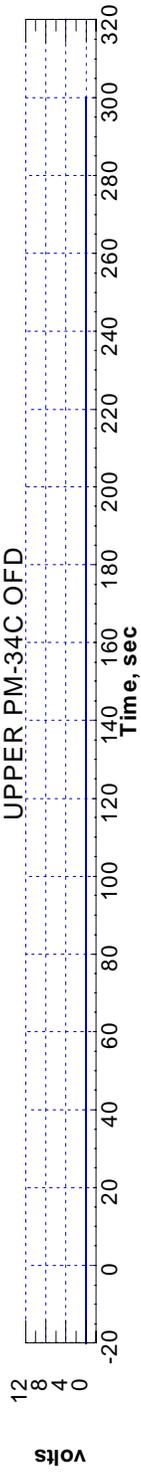
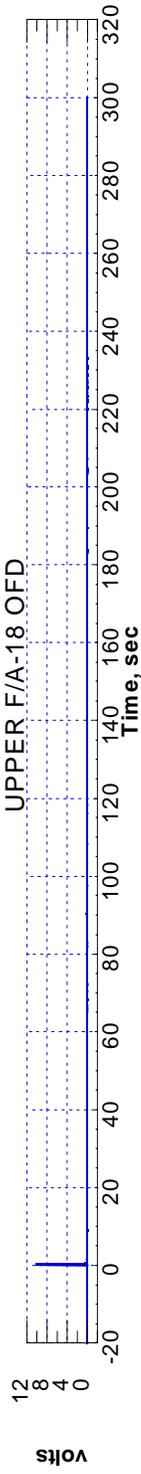
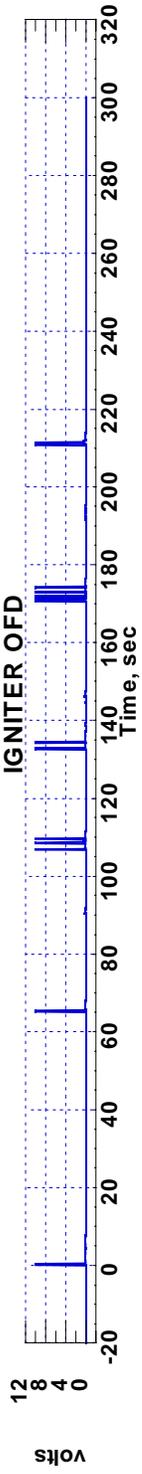
Test 17
Temperature vs Time



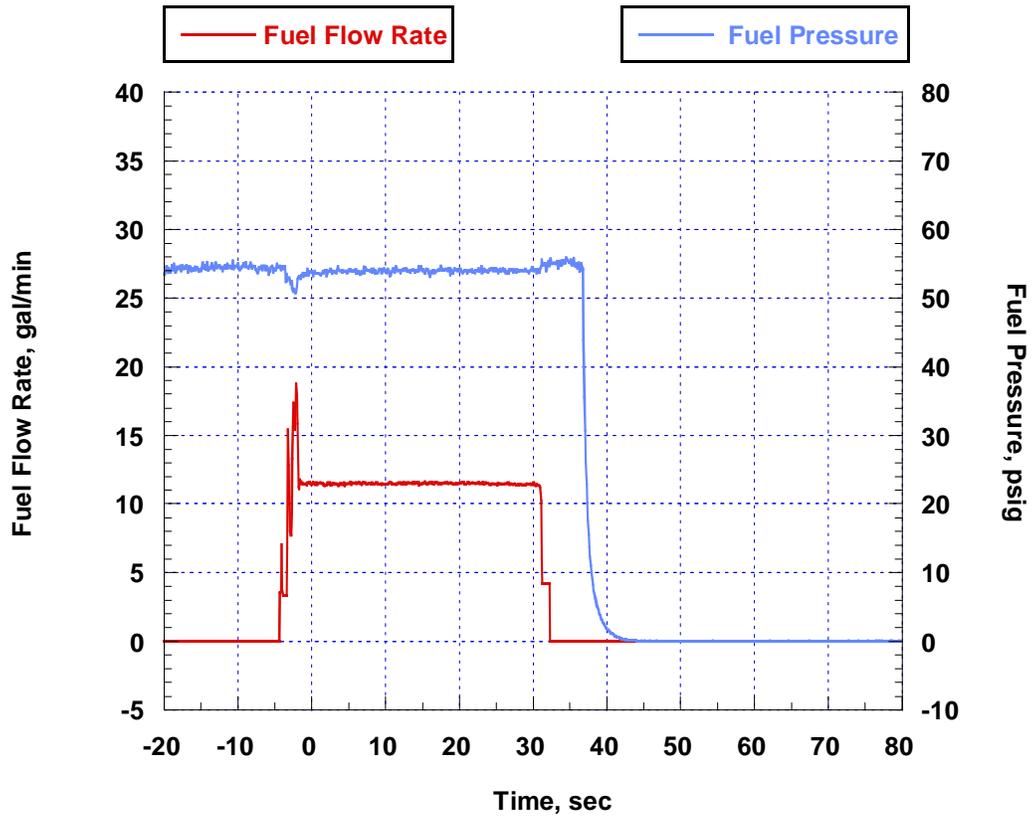
Test 17
Temperature vs Time



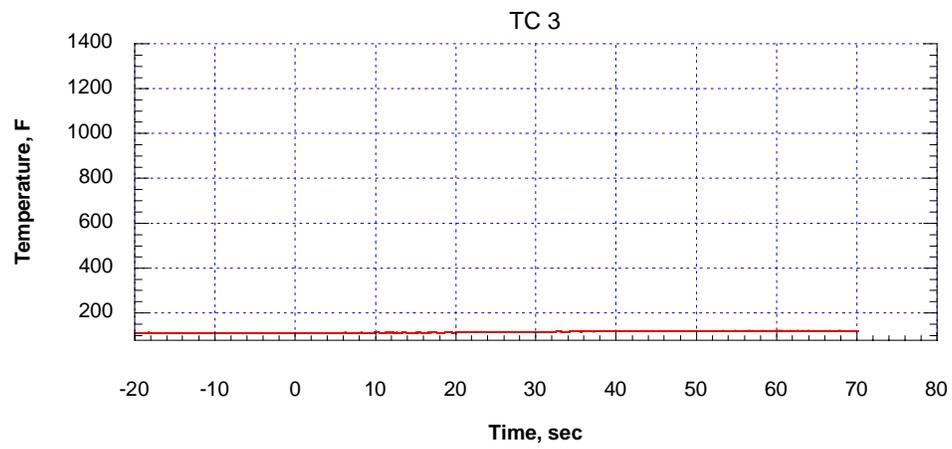
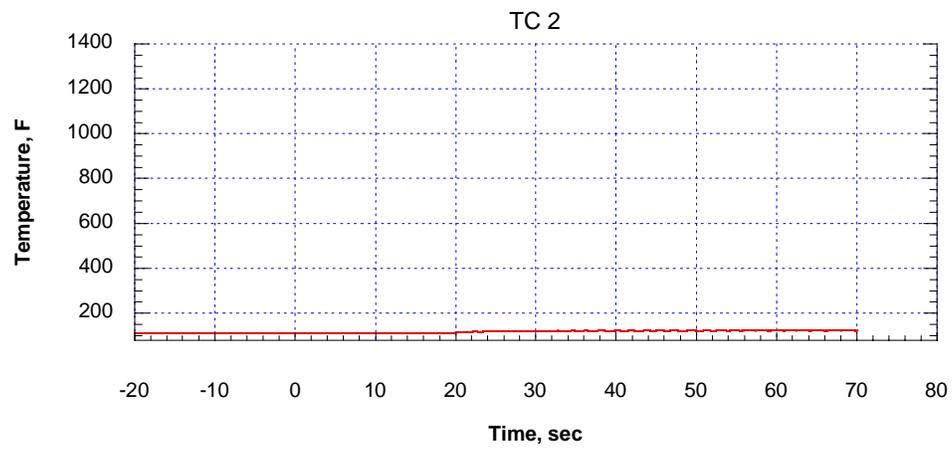
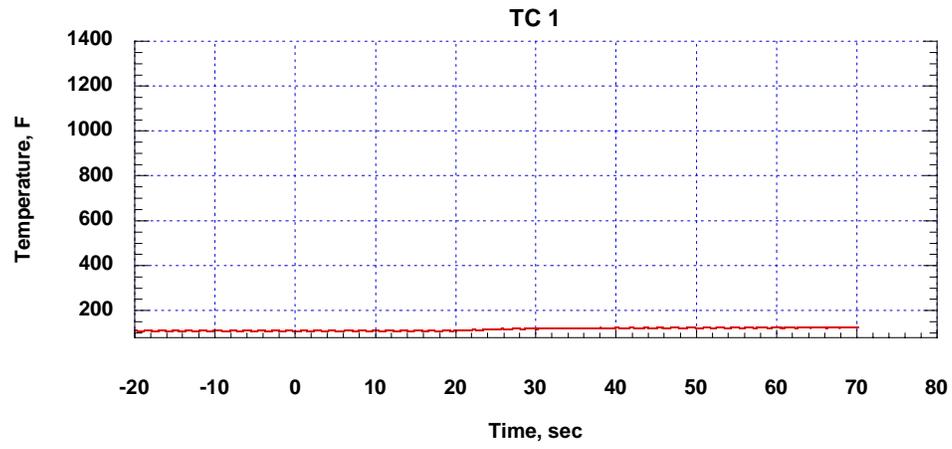
Test 17
Optical Fire Detector Signal vs Time



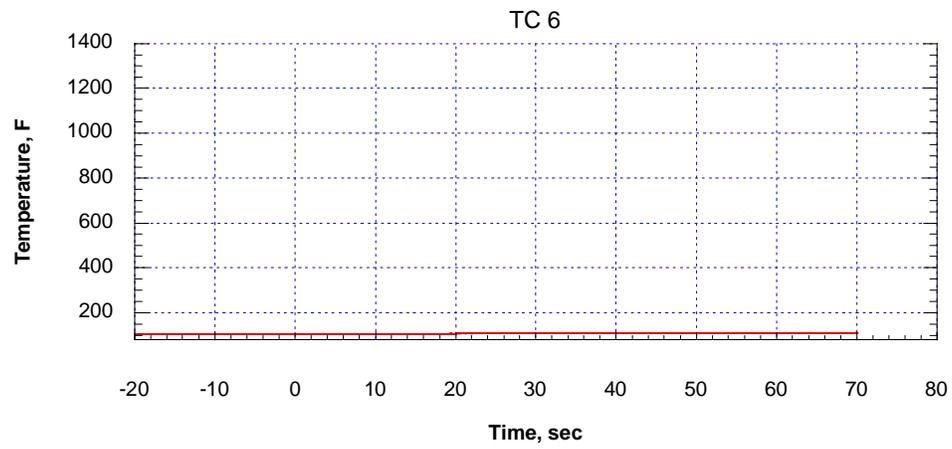
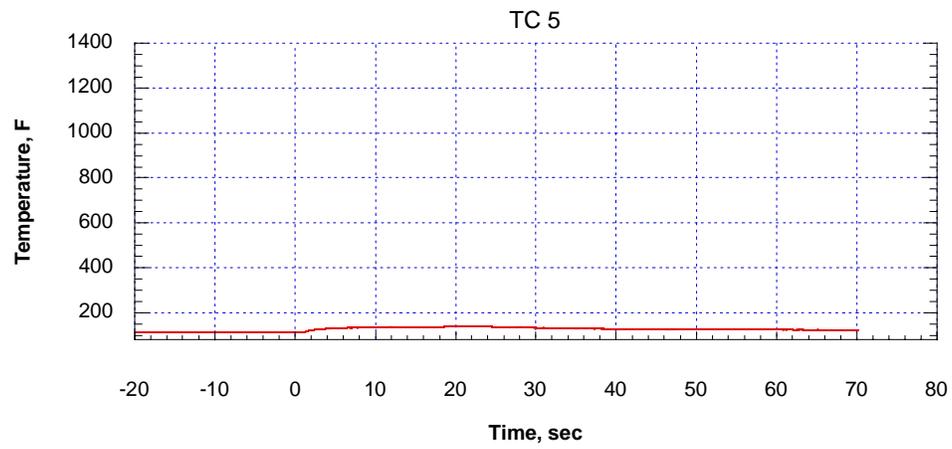
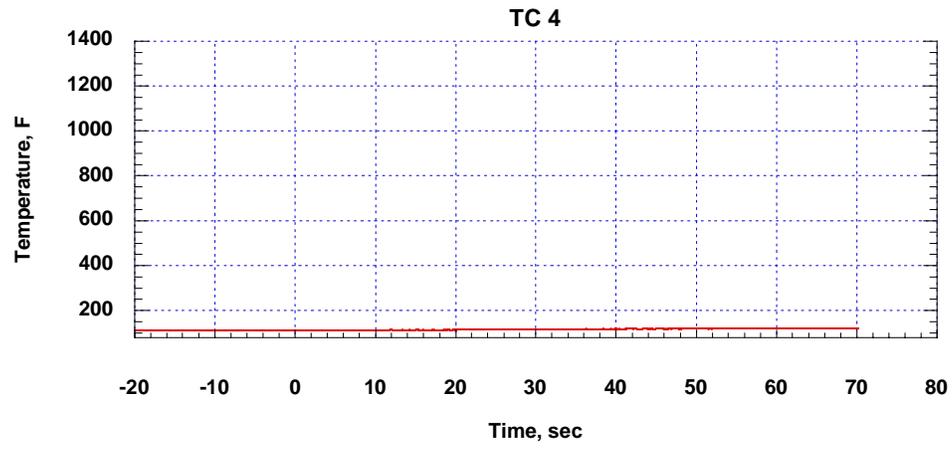
Test 17
Fuel Pressure and Flow Rate vs Time



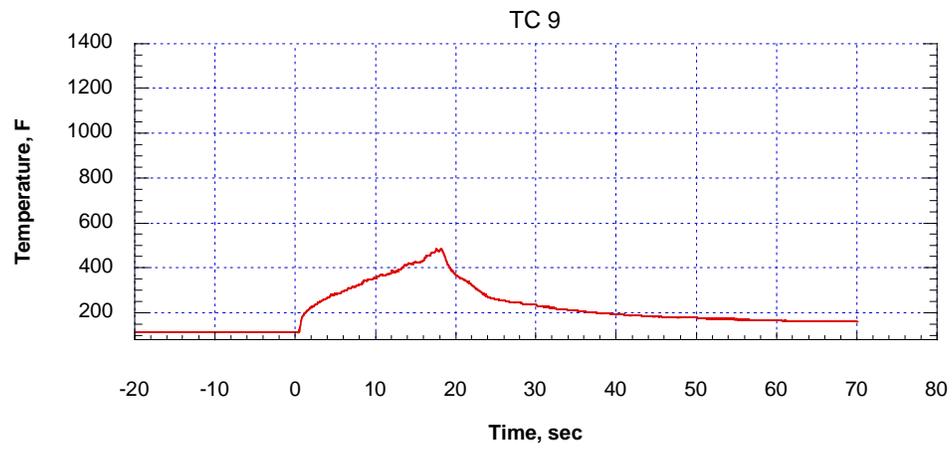
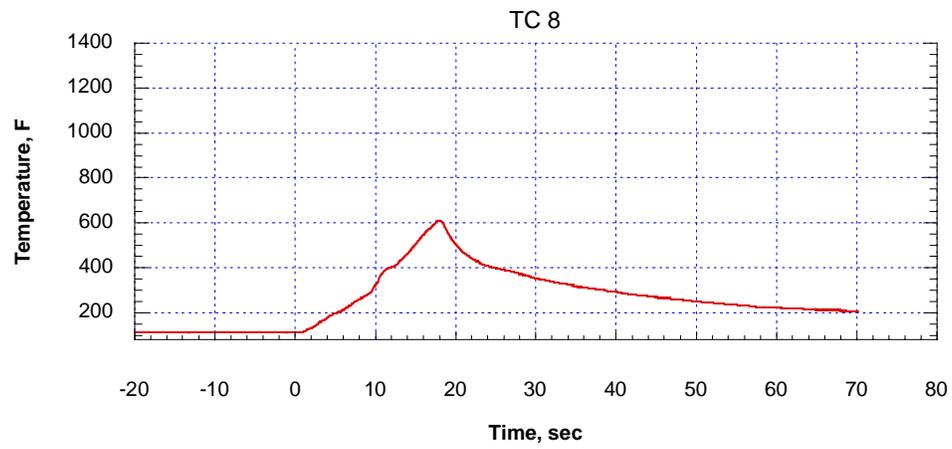
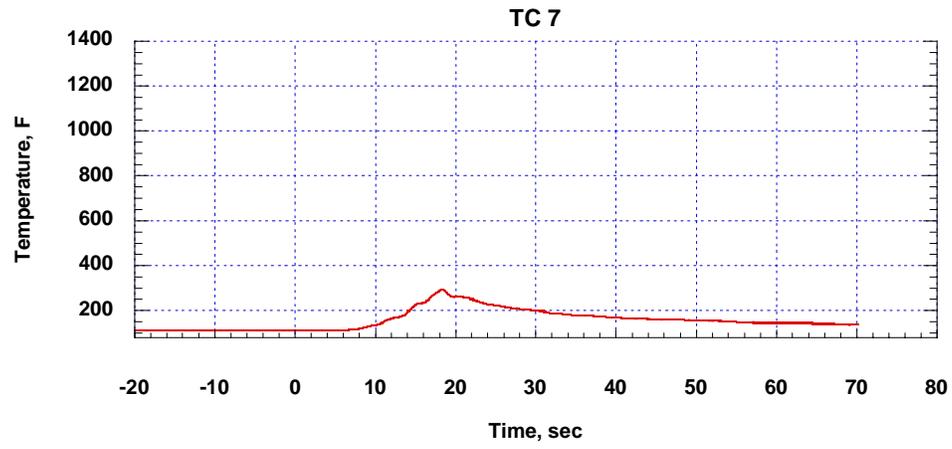
Test 18
Temperature vs Time



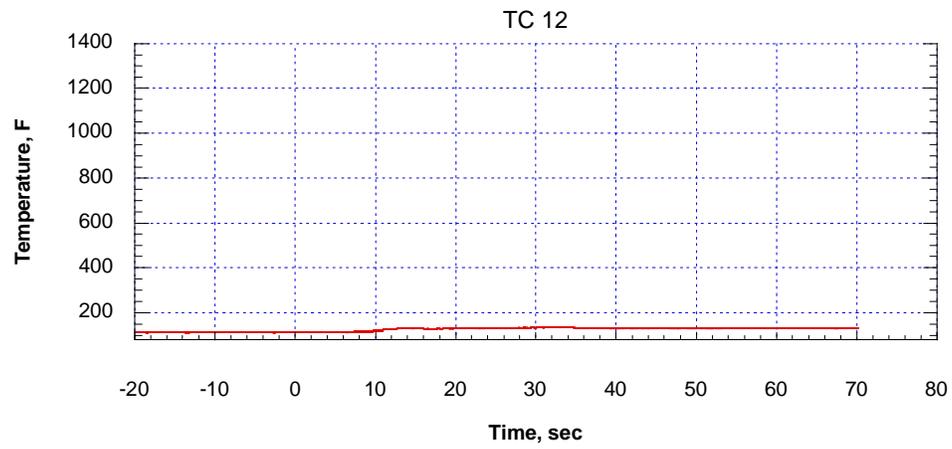
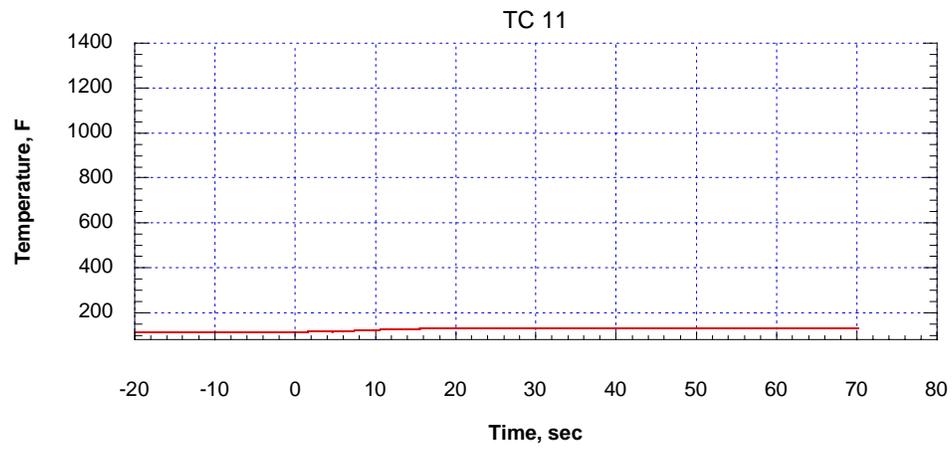
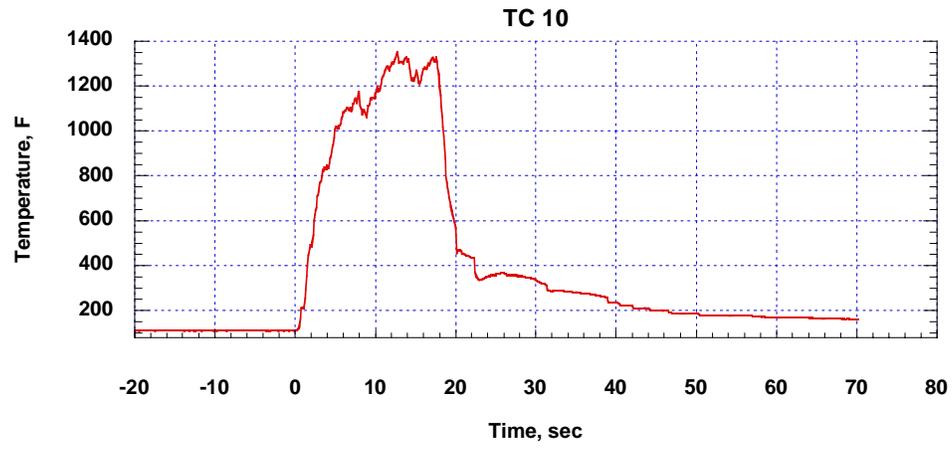
Test 18
Temperature vs Time



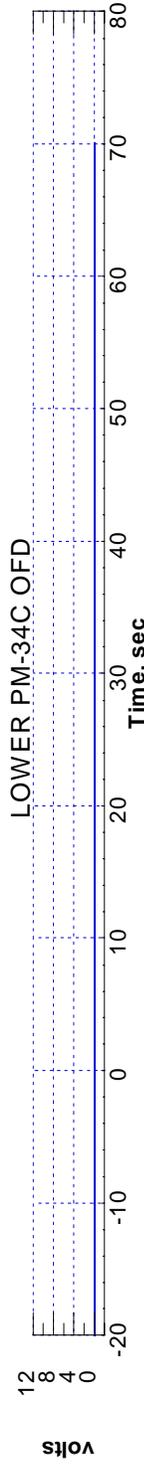
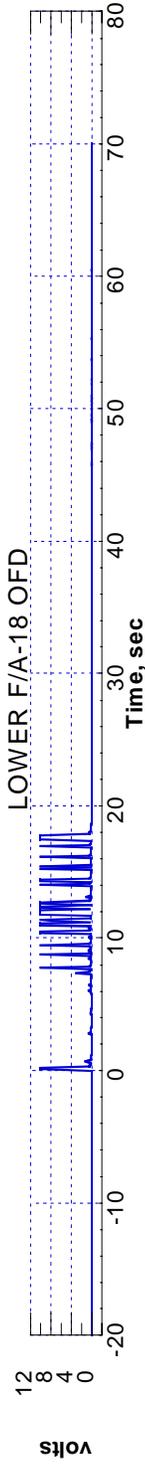
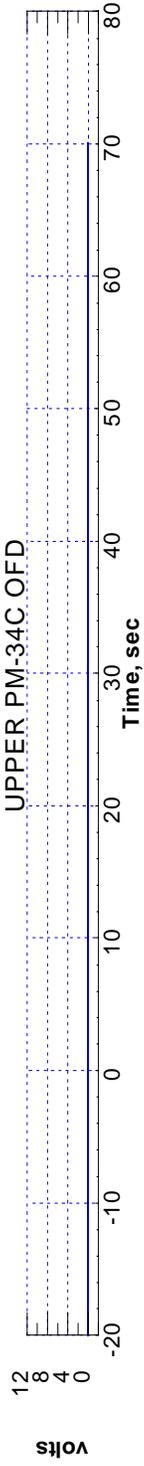
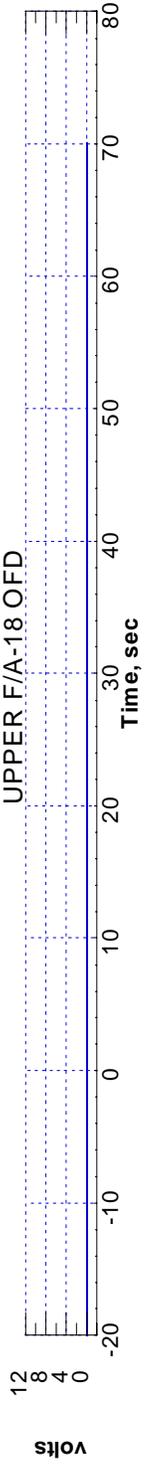
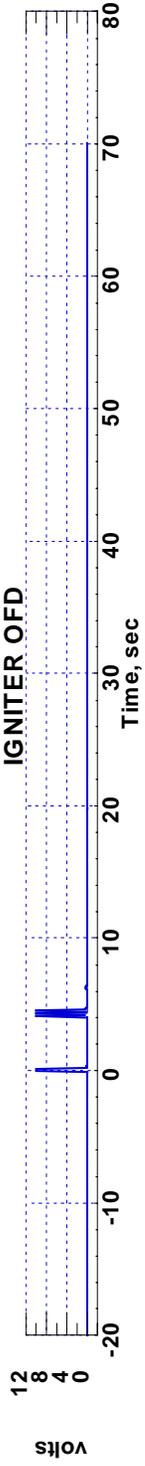
Test 18
Temperature vs Time



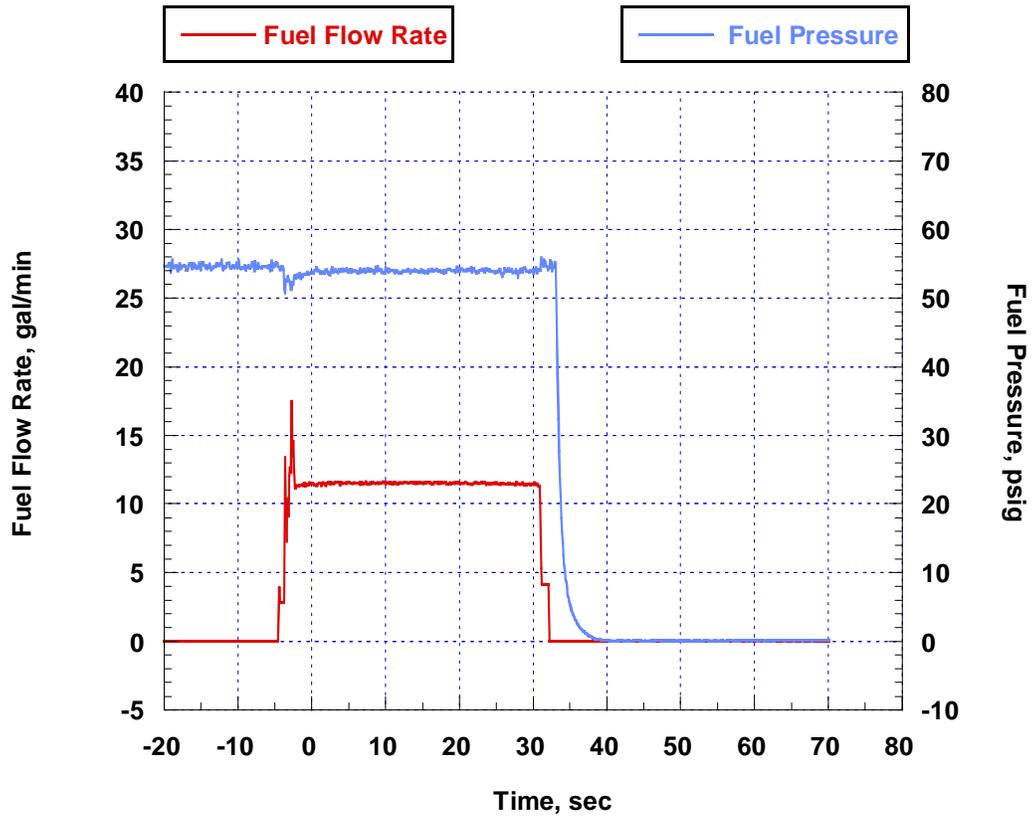
Test 18
Temperature vs Time



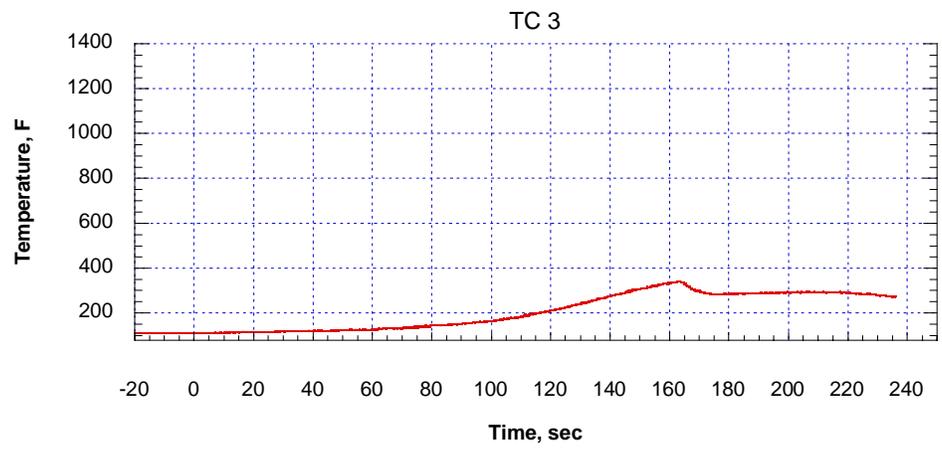
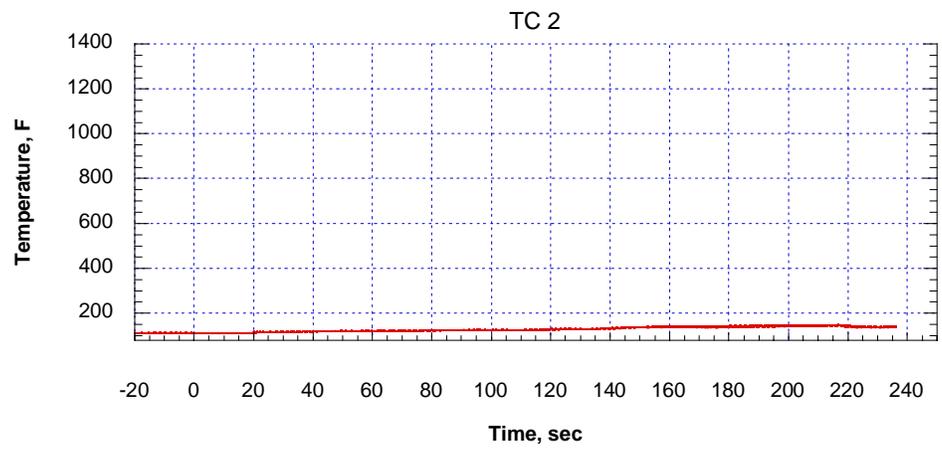
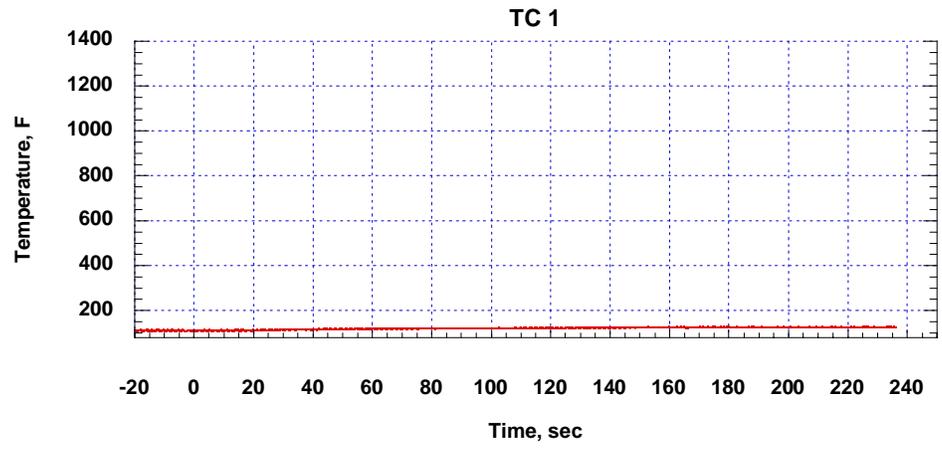
Test 18
Optical Fire Detector Signal vs Time



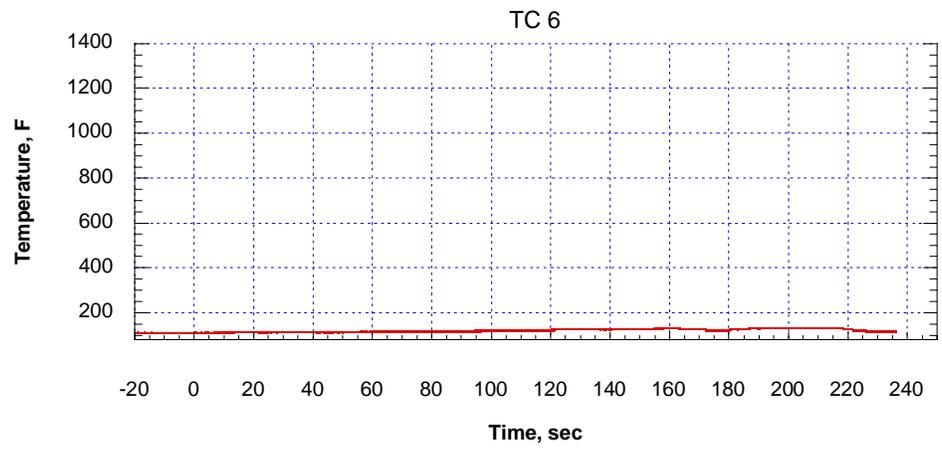
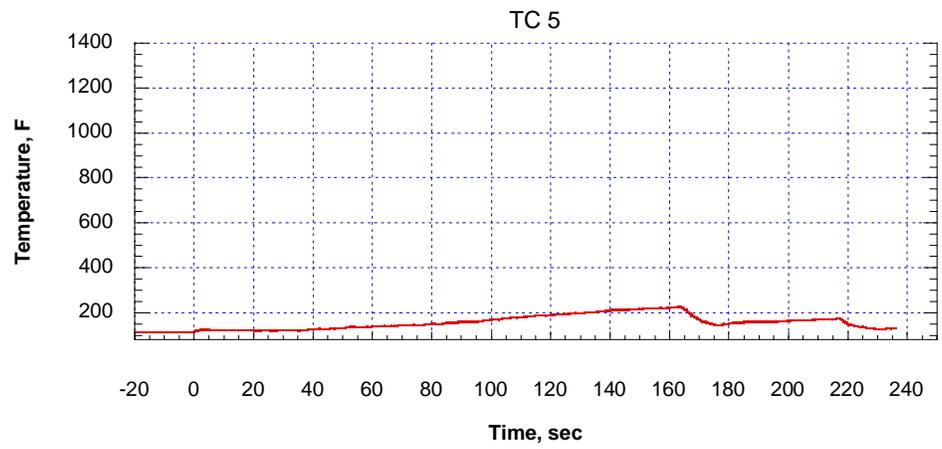
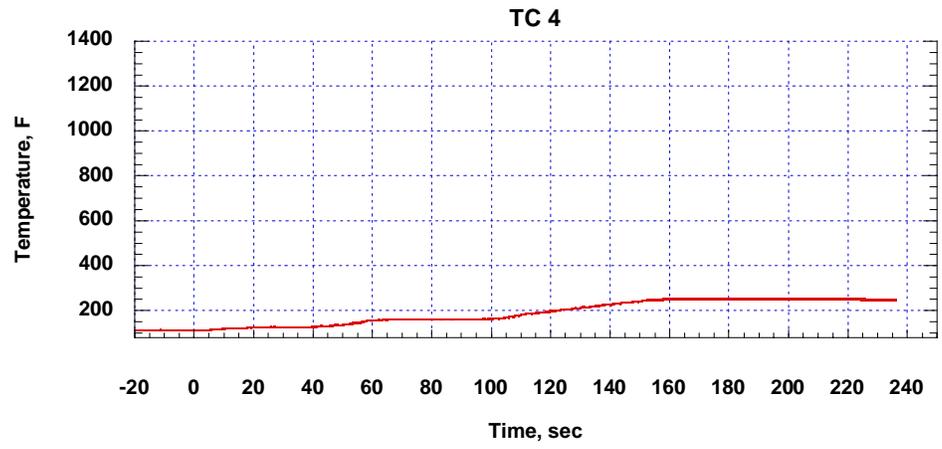
Test 18
Fuel Pressure and Flow Rate vs Time



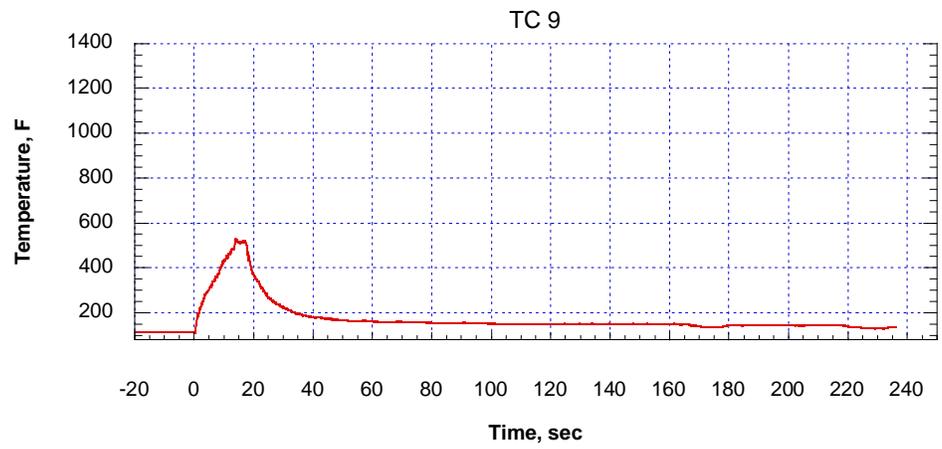
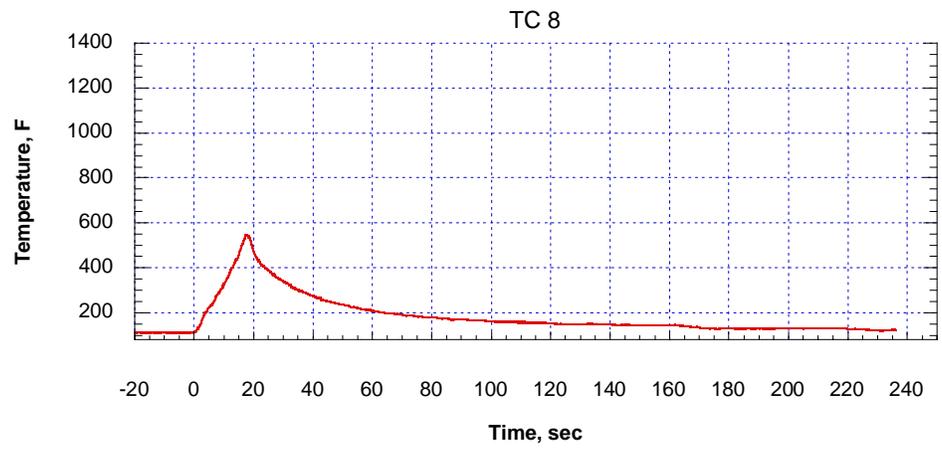
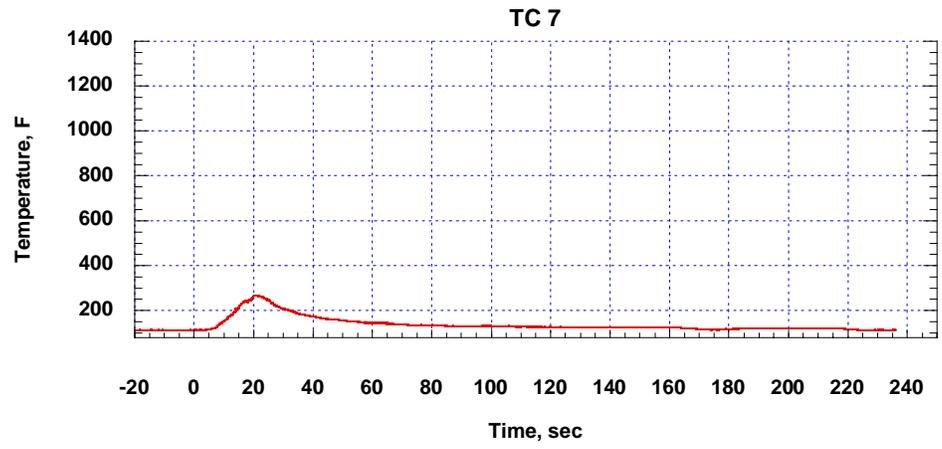
Test 19
Temperature vs Time



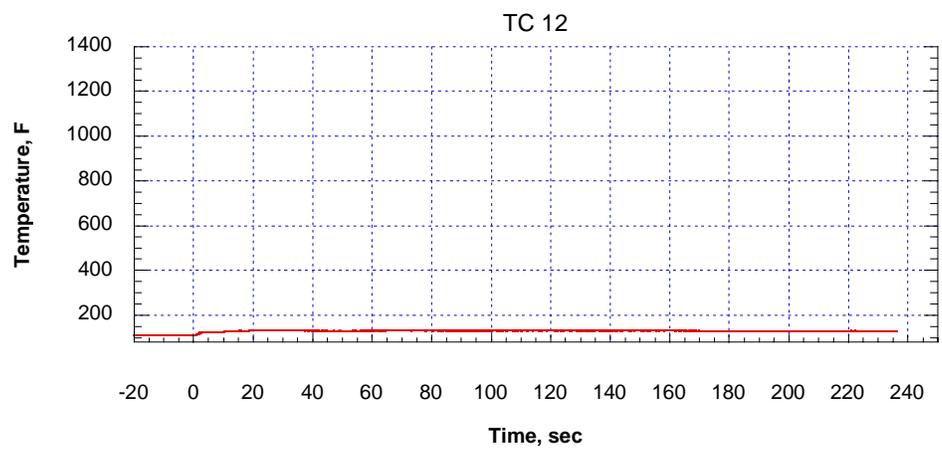
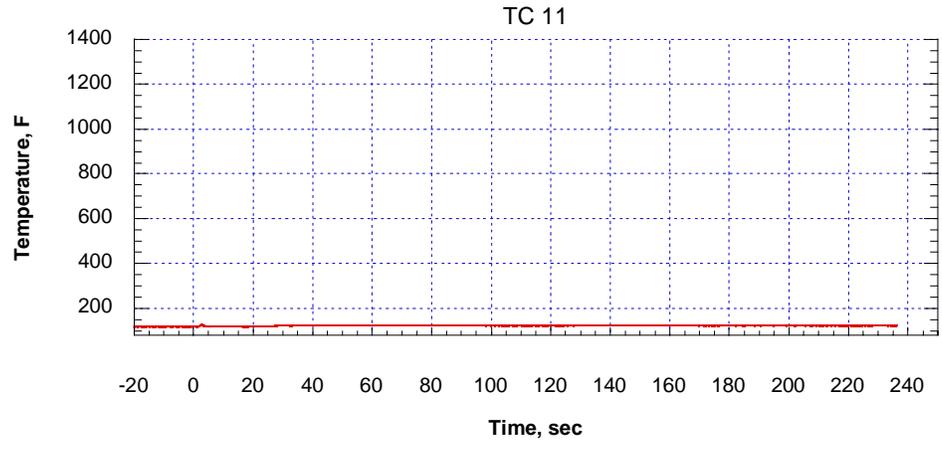
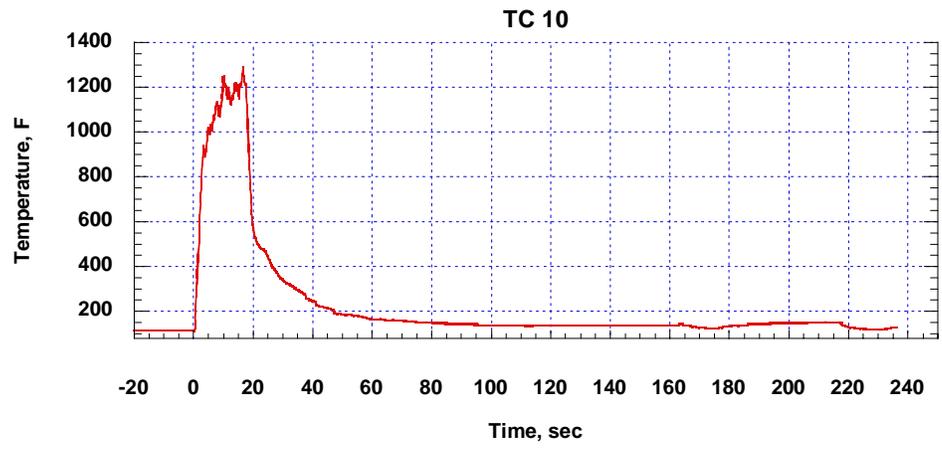
Test 19
Temperature vs Time



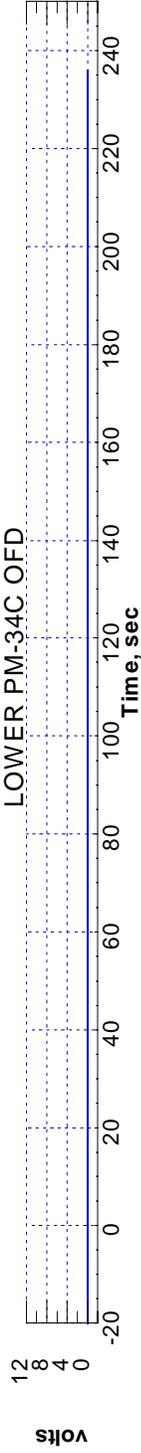
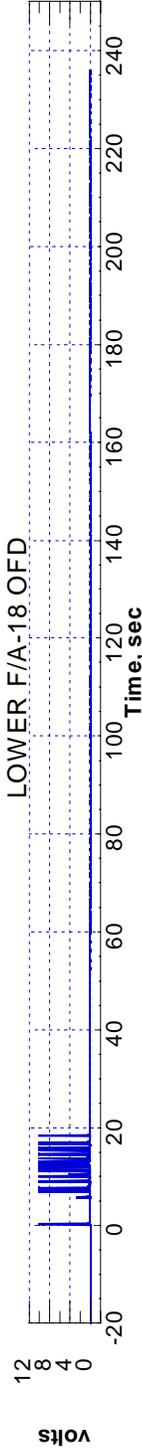
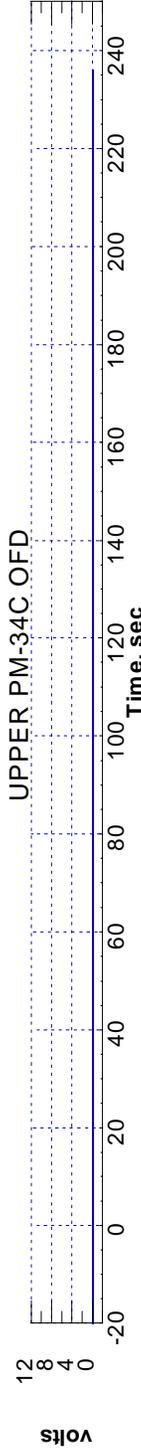
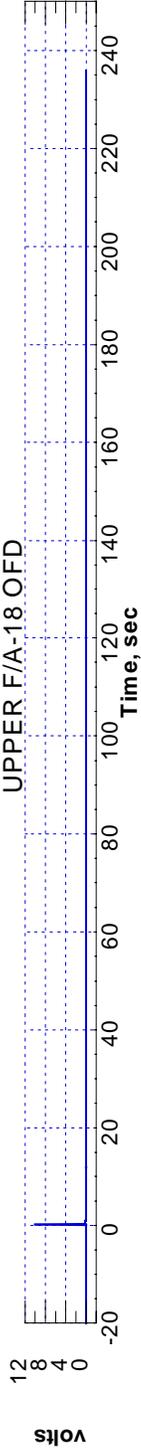
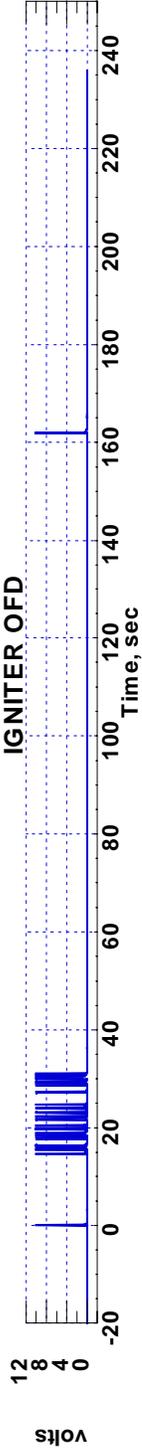
Test 19
Temperature vs Time



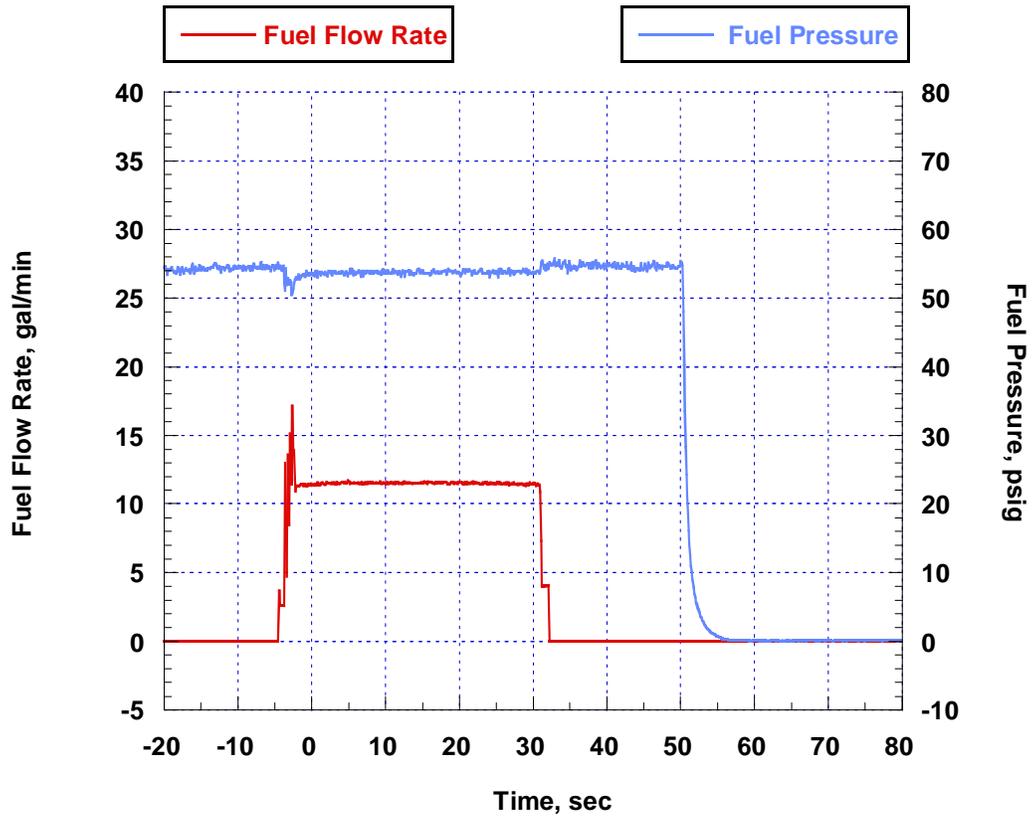
Test 19
Temperature vs Time



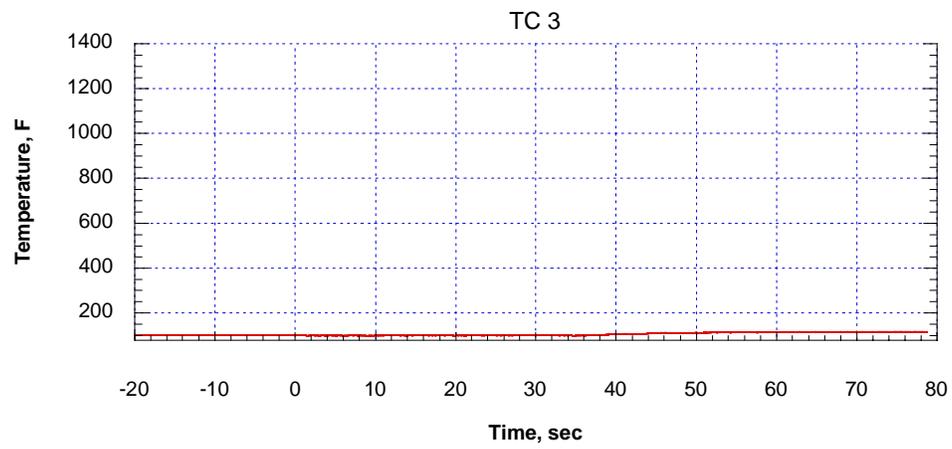
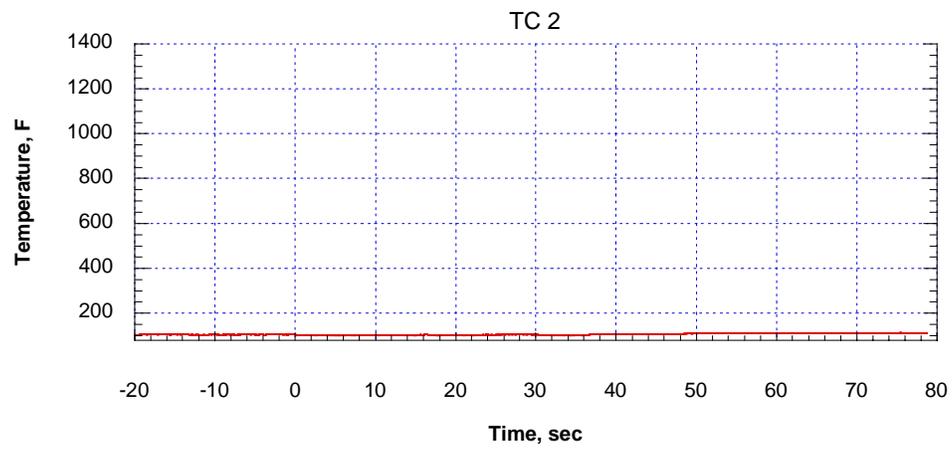
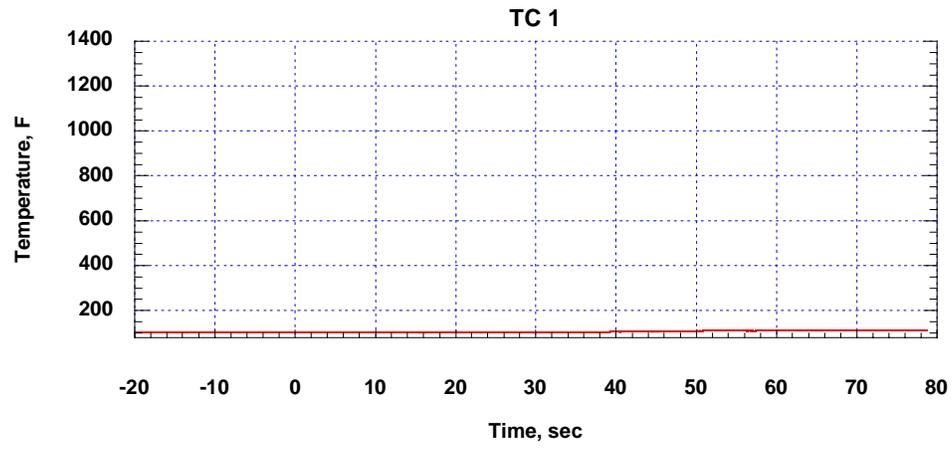
Test 19
Optical Fire Detector Signal vs Time



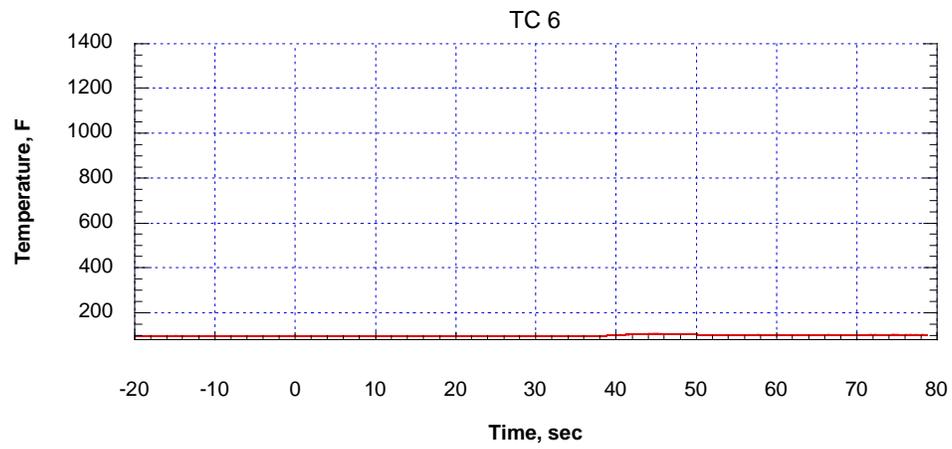
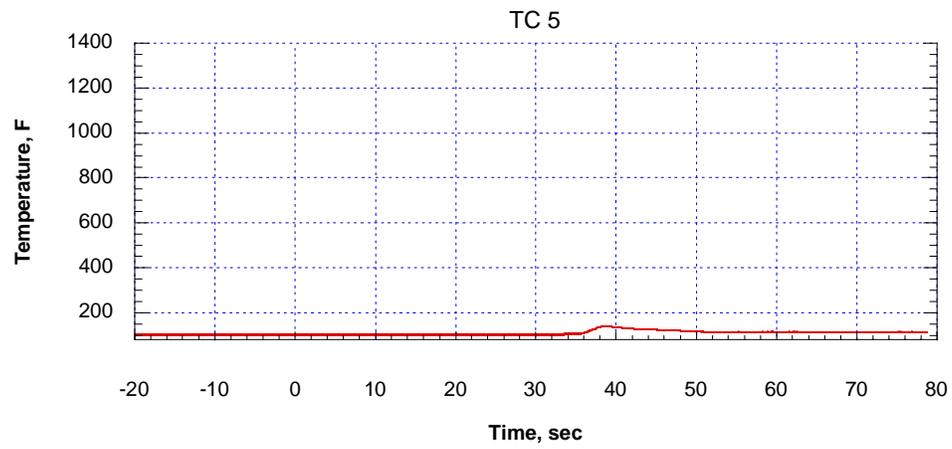
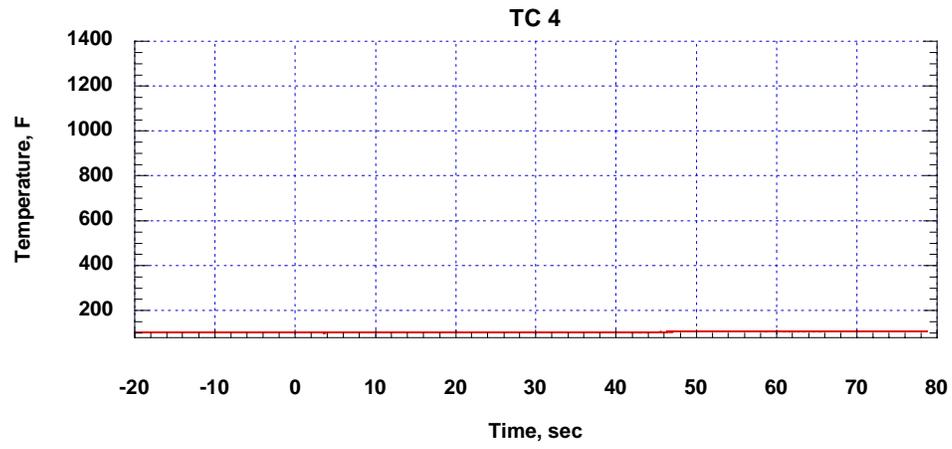
Test 19
Fuel Pressure and Flow Rate vs Time



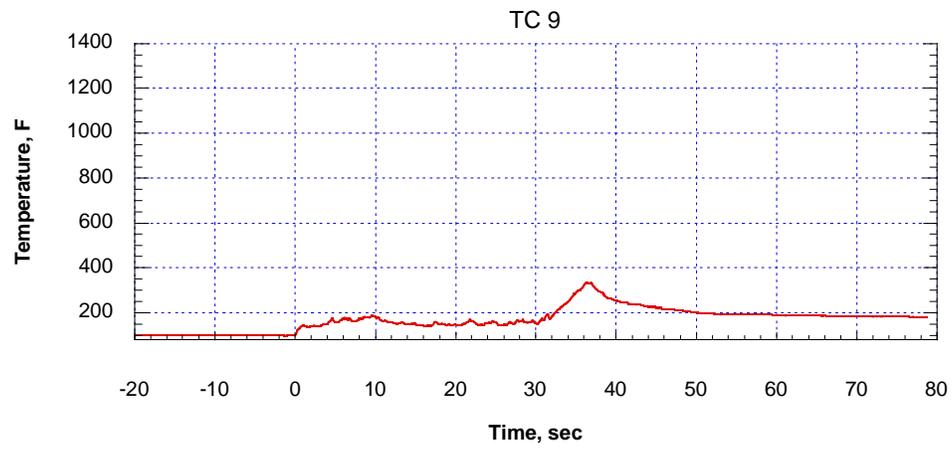
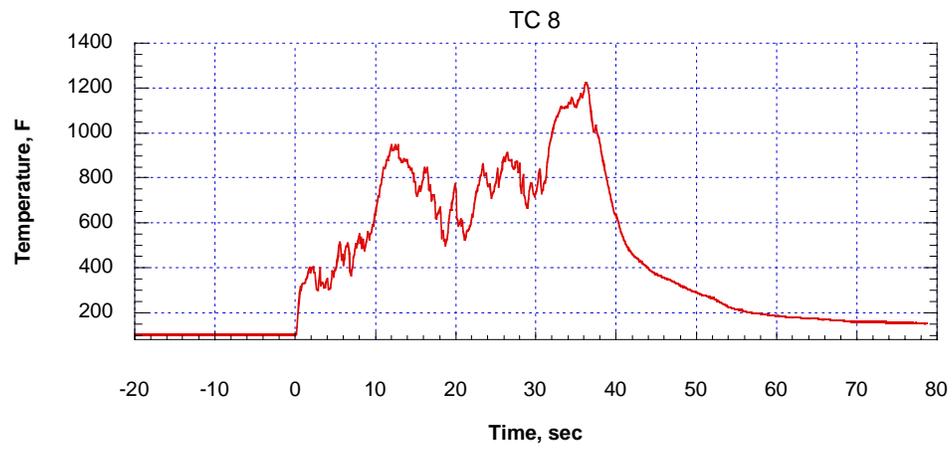
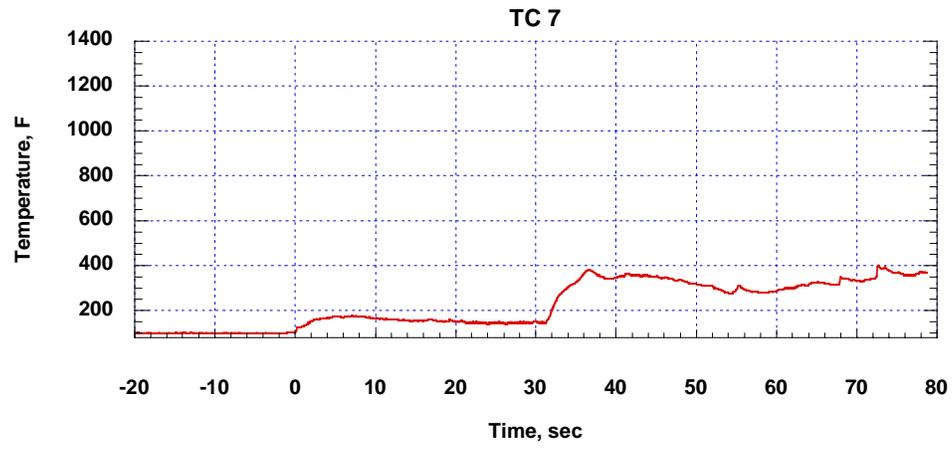
Test 20
Temperature vs Time



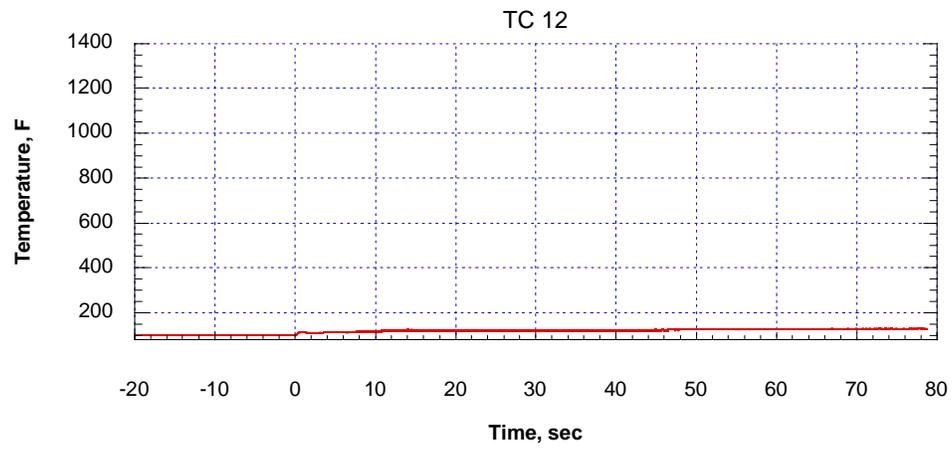
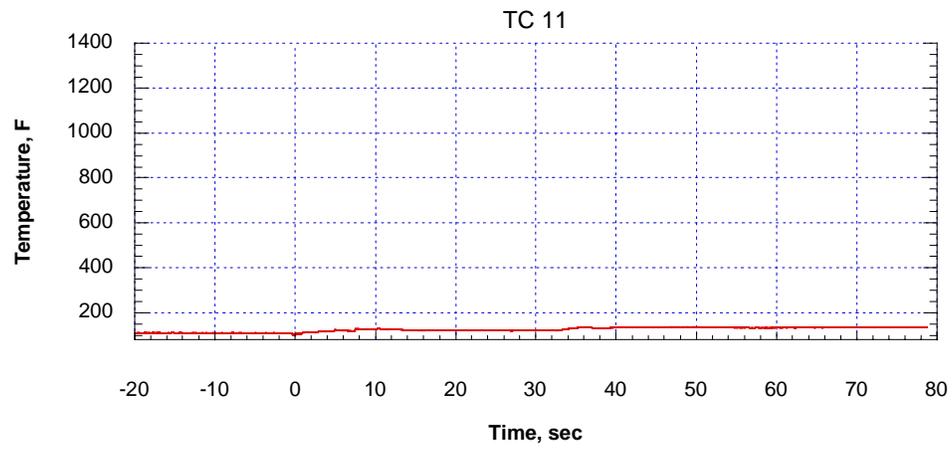
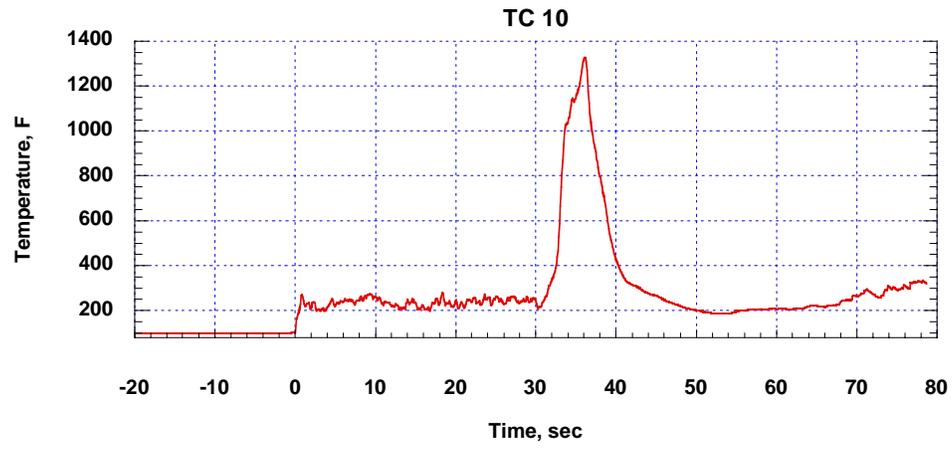
Test 20
Temperature vs Time



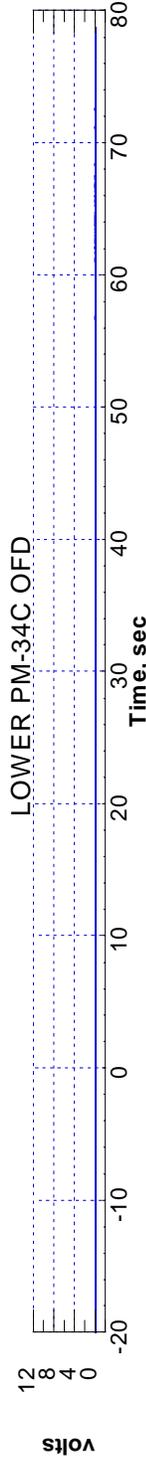
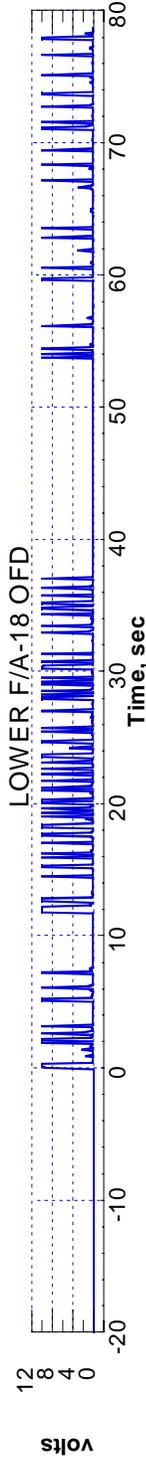
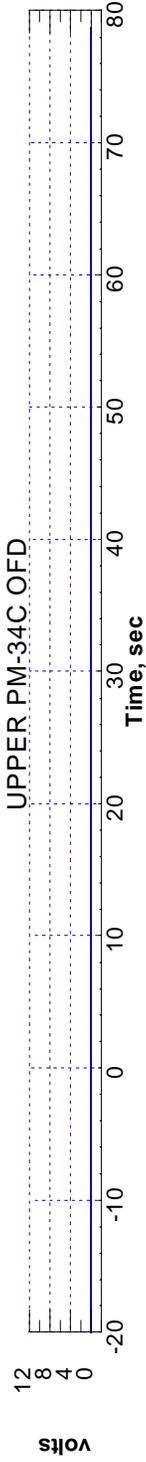
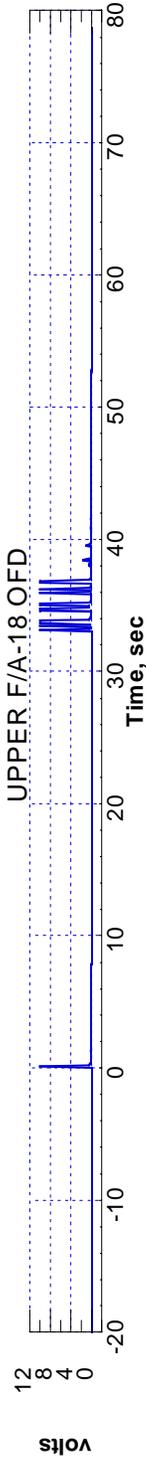
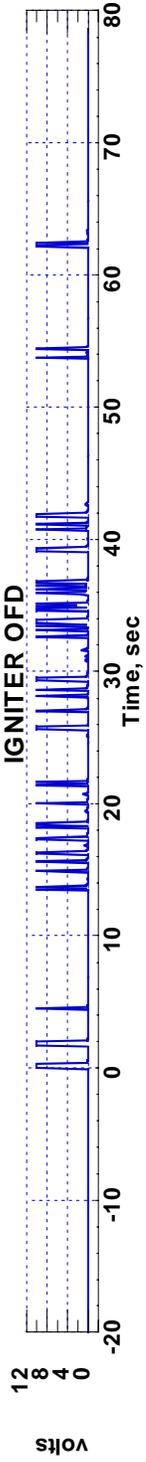
Test 20
Temperature vs Time



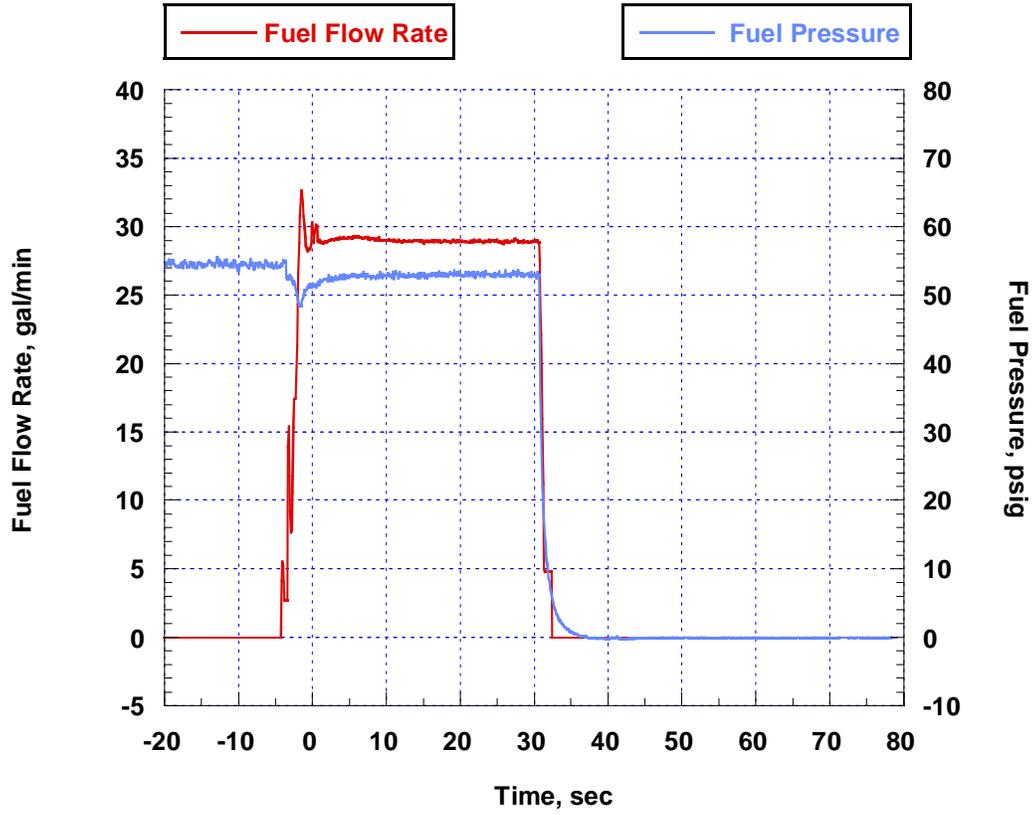
Test 20
Temperature vs Time



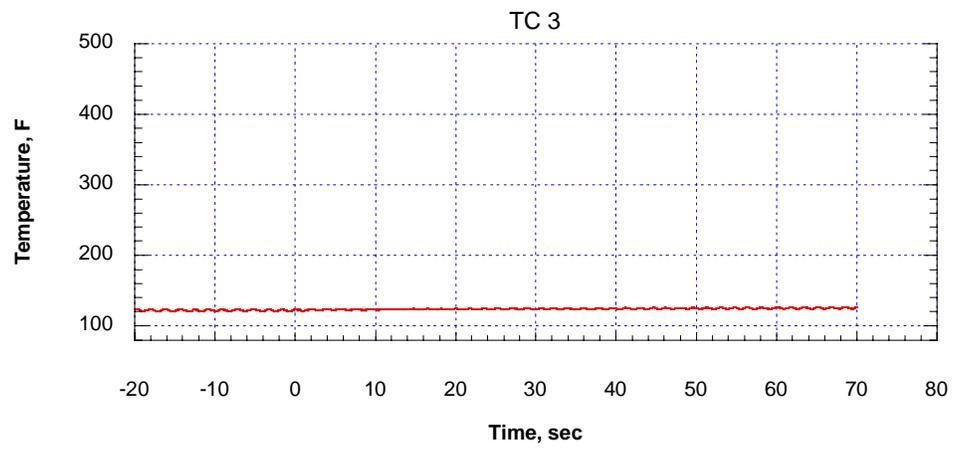
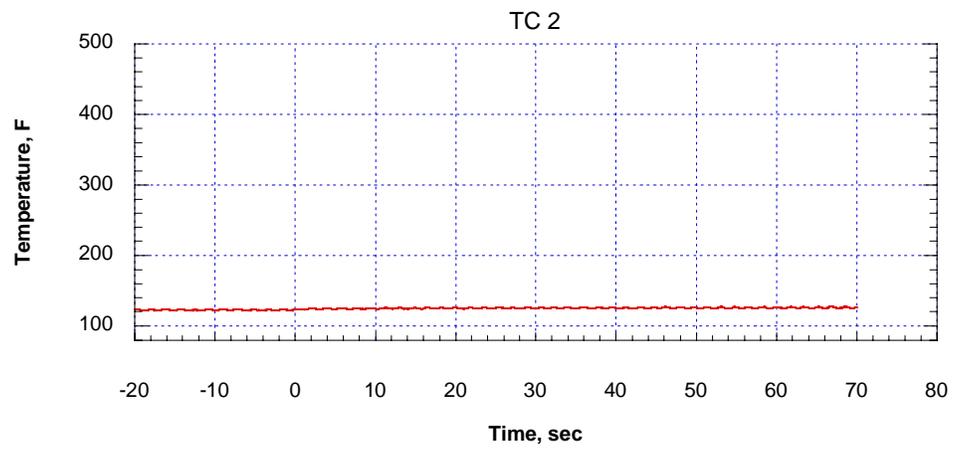
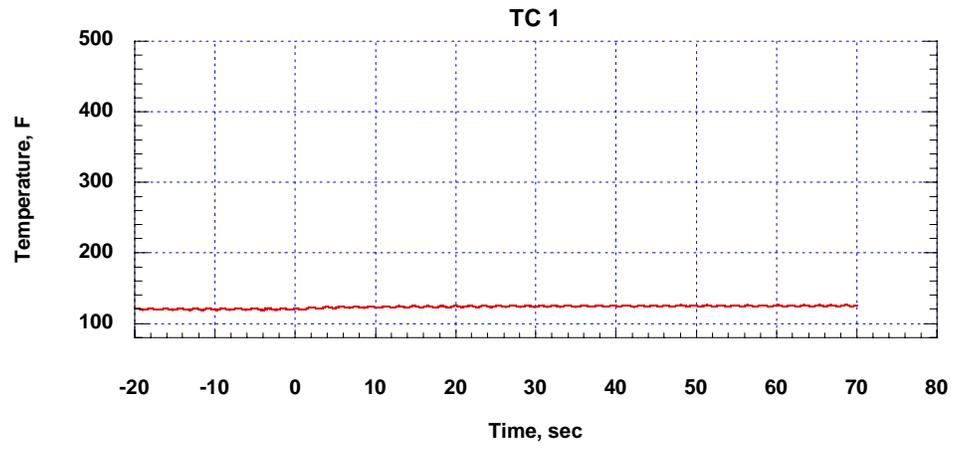
Test 20
Optical Fire Detector Signal vs Time



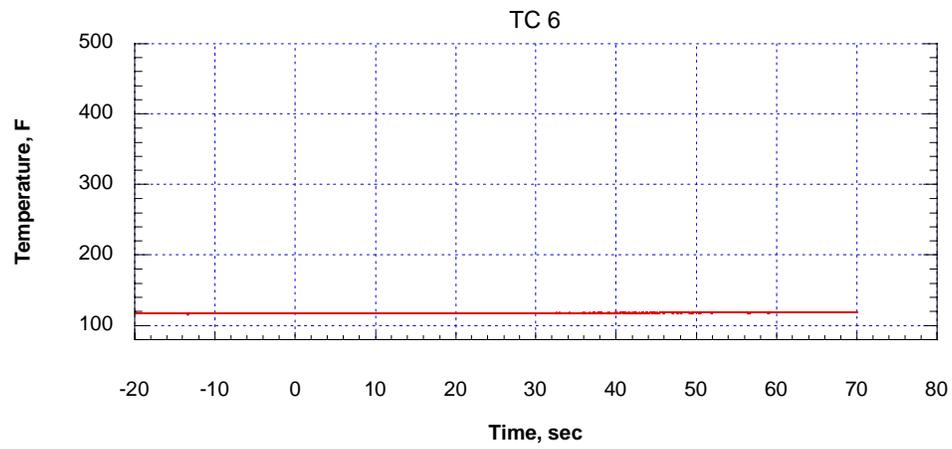
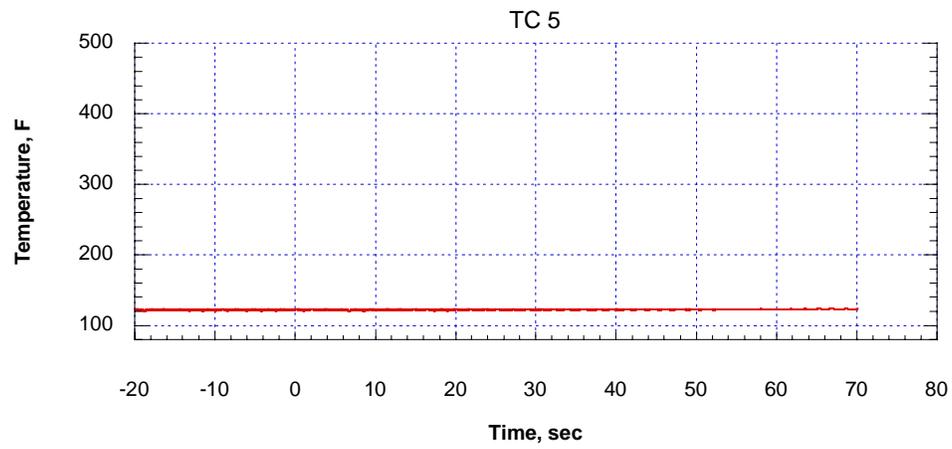
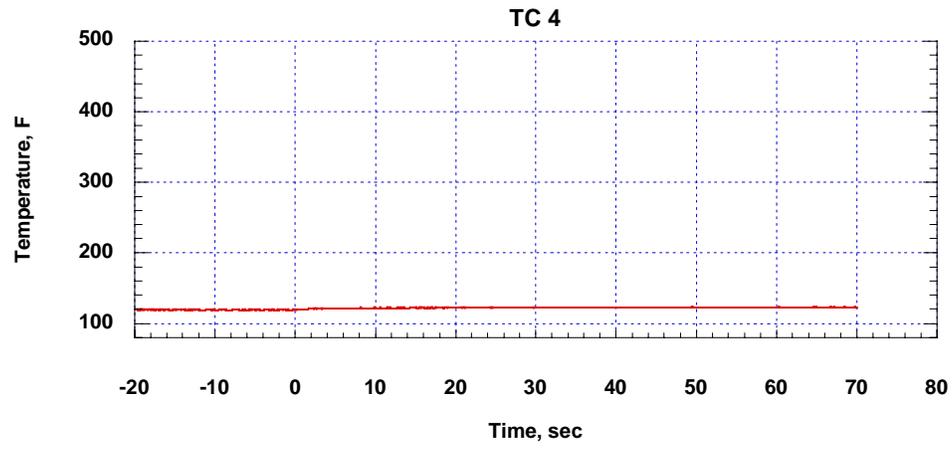
Test 20
Fuel Pressure and Flow Rate vs Time



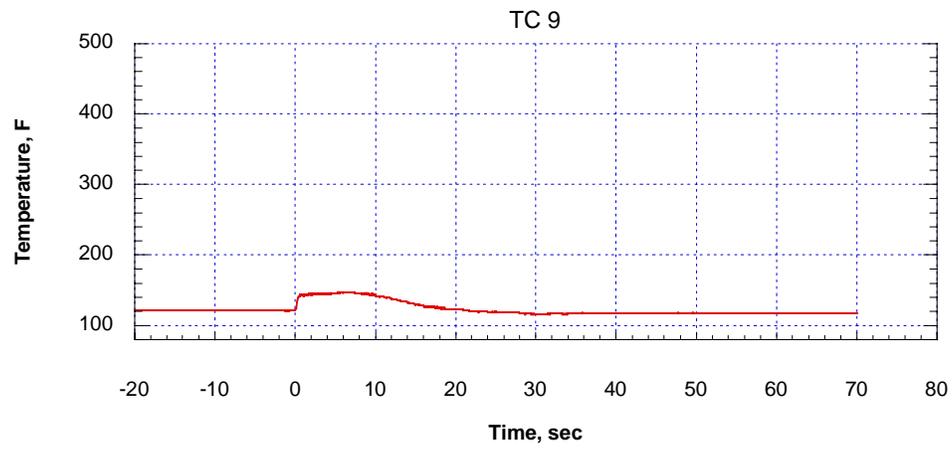
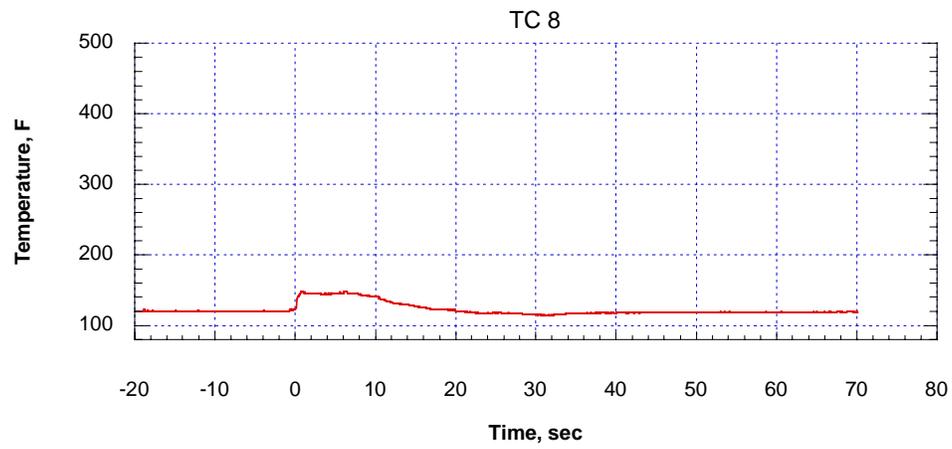
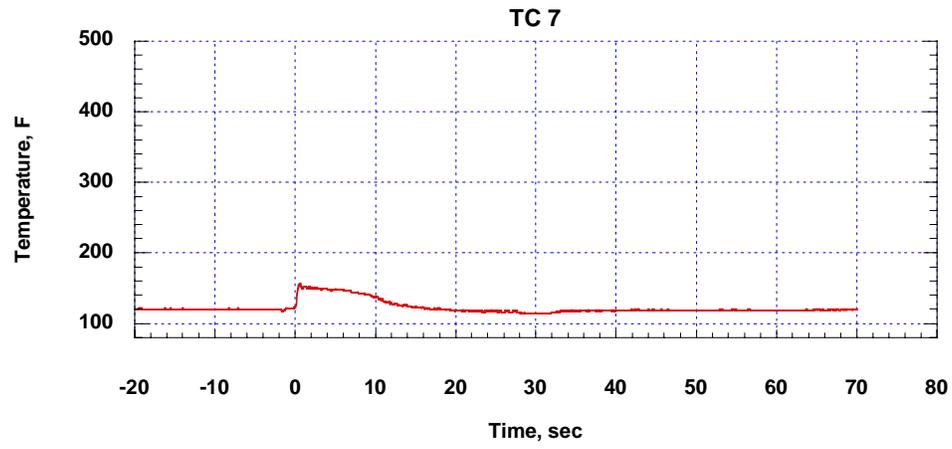
Test 25
Temperature vs Time



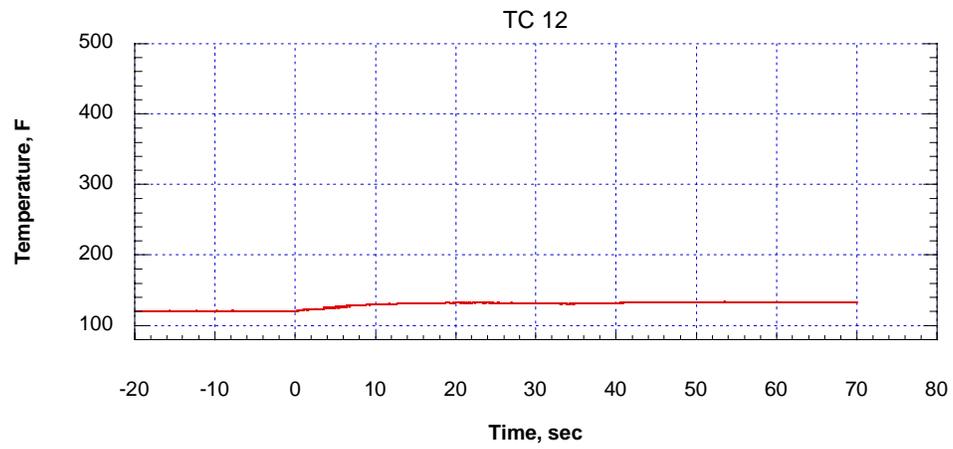
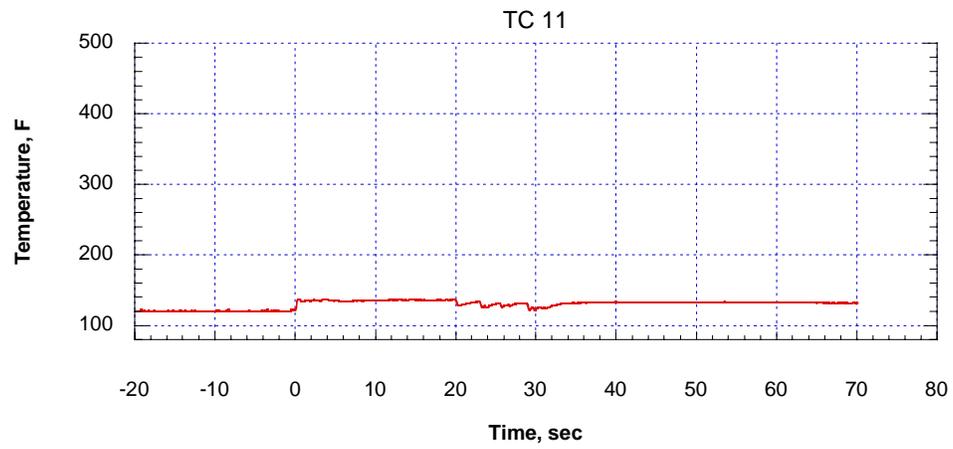
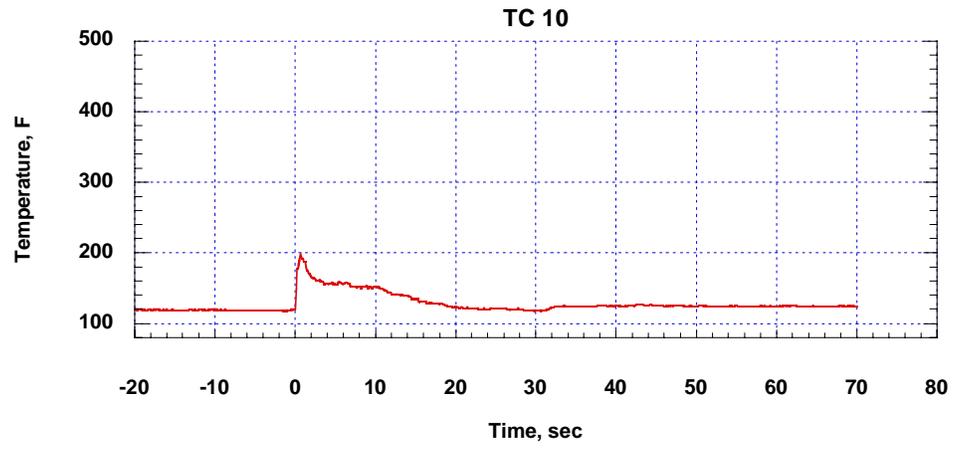
Test 25
Temperature vs Time



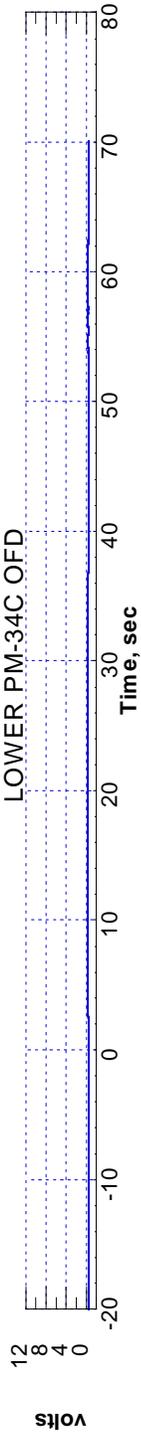
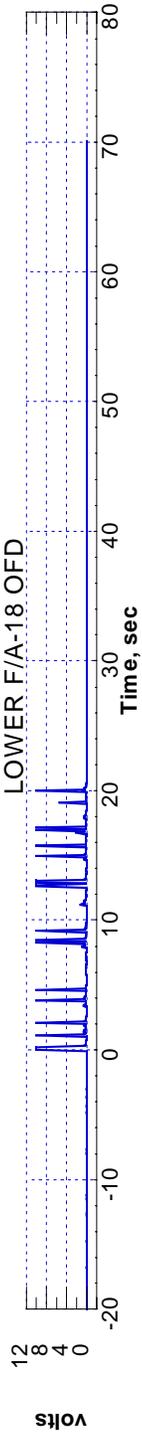
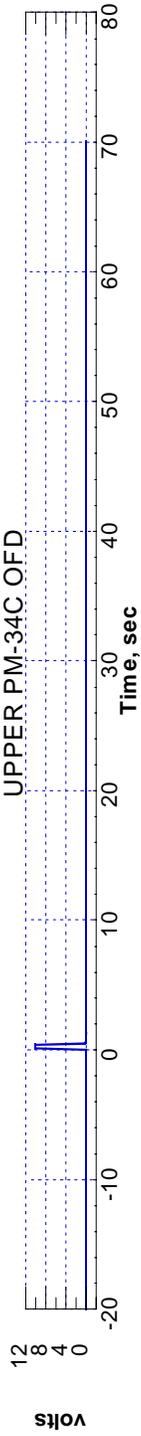
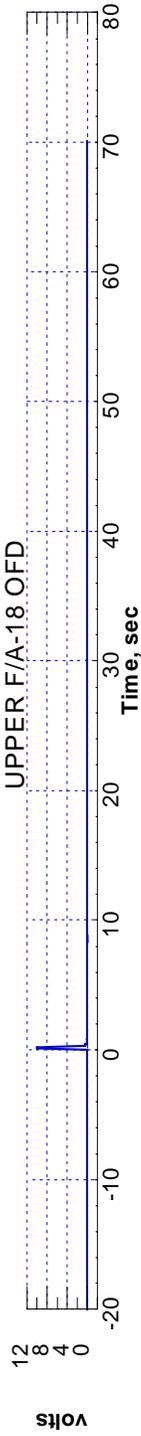
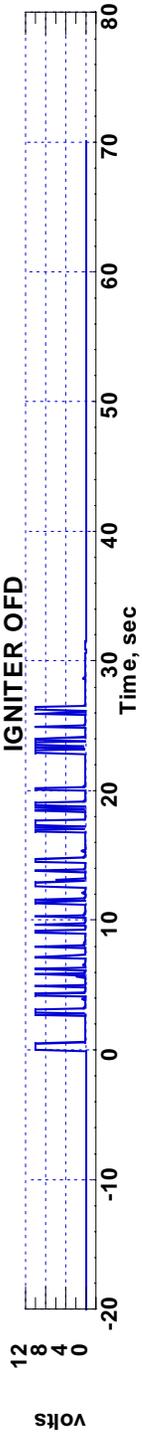
Test 25
Temperature vs Time



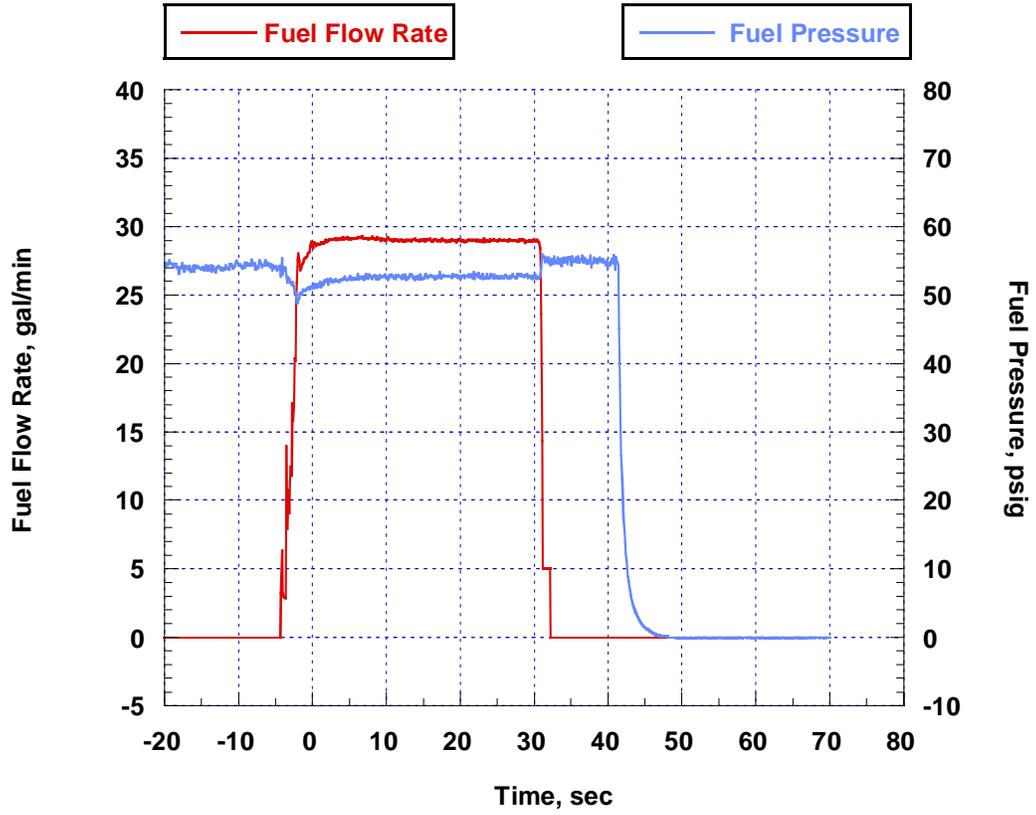
Test 25
Temperature vs Time



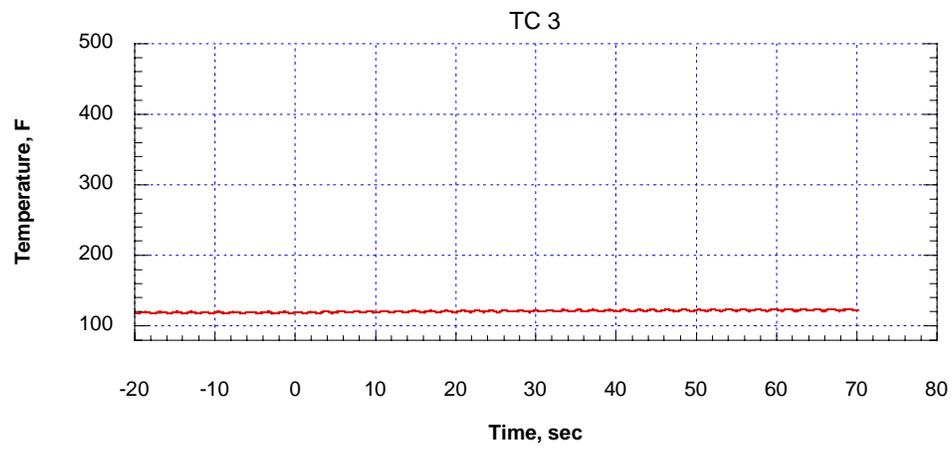
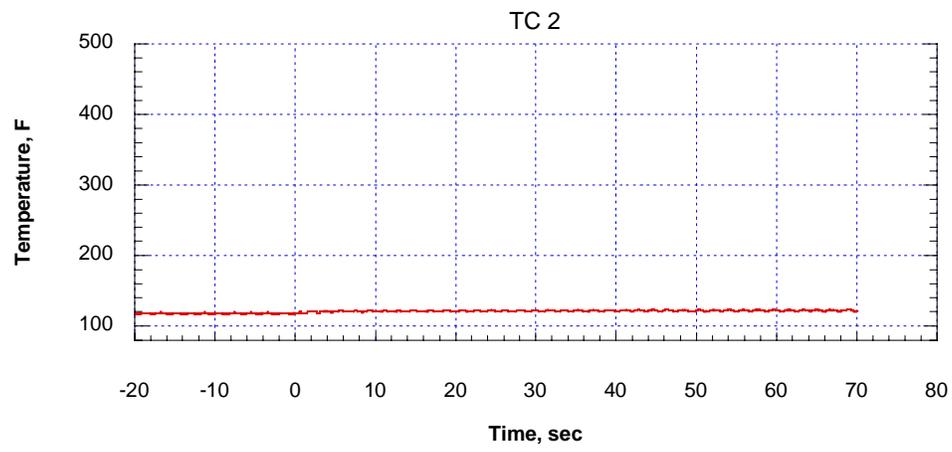
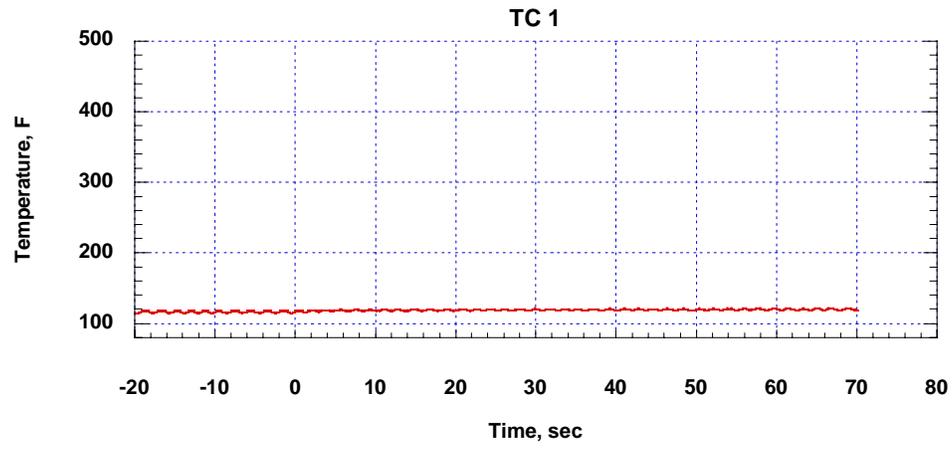
Test 25
Optical Fire Detector Signal vs Time



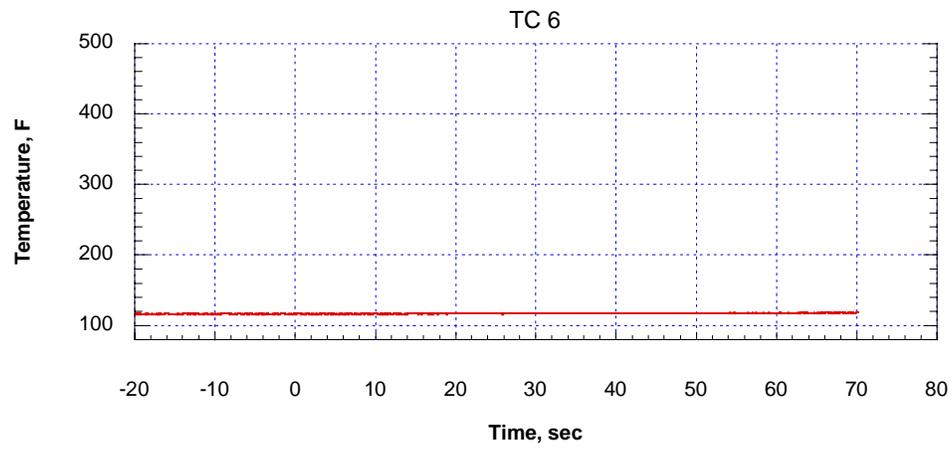
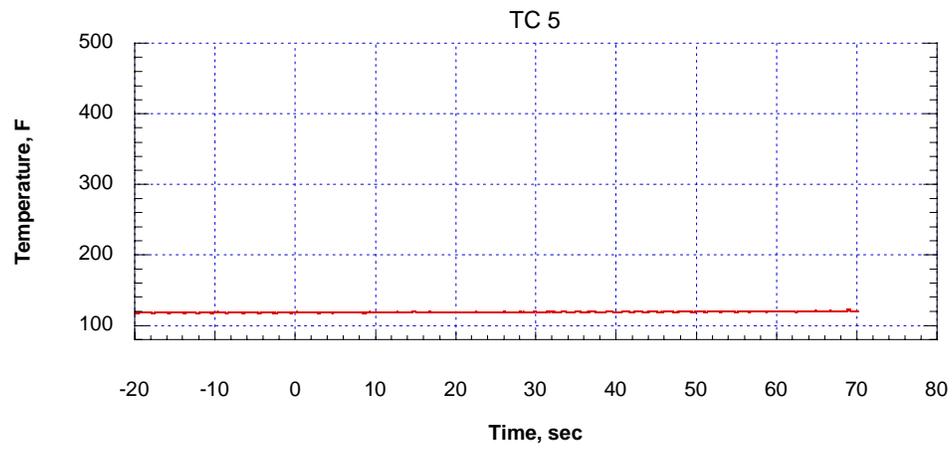
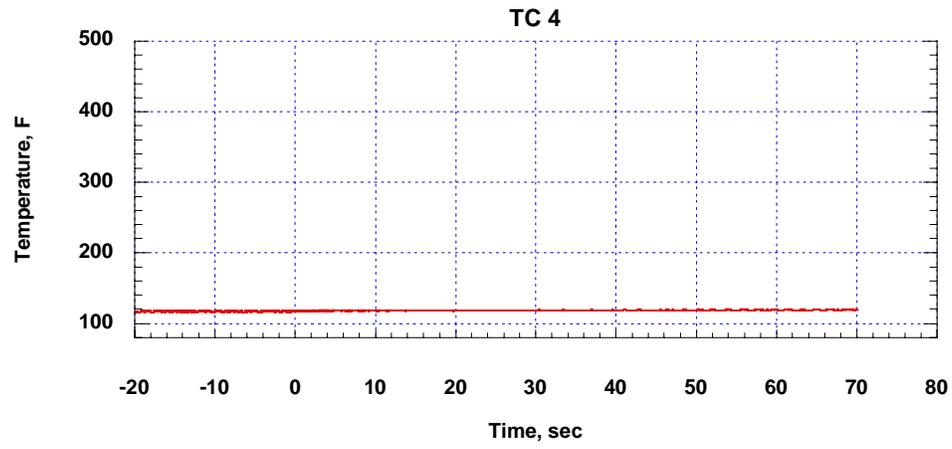
Test 25
Fuel Pressure and Flow Rate vs Time



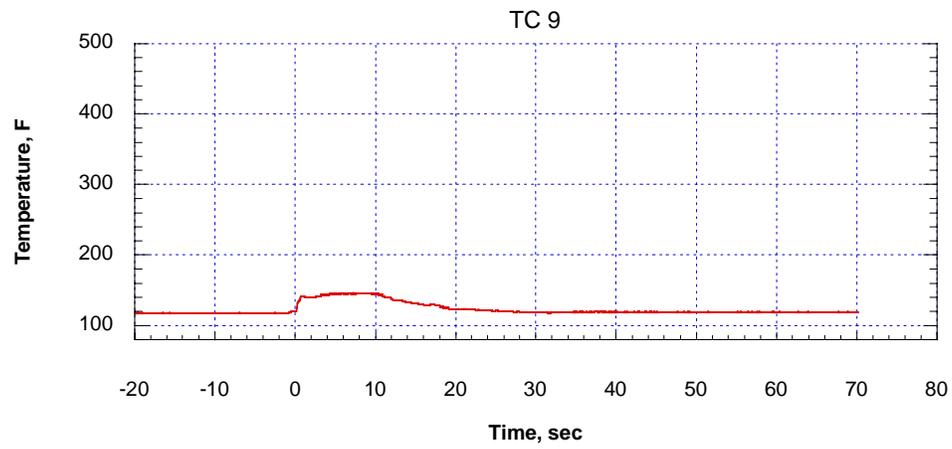
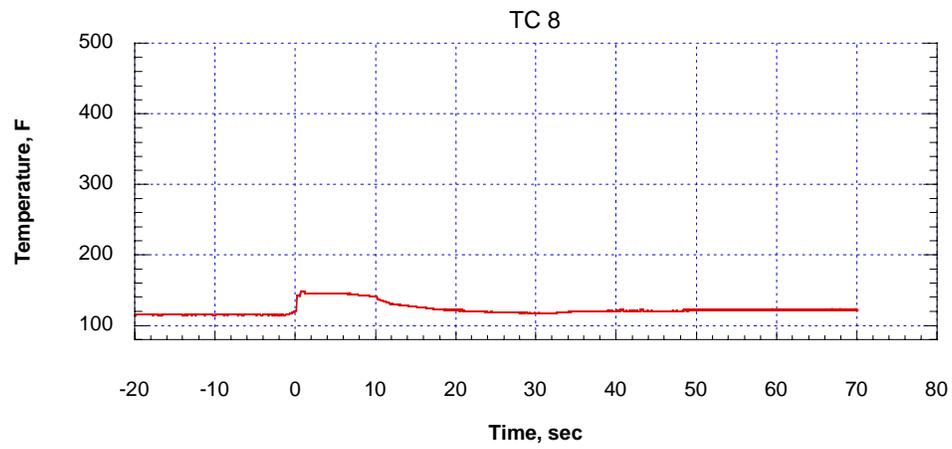
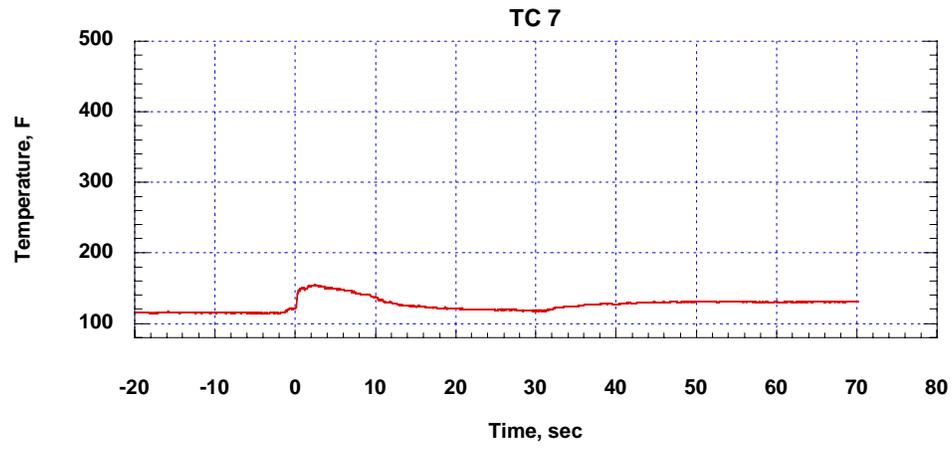
Test 26
Temperature vs Time



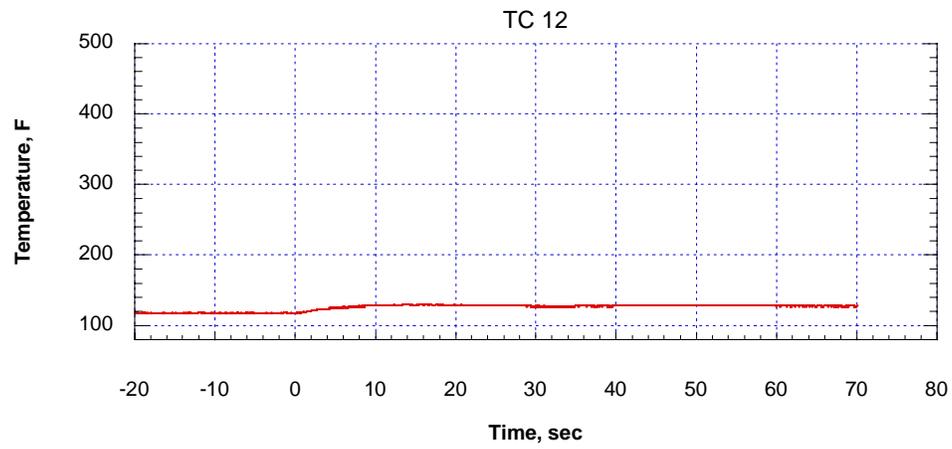
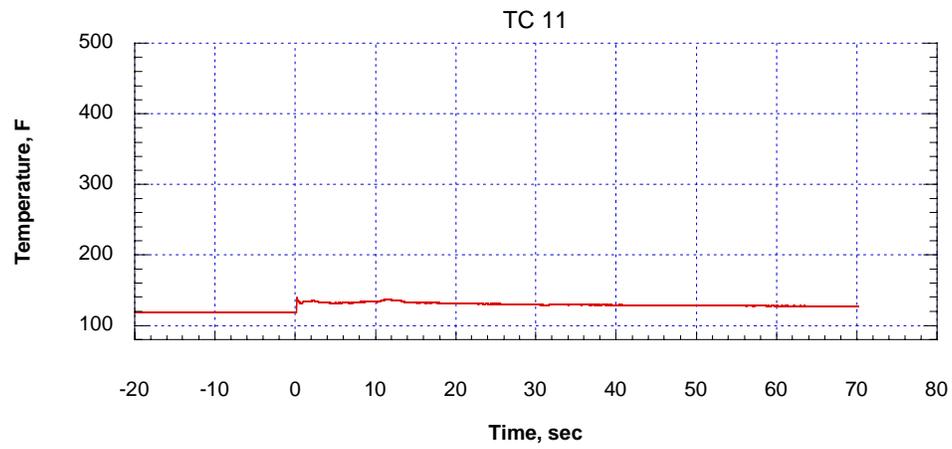
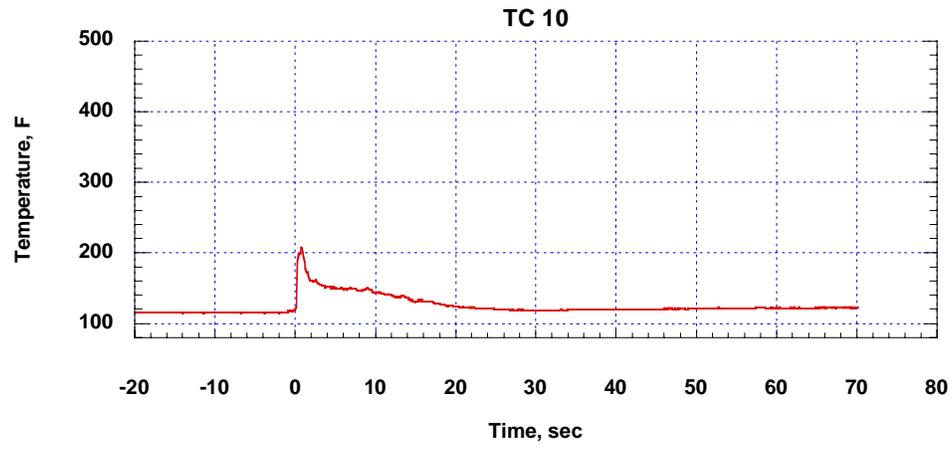
Test 26
Temperature vs Time



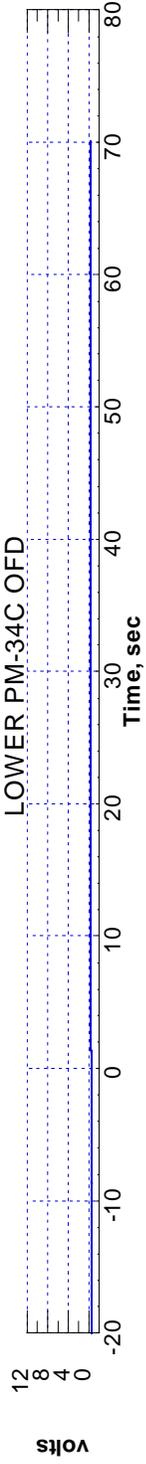
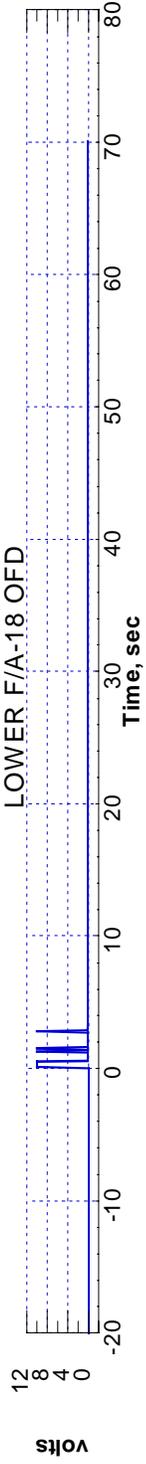
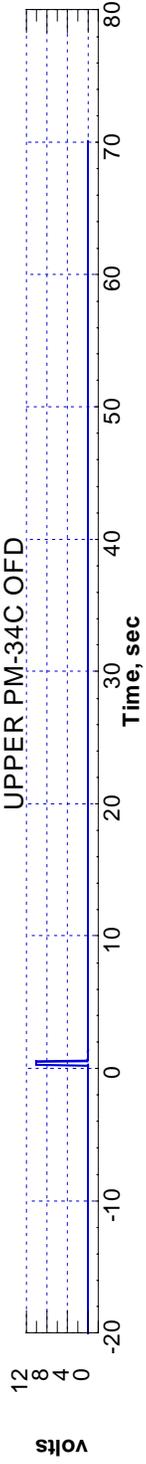
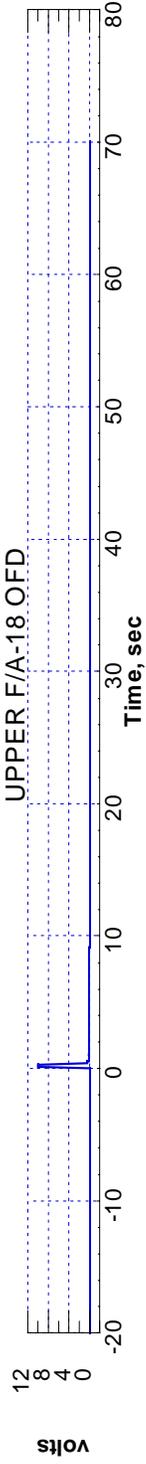
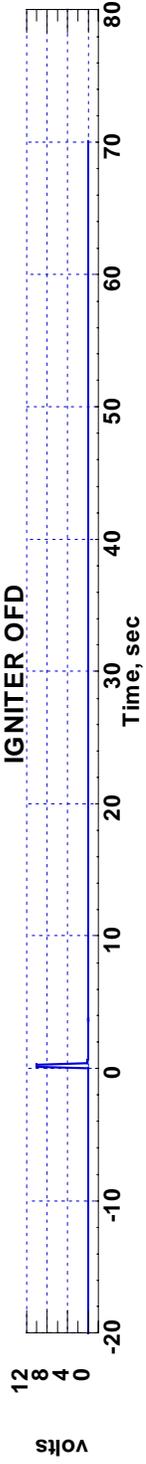
Test 26
Temperature vs Time



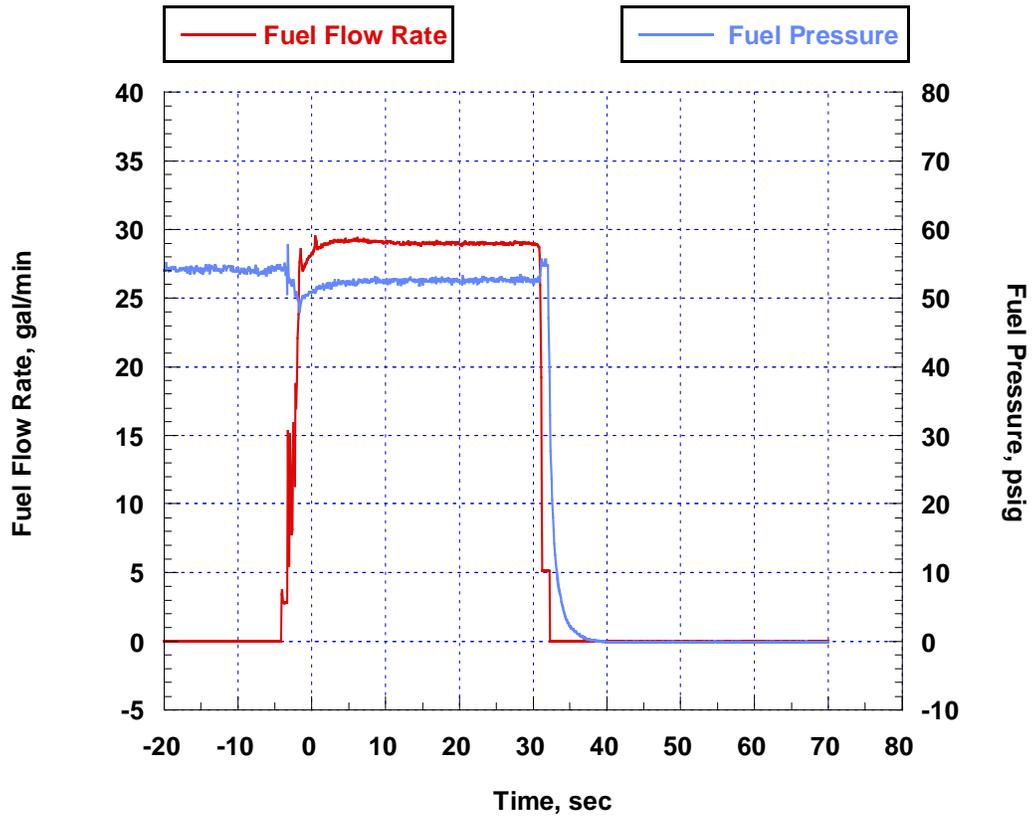
Test 26
Temperature vs Time



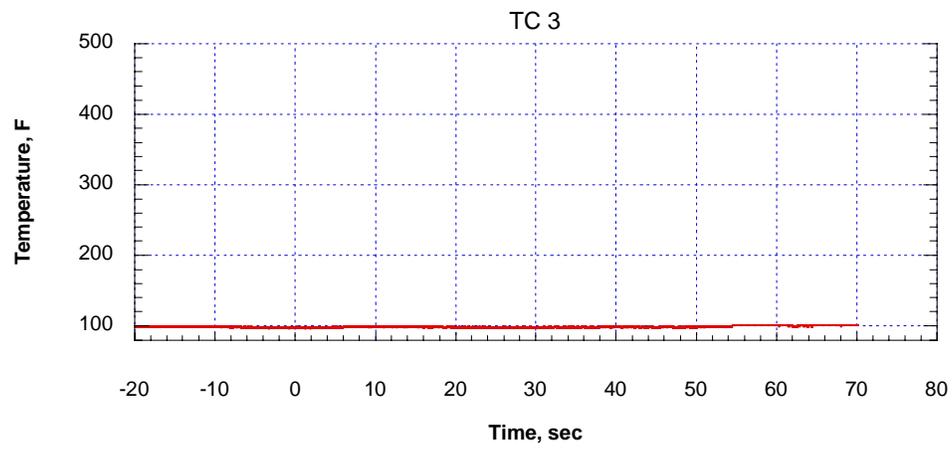
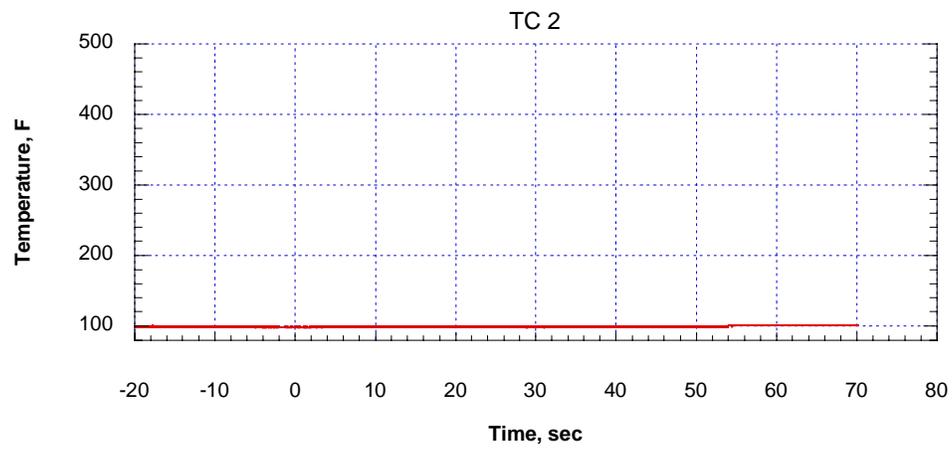
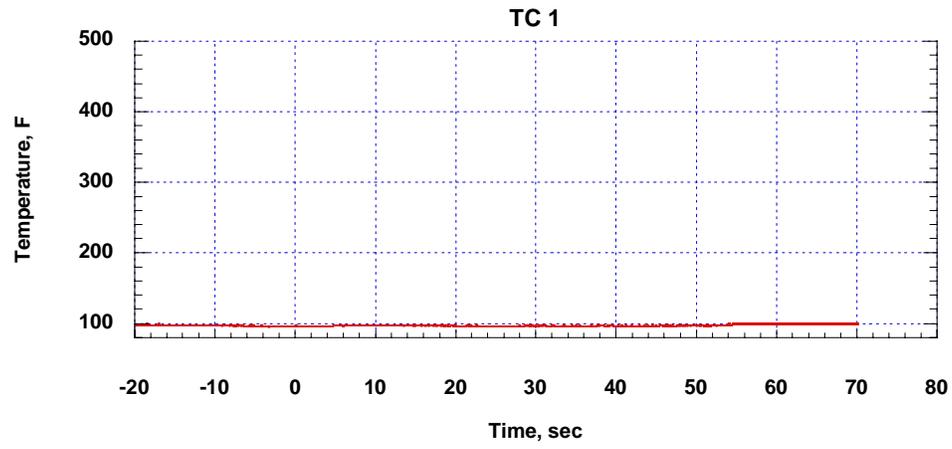
Test 26
Optical Fire Detector Signal vs Time



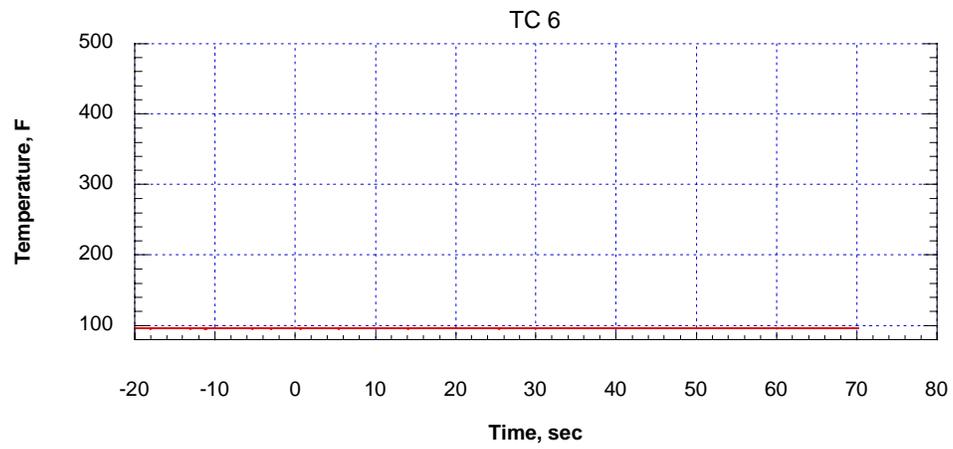
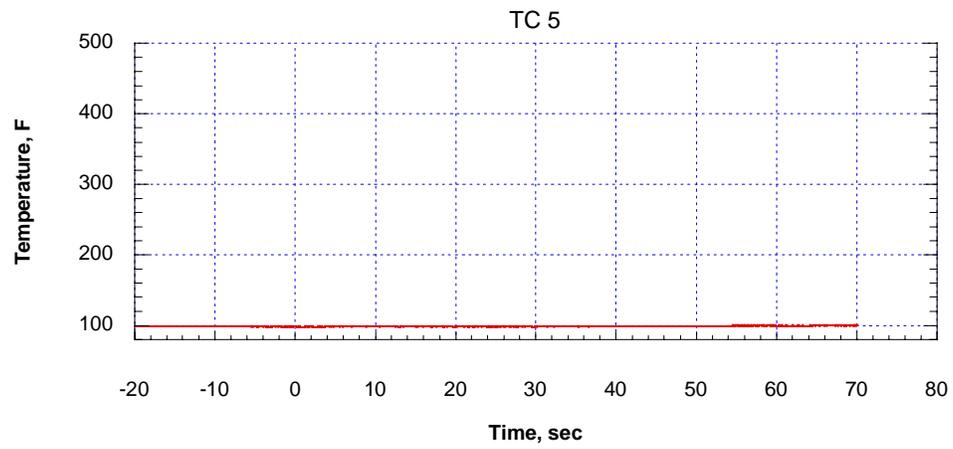
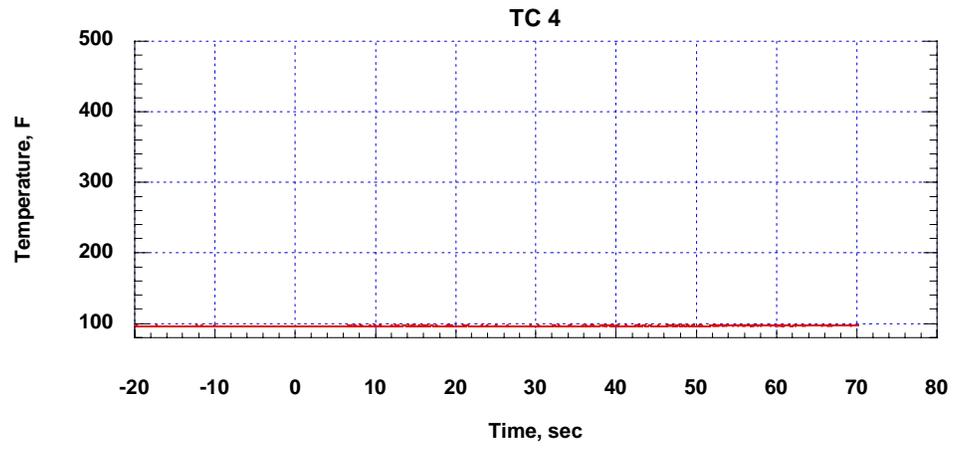
Test 26
Fuel Pressure and Flow Rate vs Time



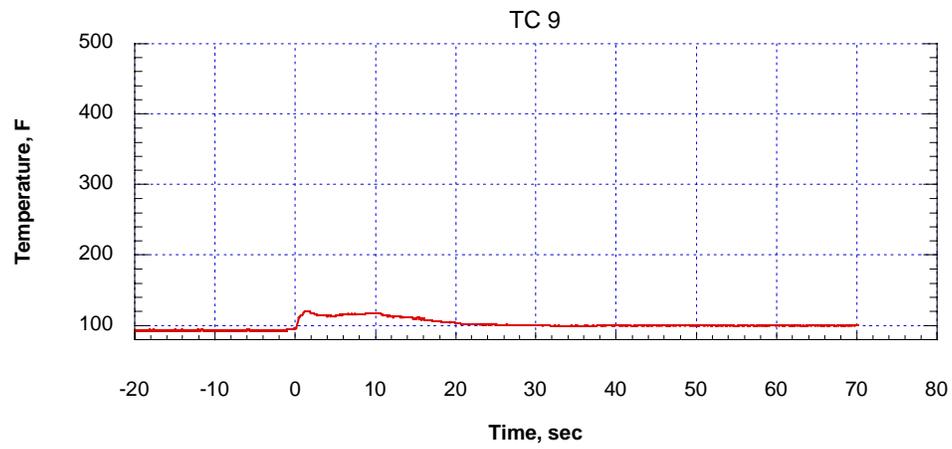
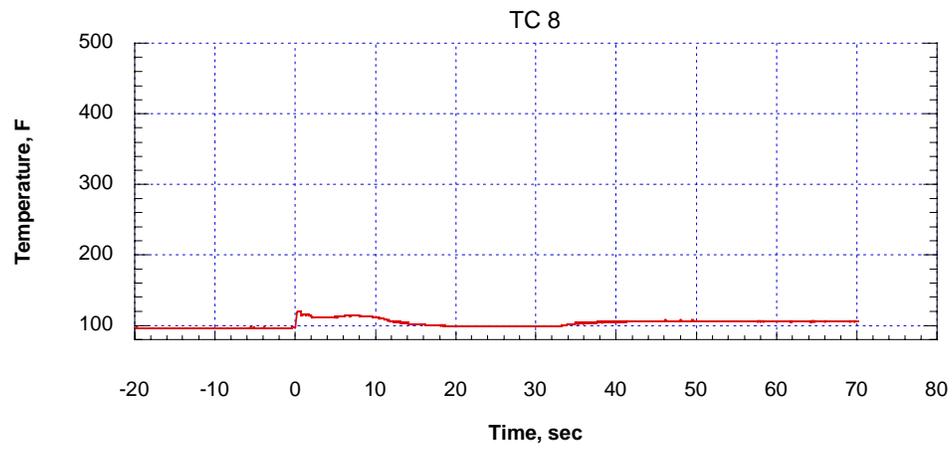
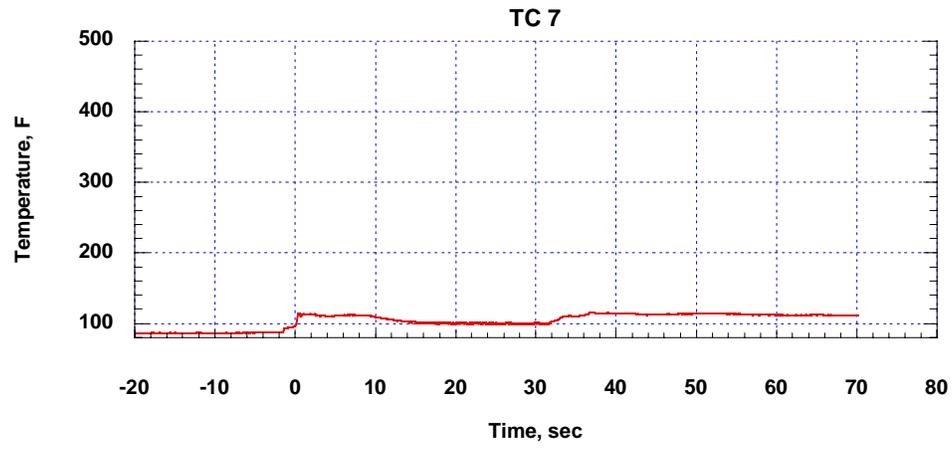
Test 27
Temperature vs Time



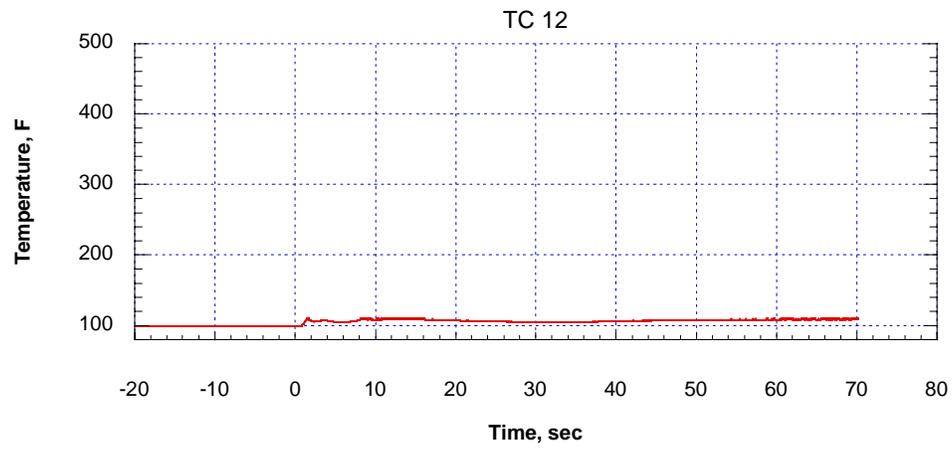
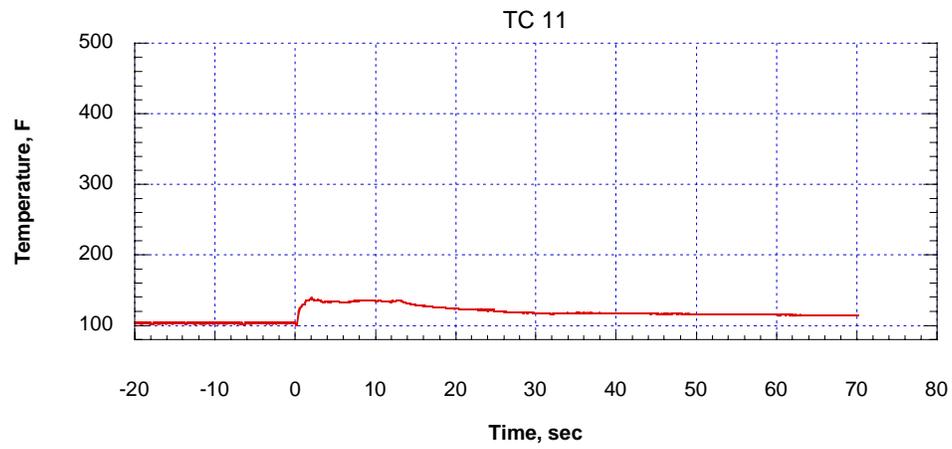
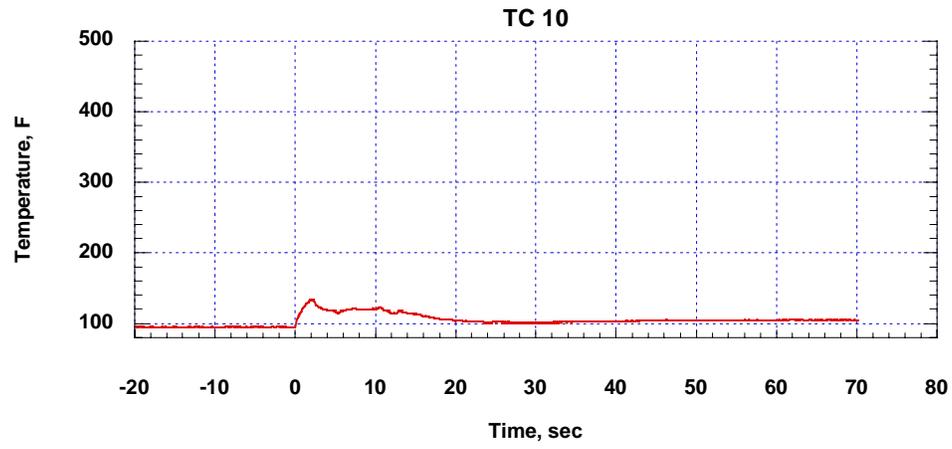
Test 27
Temperature vs Time



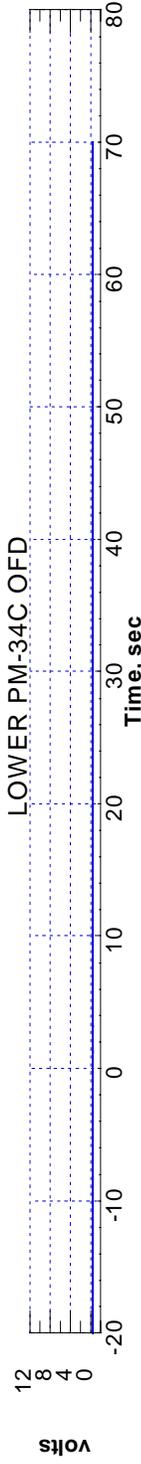
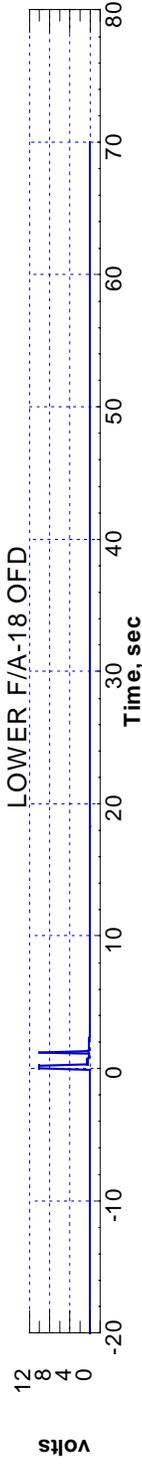
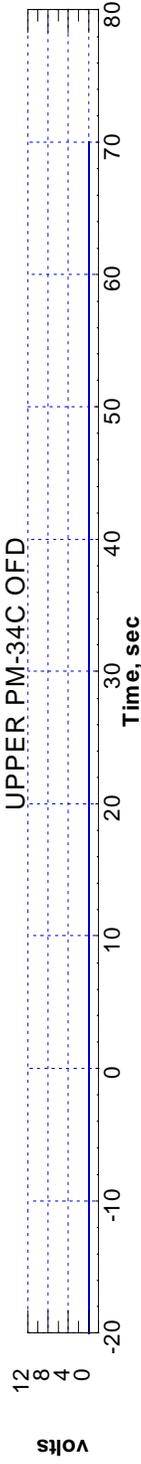
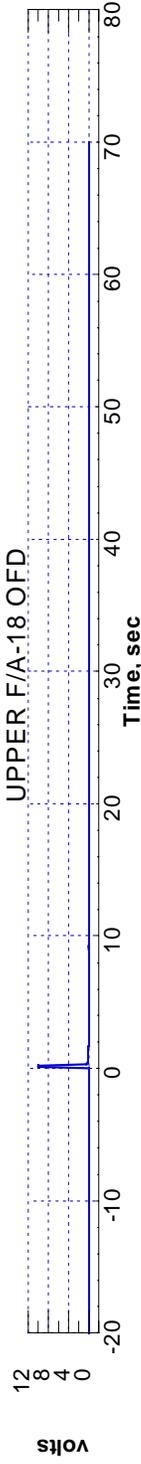
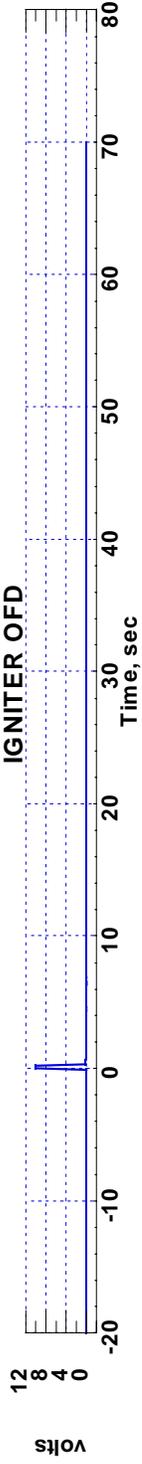
Test 27
Temperature vs Time



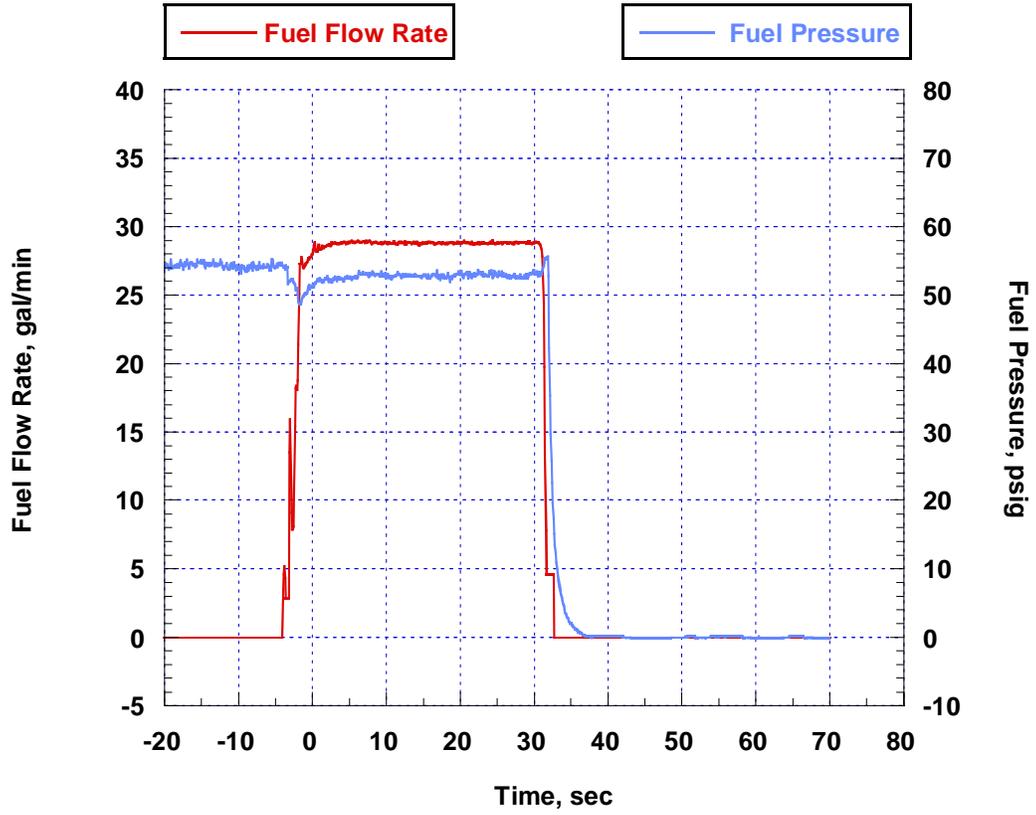
Test 27
Temperature vs Time



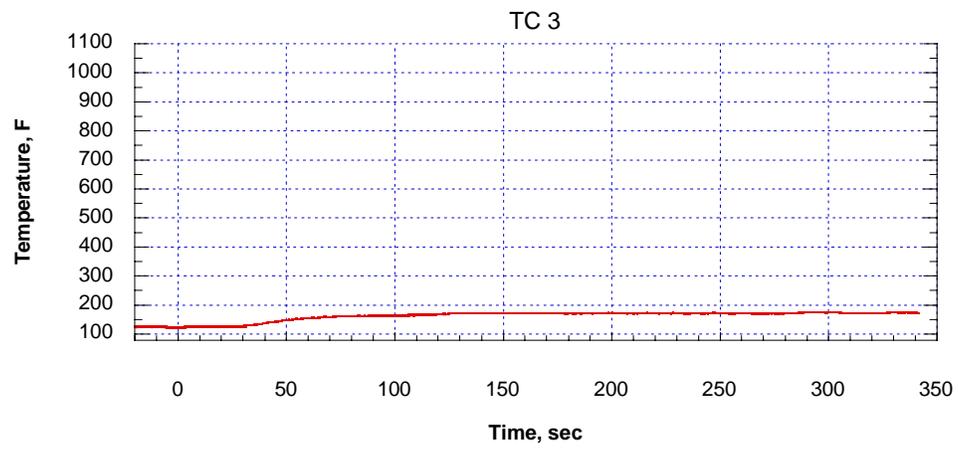
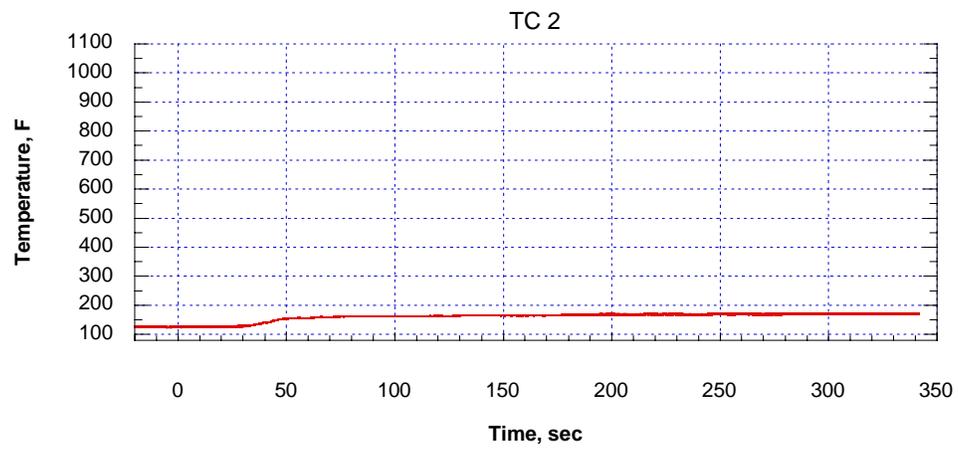
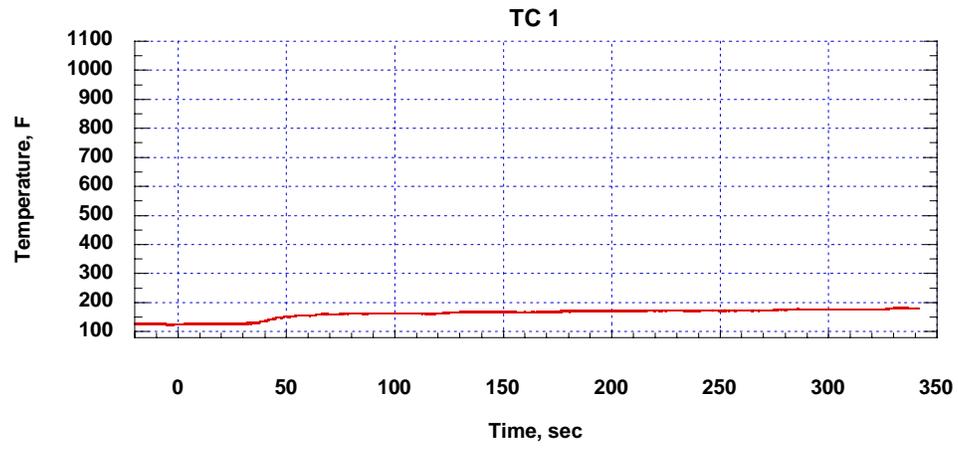
Test 27
Optical Fire Detector Signal vs Time



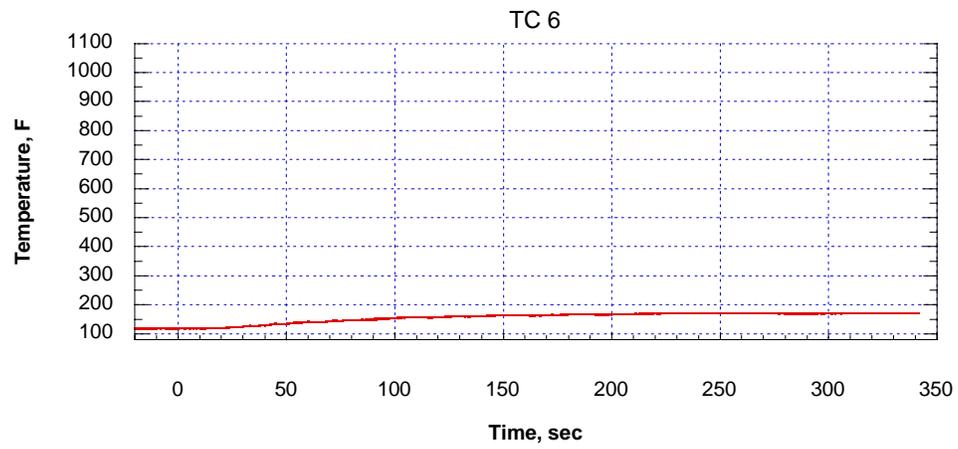
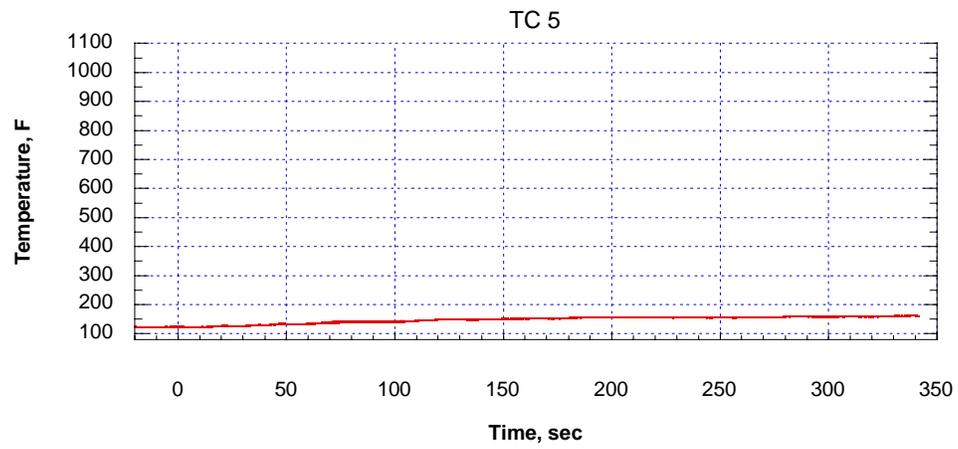
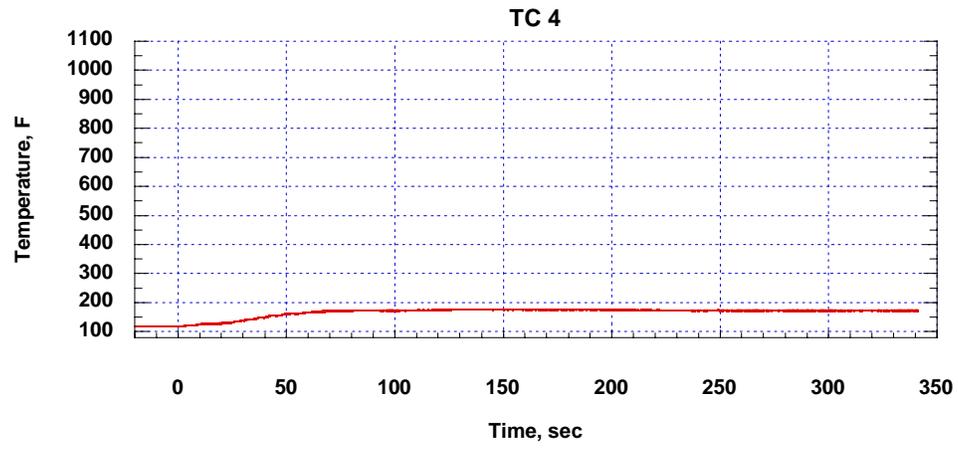
Test 27
Fuel Pressure and Flow Rate vs Time



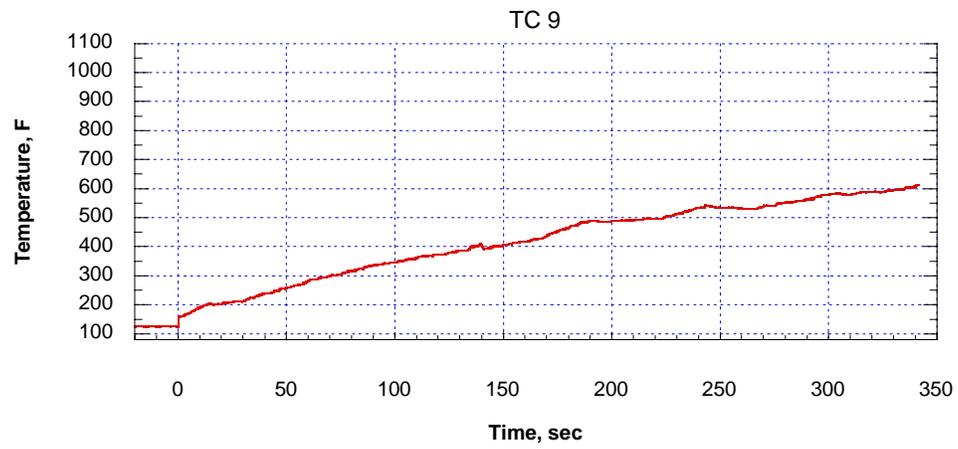
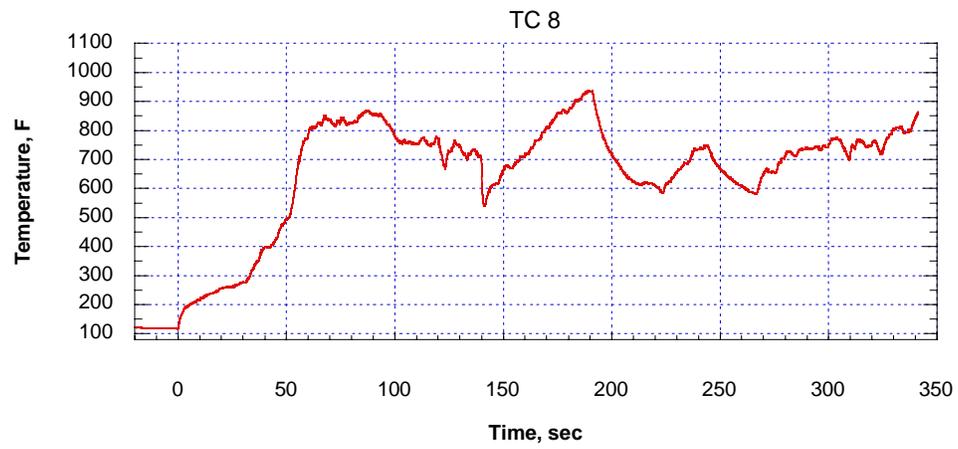
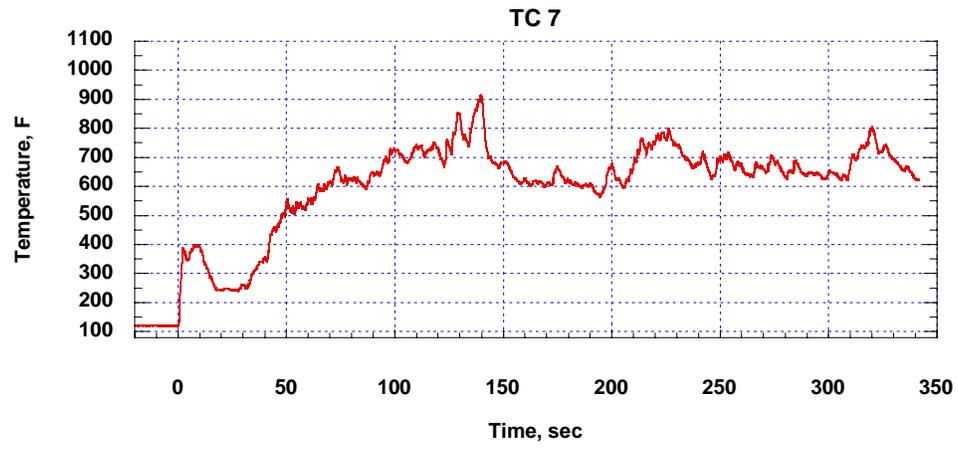
Test 31
Temperature vs Time



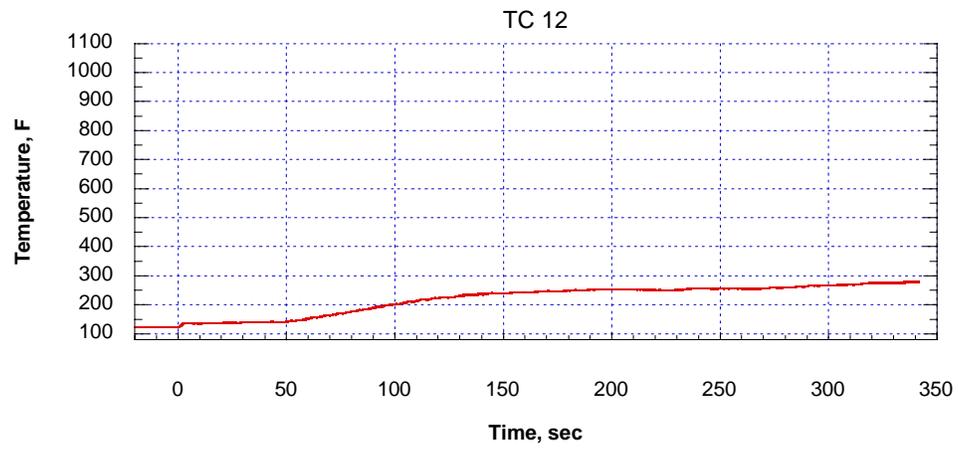
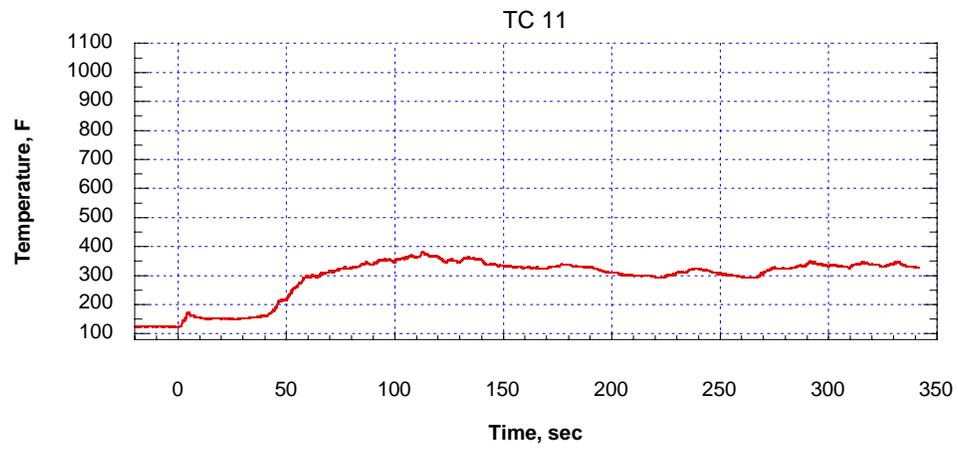
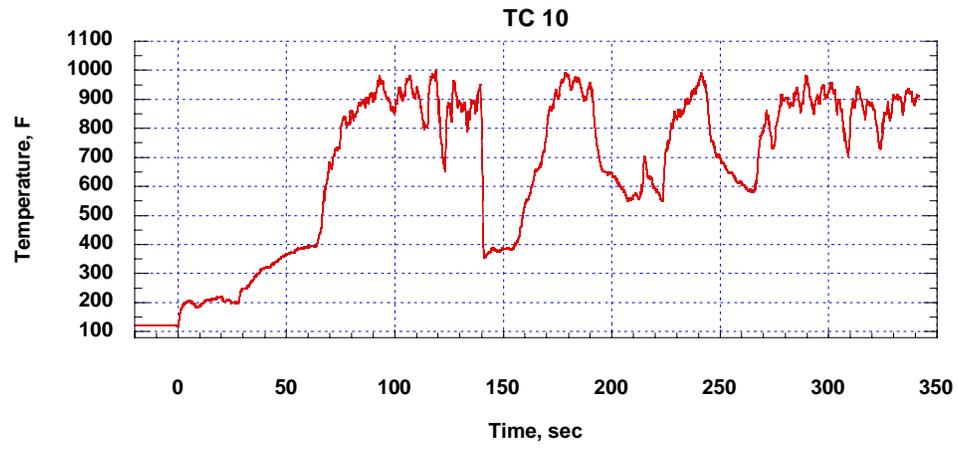
Test 31
Temperature vs Time



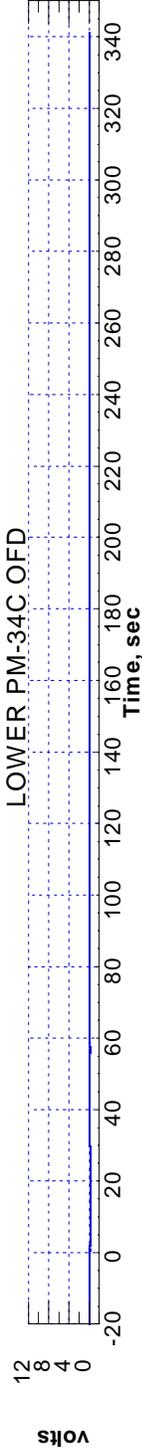
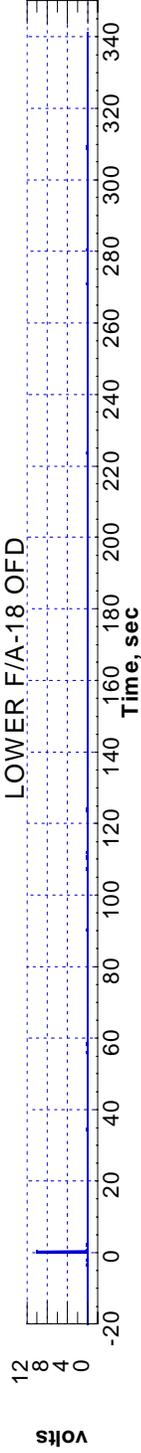
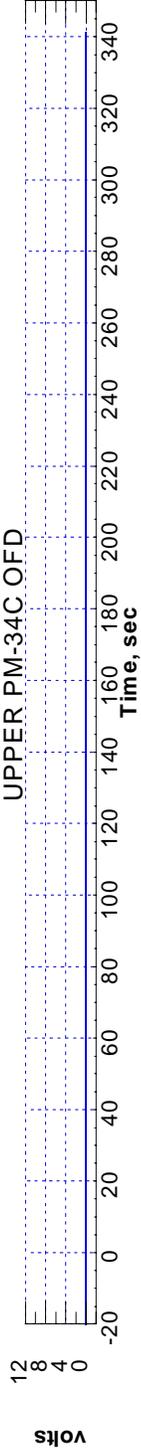
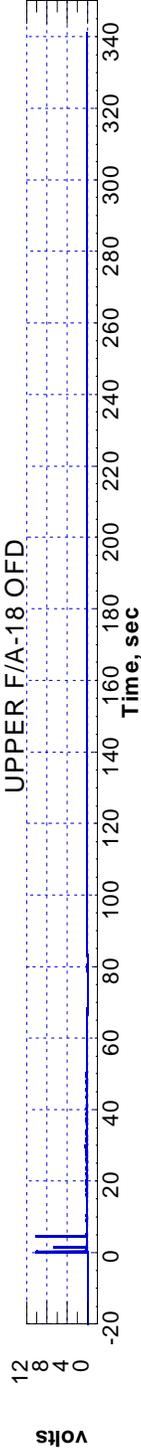
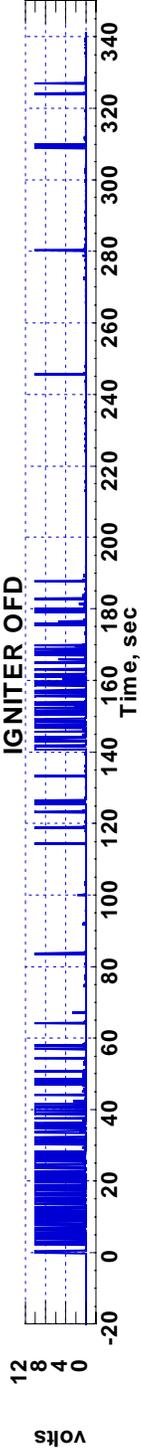
Test 31
Temperature vs Time



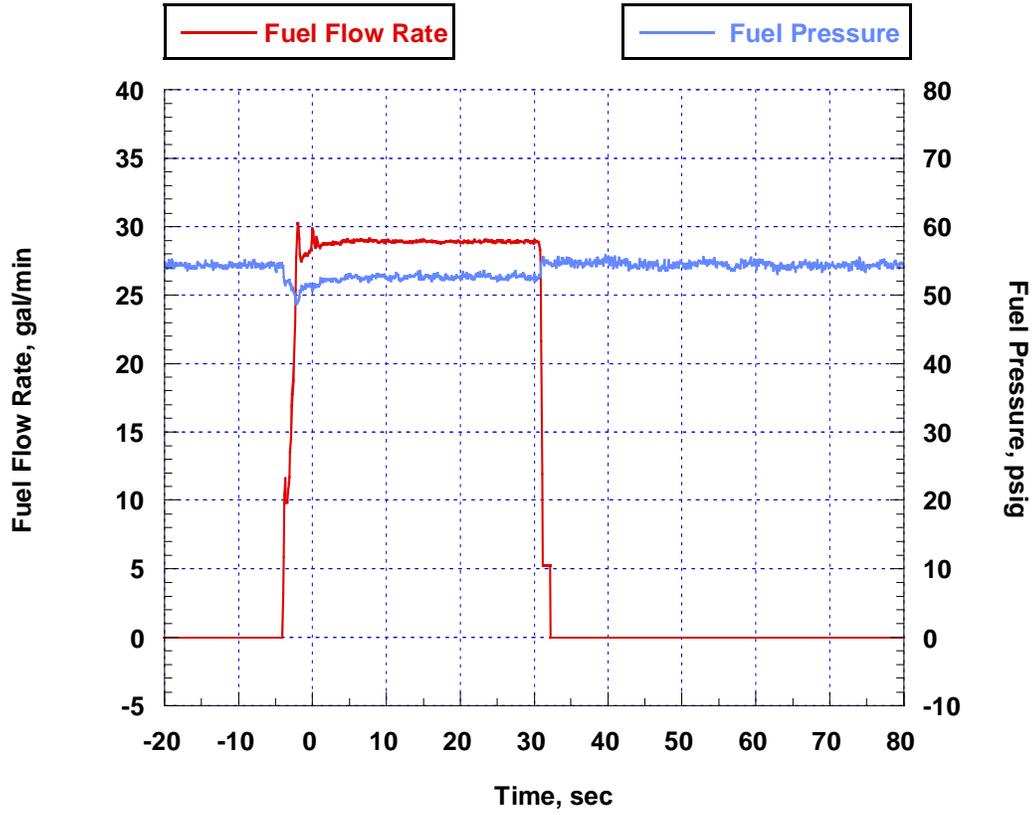
Test 31
Temperature vs Time



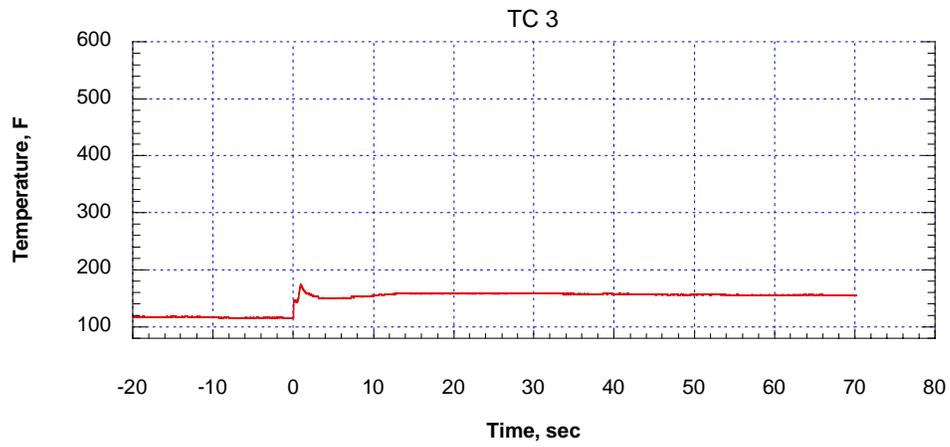
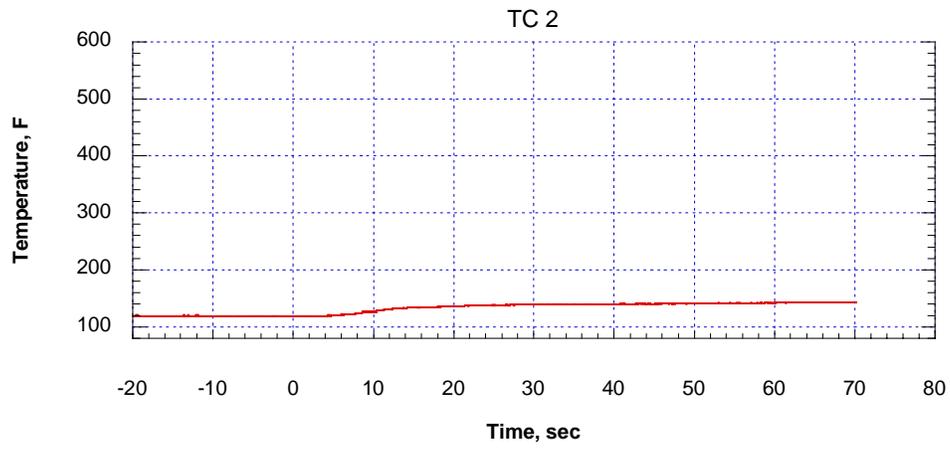
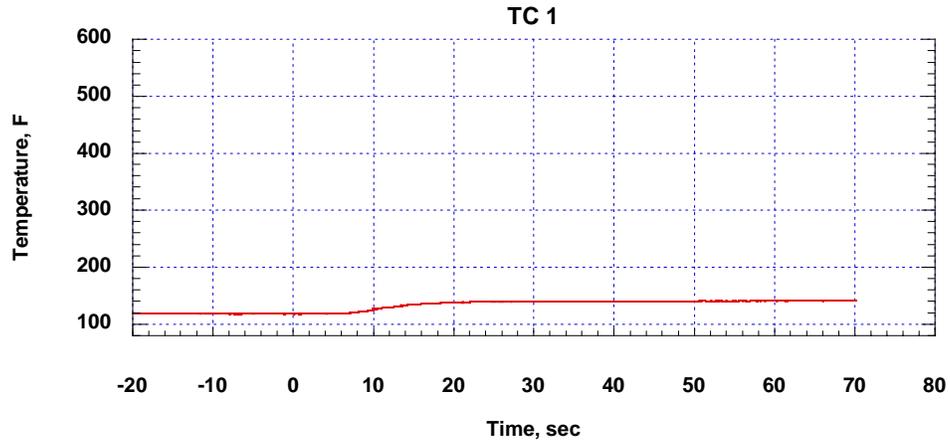
Test 31
Optical Fire Detector Signal vs Time



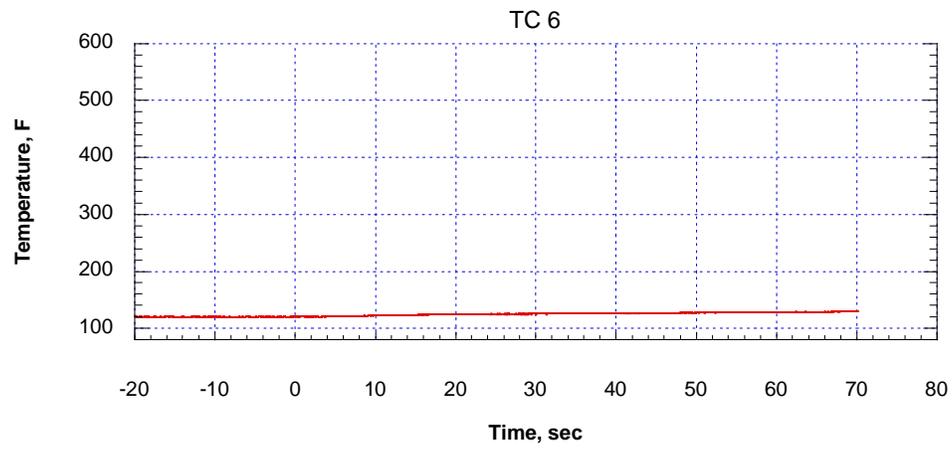
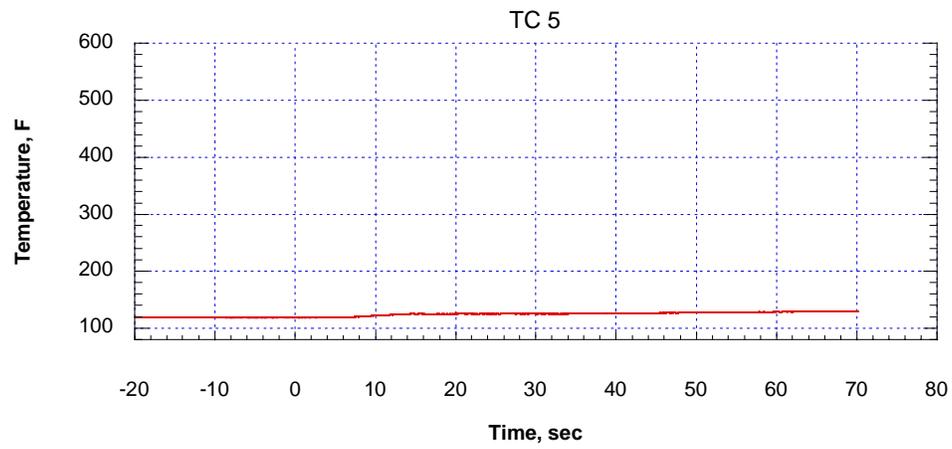
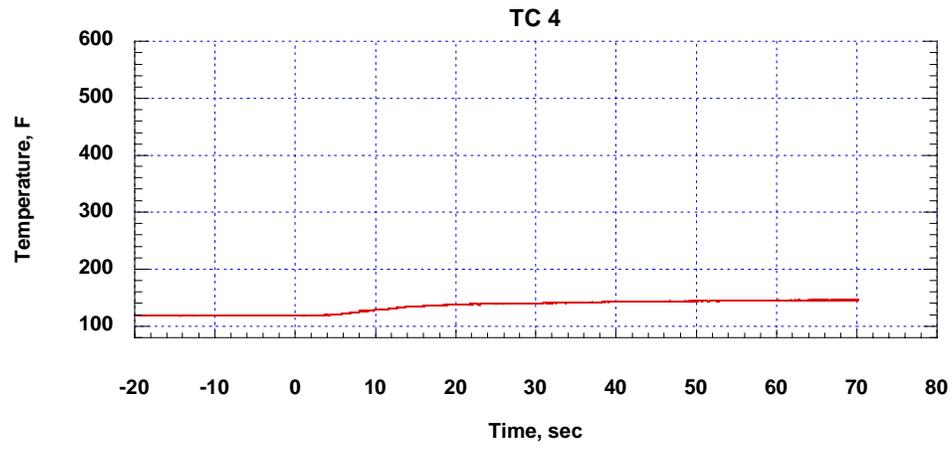
Test 31
Fuel Pressure and Flow Rate vs Time



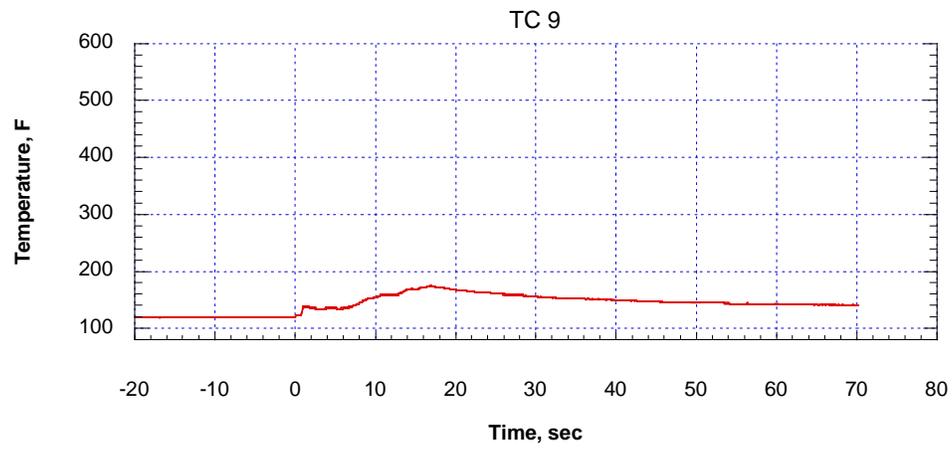
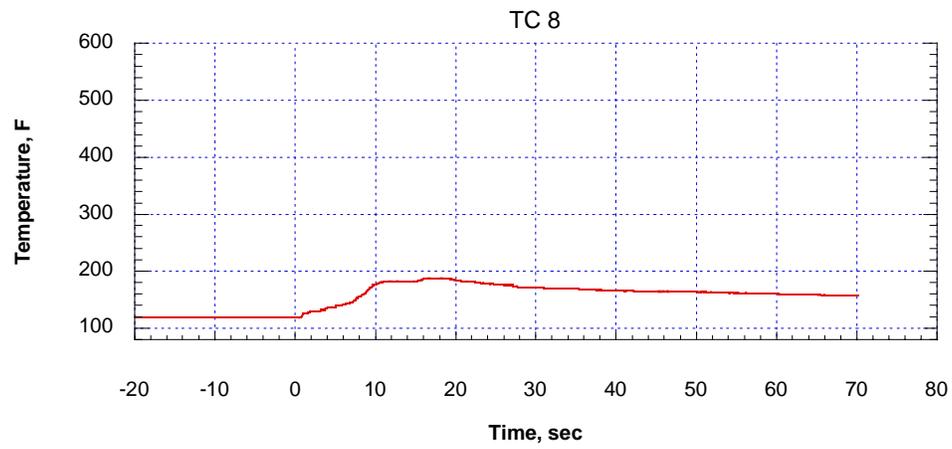
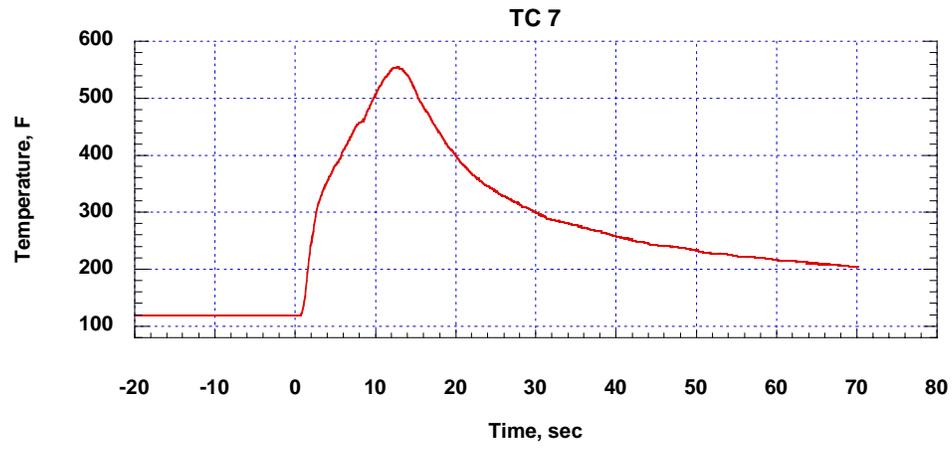
Test 32
Temperature vs Time



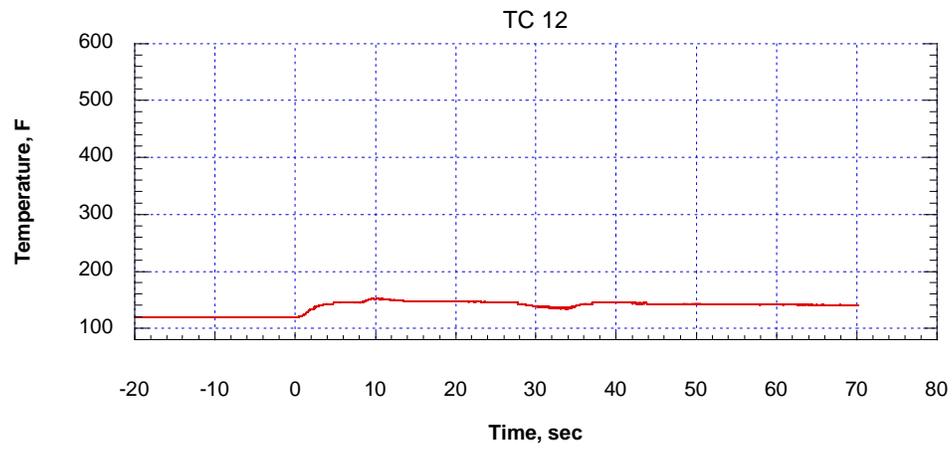
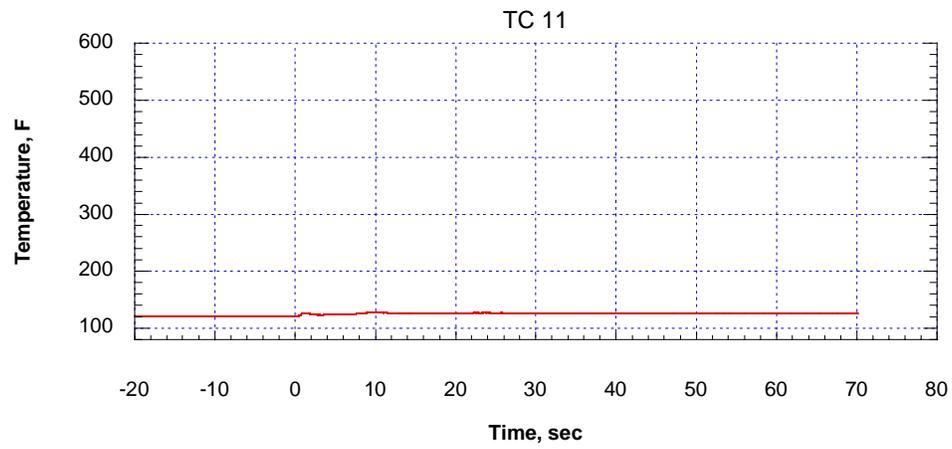
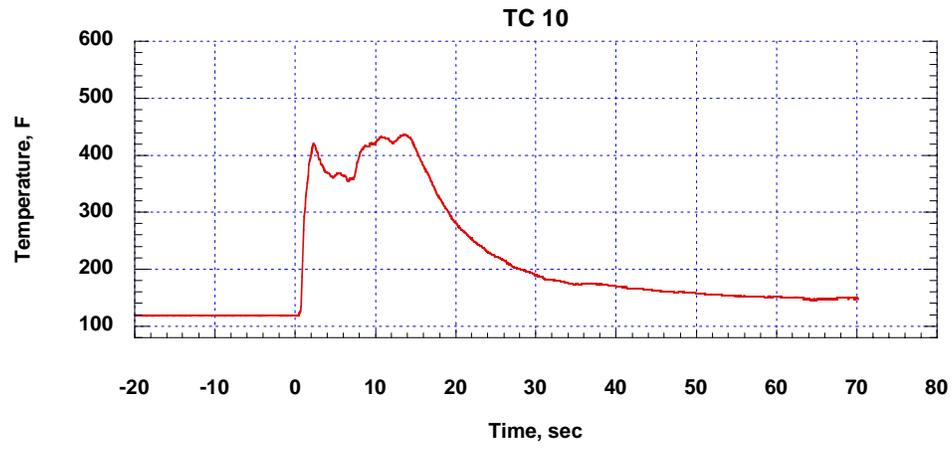
Test 32
Temperature vs Time



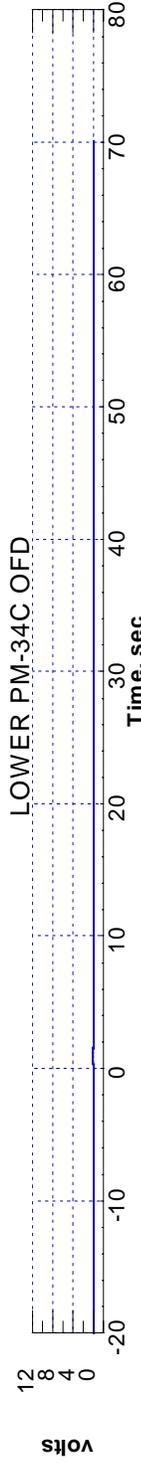
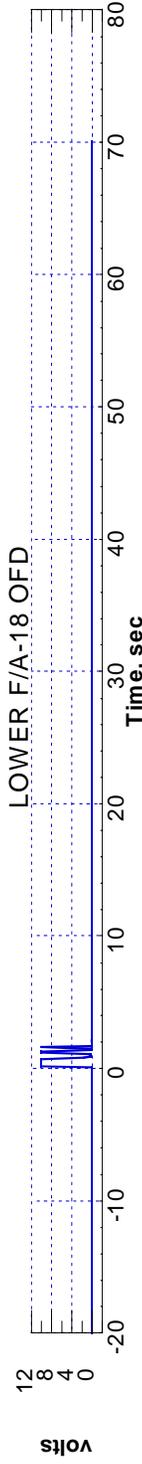
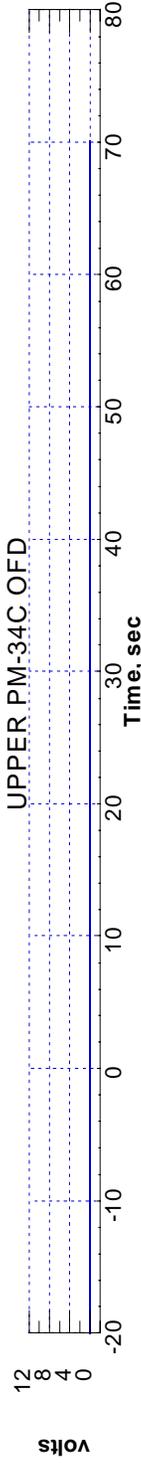
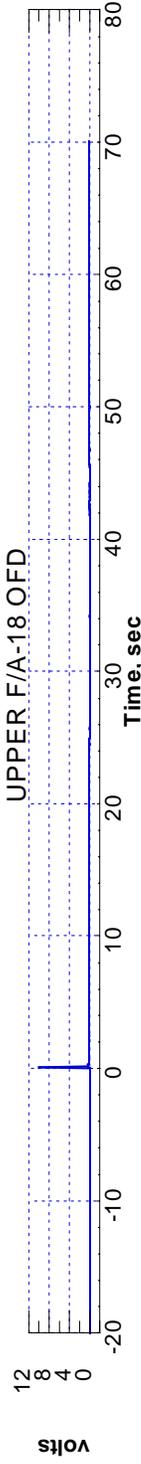
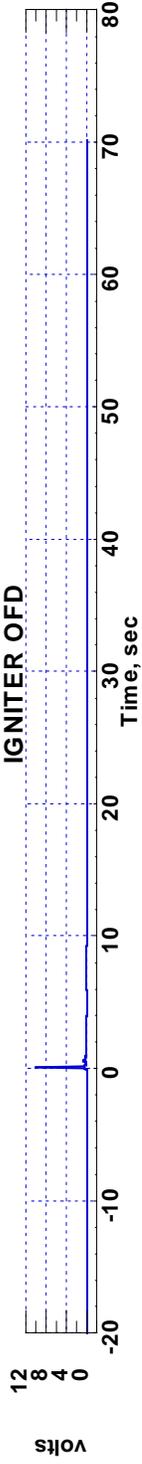
Test 32
Temperature vs Time



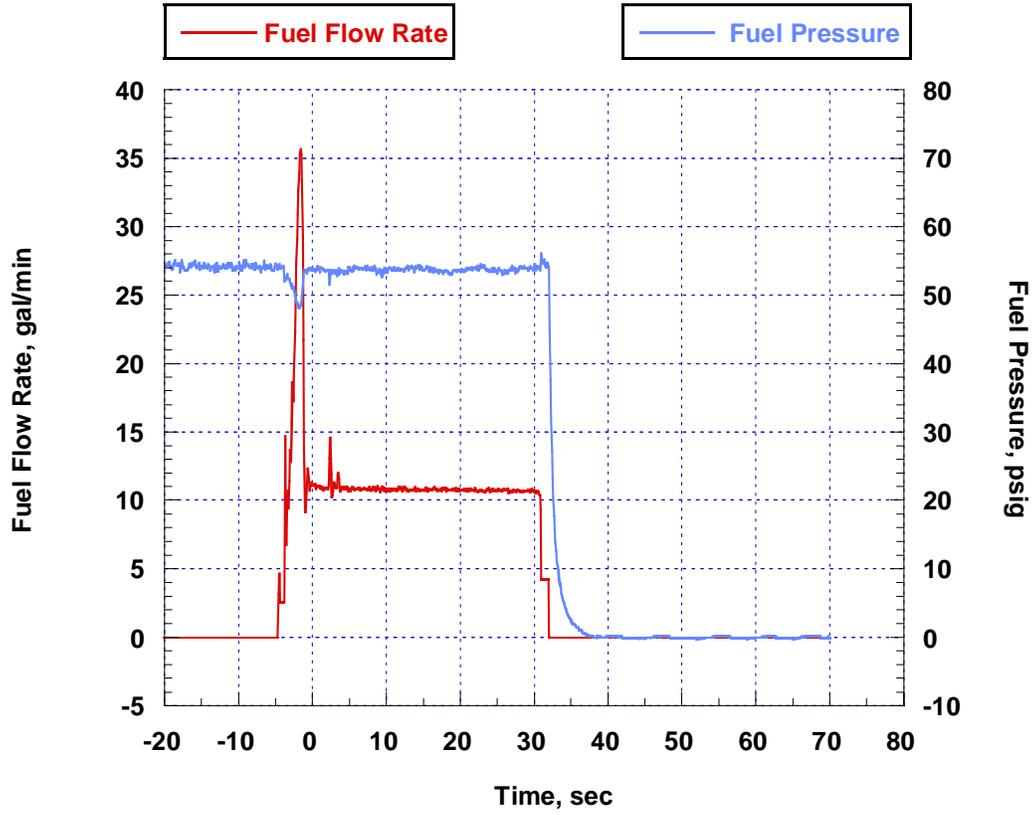
Test 32
Temperature vs Time



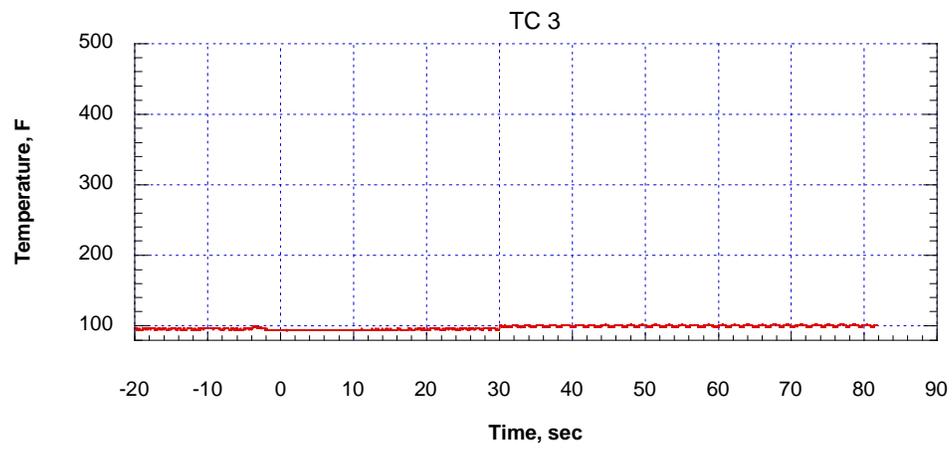
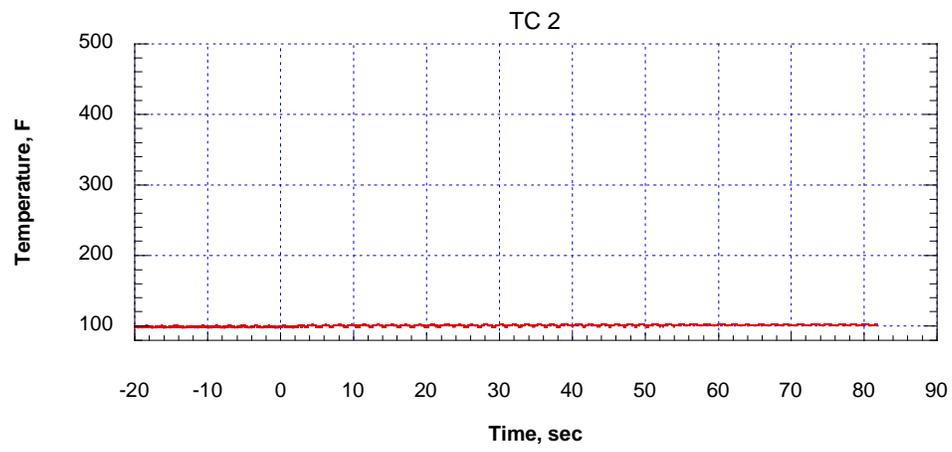
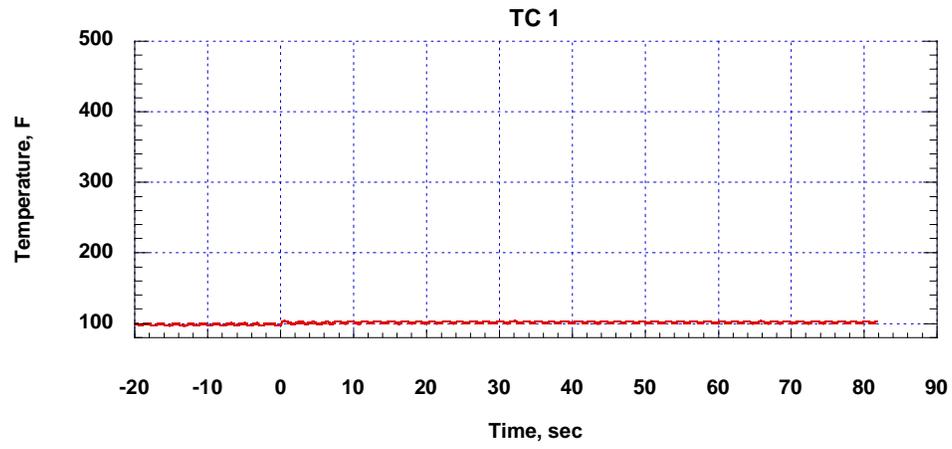
Test 32
Optical Fire Detector Signal vs Time



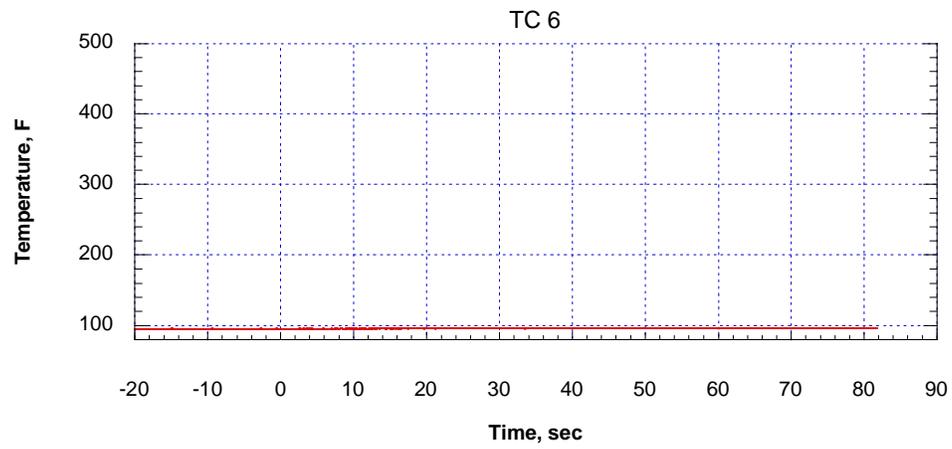
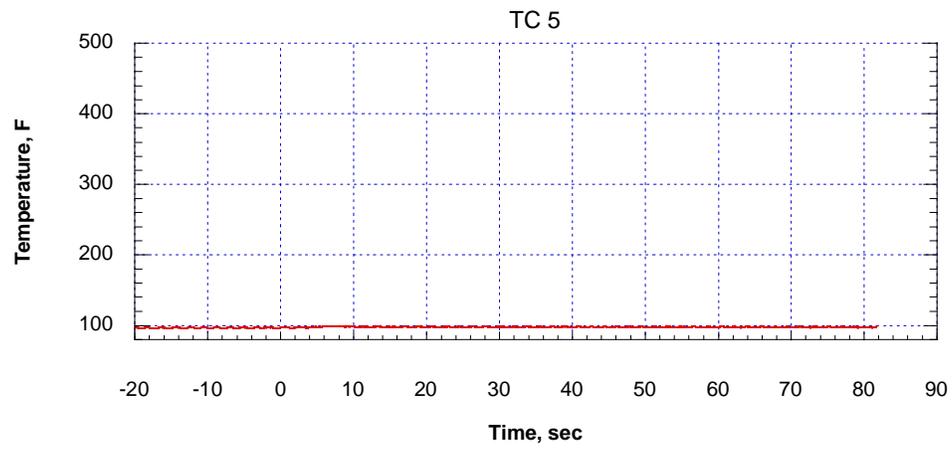
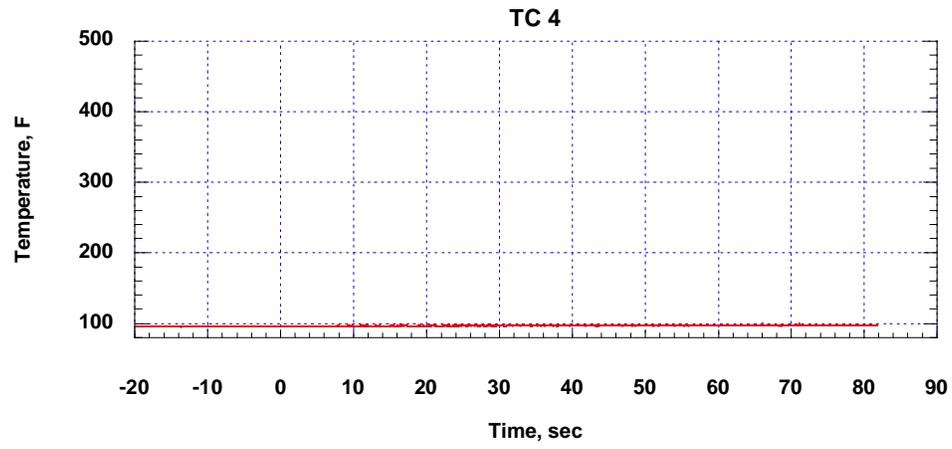
Test 32
Fuel Pressure and Flow Rate vs Time



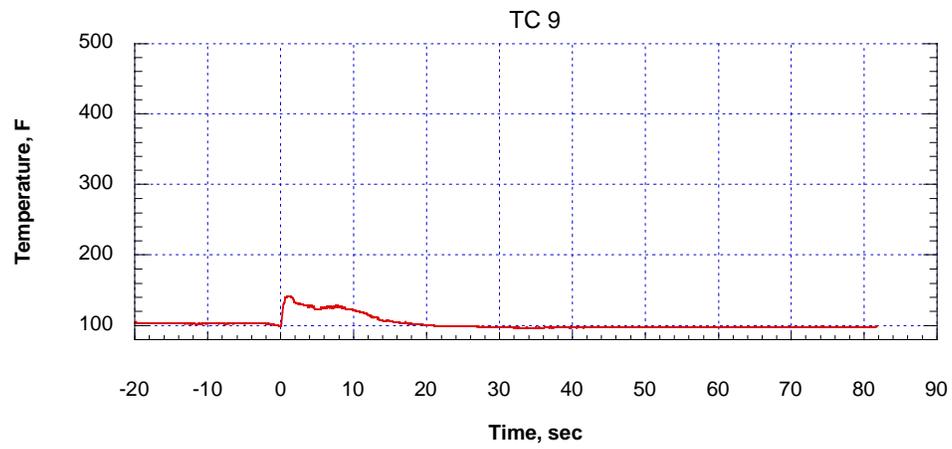
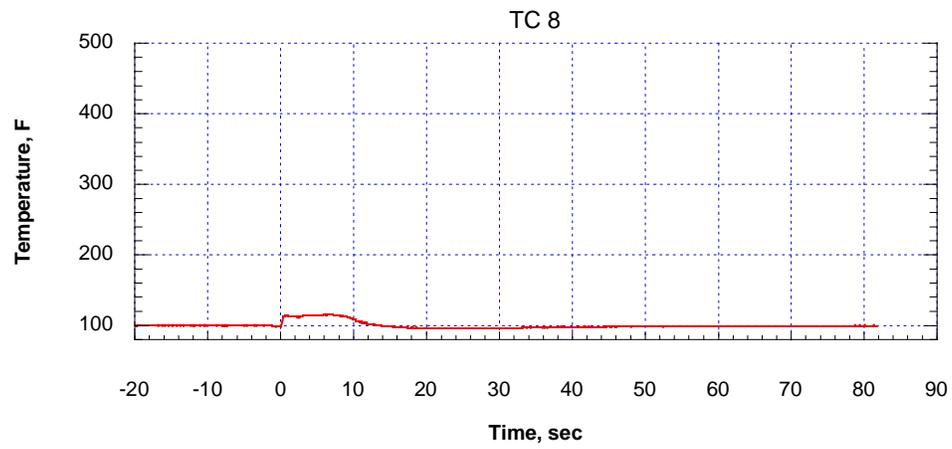
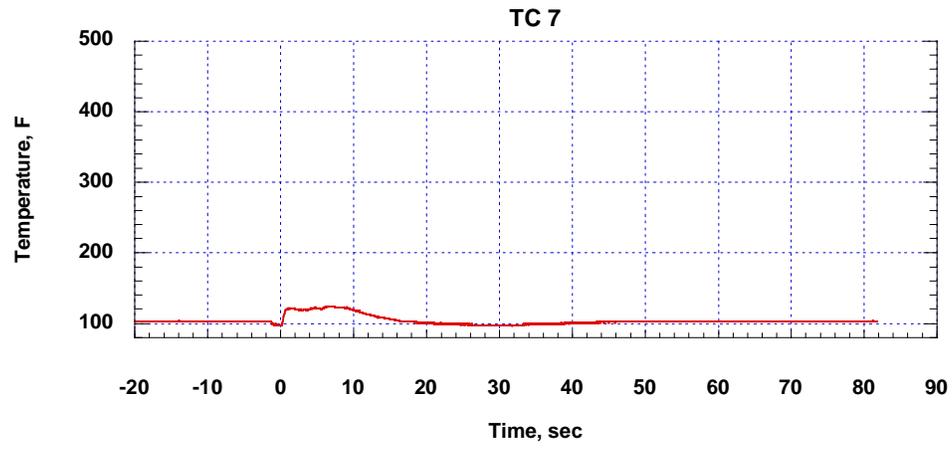
Test 33
Temperature vs Time



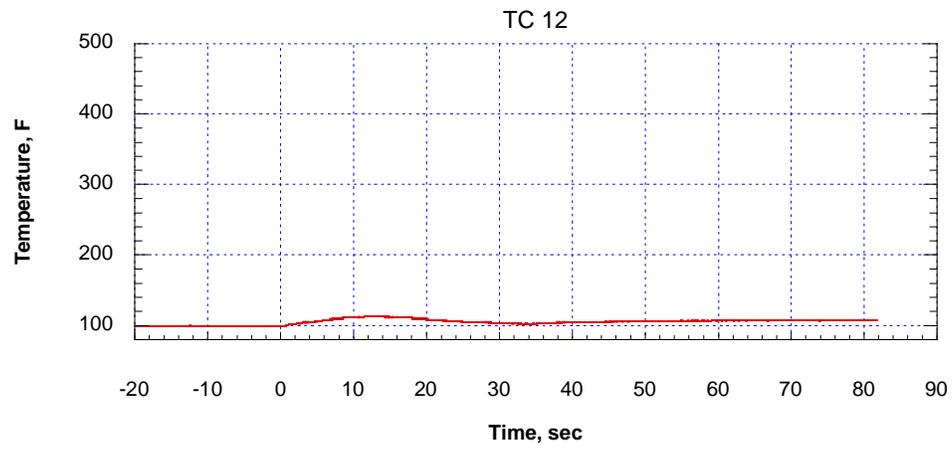
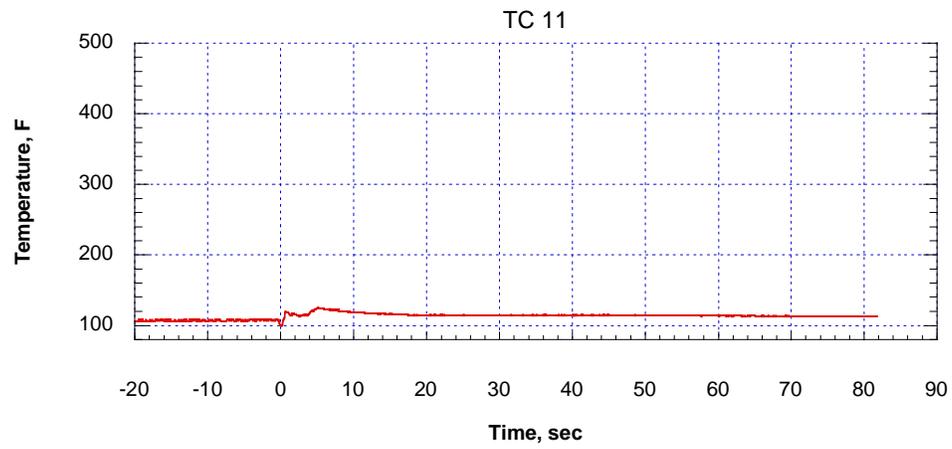
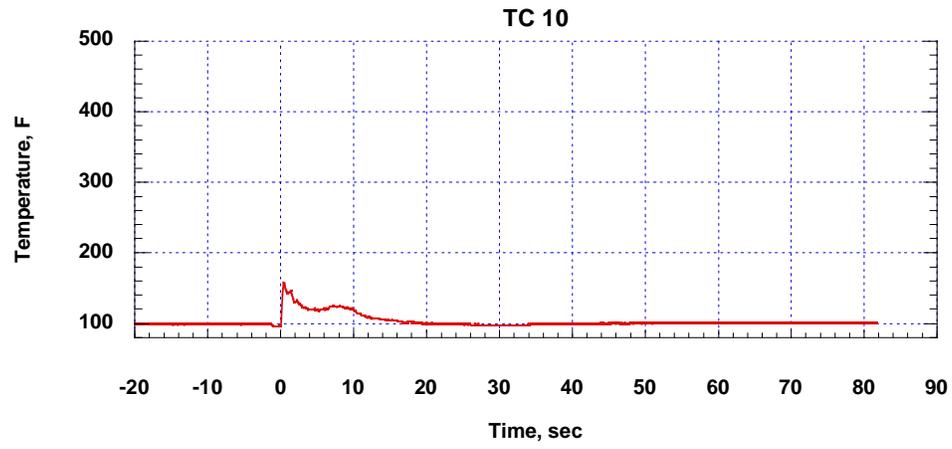
Test 33
Temperature vs Time



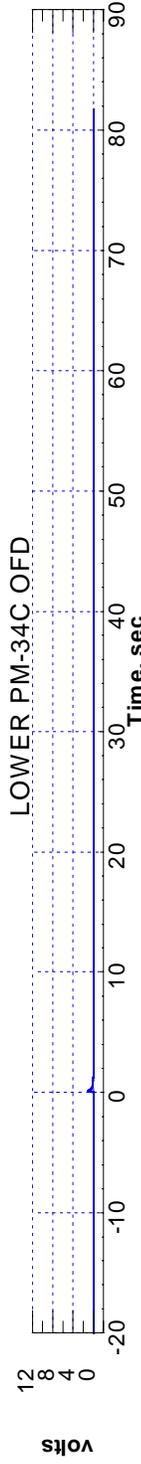
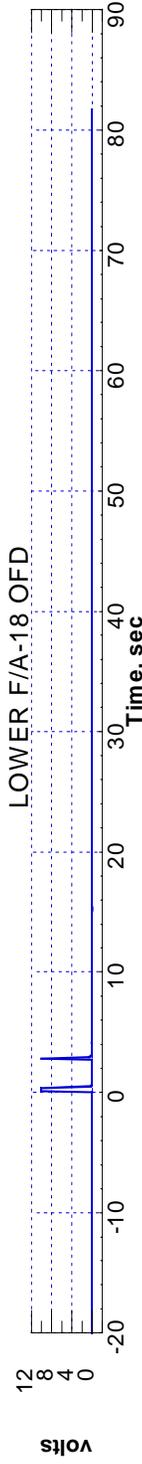
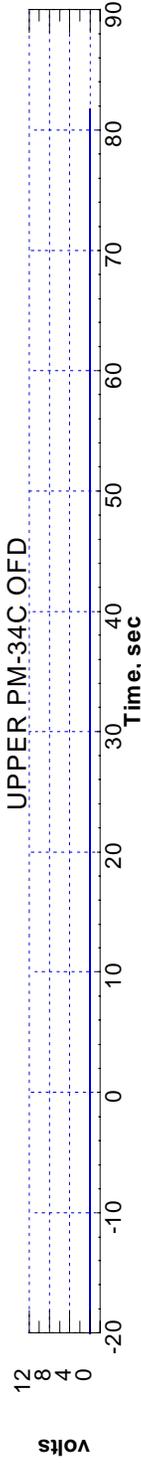
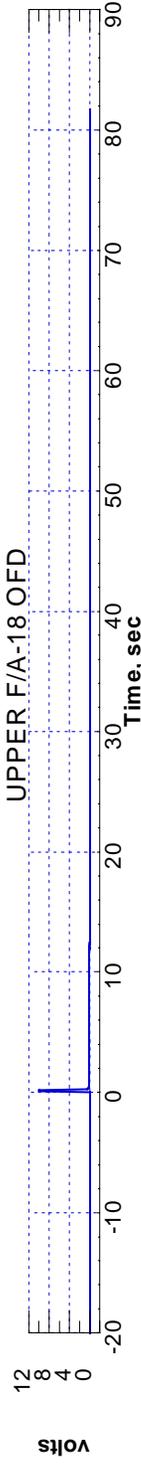
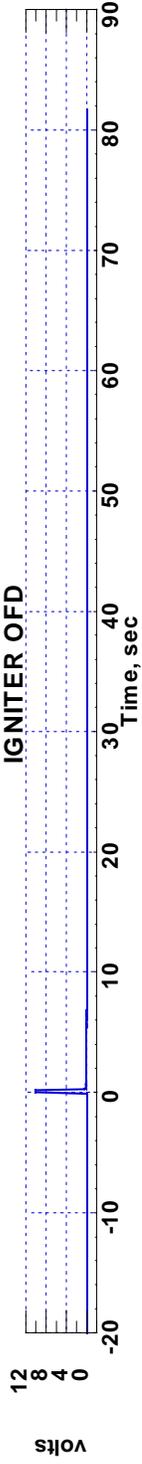
Test 33
Temperature vs Time



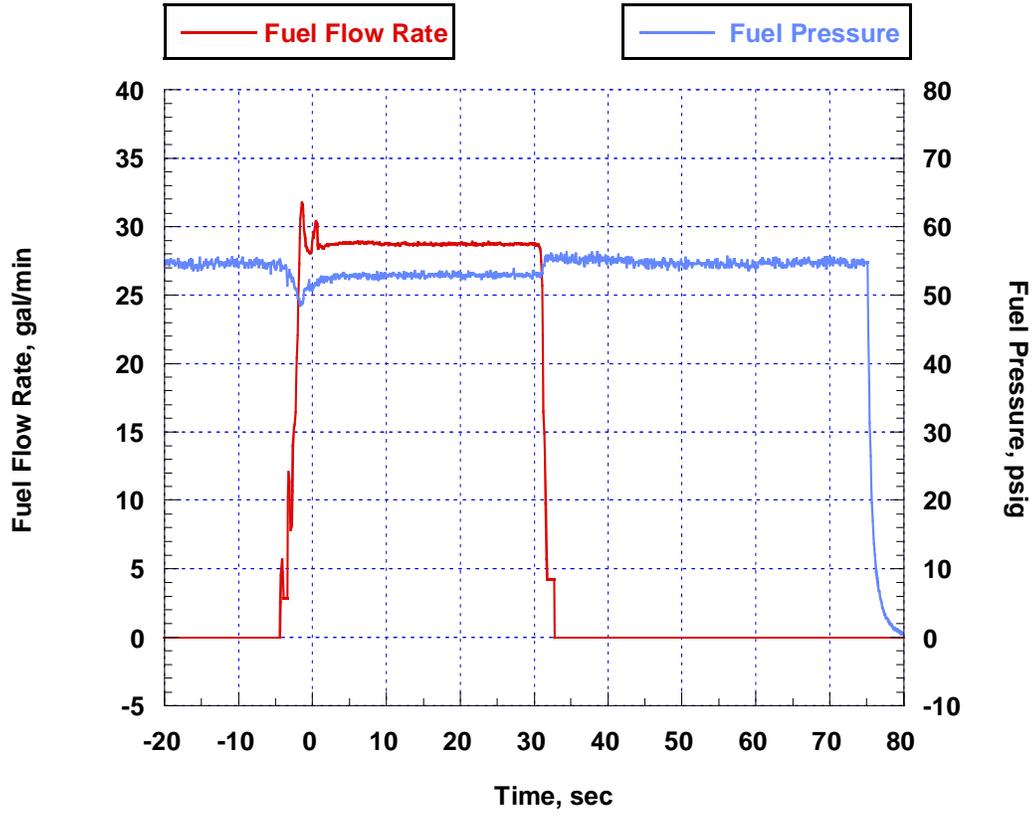
Test 33
Temperature vs Time



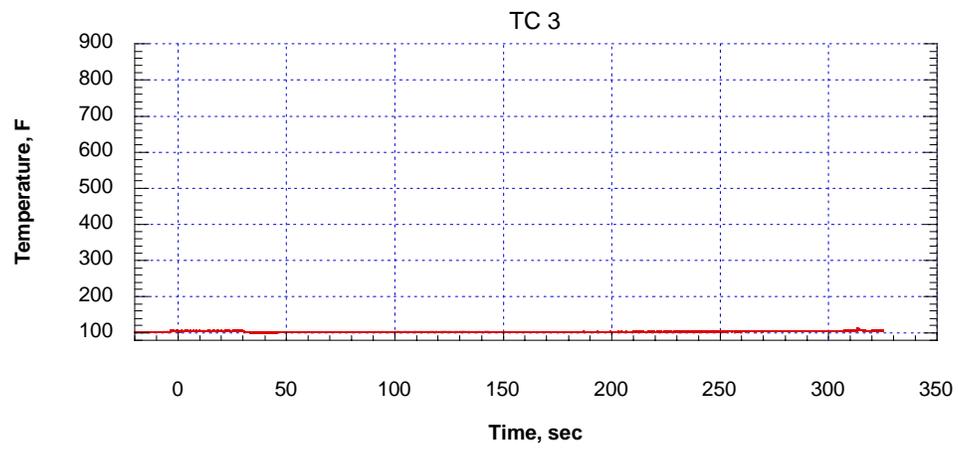
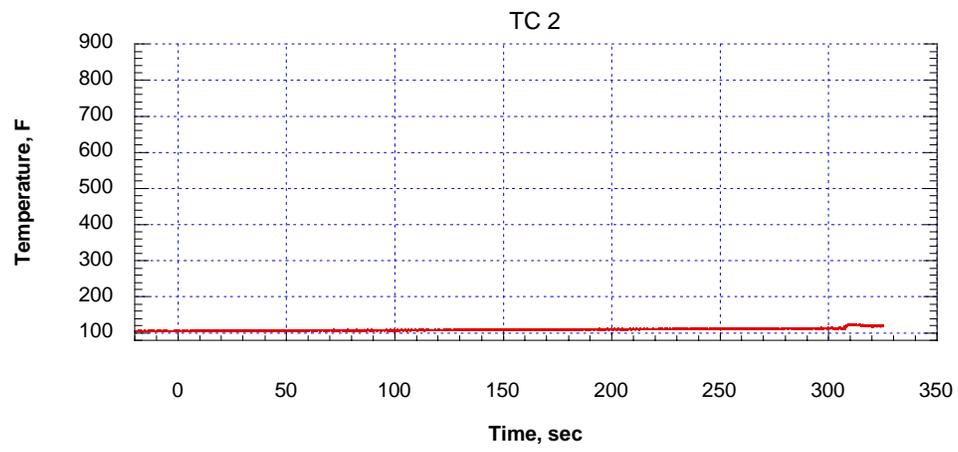
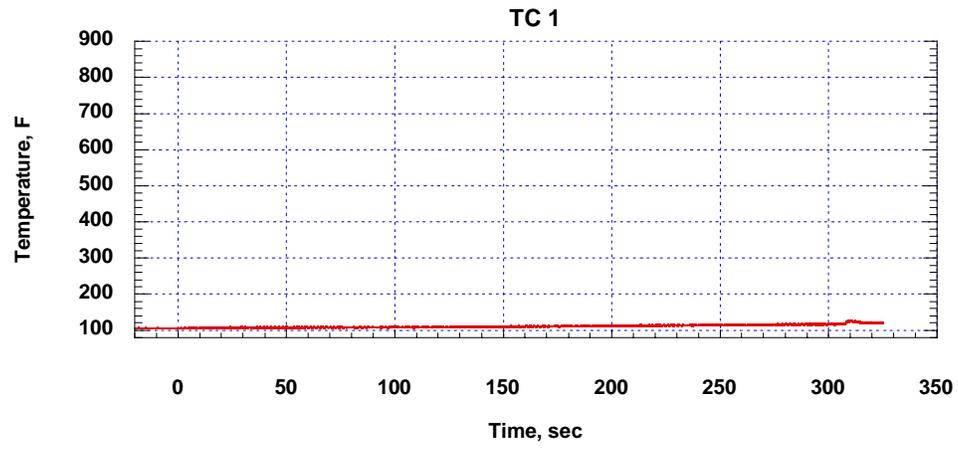
Test 33
Optical Fire Detector Signal vs Time



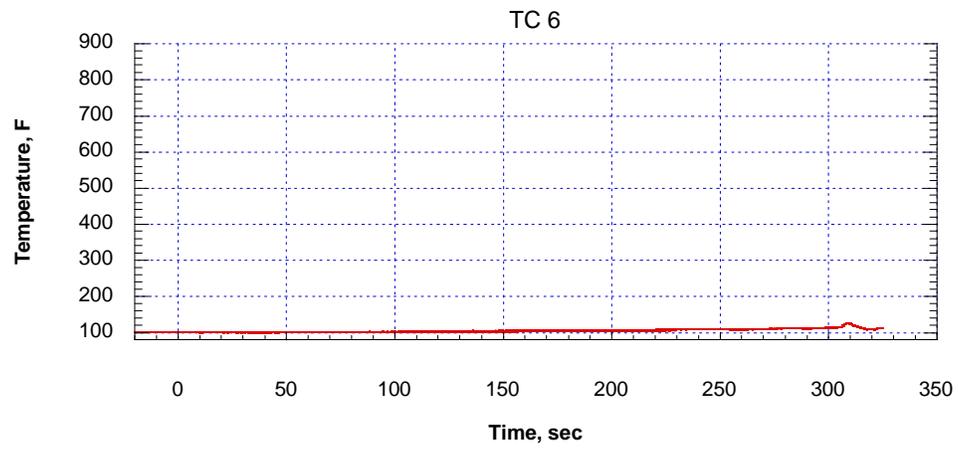
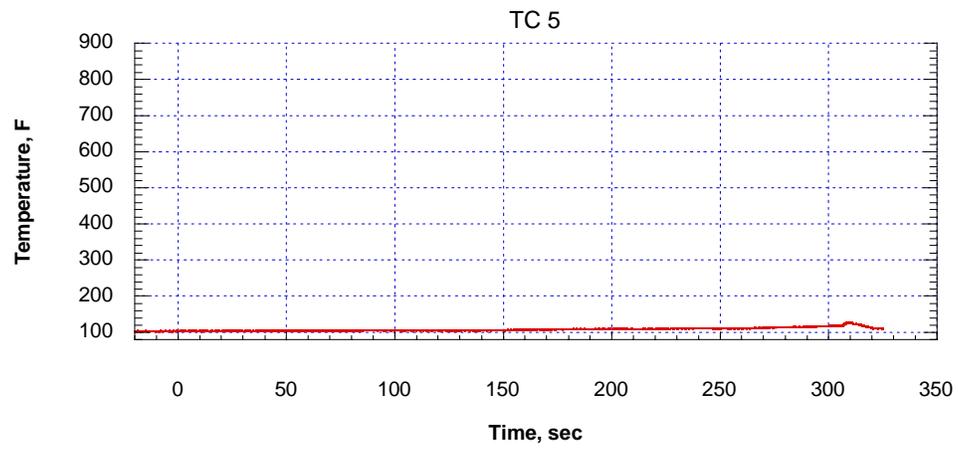
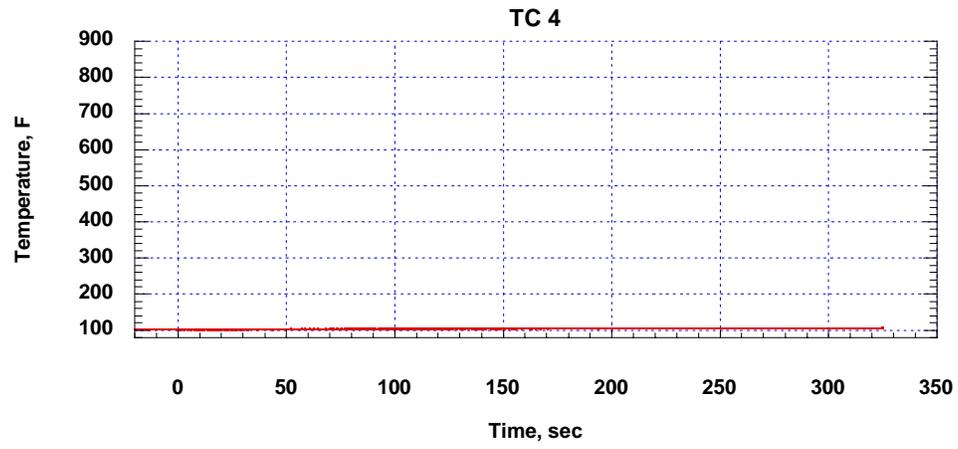
Test 33
Fuel Pressure and Flow Rate vs Time



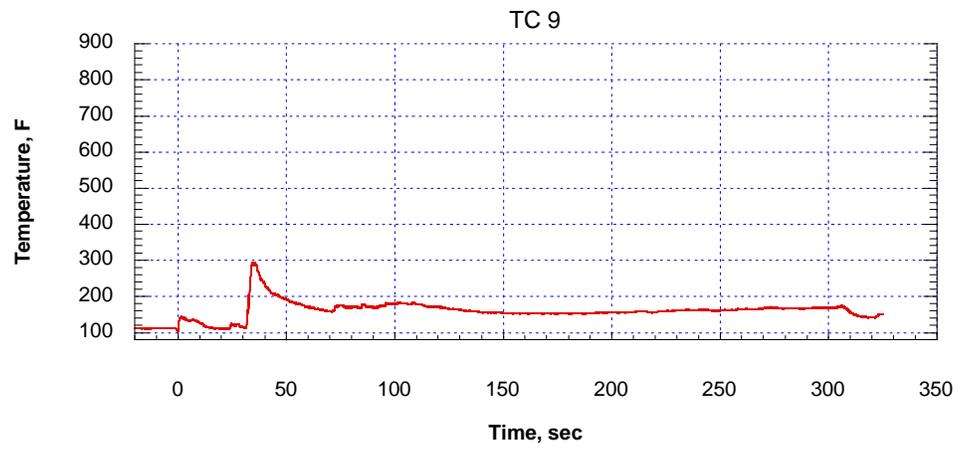
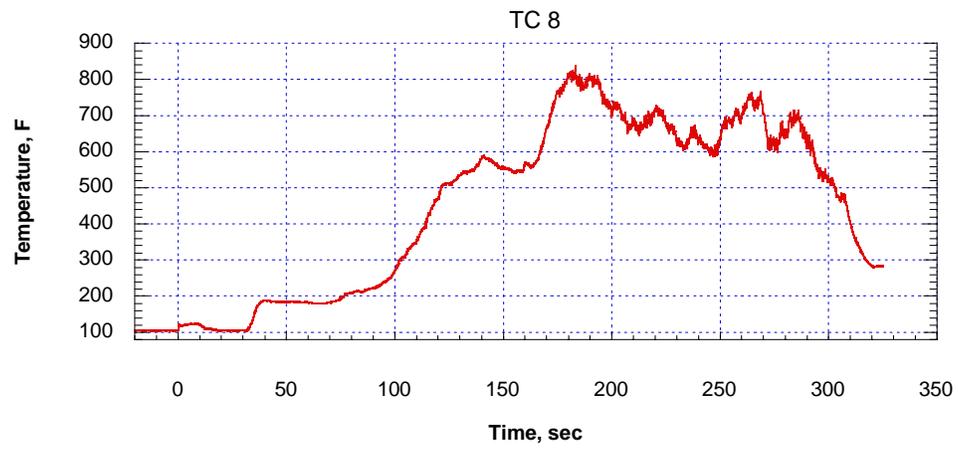
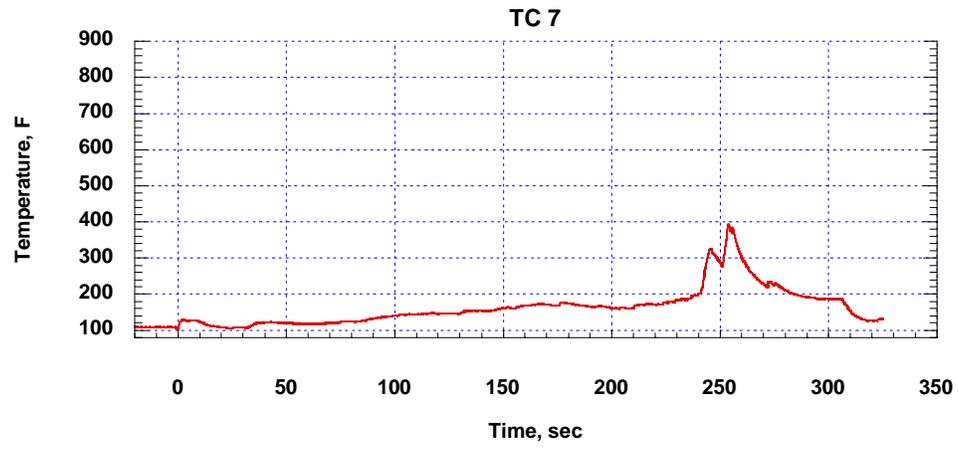
Test 34
Temperature vs Time



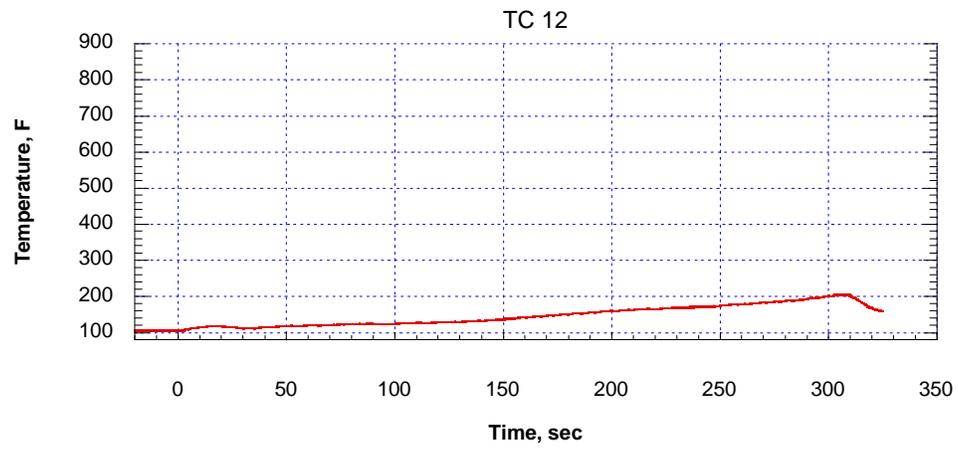
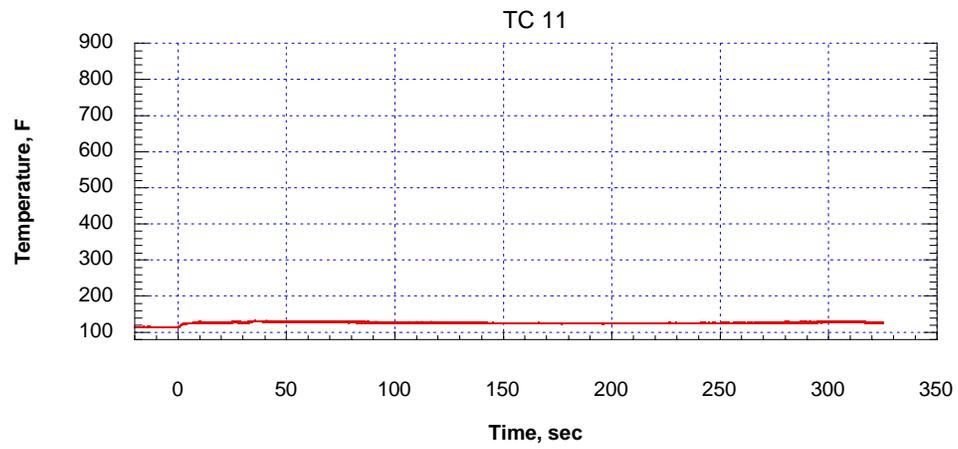
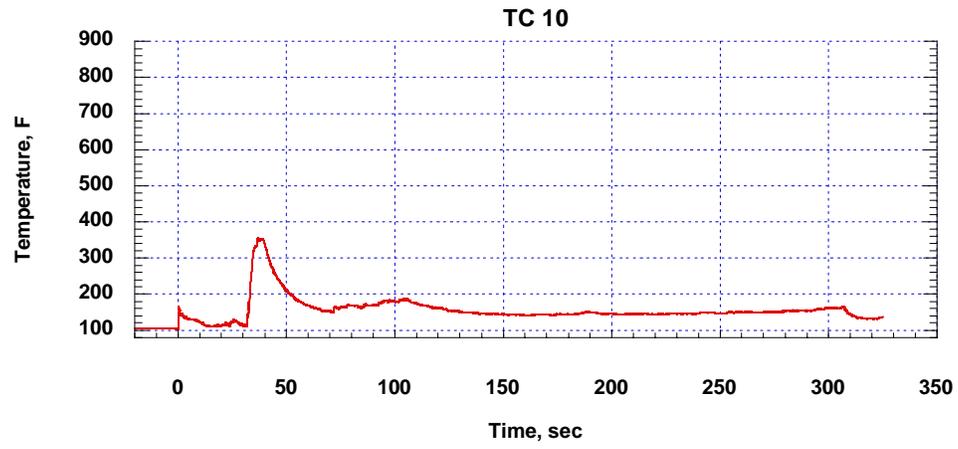
Test 34
Temperature vs Time



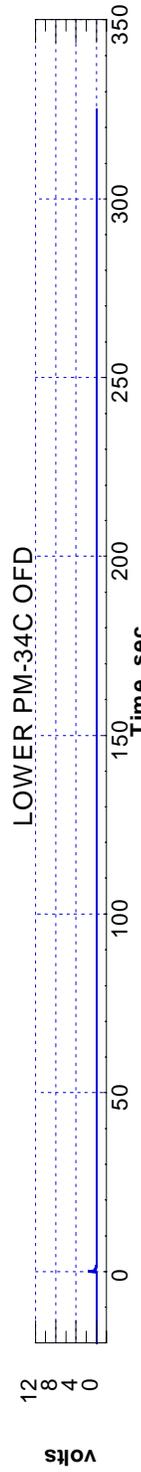
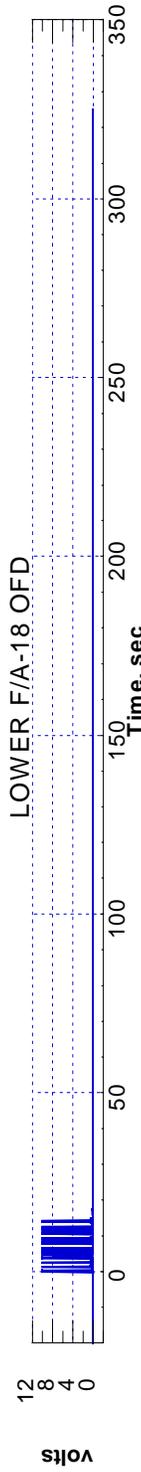
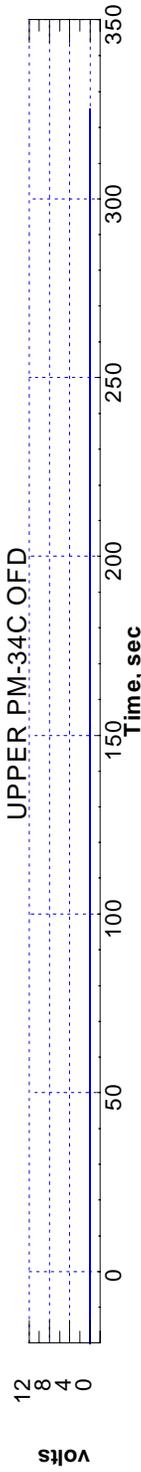
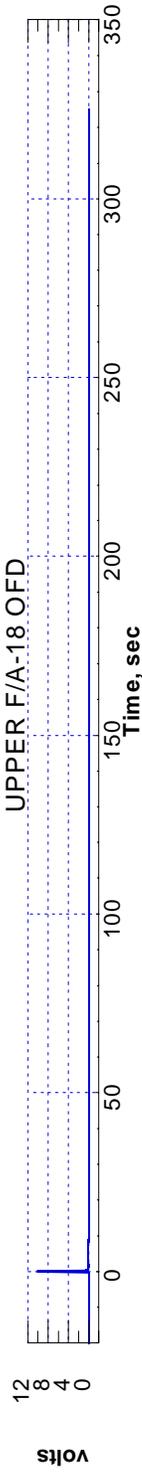
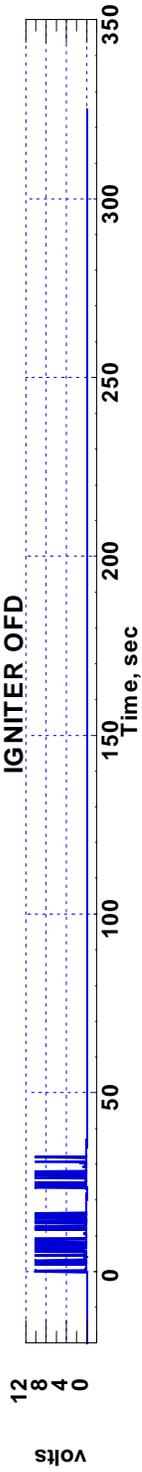
Test 34
Temperature vs Time



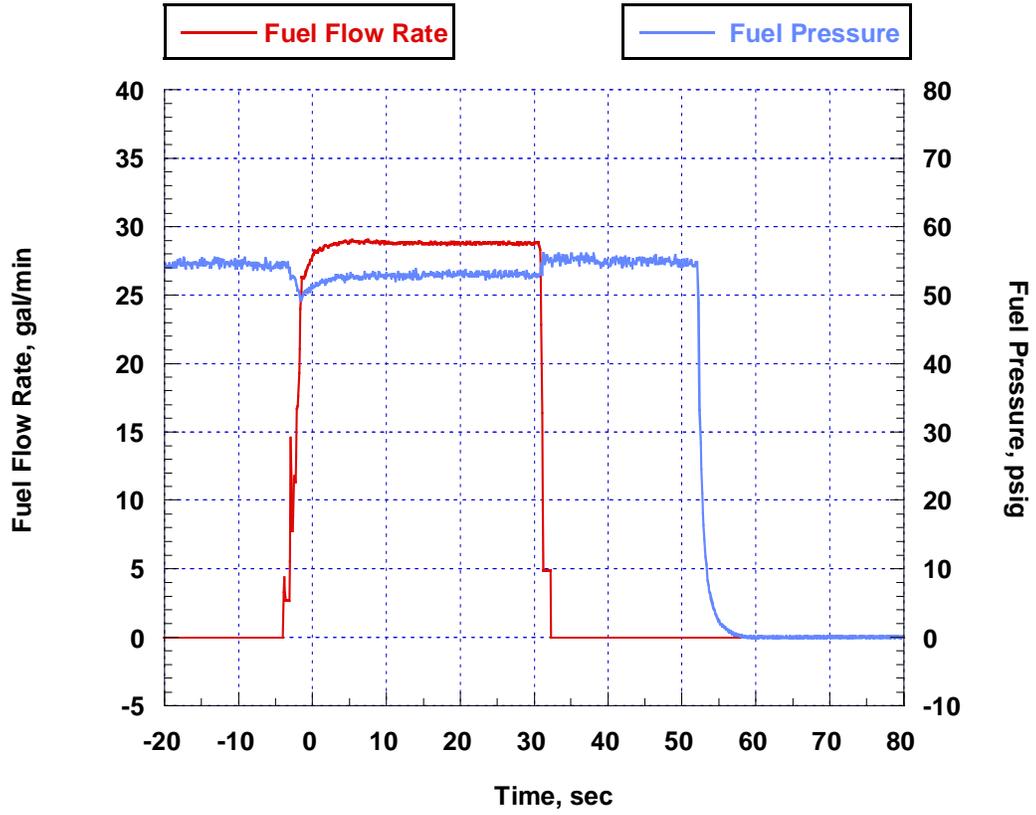
Test 34
Temperature vs Time



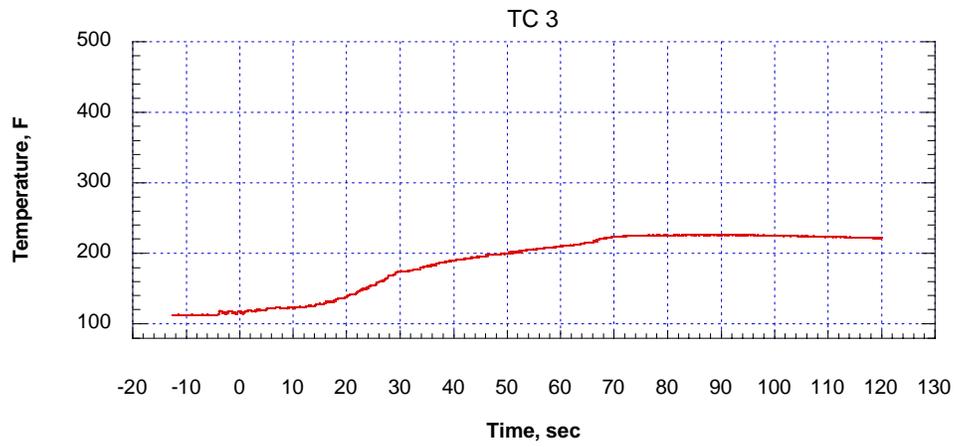
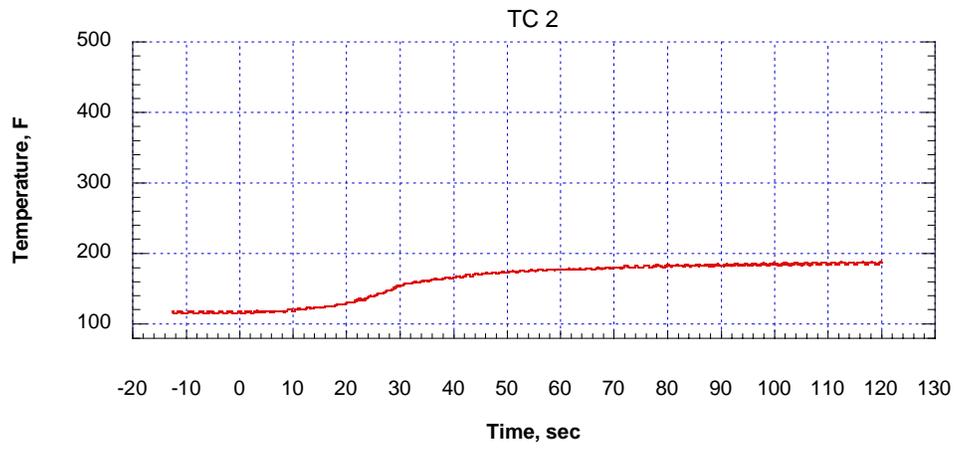
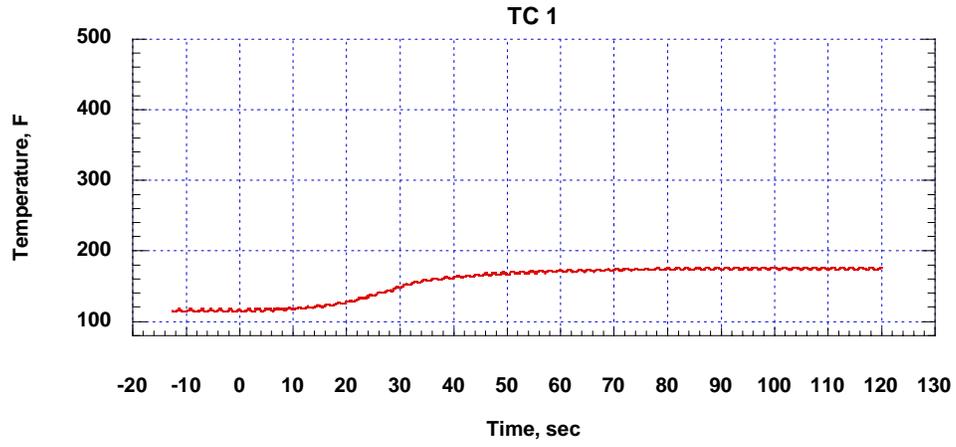
Test 34
Optical Fire Detector Signal vs Time



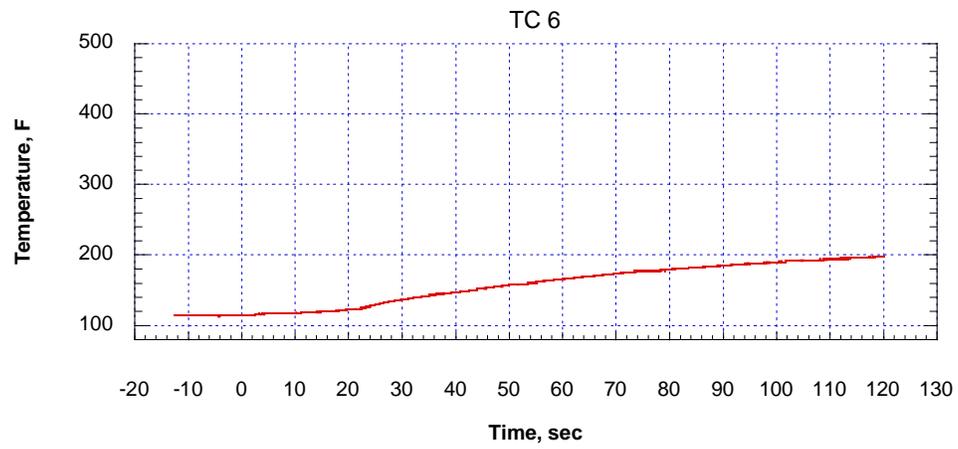
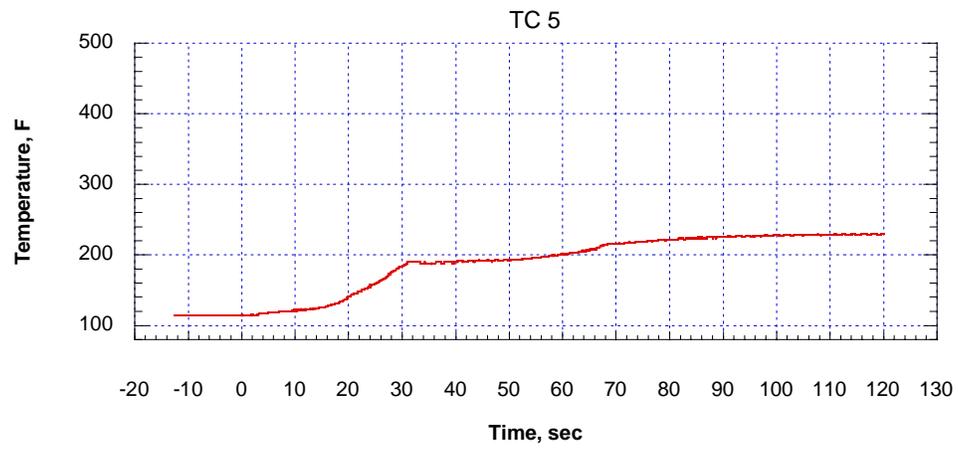
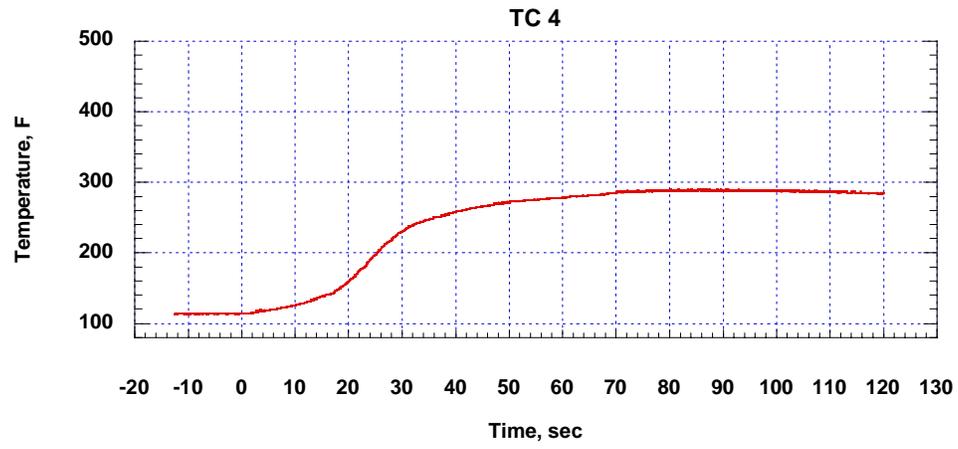
Test 34
Fuel Pressure and Flow Rate vs Time



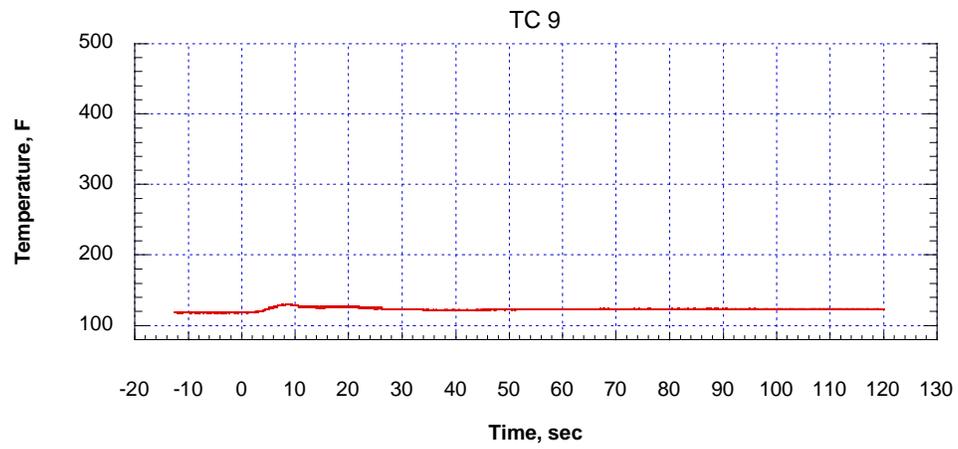
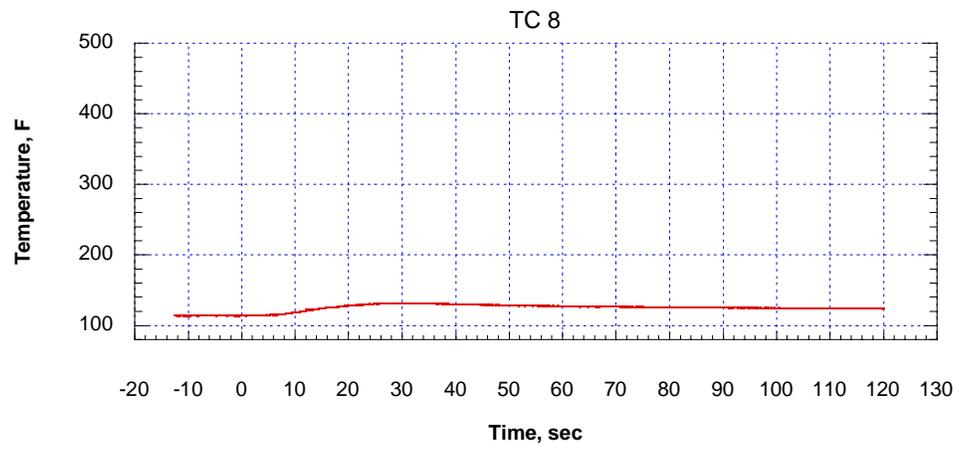
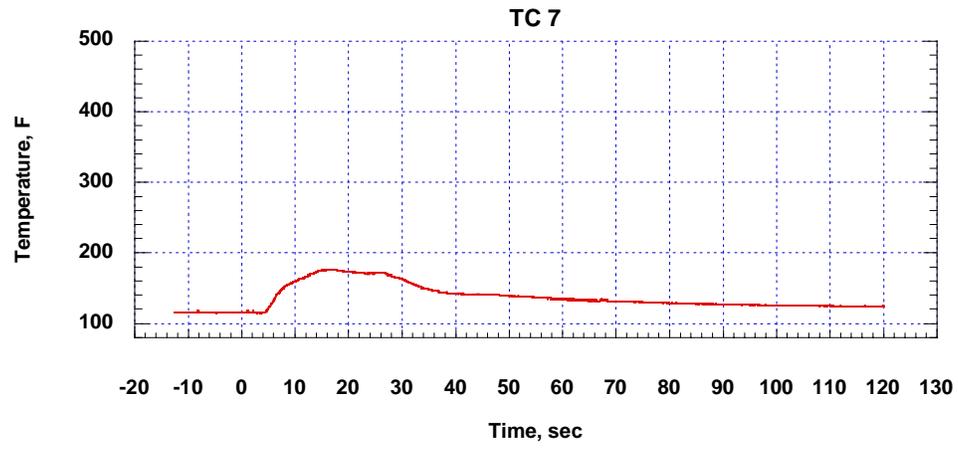
Test 35
Temperature vs Time



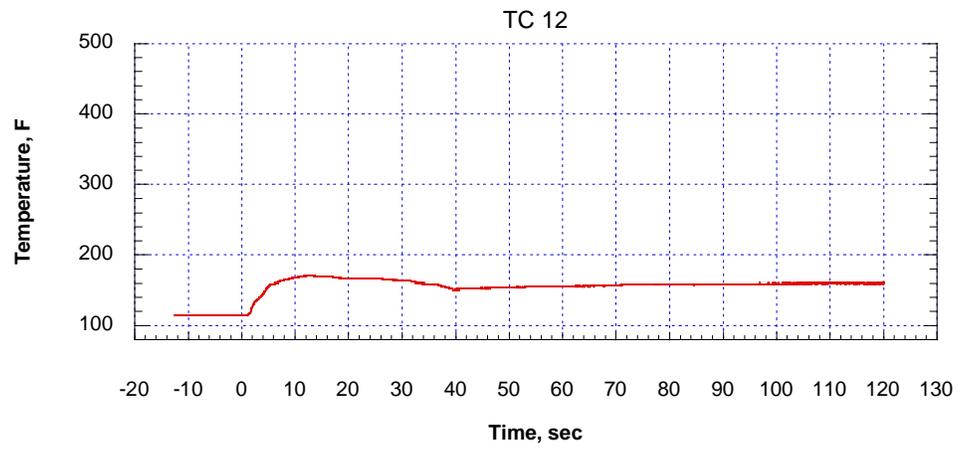
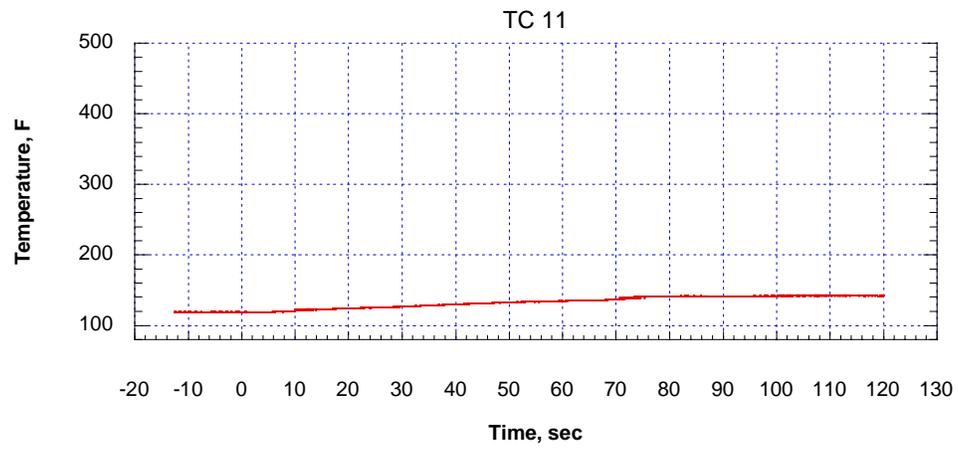
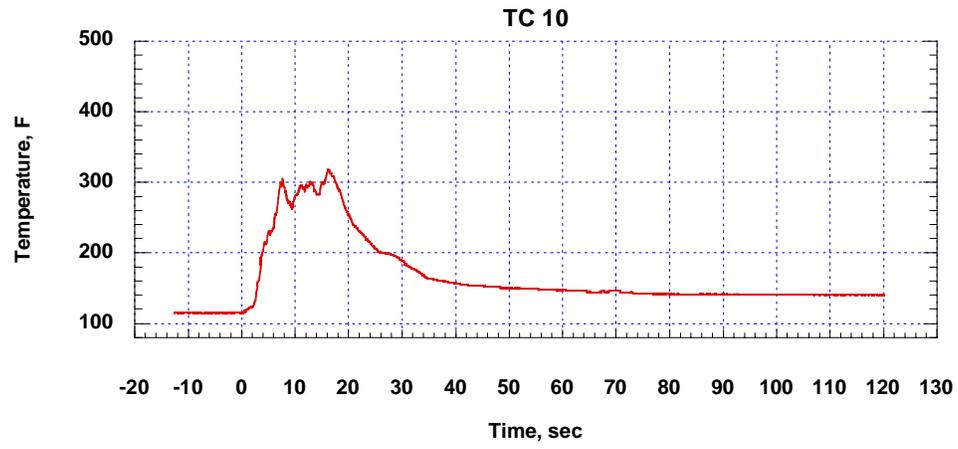
Test 35
Temperature vs Time



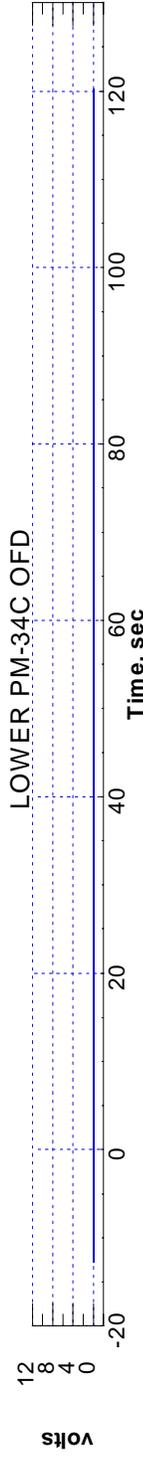
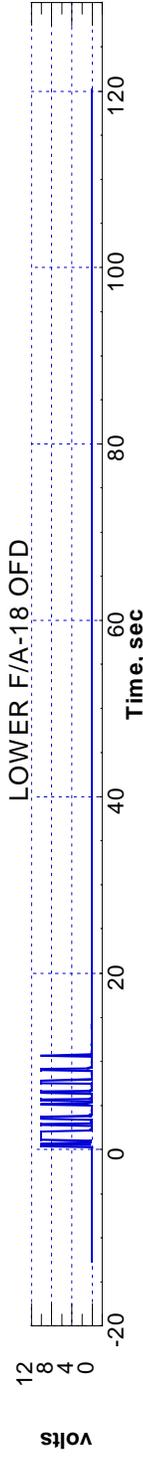
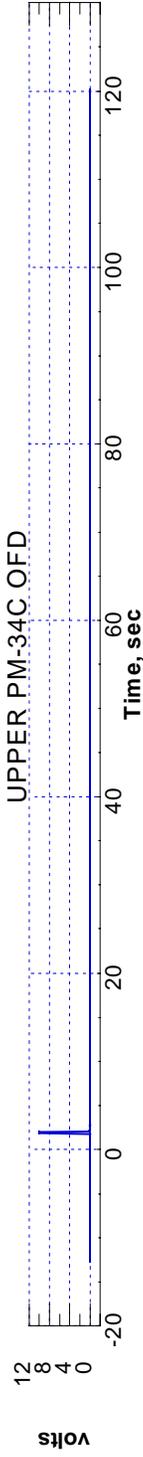
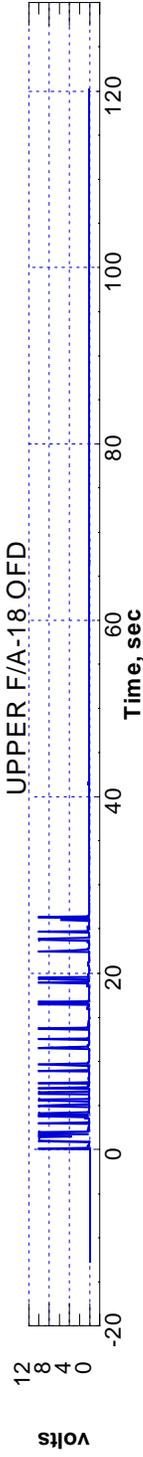
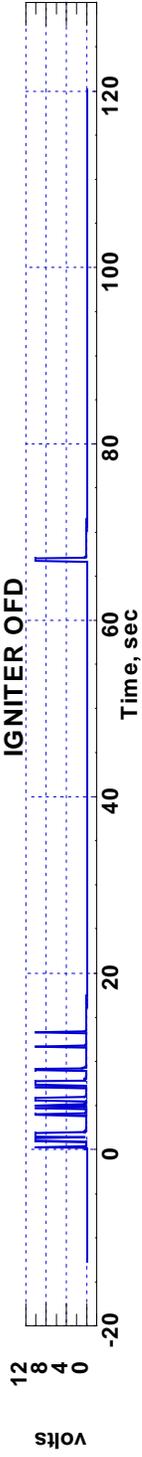
Test 35
Temperature vs Time



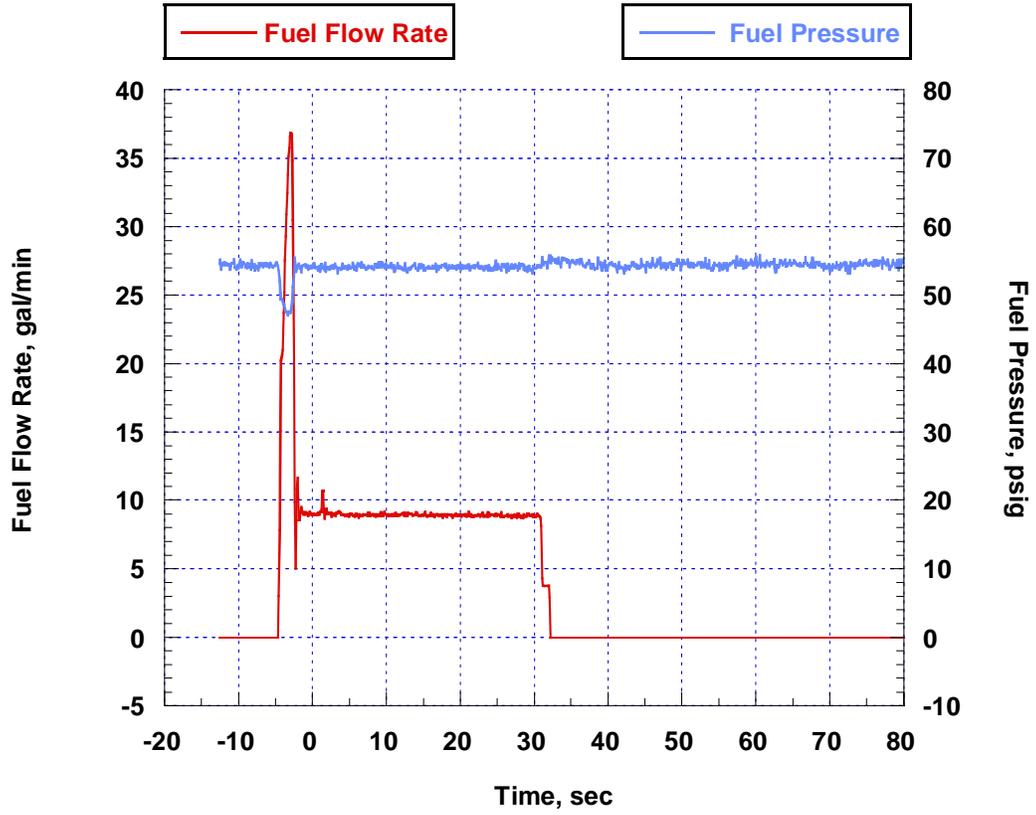
Test 35
Temperature vs Time



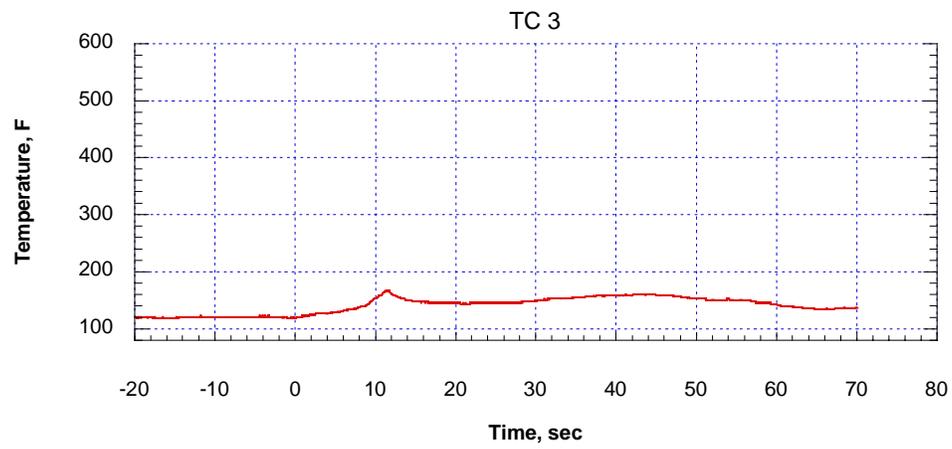
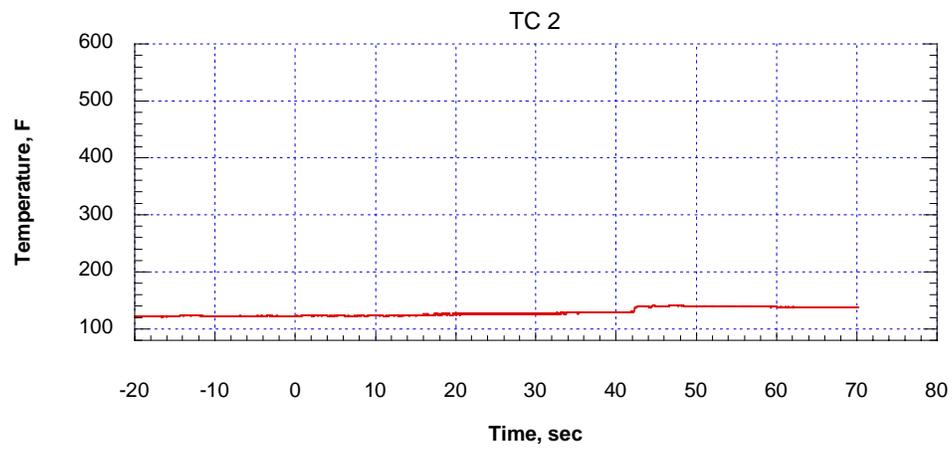
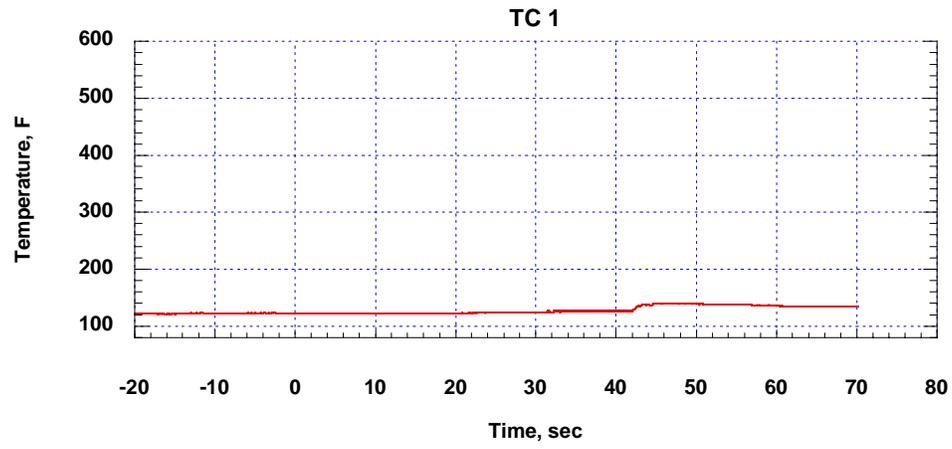
Test 35
Optical Fire Detector Signal vs Time



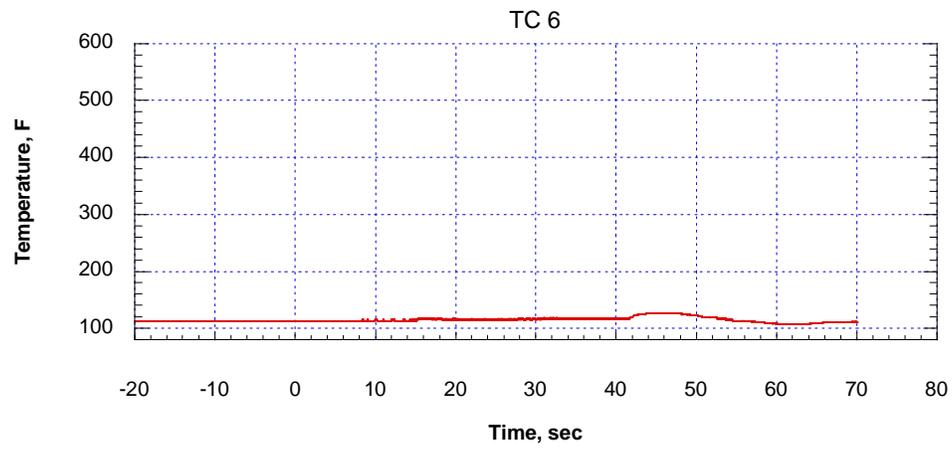
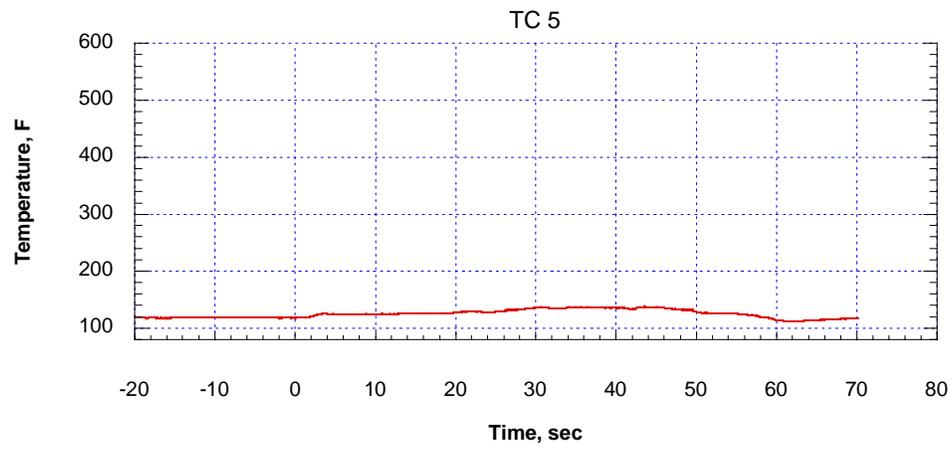
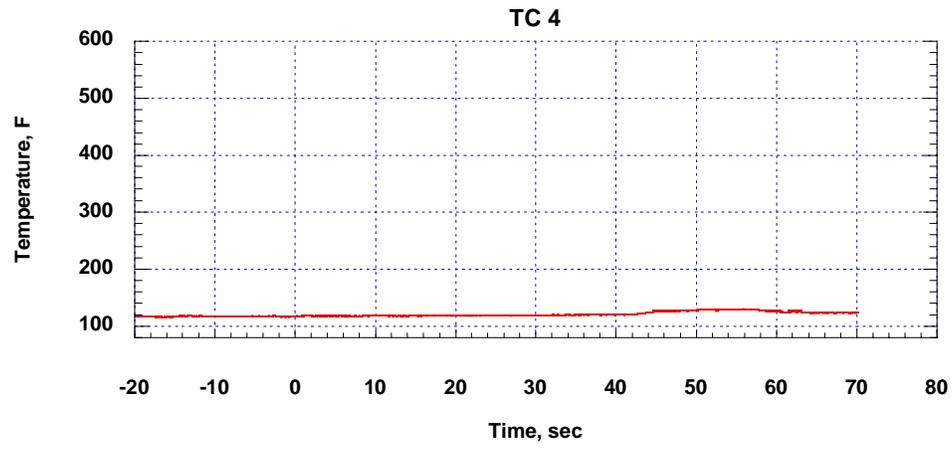
Test 35
Fuel Pressure and Flow Rate vs Time



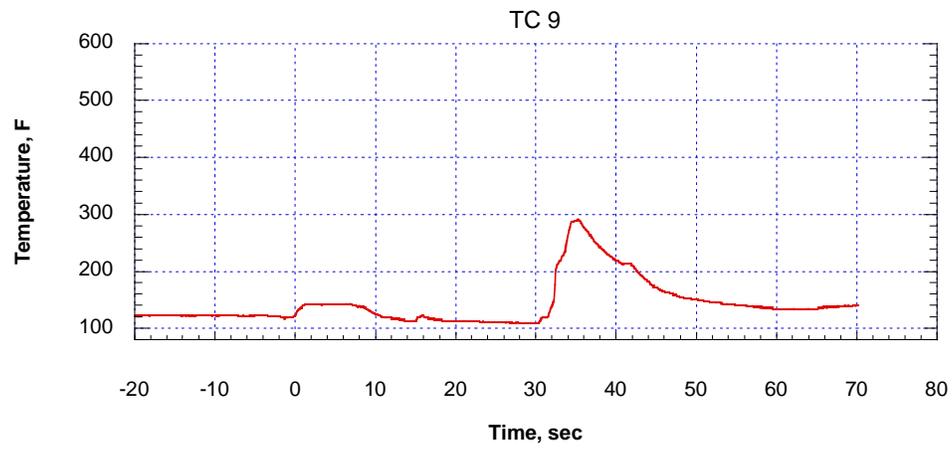
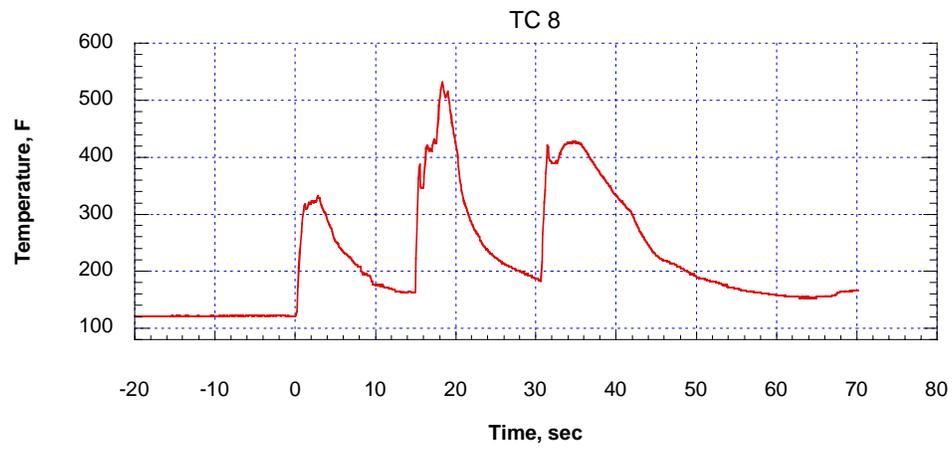
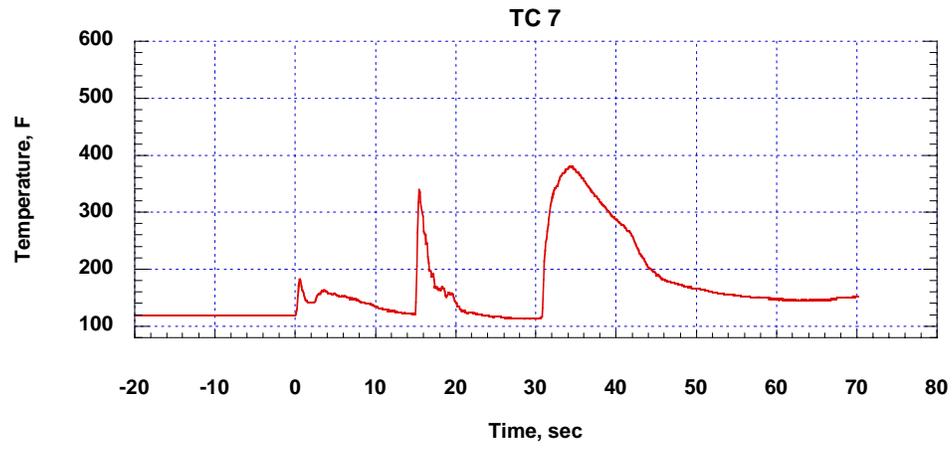
Test 36
Temperature vs Time



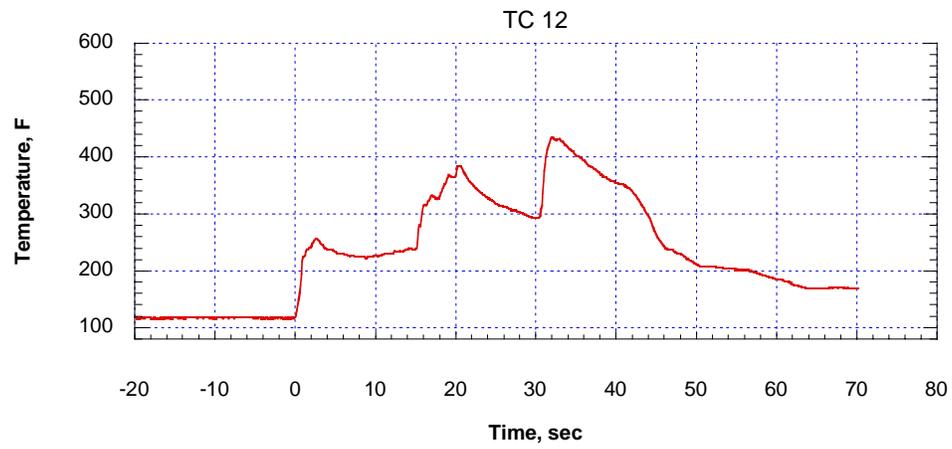
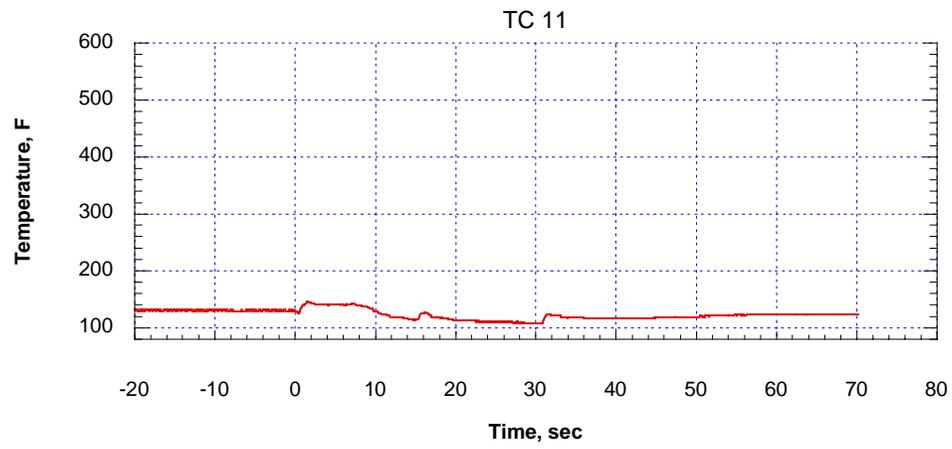
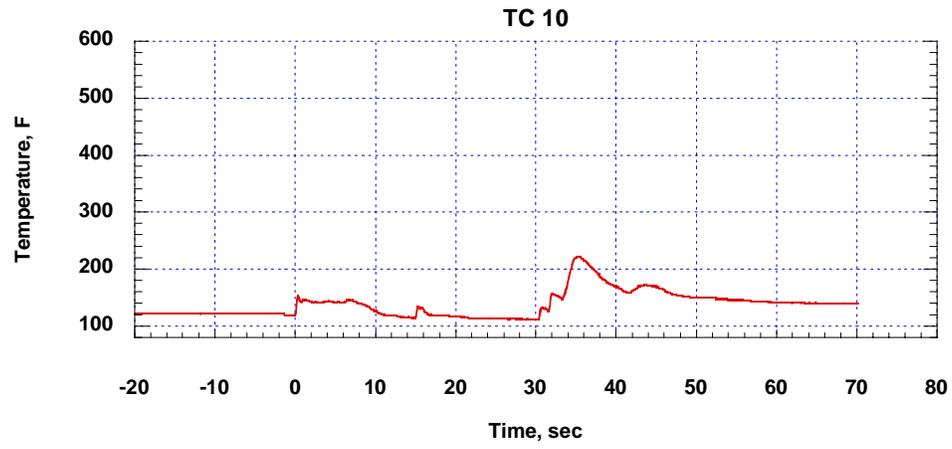
Test 36
Temperature vs Time



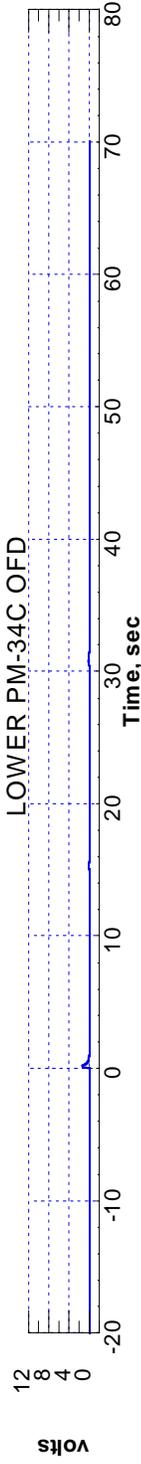
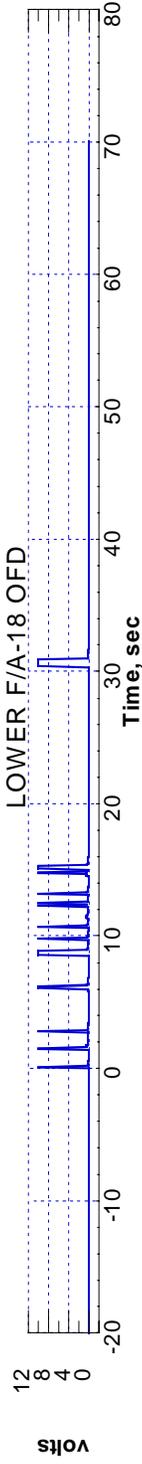
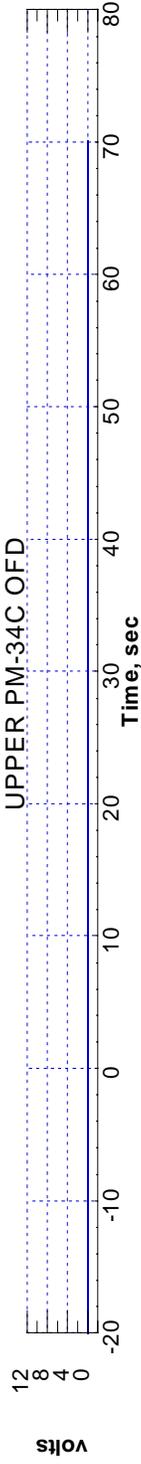
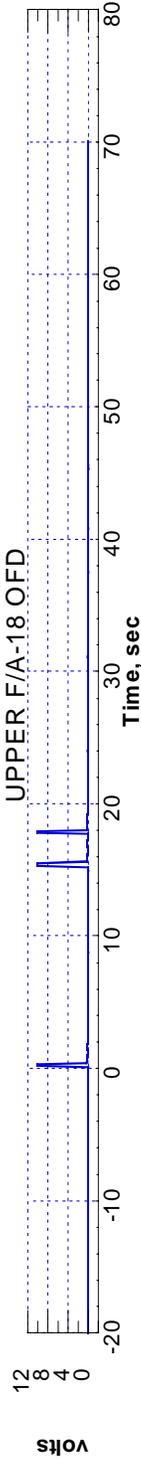
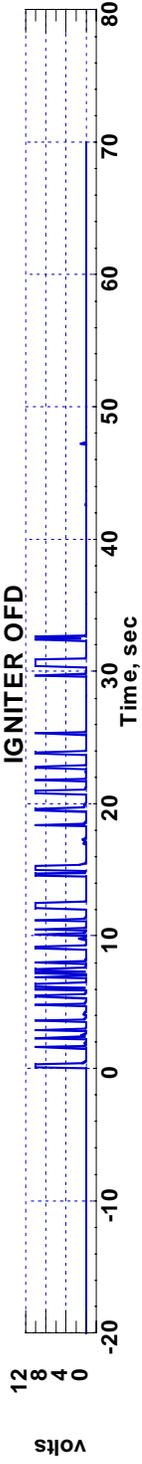
Test 36
Temperature vs Time



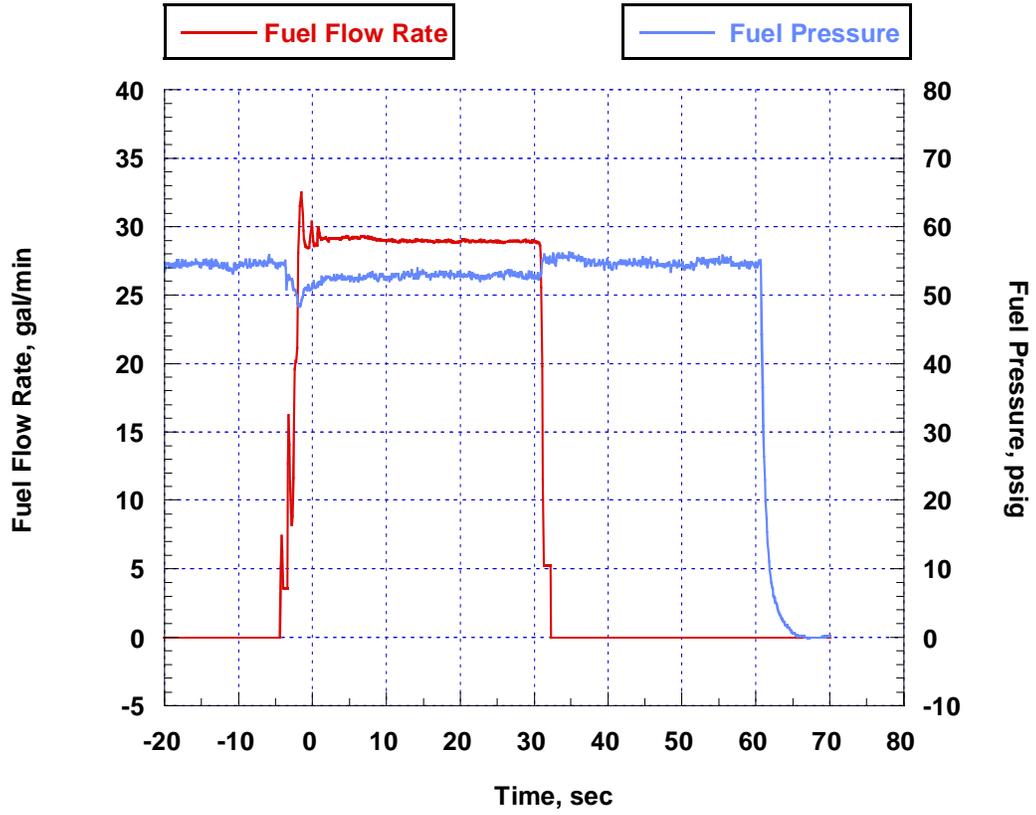
Test 36
Temperature vs Time



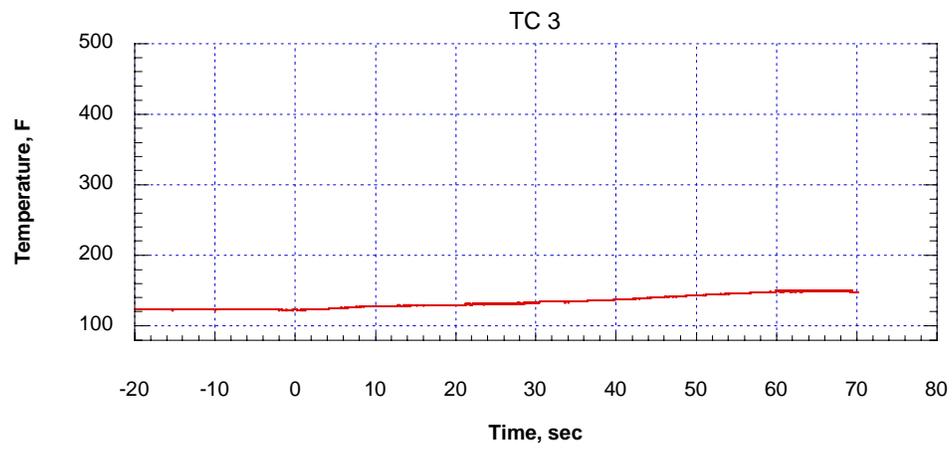
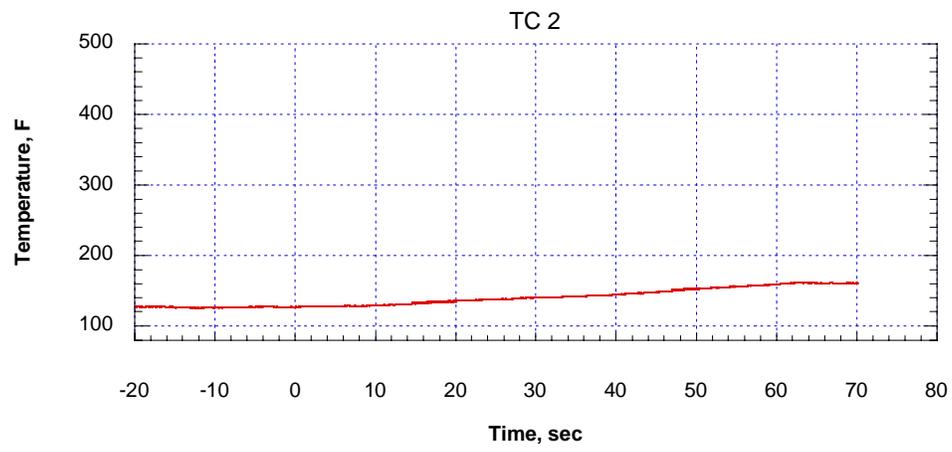
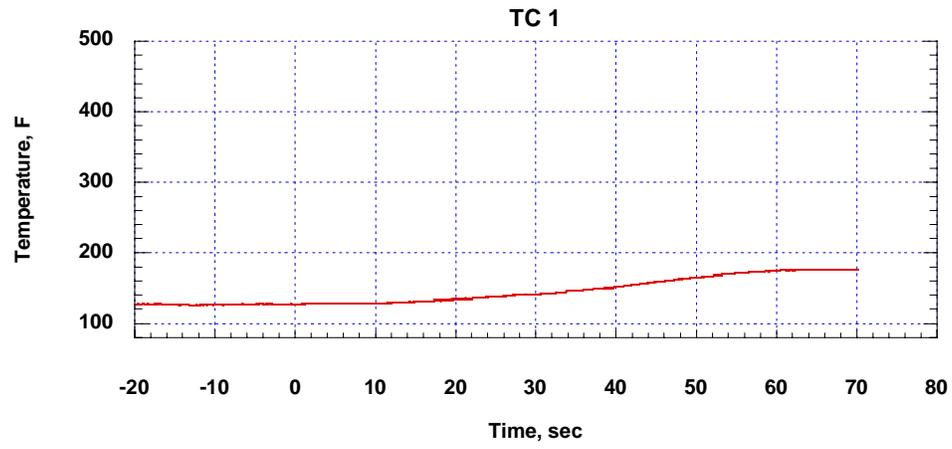
Test 36
Optical Fire Detector Signal vs Time



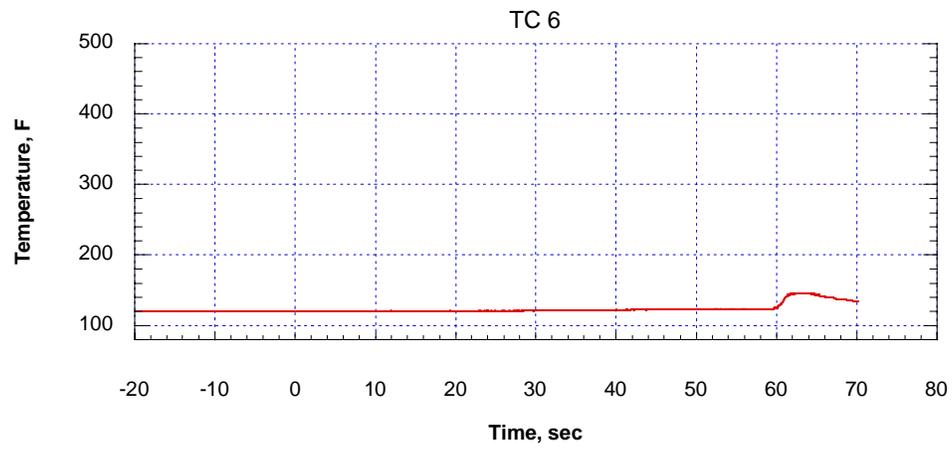
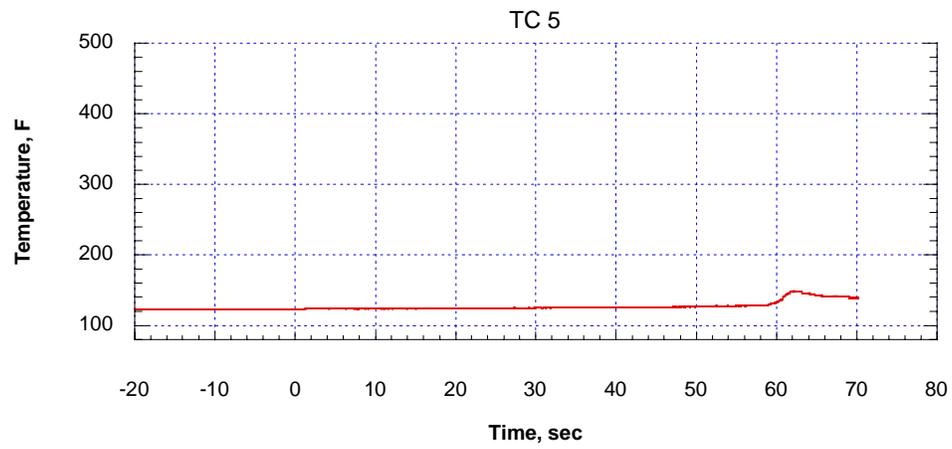
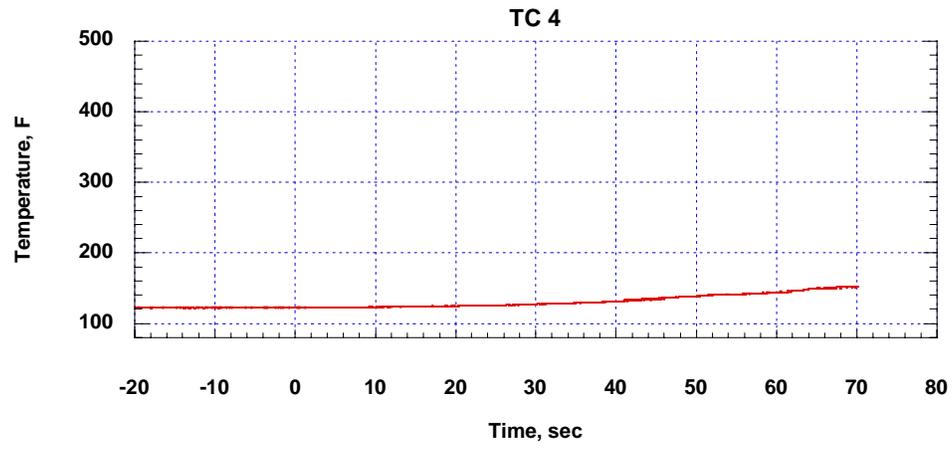
Test 36
Fuel Pressure and Flow Rate vs Time



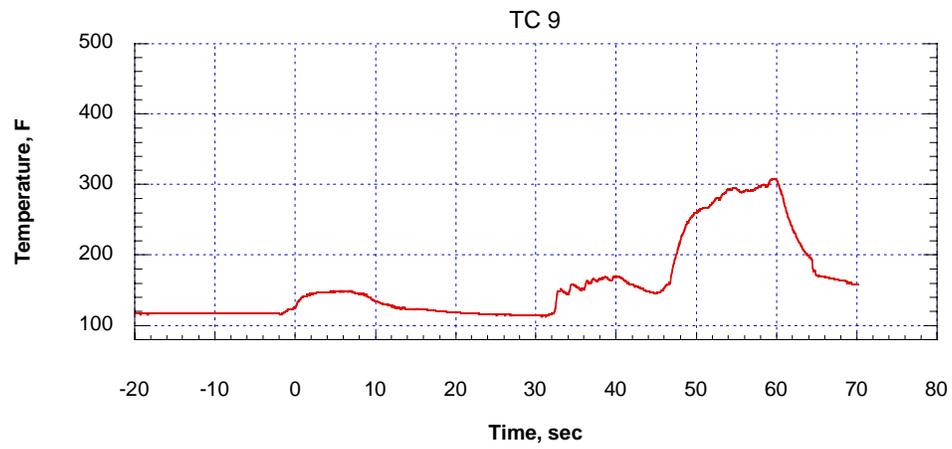
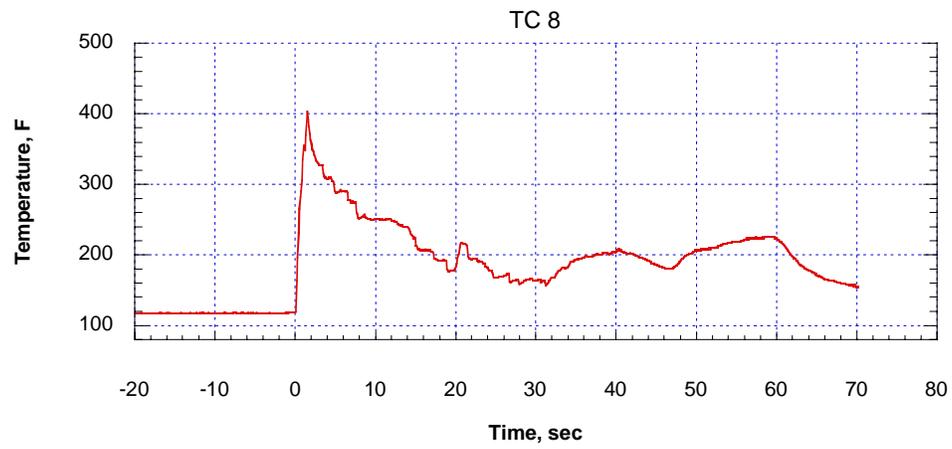
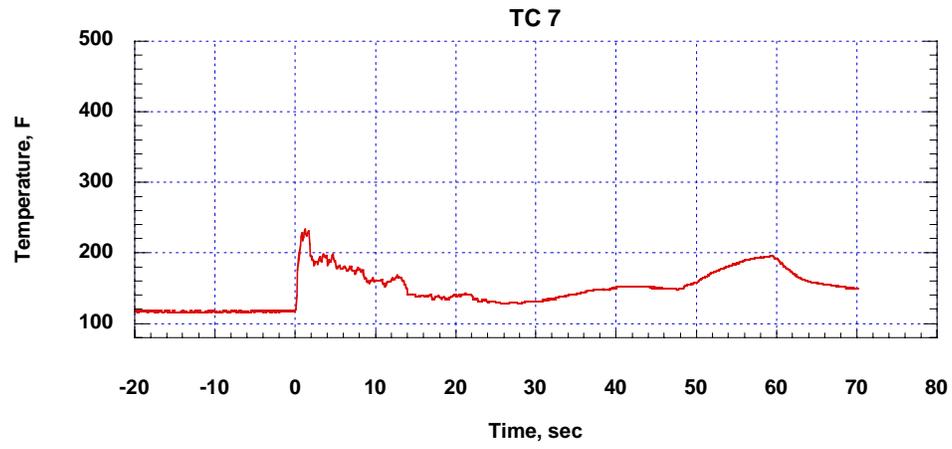
Test 37
Temperature vs Time



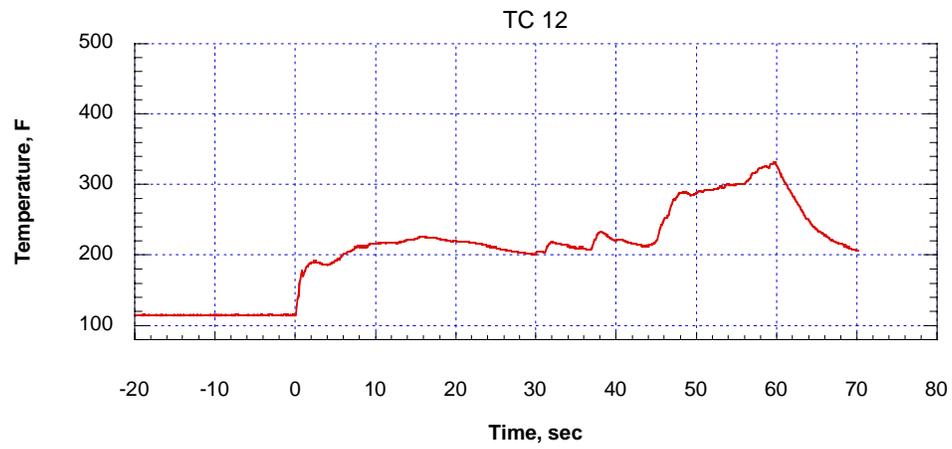
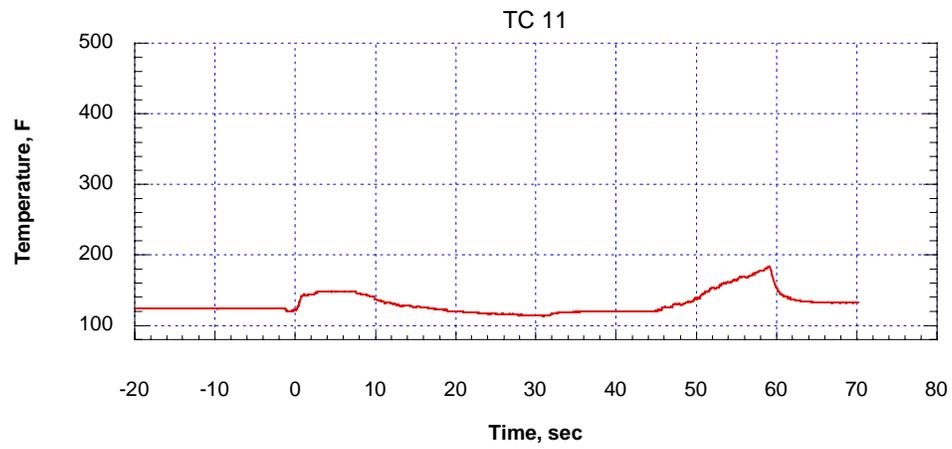
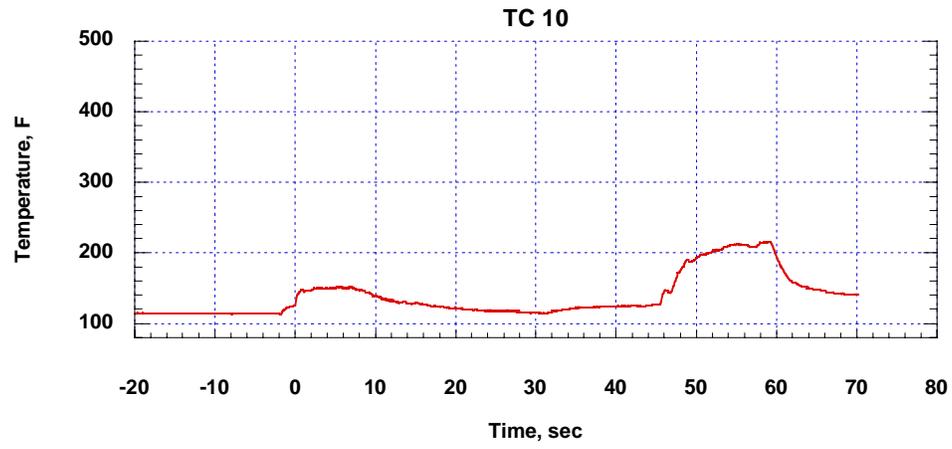
Test 37
Temperature vs Time



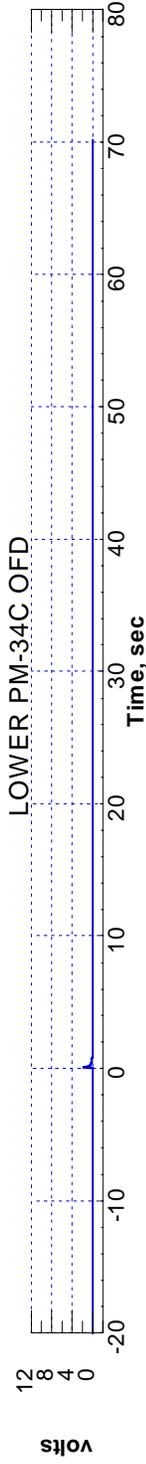
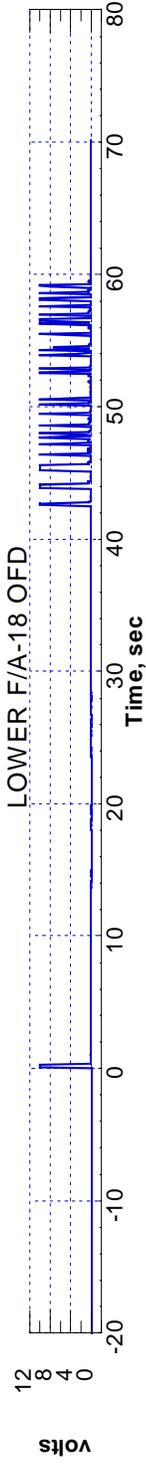
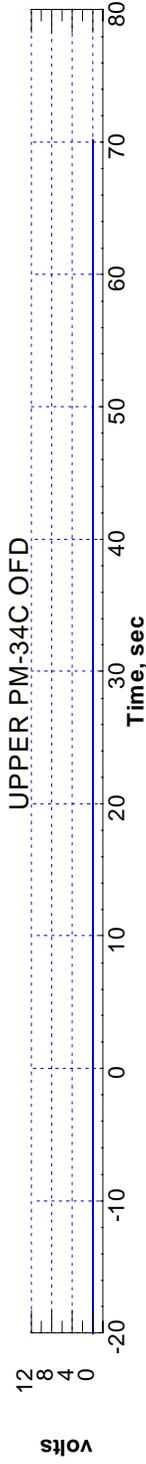
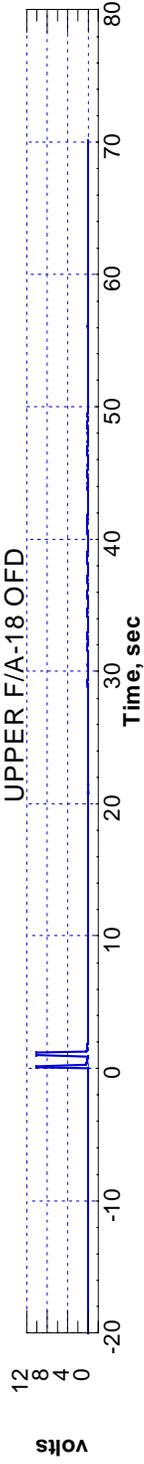
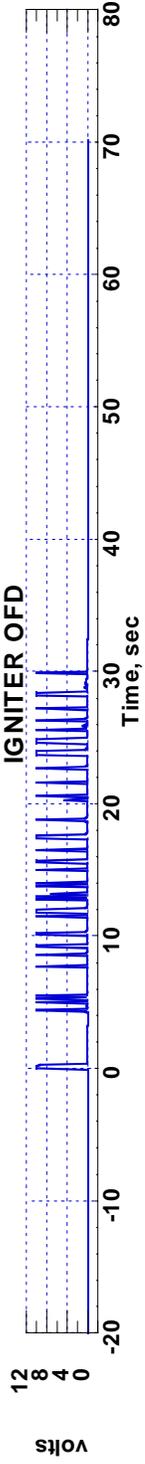
Test 37
Temperature vs Time



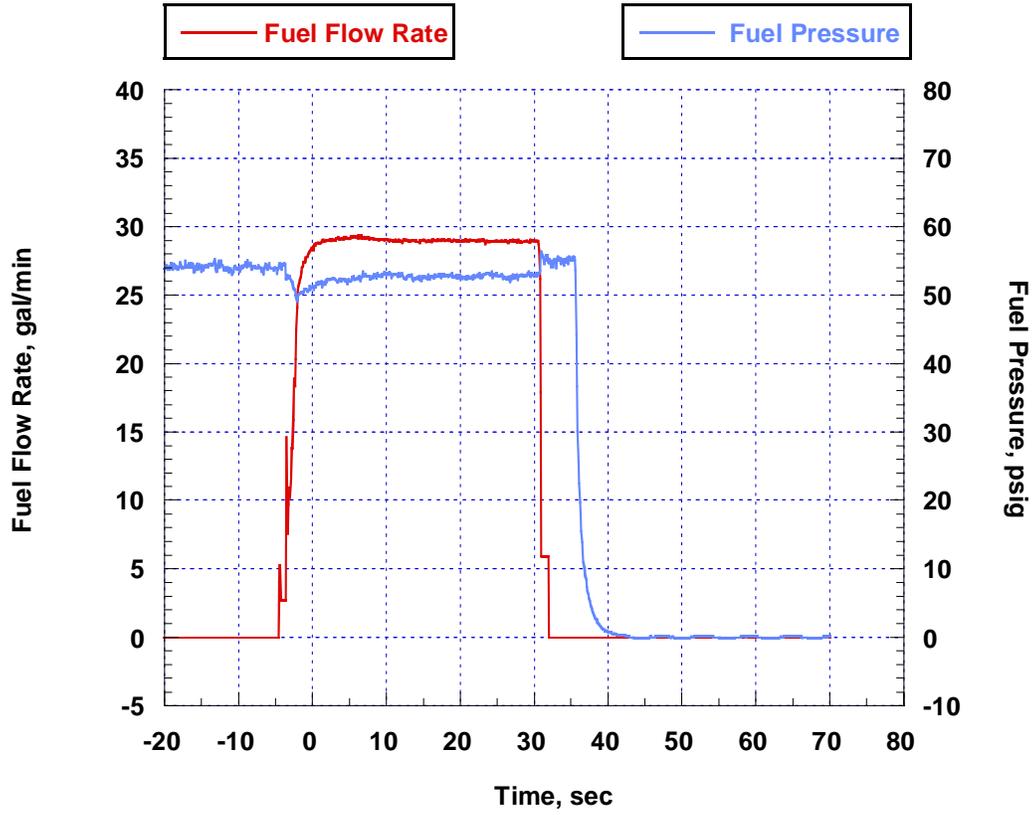
Test 37
Temperature vs Time



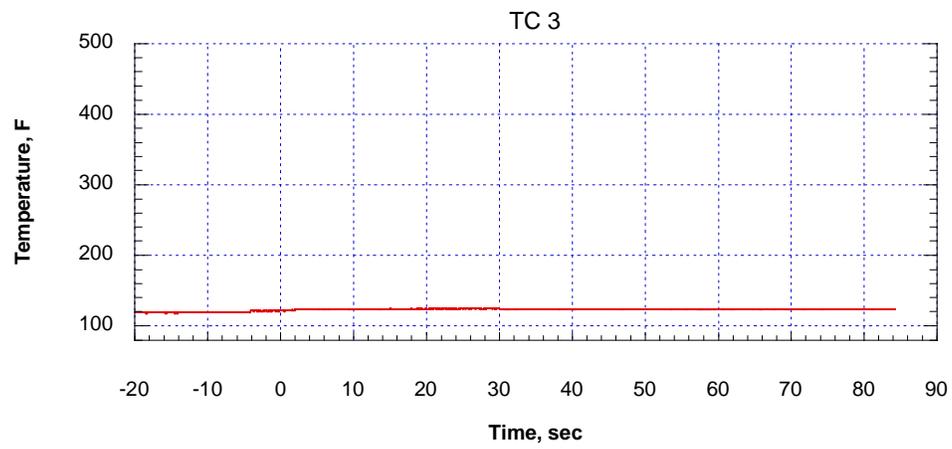
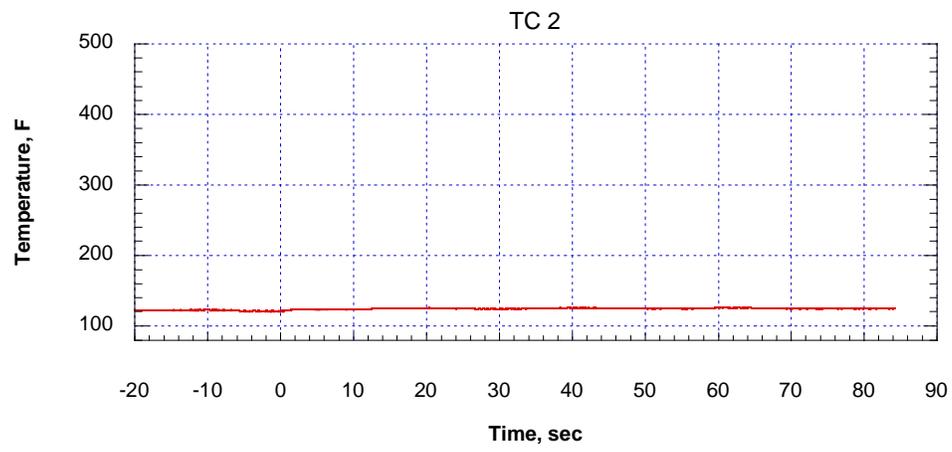
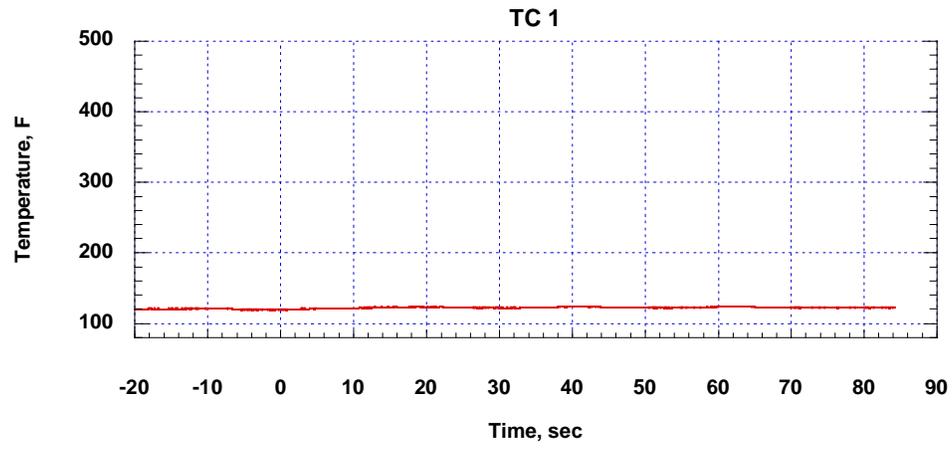
Test 37
Optical Fire Detector Signal vs Time



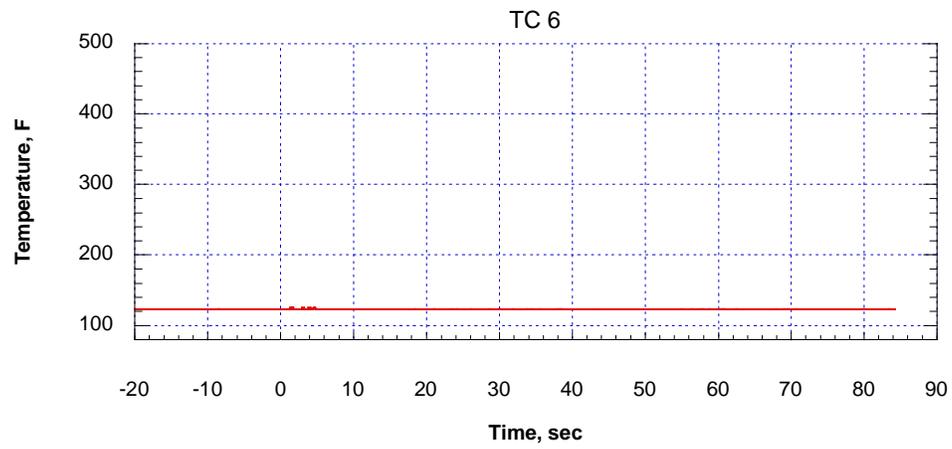
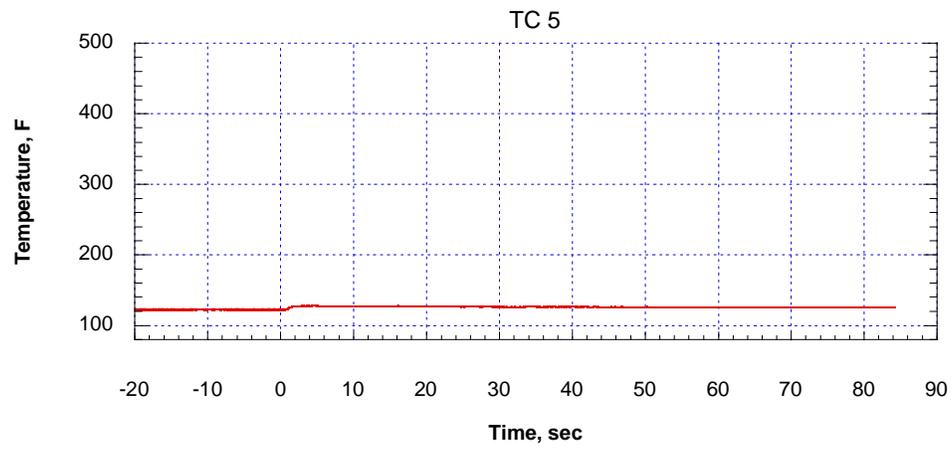
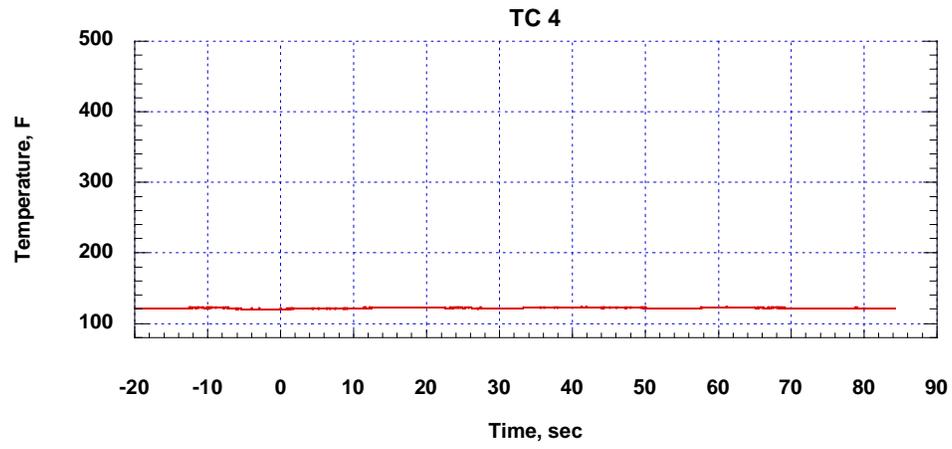
Test 37
Fuel Pressure and Flow Rate vs Time



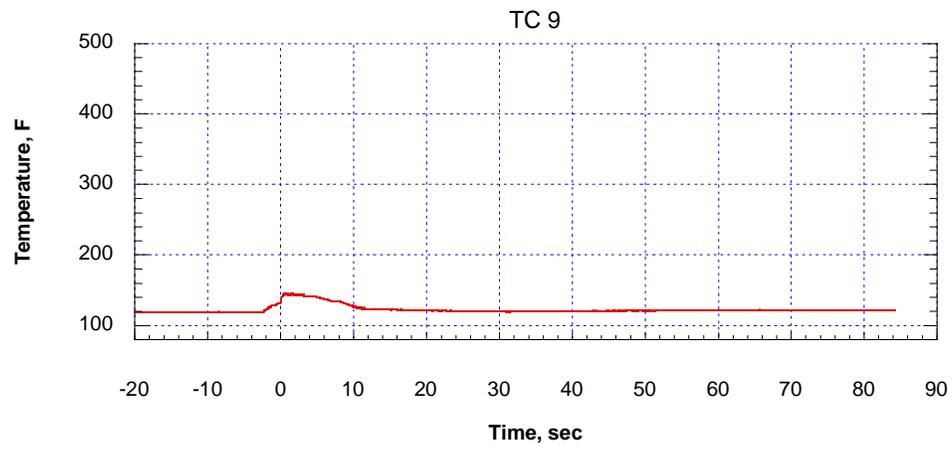
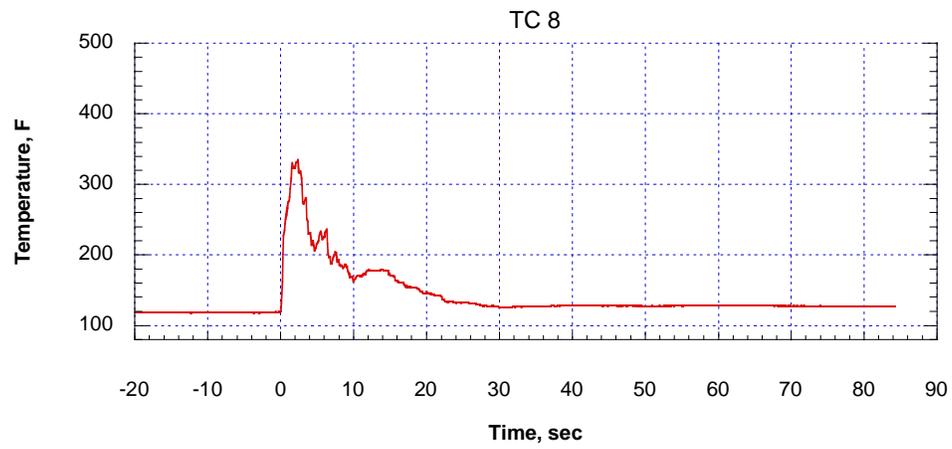
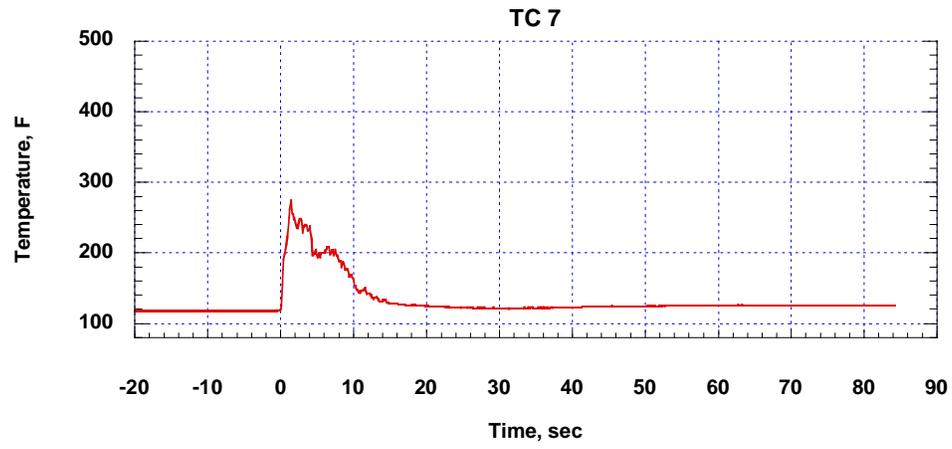
Test 38
Temperature vs Time



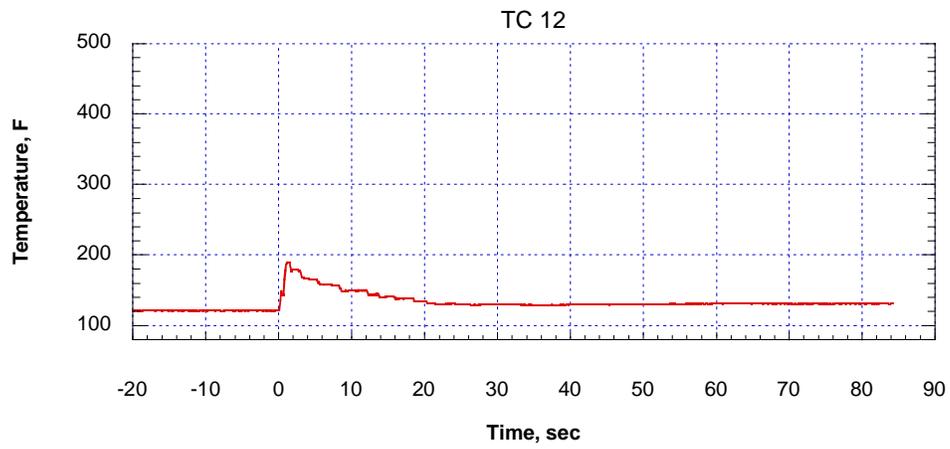
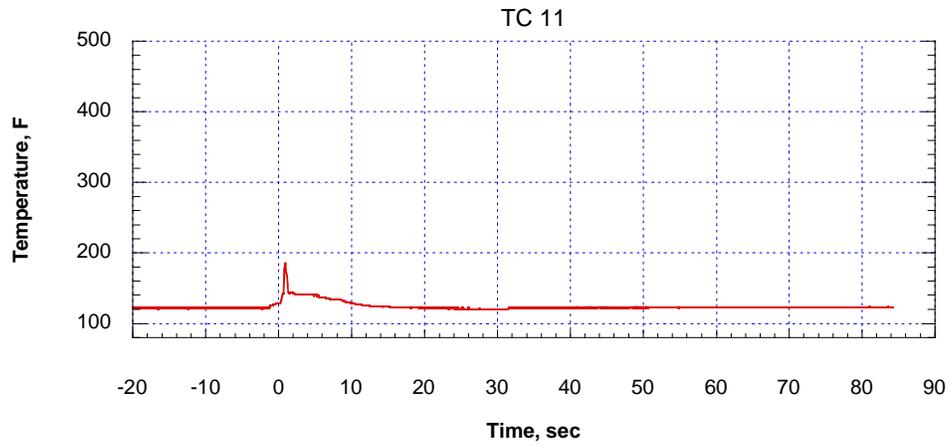
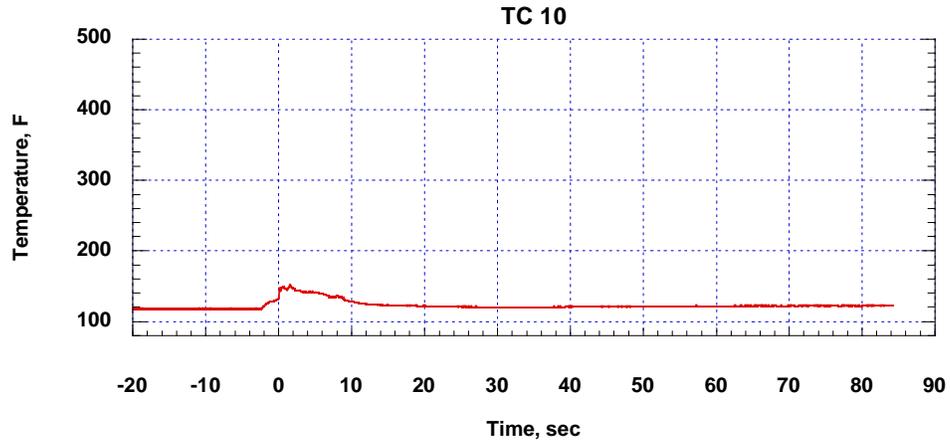
Test 38
Temperature vs Time



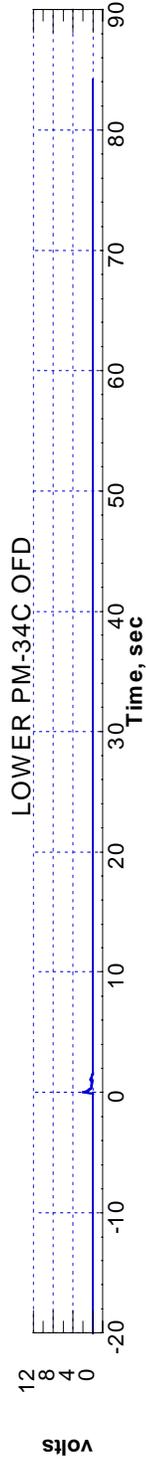
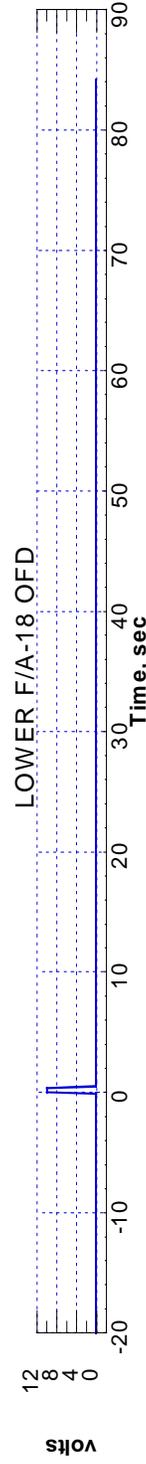
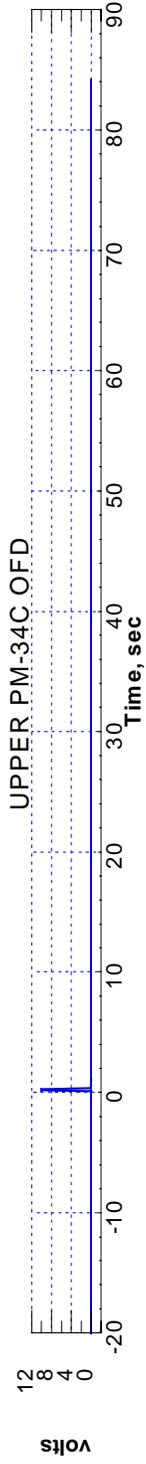
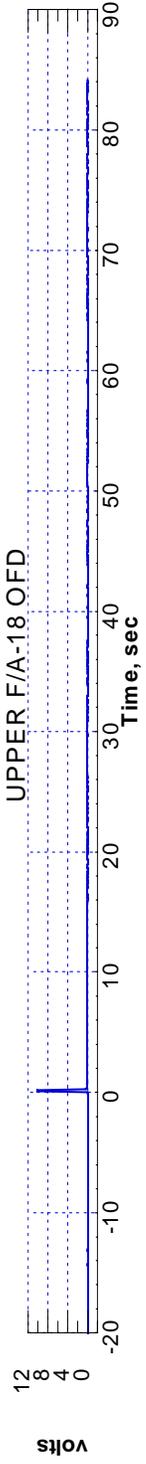
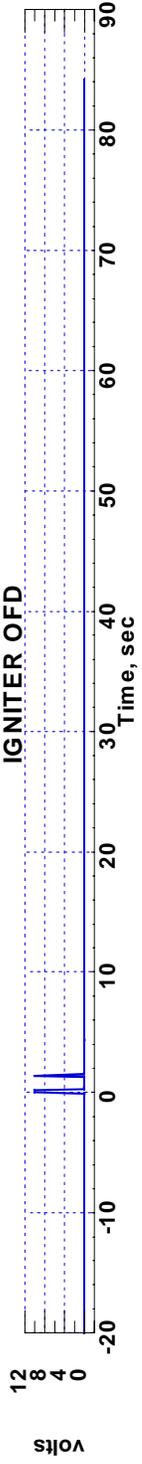
Test 38
Temperature vs Time



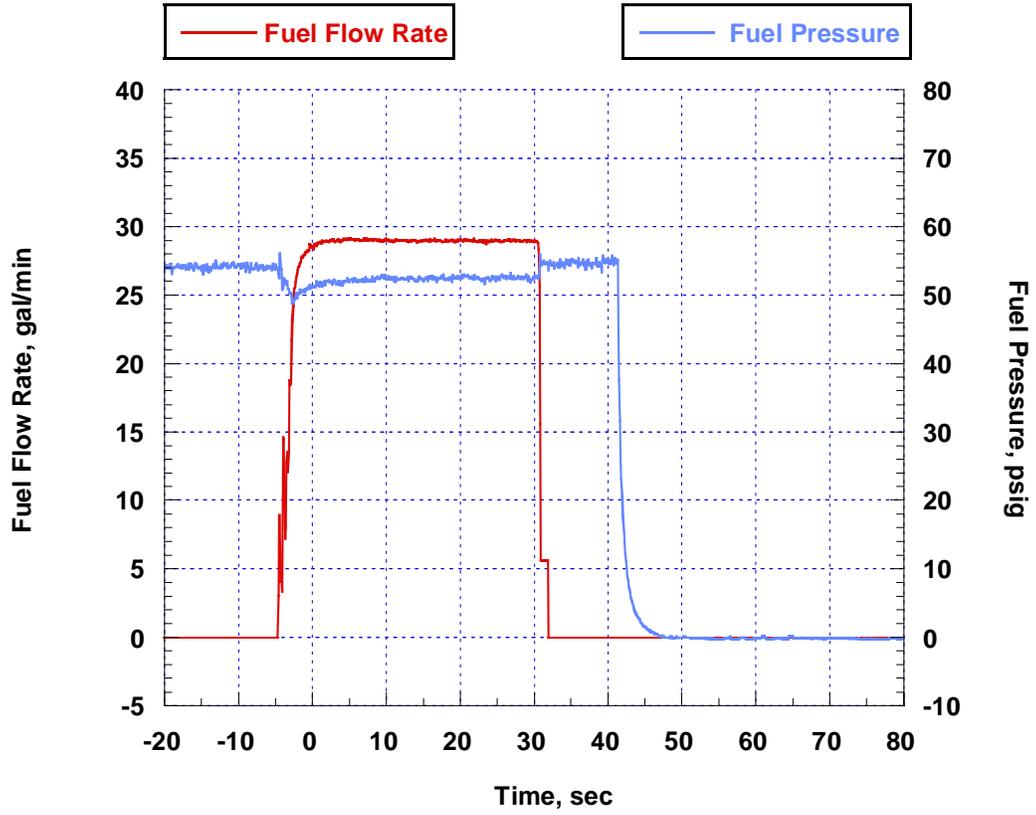
Test 38
Temperature vs Time



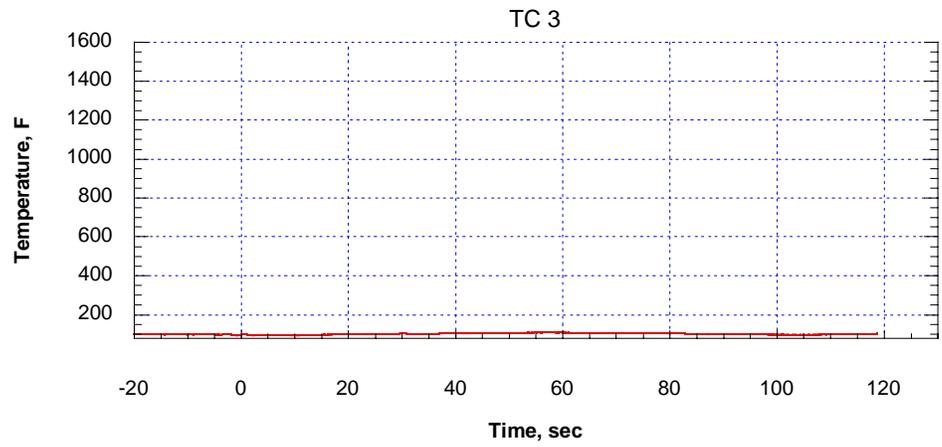
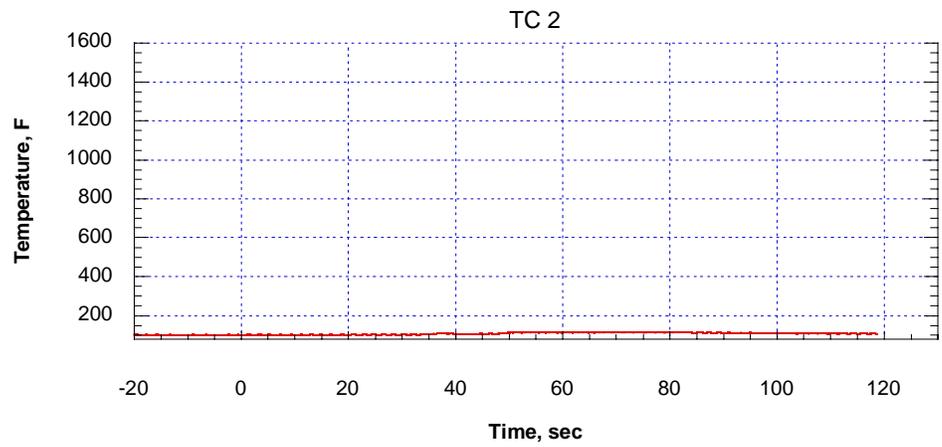
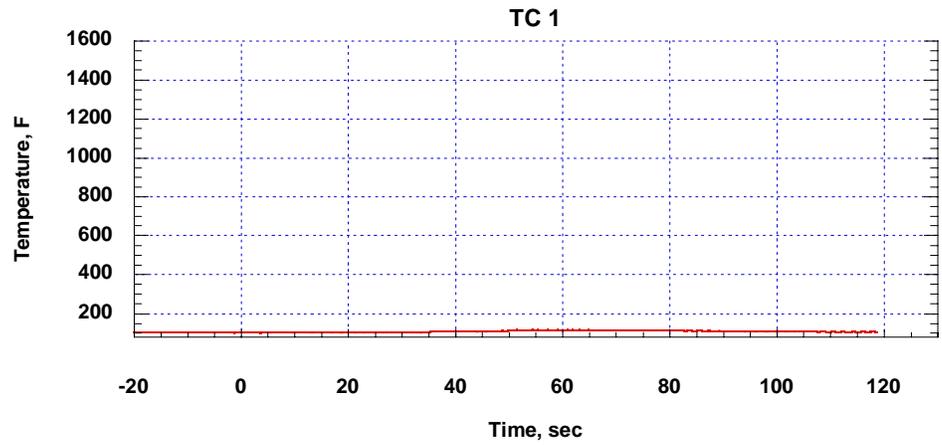
Test 38
Optical Fire Detector Signal vs Time



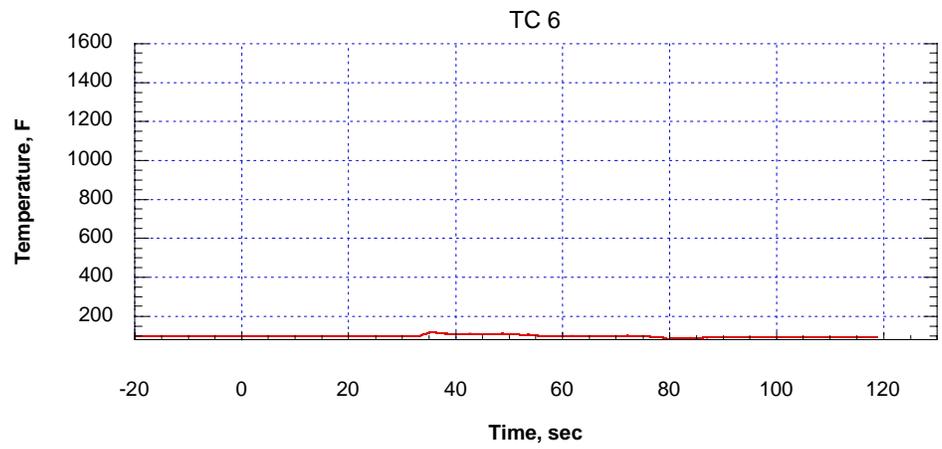
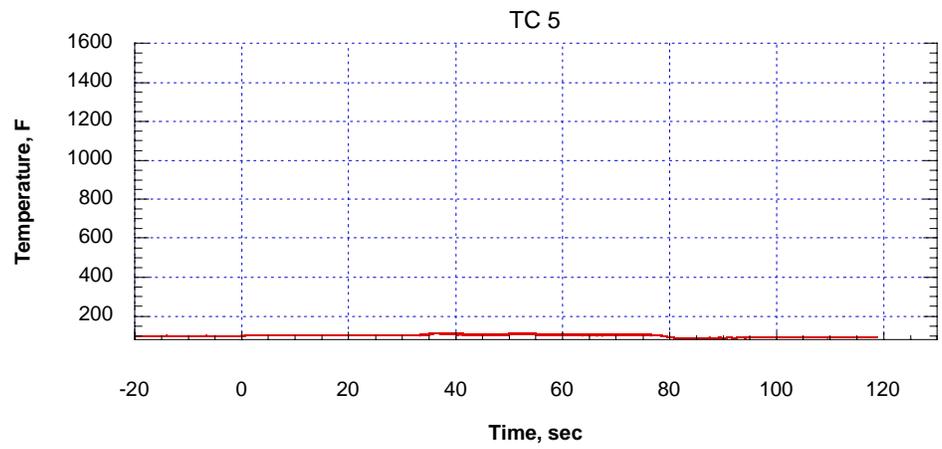
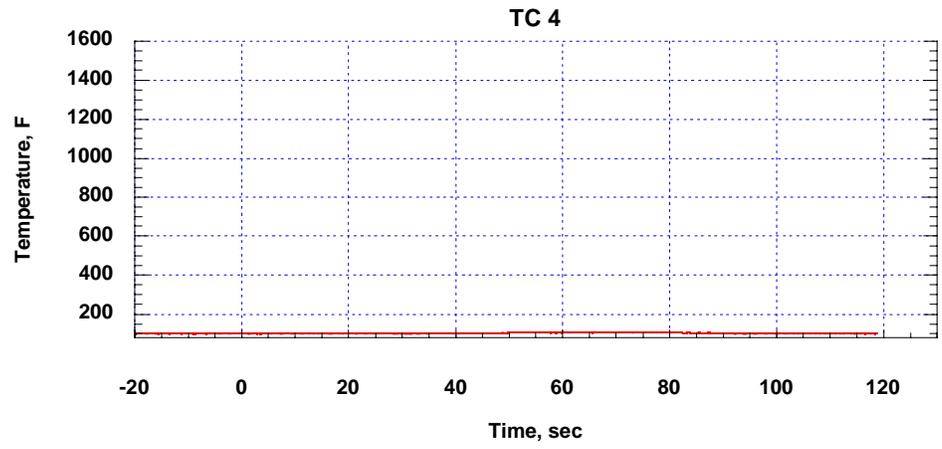
Test 38
Fuel Pressure and Flow Rate vs Time



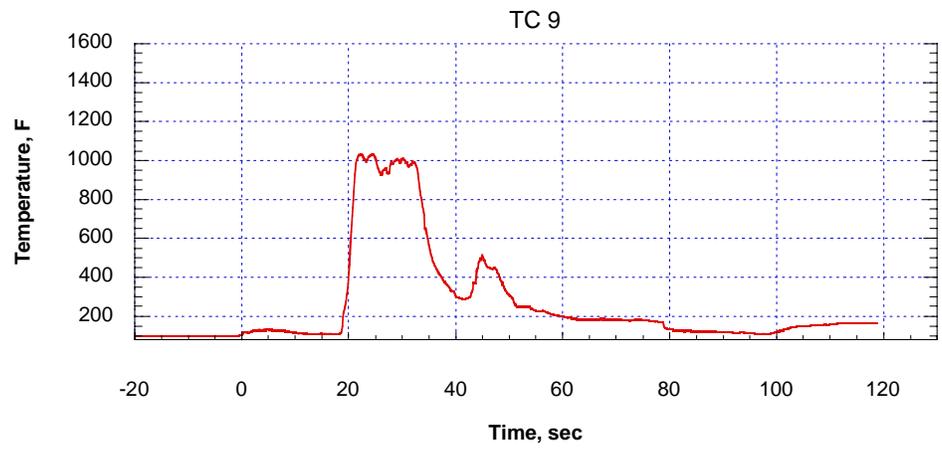
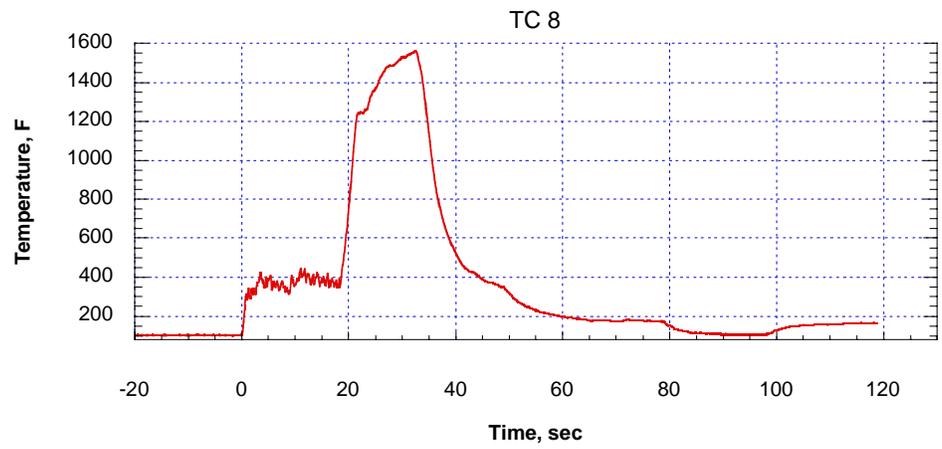
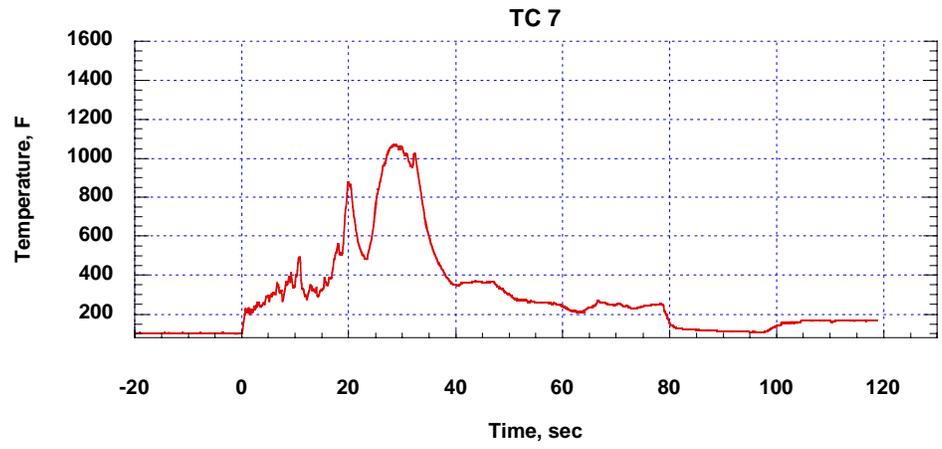
Test 39
Temperature vs Time



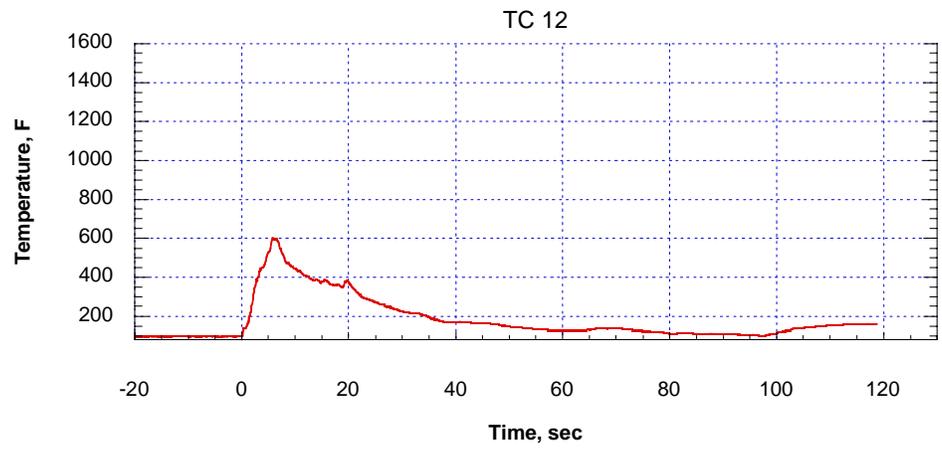
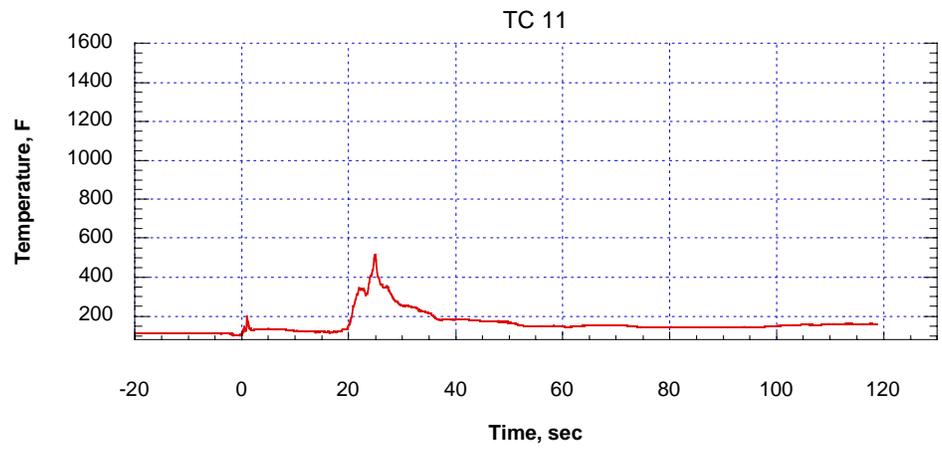
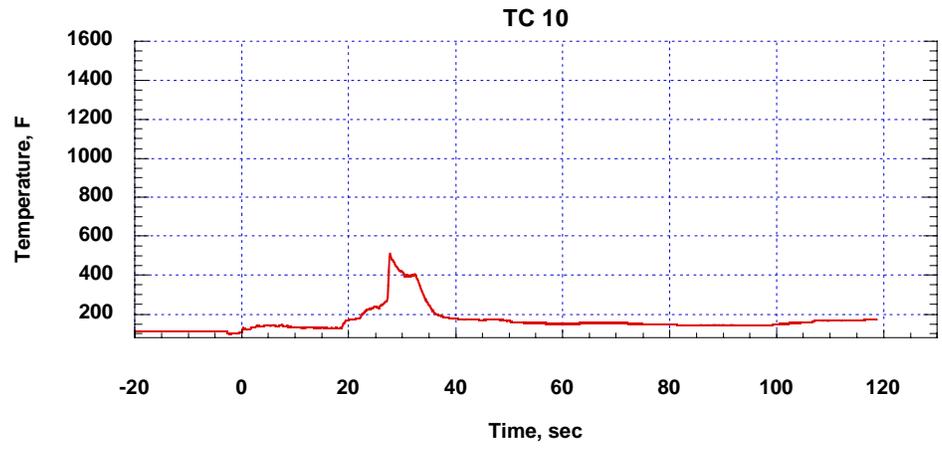
Test 39
Temperature vs Time



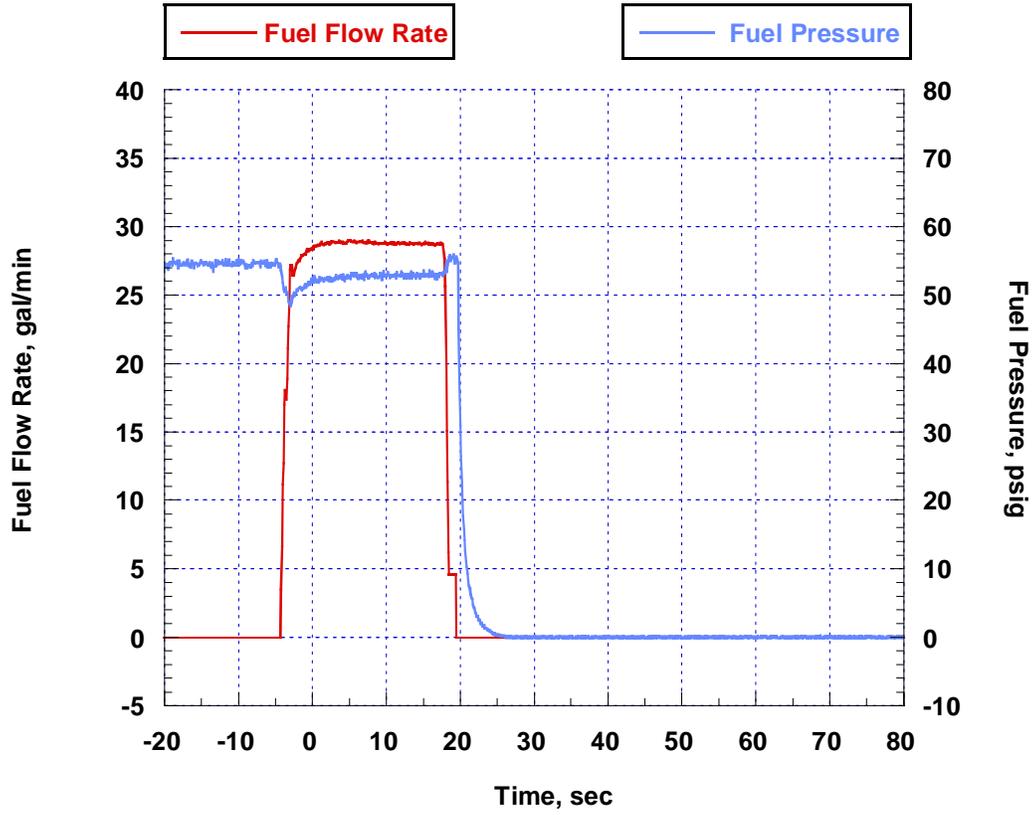
Test 39
Temperature vs Time



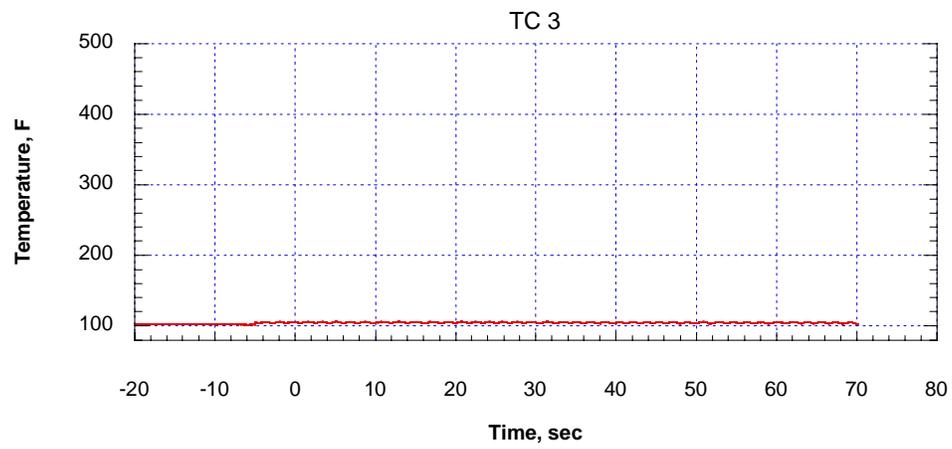
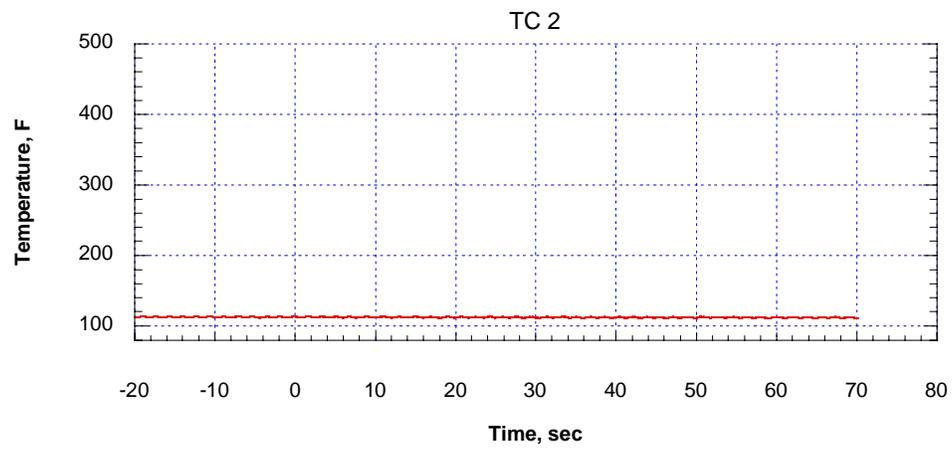
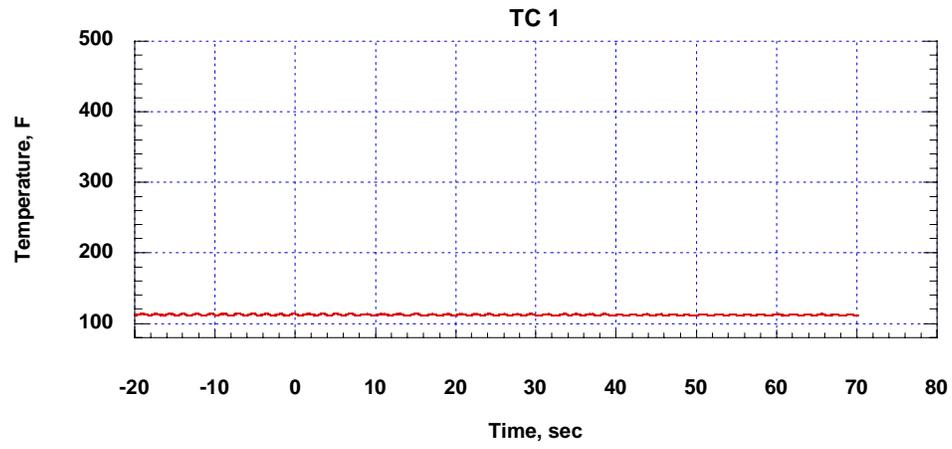
Test 39
Temperature vs Time



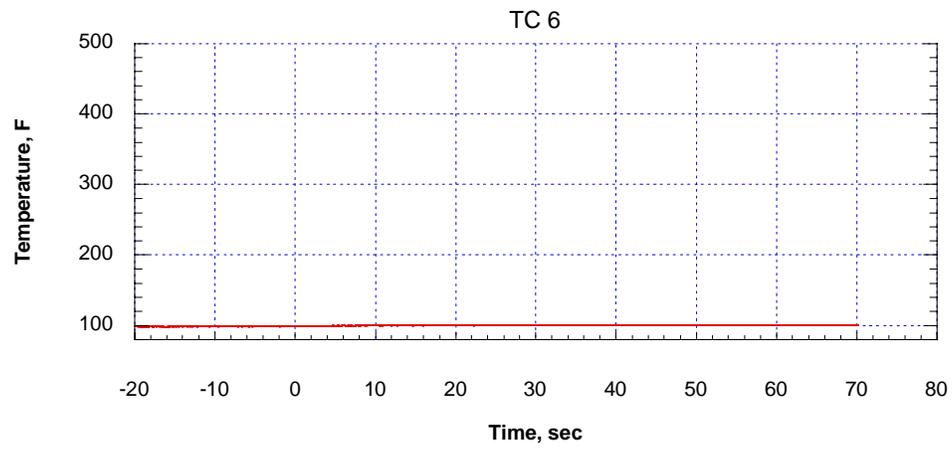
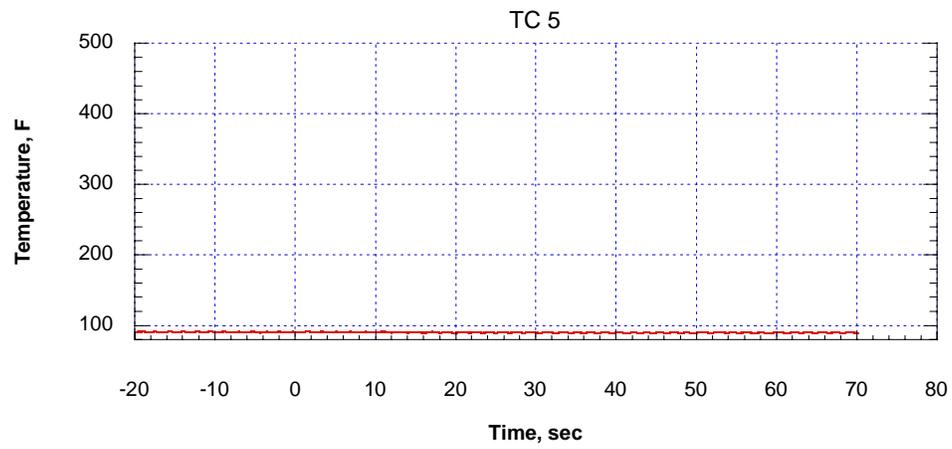
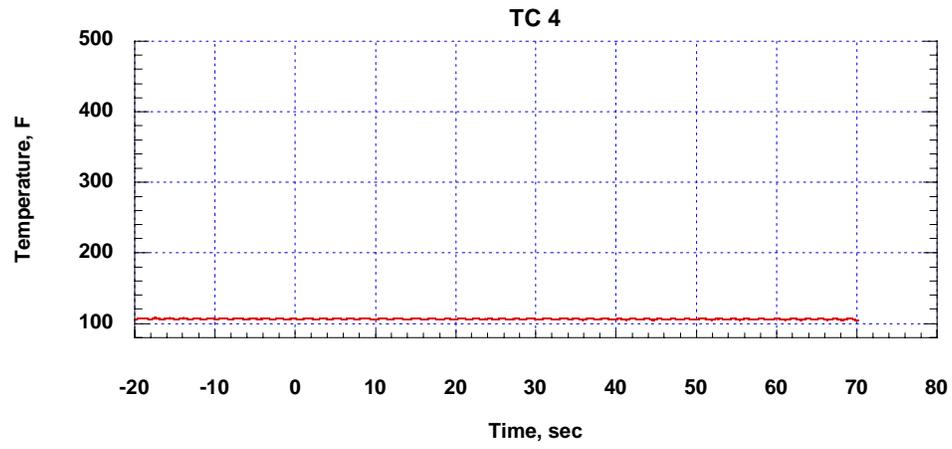
Test 39
Fuel Pressure and Flow Rate vs Time



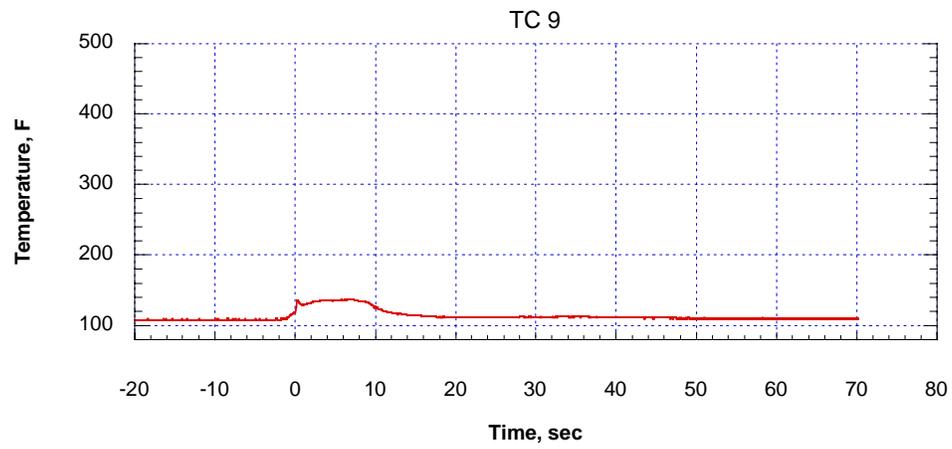
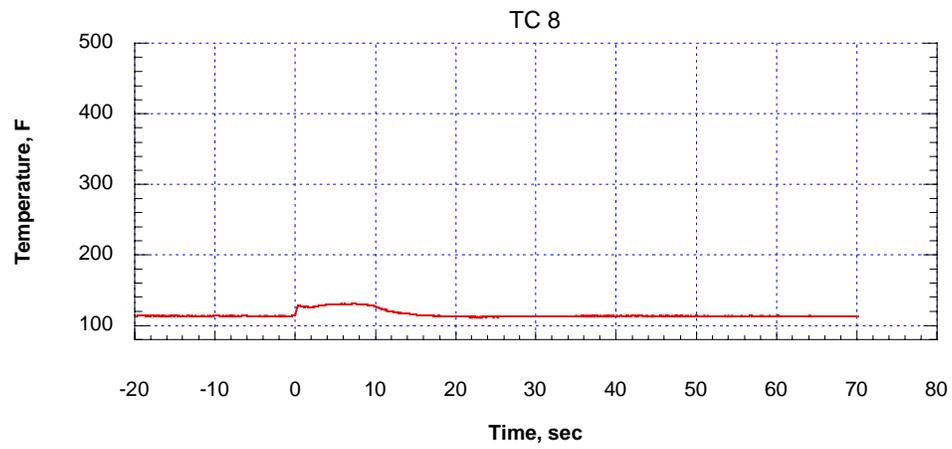
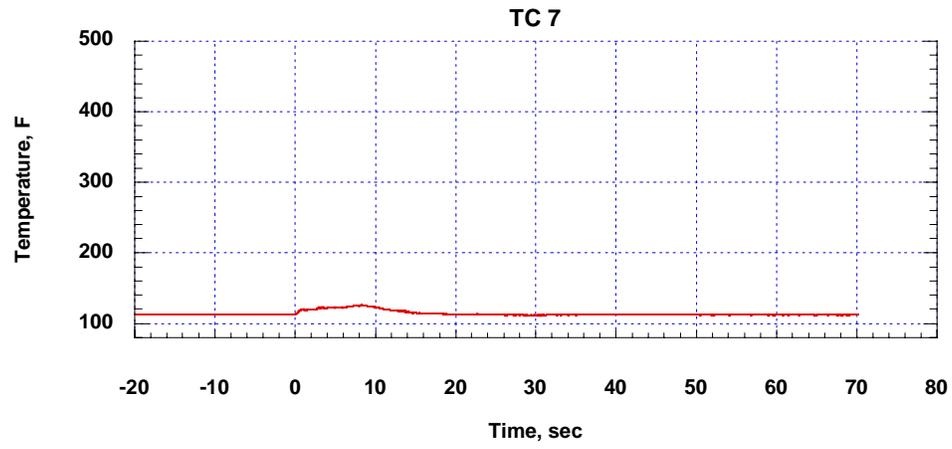
Test 40
Temperature vs Time



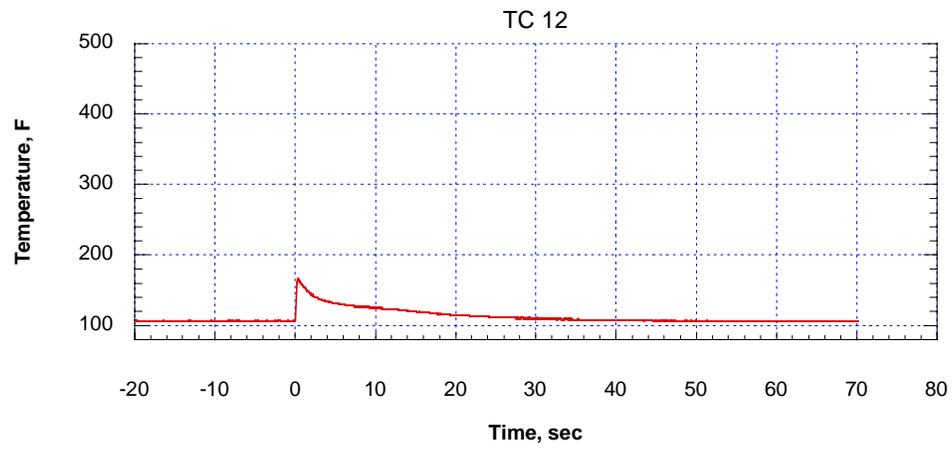
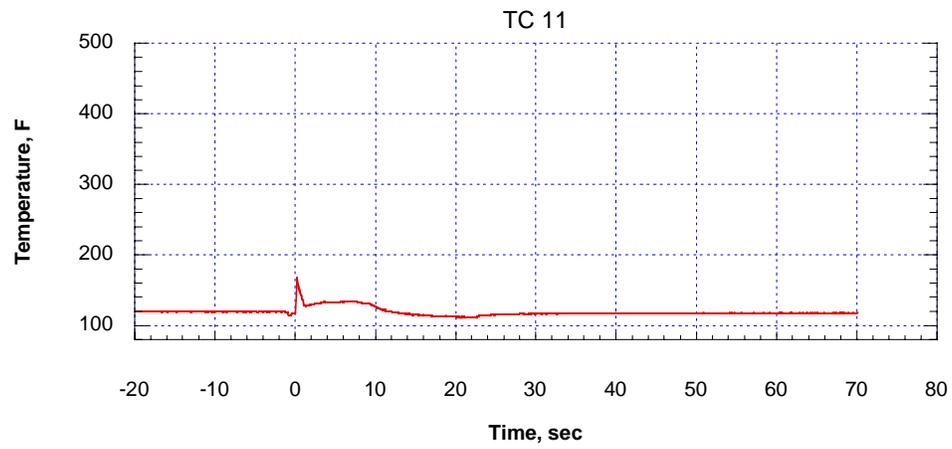
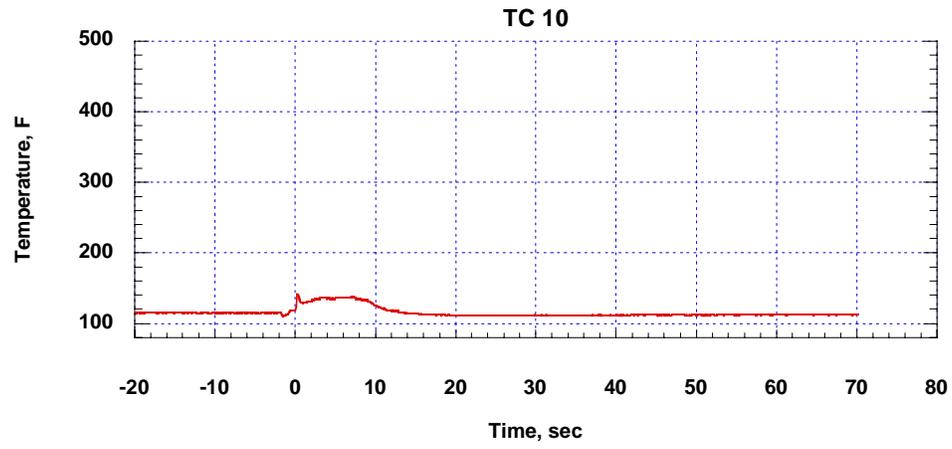
Test 40
Temperature vs Time



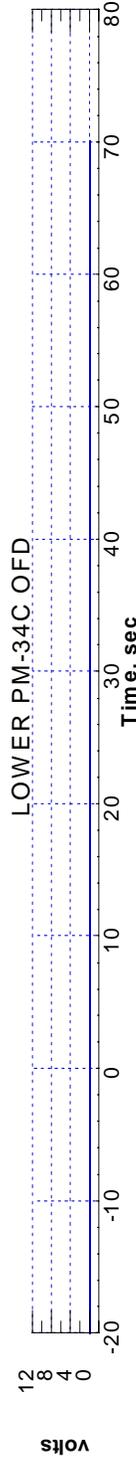
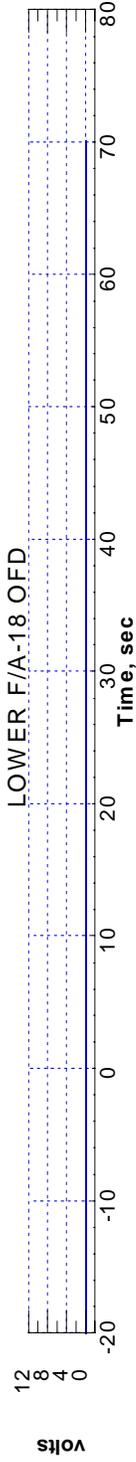
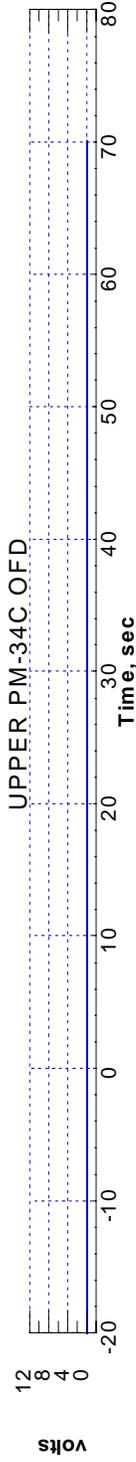
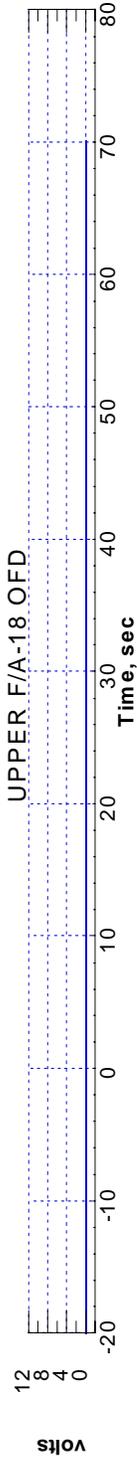
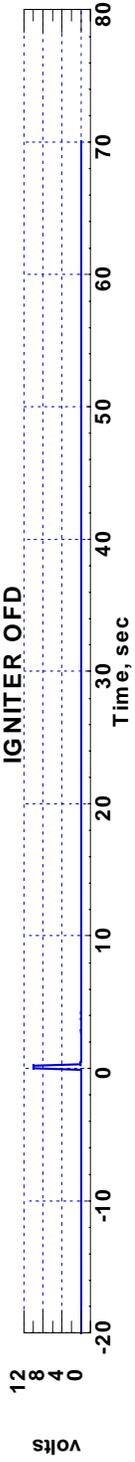
Test 40
Temperature vs Time



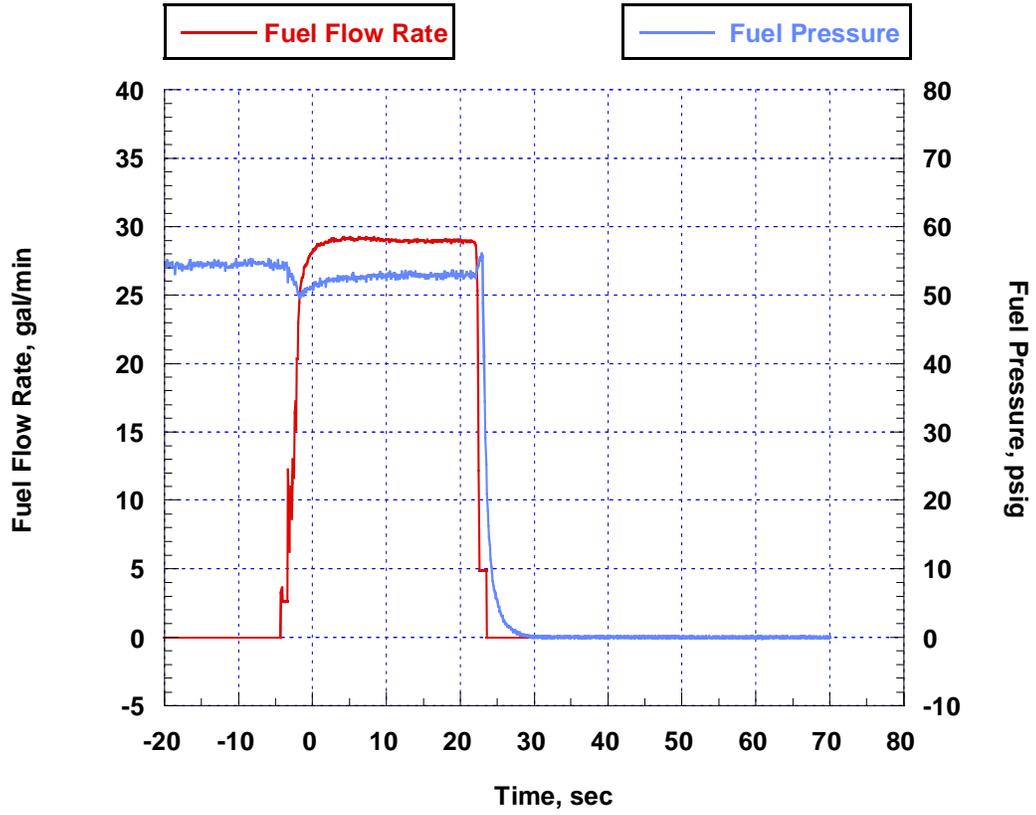
Test 40
Temperature vs Time



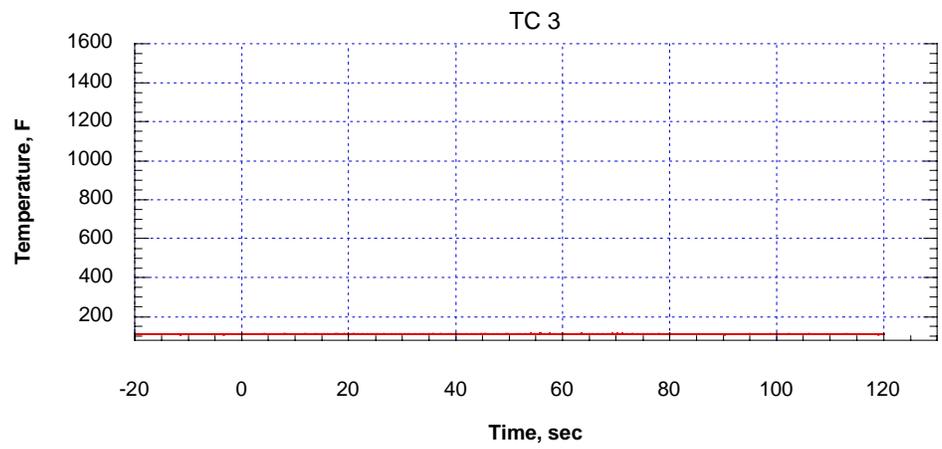
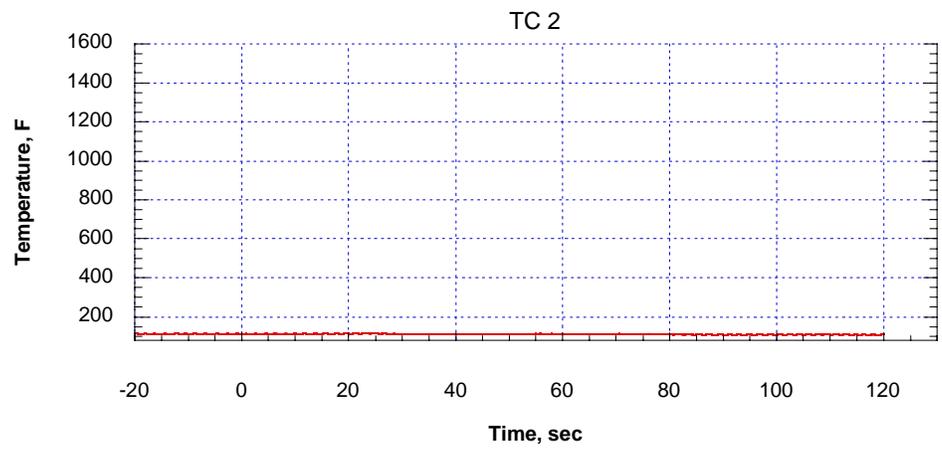
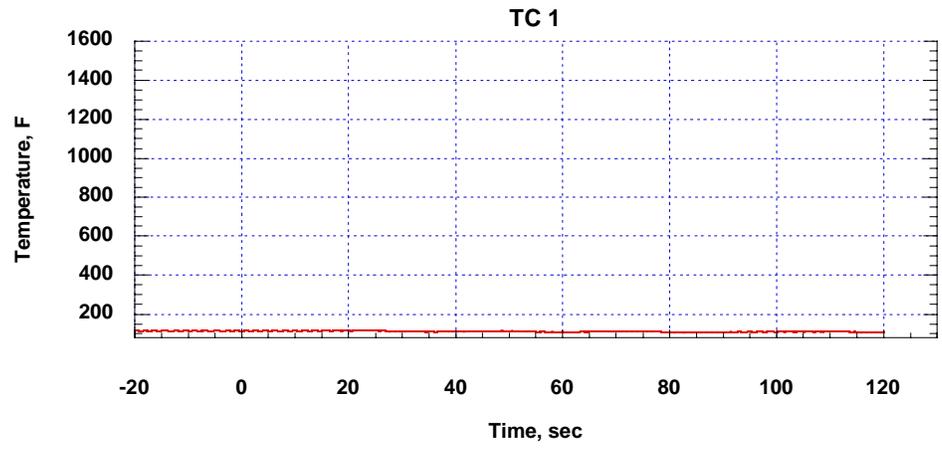
Test 40
Optical Fire Detector Signal vs Time



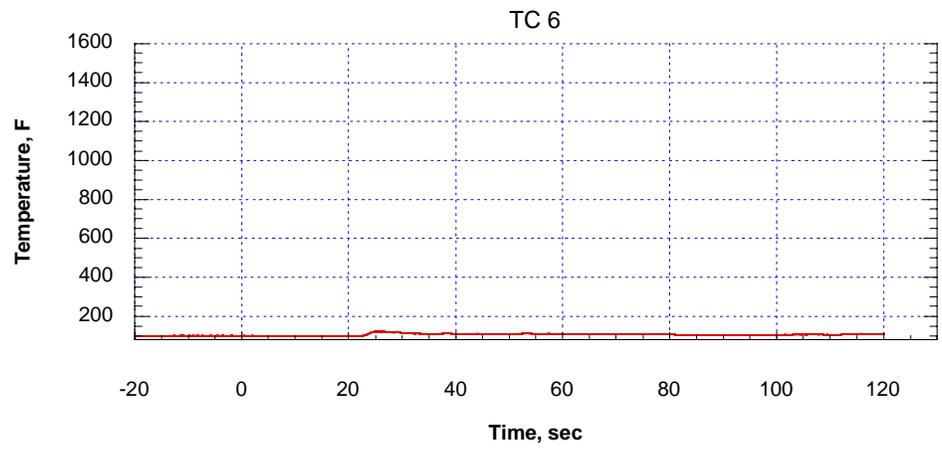
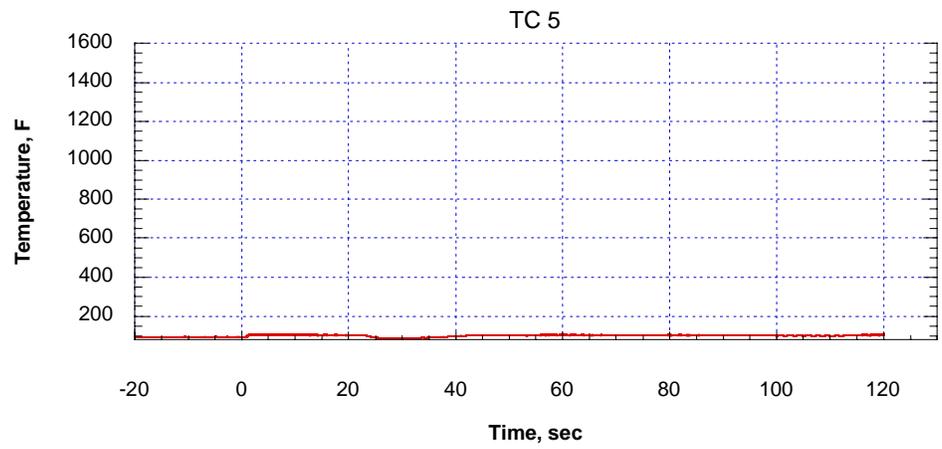
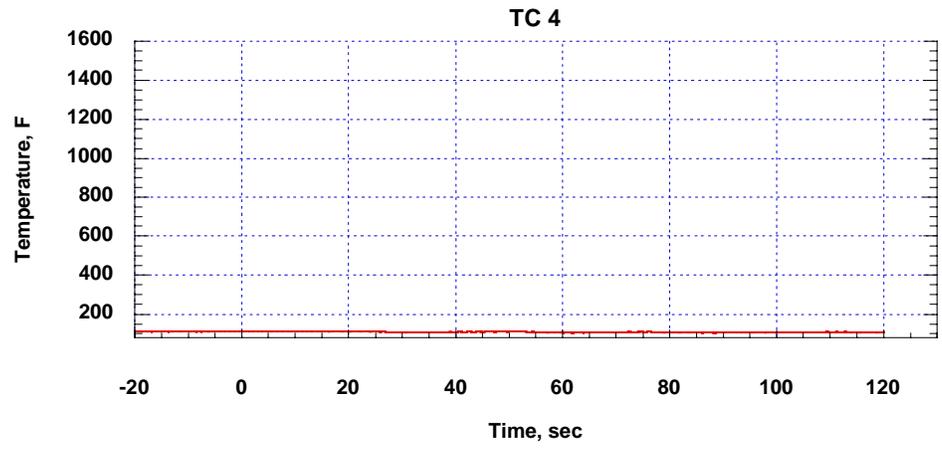
Test 40
Fuel Pressure and Flow Rate vs Time



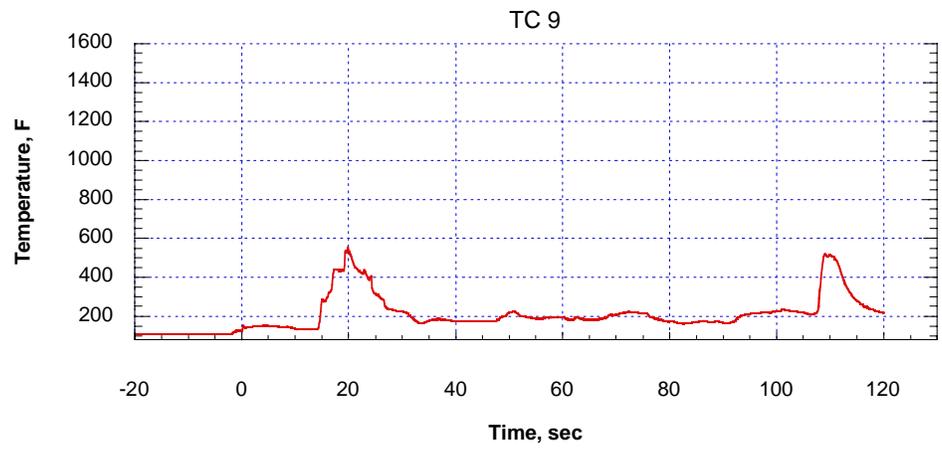
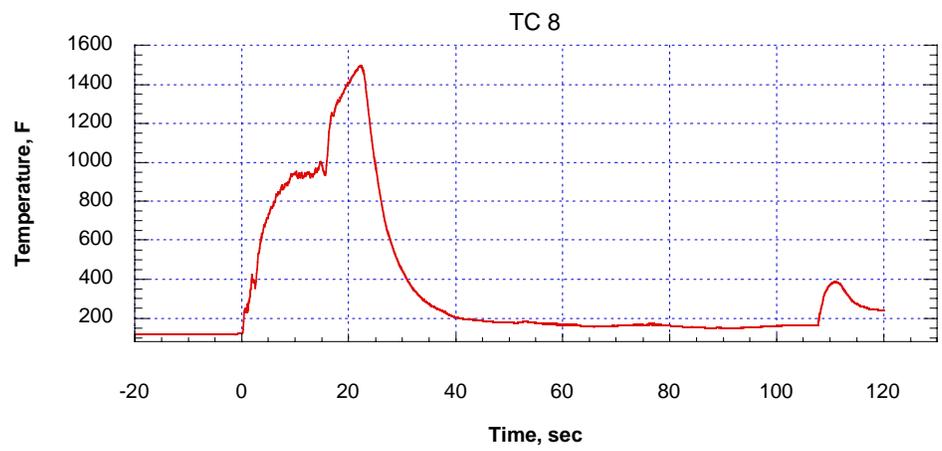
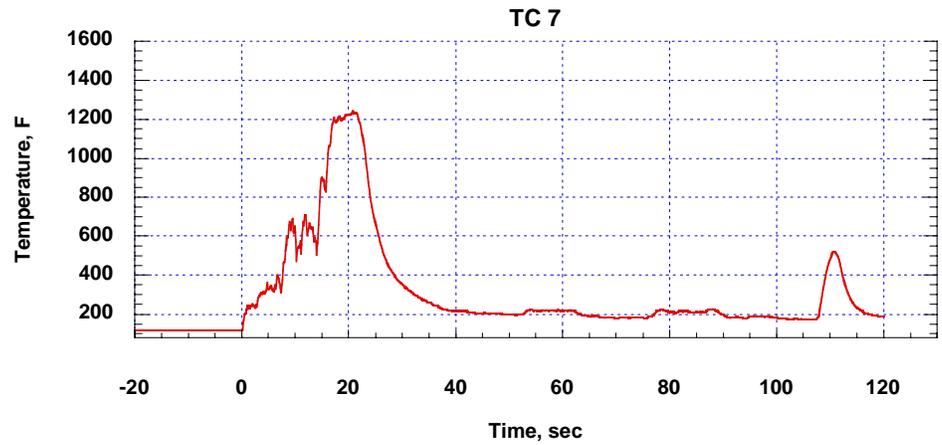
Test 41
Temperature vs Time



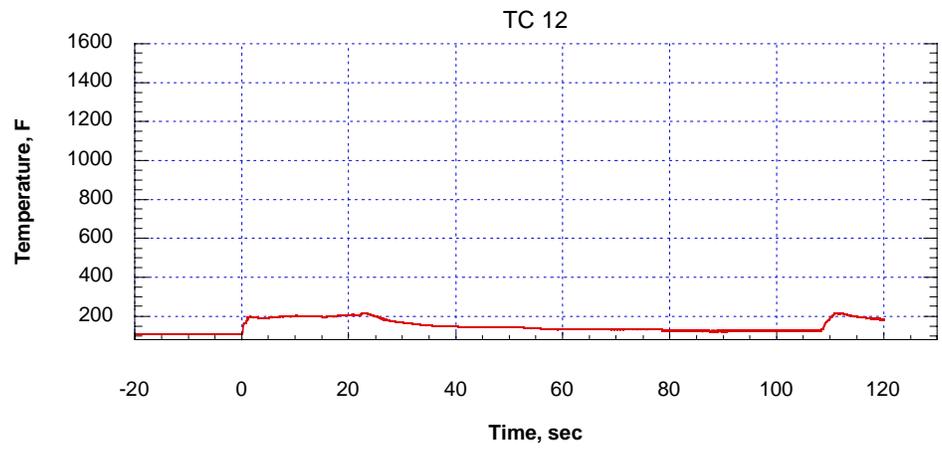
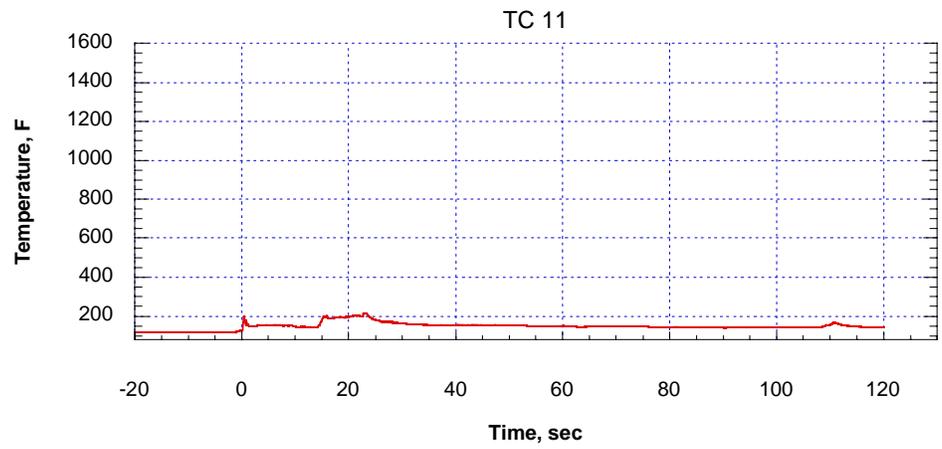
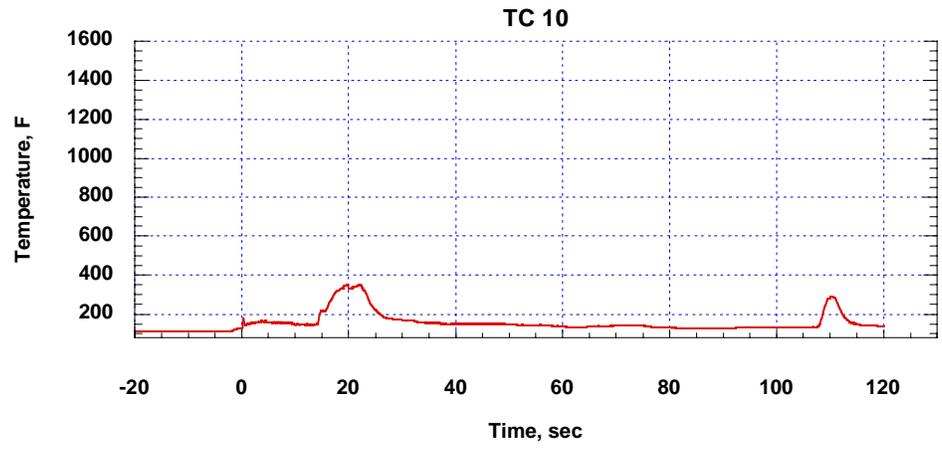
Test 41
Temperature vs Time



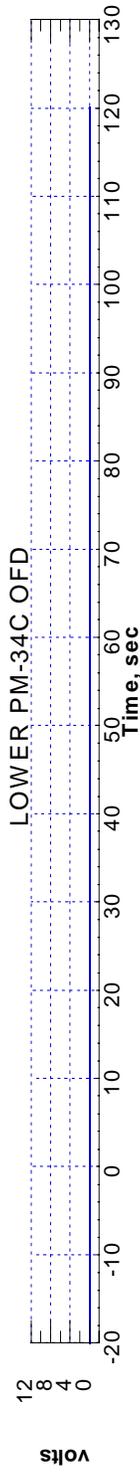
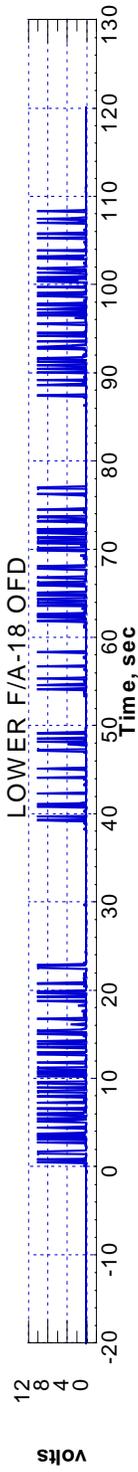
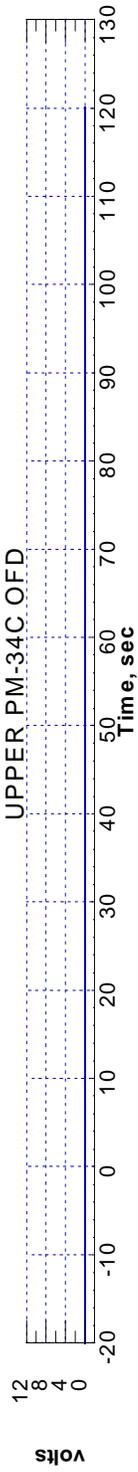
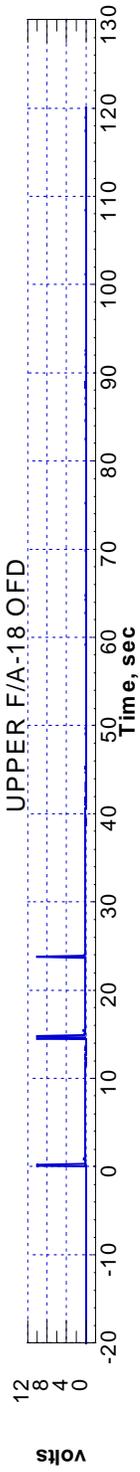
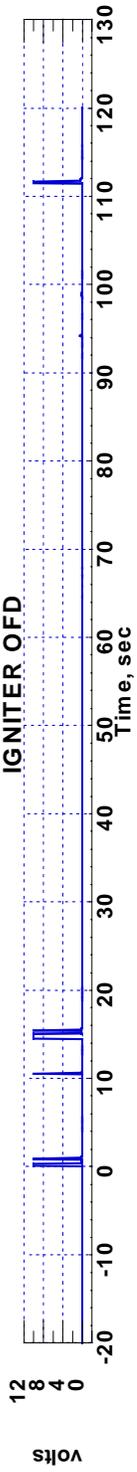
Test 41
Temperature vs Time



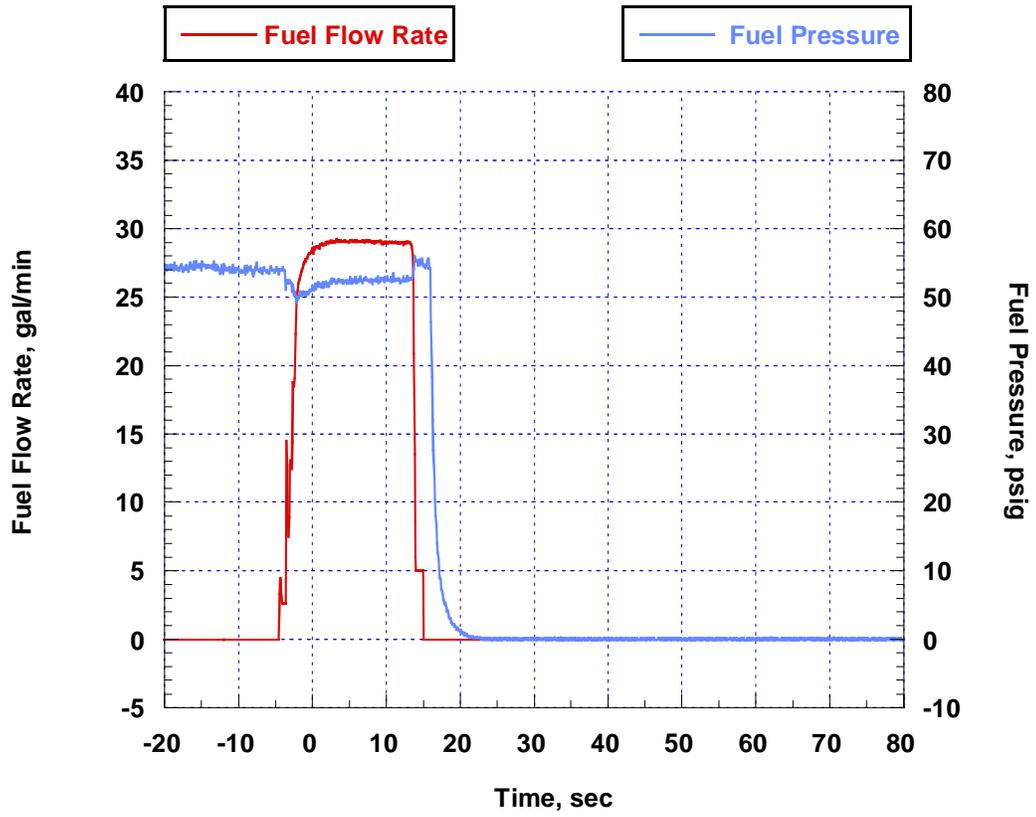
Test 41
Temperature vs Time



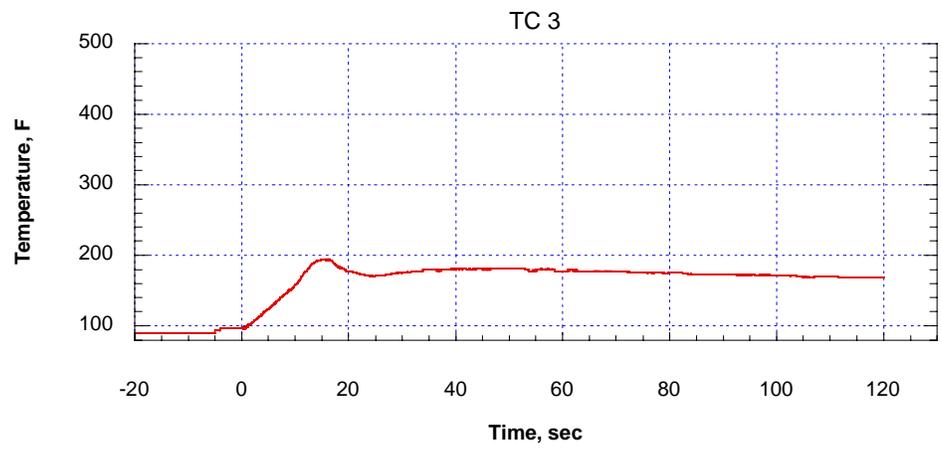
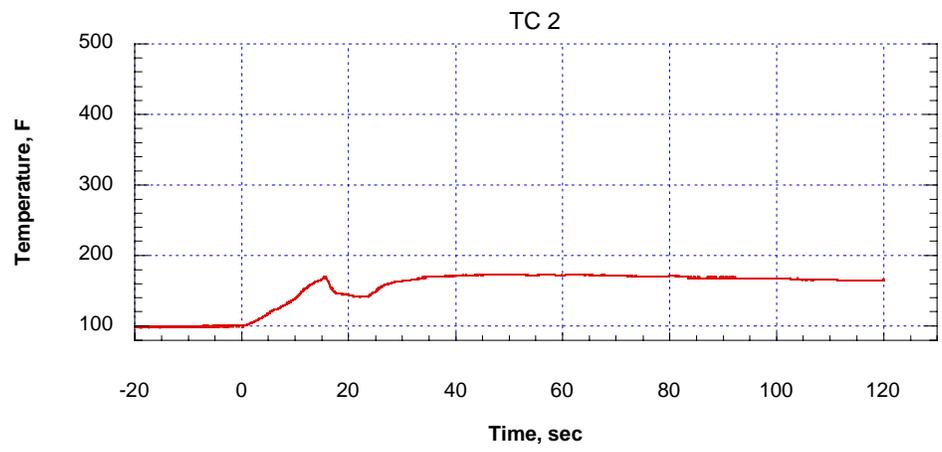
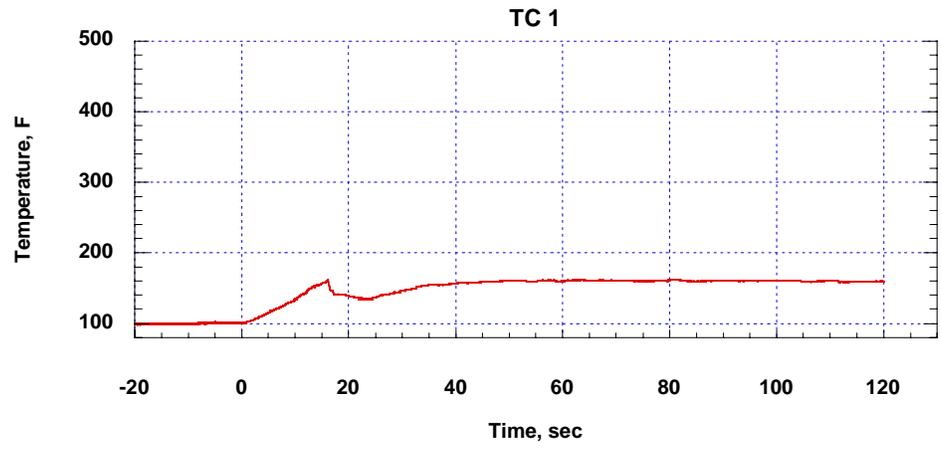
Test 41
Optical Fire Detector Signal vs Time



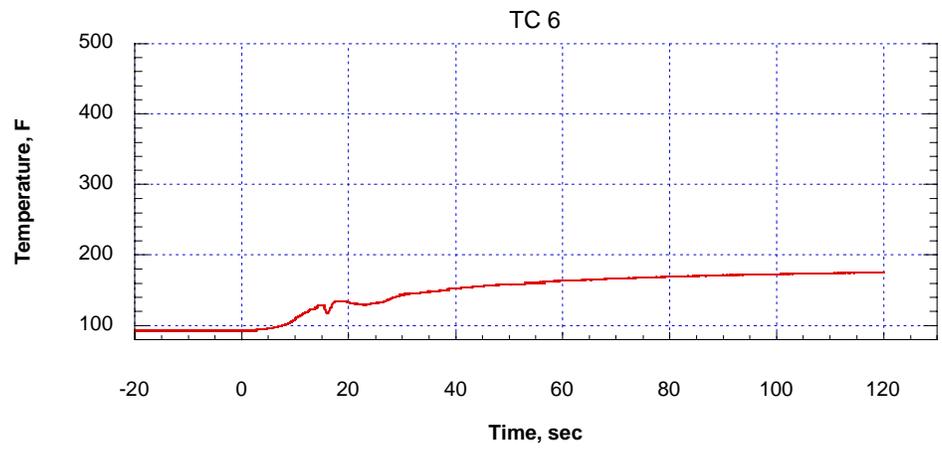
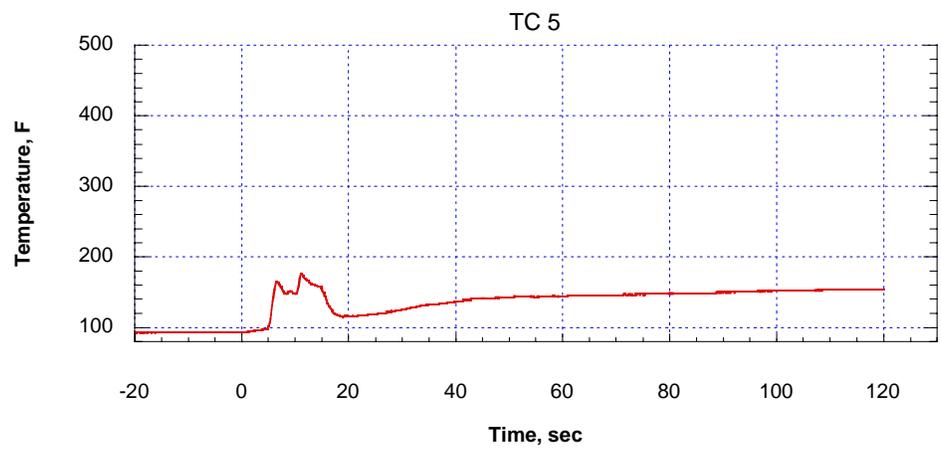
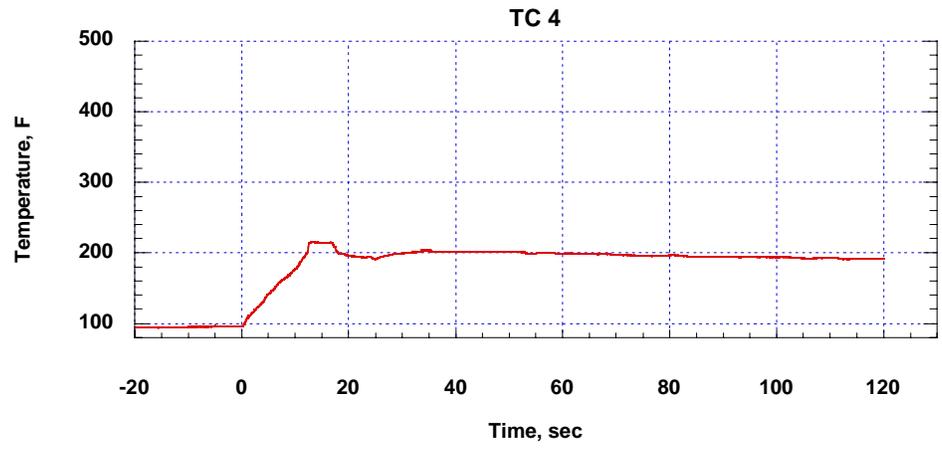
Test 41
Fuel Pressure and Flow Rate vs Time



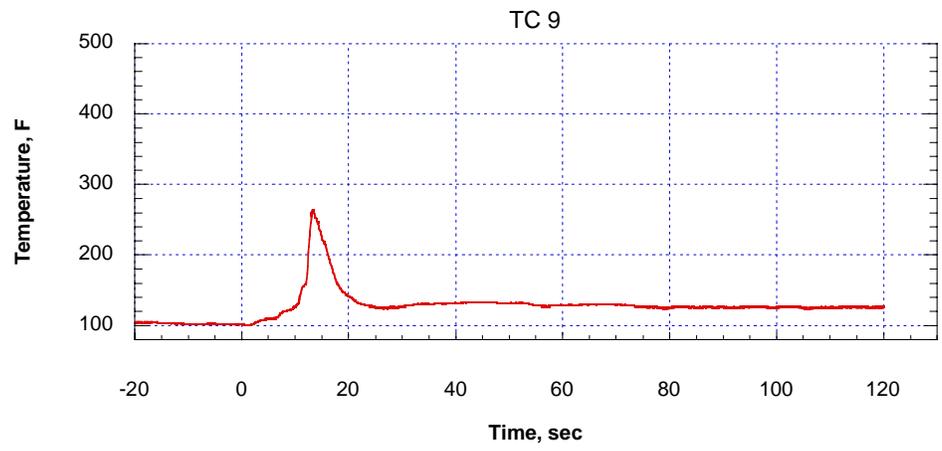
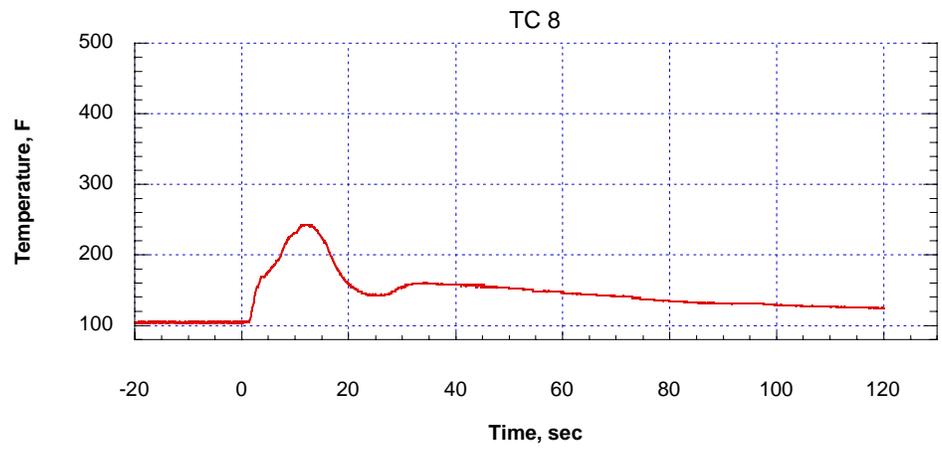
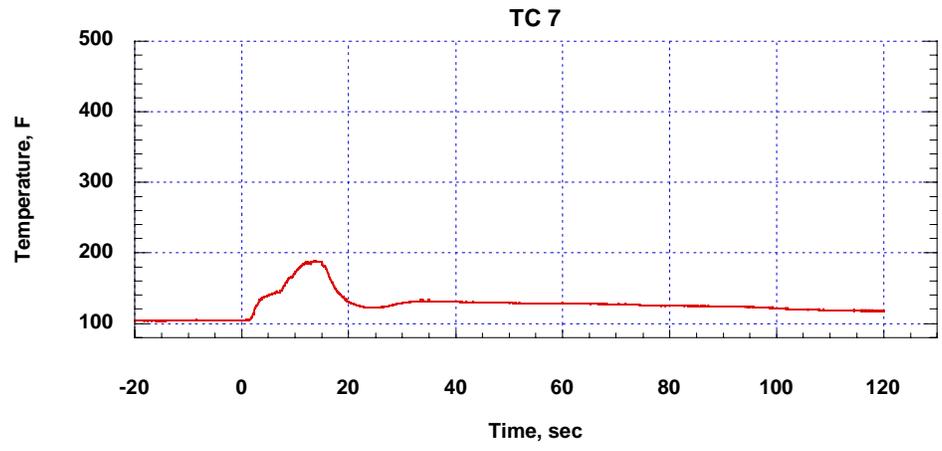
Test 43
Temperature vs Time



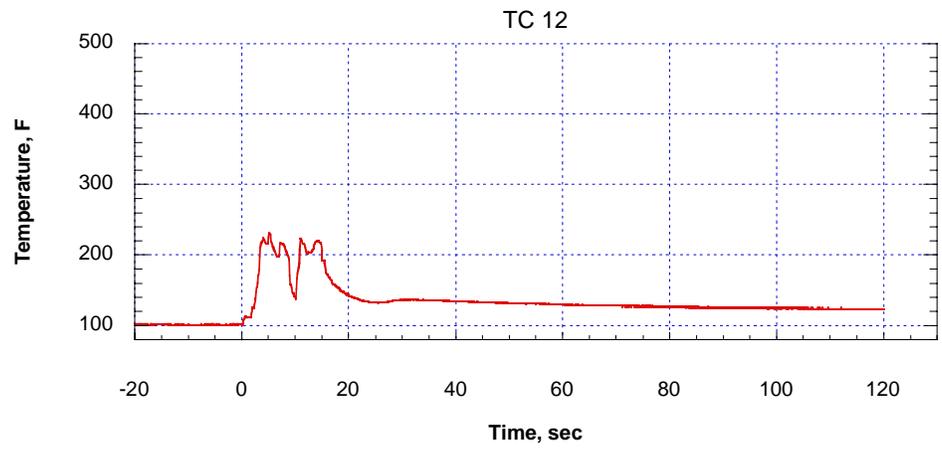
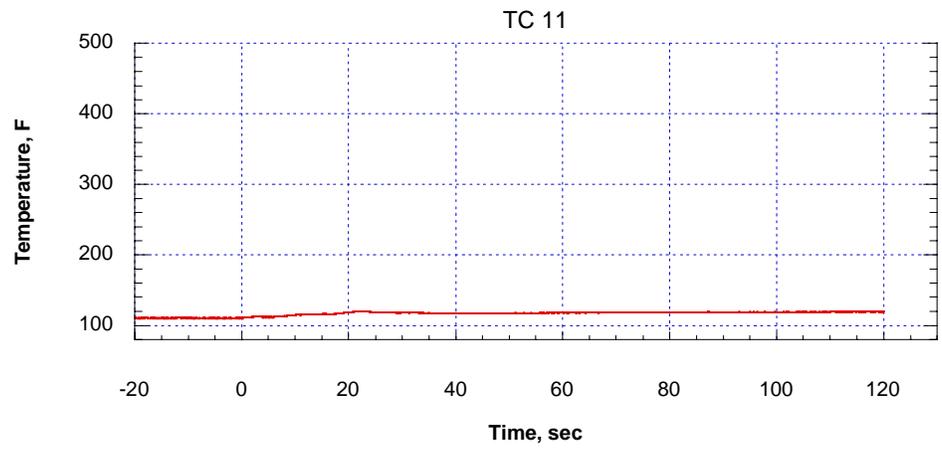
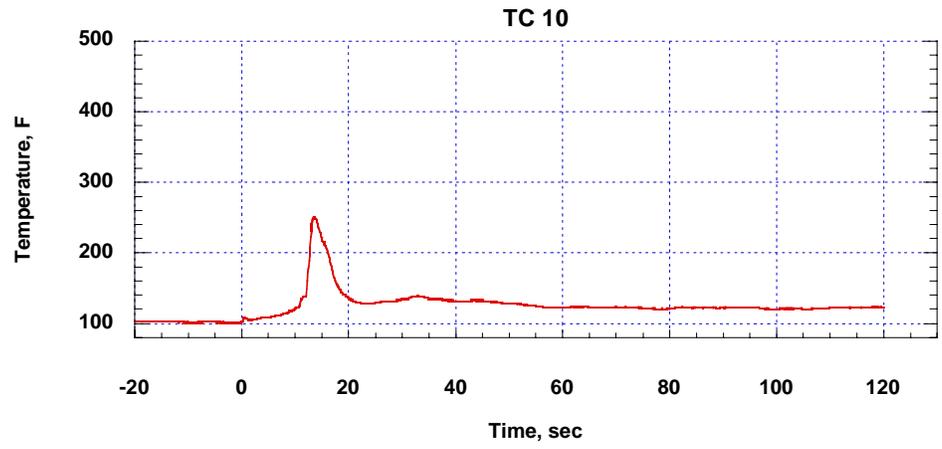
Test 43
Temperature vs Time



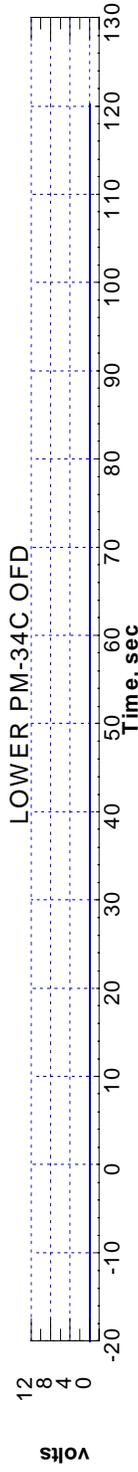
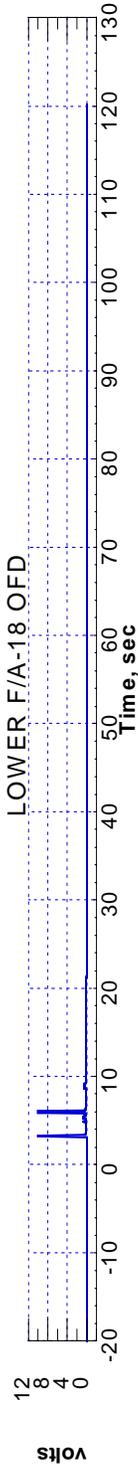
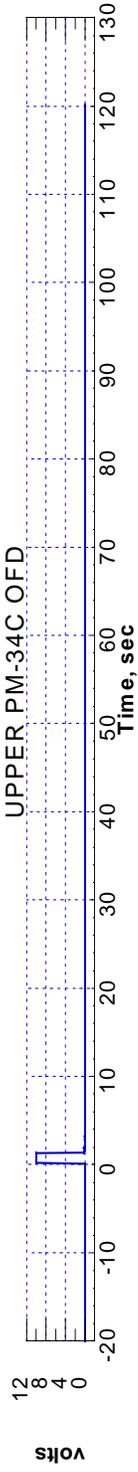
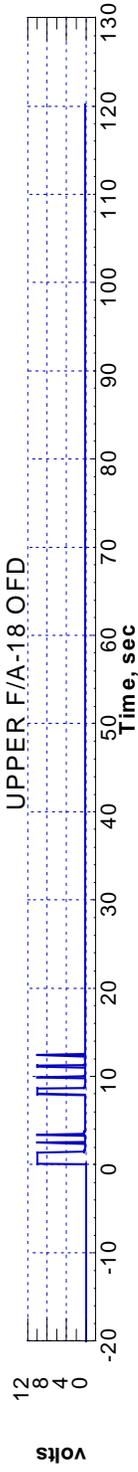
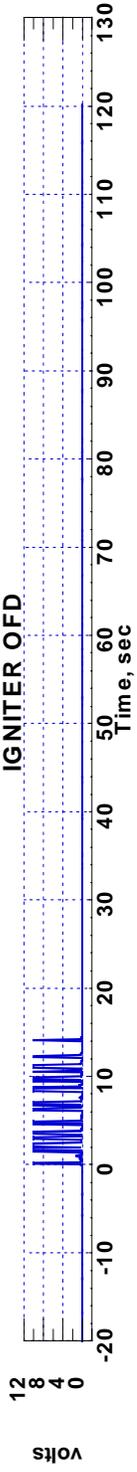
Test 43
Temperature vs Time



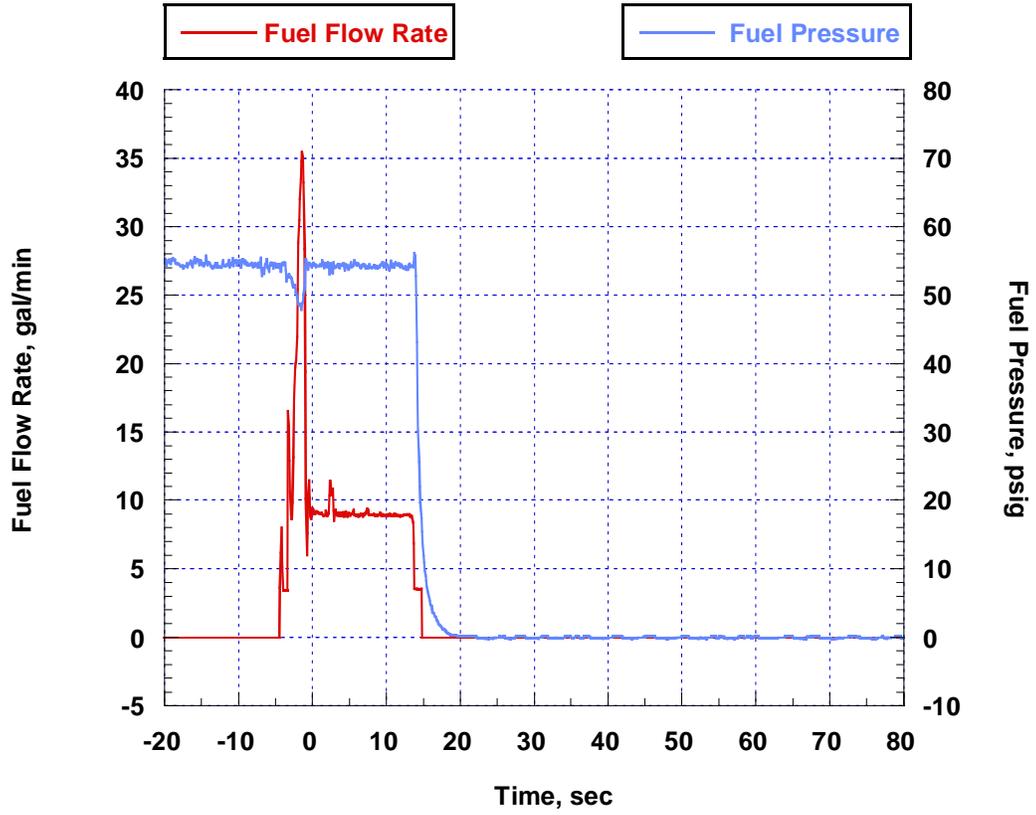
Test 43
Temperature vs Time



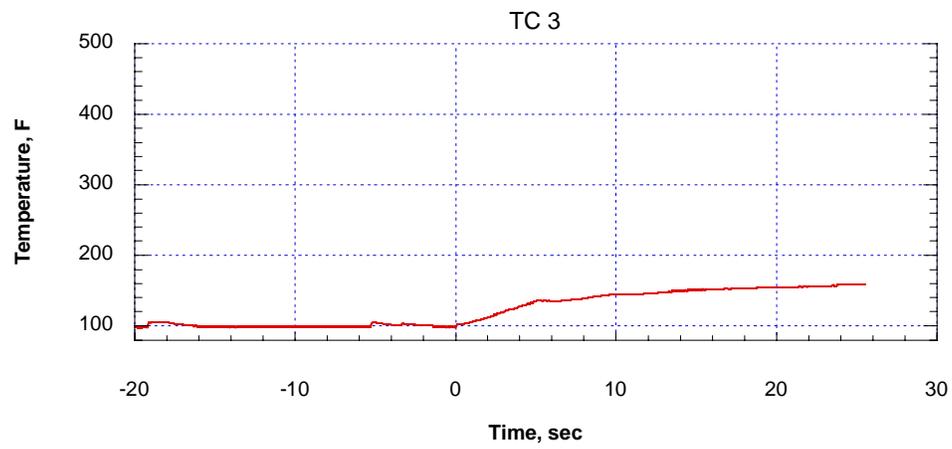
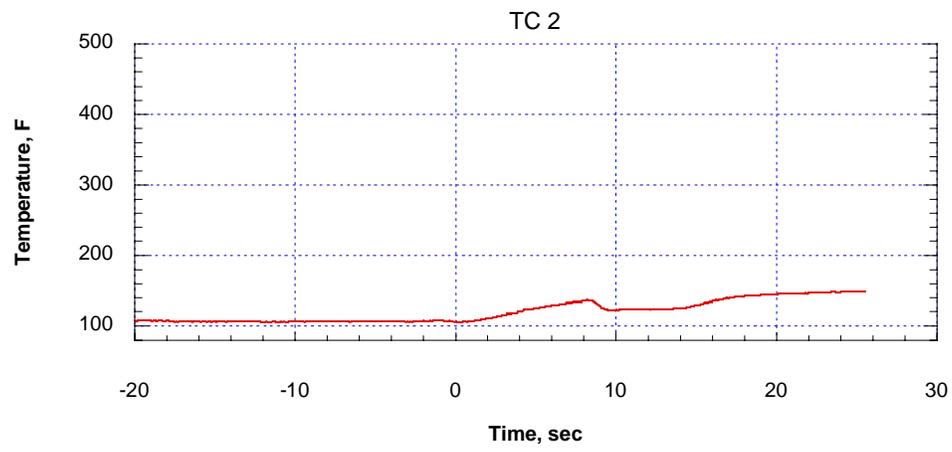
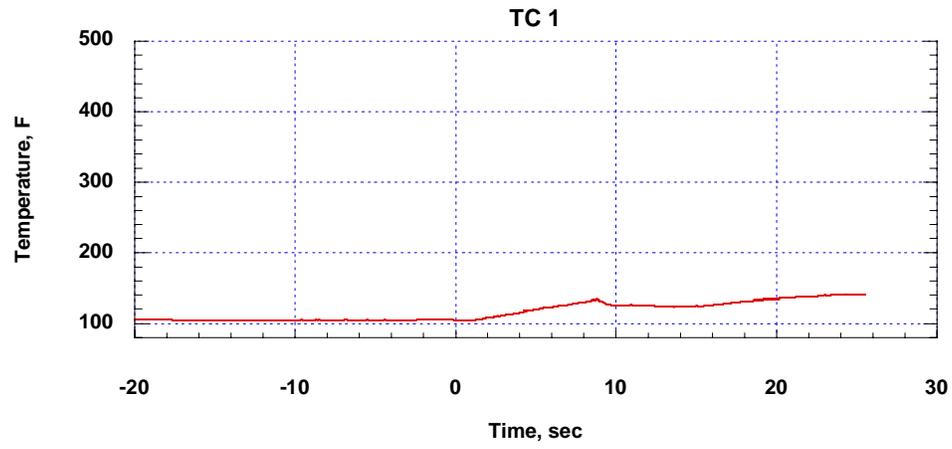
Test 43
Optical Fire Detector Signal vs Time



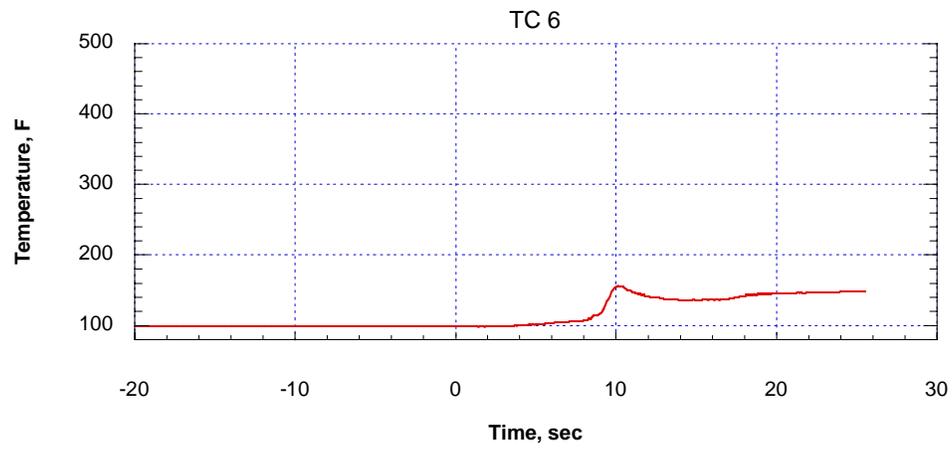
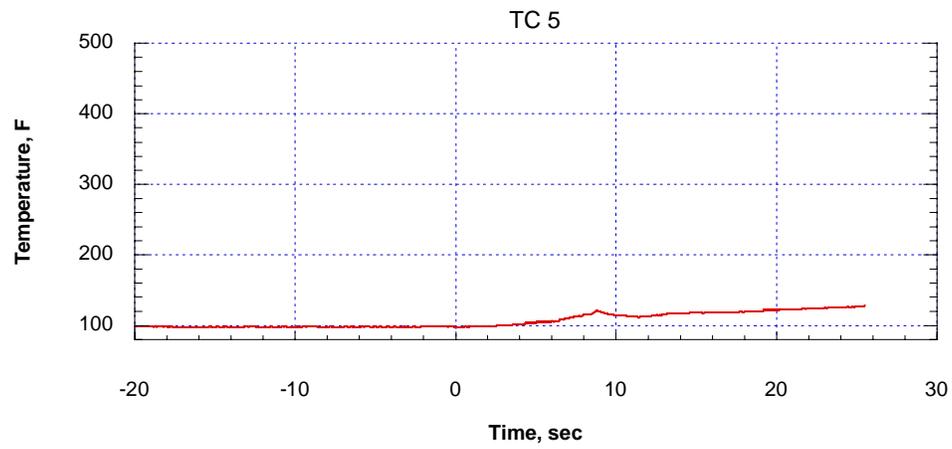
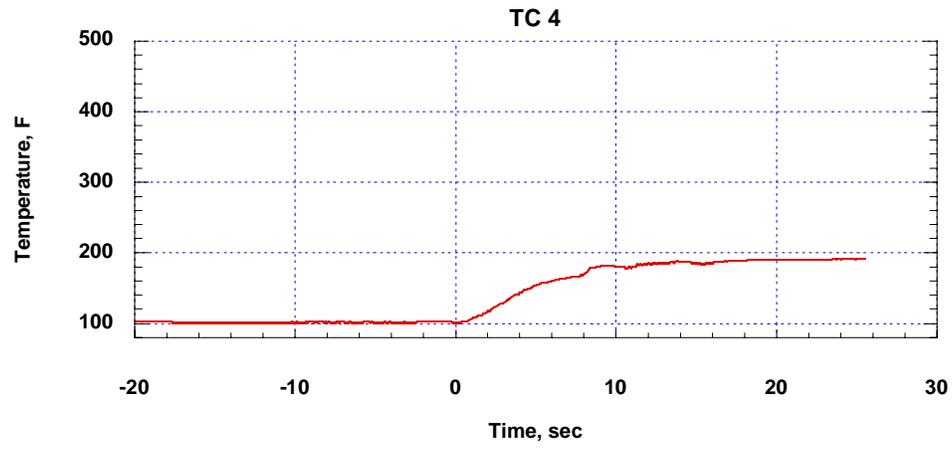
Test 43
Fuel Pressure and Flow Rate vs Time



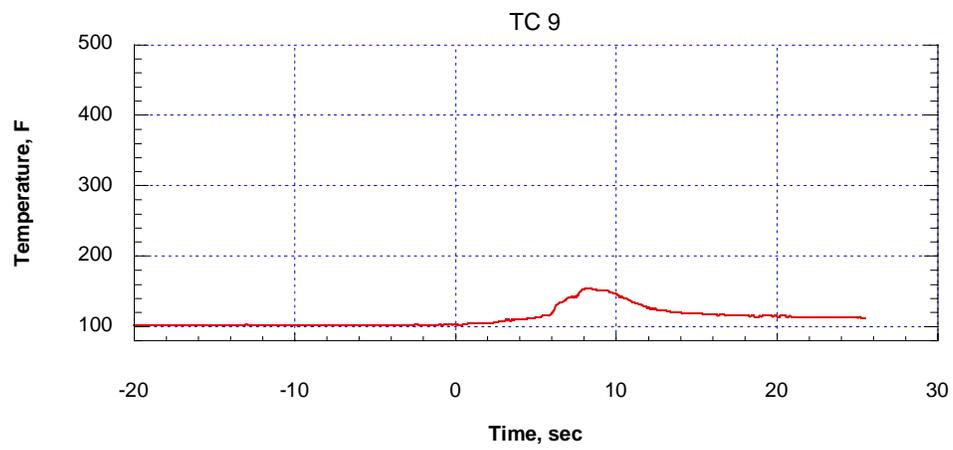
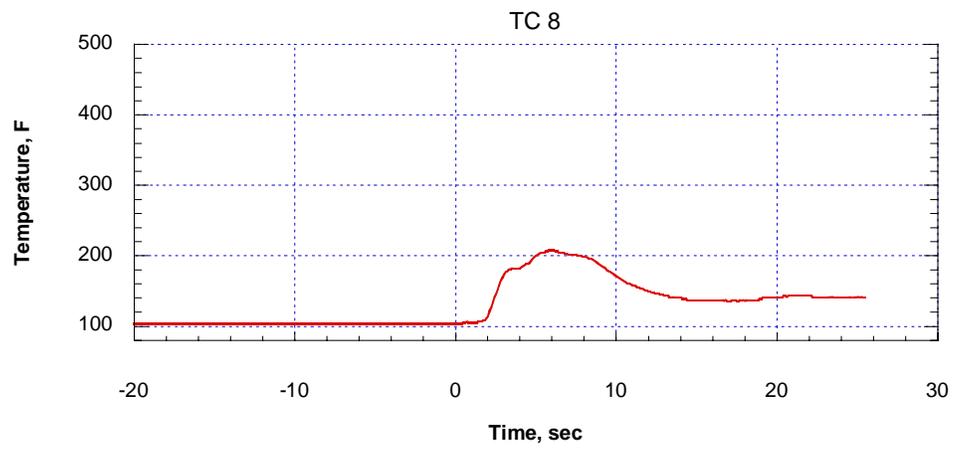
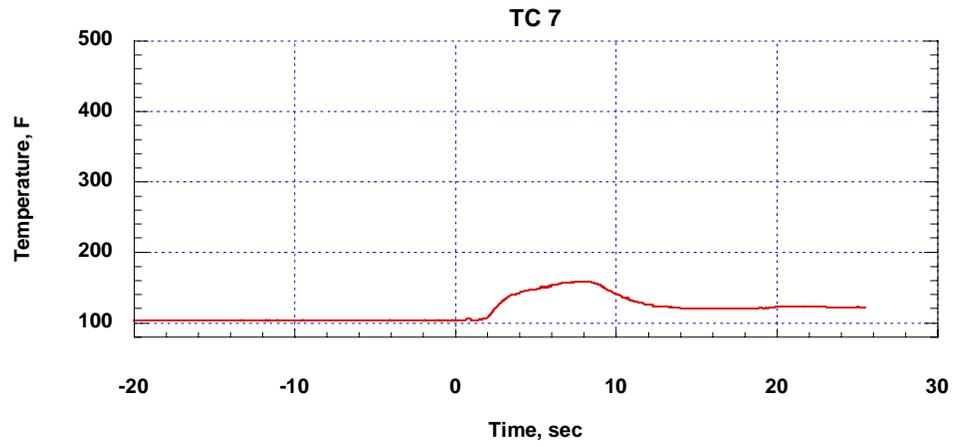
Test 44
Temperature vs Time



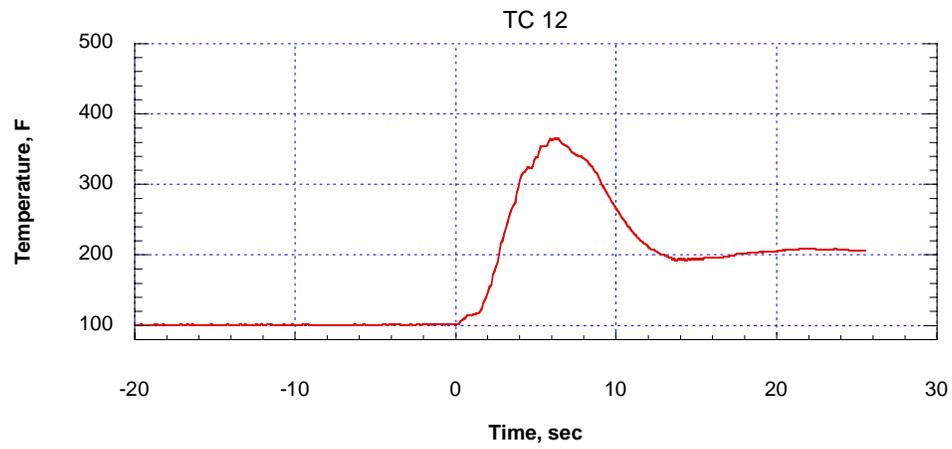
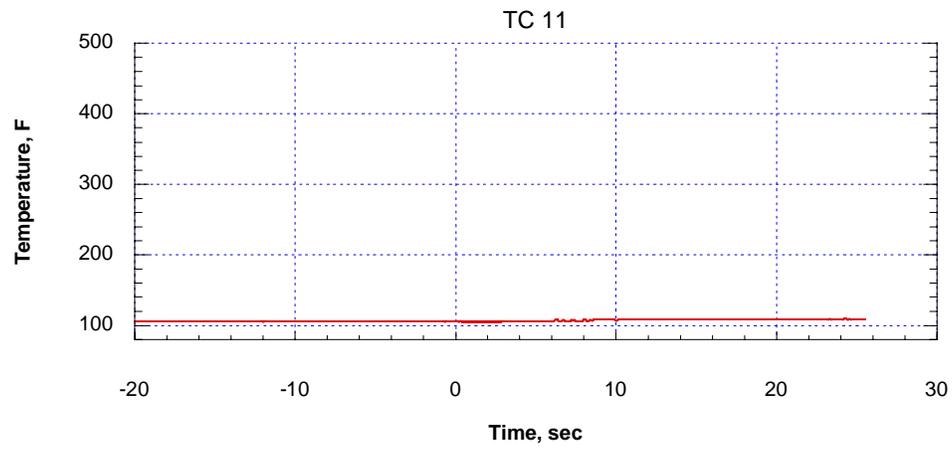
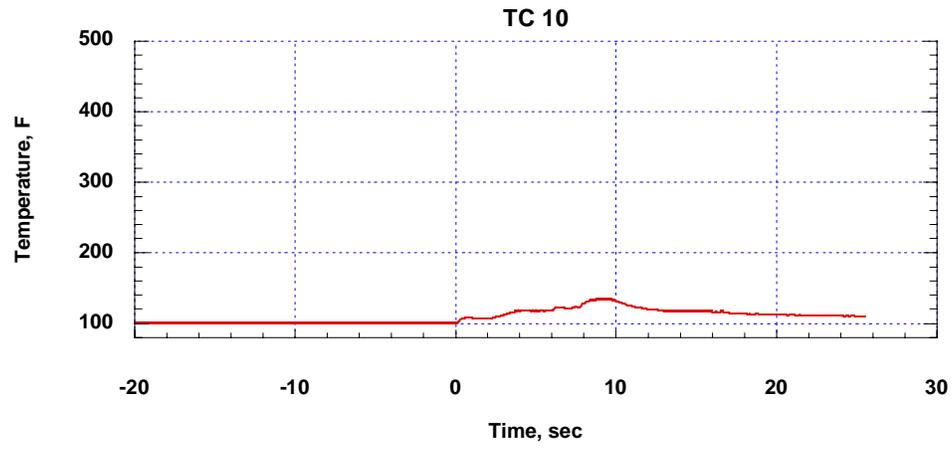
Test 44
Temperature vs Time



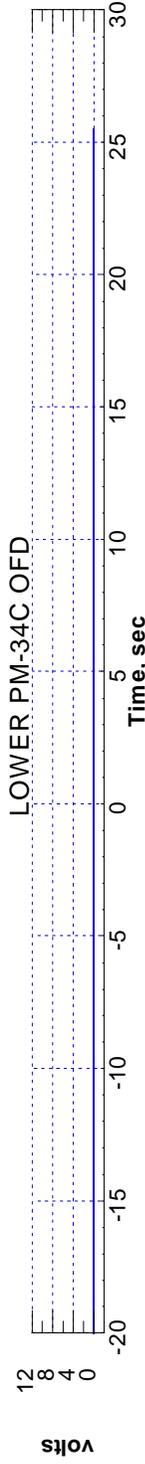
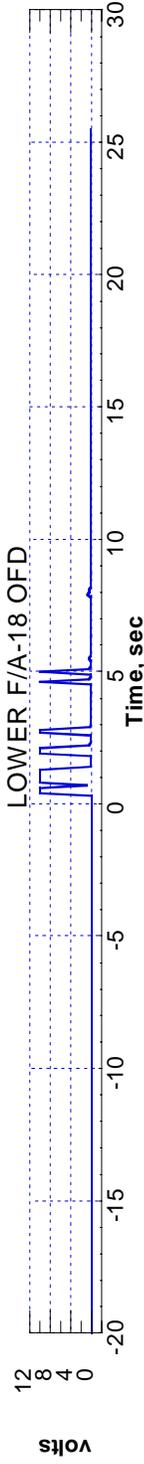
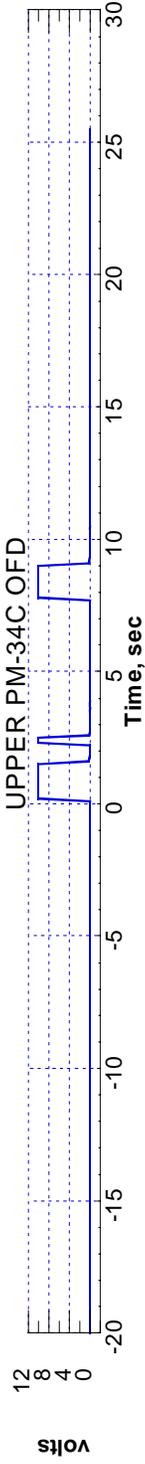
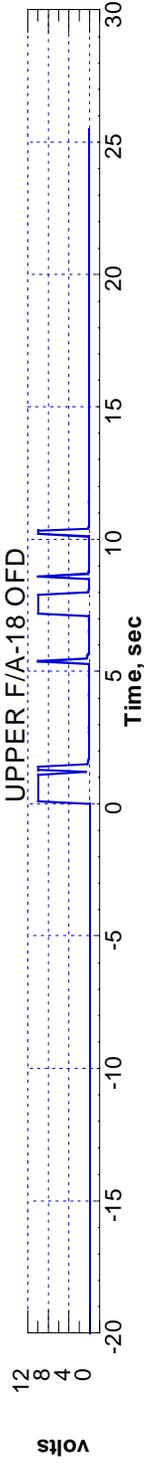
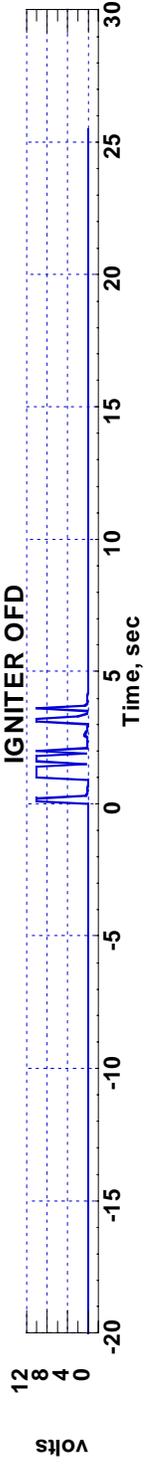
Test 44
Temperature vs Time



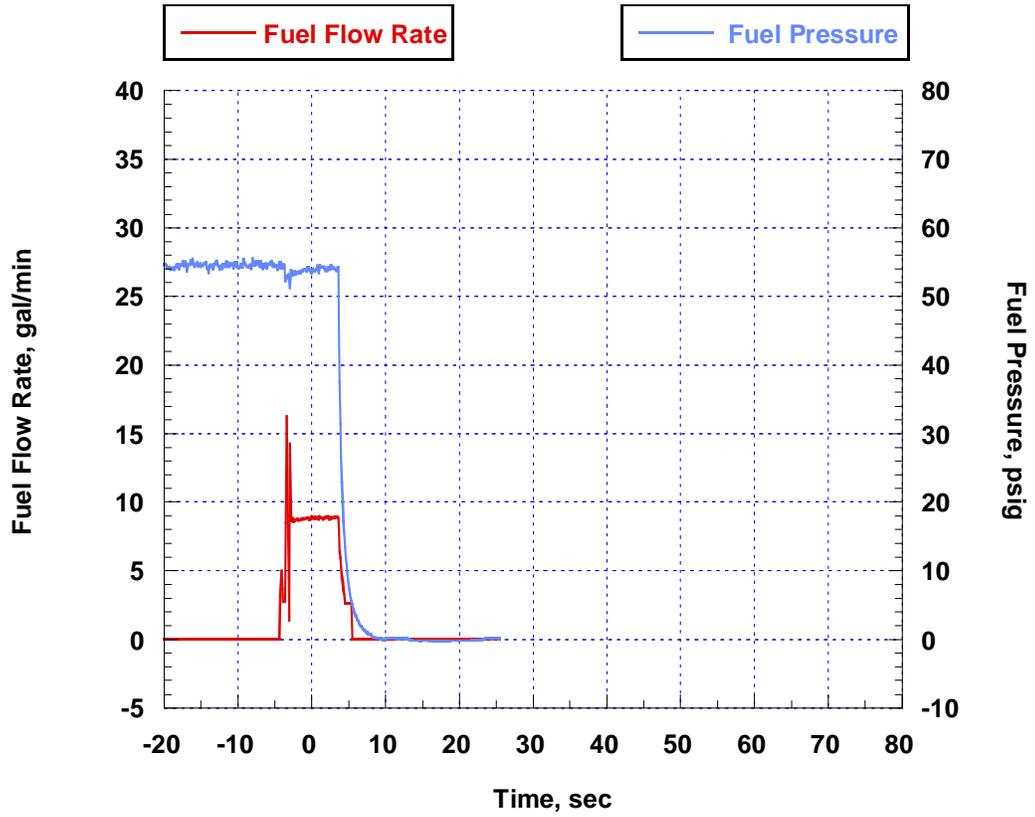
Test 44
Temperature vs Time



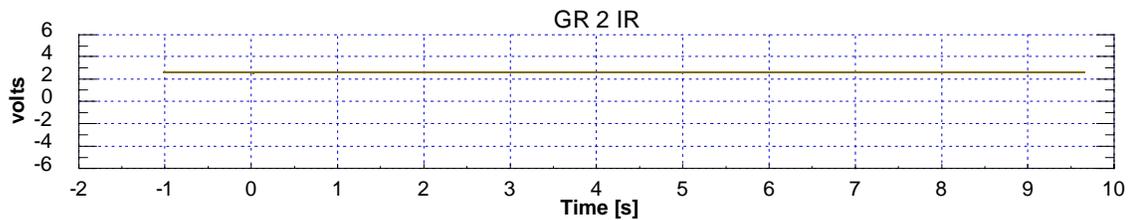
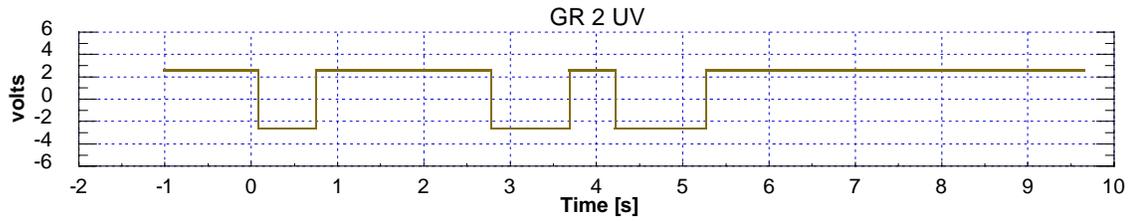
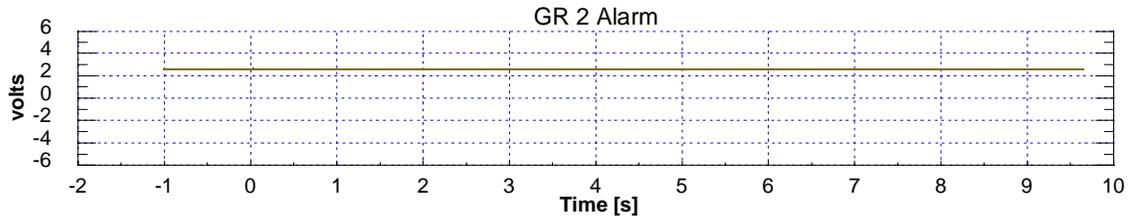
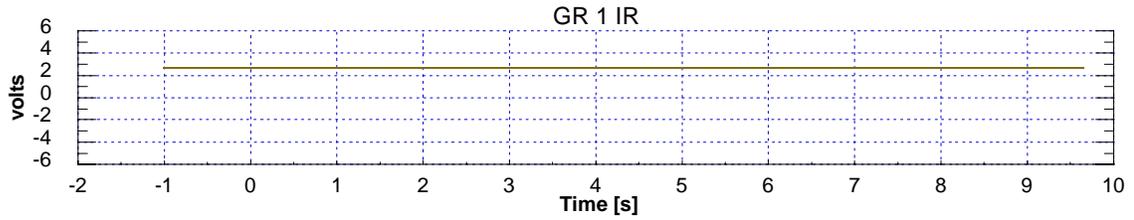
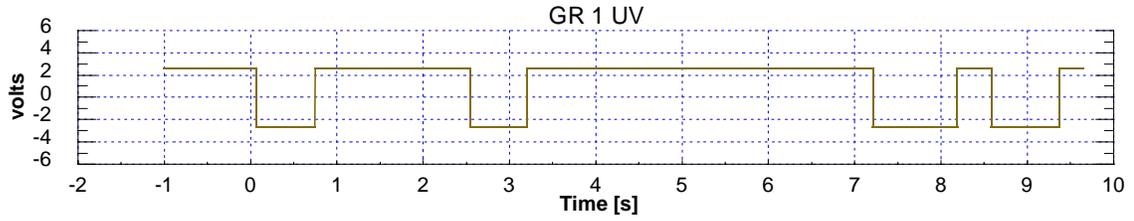
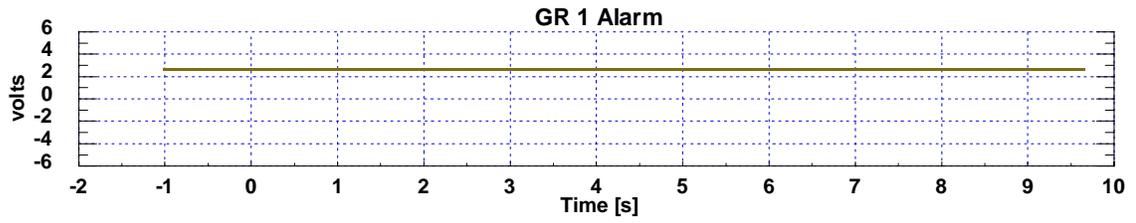
Test 44
Optical Fire Detector Signal vs Time



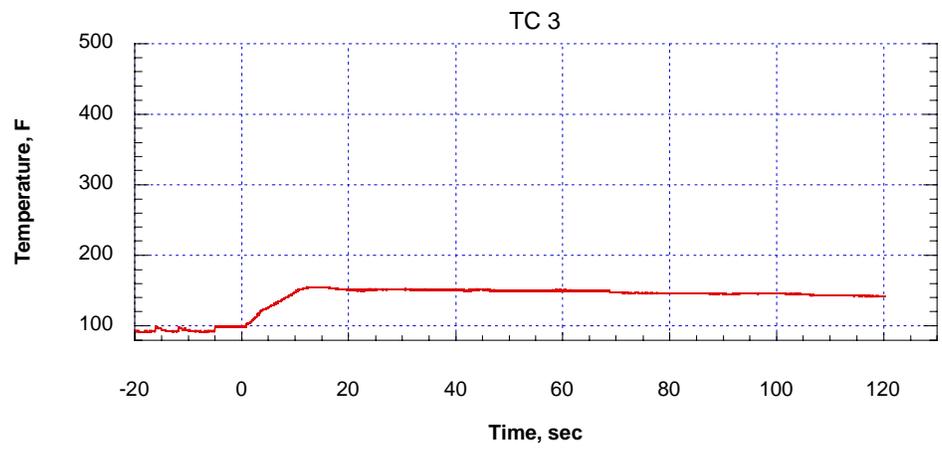
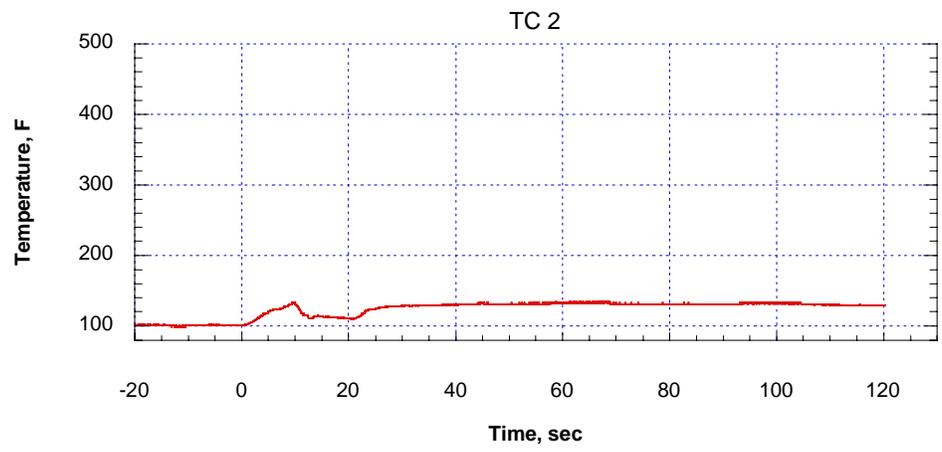
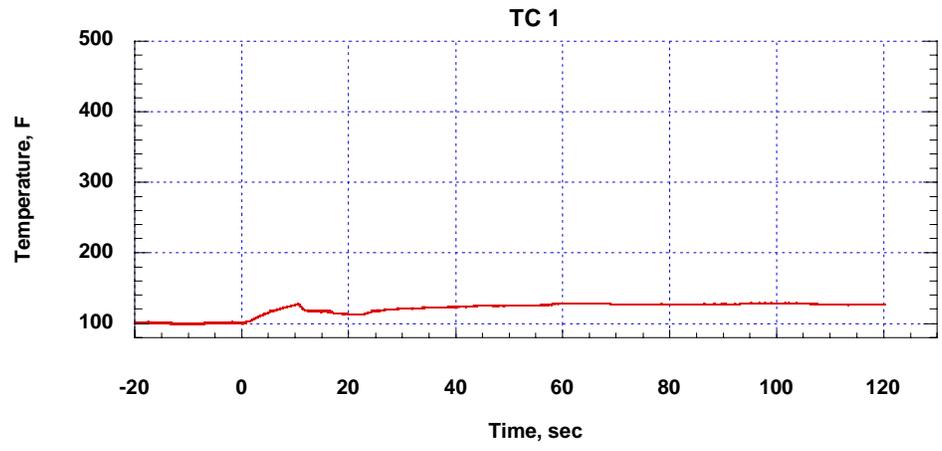
Test 44
Fuel Pressure and Flow Rate vs Time



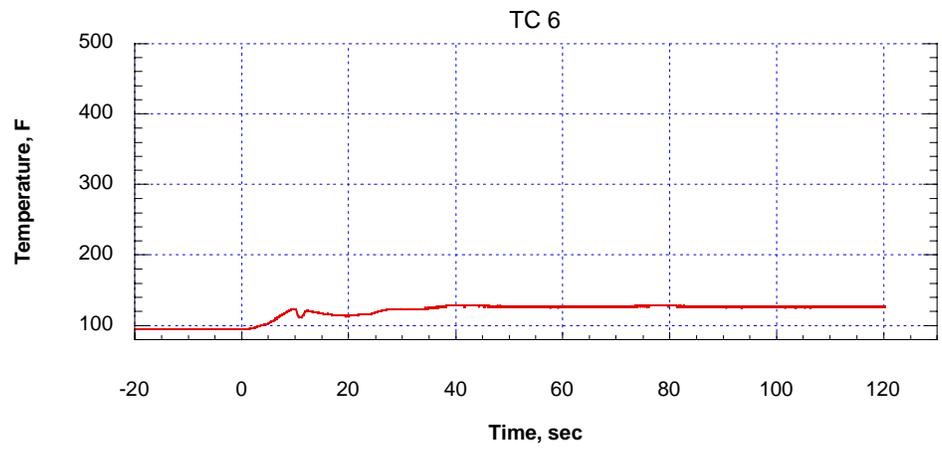
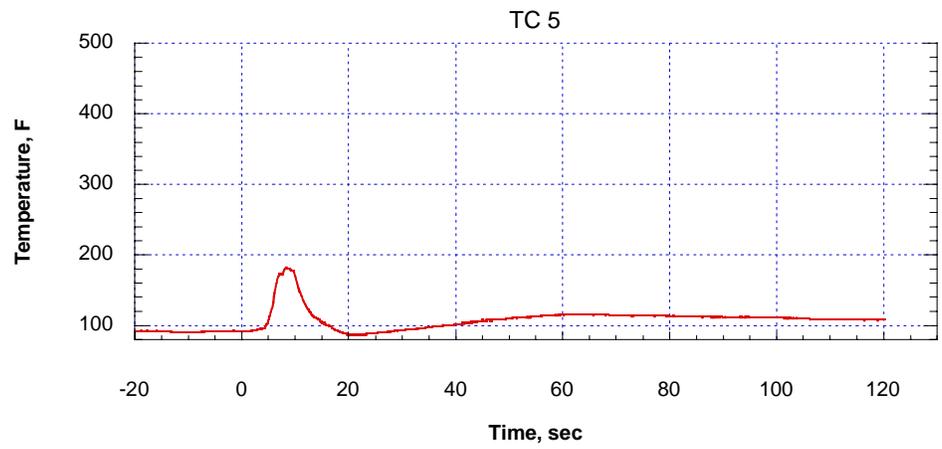
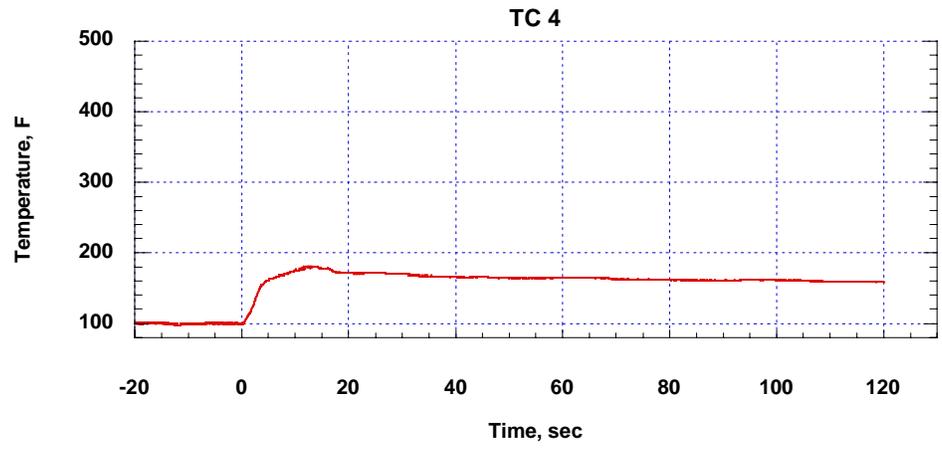
Test 44
High-Frequency Alarm Data vs Time



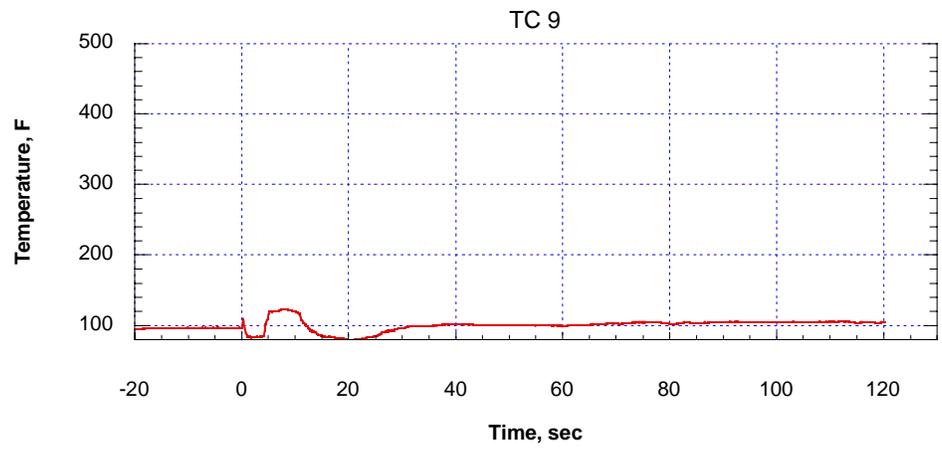
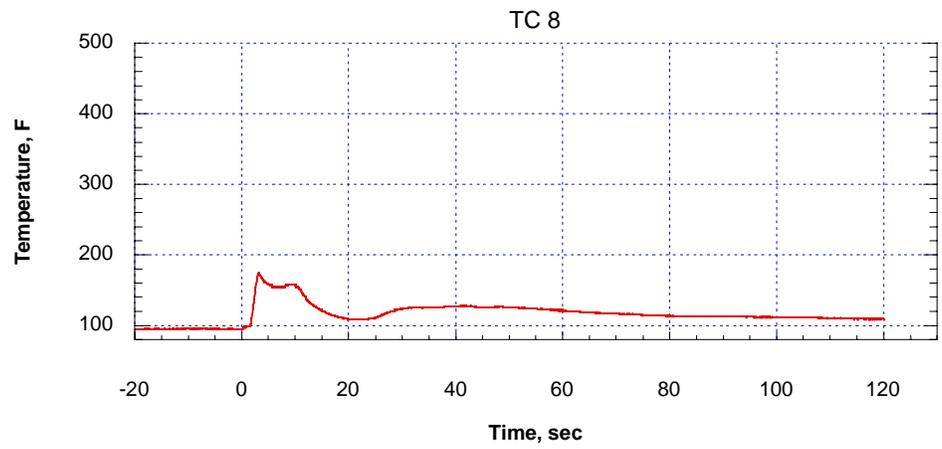
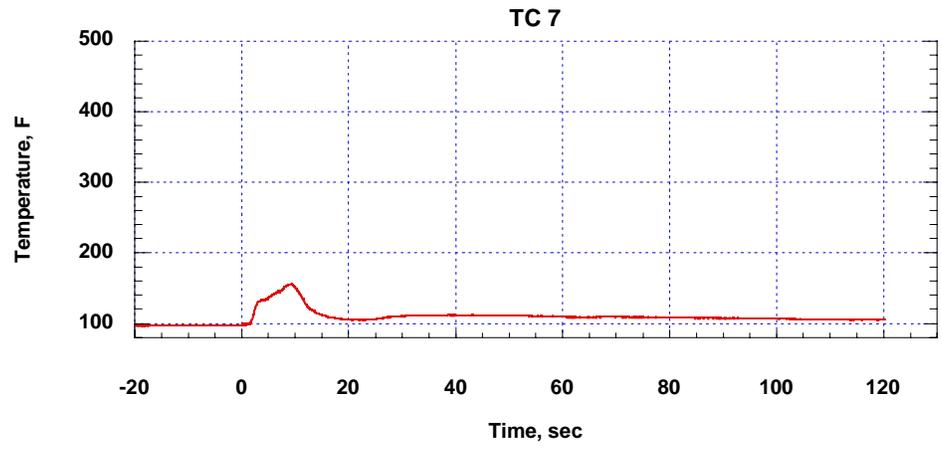
Test 45
Temperature vs Time



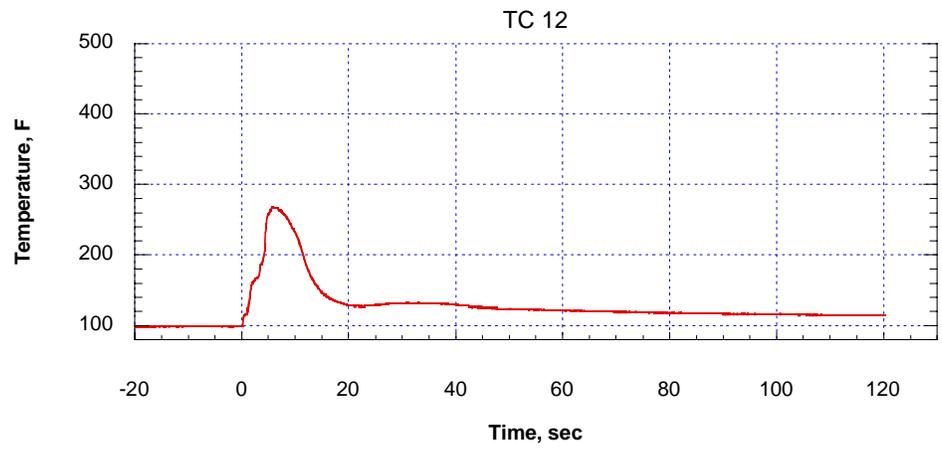
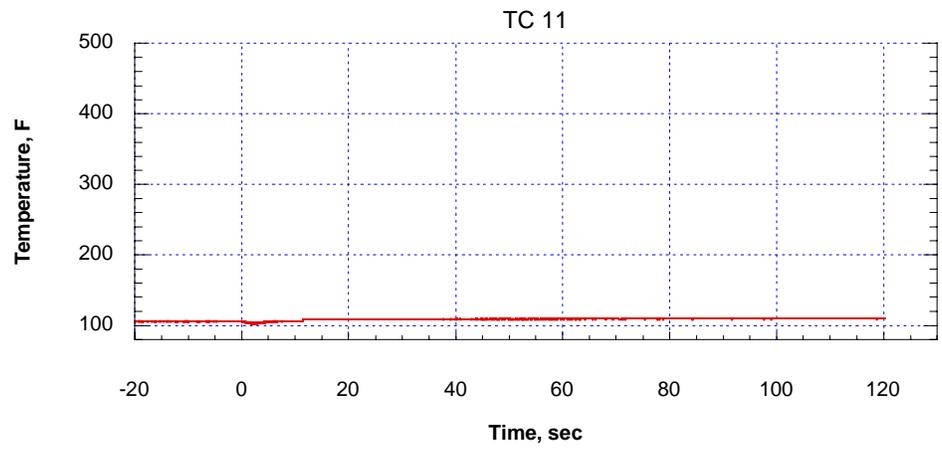
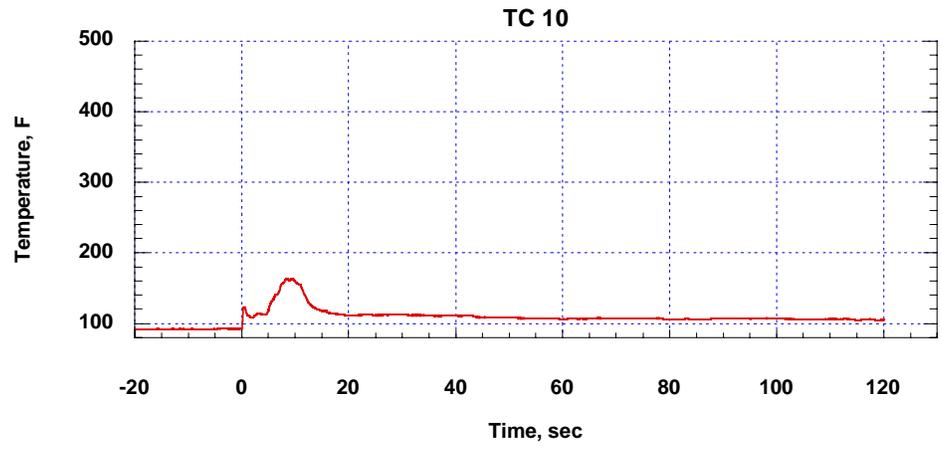
Test 45
Temperature vs Time



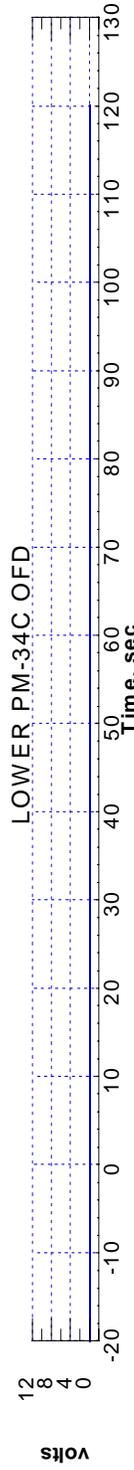
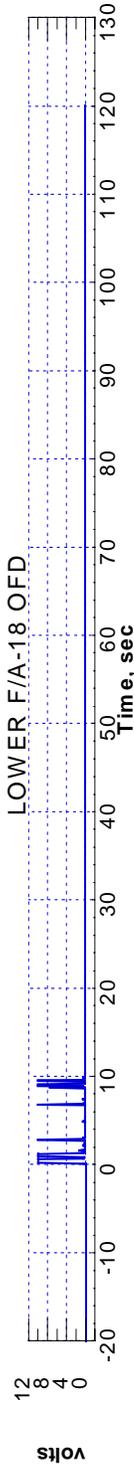
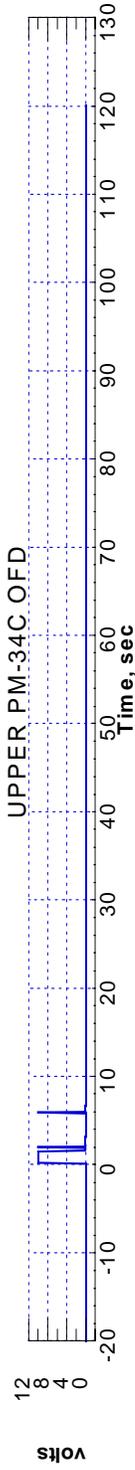
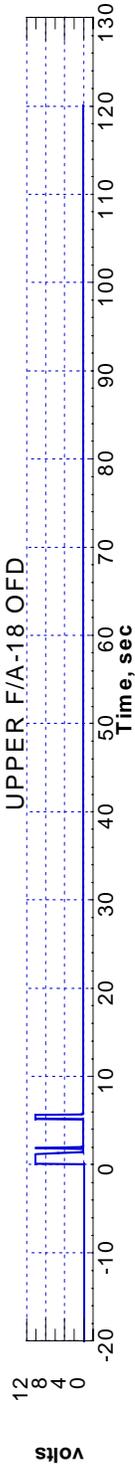
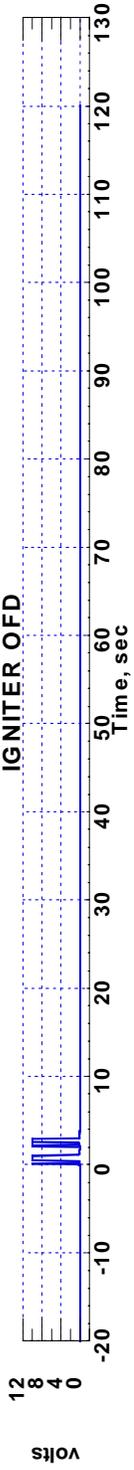
Test 45
Temperature vs Time



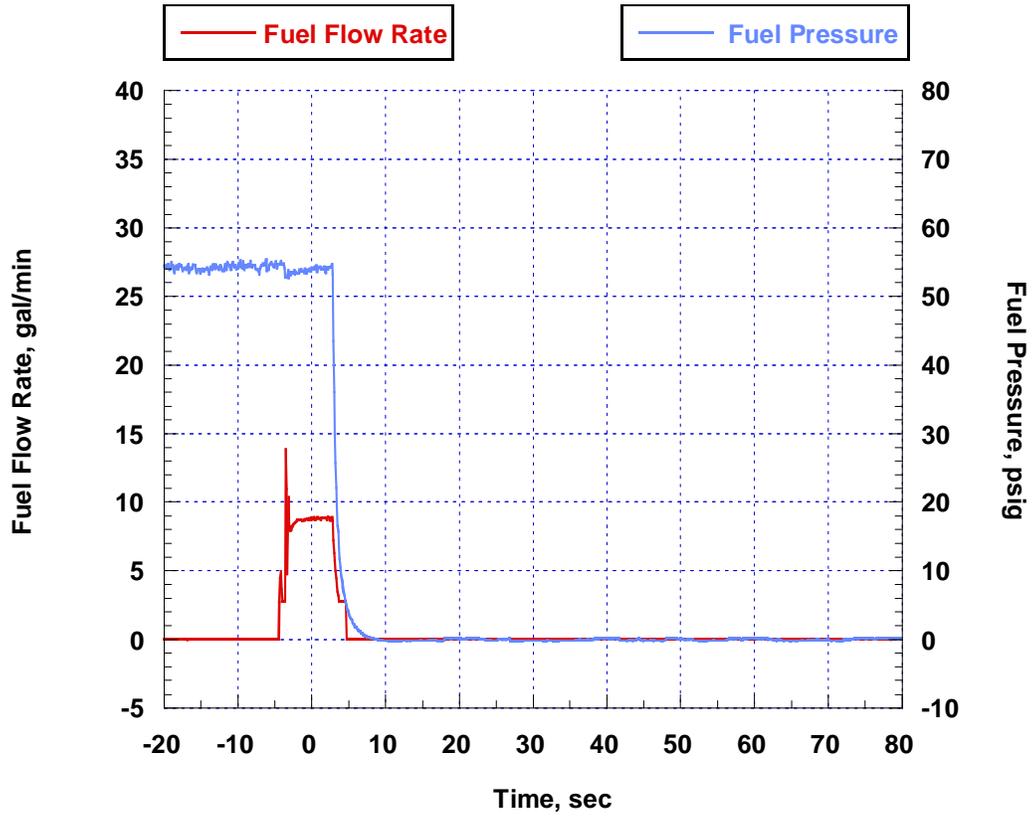
Test 45
Temperature vs Time



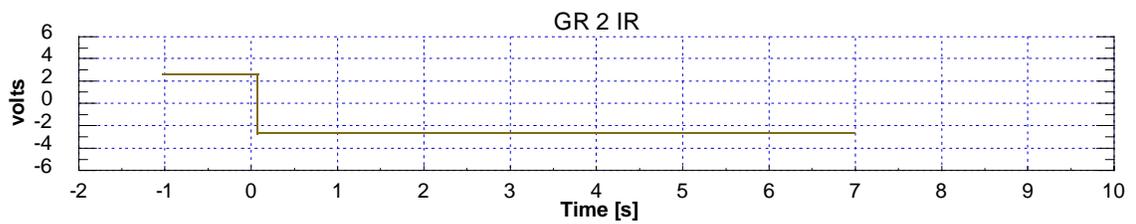
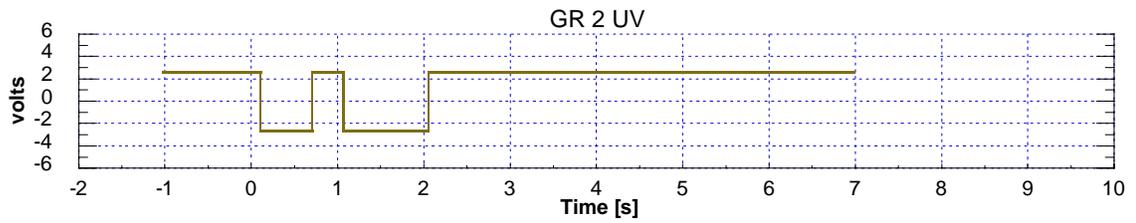
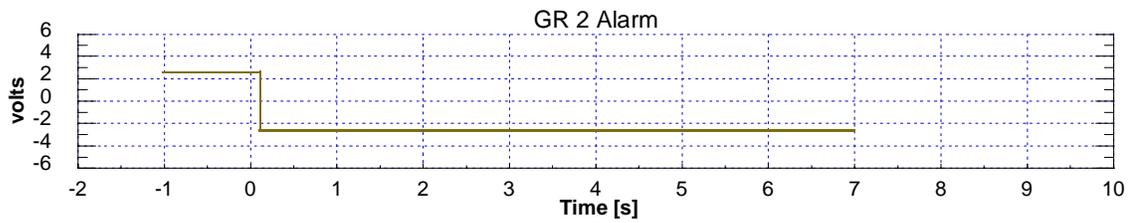
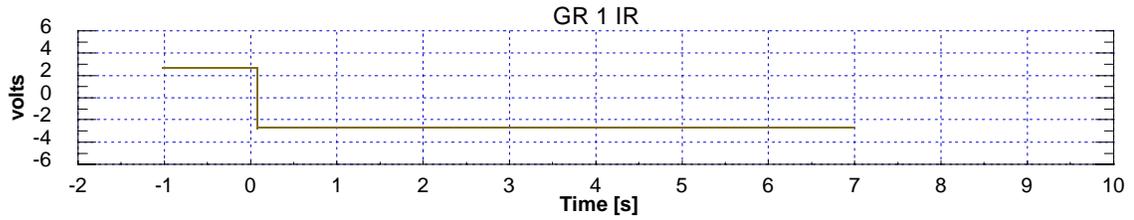
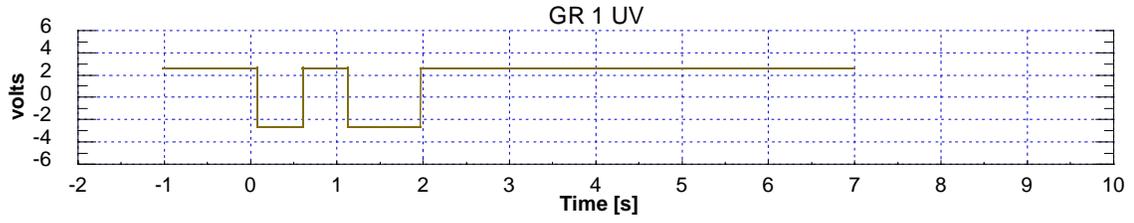
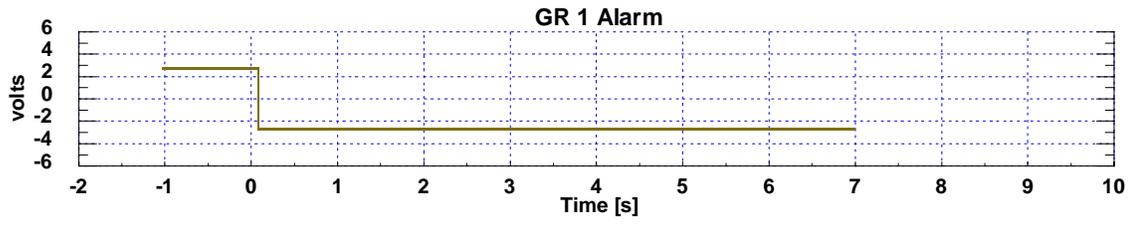
Test 45
Optical Fire Detector Signal vs Time



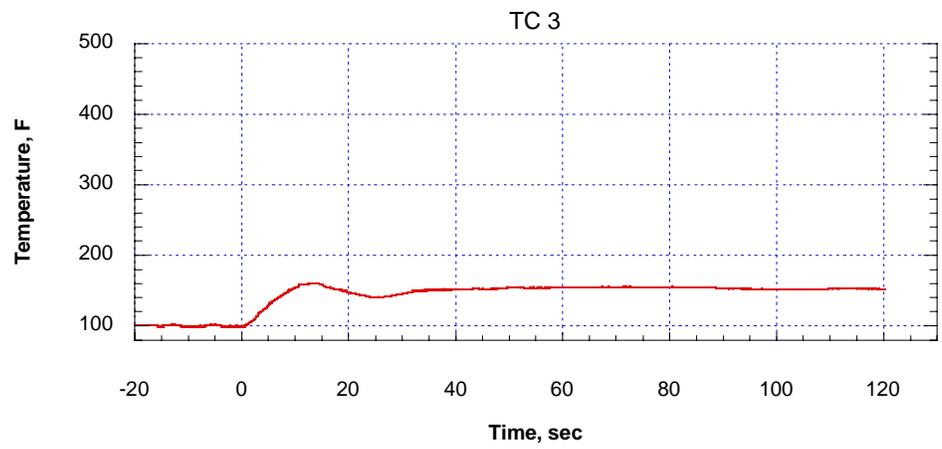
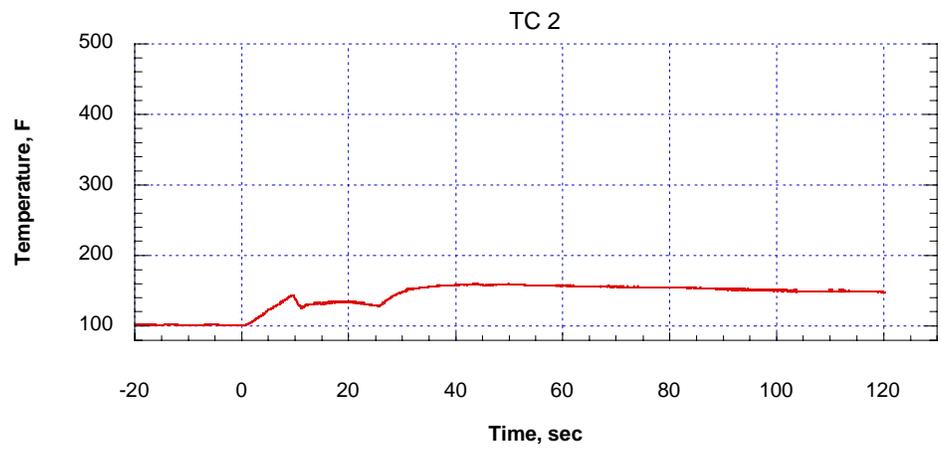
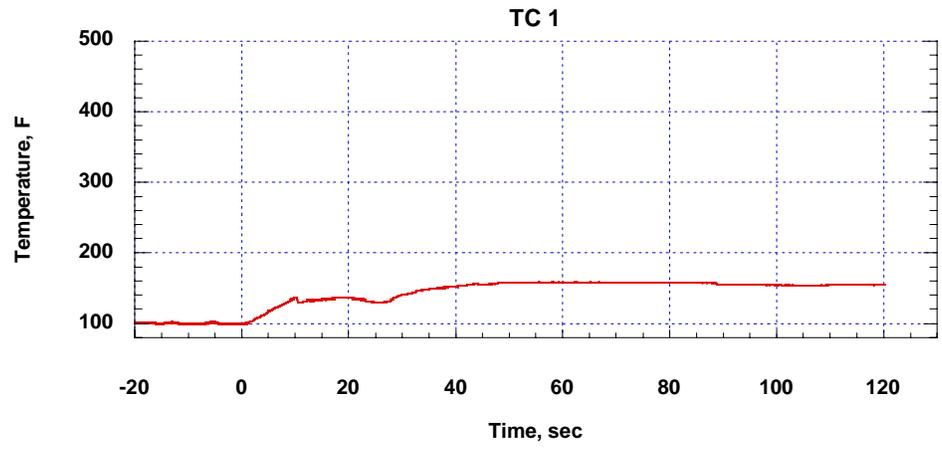
Test 45
Fuel Pressure and Flow Rate vs Time



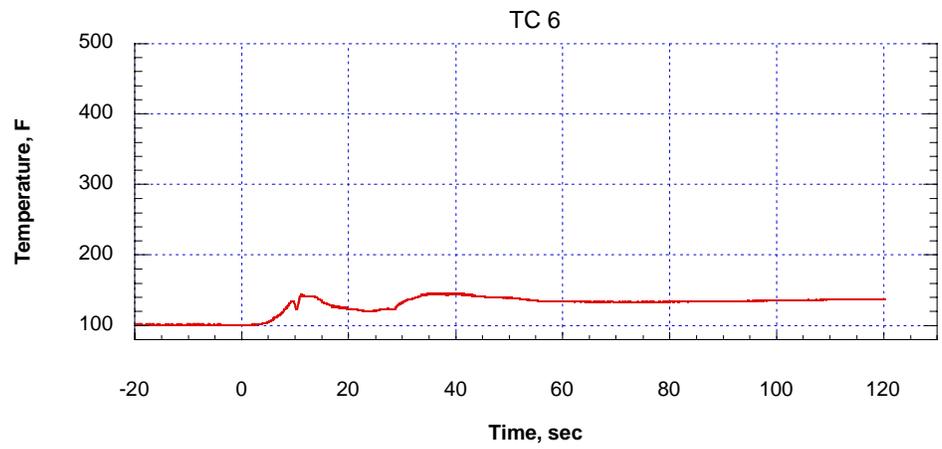
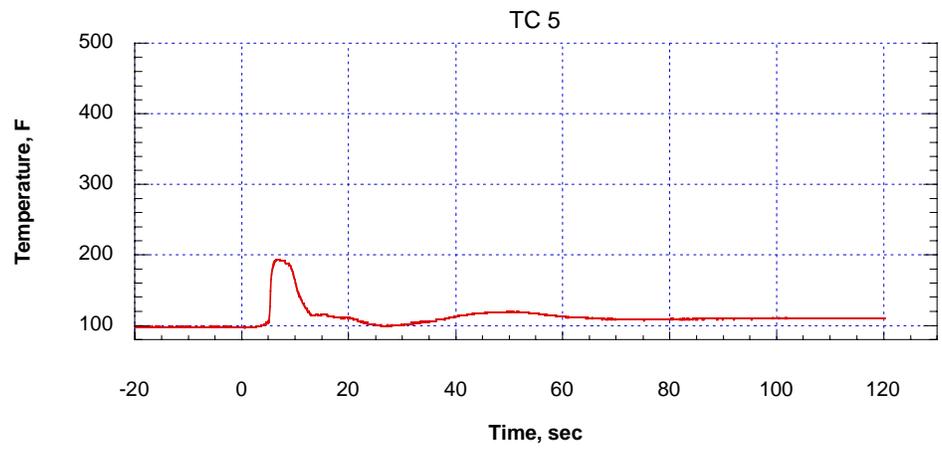
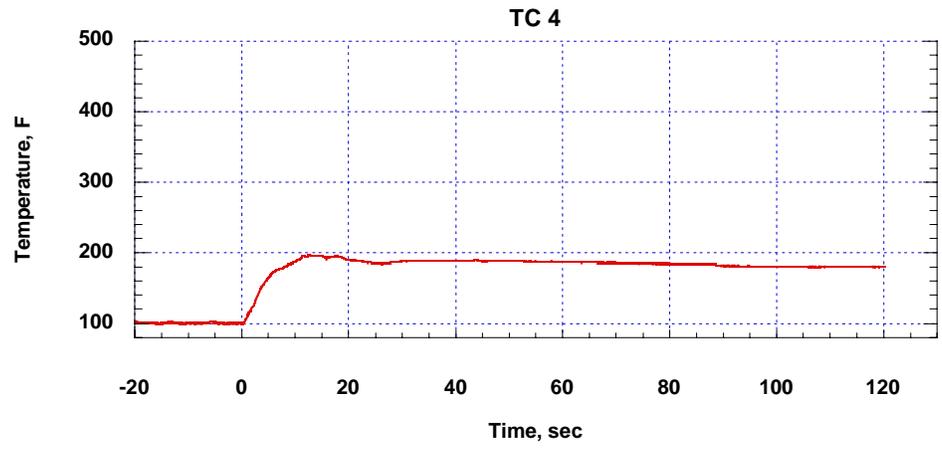
Test 45
High-Frequency Alarm Data vs Time



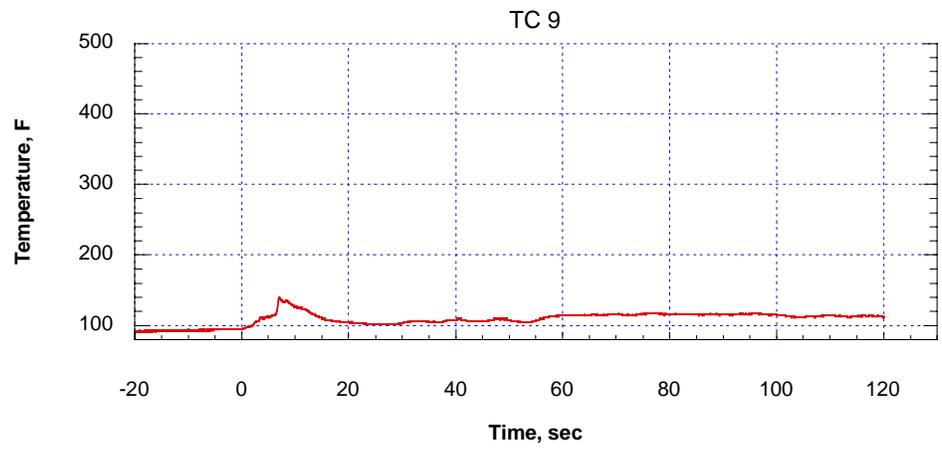
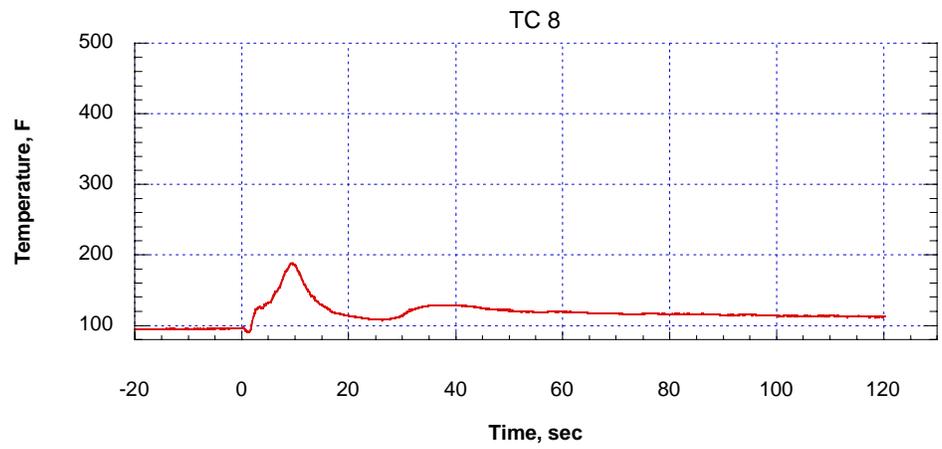
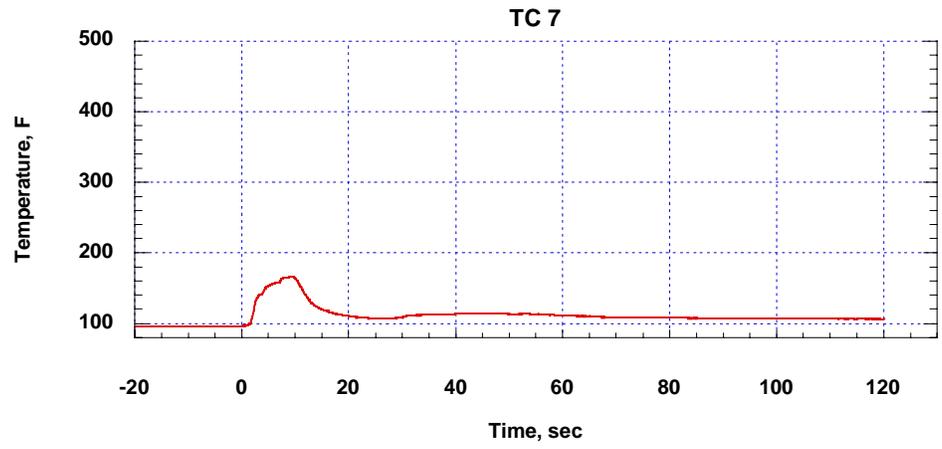
Test 46
Temperature vs Time



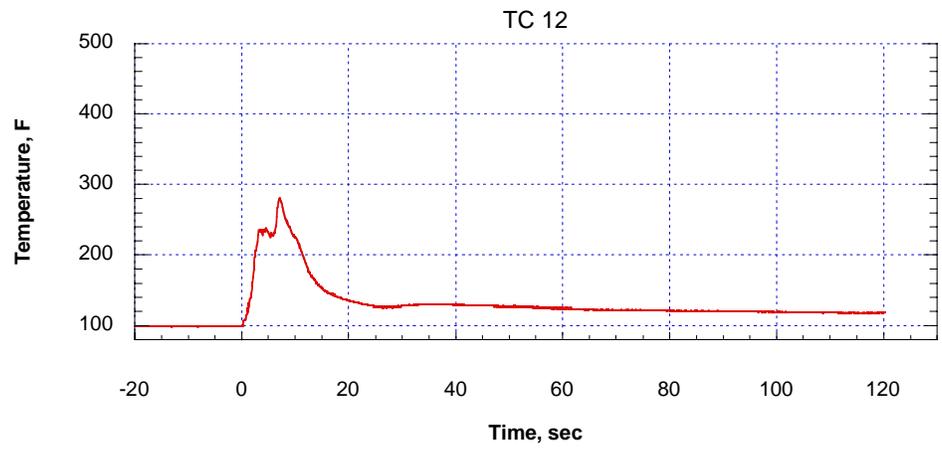
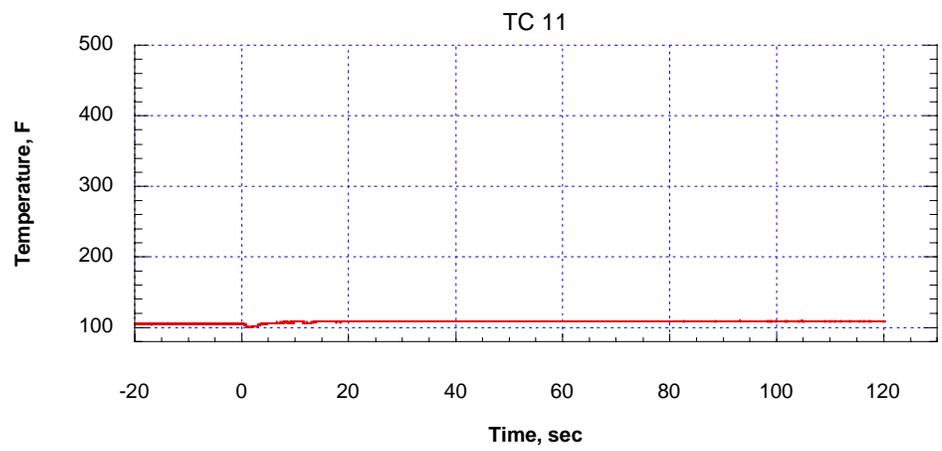
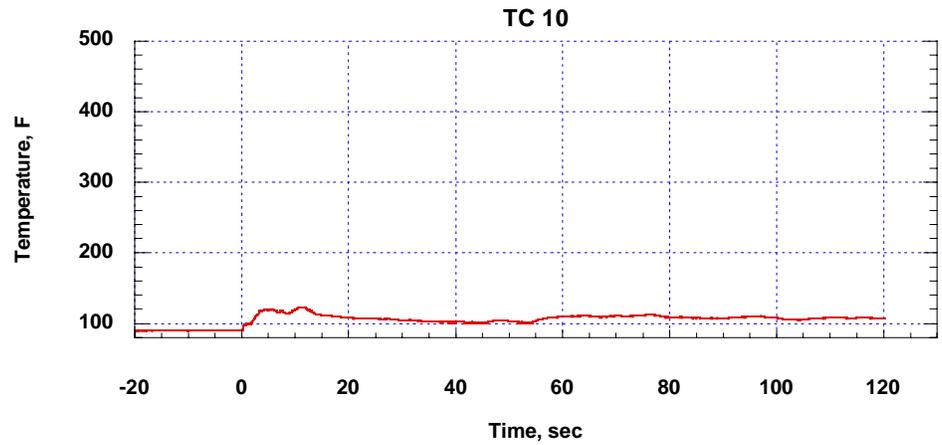
Test 46
Temperature vs Time



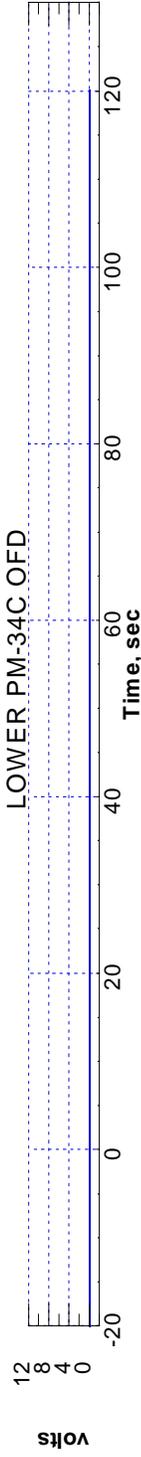
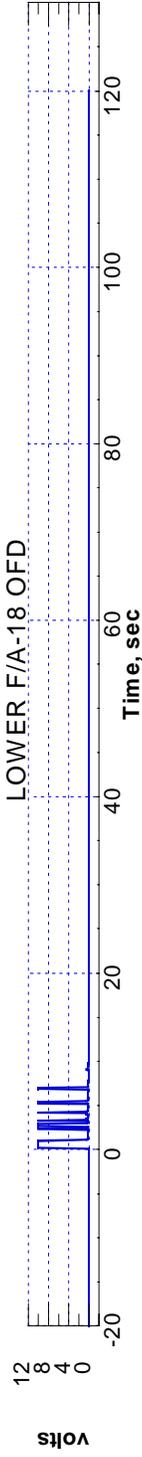
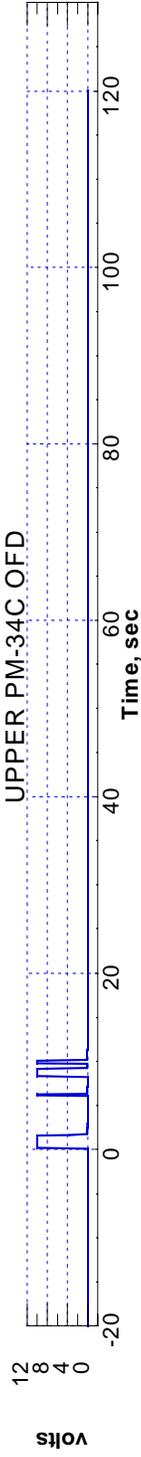
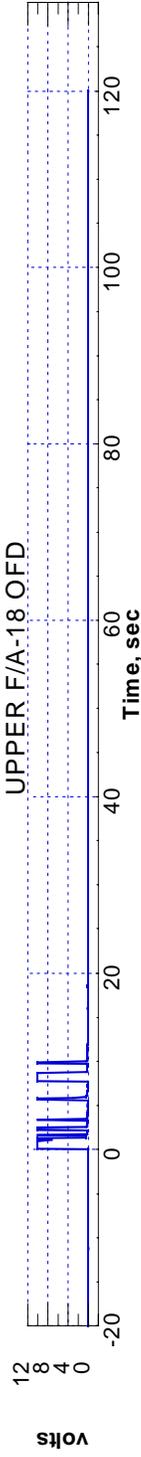
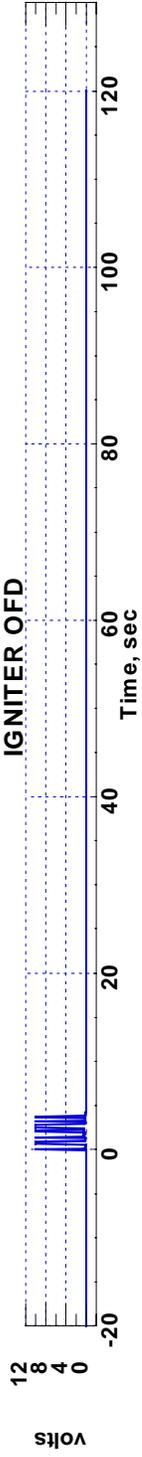
Test 46
Temperature vs Time



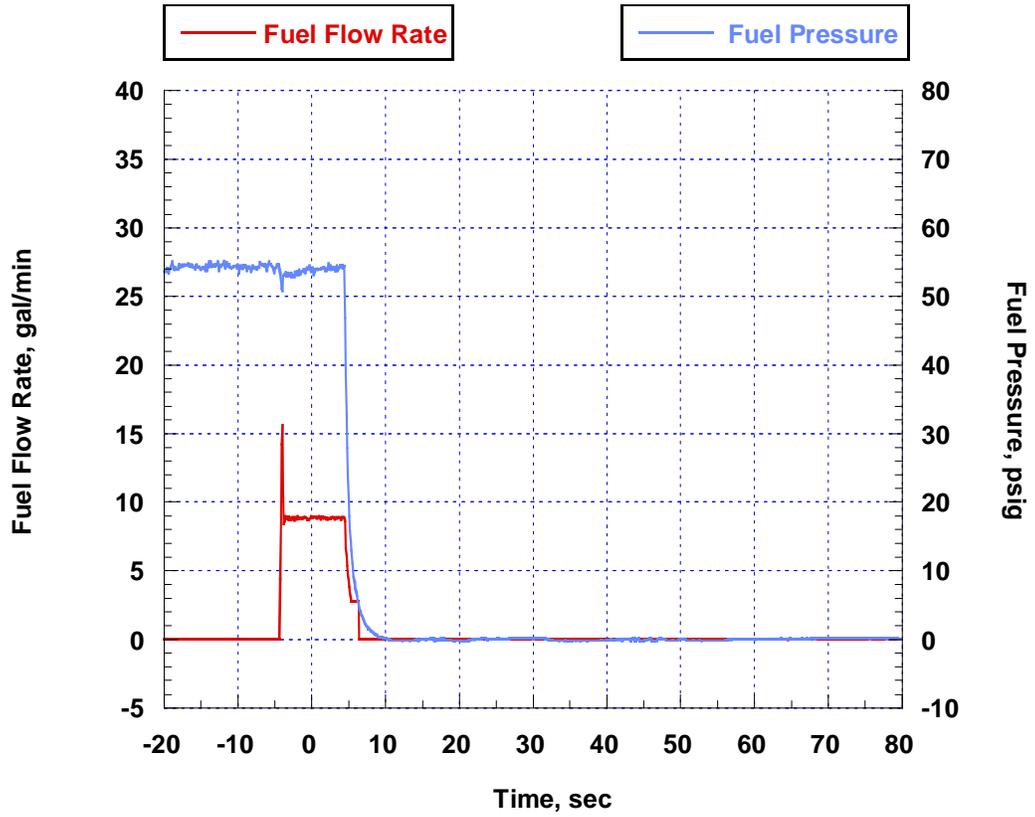
Test 46
Temperature vs Time



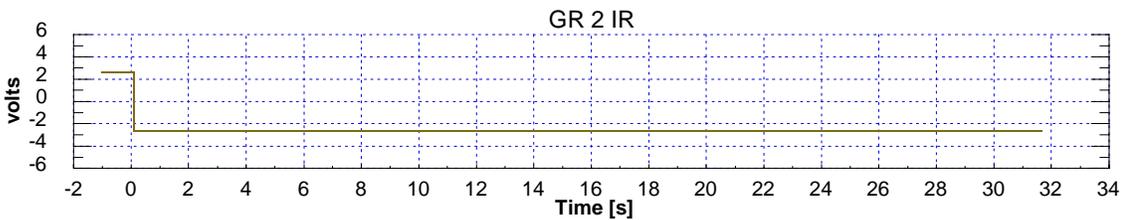
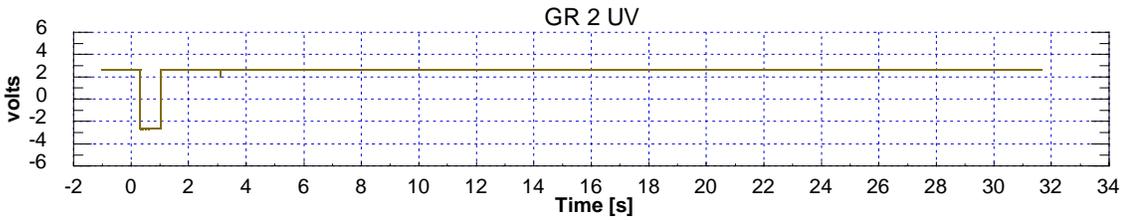
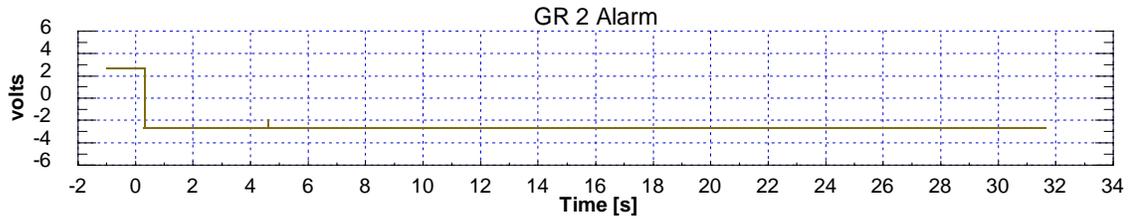
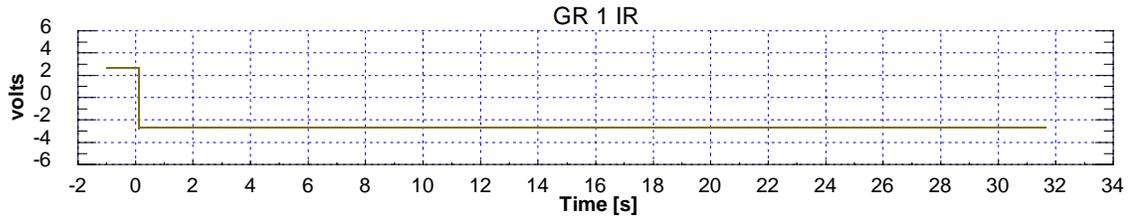
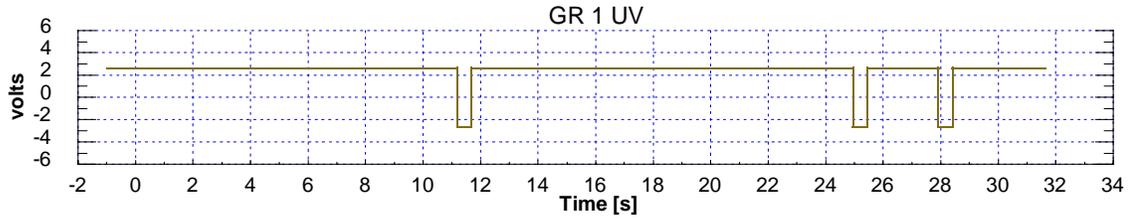
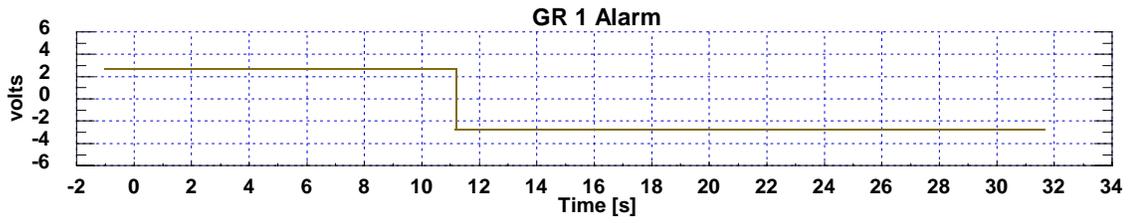
Test 46
Optical Fire Detector Signal vs Time



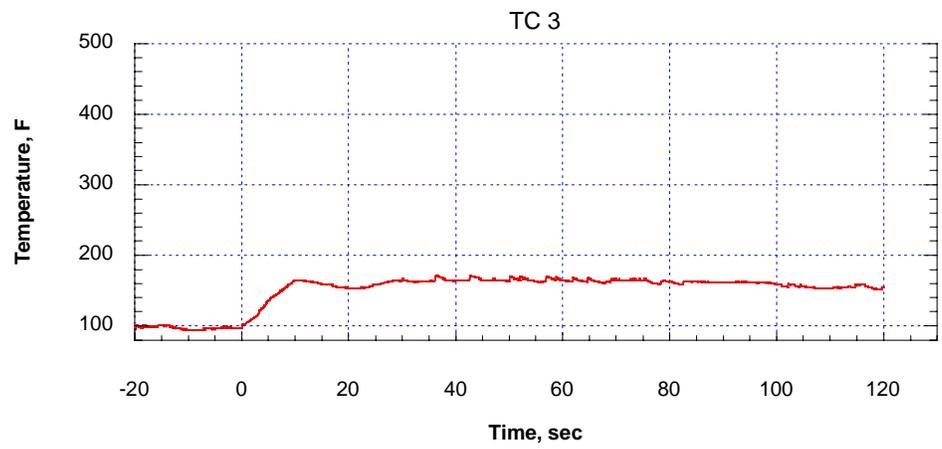
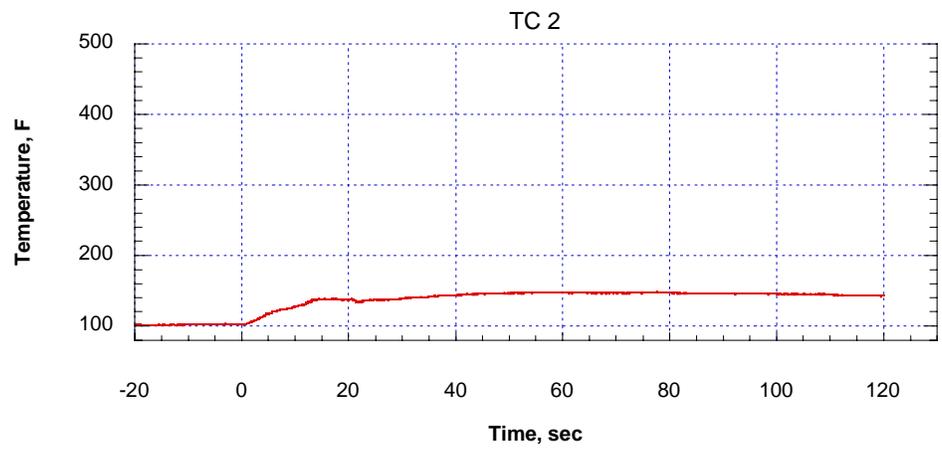
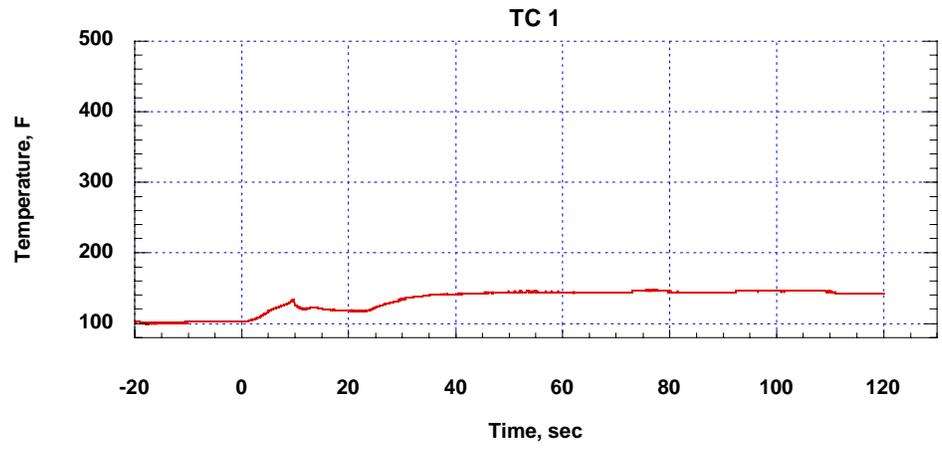
Test 46
Fuel Pressure and Flow Rate vs Time



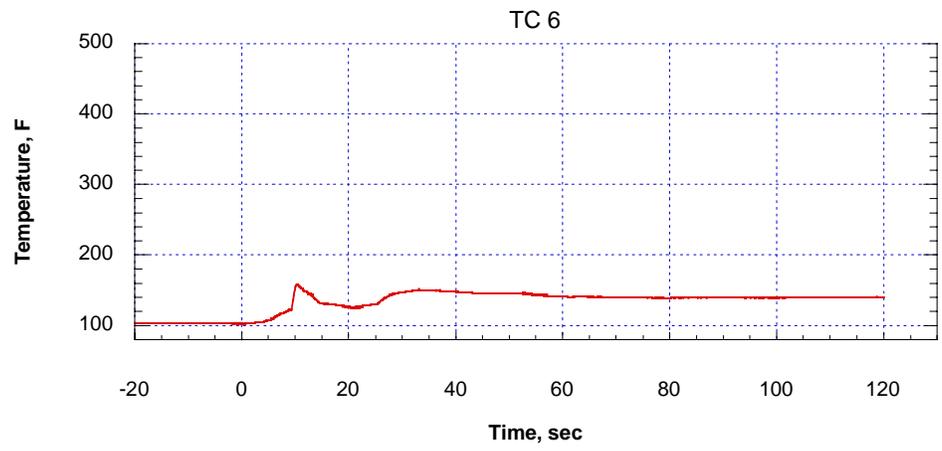
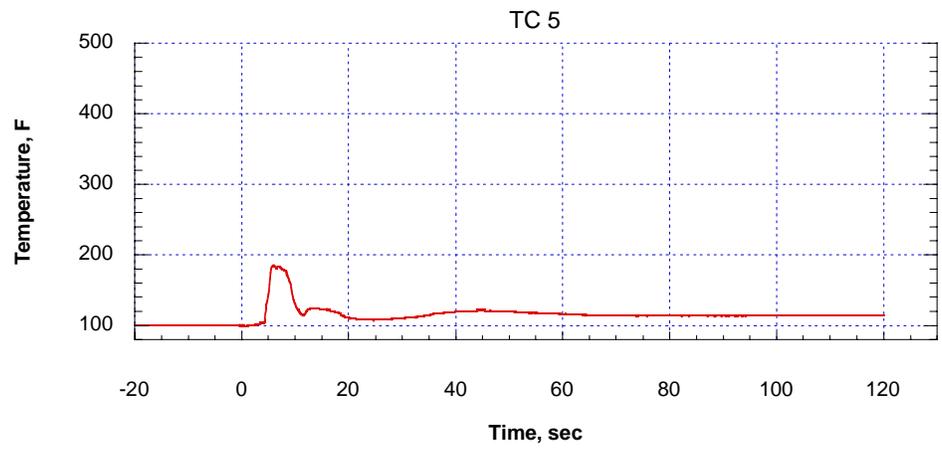
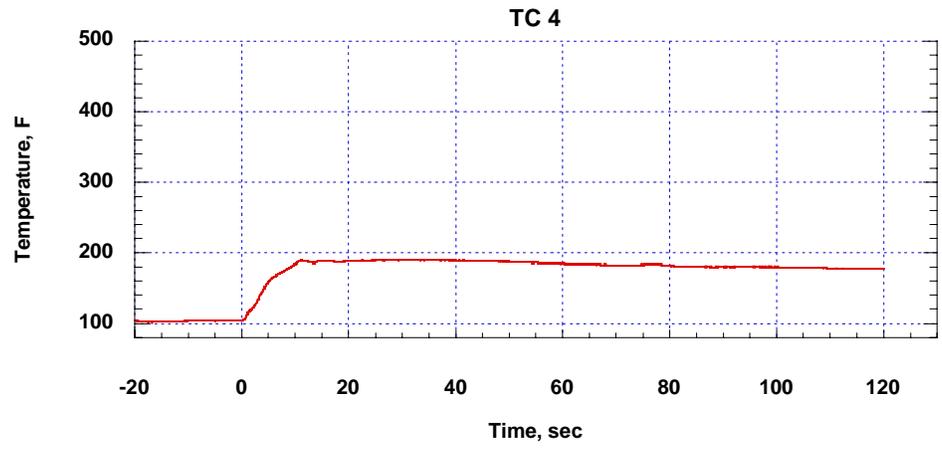
Test 46
High-Frequency Alarm Data vs Time



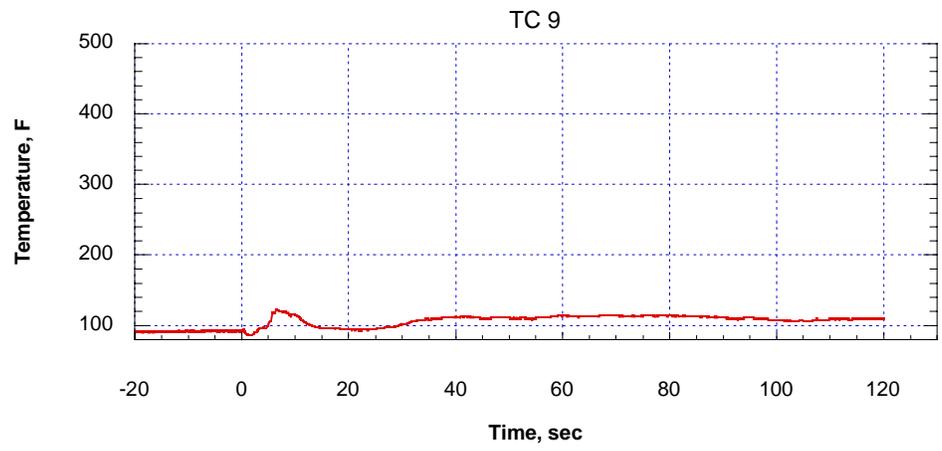
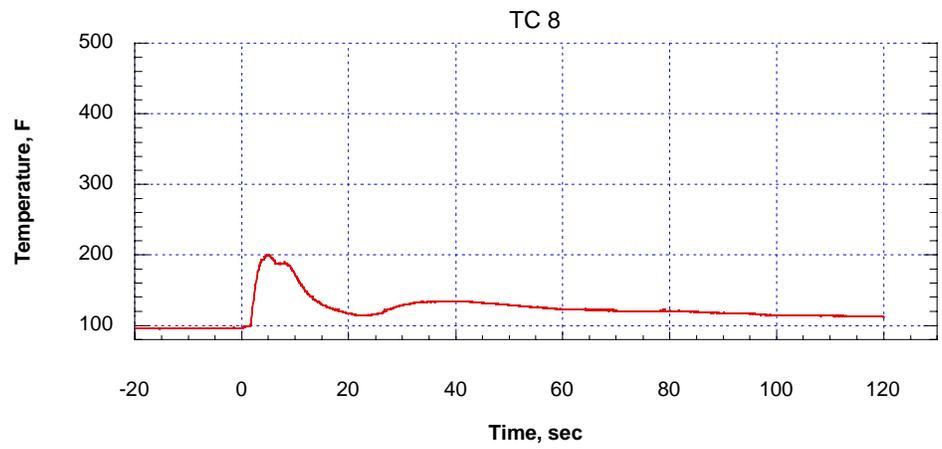
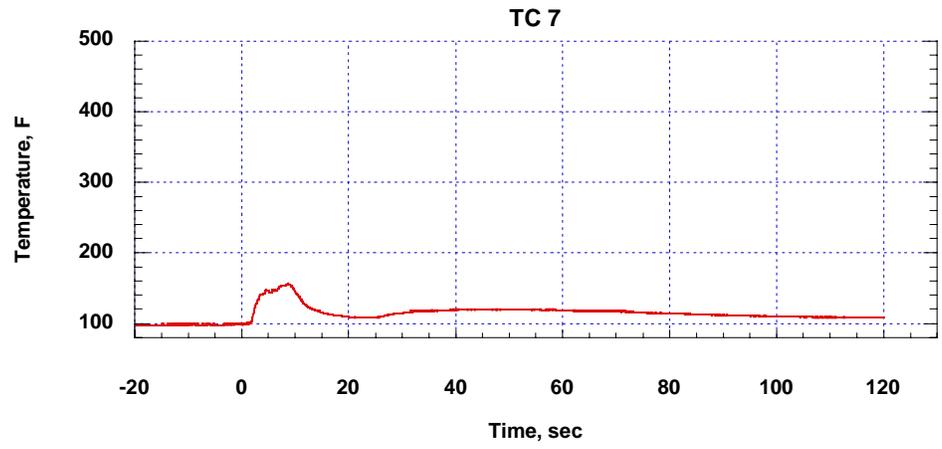
Test 47
Temperature vs Time



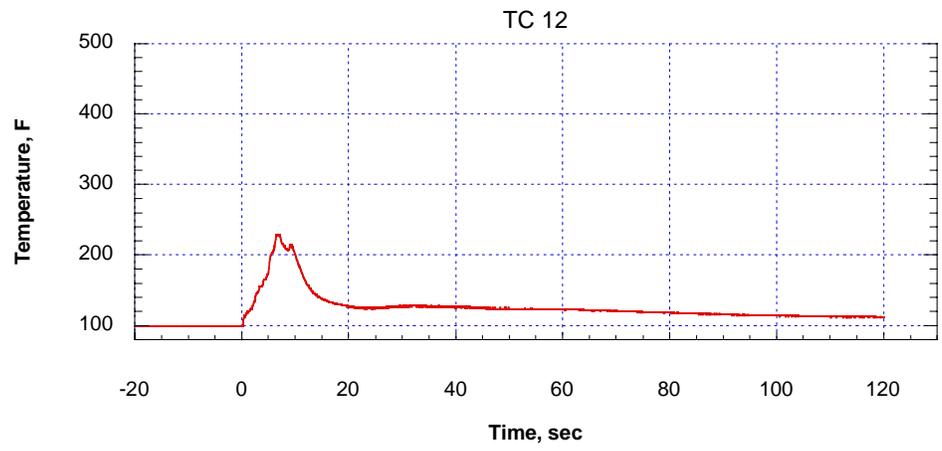
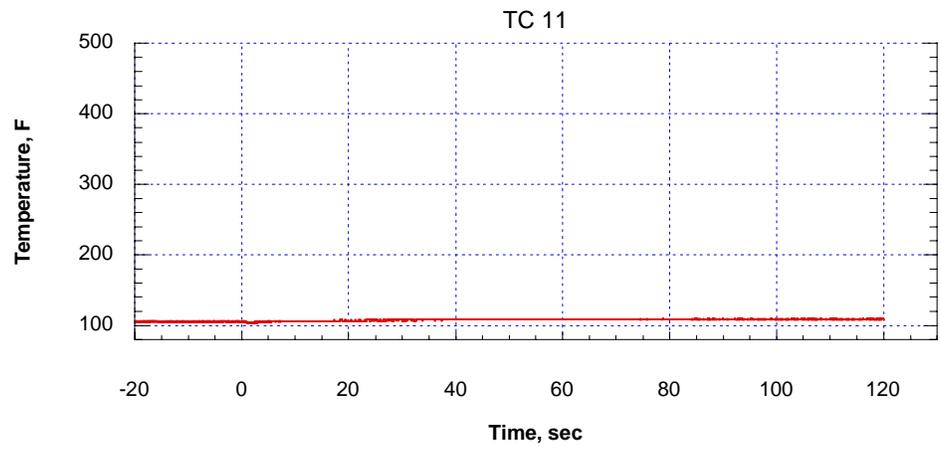
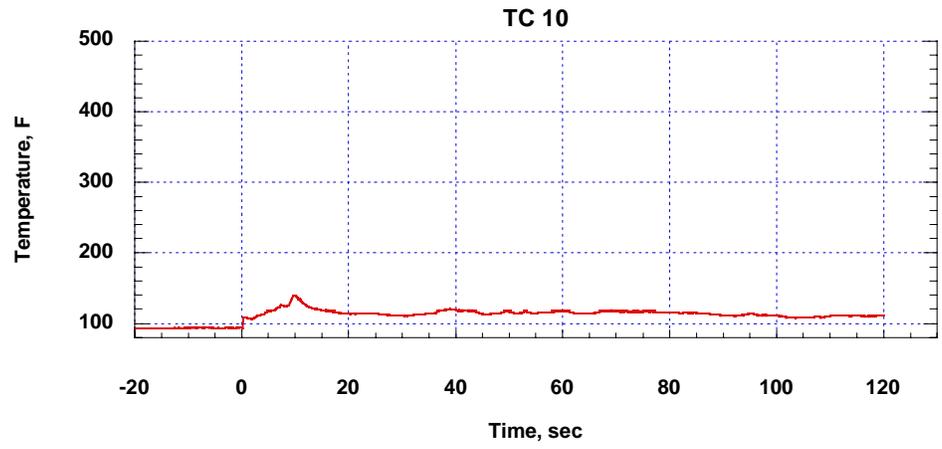
Test 47
Temperature vs Time



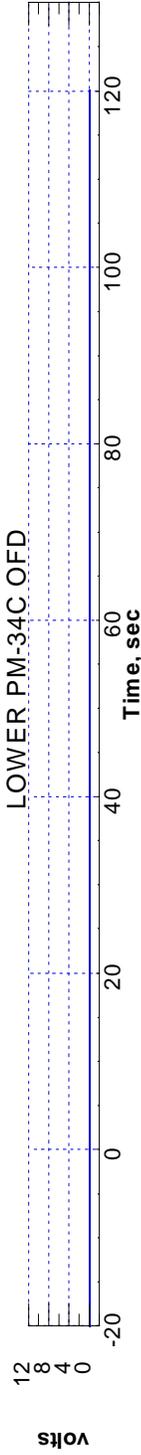
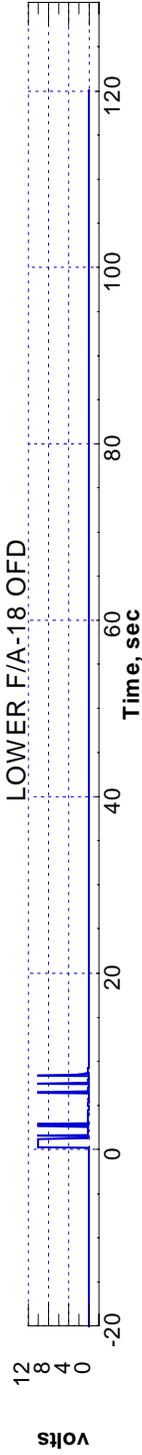
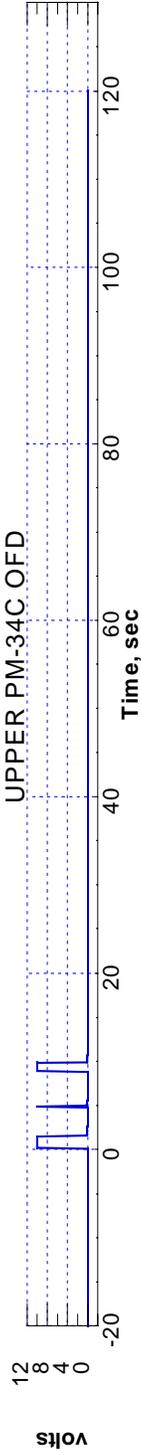
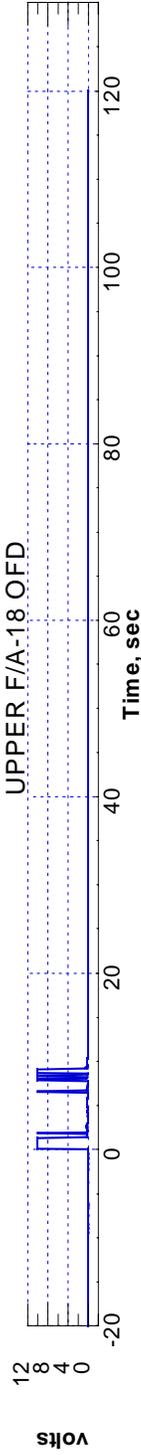
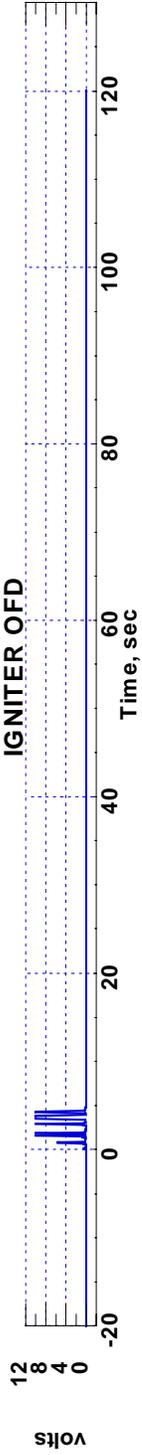
Test 47
Temperature vs Time



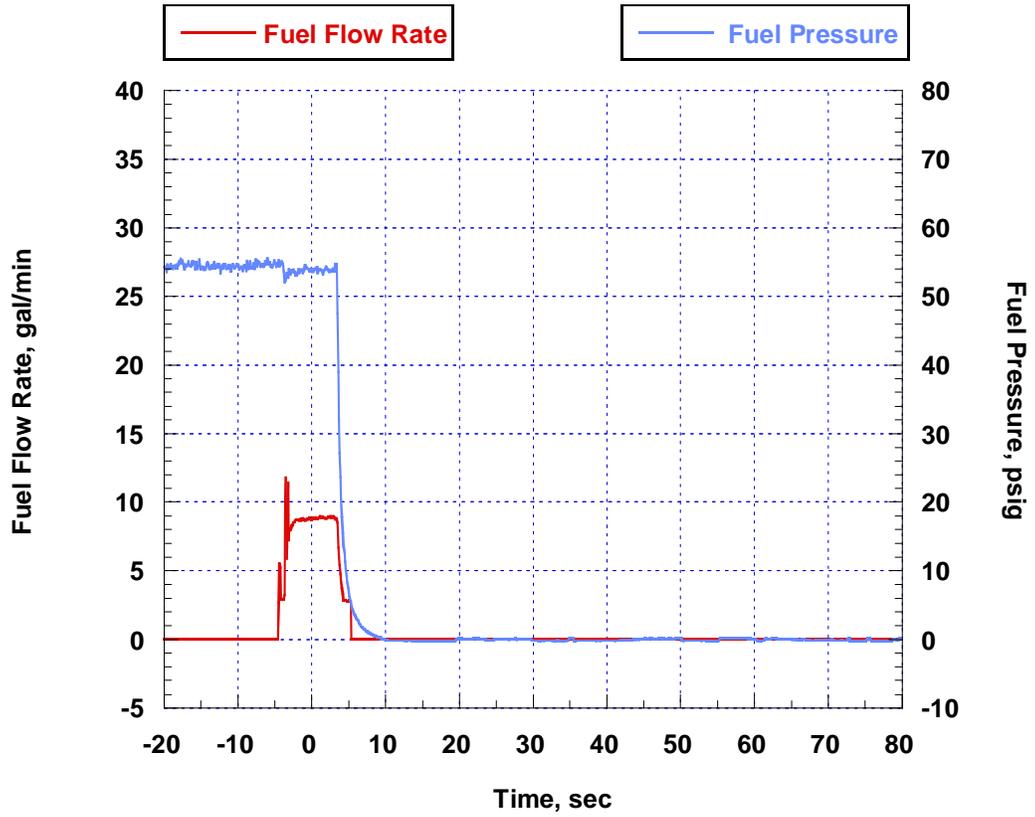
Test 47
Temperature vs Time



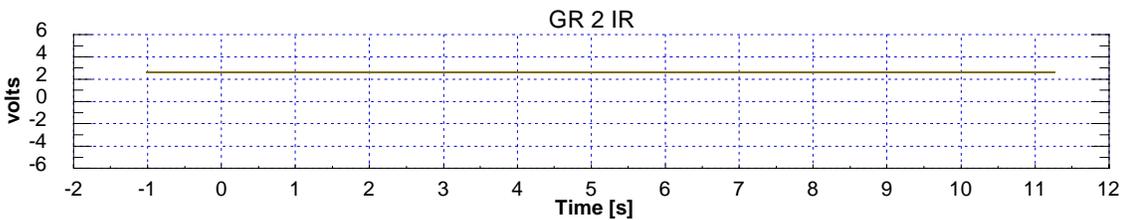
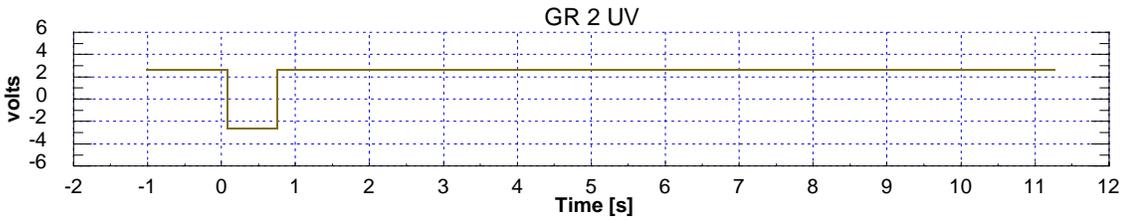
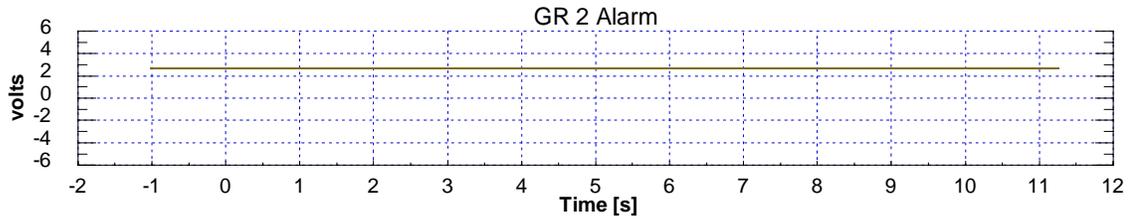
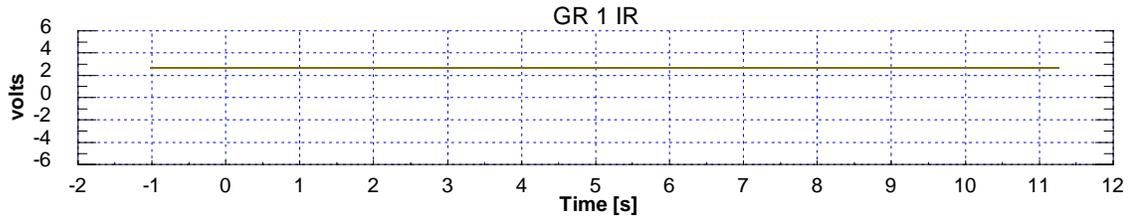
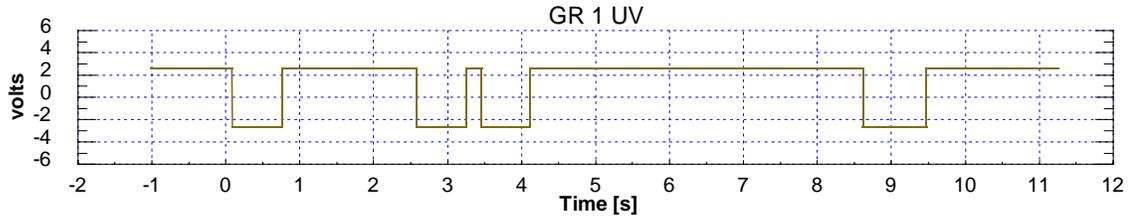
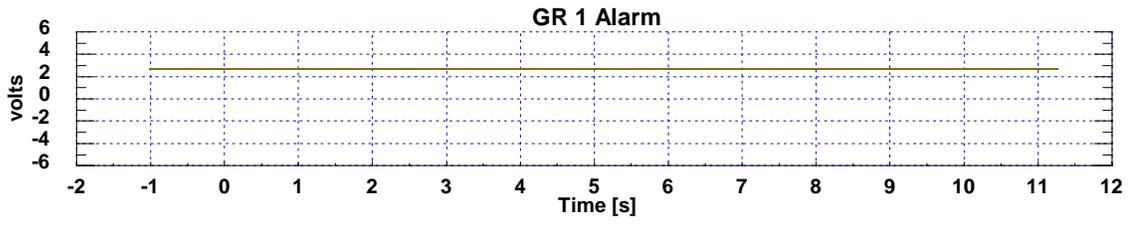
Test 47
Optical Fire Detector Signal vs Time



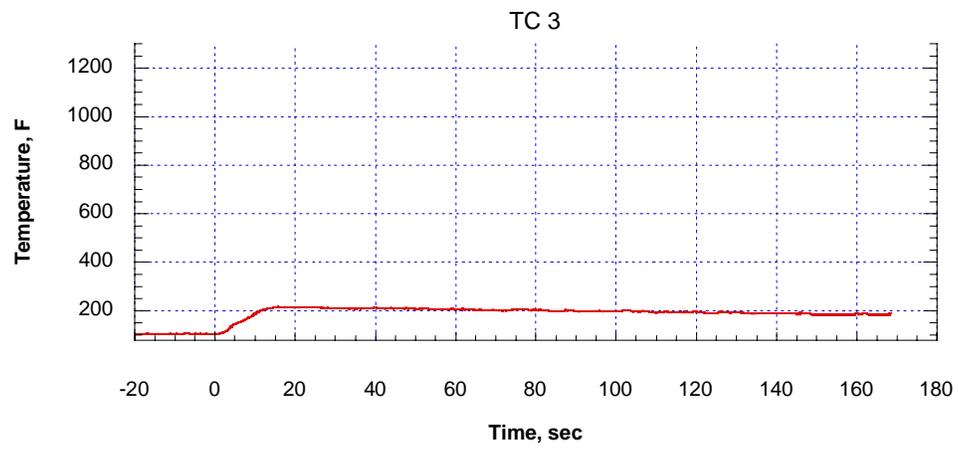
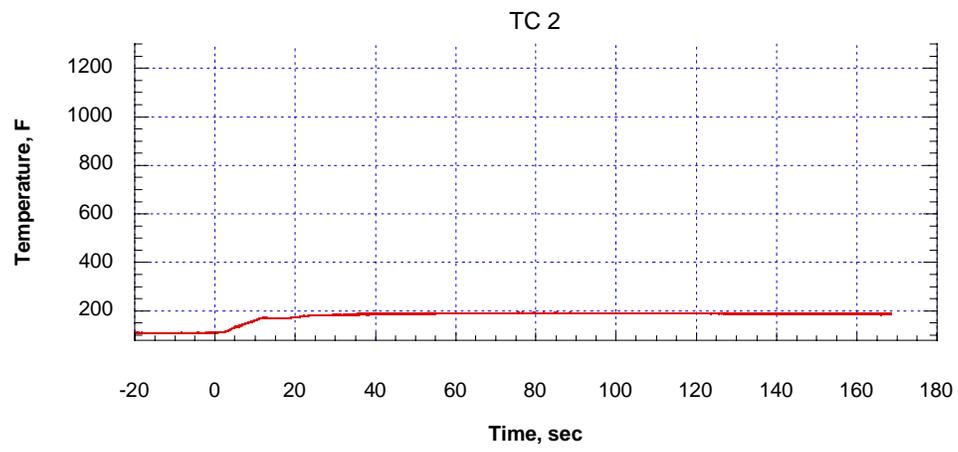
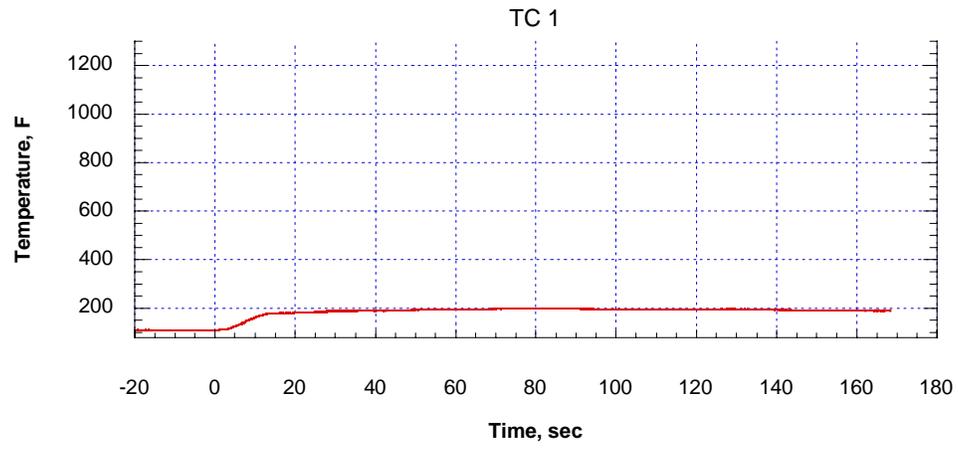
Test 47
Fuel Pressure and Flow Rate vs Time



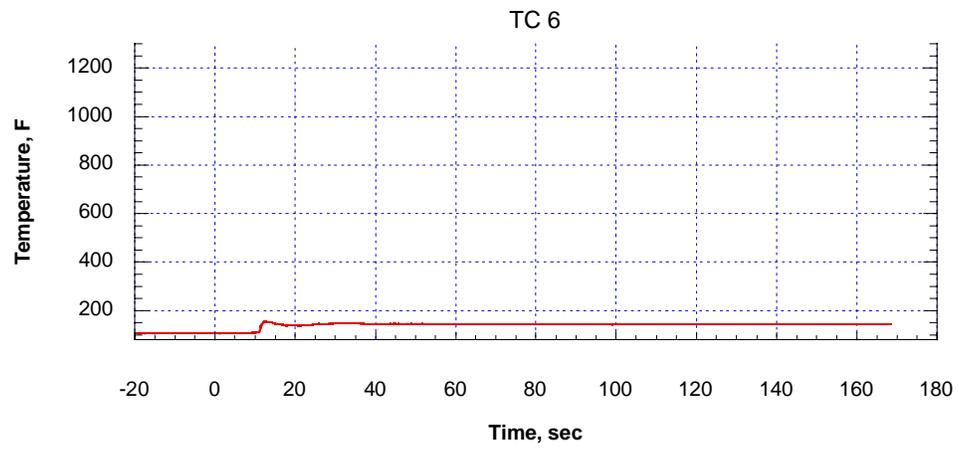
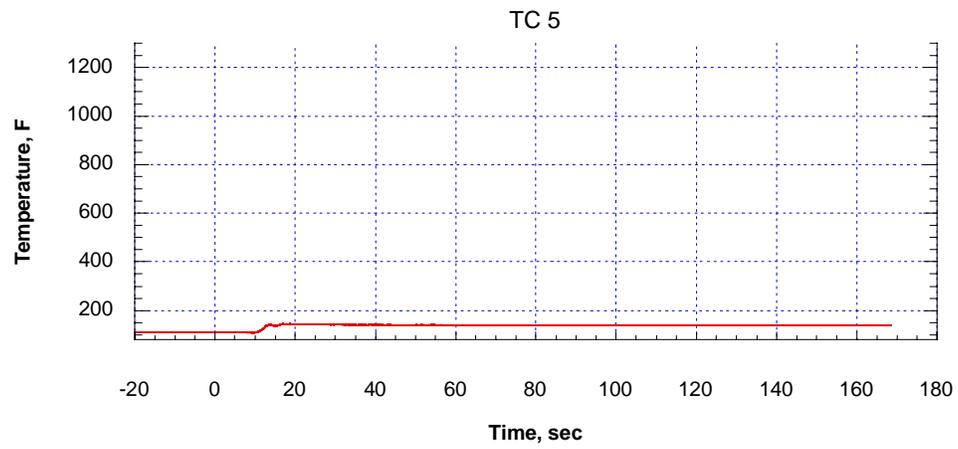
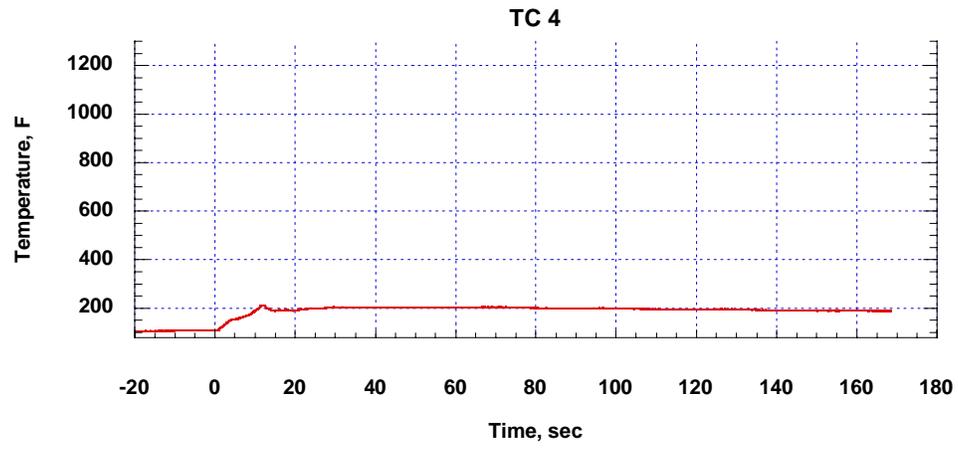
Test 47
High-Frequency Alarm Data vs Time



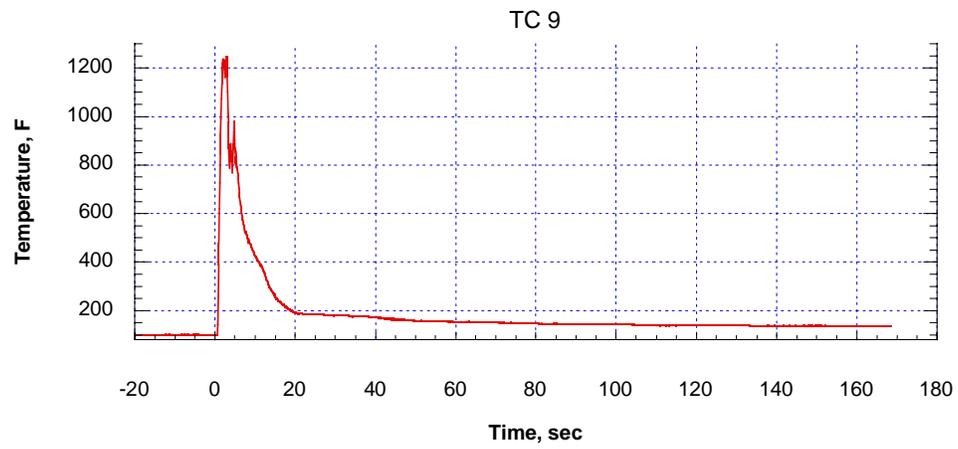
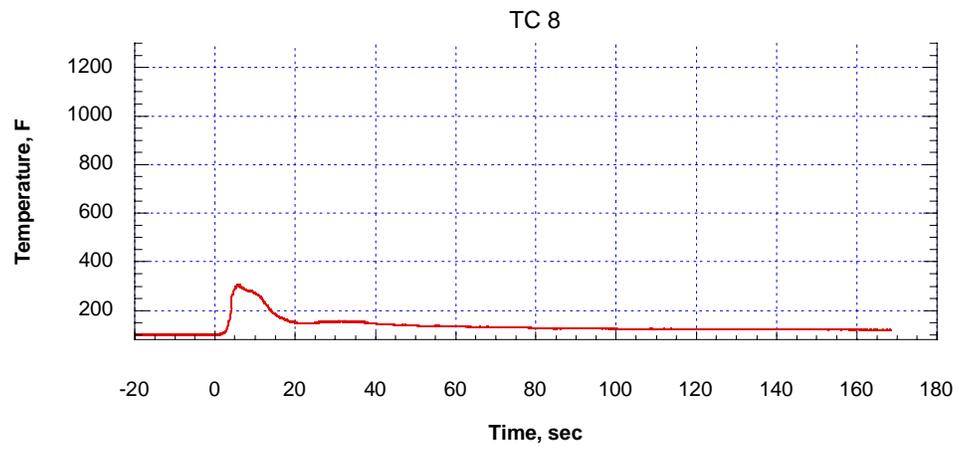
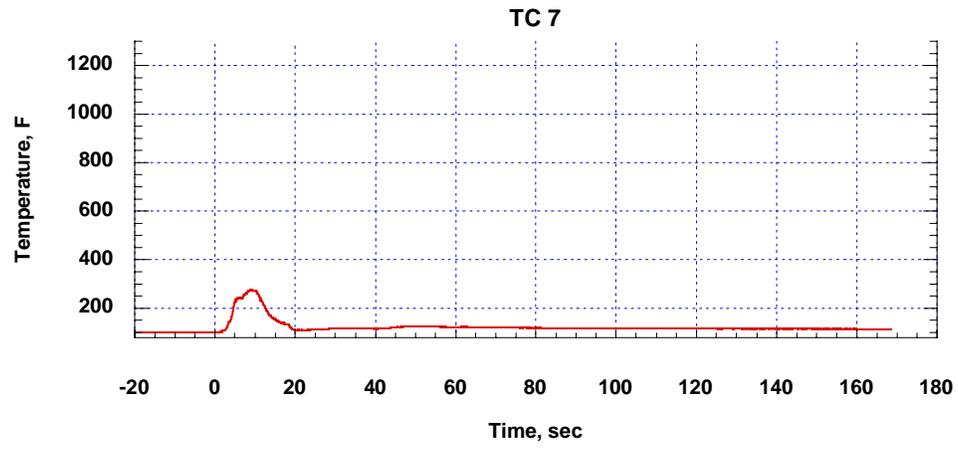
Test 52
Temperature vs Time



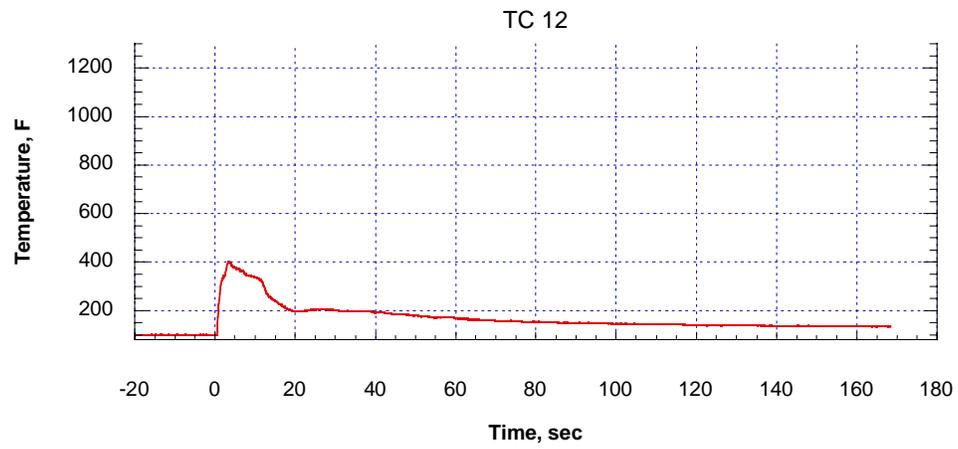
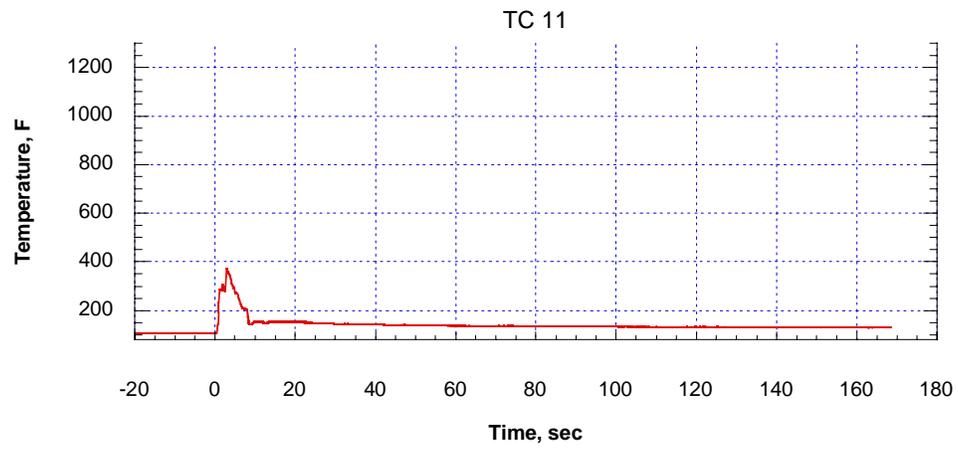
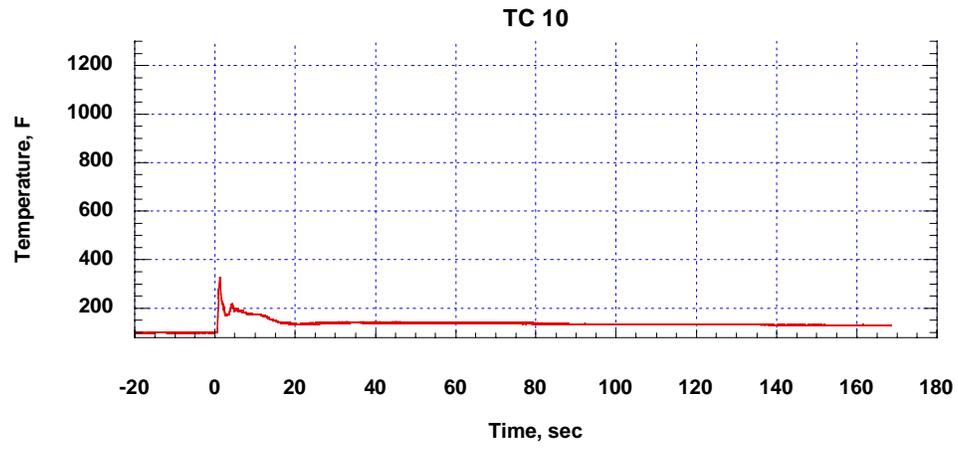
Test 52
Temperature vs Time



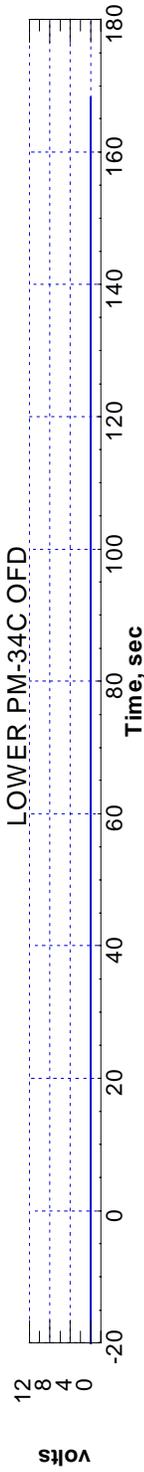
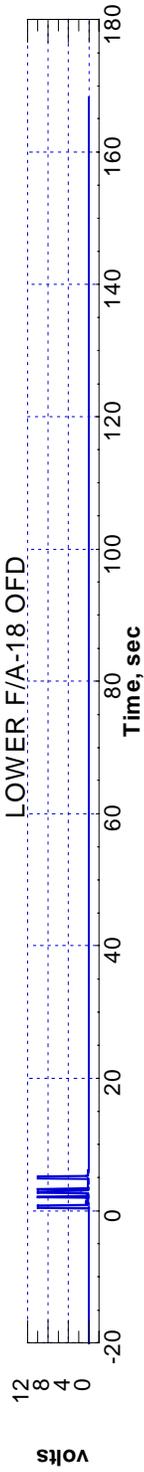
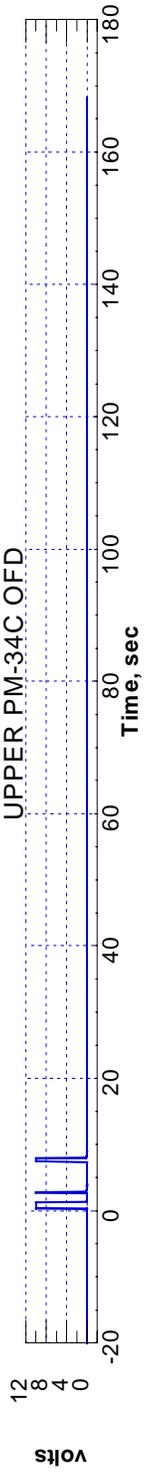
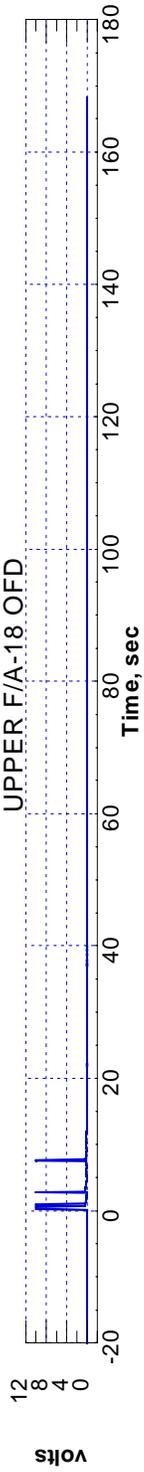
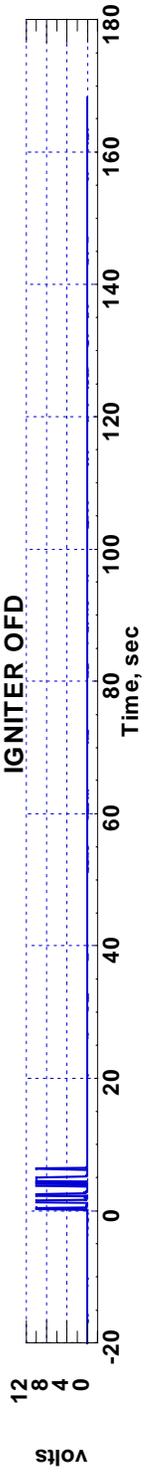
Test 52
Temperature vs Time



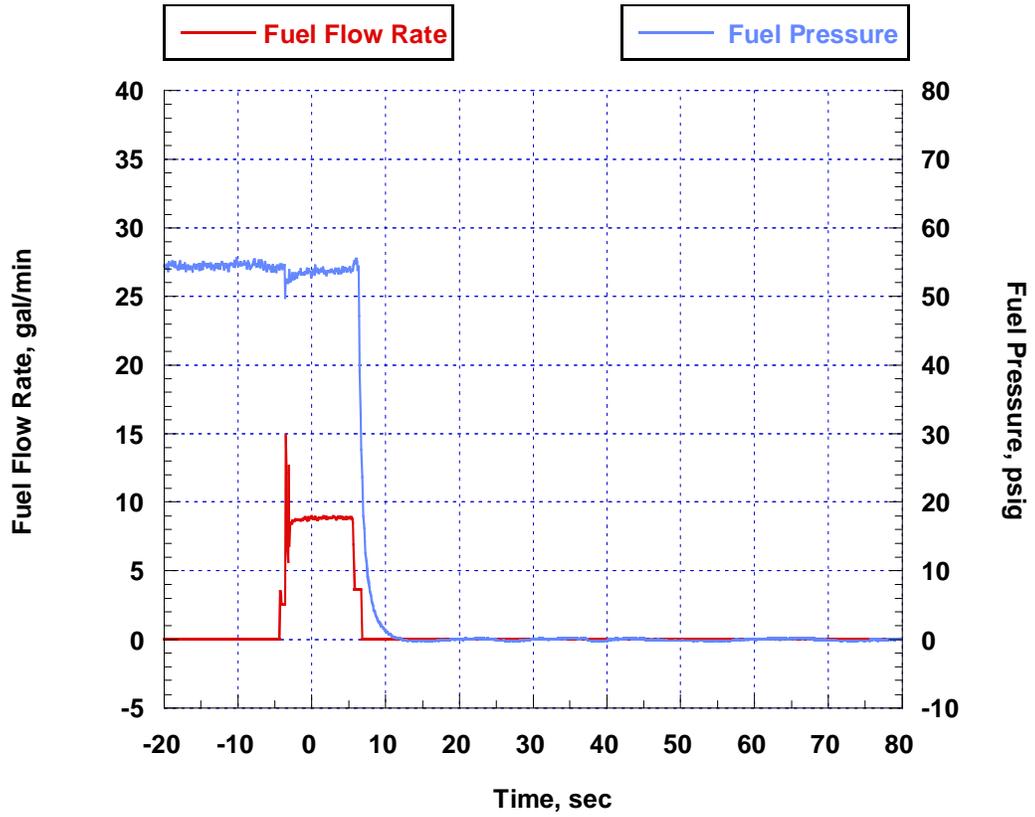
Test 52
Temperature vs Time



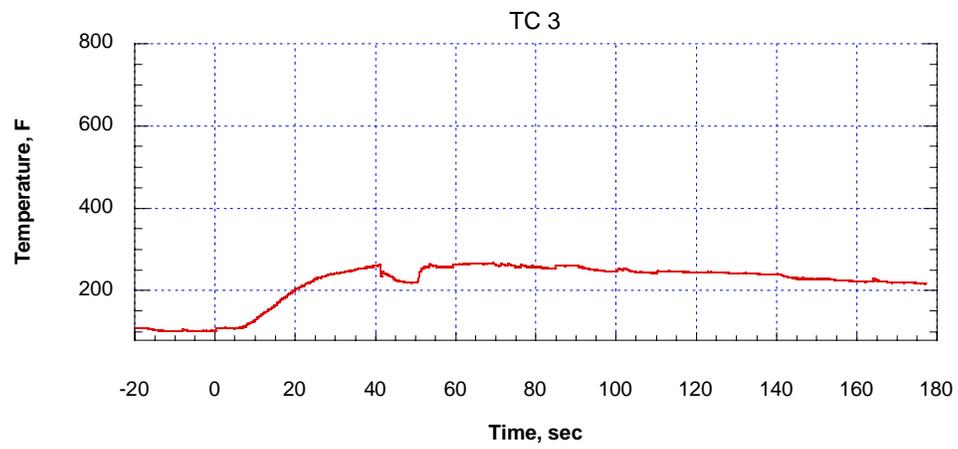
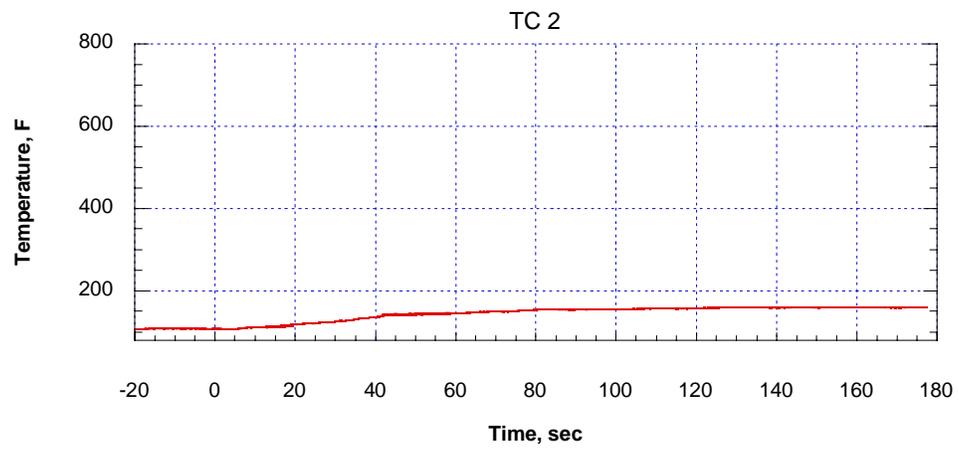
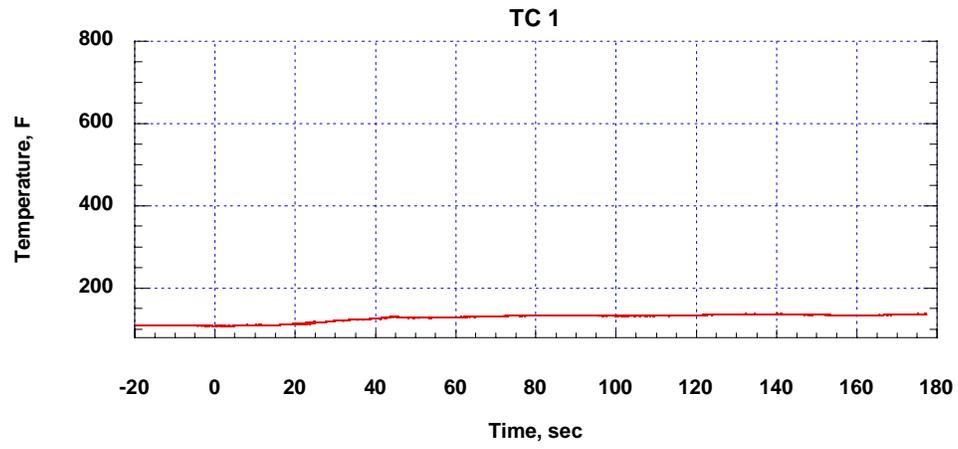
Test 52
Optical Fire Detector Signal vs Time



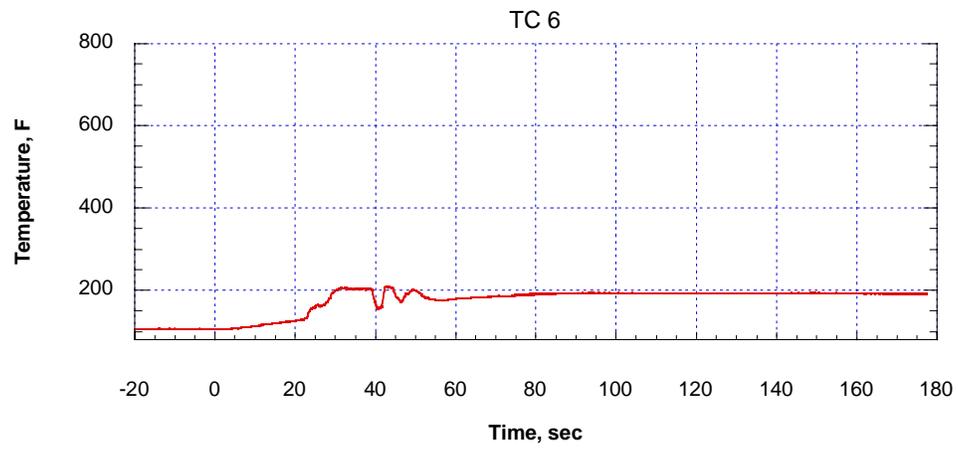
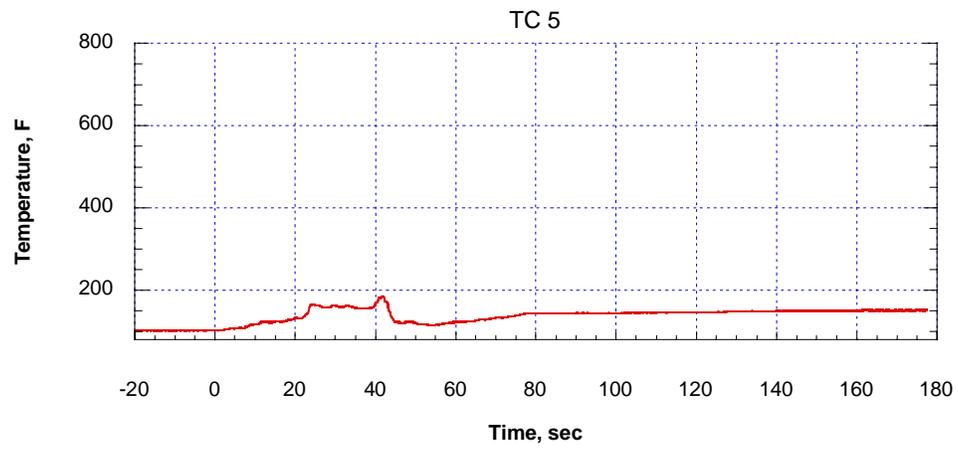
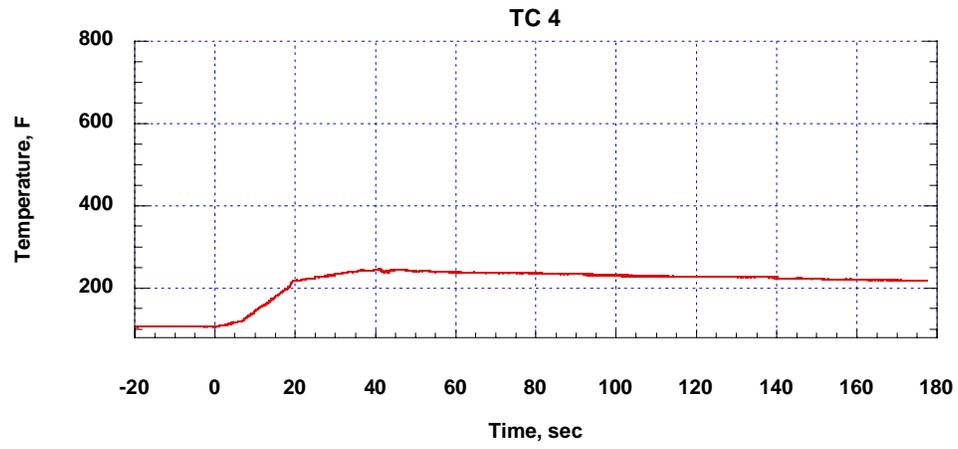
Test 52
Fuel Pressure and Flow Rate vs Time



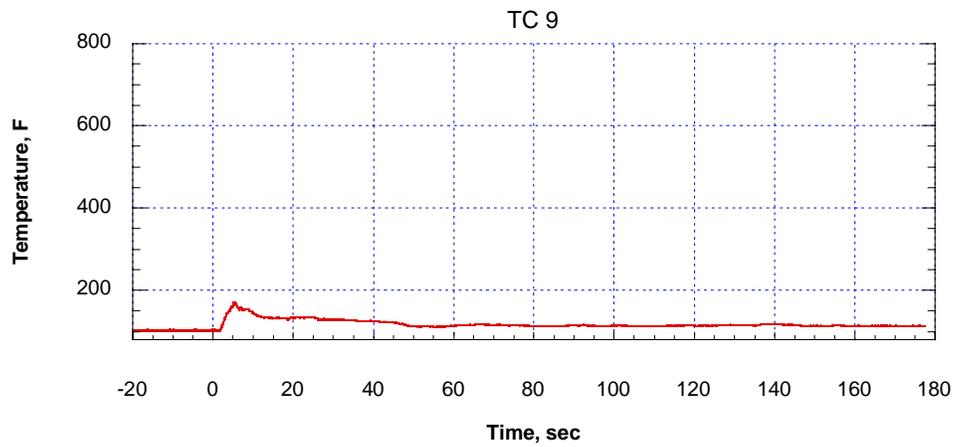
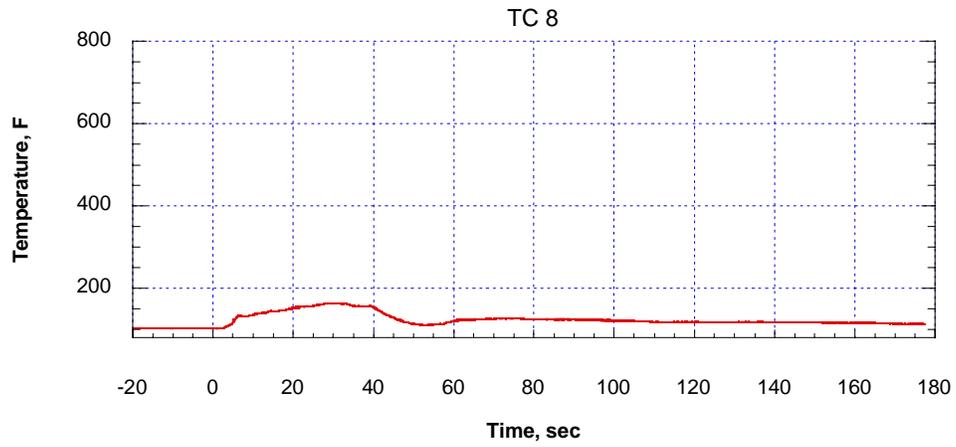
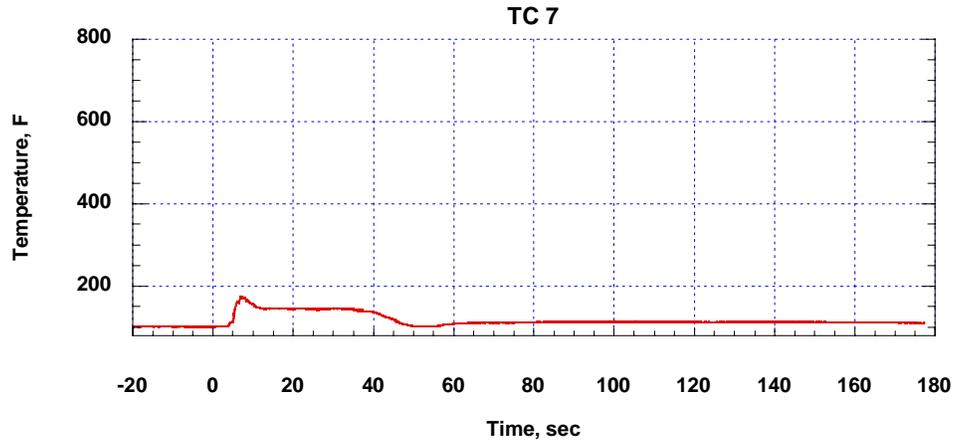
Test 53
Temperature vs Time



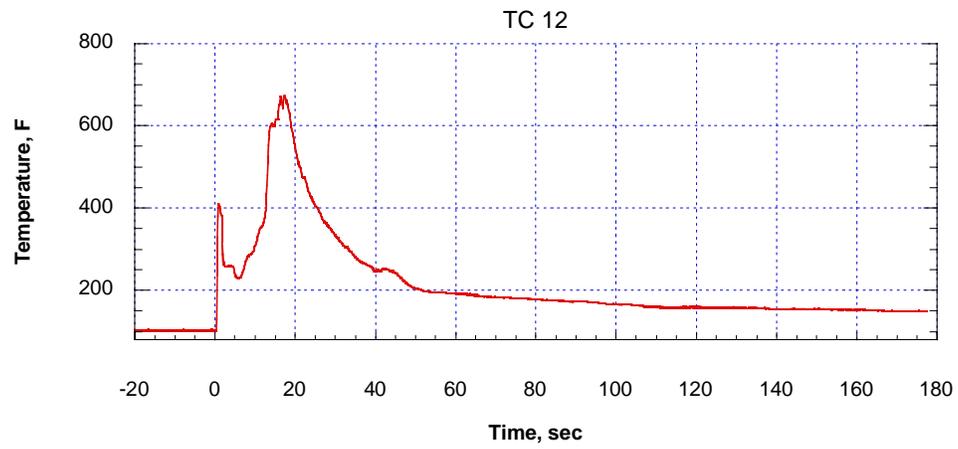
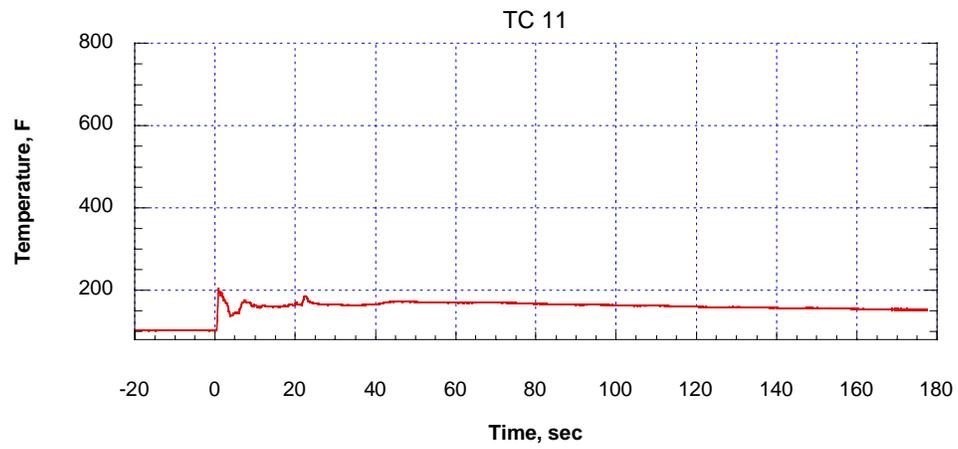
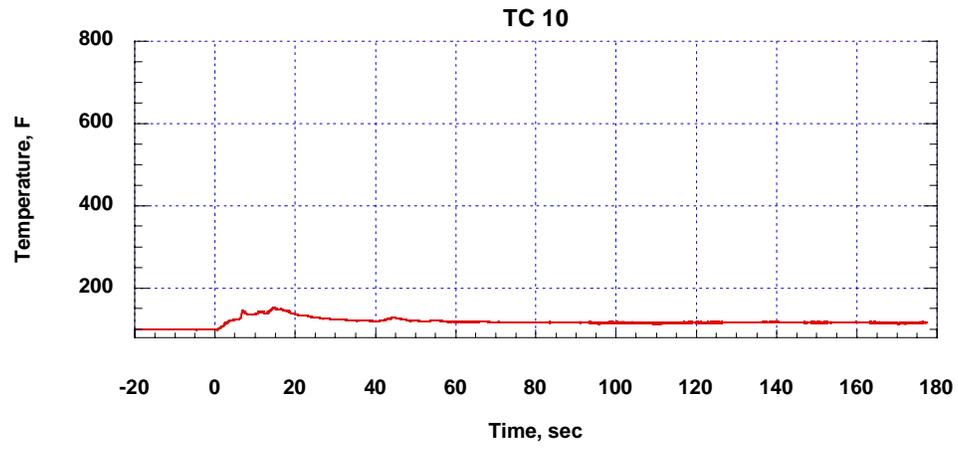
Test 53
Temperature vs Time



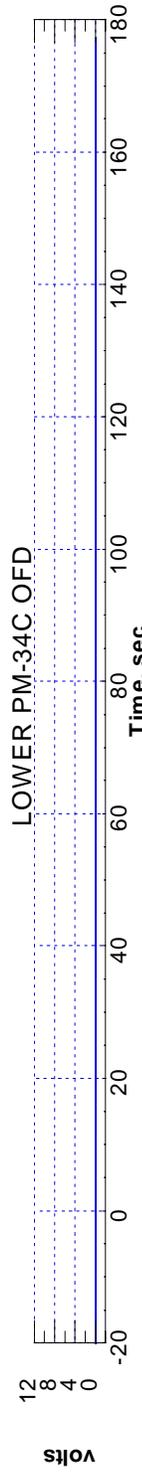
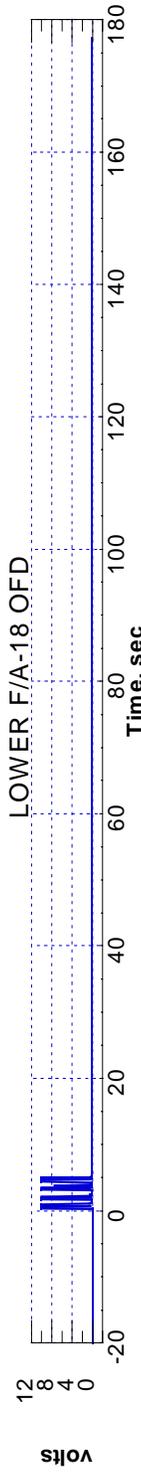
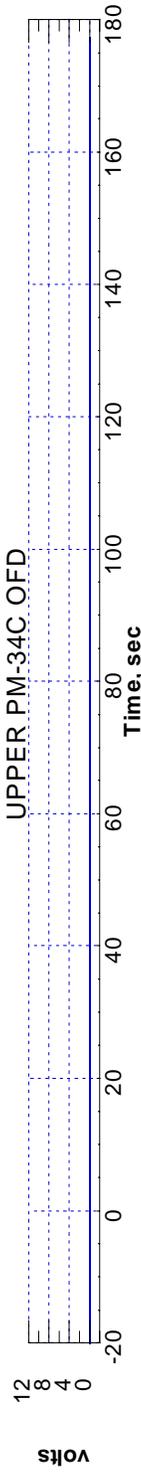
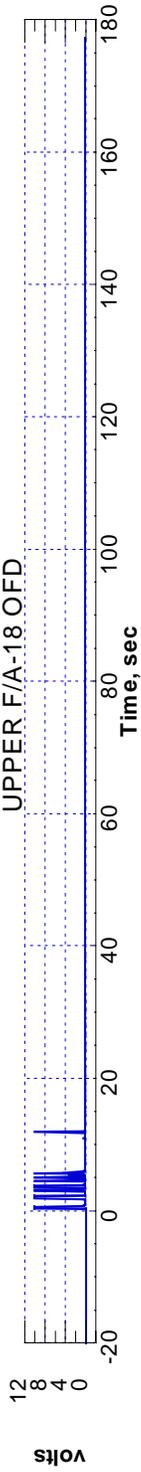
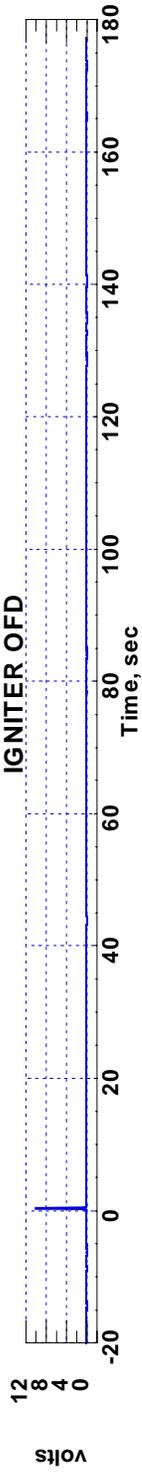
Test 53
Temperature vs Time



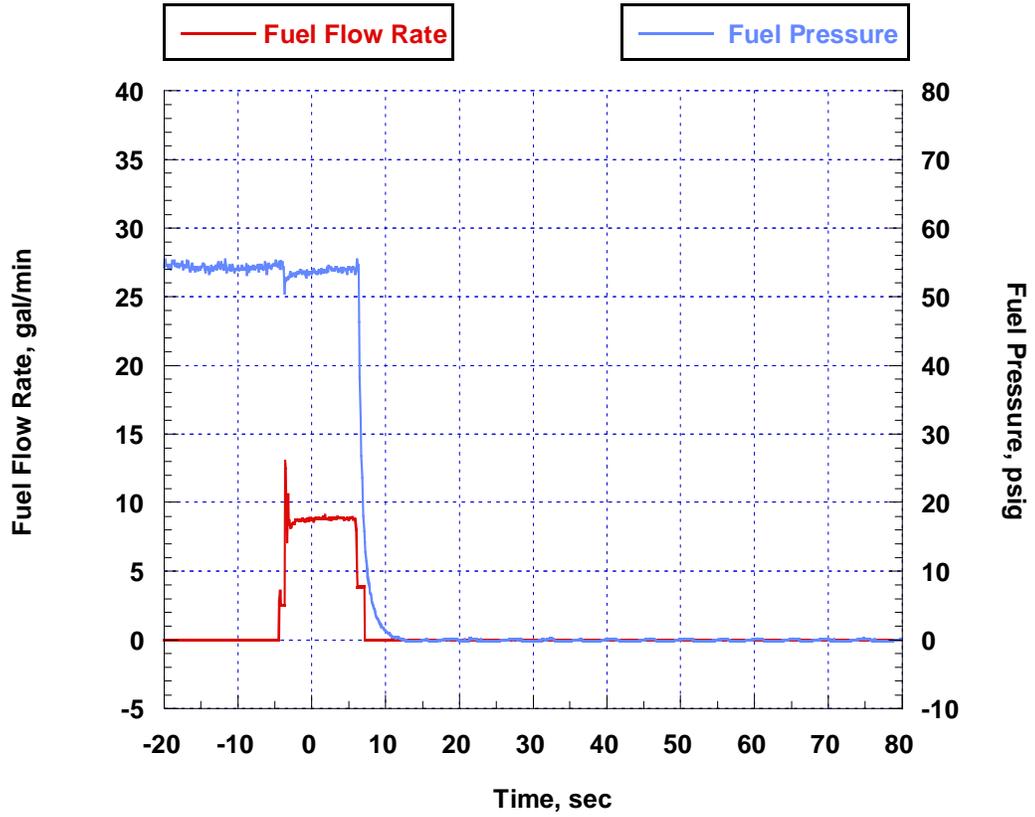
Test 53
Temperature vs Time



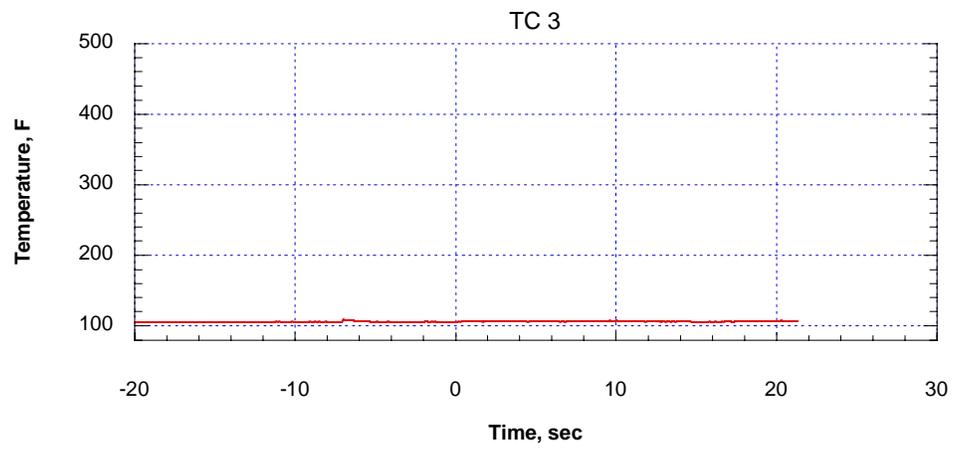
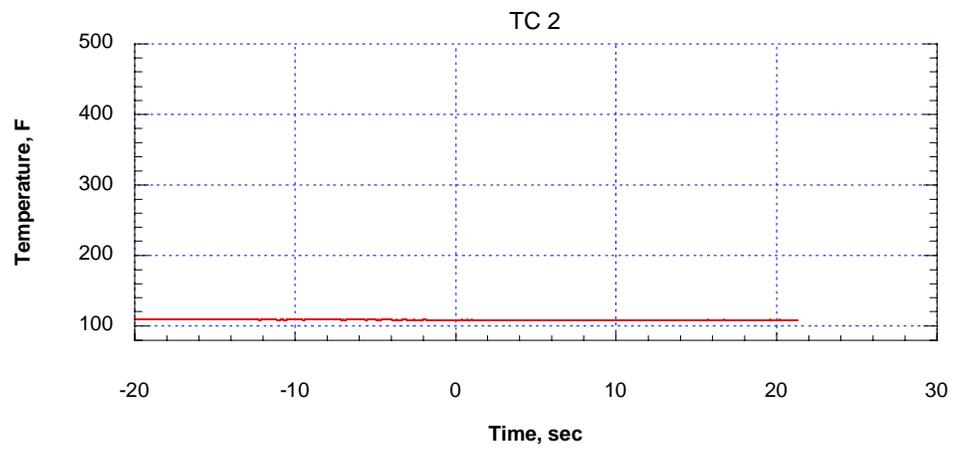
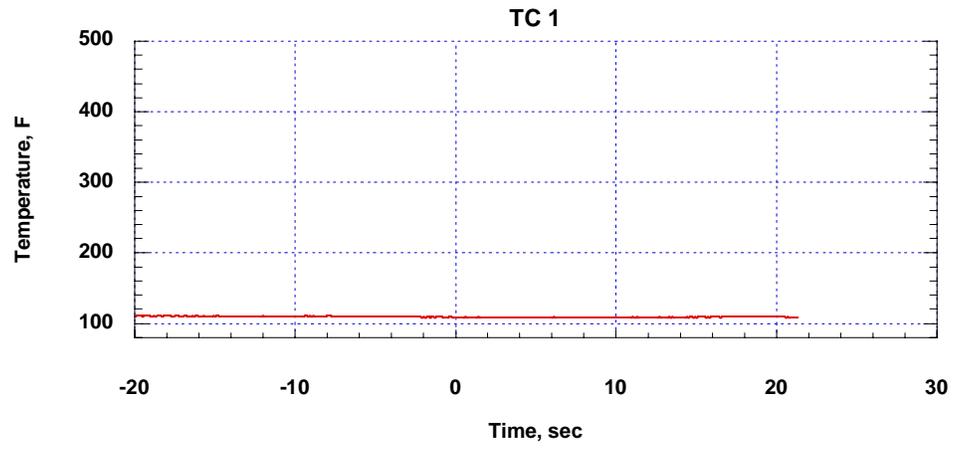
Test 53
Optical Fire Detector Signal vs Time



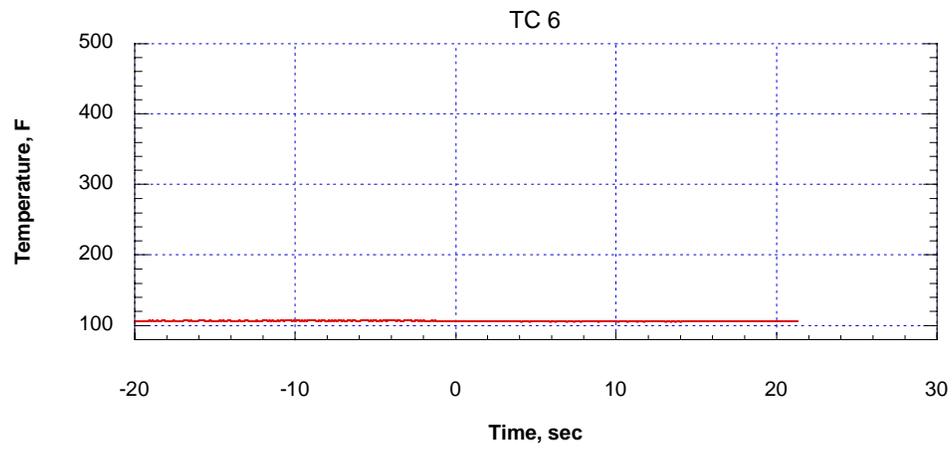
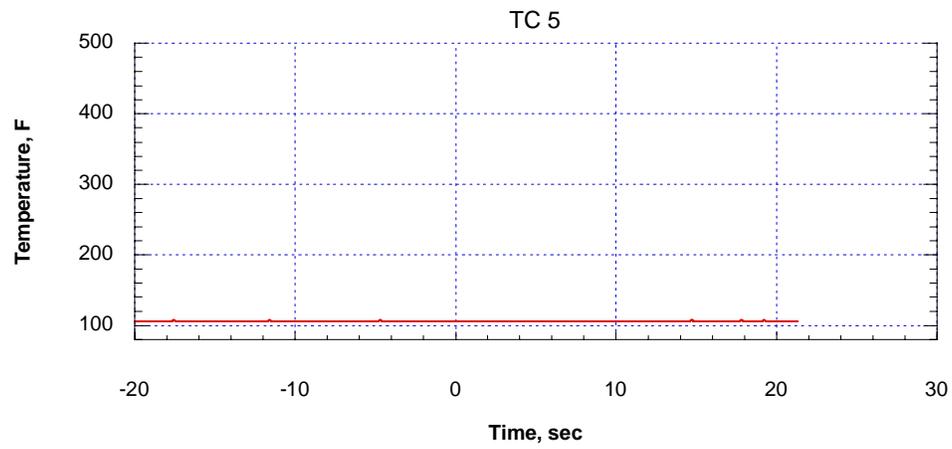
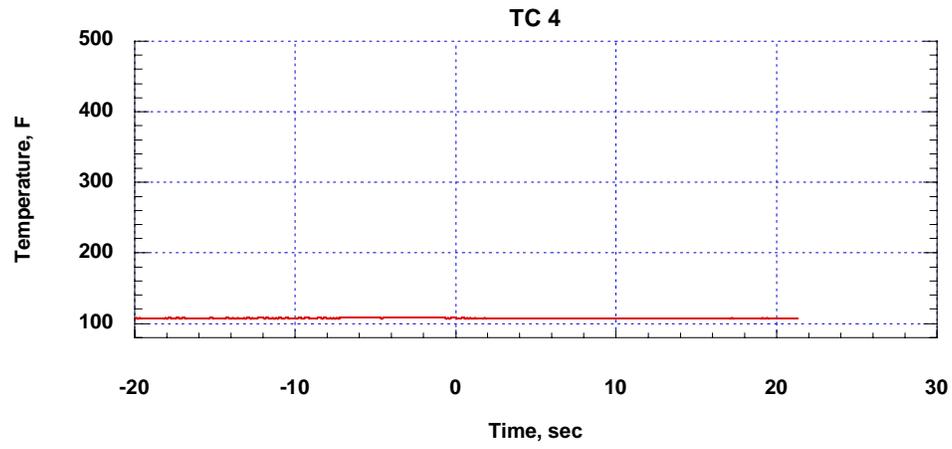
Test 53
Fuel Pressure and Flow Rate vs Time



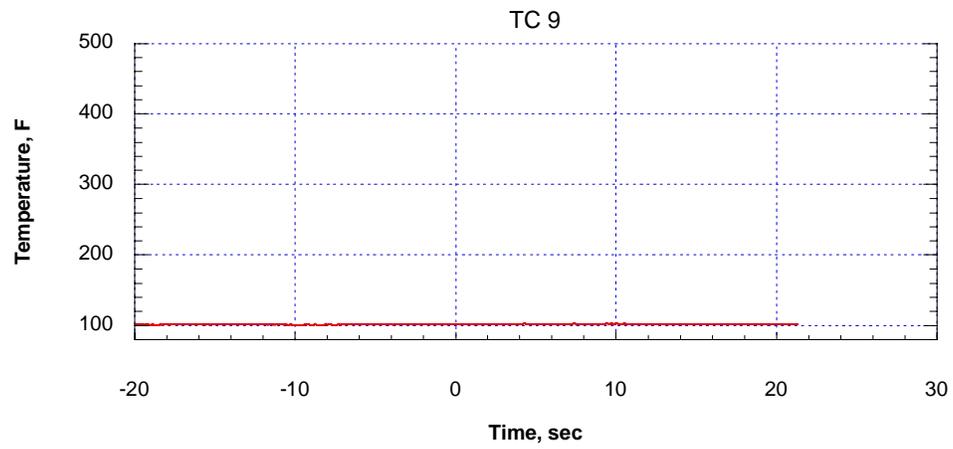
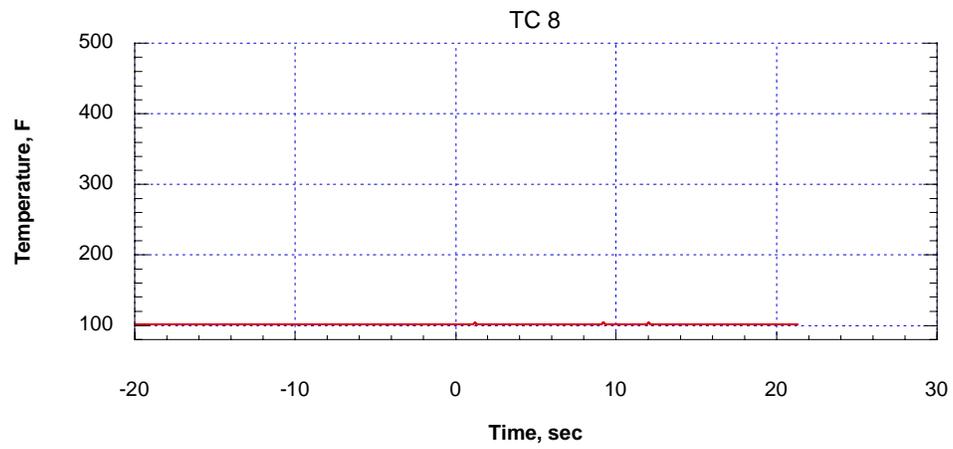
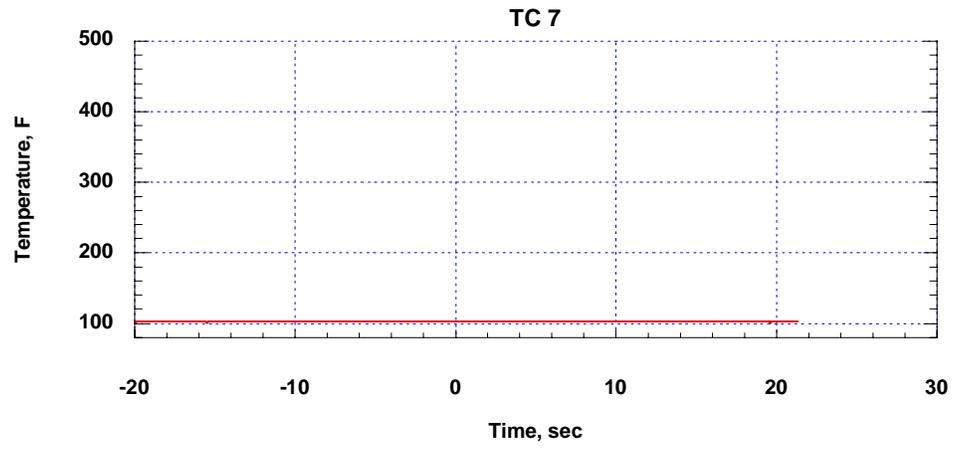
Test 54
Temperature vs Time



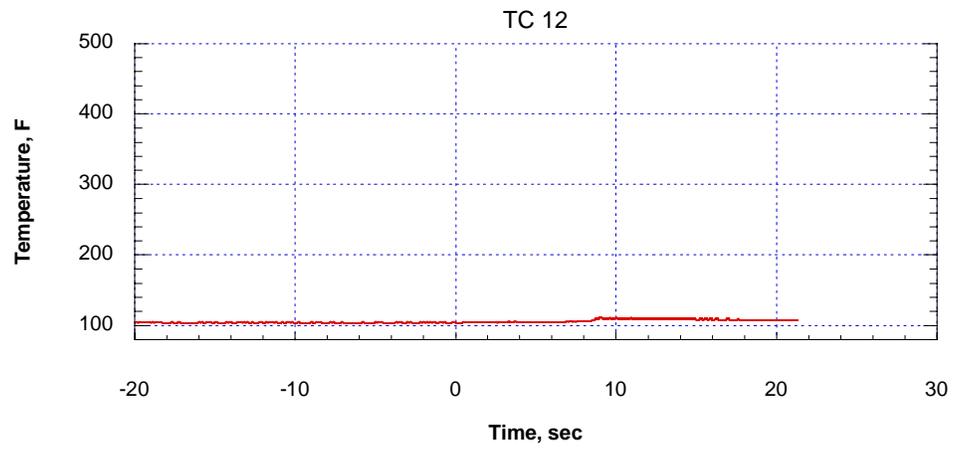
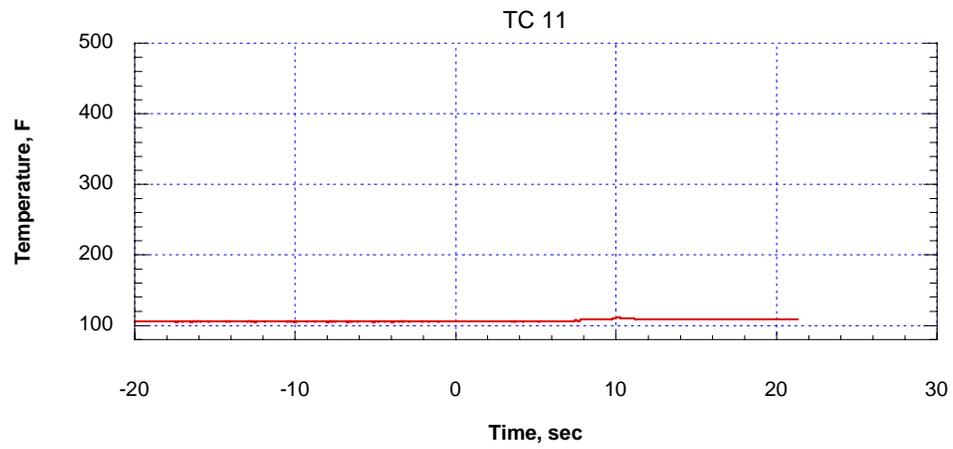
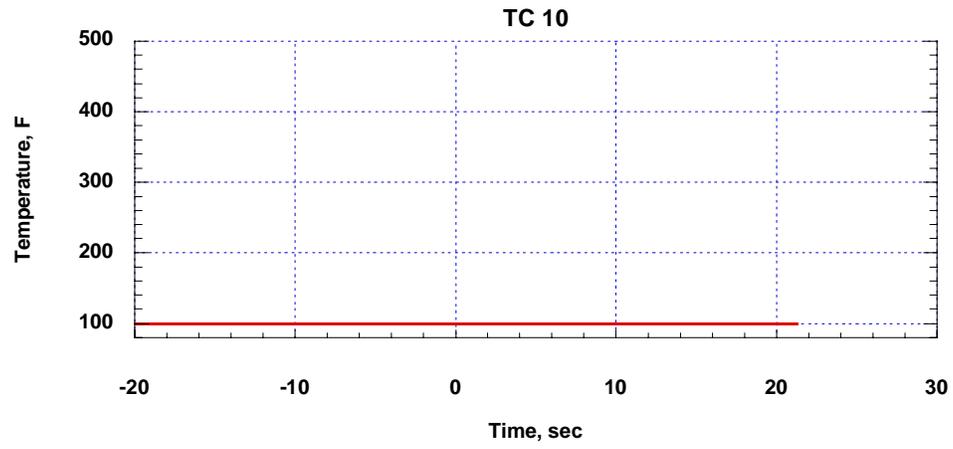
Test 54
Temperature vs Time



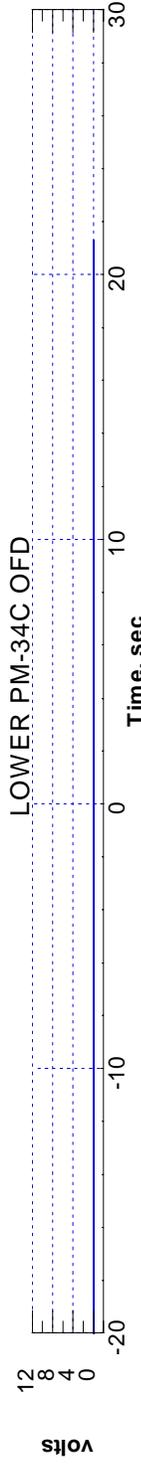
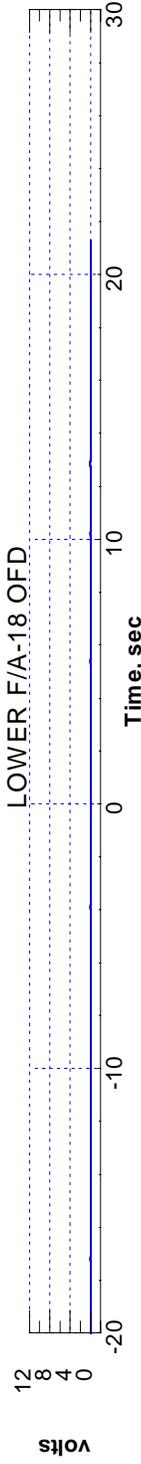
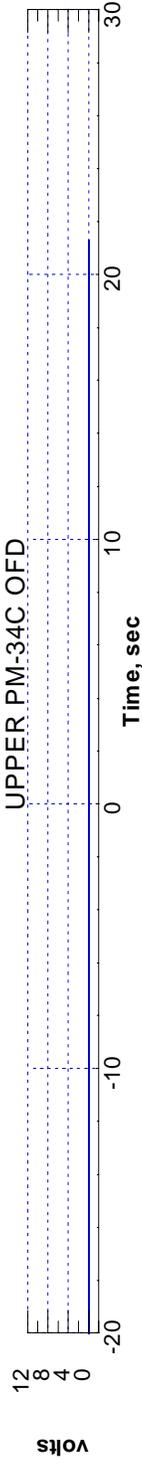
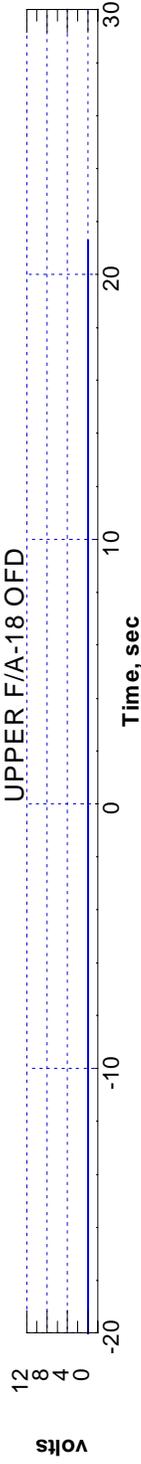
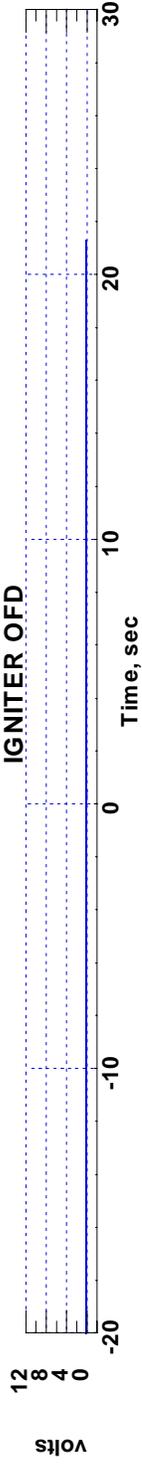
Test 54
Temperature vs Time



Test 54
Temperature vs Time



Test 54
Optical Fire Detector Signal vs Time



Test 54
Fuel Pressure and Flow Rate vs Time

