UNITED STATES DEPARTMENT OF LABOR
Mine Safety and Health Administration

Report on Issues Related To High Temperature Disposable Diesel Particulate Filters Including Laboratory Results on Kindling Temperatures

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-Originating Office-

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Table of Contents

<u>**Executive Summary**</u>

During the past several months, the Mine Safety and Health Administration (MSHA) has received reports of high temperature disposable diesel particulate filters (HTDPF) combusting while being operated on underground coal diesel equipment. The incidents reported were observed as a “shower of sparks” emitting from the exhaust port of the filter housing and reports of actual flames exiting the filter housing. These reports have all originated from MSHA’s Coal Mine Safety and Health District 9.[1] MSHA conducted an investigation on each reported incident. Upon the completion of the field investigations, it was discovered that the diesel particulate matter (DPM) combined with fuel/oil collecting on the filter media was the material that had ignited and burned, not the filter media.

These field investigations led to further laboratory investigations, including small-scale and full-scale testing of the high temperature diesel particulate filters at MSHA’s Approval and Certification Center, located in Triadelphia, WV. MSHA and the National Institute for Occupational Safety and Health (NIOSH) collaborated on the testing of the high temperature disposable diesel particulate filters to determine the kindling temperature of the DPM.[2]

The results of small-scale testing of the filters indicated that DPM collected on the filters could ignite through a wide range of temperatures. The range of ignition temperatures on the small-scale testing varied from a low temperature of 550 ^{o}F, to a maximum temperature of over 1100 ^{o}F. The large temperature variance is associated with the hydrocarbon contaminants added to the filter samples. Testing also revealed that the high temperature filters media steel support screen, which oxidizes and rusts due to exposure to moisture, will glow when exposed to a heated air flow. The observed sparking and glowing of the rust appears to be a result of the heat produced by the DPM combustion and not a cause of the DPM ignition.

The results of full-scale testing of high temperature filters, under the given laboratory testing conditions, showed it was possible to ignite DPM collected on high temperature diesel particulate filters at temperatures equal to and above 645 ^{o}F. The ignition temperatures varied due to the conditions of the various filters that were received from the field. The full-scale testing showed that a fire hazard exists if DPM deposits on high temperature disposable diesel filters are exposed to exhaust gas temperatures at or above 645 ^{o}F. The small scale testing showed that a fire hazard exists if the DPM-loaded high temperature filters are exposed to exhaust gas temperatures at or above 550 ^{o}F. Both tests showed a lowering of the ignition or kindling temperature depending on the presence of foreign hydrocarbons.

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[1] District 9 has approximately 40 percent of the diesel machines in the U.S.A.
[2] Kindling temperature is synonymous with the ignition temperature of a material, which is the minimum temperature a substance should attain in order to ignite under specific test conditions.

Introduction

This report describes tests conducted to determine the ignitability of DPM accumulations on high temperature disposable diesel particulate filters (HTDPF, hereinafter referred to as filters). These filters are used as an aftertreatment device to control DPM. In cooperation with NIOSH, tests were conducted by MSHA's Mechanical and Engineering Safety Division (M&ESD) of the Approval and Certification Center (A&CC) located in Triadelphia, WV. Several tests were conducted on the filters, ranging from small-scale to full-scale testing, and followed the test plan developed by MSHA, NIOSH, United Mineworkers of America and Industry. The objective of this testing was to determine the safe operating exhaust gas temperature that filters can be exposed to without posing a fire hazard.

Background

Between the months of May and June of 2004, there were three reported DPM high temperature filter ignitions on diesel-powered equipment in MSHA's Coal Mine Safety and Health (CMS&H) District 9. At the request of CMS&H District 9, these incidents were investigated by M&ESD. A summary describing the investigation into each incident is listed below.

Incident #1

On May 3, 2004, a DPM-laden filter fire occurred on a diesel powered portable air compressor (Atlas Copoc, 365 CFM, 113 Bop) driven by a Deutz BF 4M 1012 diesel engine while located on the surface of a coal mine. The compressor was equipped with a single filter located in a single filter housing mounted on top of the air compressor.

The incident occurred during the start-up of the referenced diesel-powered compressor unit. The start-up was typical; eight to ten attempts were made in an effort to start the cold engine. As a result, the initial exhaust discharge was laden with a high concentration of diesel particulate matter and unburned fuel (soot/combustible material). This condition is normal on start-up due to the additional/parasitic load placed on the engine by the air compressor unit and the governor assembly fuel demand of 200% of the full fuel delivery.

Immediately after start-up, the excess fuel condition (fuel demand of 200% of the full fuel delivery) is corrected by the governor assembly; however, due to the start-up duration with the parasitic load of the compressor, accumulations of combustible material occurred in the filter system. At this point, high temperature exhaust gases discharged through the filter system, and in turn, ignited the combustible material. The fire was extinguished within approximately five minutes.

Incident #2

On June 5, 2004, a DPM laden filter fire occurred on a heavy-duty Caterpillar grader powered by a CAT 3304 diesel engine while operating in an outby area of an underground coal mine. The Caterpillar grader was equipped with a dual element in-line filter housing that contained two Donaldson filters. These filters were reported to have had over 100 hours of operation. The grader was equipped with a back pressure gauge, but it was not functioning at the time of the filter incident.

The Caterpillar grader operator reported that he was operating the equipment on a slight downgrade, but was not grading the bottom at the time. He then noticed a large “shower of sparks” exiting the orifice of the dual filter exhaust housing. He immediately pulled the grader into a cross cut and shut the engine off. There was no smoke, flames or sparks emitting from the filter housing after the engine was shut off. The filters were later removed and replaced with two Donaldson filters that had been taken from a Getman tow tractor.

Incident #3

Also on June 5, 2004, a second filter fire occurred on a heavy duty Getman tow tractor powered by a Mercedes 906 diesel engine while operating on the surface of the underground mine involved in Incident #2. The Getman tow tractor was equipped with a dual element in-line filter housing that contained two Donaldson filters. These filters had recently been involved in a washing/laundering process to remove accumulated DPM from the filter media and screen. The washing process is performed to extend the duty cycle of the filter. The washing process is discussed in further detail in Attachment 1. The two “newly laundered” filters had not been in service after being returned from the laundering process.

The Getman tow tractor was operated for approximately one hour to haul a trailer containing 15 tons of gravel when it was reported that a “shower of sparks” exited the filter housing exhaust orifice. This event was very similar to the “shower of sparks” reported on the Caterpillar grader. However, the filters on the Getman had much less hours of operation than the filters on the grader.

These filter incidents involving sparking and fires were the only filter events officially reported to MSHA. In light of these investigations into the three filter incidents, MSHA issued a Program Information Bulletin (PIB) No. P04-17 concerning *Potential Fire Hazard of Diesel Particulate Matter Collected on High Temperature Disposable Diesel Particulate Filters (Attachment 2).* This PIB was issued to the mining industry conveying that these filters, if not properly selected and used, could result in a fire hazard.

After issuance of PIB P04-17, some coal operators in District 9 took the initiative to resolve the "shower of sparks" issue that may occur in the filter. One operator has designed and fabricated several systems in order to mitigate the potential filter fire issue. On August 3, 2004, these systems were evaluated by MSHA's CMS&H District 9 and M&ESD. A brief summary of these three systems follows:

Three heavy-duty Wagner 20X converted shield haulers, all powered by Deutz diesel engines (Model Number BF6M1013C), were equipped with different systems attempting to mitigate the "shower of sparks" issue.

Spark Arrestor

The first shield-hauler used a design that incorporated a spark arrestor attached to the exhaust of the in-line dual-filter housing. This system was designed with a high temperature engine shut down feature. The spark arrestor system takes no preventative measures to cool the exhaust gases entering the filter housing. The basic principle of this system is that, in the event involving a filter, the fire would result in a temperature rise; and therefore the high temperature shutdown would shut the engine off. If sparks were generated before the engine was shutdown, the spark arrestor would contain and cool the sparks before exiting into the mine atmosphere. The filters would remain in the filter housing until they cooled to a temperature where they could be changed out.

Water-Injection System

The second shield hauler was equipped with a water-injection system that utilized a water-spray nozzle to inject water directly into the hot exhaust gases. This spray would not inject water continuously. The water spray nozzle was connected to a temperature sensor so that when the exhaust gases reached a specified temperature, the pump would engage and spray water into the exhaust. This water spray would then cool the exhaust gases before entering the in-line dual-filter housing.

Water Scrubber System

The third and final system evaluated was a water scrubber system connected to the shield hauler's exhaust system. In this type of system, the hot exhaust gases pass through a box containing water, thereby cooling the hot exhaust gases before entering the filter.

A detailed report of the M&ESD's evaluation of the three systems is in Attachment 3.

Small-Scale Testing

While conducting investigations into the “shower of sparks” events, the M&ESD began conducting small-scale testing on filters that had accumulated DPM. There were two basic small-scale tests conducted. The first test utilized a hot air furnace (used for various material ignition temperature testing). The second test incorporated a heat gun arrangement that exposed DPM loaded filter samples to various high temperatures to monitor their ignition characteristics. M&ESD developed the test apparatus to determine when, and at what temperature DPM will combust when collected on filters.

Setchkin Hot Air Furnace Testing

M&ESD requested the assistance of the Quality Assurance & Materials Testing Division (QA&MTD) to perform spontaneous ignition temperature (SIT) testing on the filters that had accumulations of DPM on the filter media. The test procedure used for this testing was the ASTM D 1929-96, *Standard Test Method for Determining Ignition Temperature of Plastics* (Procedure 8.2). The test apparatus used for this test was the Setchkin Hot Air Furnace.

The following is a summary of the test results;

- Deutz 1012 engine DPM on a Donaldson P604516 high temperature filter can be consumed at air temperatures exceeding 1283 ^{o}F. [3]
- Mercedez 906 engine DPM deposited on a Donaldson P604516 high temperature filter can ignite and glow at an air temperature of 982 ^{o}F.
- DPM from a Caterpillar 3306 PCNA engine deposited on a Filter Service and Testing (FST-115-26-NH) filter can ignite and glow at an air temperature of 1182 ^{o}F.
- Used engine oil and diesel fuel deposited on a FST-115-26-NF high temperature filter (with DPM accumulations on media) can ignite and burn at an air temperature of 561 ^{o}F.

A complete report on the SIT testing performed in the Setchkin Hot air furnace is in Attachment 4.

[3] After test sample was heated to air temperatures exceeding 1283 ^{o}F none of the original DPM sample remained in the test apparatus. The sample was incinerated during testing, yet there was no visual glowing/flame or rise in temperature to indicate ignition of the sample.

Heat Gun Testing

This test set-up used a sample of approximately 6 inches by 5 inches of the filter media, including supporting wire screen mesh, and encompassed about 10 to 12 pleats. The sample was secured vertically in a rack. Three thermocouples were embedded in the front face of the filter media (collecting face for DPM) under the wire screen mesh. These thermocouples measured the filters "surface" temperature at three different locations on the filter media face during the testing.

The heat source used in the testing was a Liester *Hotwind S* commercial heat gun. The heat gun was rated at a maximum temperature of 800 ^{o}C (1472 ^{o}F), and was equipped with a potentiometer for temperature control. Heat was gradually introduced to the filter by moving the heat gun progressively closer to the filter sample.

Filter samples tested were supplied by several mine companies and filter manufacturers, and had varying amounts of DPM collected on the media. Filter samples were tested, with and without foreign hydrocarbons added to the surface of the media, to reproduce the worst-case situation that a filter may be exposed to in the field.[4] See Attachment 5 for the Heat Gun testing reports.

Ignition temperature results of the heat gun filter samples tested, with and without foreign hydrocarbons added covered a broad range, dependent upon the presence of diesel fuel/engine oil. The results of the heat gun testing are summarized in Table 1.

[4] Foreign or additional hydrocarbons used during testing were new/used engine oil and diesel fuel.

Table 1: Summary of Heat Gun Testing on Filter Media with and without the addition of hydrocarbons

Filter Sample	Additional Hydrocarbon Used	Ignition Temp. (F)	Observations
Sample taken from Filter involved in Getman incident (Donaldson)	None	875	Small areas of glowing red combustion, propagated in all directions
Sample taken from filter that was efficiency tested on lab engine (FST filter)	None	1100	Red glowing of media and screen, but no self sustaining combustion occurred Regeneration occurred
Sample taken from Filter involved in Getman incident (Donaldson filter)	None	950	Glowing red combustion propagated across sample face Removed from heat, continued to glow 10 – 15 seconds
Sample taken from filter that was efficiency tested on lab engine (FST filter)	50/50 mix of clean oil & diesel fuel	700-800	Large continuous DPM ignition
Sample taken from filter that was efficiency tested on lab engine (Donaldson filter)	60/40 mix used engine oil & diesel fuel	550-650	Sparks and isolated larger ignition of DPM
Sample taken from filter that was efficiency tested on lab engine (Donaldson filter)	60/40 mix used engine oil & diesel fuel	550-675	Heavy sparks and isolated ignitions of DPM

Test results of the Heat Gun testing were found to cover a large range of DPM ignition temperatures. This can be explained by 1) the varying chemical makeup of the DPM dependent upon engine output 2) the addition of foreign hydrocarbons to the filter samples, and 3) other variables that are not repeatable or controllable in this test setup. This test did indicate that the ignition temperature of dry DPM (without hydrocarbons added) can vary from filter to filter depending upon the output of the engine exhaust which it is filtering.

The test also showed that the DPM collected on a high temperature filter has the potential to ignite and burn at reasonably lower temperatures with foreign hydrocarbons added to the media. This result was expected due to the lower spontaneous ignition temperature of the hydrocarbons used. The hydrocarbons acted as an aid to ignition of the DPM collected on the filter.

This test method indicated that dry DPM was difficult to ignite at temperatures lower than 800 to 900 ^{o}F. However, when hydrocarbons were used, the ignition temperature ranged from 550 to 800 ^{o}F. There were signs of combustion at temperatures lower than 550 ^{o}F when filters with hydrocarbons added were tested. These indications were small amounts of smoking and sparking occurred at temperatures as low as 250 ^{o}F, although visual ignition and propagation of the flame did not occur until 550 ^{o}F.

Full-Scale Testing

After discussions within MSHA, and subsequent discussions with NIOSH and the Coal Diesel Partnership, it was decided that a test series was needed using a diesel engine with a real filter canister installation. These filters would be tested on the Caterpillar 3306 PCNA engine located at the A&CC diesel laboratory. These tests were set up and conducted so that the test could, as near as possible, duplicate the filters' designed application on diesel equipment in the field. Compared to the small scale-tests, the full-scale testing duplicated the closest configuration and conditions that a high temperature disposable diesel particulate filter would be exposed to in a typical mining environment. Used filters were delivered from filter manufacturers and from mines, and these were tested under conditions expected to occur during actual mining operations. Specifically, the tests involved filters where DPM and unburned fuel/oil are contaminants are deposited on the filter; rather than being allowed to evaporate off as in the heat gun and hot air furnace tests.

"Tentative Test Protocol for Reproducing Field Events and Determining Kindling Temperature of Diesel Exhaust Components Captured by High Temperature Disposable Filters" (Included as Appendix A of Attachment 6) was developed by MSHA, NIOSH, and other members of the Coal Diesel Partnership. The primary goal was to determine the nature of the reported events and what exhaust temperature produced DPM ignitions on filters.

The tests were conducted to progressively increase the exhaust gas temperature to which the filters were exposed and to observe the effects on the filters. Twenty eight filter tests were conducted. Observed effects during these tests included filters smoking from DPM collected on the filter media, sparks being emitted from the filter canister outlet, glowing of filter media or deposited DPM, ignition of DPM deposits, and after-test filter damage or DPM regeneration.

The engine's exhaust backpressure was one parameter that was measured and recorded in the laboratory. The exhaust backpressure measures the amount of pressure that the exhaust gas exerts against the engine. Engine manufacturers specify a maximum allowable backpressure for each engine model. This backpressure specification cannot be exceeded in order for the engine to be considered in approved condition. Excessive backpressure may damage the engine or lead to the filter becoming overloaded with DPM. An overloaded DPM filter could have a higher potential to catch on fire.

On most of the dirty filters received from the field, an exhaust backpressure measurement could not be measured or recorded in the laboratory. The absence of a backpressure measurement with the DPM filter attached to the test engine in the laboratory indicated that these filters may have already been run too long and the internal parts of the filter may have disintegrated. This would allow DPM to bypass the filter media and may result in an increase DPM concentration in the mine. No measurable backpressure would indicate that the machine, to which the filter was attached, would not be in compliance with the DPM regulation under 72.500 through 72.502.

Normally, a HTDPF filter will build up exhaust backpressure as the engine is run. The exhaust backpressure will start low with a "clean" DPM filter and continue to increase pressure until the maximum allowable backpressure is achieved, and the filter is changed out. Clean HTDPFs that were loaded with DPM during the laboratory test showed this progression of exhaust backpressure. However, the DPM in the exhaust can bypass the filter media if the filter is compromised or damaged during service and used beyond its useful life. This situation will be indicated by a consistently low exhaust backpressure measurement along with reduced DPM filtering. A machine operator must be aware of the condition of the filter installed on the machine. Exhaust backpressure is a good indicator of the on-going condition of the filter.

Filters selected for testing were supplied by manufacturers and mine operators located in District 9. This was the district were the reported filter incidents occurred, and since there is no significant difference in the DPM makeup from district to district within the country, it was unnecessary to test high temperature filter samples from other coal districts. The following is a list of filters that were tested:

- Donaldson P604516, newest generation filters received new and loaded with DPM from the Caterpillar 3306 PCNA engine.
- Filter Service and Testing Corporation (FSTC) assorted used filters that were dirty and awaiting reconditioning; possibly a mix of inby and outby filters.
- Donaldson P604516, newest generation filters; received from Canyon Fuels LLC after being used 25-35 hours on mine equipment with the Mercedes 906 electronic engine, 2 sets of dirty filters and 1 set of used filters laundered and ready for re-use.
- Donaldson P604516 newest generation filters received from Energy West Mining; 2 pair of filters loaded to "end-of-life" on an inby machine using a Caterpillar 3306 PCNA engine with a water scrubber.
- FSTC used filters; 3 filters loaded at Oxbow Mine on an inby machine using a Caterpillar 3306 PCNA engine with a water scrubber.
- FSTC used filters; 3 filters loaded at Oxbow Mine on an outby EIMCO 975 with machine using a Caterpillar 3306 PCNA engine.

The summary of the results of the tests conducted on the filters are shown in Table 2. The complete full-scale testing report covering all tests conducted on the Caterpillar 3306 PCNA engine is in Attachment 7.

Table 2: Summary of full scale ignition testing conducted on HTDPFs.

Test Number	Filter Pair	Condition	Observations
1	Donaldson P604516 special	Loaded at MSHA from new	Smoking, no effect to 1075F
2	Donaldson P604516 special same pair as 1	Continued loading at MSHA	Smoking, no effect to 1050F
3	Donaldson P604516 special same pair as 1, 2	Continued loading at MSHA	Smoking, no effect to 1050F
4	Donaldson P604516 special same pair as 1, 2, 3	Continued loading at MSHA	Smoking, no effect to 1050F
5	FSTC	Field Used, no observed rusting	Smoke, heated direct to 1000F, filter #2 ignited and burned
6	FSTC	Field Used, no observed rusting	Smoke, Filter #1 ignited and burned at 780F
7	FSTC	Used, Filter #2 heavy loaded and rusted	Smoke, Filter #2 ignited at or below 650F and burned
8	FSTC	Used, Surviving filters from tests 6 and 7	Smoke, test interrupted due to lightening strike on test lab – reached 730F with smoking only
9	FSTC, from 8	Filters from Test 8 loaded further at MSHA	Smoke only up to 780F
10	FSTC, from 8, 9	Filters from Tests 8 and 9 loaded further at MSHA	Smoke, ignition of #2 filter at 845F
11	Donaldson P604516 special (Skinner Set #1)	Used Outby Mercedes 906 (25-35hr)	Smoke, small glow/ignition Filter #2 at 1040F and again at 1077F, glowing areas extinguished after short period. Filter #1 appeared regenerated.
12	Donaldson P604516 special (Skinner Set #2)	Used Outby Mercedes 906 (25-35hr)	Smoke, no effect to 1055F. Filter #1 again appeared regenerated
13	Donaldson P604516 special (Skinner Set #2) same as 11	Used Outby Mercedes 906 (25-35hr), loaded by MSHA	Heavy smoke, sparks at 950F, no other effects up to 1070F
14	Donaldson P604516 special (Skinner Set #2) same as 11, 12	Used Outby Mercedes 906 (25-35hr), loaded by MSHA	Smoke, Sparks at 870F, 1000F

15	Donaldson P604516 special (Skinner Set #2) same as 11, 12, 13	Used Outby Mercedes 906 (25-35hr), loaded by MSHA	Smoke, Filter #2 small glow/ignition and sparks at 990F, again at 1061
16	Donaldson P604516 special	Used Inby water scrubber, CAT 3306	Filter #2 Ignited and Burned at 645F or below
17	FSTC	Used Inby Water Scrubber, CAT 3306	Heavy smoke, small ignition at 850F (self extinguished), large ignition and burning #2 filter at 1000F
18	FSTC	Mixed Pair Used Inby/Outby, CAT 3306	Heavy smoke, filter #1 and #2 ignited and burned at 645F or below. Both continued to burn even after removal from filter canister
19	Donaldson P604516 special	Used Inby, light rust.	Heavy smoke, filter #2 ignited and burned, 645F or below.
20	FSTC	Used Outby	Smoke only up to 985F, media fell apart near exhaust outlet hole.
21	Donaldson P604516 special	Used Outby Mercedes 906 (25-35hr), then laundered and tested clean	Light smoke only to 870F
22	Donaldson P604516 special, same as 20	Used Outby Mercedes 906 (25-35hr), then laundered and tested clean, loaded at MSHA for 9.5hr.	Heavy smoke, sparks at 745F, 790F, 870F and 1035F, Filter #1 appeared regenerated.
23	Donaldson P604516 special	Used Outby Mercedes 906 loaded to BP limit	Light smoking, ignition and burning of #2 filter at 880F, with large continuous shower of sparks
24	Donaldson P604516 special	Used Inby CAT 3306, loaded to BP limit[5]	Heavy smoke, ignition and burning of Filter #2 at or below 649F. Filter #1 smoking when removed from canister.
25	FSTC	Filters loaded at MSHA (filters previously used for efficiency	Massive smoking caused by oil injection. No observed sparking or ignition up to 870F

[5] Only one of these inby filters were received for testing. So the inby filter received was installed at Filter #2, while another P604516 filter loaded by MSHA was placed in the Filter #1 position.

		tests)	
26	FSTC	New filters Loaded at MSHA, tested with oil injected into exhaust stream	Massive smoking caused by oil. Some sparks observed at 760F, tested to 870F max.
27	FSTC	Same filters as test 25, oil injected closer to filter can inlet	Massive smoking caused by oil. Sparks observed at 768F, tested to 864F max. Examination after test showed small burn through on #2 Filter
28	FSTC	Mixed pair of oil soaked filters from tests 25 and 26, further loaded with DPM by MSHA ~5hrs (no oil injected during tests)	Heavy smoking of filters. Sparks observed at 965F.

Findings

The testing conducted on the kindling temperatures of DPM accumulations collected on filters resulted in a broad range of temperatures. The overall findings from all testing conducted are as follows:

- Small-scale testing utilizing the Heat Gun apparatus without the presence of any foreign hydrocarbon added to the filter samples resulted in ignition temperatures of 875 ^oF, 950 ^oF and 1100 ^oF.

- Small-scale testing utilizing the Heat Gun apparatus with the presence of additional hydrocarbons resulted in ignition temperatures ranging from 550 ^oF to 800 ^oF.

- The ignition temperature testing conducted in the Setchkin hot air furnace without the presence of hydrocarbon mixtures added to the filter sample resulted in ignition temperatures at 982 ^oF, 1182 ^oF, and 1283 ^oF.

- The ignition temperature testing conducted in the Setchkin hot air furnace with hydrocarbon mixtures added to the filter sample resulted in an ignition temperature as low as 561 ^oF.

- The full-scale testing was performed using filters that contained collected DPM only. Ignition and surface combustion was recorded at temperatures ranging from 645 ^oF to 1077 ^oF. No additional hydrocarbons were added during these tests.

Conclusions

The full-scale and small-scale testing conducted with the DPM deposits on high temperature diesel particulate filters resulted in a wide range of ignition or kindling temperatures. According to the full-scale testing data, DPM deposits on high temperature filters can ignite and burn at temperatures as low as approximately 650 ^oF. More emphasis was placed on the full-scale test results rather than the small scale-testing, because the filters were subjected to conditions that very closely simulate a mining application.

The following table was developed as guidance to evaluate the probability of the fire risks associated with exposing diesel-laden high temperature filters to various exhaust gas temperatures. Table 3 was developed based on the high temperature filter testing data.

Table 3: Kindling potential associated with filters with accumulated DPM exposed to high exhaust gas temperatures. (Temperatures are in ^{o}F)

EXHAUST GAS TEMPERATURE	**POTENTIAL FOR DPM-LADEN FILTER KINDLING[6]**
302	NONE
500	Filter kindling: improbable – unlikely to occur but possible under unexpected engine operating conditions[7].
550	Filter kindling: remote – unlikely but can reasonably be expected to occur under expected engine operating conditions[8]. Filter kindling was observed during small scale tests.
650	Filter kindling: occasional – will occur several times per year with widespread use of filters under expected engine operating conditions[7].
750	Filter kindling: probable – will occur frequently with widespread use of filters under normal engine operating conditions.
Above 750	Filter kindling: frequent – will be continuously experienced with widespread use of filters under normal engine operating conditions.

[6] This chart is based on the assumption that the exhaust gas temperature is limited by a highly reliable temperature control system.

[7] **Unexpected engine operating conditions**: Abnormal engine faults that cause a massive dosing of the filter with unburned hydrocarbons. These conditions are devastating to the engine or mining machine. Examples are total/multiple valve seals/guides failure, complete injection system failure, a sudden catastrophic turbo loss, massive engine over fueling, extremely bad programming (or CPU loss) on an electronic engine.

[8] **Expected engine operating conditions**: Operating conditions that may be expected due to poor maintenance or operating practices. These conditions lead to a build up of DPM on the filter heavy in organic hydrocarbons that can ignite at or below 650 ^{o}F. These conditions include operating old engines with higher than normal oil consumption, older engine designs that produce DPM unusually high in organics, engine improperly derated for altitude, improperly functioning injectors, air leaks in the fuel pump or injection system, machines that idle excessively, machines that are almost always used under light load conditions with a rare excursion to high exhaust temperatures, mixing used inby and outby filters, gradual turbo charger loss of performance, running a turbocharged engine at low torque excessively where boost is too low, etc.

After analyzing the test data, certain trends and patterns were discovered throughout the full and small-scale testing.

1. Ignition of DPM-laden high temperature filters appeared to be dependent on the amount of DPM deposits within the filter media. A qualitative association between the amount of DPM collected on the filter and the ignition characteristics observed. A quantitative relationship between the amounts of DPM on filter media to ignition temperature was not established.

2. Based on the testing conducted, ignition of DPM on HTDPF depends on the chemical make-up of the DPM. The greater the amount of organics within the filter media, the greater the likelihood of the combustibles on the filter igniting at a lower exhaust gas temperature. This could be an issue if a piece of equipment is not properly maintained. Diesel engines experience abnormal mechanical problems (leaking injectors, oil blow by, valve problems, turbo failure, high oil consumption, etc.), all of which have the potential for unwanted additional hydrocarbons collecting on the filter media. If these oils/diesel fuels accumulate on the filter media of a non-cooled exhaust system, there is a potential for the hot exhaust gases to ignite the additional hydrocarbons present.

3. DPM on HTDPF loaded on an inby wet scrubber system ignite at a lower temperature than filters loaded on outby dry un-cooled exhaust systems. These cooled systems may filter out more of the cooled hydrocarbons than the filters used on un-cooled systems resulting in more fuel present in the filter media. The un-cooled exhaust gases are at a higher temperature; therefore the hydrocarbons do not condense in the higher exhaust gas temperatures and pass through the filter media. This may result in outby machine filters kindling at a higher temperature than those filters used on inby wet systems. Any engine malfunction that could lead to oil being sprayed on the filter through the exhaust could lead to these lower kindling temperatures.

4. As previously mentioned, laundering or washing of the filters is performed to extend the usable life of the filter. This washing process results in the steel filter media support screen to oxidize and accumulate rust. Based on small-scale testing this rusty metal screen will glow and spark when subjected to a high temperature air flow. The sparks are small in mass therefore low in intensity and cool quickly. The heating and sparking of the rust on the screen appears to be a result of the DPM or organics heating and combusting, not the cause of the ignitions. It should be noted that some operators are avoiding washing filters due to the possible damage inflicted on the filter media and support screen. If the filter media has been damaged the filter will not effectively capture DPM, therefore decreasing the filters efficiency.

5. The kindling potential for DPM-laden filters is dependent on the operating conditions of the engine and the potential for the build-up of DPM heavy in organic hydrocarbons on the filter. DPM heavy with organic hydrocarbons can ignite at or below 650 ^{o}F. Operating conditions due to poor maintenance and operating practices may contribute to the build-up of DPM heavy in hydrocarbons. Massive dosing of the filter with unburned hydrocarbons, caused by abnormal engine faults and unexpected engine operating conditions that are devastating to the engine or mining machine, can ignite at or below 550 ^{o}F.

Alternative Aftertreatment Technology

DPM filters on diesel powered equipment can be used to meet the underground coal DPM emission standards specified in 30 CFR 72.500 – 72.502. Mine operators have a choice of control technologies to use and these choices can change as new technologies are introduced to the mining industry. Technologies such as heat exchangers using water or air are commercially available. This report has discussed the use of HTDPF, however, as discussed in the PIB attached to this report, ceramic filters are also commercially available for installation. The ceramic filters are used nationwide with a great deal of success. There are approximately 180 pieces of coal diesel equipment fitted with a ceramic trap system within the United States. When properly sized, installed, and maintained ceramic traps can be a viable DPM filtering alternative when the engines exhaust gases are typically high due to the machine's duty cycle. Ceramic DPM filters are being used successfully in MSHA Districts 3, 6, 8, 9, and 11. Several mines within these districts have reported using ceramic filters without experiencing any problems.

Final Implementation Phase of Coal DPM Standard

The final phase of the coal DPM standard becomes effective on January 19, 2005. Each piece of nonpermissable heavy-duty diesel-powered equipment, generators, and air compressor, operated in an area of an underground coal mine must not emit more than 2.5 grams per hour of DPM. The current standard is 5.0 grams per hour of DPM. Prior to January 19, 2005, many engines could meet the 5.0 grams per hour standard without a DPM filter. However the majority of those engines will need to have a DPM filter installed in order to comply. In addition, some machines that currently have a DPM filter installed to meet the 5.0 grams per hour standard may need a more efficient filter for compliance with 2.5 grams per hour. Table 4 shows DPM filters available to meet 2.5 g/hr based on the engine's Particulate Index.

Table 4: DPM Filters Available to Meet 2.5 gr/hr

Particulate Index (PI), cfm	**Percent Filter Efficiency to Meet 2.5gr/hr**	**Available DPM Filters ***
Greater than 12,000 cfm	95	Paper/Synthetic at a maximum exhaust gas temperature of 302^o F
Less than or equal to 12,000 cfm	87	Ceramic – Silicon Carbide or filters listed for PI's above 12,000 cfm
Less than or equal to 10,500 cfm	85	Ceramic - Cordierite Media or filters listed for PI's above 10,500 cfm
Less than or equal to 8,500 cfm	83	HTDPF, at a maximum exhaust gas temperature of 650^o F** or filters listed for PI's above 8,500 cfm

* Vendor Listings and Filter Description at the following internet address: http://www.msha.gov/01-995/Coal/DPM-FilterEfflist.pdf

**For DPM Filtering Efficiency.

Examples of Filter Applications to Engines to meet 2.5 gr/hr standard:

1. Caterpillar 3306 PCNA and 3304 PCNA, PI of 23,000 cfm and 15,000 cfm, respectively. Available filter: paper or synthetic used at a maximum exhaust gas temperature of 302^o F.

2. Deutz-MWM 916, PI of 11,500 cfm. Available filter: Ceramic-Silicon Carbide at any exhaust gas temperature, or paper or synthetic used at a maximum exhaust gas temperature of 302^o F.

3. Perkins 1004-40T, PI of 9000 cfm. Available filters to use: Ceramic – Cordierite, Ceramic – Silicon Carbide at any exhaust gas temperature, or paper or synthetic used at a maximum exhaust gas temperature of 302^o F.

4. Deutz BF4M2012, PI of 3000 cfm. Available filters to use: Any type listed in chart above.

Recommendations

Testing data and field reports have shown that when DPM is exposed to high exhaust temperatures, or contaminated with hydrocarbons within the filter media, there is a possibility of a fire. Many preventative steps or precautions can be taken by the mine operator to safely operate diesel machinery when equipped with high temperature diesel particulate filters.

DPM controls, suitable for the machine's exhaust gas temperature, must be appropriately selected, correctly installed and properly maintained. Steps towards operating safely with HTDPF include:

1. *Institute a good preventative maintenance plan.*
   Testing data has shown that filters that are overloaded with DPM have tendency to ignite easier than lightly loaded filters. This would equate to implementing a filter changing protocol for exchanging filters when needed, and not running filters for extended periods of time.

2. *Properly maintain the machines diesel engine.*
   An abnormal operating engine (leaky injectors, old engine, oil blow by, etc.), can generate organic hydrocarbons within the filter media, leading to the possibility of a filter fire at a lower temperature than otherwise would be expected.

3. *Provide proper training.*
   Any person operating diesel-powered equipment using HTDPF should be properly trained in maintaining or working around this equipment. Operators should adhere to the manufacturer's specifications and recommended practices on the uses of HTDPF.

Next Steps

MSHA will issue a second PIB as a follow-up to the PIB No. PO4-17. This second PIB will cover safe recommended practices for using high temperature filters including specific exhaust temperature guidelines. The PIB will also emphasize the importance of exhaust cooling, proper maintenance best practices, and utilizing other alternative aftertreatment devices such as ceramic filters and dry system technology.

List of Attachments

Attachment 1: Summary of Filter Washing Process

Attachment 2: MSHA's PIB No. P04-17 Potential Fire Hazard of Diesel Particulate Matter Collected on High Temperature Disposable Filters.

Attachment 3: Wagner 20X Shield Hauler (Systems Designed to Prevent Shower of Sparks) Evaluation Report.

Attachment 4: Setchkin Hot Air Furnace Ignition Temperature Laboratory Report

Attachment 5: Heat Gun Laboratory Testing Reports

Attachment 6: Laboratory Report – Full-Scale Testing of DPM Laden High Temperature Diesel Particulate Filters

Summary of Filter Washing Process

Some coal mine operators in District 9 are utilizing a washing process to extend the life cycle of the high temperature fiberglass filter. Once the filter has collected DPM within and on the filter media, the filter is shipped to ERAM Filters Shop in Price, UT. This shop cleans the accumulated DPM off the filter media, therefore allowing the filters to be used on diesel equipment for another exhaust filtering cycle.

The basic washing process is relatively simple. Specific details involving the washing process have been omitted due to proprietary concerns. A summary of the filter laundering procedures are as follows:

- Upon receipt from the mine the filter is inspected for structural damage, mesh integrity and soot loading.
- The filter is next blown out with compressed air (outside to inside) to dislodge loose material.
- The filter is next placed in the ultrasonic cleaning tank. The bath solution circulates from outside the filter to the inside to dislodge accumulated material.
- The filter is then placed in a second bath of the same solution where the bath solution is circulated from the inside of the filter to the outside of the filter.
- Following the ultrasonic cleaning baths the filter is hand rinsed with water and drip dried.
- The filter is next oven baked to dry the filter media.
- After drying, the filter is blown out with compressed air to insure that all loose material is removed.
- A final filter inspection is performed by placing the filter over a light source and checking for light or dark spots. Light spots can indicate a hole in the filter and dark spots can indicate that the filter is not thoroughly cleaned.

Once laundering of filter is complete, the filter is then shipped back to the mine location.

ISSUE DATE: July 20, 2004

PROGRAM INFORMATION BULLETIN NO. P04-17

FROM:	RAY McKINNEY Administrator for Coal Mine Safety and Health
	ROBERT M. FRIEND Administrator for Metal and Nonmetal Mine Safety and Health
	MARK E. SKILES Director of Technical Support
SUBJECT:	Potential Fire Hazard of Diesel Particulate Matter (DPM) Collected on High Temperature Disposable Diesel Particulate Filters (HTDPF)

Who needs this information?

This Program Information Bulletin (PIB) affects underground coal and metal/nonmetal mine operators using diesel-powered equipment, manufacturers of diesel-powered underground mining equipment (including manufacturers of exhaust aftertreatment control devices and systems), miners' representatives, and Mine Safety and Health Administration (MSHA) personnel.

Why is MSHA issuing this bulletin?

MSHA is issuing this bulletin to alert the mining industry of a potential fire hazard associated with DPM collected on HTDPFs used on diesel-powered equipment. The HTDPF serves as an aftertreatment device to control DPM.

What problems are being associated with these HTDPFs?

MSHA is investigating several recent events in which a potential fire hazard has been reported to be associated with HTDPFs used on non-permissible diesel powered equipment in underground coal mines. These events, which include glowing, sparking, and heating of the material collected on the filter media, have been reported on generators, air compressors, skid loaders, and tow vehicles.

MSHA is fully investigating these events and will provide more information as it becomes available. In addition, MSHA is performing additional laboratory tests and may make other recommendations once the test results are more conclusive. At this time, MSHA believes these events may be related to the HTDPFs being exposed to high exhaust gas temperatures greater than 650°F. The 650°F temperature is the maximum temperature the HTDPF can be exposed to and still maintain the DPM collection efficiency of 83 percent specified by the manufacturer. The filter media is not combusting, but the DPM collected and stored in the HTDPF combined with un-burnt diesel fuel and lubrication oils present on the filter media are being combusted when exposed to these exhaust gas temperatures.

The potential for fire can also increase when the filter becomes over loaded with DPM which is indicated by excessive exhaust backpressure. Mine operators should monitor the exhaust backpressure to minimize this fire potential. When the engine's exhaust backpressure limit is exceeded, the engine is considered to be out of compliance with the engine approval.

Mine operators should consider DPM control devices such as ceramic diesel particulate traps when the machine's exhaust gas temperatures operate above 650°F. Mine operators should verify that the machine's operating exhaust gas temperatures are within the DPM control device's operating limit as specified by the manufacturer.

Where can I find more information?

More information on diesel exhaust filters can be obtained from MSHA's Diesel Particulate Rules Single Source Page (http://www.msha.gov/01-995/dieselpart.htm) and the National Institute for Occupational Safety and Health's (NIOSH's) Mining Safety and Health Research Topics (http://www.cdc.gov/niosh/mining).

What is the background for this bulletin?

MSHA's final diesel particulate rules for underground coal mines and metal and nonmetal mines established new requirements for DPM over a phased-in schedule. This bulletin alerts miners and mine operators of a potential fire hazard associated with DPM material which collects on the HTDPF. MSHA provides recommendations for assisting mine operators in choosing the correct diesel particulate filter (DPF) for their specific machine application.

Who are the contact persons for this bulletin?

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What is the authority for this bulletin?
30 CFR Part 72 Subparts D, 30 CFR Part 75 Subpart T and 30 CFR Part 57 Subpart D.

Who will receive this bulletin?
Program Policy Manual Holders
Miners' Representatives
Underground Mine Operators
Special Interest Groups

EVALUATION OF SYSTEMS DESIGNED TO RESOLVE HIGH TEMPERATURE FILTER "SHOWER OF SPARKS" ISSUE

Date of Evaluation: August, 3, 2004

Location: Dug Out Coal Mine - Price, UT

At the request of the Coal Mine Safety and Health District 9, Mike Hockenberry of Technical Support's Mechanical and Engineering Safety Division (M&ESD), traveled to Dug Out mine near Price, UT to evaluate systems designed to resolve the high temperature filter "shower of sparks" issue. Steve Forbush (Skinner) designed three different systems to be used on Wagner 20X converted shield haulers. This evaluation was to take place during a scheduled longwall move by the mine, but when Tech. Support arrived at the mine the longwall move had been postponed until the weekend. Therefore the three shield haulers were evaluated while located on the surface of the mine. Technical Support was accompanied by John Hancock, an MSHA District 9 inspector.

<u>No. 1 Wagner 20X – Spark Arrestor</u>

The first Wagner 20X shield hauler, designated No. 1 was equipped with a spark arrester assembly that was designed by Skinner (See Figure One & Two). The Wagner 20X heavy duty equipment was powered by a diesel engine manufactured by Deutz, model number BF6M1013C. All three Wagner 20X shield haulers were equipped with this same Deutz diesel engine. This heavy duty Wagner 20X shield hauler was equipped with a dual filter housing exhausting into a spark arrestor. This shield hauler was also equipped with a back pressure gauge, located in the operator's compartment, but was not in operating condition at the time of the evaluation. The back pressure gauge was replaced while MSHA was on site. The mine operates under a two entry longwall panel development system; therefore the entire exhaust including the turbo was wrapped with insulation.

This spark arrestor assembly was tested and evaluated by John Hancock on a prior occasion while located at Mac's Mining Repair shop in Huntington, UT. The intent of the spark arrestor is that in the event of a fire or "shower of sparks" of the high temperature filter in the filter housing, the spark arrestor would contain, and cool any sparking material before it exits into the mine atmosphere. The spark arrestor system was equipped with an engine shutdown that was wired to a Skorsky helicopter temperature sensor. This sensor was located in the piping between the exhaust of the filter housing and the entrance to the spark arrestor. If the temperature reaches 1100 ^{0}F the engine would shutdown, indicating that the high temperature filter was experiencing a fire or some type of exothermic reaction.

This system allows for the fire or "shower of sparks" to occur, but contains the sparks within the filter housing and the spark arrestor. This spark arrestor will not, nor was it designed to function as a flame arrestor.

<u>No. 2 Wagner 20X – Exhaust Water Injection System</u>

The second shield hauler evaluated was equipped with a water injection system that sprays water directly into the exhaust piping to cool the hot exhaust gases (See Figures Three & Four). This Wagner 20X shield hauler was equipped with a dual filter housing exiting out a single exhaust port. This heavy duty shield hauler was also equipped with a back pressure gauge, located in operator's compartment, but was not in operating condition at the time of the evaluation. The back pressure gauge was replaced while MSHA was on site. The entire exhaust piping, including the turbo, was wrapped with insulation.

A temperature sensor was located through a port in the exhaust piping approximately three feet from the turbo. This sensor was wired to a switch that was set to close at approximately 500 ^{0} F, which grounds the water pump, therefore activating the water spray in the exhaust piping. The water spray has a flow rate of approximately 4 gallons per hour, and is located about 18 inches down stream of the temperature switch mounted in the 90 degree bend of the exhaust piping. The system was equipped with a 50 gallon water reservoir.

Two tests were conducted on the No. 2 shield hauler while on site. During the first test the water injection spray system was allowed to run as it would under normal conditions. The engine was operated under full torque stall to get the exhaust temperatures high enough to simulate the conditions that the engine may experience under load. Two thermocouples were used to monitor temperature just down stream of the water spray, and another thermocouple monitored the exhaust gas temperature exiting the filter housing. Skinner had conducted these tests before with successfully cooling the exhaust gases several hundred degrees. Results of the first test indicated that the exhaust gas temperature exiting the filter housing first thermocouple was reading 200 degrees greater than the upstream thermocouple. This could be explained due to the water from the injection spray was cooling the temperature probe on the upstream thermocouple, resulting in false exhaust gas temperature readings. This was explained to Skinner by Tech. Support, and new thermocouple locations were discussed for future testing, that would give a reading that was more indicative of actual cooling potential of the water spray system.

The second test was run without the system water spray connected to the exhaust system. This test showed that the maximum exhaust temperature near the water spray port was approximately 750 degrees F, with the exhaust gas temperature exiting the filter housing indicating 550 degrees F. This test was conducted to get a baseline of the exhaust temperatures under normal operating conditions, without the cooling of the exhaust gases with the water spray.

No. 3 Wagner 20X – Water Scrubber System

The third shield hauler evaluated was equipped with a water scrubber system that cools exhaust gases as they mix with the water in the reservoir (See Figures Five & Six). This heavy duty Wagner 20X shield hauler was equipped with a single filter housing exiting through a single exhaust port. This shield hauler was also equipped with a back pressure gauge, located outside the operator's compartment, which appeared to be functioning properly during testing. The entire exhaust piping, including the turbo, was wrapped with insulation.

This water scrubber was designed and fabricated in Mac's Mining Repair shop in Huntington, UT. The hot exhaust gases enter the scrubber "box" through a four inch opening in the top of the scrubber water reservoir. This pipe extends down through the inside of the scrubber where it splits into two sweeping three inch pipes, and is directed toward the top of the scrubber box. Each three inch pipe enters a larger four inch pipe and extends vertical nearly reaching the top of the scrubber box. As hot exhaust gases flow through these pipes they begin to pull water in with the gases through the opening where the three inch pipe enters the four inch. As the water is pulled to the top of the scrubber, the exhaust gases are cooled and exit the scrubber, but the water drops back down into the scrubber reservoir. The cooled exhaust gases exit the scrubber and are then filtered by a single high temperature filter.

The scrubber reservoir will hold approximately 95 gallons of water when full. The scrubber is also equipped with a thermocouple that is attached to high temperature warning light located in the operators compartment. This light was tested, and activated at approximately 314 degrees F. The light would warn the operator of elevated exhaust temperatures indicating a low level of water in the scrubber.

Several tests were conducted on the No. 3 shield hauler to determine the cooling affect of the scrubber system on exhaust gases. The engine was run at full torque stall, and temperatures of the exhaust gases exiting the filter housing were monitored, as well as back pressure. There were no thermocouple ports available to test the scrubber inlet temperatures. The scrubber water was drained a little between each test to monitor how the scrubber would cool the exhaust with varying amounts of water available. The results are listed in Table One.

SCRUBBER WATER LEVEL	OUTLET EXHAUST TEMP. (F)
FULL	136
¾	148
½	179
¼	270
EMPTY	424
EMPTY(2ND RUN)	446

Table One: No. 3 Wagner 20X shield hauler was operated under torque stall. Scrubber water levels were changed and filter housing exhaust temperatures were recorded.

NOTE: No high temperature filter was used during the testing of the scrubber.

Temperature logging was conducted on the three Wagner 20X shield haulers during the longwall move. Each shield hauler was equipped with two data loggers, and the test will be run on each hauler for 24 hours while operating under normal "longwall move" conditions and work loads. This data will be downloaded by Skinner and emailed to the M&ESD upon completion of the longwall move at Dug Out mine. All temperature logging data was received on August 12, 2004. A summary of the temperature data for all three systems can be found in Table Two. The locations of the thermocouples are as follows:

<u>Shield Hauler No. 1 – Spark Arrestor</u>: One probe located on the inlet to the filter housing, and one probe between the exhaust of the dual filter housing and the spark arrestor.

<u>Shield Hauler No. 2 – Water Injection System</u>: One probe located in the inlet to the dual filter housing, and the second located in the exhaust port of the dual filter housing.

<u>Shield Hauler No. 3 – Water Scrubber System</u>: One probe located in the inlet to the water scrubber, and the second located on the outlet of the scrubber before entering the single filter housing

Conclusion

After evaluating the three systems, the two systems that actually cooled the exhaust before entering the high temperature filters appear to be the best options, when it comes to limiting the filters from high exhaust temperatures. The water injection cooled the hot gases approximately 400 degrees F, and the water scrubber, while operating with full water level, exceeded the injection system's cooling by lowering the exhaust gases approximately 550 degrees F (assuming exhaust gas scrubber inlet temperature was about 750 degrees F).

Unlike the two aforementioned systems that utilize water, the spark arrestor system does nothing to limit the filter from being exposed to high temperature exhaust gases. This system allows the fire or thermal event to occur before any actions are taken. The systems using the water to cool the exhaust gases are taking preventative measures to insure the filter is not subjected to very high exhaust temperatures which could result in a filter fire.

The scrubber system displayed the most cooling ability in the limited tests performed at the mine. In terms of fire hazards of high temperature filters being exposed to high exhaust gas temperatures, the scrubber system would be the most affective option of the three systems evaluated. After receiving and reviewing the temperature logging data, the scrubber system seemed to cool the exhaust gases most effectively.

FIGURE ONE: No. 1 WAGNER 20X SHIELD HAULER EQUPPED WITH SPARK   ARRESTOR ASSEMBLY

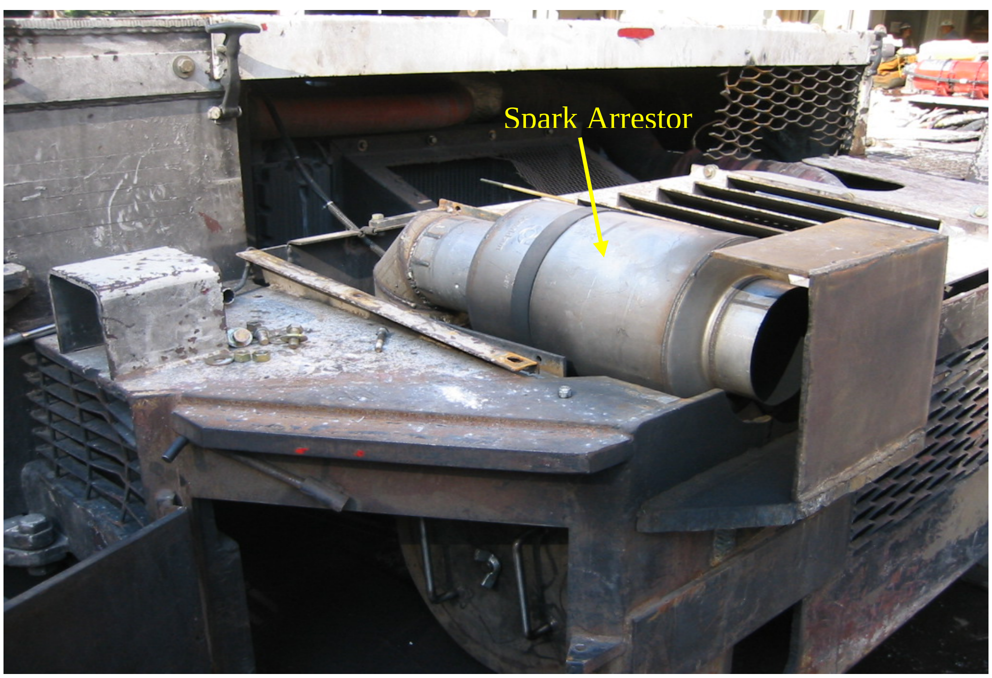

FIGURE TWO: SPARK ARRESTOR SYSTEM

FIGURE THREE: No. 2 WAGNER 20X SHIELD HAULER EQUIPPED WITH WATER INJECTION SYSTEM

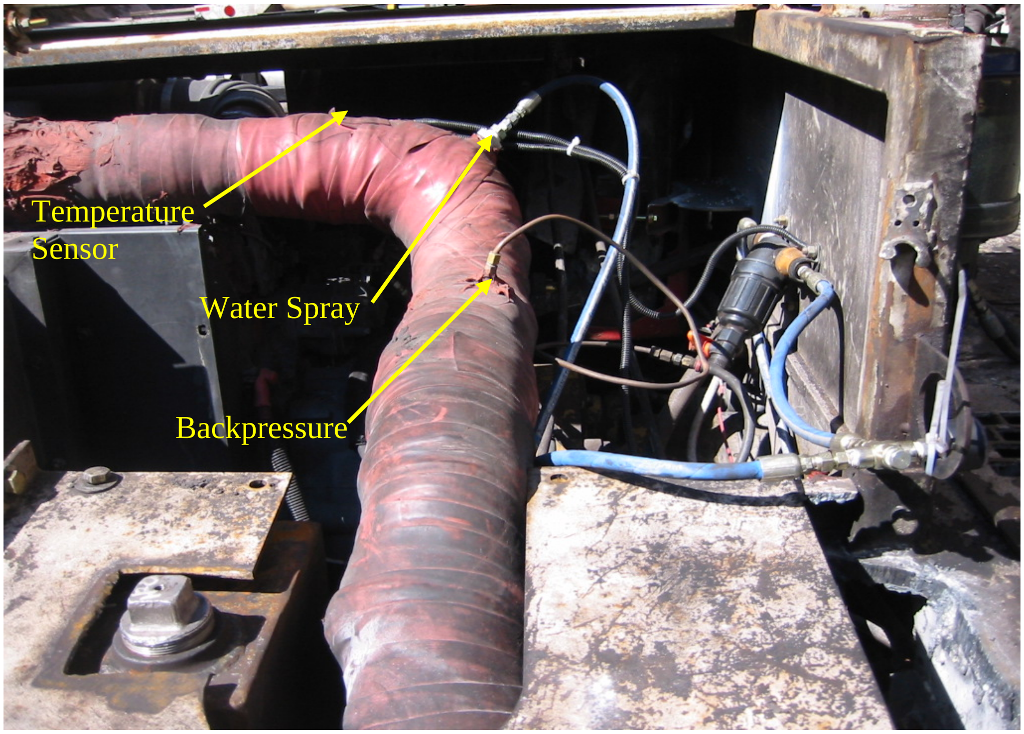

FIGURE FOUR: WATER INJECTION SYSTEM

FIGURE FIVE: No. 3 WAGNER 20X SHIELD HAULER EQUIPPED WITH WATER SCURBBER SYSTEM

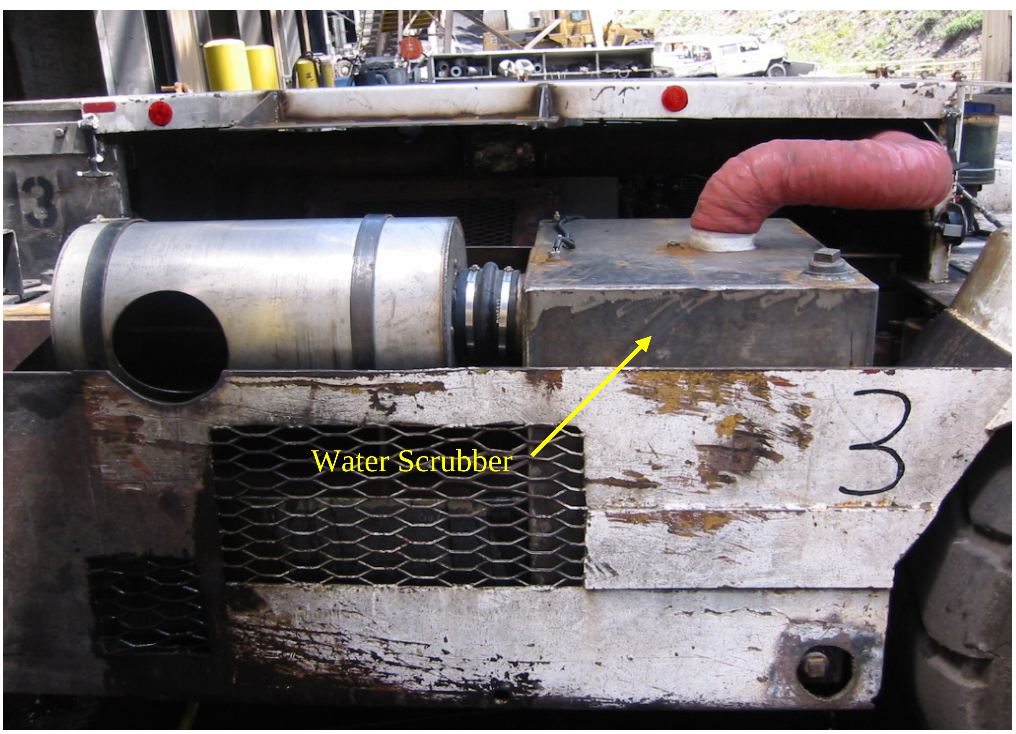

FIGURE SIX: WATER SCRUBBER SYSTEM

System Used on Wagner 20X Shield Hauler	Maximum Temperature (^oF)	Average Temperature (^oF) *
Spark Arrestor (Cool Side)[1]	851	459
Spark Arrestor (Hot Side)[2]	918	466
Water Injection (Cool Side)	**	**
Water Injection (Hot Side)	837	357
Water Scrubber (Cool Side)	404	108
Water Scrubber (Hot Side)	785	226

Table Two: Summary of temperature data taken over a 24 hour period during typical long wall move.

*The average temperature is calculated over a 24 hour period. The data logger operates and records throughout the entire test period. During this time period the equipment is operated under load and there are times when the equipment may be idling or shut off. This indicates an average temperature that is lower than if average temperature was calculated while equipment was pulling shields only.

[1]Cool side temperature indicates location of temperature probe. This is the temperature on the outlet side of the dual filter housing for the spark arrestor system and water injection system. The cool side location for the water scrubber is the outlet of the scrubber, entering the single filter housing.

[2]Hot Side temperature indicates location of temperature probe. This is the temperature on the inlet side of the dual filter housing for the spark arrestor system and water injection system. The hot side location for the water scrubber is the inlet side to the scrubber.

**Data logger malfunction.

UNITED STATES DEPARTMENT OF LABOR
Mine Safety and Health Administration

Laboratory Determination of Ignition Temperatures for Fiber Glass Filters Loaded with Diesel Particulate Matter, Sufco Mine, Mine ID 42-00089, Salina, Utah

PAR 0090142 A50
August 2004

By

DAVID S. CREAMER, Chemist

-Originating Office-

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Table of Contents

Introduction

The Quality Assurance & Materials Test Division (QA&MTD), Approval and Certification Center (A&CC) conducted tests as part of the technical assistance to the Mechanical and Engineering Safety Division (M&ESD). The purpose of this investigation was to determine ignition temperatures of two materials deposited on fiber glass filters: Diesel Particulate Matter (DPM) and a mixture of used engine oil & Diesel fuel.

Abstract

In a Setchkin furnace, substantially higher air temperatures are required to spontaneously ignite Diesel Particulate Matter (DPM) than those temperatures needed to ignite a mixture of used engine oil and Diesel fuel when these materials are deposited on fiberglass filters.

- Deutz 1012 DPM on a Donaldson P604516 filter can be incinerated at air temperatures exceeding 1283 ^{o}F.
- Getman DPM deposited on a Donaldson P604516 filter can ignite and glow at an air temperatures of 982^{o}F.
- "Fresh" DPM deposited on a FST-115-26-NH filter can ignite and glow at an air temperatures of 1182^{o}F.
- Used engine oil and Diesel fuel deposited on a FST-115-26-NH filter (with DPM) can ignite and burn at an air temperatures of 561^{o}F.

Background

MSHA has received reports that filters used to remove particulate from the exhaust of Diesel engines in outby sections of underground coal mines have ignited. The M&ESD provided all of the materials to be tested:

- On June 23, 2004, we received three Donaldson (high temperature, P604516) filters. All three filters were reported to be from the Sufco Mine (Mine ID 42-00089) and said to have ignited and burned while in use. One of the filters (taken from a Getman tow truck) had been "washed". The other two filters had been taken from a road grader.
- On the same date, we received a container of DPM. The container was marked "DPM Particulate Fluff from Diesel powered air compressor. Deutz 1012, Sufco Mine".
- On July 7, the M&ESD provided the QA&MTD with a section of Diesel exhaust filter said to be loaded with 'fresh' DPM. The section of filter was identified as part of a FST-115-26-NH filter and was approximately 2 feet long and 9 inches (29 pleats) wide. The section of filter was black with DPM.
- On July 14, we received a spray bottle containing a mixture of used engine oil and Diesel fuel.

Experimental Approach
The QA&MTD used a Setchkin furnace to determine a Spontaneous Ignition Temperature (SIT) for variations of filter media, DPM and engine oil/Diesel fuel.

SIT determinations are made without a pilot light. The sample is placed in the furnace for 10 minutes during which time it was exposed to heated air. The heated air has a velocity of 5 ft. /min. as per ASTM D 1929-96, Standard Test Method for Determining Ignition Temperature of Plastics (Procedure 8.2).
In the first nine tests (*i.e.* Tests of Burned-over Donaldson Filter Media with Supplementary DPM), we placed the samples in pans. In subsequent tests, we placed the filters directly in the hot air flow with the folds running vertically.

During the handling of filter samples, filter media and DPM were lost due to movement of the samples and the accuracy of weighing was adversely affected. The samples of filter which we tested included metal screen and fiberglass media.

Figure 1. Setchkin furnace
The furnace is 9.5 inches high. During a test, the sample hangs in the center of a 4-inch wide, vertical tube. Hot air flows upward past the sample.

Tests of Burned-over Donaldson Filter Media with Supplementary DPM
Burned-over section of the Getman filter were cut out. The section included wire screen and fiberglass. Out of that section, we cut 3 pleats of the filter each approximately 20 mm x 20 mm. Each of these pleats had a single fold. The effective area of each cut pleat was 40 mm x 20 mm. All three pleats had a total effective area of 2400 square mm (3.7 square inches) and a total mass of 1.47 grams. All of the visible DPM had been burned away. The fiber glass filter media had a rusty, red color.

For the first four tests, the filter pleats were put into a pan (1½ inch in diameter by ½ inch deep) and loaded them with successively higher amounts of DPM and then placed them into a Setchkin, hot air furnace for 10 minutes periods at successively higher temperatures. For subsequent tests, no additional material was added, but air temperatures were increased as testing continued. The maximum amount of DPM deposited on the filter pleats was approximately 0.2 grams. The DPM deposited on these pleats was from the "Deutz 1012, Sufco Mine" container.

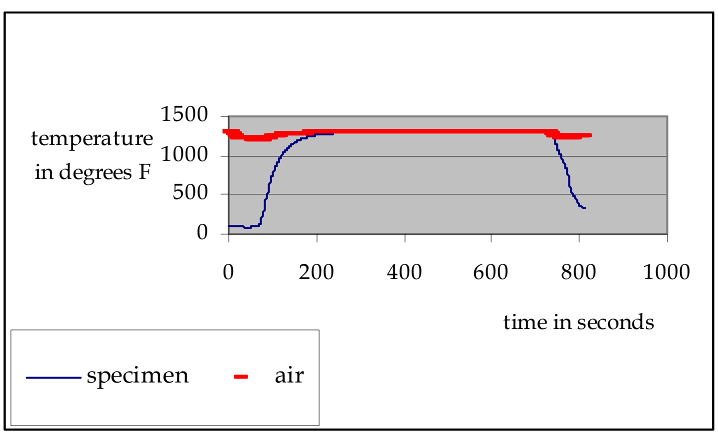
The air temperatures to which the samples of filter & DPM were exposed ranged from 542 °F to 1305 °F.

We observed no smoke from the samples during any of the tests. The samples did not exhibit evidence of exothermic activity during the tests. The samples were effected only at the upper temperature ranges:

- When air temperature exceeded 1150 °F some of the DPM agglomerated and charred.
- When air temperature exceeded 1283 °F all of the DPM appears to have incinerated, but did so with out any perceptible heat of combustion or flame. The DPM appears to have left a white ash after incinerating.

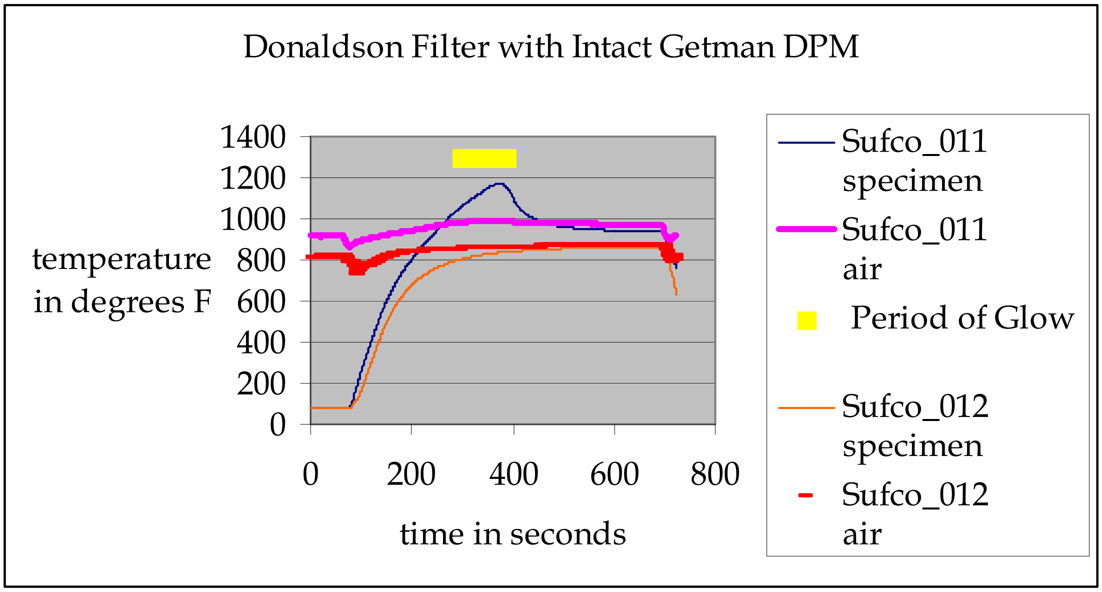
For test results, see Table 1.

Graph 1. The last sample with Deutz 1012 DPM. Although all of the DPM was incinerated, no heat of combustion was detected.



Tests of Donaldson Filter Media with Intact DPM
A section of the Getman filter which carried significant deposits of DPM was cut away. This section was about 6 inches long x 1.5 inch wide x 2 inches deep. We quartered this section into pieces about 1.5 inches long. These pieces averaged about 14 grams each.

Three ignition tests were performed on the three pieces of filter. The pieces introduced into air temperatures of 741 °F and 812 °F did not ignite; they were not visibly affected by the test. However, the third piece ignited at an air temperature of 982 °F. The sample glowed for 2 minutes after which time combustion ceased. No flame or smoke was observed. For test results, see Table 2.



Graph 2. The Sufco_011 sample began to glow at an air temperature of 982°F. The sample temperature had started to rise prior to ignition.

The Sufco_012 sample failed to ignite after air temperature reached 872°F.

Tests of FST Filter Media with Intact DPM

The QA&MTD performed a series of five ignition tests on samples taken from the section of FST filter provided by M&ESD. Each sample was approximately 1.5 inch long x 1.5 inch wide x 1.75 inch deep. Sample was placed into a Setchkin, hot air furnace for 10-minute periods at successively higher temperatures.

The first two samples were placed in the furnace where the maximum temperature was 864 °F, and then 958 °F. The exposure to these temperatures did not visibly effect the samples significantly. We observed no smoke, flame, glow or exothermic activity from the samples during these tests.

During the third test, the sample began to exhibit evidence of exothermic activity when the air temperature in the furnace passed 978 °F. The DPM deposited on the filter was not completely incinerated when the ten minute test period expired. The maximum temperature the furnace reached during those ten minutes was 1098 °F. Observed no smoke, flame or glow from the sample during this test.

Both of the last two samples were exposed to air temperatures above 1145 °F. Both of these samples exhibited exothermic activity which lasted for approximately 1½ minute. Both samples visibly glowed. We saw no DPM on the filters after the samples were removed from the furnace. (i.e. The samples were white after the test.) We observed no smoke or flame from the samples during these tests. For test results, see Table 3.

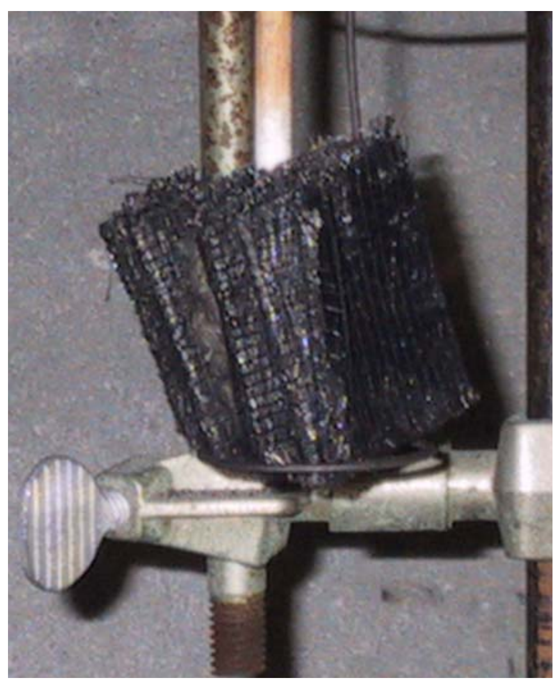


Figure 2. This is the FST sample, before it was placed in the furnace. The sample is approximately 1.5 inches high. The white tube covers a thermocouple which is embedded in the sample.

<u>Tests of FST Filter Media with Intact DPM and Supplementary Engine Oil/Diesel Fuel</u>

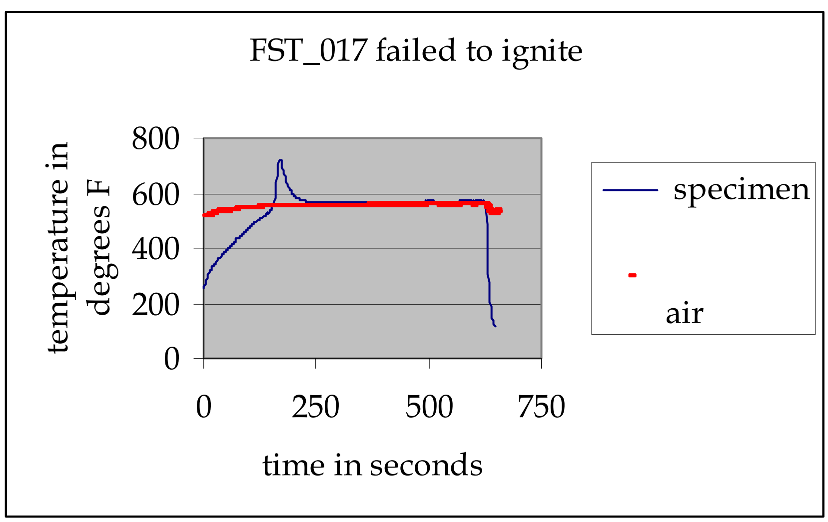
The QA&MTD performed a series of 12 ignition tests on pieces taken from the section of FST after wetting the pieces with a mixture of engine oil and Diesel fuel. Each piece was approximately 1.5 inch long x 1.5 inch wide (*i.e.* four pleats) x 1.75 inch deep. Each wetted sample was placed into a Setchkin, hot air furnace for 10 minutes (or until after it ignited).

The air temperatures in the furnace ranged from 504 $^{\circ}$F to 815 $^{\circ}$F. Each sample began emitting smoke soon after insertion into the furnace; it was a white smoke and fairly thick. The lowest ignition temperature observed was 561°F.

The minimum ignition temperature found (561°F) was attained during an ignition test where the initial air temperature in the Setchkin was 548°F. When the amount of engine oil/Diesel mixture deposited on the filter was varied from 0.02 grams per square inch to 0.09 grams per square inch and the initial air temperature of the furnace held in the 542°F to 550°F range, we found that ignition occurred at 0.09 grams per square inch, but did not occur at 0.02 grams per square inch or 0.04 grams per square inch. However, in those instances where the samples did not ignite, the samples did exhibit exothermic activity.

In the two tests where 0.02 grams of oil per square inch and 0.04 grams of oil per square inch were deposited on the filter, and no ignition was observed. When viewed along side the test on July 15, where a sample with 0.09 grams of oil per square inch ignited, we see an indication that the more engine oil/Diesel deposited on the filter, the more likely the filter is to ignite in an initial air temperature of 542°F to 550°F. For test results, see Table 4.

Graph 3. The exothermic energy generated during this test was not sufficient to ignite the sample.



Discussion of the Test Results

The QA&MTD ran two series of tests with the Donaldson P604516 filter from the Getman Tow Truck: one series with supplementary, "Deutz 1012" DPM and the other series with intact, Getman DPM. The Deutz DPM appears to be more refractory than the Getman DPM.

- At temperatures exceeding 1283 ^{o}F, the Deutz DPM incinerated, but did so with out any perceptible heat of combustion or flame.
- The Getman DPM spontaneously ignited at 982^{o}F. Glow was the form of combustion.

The QA&MTD ran two series of tests using the FST filter with 'fresh' DPM: one series without supplementary material and one series with a mixture of used engine oil and Diesel fuel.

- The FST with only DPM spontaneously ignited at 1182^{o}F. Glow was the form of combustion.
- The FST with both DPM and the mixture spontaneously ignited at 561^{o}F with a flash. For tests where ignition occurred, the flaming combustion in these samples appeared to be limited to the burning of the engine oil/Diesel mixture.
    - The burning lasted for a short period (averaging about 54 seconds) after which combustion ceased.
    - The mass lost during the combustion was essentially the same as the mass of the engine oil/Diesel mixture sprayed unto the pieces of filter.
    - The samples had essentially the same appearance after the test as before the test.

Test Data

Sufco test	estimated total mass of DPM piled unto the filter prior to the test	initial air temp. for the test	max. air temp. during the test	Sample glow	test results
1	0.003 grams	542°F	555°F	n.a.	No smoke, no flame, no glow, no exothermic activity.
2	0.027 grams	566°F	605°F	n.a.	No smoke, no flame, no glow, no exothermic activity.
3	0.128 grams	636°F	652°F	n.a.	No smoke, no flame, no glow, no exothermic activity.
4	0.215 grams	669°F	671°F	n.a.	No smoke, no flame, no glow, no exothermic activity.
5	0.215 grams	742°F	751°F	n.a.	No smoke, no flame, no glow, no exothermic activity.
6	0.215 grams	770°F	-	n.a.	No smoke, no flame, no glow, no exothermic activity.
7	0.215 grams	909°F	-	n.a.	No smoke, no flame, no glow, no exothermic activity.
8	0.215 grams	1150°F	1178°F	1167°F	No smoke, no flame, no exothermic activity. The observed glow was not brighter than the furnace interior. Some of the DPM agglomerated and charred over a 10 minute period.
9	0.025 grams	1283°F	1305°F	1227°F	No smoke, no flame, no exothermic activity. The observed glow was not brighter than the furnace interior. Essentially all of the DPM was incinerated over a 10 minute period.

Table 1 Data from Tests of Burned-over Donaldson Filter Media with Supplementary DPM

Sufco test	Pre-test mass of sample	initial air temp. for the test	max. air temp. during the test	Sample glow	test results
10	14.43 grams	741ºF	766ºF	n.a.	No smoke, no flame, no glow, no exothermic activity.
11	17.32grams	920ºF	987ºF	982ºF	No smoke, no flame. Exotherm preceded glowing combustion.
12	11.33 grams	812ºF	872ºF	n.a.	No smoke, no flame, no glow, no exothermic activity.

Table 2 Data from Tests of Donaldson Filter Media with Intact DPM

FST test	Total pre-test sample mass	initial air temp. for the test	max. air temp. during the test	Sample glow	test results
1	14.65 grams	828ºF	864ºF	n.a.	No smoke, no flame, no glow, no exothermic activity.
2	10.58 grams	926ºF	958ºF	n.a.	No smoke, no flame, no glow, no exothermic activity.
3	10.49 grams	1063ºF	1098ºF	n.a.	No smoke, no flame, no glow. Exothermic activity. Much of the DPM incinerated over a 10 minute period.
4	10.28 grams	1145ºF	1192ºF	1182ºF	No smoke, no flame. Exothermic activity, glowing combustion. Essentially all of the DPM was incinerated over a 10 minute period.
5	10.14 grams	1250ºF	1290ºF	1274ºF	No smoke, no flame. Exothermic activity, glowing combustion. Essentially all of the DPM was incinerated over a 10 minute period.

Table 3 Data from Tests of FST Filter Media with Intact DPM

FST test	pre-test filter mass	mass of oil deposited on filter media	oil per square inch of filter media	ratio of oil added to mass loss	Duration of burning	initial air temp. for the test	temp. at which ignition occurred	test results
6	10.80 grams	0.78 grams	0.04 grams	0.94	32 seconds	815ºF	861ºF	Smoke, flash of flame followed by burning of oil/Diesel mixture.
7	10.84 grams	1.24 grams	0.06 grams	0.95	64 seconds	771ºF	812ºF	Smoke, flash of flame followed by burning of oil/Diesel mixture.
8	10.32 grams	1.37 grams	0.07 grams	1.05	50 seconds	730ºF	797ºF	Smoke, flash of flame followed by burning of oil/Diesel mixture.
9	10.20 grams	1.26 grams	0.06 grams	0.98	42 seconds	659ºF	680ºF	Smoke, flash of flame followed by burning of oil/Diesel mixture.
10	9.95 grams	1.67 grams	0.08 grams	1.00	77 seconds	650ºF	754ºF	Smoke, flash of flame followed by burning of oil/Diesel mixture.
11	10.36 grams	1.58 grams	0.08 grams	1.10	n.a.	494ºF	n.a.	Smoke and exothermic activity. No glow, no ignition.
12	11.97 grams	1.53 grams	0.07 grams	1.02	42 seconds	592ºF	650ºF	Smoke, flash of flame followed by burning of oil/Diesel mixture.
13	9.41 grams	1.94 grams	0.09 grams	1.01	68 seconds	542ºF	580ºF	Smoke, flash of flame followed by burning of oil/Diesel mixture.
14	11.09 grams	0.46 grams	0.02 grams	0.85	n.a.	504ºF	n.a.	Smoke and exothermic activity. No glow, no ignition.
15	10.44 grams	0.91 grams	0.04 grams	1.02	n.a.	543ºF	n.a.	Smoke and exothermic activity. No glow, no ignition.
16	11.30 grams	not recorded	not recorded	n.a.	<60 seconds	548ºF	561ºF	Smoke, flash of flame followed by burning of oil/Diesel mixture.
17	12.69 grams	0.32 grams	0.02 grams	0.20	n.a.	550ºF	n.a.	Smoke and exothermic activity. No glow, no ignition.

Table 4 Data from Tests of FST Filter Media with Intact DPM and Supplementary Engine Oil/Diesel Fuel

Small Scale Filter Ignition Testing:

Heat Gun tests conducted on diesel particulate matter accumulations on high temperature diesel particulate filter media.

Date: August 25, 2004

By: Michael Hockenberry, Fire Protection Engineer

Introduction:

This report describes tests completed to determine the ignition temperatures, and burning characteristics of used high temperature diesel particulate filters with accumulations of diesel particulate matter. High temperature filter samples were taken from two different Donaldson P604516 filters, and one from a Filter Service & Testing Corporation FST-115-26-NH. One Donaldson filter sample was taken from a filter that had been involved in a “shower of sparks” incident on a Getman tow tractor. The second Donaldson filter sample had been efficiency tested on MSHA’s CAT 3306 PCNA engine. The FST filter had also been previously efficiency tested on MSHA’s test engine, and had accumulated DPM during 2 hour test runs.

The test setup was an apparatus designed by the Mechanical and Engineering Safety Division. A small filter sample (approximately 5x5 inches) was placed between two metal pipe flanges with thermocouples embedded on both sides of sample. The filter was heated by a Leister Hotwind S commercial heat gun, located approximately 5 inches from filter sample. The heat gun’s hot air was ventilated or pulled through the piping by a commercial shop-vac, connected in line on the opposite side of the heat gun. All metal piping used was approximately 2 ½ inch inside diameter. See Figure 1 for test setup.

The intent of this testing set up was to conduct small scale testing on high temperature filters (with accumulated DPM) in order to determine the ignition temperature of the DPM. Several attempts were made with this set up, but problems were encountered. The way the piping was constructed made it nearly impossible to observe the sample that was being tested. The second problem was the set up created difficulty in observing any sparks that may occur during testing. The final problem experienced in this set up was the filter sample needed to be flattened when placed in between the pipe flanges. To better simulate how the filters media is used in the field, the filter media needed to be intact exposing pleats to the heat source.

These issues were resolved by reconfiguring the test setup to better evaluate the exact moment if and when the DPM ignites. The second test setup used a sample approximately 6x5 inches of the filter media, including support screen. This sample exposed approximately 10 – 12 pleats to the heat. The sample was secured vertically in a metal rack. There were two thermocouples located within the filter sample to monitor for surface temperature. The same heat gun was reused in this modified test set up. Figure 2 shows modified test setup.

The test procedure for the heat gun test is as follows:

1. Secure filter sample in rack, with thermocouples in desired locations.
2. Heat gun is then run through a 5-minute warm up process.
3. The filter sample is then placed directly in front of exhausting hot air exiting the heat gun.
4. The starting distance of the sample from the heat gun outlet is noted.
5. When temperature of thermocouples stops rising or fluctuating, sample is moved closer to the heat gun to increase sample temperature.
6. This is repeated until DPM on sample ignites or until sample can not be moved closer to heat gun.
7. Filter sample surface reactions are observed, as well as temperatures are recorded.

<u>Results:</u>

The following details the setup, observations, and temperatures recorded during the three filter sample tests. The method of testing the small high temperature filter samples was a simple test to determine approximate temperatures at which DPM would ignite on filter media. The testing resulted in a range of temperatures at which the samples actually displayed surface combustion, yet typically this was difficult without the addition of oils or diesel fuels. The lowest ignition temperature of the DPM on filter media was 875 ^{o}F. No accelerants were applied to filter samples during the following heat gun testing.

Test 1:

Filter Manufacturer: Donaldson (Washed) From Getman Tow Tractor
Filter Model: P604516 High Temp. Filter
Sample Size: 6x5 inches, 10 pleats (Approx)
Heat Source: Leister Hotwind S commercial heat gun
Temperature Measurement: 2 thermocouples mounted at peaks and valleys of pleats, embedded in filter media.

Observations during testing:

- No visual change of filter sample until sample was moved within 8 inches from heat gun. At this point the, the temperature reached approximately 875 ^{o}F. At this temperature the right side of sample began glowing red, glowing combustion then propagated across face of sample. See Figure 3 for filter sample with glowing surface combustion.

Test 2:

Filter Manufacturer: Donaldson (Washed) From Getman Tow Tractor
Filter Model: P604516 High Temp. Filter
Sample Size: 6x5 inches, 10 pleats (Approx)
Heat Source: Leister Hotwind S commercial heat gun
Temperature Measurement: 2 thermocouples mounted at peaks and valleys of pleats, embedded in filter media.

Observations during testing:

- Moved sample closer continuing to increase filter sample temperature. No visual changes until sample reached approximately 950 ^{o}F. At this temperature glowing red surface combustion of the DPM propagated across the sample.
- Heat was then removed and DPM continued to combust and glow for 10 - 15 seconds.

Test 3:

Filter Manufacturer: Filter Service and Testing Corp.
Filter Model: FST -115-26-NH high temperature filter
Sample Size: 6x5 inches, 10 pleats (Approx)
Heat Source: Leister Hotwind S commercial heat gun
Temperature Measurement: 2 thermocouples mounted at peaks and valleys of pleats, embedded in filter media.

Observations during testing:

- Heated sample up through 1000 ^{o}F without any signs of ignitions of the DPM. At approximately 1030 ^{o}F media began to glow red, but no signs of glowing surface combustion. Maximum temperature was approximately 1080 ^{o}F without any surface combustion, only the media glowed a dull red.
- After removing heat the surface of the media that was subject to the heat did not have any black DPM. The DPM did thermally decompose while exposed to such high heat, but did not ignite and visibly burn.

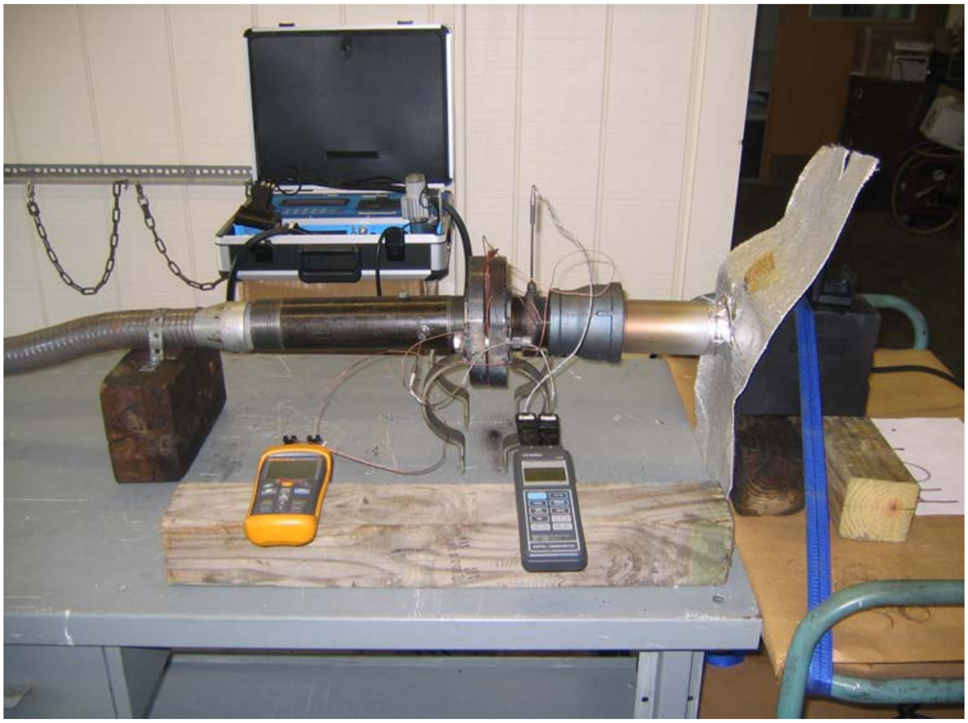


Figure 1: Original Heat Gun Test Setup.

Figure 2: Modified Heat Gun Test Setup.

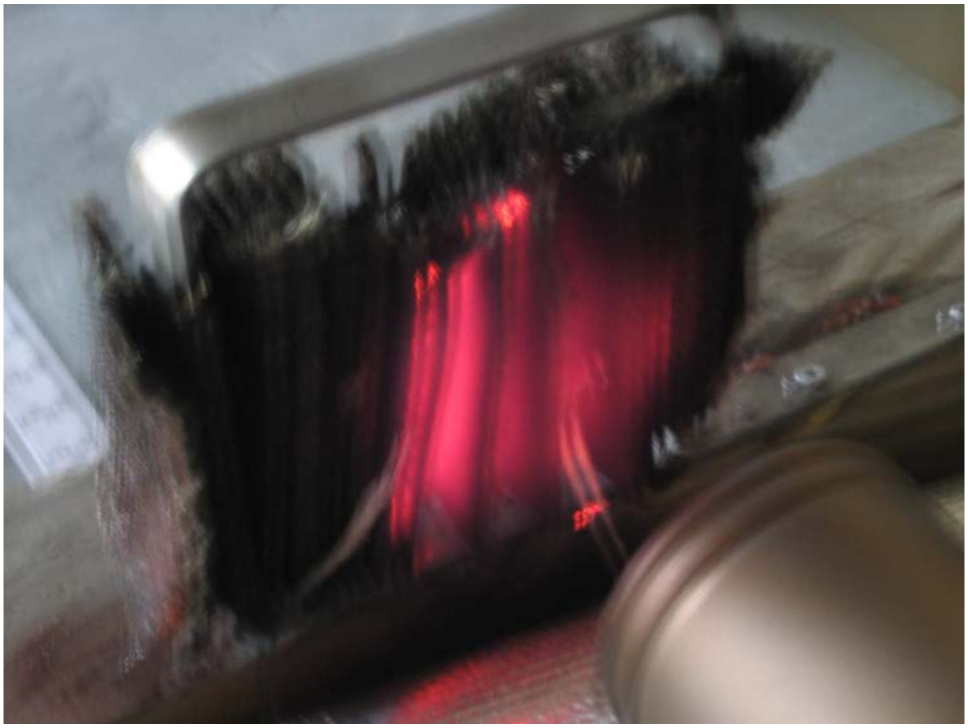


Figure 3: Filter Sample with Glowing Red Surface Combustion.

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Filter Ignition Tests:
Heat Gun Tests of used High Temperature Filters with Accelerants Added

Date: 15 July 2004
By: Russell Stackpole, Mechanical Engineer

Introduction:

This report describes tests completed to determine the ignition potential and characteristics of used high temperature filters (with DPM accumulations) when an accelerant is applied to the filter surface. The filter samples tested were taken from a Filter Service and Testing Corporation FST-115-26-NH filter and a Donaldson P604516 filter. Both were previously efficiency tested on MSHA's CAT 3306 PCNA engine and had accumulated DPM during 2-4 hour test runs.

The accelerant used in the test was either an approximate 50/50 mix of new engine oil[1] and diesel fuel or an approximate 60/40 mix of used engine oil[2] and diesel fuel. These accelerants were applied to the filter samples using a spray bottle applicator and application amounts varied from heavy to light.

The test setup used a sample of approximately 6x5 inches of the filter media, encompassing about 12 filter pleats. The sample was held vertically in a rack. Three thermocouples were embedded in the front face of the filter media (collecting face for DPM) under the wire screens. These would measure the filters "surface" temperature at three locations on the filter during the test[3]. The heat source used to heat the filters was a Liester *Hotwind S* commercial heat gun. Heat was gradually applied to the filter by moving the heat gun progressively closer to the filter sample. Figures 1 and 2 shows the test setup used for the experiments.

[1] 15W-30 engine oil.
[2] Used engine oil drained from a CAT 3306 PCNA at MSHA.
[3] These temperatures would be representative of the filter sample's temperature, not necessarily the temperature of the heated air blown on the filter, which is potentially much higher.

Figure 1: Filter Sample placed on rack for testing, with thermocouples applied.

Figure 2: Sample ready for testing showing heat gun in position.

Results:

The following details the setup and observations recorded during the 3 tests completed. All three tests were videotaped to document the tests, and the video is available for review.

Test 1:

Filter Manufacturer: Filter Service and Testing Corp.
Filter Model: FST-115-26-NH high temperature filter
Sample Size: 6x5in., 12 pleats (approx)
Heat Source: Leister Hotwind S heat gun
Accelerant: 50/50 mix of new engine oil and diesel fuel, heavy application (3 sprays), left to sit for ~3 hours before test.
Temperature Measurement: 3 thermocouples mounted at peaks of pleats, embedded in filter media
Test Time: 7 minutes, approx.

Image of DPM Ignition: see Figure 3

Observations during test:

- Small surface sparks, or flashes, on filter at 320F
- More sparks 320-400F
- Filter smoking 400-500F
- Sparks and isolated larger ignitions of DPM at 480F
- More isolated ignitions of DPM 650-700F
- Large continuous DPM ignition 700-800F
- Another continuous DPM ignition 700-800F

Test 2:

Filter Manufacturer: Donaldson.
Filter Model: P604516 high temperature filter
Sample Size: 6x5in., 12 pleats (approx)
Heat Source: Leister Hotwind S heat gun
Accelerant: 60/40 mix of used engine oil and diesel fuel, heavy application (2 sprays), left to sit for overnight before test.
Temperature Measurement: 3 thermocouples mounted at peaks of pleats, embedded in filter media
Test Time: 6.5 minutes, approx.

Image of DPM Ignition: see Figure 4

Observations during test:

- Small surface sparks, or flashes, on filter at 250-300F
- Filter Smoking 300-450F
- More sparks 300-400F
- Heavy Filter smoking 400-500F
- Sparks and isolated larger ignitions of DPM at 550-650F
- More Sparks DPM 550-675F
- Large continuous DPM ignition 750F, with burn temp ~970F
- Another continuous DPM ignition 750F
- Another continuous DPM ignition 600-900F
- Another continuous DPM ignition 600-900F
- DPM burning after heat source removed

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Test 3

Filter Manufacturer: Donaldson.
Filter Model: P604516 high temperature filter
Sample Size: 6x5in., 12 pleats (approx)
Heat Source: Leister Hotwind S heat gun
Accelerant: 60/40 mix of used engine oil and diesel fuel, light application (2 sprays – one on video), tested immediately after second spray.
Temperature Measurement: 3 thermocouples mounted peaks of pleats, embedded in filter media
Test Time: 6 minutes, approx.

Image of DPM Ignition: see Figure 5

Observations during test:

- Filter Smoking 250F
- Small surface sparks, or flashes, on filter at 275-300F
- More sparks 250-350F
- More sparks 350-400F
- Heavy Filter smoking 400-500F
- Near Continuous Sparks 550-700F
- Continuous Burning at end cap potting compound
- Heavy Sparks and isolated ignitions of DPM 550-675F
- Large continuous DPM ignition 750-800F
- Another continuous DPM ignition 650-750F

Conclusion:

The tests described in the previous section show that the DPM matter collected on a high temperature filter has the potential to ignite and burn at reasonably low temperatures if an accelerant hydrocarbon is present on the filter. Whereas dry particulate might be expected to burn in the 900-1100F range, when a hydrocarbon is present to act as an aid to ignition, the temperature at which the DPM may ignite is reduced significantly.

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The method of test used here is not capable of determining an exact ignition temperature for DPM in the presence of diesel fuel or engine oil. However, the tests indicate that the ignition temperature can be well below the 900-1100F range of dry particulate. Ignition under the conditions used in this test is virtually guaranteed at 800F. From the limited data presented here, ignition of DPM in the presence of fuel or engine oils is highly likely when the temperatures of the filter reach 550-700F.

Though the data presented here appears to show that significant sparks are produced above only 300F, it must be understood that the temperature data reported is only a record of three thermocouples embedded in the filter pleats. This method of measurement cannot account for localized heating of certain areas of the filter, nor accurately represent the temperature of the heated air striking the filter surface. Accounting for these limitations, it is still clear that filter ignitions can be a real concern when exhaust temperatures climb above 600F.

Figure 3: Image of Continuous DPM burning from Test 1 (from video).

Figure 4: Image of Continuous DPM burning from Test 2 (from video).

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Figure 5: Image of Continuous DPM burning from Test 3 (from video).

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Mechanical Engineering and Safety Division
Diesel Laboratory

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Test Lab Report:

High temperature filter ignition tests conducted on a CAT 3306PCNA engine using a dual element inline filter canister connected to the exhaust manifold.

PAR No. 090100

Date: August 27 2004

By: Russell Stackpole, Mechanical Engineer

Major Components Used in Tests:

1. CAT 3306 PCNA Engine, serial # 23C994.
2. EIMCO water-cooled exhaust Manifold.
3. Adaptor Flange and 4" pipe for connection to exhaust manifold.
4. Dual (two-filter) in-line filter canister, typical of field installations (built by Gary Poteet).
5. 1000 HP GE dynamometer with Superflow ProATC control system.
6. Logic Beach Hyperlogger portable data logger.
7. Video camera and VCR for recording events at the filter can exhaust outlet.

Filters Used for Testing:

1. Donaldson P604516 "special[1]" filters received new and loaded with DPM from CAT 3306 engine at MSHA.
2. Filter Service and Testing Corporation[2] (FSATC) used filters (mixed bag received for recycling; probably both inby and outby filters).
3. Donaldson P604516 "Special" filters; received from Canyon Fuels LLC after being used 25-35hours on Mine equipment with a Mercedes 906 electronic engine; 2 sets of dirty filters, 1 set of used filters laundered and ready for re-use.

[1] Donaldson P604516 "Special" filters are the newest generation of this high temperature filter which uses a ceramic potting agent to attach the end caps. No versions of the P604516 filter using the older silicon potting compound were received for testing, even though it was the older model involved in the field ignition incidents.
[2] FSATC contact: Sim Bunderson.

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4. Donaldson P604516 “Special” filters received from Energy West Mining; 2 pair of filters loaded to “end-of-life” on an inby (water scrubber) machine running a CAT 3306 PCNA engine.
5. FSATC filters; 3 filters loaded at Oxbow Mine on an inby (water scrubber) machine running a CAT 3306 engine.
6. FSATC filters; 3 filters loaded at Oxbow Mine on an outby EIMCO 975 with a CAT 3306 engine.
7. Donaldson P604516 ‘special’ filters; pair received from Canyon Fuels LLC after being used ~77 hours on mine equipment with a Mercedes 906 electronic engine, loaded to backpressure limit for engine.
8. Donaldson P604514 ‘special’ filter; single filter received from Canyon Fuels LLC after being used on an inby CAT3306 with a wet scrubber.
9. FSATC filters which had been previously used by MSHA for efficiency and other tests on a CAT3306.

Introduction:

The following report describes high temperature filter ignition tests completed at MSHA’s A&CC diesel laboratory. These tests were run to attempt to determine the factors that cause filter ignitions that have been reported in the field, and to determine the range of temperatures and conditions that initiate these events. The ultimate use for the data is to determine a maximum safe operating temperature for high temperature exhaust filters in order to prevent future filter fires.

The testing was conducted on a CAT 3306 PCNA engine with a dual element in-line filter canister installed at the outlet of the engine exhaust manifold. This setup uses components typical of field installations, with the exception of piping between the exhaust manifold and the filter canister, which can vary greatly depending on the mining machine.

The tests were conducted to progressively test filters at higher exhaust temperatures and observe the effects on the filter. Observations were looking for behavior such as filters smoking, sparks being emitted from the filter can outlet, glowing of filter media or deposited DPM, ignition of filter, and any

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after-test observations on filter damage or DPM regeneration. Twenty one tests were conducted.

Background:

The use of high temperature filters have become common on outby mining machines to comply with the requirements of the MSHA DPM regulation. The high temperature filters are also being commonly used on inby (primarily water scrubber) permissible machines to provide “better protection” from filter fires in the case when water scrubbers inadvertently run out of water in the scrubber.

In the case of inby applications the Donaldson P604516 high temperature filter has been tested and found equivalent to the standard paper filter. Under high temperature conditions the P604516 filter has been found to be 83% efficient if exhaust temperatures are kept to 650F and below. For higher temperature use, its performance degrades significantly.

The Filter Service and Testing Corporation (FSATC) filters use a similar media to the Donaldson filter and are being used in similar or like applications. MSHA tests of this media have been conducted for high temperature use, but no efficiency results have been published to date. Equivalence tests to paper filters for permissible applications have not been conducted to date.

In field use, cases of these filters igniting were reported to MSHA. Descriptions of these events have varied; from a “shower of sparks”, to “glowing filters”, to actual “open flame” events. MSHA investigated these reported incidents, examined and collected damaged filters. The investigation results are summarized in a separate document.

Based on these incidents, MSHA conducted a series of laboratory tests on filter samples taken from filters collected in the field and from filters efficiency tested at the MSHA diesel laboratory. These tests included ignition tests in a test furnace and a demonstration setup using a filter sample heated using a heat gun. Multiple variables were tested to attempt to identify an ignition temperature for the loaded DPM filter. The results of these tests are also detailed in separate documents.

After discussions within MSHA, and discussions with NIOSH and the Diesel Partnership, it was decided that a test series was needed using a diesel engine with a real filter can installation. Used filters were to be delivered from filter manufacturers or from mine operators, and these were to be tested under “real world” conditions. The primary goal was again to determine the nature of these events and what exhaust temperatures produce ignitions. This report documents those tests.

A tentative test protocol was worked out by MSHA, NIOSH, and other members of the Diesel Partnership. This document may be found in Appendix A. The goals and general methodologies envisioned in the Protocol have been followed in the tests subsequently conducted, though some of the methods suggested in the protocol had to be adjusted in the interest of practicality, time constraints, and knowledge gained as the tests progressed. These types of adjustments and ‘improvements’ were to be expected, considering no person in MSHA or NIOSH had any experience with the type of test being attempted and neither had anyone involved in the protocol observed any of the field incidents to guide them in a laboratory test procedure.

Test Equipment and Method:

The test setup used is shown in Figure 1 and 2. The engine used for the tests was a Caterpillar 3306 PCNA engine, serial number 23C994. This engine is owned by the Getman Corporation and had been previously used for various tests in the diesel laboratory. The last emission test performed on the engine showed that the engine was performing to within the approval specifications for this engine model, though recent emissions data on the engine was not available. The engine was installed on the diesel laboratories 1000HP GE dynamometer.

The tests were controlled and data recorded using the Superflow ProATC control system. Due to damage to the ProATC system caused by a lightning strike during one of the tests, subsequent test data were recorded using a Logic Beach Hyperlogger portable data acquisition system. The primary data of importance in either case was the exhaust temperature exiting the engine and temperature of the filters measured using thermocouples embedded in the filters being tested. Data was also recorded of the torque required to induce the test temperature and data on exhaust backpressure.

For most of the testing, a video camera was focused on the exhaust outlet of the filter can and a VCR recorded the test so that any events occurring would be recorded for later review. Lab personnel also observed the filter canister visually during the test. Notes were taken on the observations and inspection of the filters after the test.

The original protocol envisioned emissions monitoring during testing, but installing emission equipment would have entailed adding fittings and pipe over the exhaust outlet of the canister, obscuring any visual observation. Since it was not known whether emissions monitoring would detect ignition events, while visual observation provided very clear indications, the emissions equipment was not added to the test setup.

The filter canister used for the testing was built by Gary Poteet at Oxbow Mine, with consultations of Sim Bunderson of FSATC. It was a dual element canister in which two filters fit back-to-back which give twice the DPM collection area as a single filter installation. This setup is typical of the field installations for higher exhaust flow engines, such as the CAT 3306. The filter canister had a single outlet hole near the outboard end of the canister, which was 6.5in diameter.

The canister is capable of being used with either FSATC or Donaldson filters. Filters are loaded into the canister through the end, and the lid is tightened down on the filters, compressing the filter gaskets to seal the system. Figure 3 shows filters installed in the canister. For the tests the filter placed into the canister first (closest to the engine) was referred to as Filter #1 and the second filter placed in the can (which aligns with the outlet hole) was referred to as Filter #2. Small gage wire thermocouples were embedded into the filters as they were placed into the canister and connected to the data acquisition system. The normal configuration for these thermocouples was:

- one embedded on the outer media surface (about mid filter length) on Filter #1
- one embedded on the outer media surface of Filter #2 about 6-8 inby the exhaust hole
- One embedded on the inside surface (where DPM is collected) of Filter #2 at the part of the filter that aligns with the exhaust hole.

The filter canister had an input connection using a 4” NPT pipe fitting. A short piece of 4” diameter steel pipe, a pipe coupling, and an adaptor flange was used to connect the filter canister to the EIMCO water-cooled manifold on the CAT engine. This arrangement is shown in Figure 4. The total length between to manifold and canister inlet was 17in. Two sampling ports where drilled in the short pipe and a thermocouple was installed in one and a combination of a thermocouple and exhaust backpressure gage was connected to the other port.

This short coupling to the engine was the most consequential deviation to the draft test protocol. While maintaining a constant engine load and varying pipe lengths to change filter input temperatures was discussed in the protocol, this would have proved too involved to accomplish. In order to test lower temperatures, a pipe length as much as eight feet would probably have been required to test temperatures in the 550-650 range. It was decided that varying the input temperature by changing the torque load on the engine was more practical. While this would vary the oxygen content of the exhaust while at temperature, it was not deemed a significant variable in the results.

As stated above, the method of raising exhaust temperatures was by varying the engine load (torque) on the engine. The rpm for all the load points was always 2200rpm, rated speed. While there were individual variations in some of the early tests, the general method of the tests were as follows:

1. Start engine at idle condition, and stabilize for 10-15 minutes
2. Fast Ramp the engine to the first (lowest) torque/temperature point.
3. Hold this load for 60-75 seconds
4. Fast ramp engine to idle and hold for 10-15 minutes.
5. Repeat steps 2, 3 and 4 at next higher torque/temperature setting.

This stepping was repeated until filter ignition or the top setpoint was reached. Individual variations and single point tests are noted in the results section. Generally, the setpoints used for most of the tests were:

1. 190ft-lb / ~650 F exhaust temperature,
2. 210ft-lb / ~700 F exhaust temperature,
3. 230ft-lb / ~750 F exhaust temperature,
4. 250ft-lb / ~800 F exhaust temperature,
5. 275ft-lb / ~870 F exhaust temperature (rated full load),
6. rated full load with 0.5-1.2% CH4 injected into the engine intake (950-1050F)[3]

Higher temperatures could have been induced using higher concentrations of injected methane. But since no normally running engine, NA or turbo, should subject filters to any higher input temperatures this seemed like an acceptable limit; if filter fires are induced above 1050F, the problem lies with the engine, not the filter.

Some of the filters were loaded with "fresh" DPM from the CAT 3306 engine before testing. Some of these were new filters, some laundered filters, and some were retests of field filters after the initial as-received tests. When loading the filters with DPM, each was loaded using various combinations of load and rpm, most of which were rather low temperature so that organic DPM would not pass through the filter as gas-phase, but collect on the filter media. All DPM loading cycles and times were recorded in the test notes. Most of these loadings used combinations of the following settings:

- idle, ~3g/hr dpm, exhaust ~190F
- 2200rpm, 45ft-lb load, ~44g/hr dpm, exhaust ~425F
- 1400rpm, 55ft-lb load, unknown dpm, exhaust ~300F.

[3] Controlling the methane injection into the intake system to a consistent level proved difficult to stabilize in these short, fast ramp tests. Generally it was attempted to run one ramp to 0.5-0.8% CH4 (yielding 900-1000F) and one at 1-1.2% CH4 (yielding 1000-1070F).

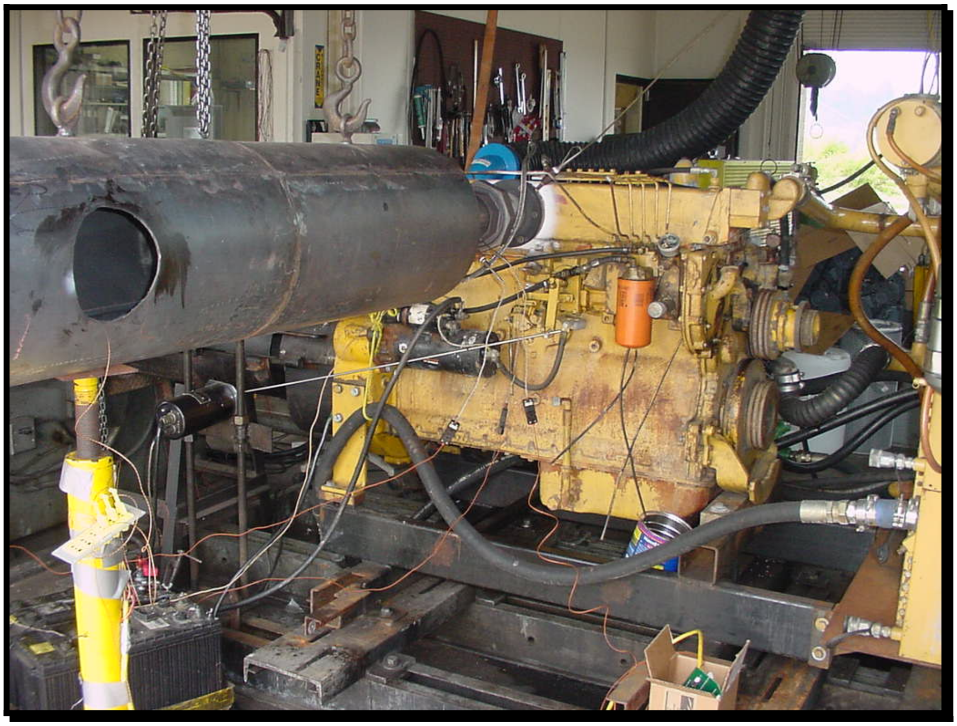

Figure 1. Filter ignition test setup.

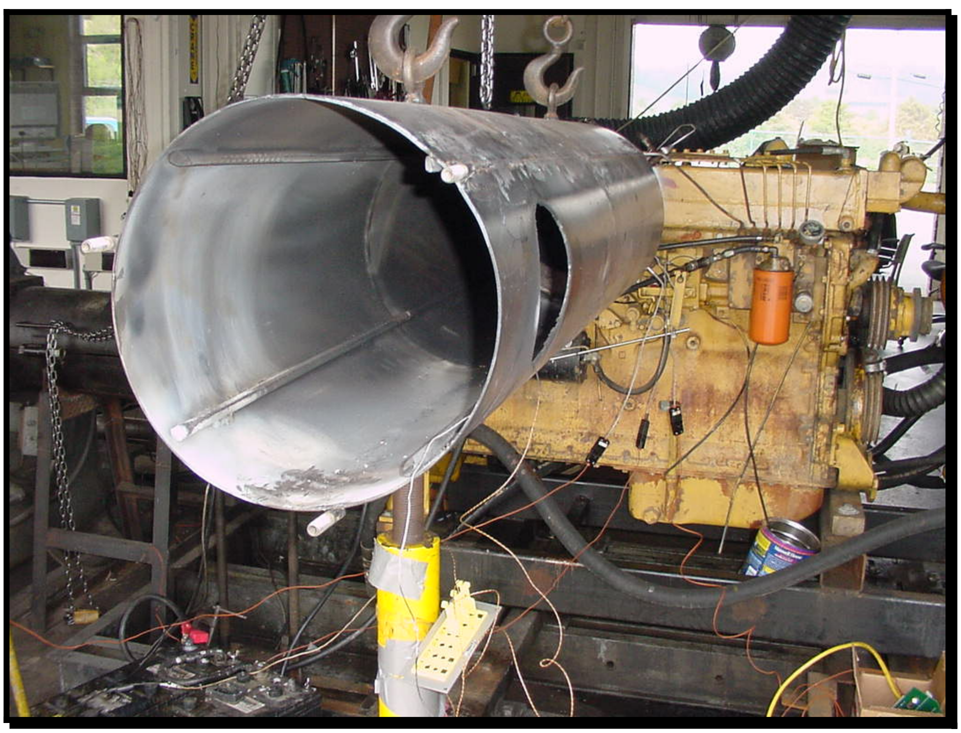

Figure 2. Filter Ignition Test Setup showing inside of filer canister.

Figure 3. Filters installed for testing, with lid ready to close.

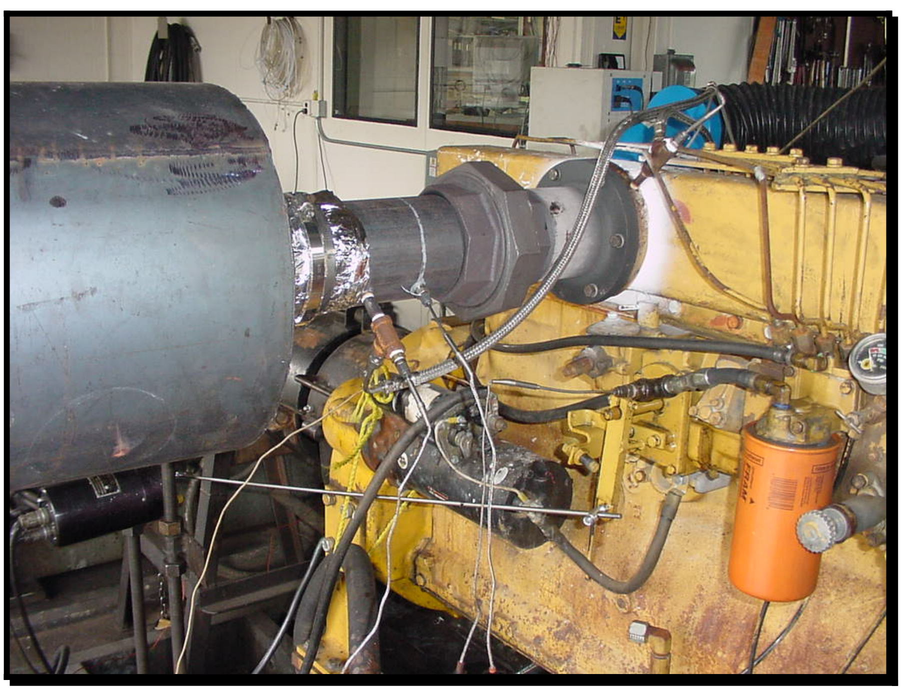

Figure 4. Connection of filter canister to engine manifold.

Results:

Twenty eight tests were conducted. Each test is detailed with a complete data sheet and with graphs and photos in Appendix B. Videotapes from the tests are available for review by interested parties. A summary of the data is shown in Table 1 below.

It is important to note here that the temperatures discussed in this text and listed in Table 1 are the peak ***exhaust*** temperatures *entering* the filter canister. These temperatures are not necessarily the ***filter*** temperature. Due to the thermal lag of heating the filter mass and the short duration of the heating cycle discussed previously, it could be expected that portions of the filter had stabilized at or near the input exhaust temperature, while other portions of the filters had not yet reached that temperature.

For many of the tests, thermocouples were placed directly on the filter media, and the data recorded on these thermocouples indicated that the actual surface temperature of the media could lag 50-150F behind the input exhaust temperature. Therefore the data reported here should not be interpreted literally as *the temperature* at which an ignition event occurred, but that an event occurred *at or before* the stated temperature. For consistency's sake, the data reported here will use this input temperature, but the data in the appendix shows plots from the filter thermocouples when that data was available[4].

The temperature of the ignition events varied from complete filter ignition *at or before* 650F, to no events at all up to temperatures exceeding 1050F. The severity of events when they did occur also varied from a few isolated sparks (Figure 5) or a glowing patch on the observable parts[5] of the filter media (Figure 6), to near total destruction of one or more of the test filters (Figure 7). Examination after testing could show not observation changes to the filter, to severe damage (Figures 8 and 9), depending upon any events that occurred.

[4] Even thermocouple data from the filters surface should not be expected to indicate the exact ignition temperature of a test. Considering that three thermocouples were placed on the filters, and that the filter surface area is quite large, it would only be pure luck if a thermocouple happened to be at the exact location where ignition occurred during the test. Initial evaluation of this data for the DRAFT REPORT did not indicate that a thermocouple had been at the exact point of ignition during any of the tests.

[5] Since not all parts of the filters were observable during the test, and embedded thermocouples were taking data from only certain position of the test filters, it cannot be conclusively said that NOTHING happened on tests which not observable effects were recorded.

On filters where no observable events occurred up to the maximum test temperature, after removing the filters from the canister it was typical to note that Filter #1 (closest to engine manifold) was visibly "cleaner" than when it was installed; the filter may not have ignited, but the test had initiated some form of *regeneration* cycle.

It was found that virtually every filter tested, whether loaded from new at MSHA, tested as-received from the field, or retested after being freshly loaded with DPM would smoke initially as it was heated up to temperatures above ~450-500F. This was interpreted as liberation of organic hydrocarbons from the DPM collected on the filter. Some of these smoke plumes were extreme and could cloud the entire test lab and obscure observation of the filter for some tests.

During the repeated steps in temperature, this smoking became less with each step and increase in temperature, indicating a loss of the organic parts of the collected DPM. This probably has biased some of the ignition or sparking data towards higher temperatures, but without a very large sampling of field filters[6], a long duration research program, and the luxury to use a single pair for only one temperature excursion, this stepping test provided the only opportunity to test several temperatures on the filters available.

The liberation of organics at higher exhaust temperatures either creates an ignitable atmosphere within the filter canister, or is an initial ignition source which then ignites the inorganic carbon content on the filter. Either way it is surely a contributor to filter ignitions. The variables that contribute to this liberation (engine type and condition, machine use conditions, inby/outby machine, etc.) could create a test program far beyond the scope of this project. Suffice it to say that inby machines with cooled exhaust and generally equipped with old engine designs would have higher organic content on the filter (which should never have a chance to be liberated due to the low exhaust temperatures). However it is completely within

[6] For example, we would need two major groups (Donaldson and FSATC). These two groups would have two sub-groups (inby and outby). We ran the stepping test at 6-7 temperature levels. So for each subgroup, 7 pair (14 filters) each loaded similarly would be needed, and two subgroups per group (14 pairs – 28 filters) and two groups (28 pairs – 56 filters all documented!). And if the subgroups are divided further by say old Tier I and new Tier II engines, the quantity of filters required nearly doubles again. This is not possible, nor necessary for identifying a maximum safe temperature for the high temperature filter.

reason to expect outby machines with high temperature filters to build up various levels of organic carbon materials on the filter depending on many factors in machine design and how it is used.

In the tests conducted it was learned that the conditions that promote, if not directly cause, filter ignitions and sparking behavior is rapid heating followed by higher oxygen contents in the exhaust. This is exactly what happens when a machine is throttled to high load to perform a task, then the operator lets of the throttle and the engine idles down quickly, leaving a hot filter in an oxygen-rich exhaust. This is how the step test evolved as the project progressed; the rapid heating and cooling cycle can promote if not ignition (some filters were clearly on fire before ramping the engine back to idle) then exacerbate the ignition into an inferno that consumes the DPM, the filter media, and melts the *steel* screen mesh on the media and sometimes melts the outer structural *steel* screen on the filter. In fact, in a few cases the filter thermocouples happened to be located where ignition occurred, and temperatures from 1800-2000F were measured during the fire.

The tests show clearly that these events as described from field incidents can be easily recreated and are not at all some isolated event. In fact the relative ease of causing them was somewhat surprising, as these filters have been tested repeatedly by MSHA (for efficiency) and no ignition events had been noted. Field events, and the tests reported here that try to duplicate the effect, point to it is the way they are *used on a machine* that is primarily governing ignition events, not just temperature, or age of filter, or amount of dpm accumulated (though all contribute). Since conditions of use are dictated by the mine machine design, the mine environment, and “the job at hand” any effort to control these conditions would be fruitless. Therefore the best control is setting a limit temperature where any of the other variables cannot cause ignition under any reasonable circumstance.

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Table 1:
Summary of Test Results

Test Number	Filter Pair	Condition	Observations
1	Donaldson P604516 special	Loaded at MSHA from new	Smoking, no effect to 1075F
2	Donaldson P604516 special same pair as 1	Continued loading at MSHA	Smoking, no effect to 1050F
3	Donaldson P604516 special same pair as 1, 2	Continued loading at MSHA	Same
4	Donaldson P604516 special same pair as 1, 2, 3	Continued loading at MSHA	Same
5	FSATC	Field Used, no observed rusting	Smoke, Heated direct to 1000F, filter #2 ignited and burned
6	FSATC	Field Used, no observed rusting	Smoke, Filter #1 ignited and burned at 780F
7	FSATC	Used, Filter #2 heavy loaded and rusted	Smoke, Filter #2 Ignited at or below 650F and burned
8	FSATC	Used, Surviving filters from tests 6 and 7	Smoke, Test interrupted due to lightening strike on test lab – reached 730F with smoking only
9	FSATC, from 8	Filters from Test 8 loaded further at MSHA	Smoke only up to 780F
10	FSATC, from 8, 9	Filters from Tests 8 and 9 loaded further at MSHA	Smoke, Ignition of #2 filter at 845F
11	Donaldson P604516 special (Skinner Set #1)	Used Outby Mercedes 906 (25-35hr)	Smoke, Small glow/ignition Filter #2 at 1040F and again at 1077F, glowing areas extinguished after short period. Filter #1 appeared regenerated.
12	Donaldson P604516 special (Skinner Set #2)	Used Outby Mercedes 906 (25-35hr)	Smoke, no effect to 1055F. Filter #1 again appeared regenerated
13	Donaldson P604516 special (Skinner Set #2) same as 11	Used Outby Mercedes 906 (25-35hr), loaded by MSHA	Heavy smoke, no other effects up to 1070F

14	Donaldson P604516 special (Skinner Set #2) same as 11, 12	Used Outby Mercedes 906 (25-35hr), loaded by MSHA	Smoke, Sparks at 870F, 1000F
15	Donaldson P604516 special (Skinner Set #2) same as 11, 12, 13	Used Outby Mercedes 906 (25-35hr), loaded by MSHA	Smoke, Filter #2 small glow/ignition and sparks at 990F, again at 1061
16	Donaldson P604516 special	Used Inby water scrubber, CAT 3306	Filter #2 Ignited and Burned at 645F or below
17	FSATC	Used Inby Water Scrubber, CAT 3306	Heavy smoke, small ignition at 850F (self extinguished), large ignition and burning #2 filter at 1000F
18	FSATC	Mixed Pair Used Inby/Outby, CAT 3306	Heavy smoke, filter #1 and #2 ignited and burned at 645F or below. Both continued to burn even after removal from filter canister
19	Donaldson P604516 special	Used Inby, light rust.	Heavy smoke, filter #2 ignited and burned, 645F or below.
20	FSATC	Used Outby	Smoke only up to 985F, media fell apart near exhaust outlet hole.
21	Donaldson P604516 special	Used Outby Mercedes 906 (25-35hr), then laundered and tested clean	Light smoke only to 870F
22	Donaldson P604516 special, same as 20	Used Outby Mercedes 906 (25-35hr), then laundered and tested clean, loaded at MSHA for 9.5hr.	Heavy smoke, large numbers of potting particles, Filter #1 appeared regenerated[7].
23	Donaldson P604516 special	Used Outby Mercedes 906 loaded to BP limit	Light smoking, Ignition and burning of #2 filter at 880F, with large continuous shower of sparks

[7] The test may have generated some sparks at 705, 790, and 870 F but could not be conformed on video as could not distinguish from potting particles. Observers out by the canister during test felt that there were some sparks.

24	Donaldson P604516 special	Used Inby CAT 3306, loaded to BP limit[8]	Heavy smoke, Ignition and burning of Filter #2 at or below 649F. Filter #1 smoking when removed from canister.
25	FSATC	Filters loaded at MSHA (filters previously used for efficiency tests)	Massive smoking caused by oil injection. No observed sparking or ignition up to 870F
26	FSATC	New filters Loaded at MSHA, tested with oil injected into exhaust stream	Massive smoking caused by oil. Some sparks observed at 760F, tested to 870F max.
27	FSATC	Same filters as test 25, oil injected closer to filter can inlet	Massive smoking caused by oil. Sparks observed at 768F, tested to 864F max. Examination after test showed small burn through on #2 Filter
28	FSATC	Mixed pair of oil soaked filters from tests 25 and 26, further loaded with DPM by MSHA ~5hrs (no oil injected during tests)	Heavy smoking of filters. Sparks observed at 965F.

[8] Only one of these inby filters were received for testing. So the inby filter received was installed at Filter #2, while another P604516 filter loaded by MSHA was placed in the Filter #1 position.

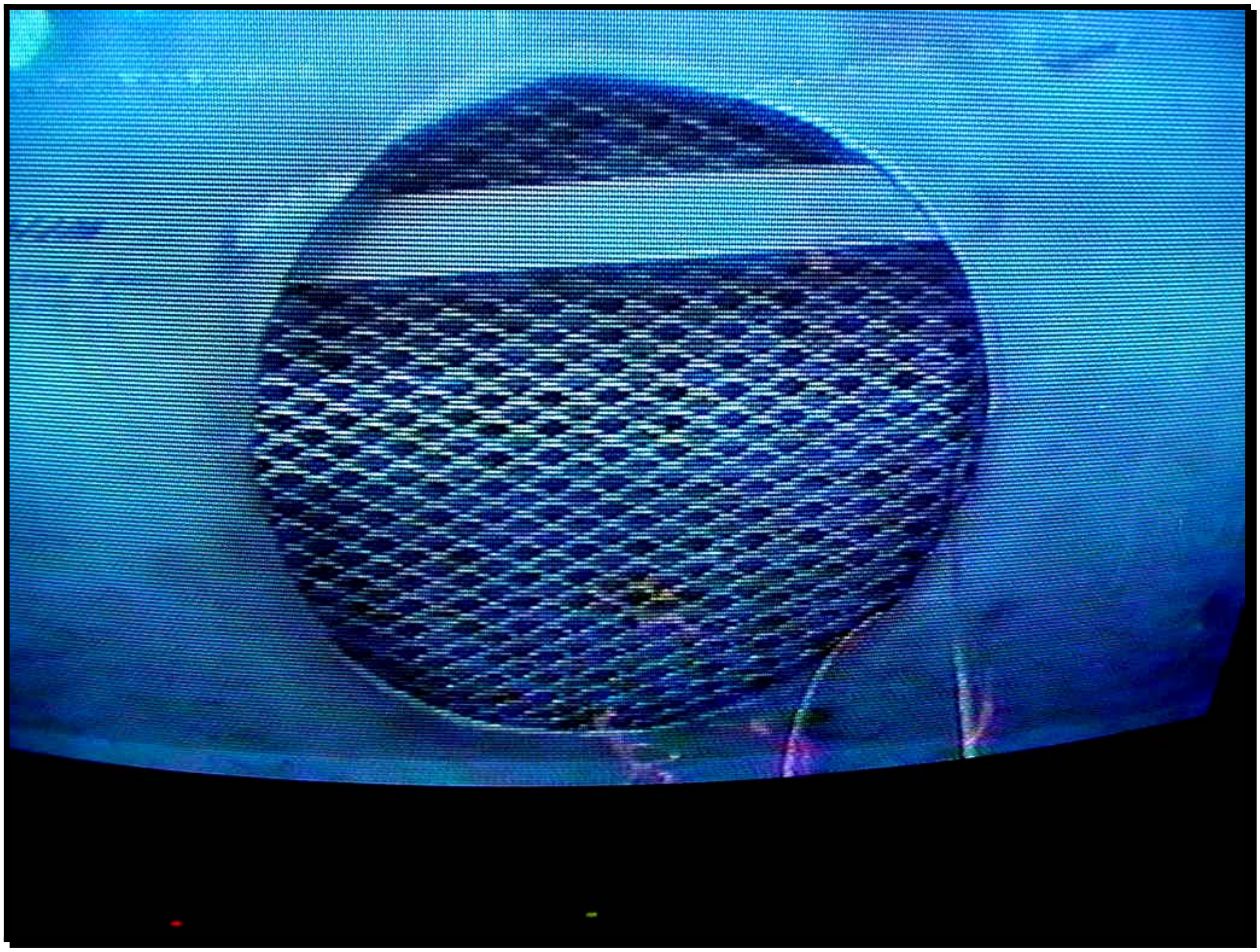

Figure 5. Example of filters emitting Sparks.

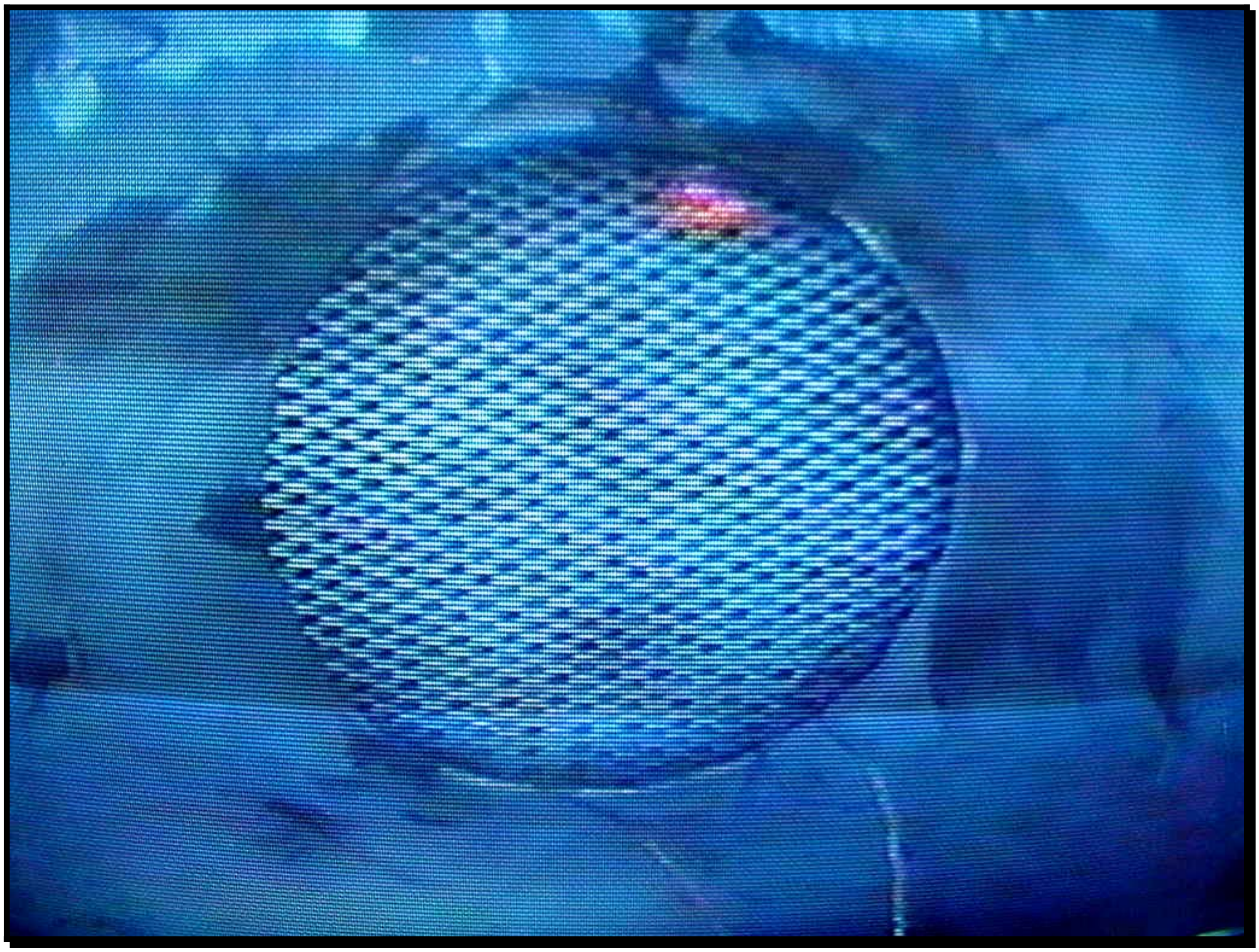

Figure 6. Example of filter Glowing.

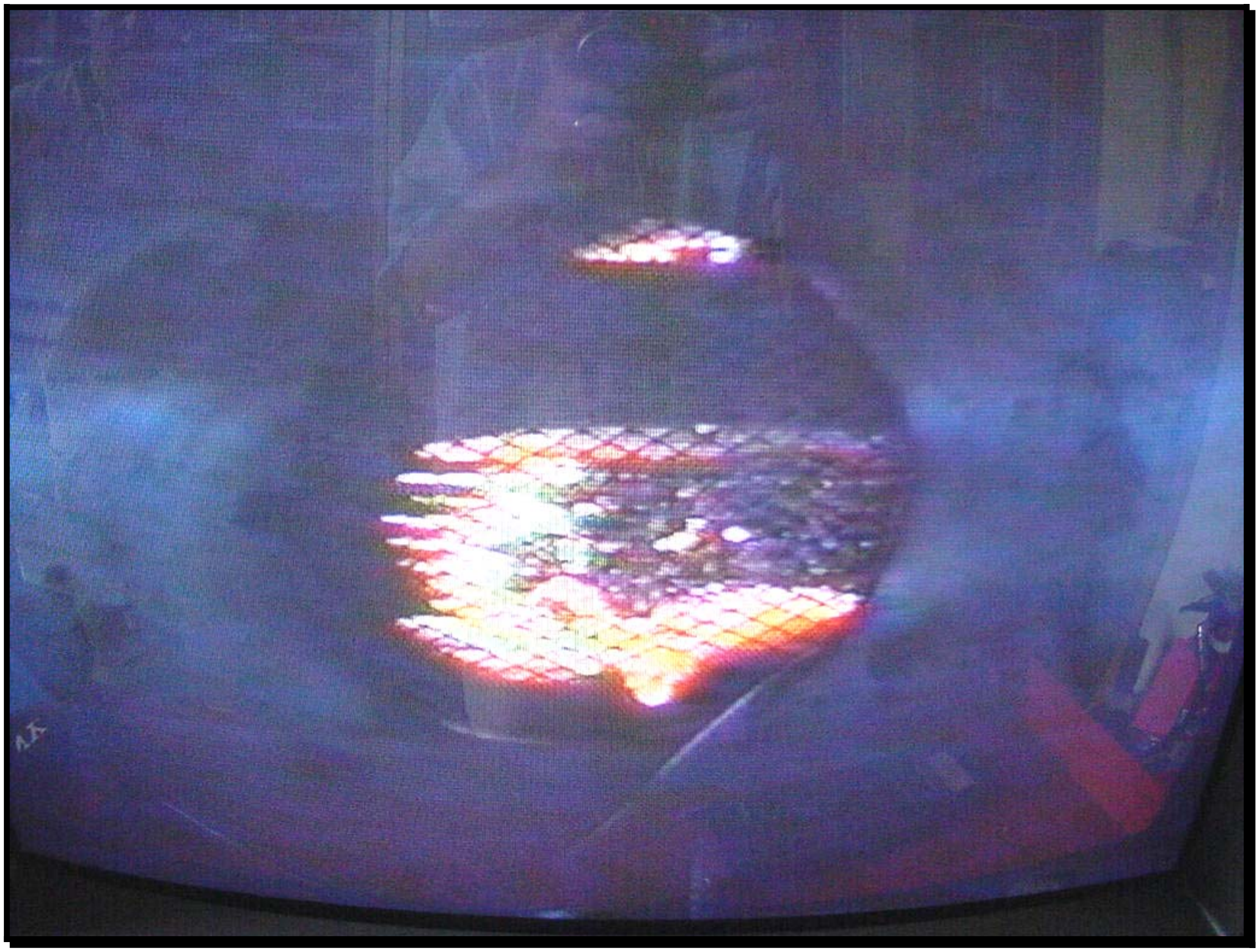

Figure 7. Example of filter Burning.

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Figure 8. Typical result of a filter ignition. Globules adhering to filter are melted glass media and steel screen.

Figure 9. An inside view of a burned-through filter after an ignition.

Conclusion:

The testing as discussed in this report, as well as the supporting documentation of field events and subscale laboratory test show that high temperature filter ignition events are real events that can be triggered with relative ease. This is an unacceptable situation in a coal mine.

This report makes no claim as to have investigated all potential variables that can contribute to such events, nor could they ever be fully investigated. In the interest of safety it seems that limits are required. As a mental exercise in what a *temperature* limit should be, Table 2 was developed for discussion purposes[9]. But whatever changes are made, the current situation cannot continue unchecked.

[9] Table 2 as it appears in this final report is a group contribution with modifications from that originally drafted by the report author. Input and changes were requested from A&CC management and MSHA Headquarters management. Questions concerning it should therefore be directed primarily to those sources.

Table 2: Projected Ignition Potential at Various Temperature Limits

EXHAUST GAS TEMPERATURE	POTENTIAL FOR DPM-LADEN FILTER KINDLING[10]
302	NONE
500	Filter kindling: improbable – unlikely to occur but possible under unexpected engine operating conditions[11].
550	Filter kindling: remote – unlikely but can reasonably be expected to occur under expected engine operating conditions[12]. Filter kindling was observed during small scale tests.
650	Filter kindling: occasional – will occur several times per year with widespread use of filters under expected engine operating conditions[7].
750	Filter kindling: probable – will occur frequently with widespread use of filters under normal engine operating conditions.
Above 750	Filter kindling: frequent – will be continuously experienced with widespread use of filters under normal engine operating conditions.

[10] This chart is based on the assumption that the exhaust gas temperature is limited by a highly reliable temperature control system.

[11] **Unexpected engine operating conditions**: Abnormal engine faults that cause a massive dosing of the filter with unburned hydrocarbons. These conditions are devastating to the engine or mining machine. Examples are total/multiple valve seals/guides failure, complete injection system failure, a sudden catastrophic turbo loss, massive engine over fueling, extremely bad programming (or CPU loss) on an electronic engine.

[12] **Expected engine operating conditions**: Operating conditions that may be expected due to poor maintenance or operating practices. These conditions lead to a build up of DPM on the filter heavy in organic hydrocarbons that can ignite at or below 650 ^{o}F. These conditions include operating old engines with higher than normal oil consumption, older engine designs that produce DPM unusually high in organics, engine improperly derated for altitude, improperly functioning injectors, air leaks in the fuel pump or injection system, machines that idle excessively, machines that are almost always used under light load conditions with a rare excursion to high exhaust temperatures, mixing used inby and outby filters, gradual turbo charger loss of performance, running a turbocharged engine at low torque excessively where boost is too low, etc.

Appendix A:

Draft Test Protocol

MSHA Approval and Certification Center
Mechanical Engineering and Safety Division
Diesel Laboratory
RR 1, Box 251
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FILTER IGNITION TESTING TEST PROTOCOL

Tentative Test Protocol for Reproducing Field Events and Determining Kindling Temperature of Diesel Exhaust Components Captured by High Temperature Disposable Filters

Version 1, July 22, 2004…Prepared by George Schankenberg
Reviewed/revised by MSHA
Version 2, July 26, 2004
Considered and Revised by Schnakenberg, Version 3, July 27, 2004

Situation: Two/three of five noted incidents of incendiary events in high temperature disposable filters (two Donaldson, one Bunderson) reported recently appear to be of the same type. The scenario for both Donaldson's (and presumably the Bunderson) seemed to involve extended periods of engine idling (twenty minutes) followed by periods of a working cycle that are different in nature. In both instances the screening between which the filtration media is sandwiched was found to be rusted to the point of disintegration into small rusty fragments that can be likened to crushed shredded wheat.

The events observed are described as a "shower of sparks" emanating from the discharge port of the filter housing with the sparking material presumably being carried by the exhaust gas stream. The report of the filter on the Caterpillar 3306 powered grader was that the grader had been washed underground, started and left on idle, then driven downhill under conditions that approximate high idle engine load. It was during this period that a shower of sparks was noted by the operator. The full report is documented elsewhere. The tandem filters had never been cleaned and had over 100 hours of time on them. The backpressure gage was inoperative. The engine was in good condition but had accumulated about 10,000 hours. The event melted the filter media that was opposite the discharge orifice of the filter canister.

The second incident occurred on a Deutz powered Getman tow on the surface. Its filters had been removed and installed on the grader so the grader could be driven to the surface. The filters installed on the grader had just arrived at the mine from being cleaned. The engine was started and idled for about 20 minutes or longer. It was then driven to pick up a load and was returning with the load when a shower of sparks was noted. The engine was shut down. The filter media appeared not to be affected.

The common elements of the events are the long period of idling prior to engine loading, and the rusty filter support screening.

A discussion with industry, labor, MSHA and NIOSH held on July 21, 2004 also led to the conclusion (paraphrased) that the sustained combustion of the captured diesel exhaust substances that produced temperatures in excess of the softening temperature of the filter media was undesirable because of the (presumed) effect on filtration efficiency. It was also noted that **a** lower temperature oxidation of the trapped substance was acceptable. Furthermore it was noted that the mass of the captured material is an important parameter on whether combustion would be sustained, grow, or diminish. The oxygen content of the exhaust, exhaust temperature, and flow velocity are additional factors. Overall it is a complex and unpredictable set of circumstances.

Test Objective: To reproduce the conditions and consequences of the events creating the reported "shower of sparks," and to determine the temperature at which the material trapped by the filter kindles and is then self sustaining in idle exhaust flows.

Procedure Overview
MSHA A&CC has two engines that can be utilized for these tests. The Deutz would require one filter and the Caterpillar 3306 would require two filters. The double filters would be arranged end to end in a single housing just like on the vehicles. The engine dynamometer would be used to control engine operation.

Detection of the ignition of the mass trapped on the filter could possibly be accomplished by measuring exhaust CO and temperature before and after the filter. Because of the dilution by the exhaust flows, small localized kindling may not be detectable. Multiple thermocouples could be distributed on the external surface of the filter, but given that the heating events appear to be localized near the discharge port, temperature measurements should be concentrated there. A direct reading infrared pyrometer and other infrared sensors installed inside of the chamber may be effective tools in making this determination.

An initial trial of engine testing for filter ignition will be conducted using a CAT 3306 PCNA engine with a double filter (end-to-end) filter canister with a single side wall outlet hole as typically used in vehicle installations. These initial trials will have minimal instrumentation (no emissions instruments), but will try to reproduce the field ignitions and define a test setup for use in the more elaborate kindling temperature determination tests.

Since neither NIOSH nor MSHA are experienced with testing of this sort, deviations from the test protocol drafted below can be expected as the experimental circumstances warrant. The actual test procedures followed will be documented.

Procedure for testing a newly "cleaned" filter – emulates field event of the Getman tow

1. Set up the double filter canister so that the length of exhaust pipe between engine manifold and inlet is approximately that for the Caterpillar grader or Getman tow.
2. Place a thermocouple in the exhaust stream at the inlet to the filter canister. Also locate ports here for exhaust particulate and gas sampling.

3. Obtain from Skinner/SUFCO filters that have been used and cleaned by the normal procedure used by SUFCO's supplier. The screening which sandwiches the filter media must be rusty and fragile. It may also be possible to accelerate rusting of the filters by placing them in an environmental chamber at high temp and humidity.
4. Check for media integrity visually using a light source inserted in the inlet side of the filter and scanning the pleated media for breaks. Mark and discard any filters with leaks.
5. Install temperature sensors on filter exterior surfaces.
6. Install the filter(s) into their housing.
7. Prepare dyno in usual fashion.
8. Start cold engine
9. Shut down and restart several times.
10. Run on low idle or low loads to load the filter with organic laden diesel aerosol. Twenty minutes is a suggested time. If possible PM sampling should be done during the loading period to be able to quantify the mass delivered to the filter.
11. Increase engine to full load (highest exhaust temperature possible).
12. Observe inlet and filter temperatures.
13. Hold for several minutes until filter temperature stabilizes.
14. If no "shower of sparks," cool down system, and load filter as per step 10 above but for a longer period.
15. Repeat steps 11 - 15 until something happens or until proceeding further is deemed futile.

Procedure for loading a filter and determining kindling temperature of

We decided that tests for kindling temperature and sustained ignition of the captured material should be performed on a filter loaded by the test engine if possible rather than using a loaded filter obtained from the field.

1. Install a length of exhaust pipe that has been experimentally determined to provide exhaust temperatures at its outlet not exceeding 650 °F. Install filter canister at this point.
2. Attach thermocouples to filter inlet and perhaps to a couple of points inside the filter along their length (inlet of first filter, inlet to second filter, opposite discharge hole,
3. Attach thermocouples to outside of filter element (opposite points on the diameter mid point of first filter, opposite discharge hole and diametrically opposite that for a total of 4 points).
4. Install filter(s) into filter housing.
5. Start engine, warm-up, and then load engine to worst case PM generating mode.
6. Monitor exhaust back pressure, CO and temperatures before and after filter.

7. When the filter is loaded to a back pressure that represents a reasonable loading (10 " wg), run the ISO 8178 certification test twice, once sampling exhaust before the filter, once after the filter. Collect samples for gravimetric and NIOSH 5040 PM determination. This step only checks for filter efficiency and may be skipped.
8. Continue loading of filter until back pressure reaches a high but acceptable level, e.g. 25 to 28 inches water gauge.
9. Run engine at a loading that produces organically rich (wet) diesel exhaust for several minutes. The loading time will be based on experience in preceding test.
10. Run the engine under load that creates the highest exhaust temperature for 5 minutes then reduce engine to low idle. Examine CO and exhaust temperatures for evidence of CO generation or heat generation by the filter.
11. Shorten the length of the exhaust pipe between filter inlet and engine manifold by 1/5 the total length and repeat step9 & 10 above.
12. If no evidence of kindling or ignition, repeat step 11 above.
13. Repeat step 12 until ignition occurs or exhaust pipe can not be shortened further.

Procedure for determining the kindling temperature of a field-loaded filter.

1. Inspect and install acceptable field-loaded filter(s) into test setup above.
2. Measure back pressure and load filter using procedure steps 5 - 7 in loaded filter test above.
3. Conduct the procedure above starting with step 7.

Analysis

The preceding loaded filter tests are designed to discover the minimum exhaust temperature that will kindle and sustain the combustion of the mass collected on the disposable filter The indicator of kindling is a CO concentration and/or temperature after the filter that is higher than the CO or temperature before the filter and a continuation or further increase upon reducing the exhaust gas flow and oxygen concentration to idle rates and concentrations.

Alternatives

NIOSH and MSHA discussed adjusting the challenge temperature by different engine loadings rather than by exhaust pipe extensions. Different engine loadings change the oxygen content of the exhaust and adds another variable into the test. Admittedly we don't know what the oxygen content should be to replicate field events, but having it change only serves to confound the results.

Timeframe

With the assumption of no engine or test instrument problems, MSHA's target completion date for testing is August 31, 2004. A final report will be available for review on September 7, 2004.

Appendix B:

Test Data and Observations

MSHA Approval and Certification Center
Mechanical Engineering and Safety Division
Diesel Laboratory

RR 1, Box 251
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FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

The following are the data, test notations and observations recorded during the full scale filter ignition test demonstration. The test setup used is shown in Figure B.1. The test setup used a Caterpillar 3306 PCNA engine, serial #23C994.

This engine was in typical condition for a used diesel engine, with some engine oil consumption due to blow by (and presumably burning), but was in Approved condition for an underground mining engine. The latest emissions data for the engine is shown in Figure B.2 and shows no unusual condition exists in the engine, except that the weighted average DPM for this engine is only ~22g/hr, while the approval test for this engine model yielded 38 g/hr.

The filter canister used in the tests is a dual element, inline filter canister. This installation is typical of that used in mines for larger 6 cylinder power plants. The canister has a 4 inch diameter input, which was connected to the exhaust of the CAT 3306 engine. The canister has a 6 5/8 inch diameter exit hole aligned with the second filter in the canister (Filter #2). The filters are loaded by removing an end cap on the canister which is held in place by 3 bolts (Figure B.3). The canister is capable of holding high temperature filters from Donaldson and FSATC with slight compression to the filters during tightening of the end cap. The canister is constructed of steel and was built by Gary Poteet at Oxbow mine.

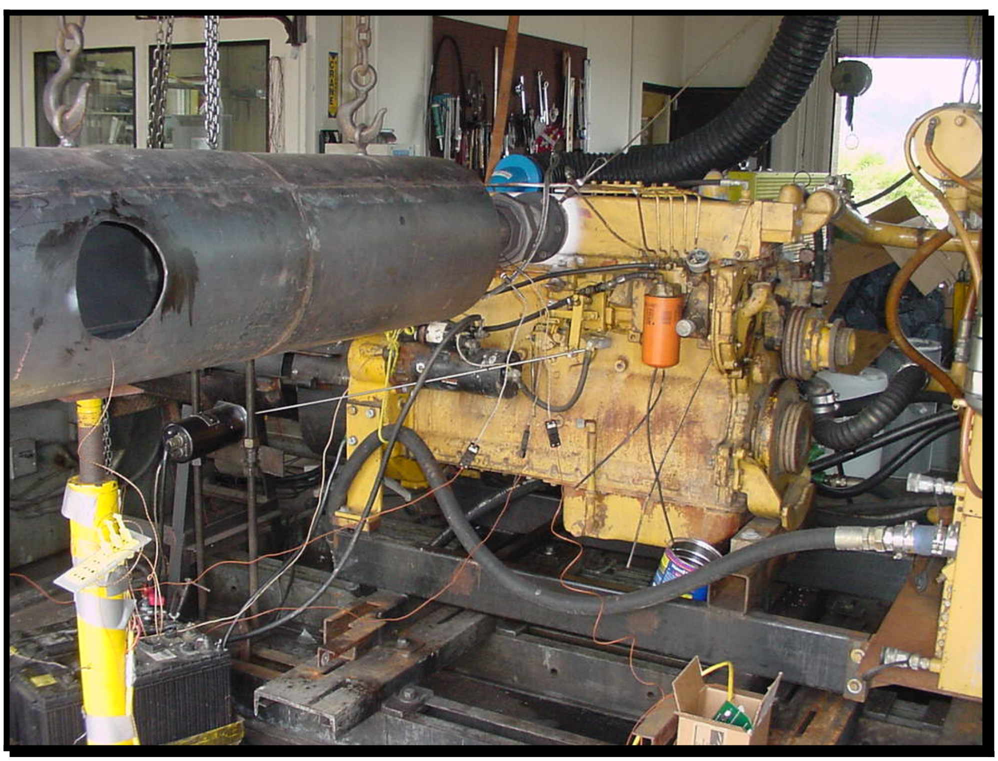

Figure B. 1. Test Setup

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FILTER IGNITION TESTING TEST DATA AND OBSERVATIONS

COMPANY NAME	Getman Corp				PART 7, SUBPART E, CATEGORY B				
DATE	9/8/2004								
ENGINE MODEL	CAT 3306 PCNA #23C994								
COMMENTS:	Engine Baseline								
TEST DATA / MODE NUMBER		1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0
RPM		2197.5	2198.0	2197.0	2192.5	1399.2	1398.8	1398.7	736.0
TORQUE lbft		318.2	239.4	159.1	35.2	391.9	293.8	196.5	12.0
HORSEPOWER		133.1	100.2	66.6	14.7	104.4	78.2	52.3	1.7
Barometric Pressure INHG		28.58	28.58	28.58	28.57	28.57	28.56	28.56	28.56
Laminar flow air temp DEG F		65.84	66.33	66.31	66.74	66.06	66.03	65.58	65.24
Laminar flow diff pressure in. of H2O		2.75	2.78	2.81	2.89	1.85	1.88	1.90	0.95
Laminar Flow cfm		326.60	329.92	333.78	343.01	219.74	223.02	225.76	112.78
Altitude Barrel Air (degF)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Air Entering Manifold/Turbo (degF)		94.56	95.13	93.78	90.89	92.72	94.00	92.00	94.14
Boost/Air In Manifold (degF)		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Altitude Barrel Pressure (inHg)		28.57	28.57	28.56	28.54	28.55	28.52	28.54	28.53
Altitude (ft)		1265	1269	1280	1292	1289	1313	1296	1307
Intake AIR Consumption lbs/hr		1390.32	1402.36	1418.79	1455.91	934.60	948.16	961.07	480.64
Intake Air Temperature DEG F		94.56	95.13	93.78	90.89	92.72	94.00	92.00	94.14
FUEL Temperature DEG F		95.06	95.78	97.13	98.69	99.98	96.89	94.80	92.44
FUEL Consumption lbs/hr		65.98	52.27	41.79	26.37	42.65	31.80	23.67	4.50
DEW Point DEG F		57.80	57.80	57.80	57.80	57.80	57.80	57.80	57.80
Grains Water (H2O) per lb dry air		73.57	73.57	73.57	73.59	73.59	73.62	73.62	73.61
Oil Temperature DEG F		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Exhaust Temperature DEG F		940.17	765.03	623.23	435.25	719.92	576.55	442.98	211.84
CC TEMP		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Coolant Temperature IN DEG F		190.671875	182.828125	170	153.5	158.84375	156.6875	145.15625	131.875
Coolant Temperature OUT DEG F		204.828125	195.953125	181.796875	163.359375	172.796875	169.5	157	143.28125
Turbo Temperature DEG F		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Oil Pressure PSI		53.50	53.43	55.42	58.49	45.90	45.84	47.13	33.24
Inlet Restriction ("H2O)		13.40	13.63	13.87	14.39	7.27	7.30	7.39	2.90
Exhaust Restriction (mmHg)		9.90	9.00	8.16	7.07	2.99	4.54	5.23	0.84
EXHAUST FLOW LB/HR		1456.30	1454.63	1460.58	1482.28	977.25	979.95	984.74	485.14
FUEL/AIR RATIO		0.0475	0.0373	0.0295	0.0181	0.0456	0.0335	0.0246	0.0094
J CONVER		0.8951	0.9141	0.9287	0.9499	0.8985	0.9211	0.9377	0.9663
ECH4 % DRY		0	0	0	0	0	0	0	0
CO2 % DRY		10.7	8.4	6.6	4.1	9.3	7.0	5.4	1.9
CO PPM DRY		256.4	292.2	374.0	372.6	188.4	161.3	149.4	1083.3
NOX PPM DRY		559.5	607.3	517.5	252.6	427.8	567.5	598.1	132.2
NO PPM DRY		541.2	580.2	462.3	216.5	409.8	520.3	552.9	96.8
NO2 PPM DRY		18.4	27.1	55.2	36.2	18.0	47.2	45.2	35.4
%O2									
NO WET		484.3854	530.3946	429.3434	205.6466	368.1724	479.2337	518.5193	93.5359
NO2 WET		16.4413	24.7381	51.2833	34.3521	16.1922	43.5070	42.3772	34.1791
CO2 WET		9.6024	7.6942	6.1499	3.9363	8.3727	6.4275	5.0389	1.8359
CO WET		0.0229	0.0267	0.0347	0.0354	0.0169	0.0149	0.0140	0.1047
G		-0.0002	0.0010	0.0019	0.0032	0.0000	0.0014	0.0024	0.0042
R		-0.0017	-0.0022	-0.0025	-0.0030	-0.0018	-0.0023	-0.0027	-0.0034
HUM&TEM CORR FACTOR		0.9989	1.0208	1.0352	1.0487	1.0026	1.0272	1.0404	1.0769
NO CORR		484.9424	519.6012	414.7565	196.1029	367.2052	466.5596	498.3926	86.8552
NO2 CORR		16.4602	24.2347	49.5410	32.7579	16.1497	42.3564	40.7323	31.7379
GAS EMISSIONS									
NO GR/HR		331.92	355.24	284.72	136.62	168.66	214.89	230.67	19.80
NO2 GR/HR		17.26	25.38	52.10	34.96	11.36	29.89	28.88	11.09
CO2 GR/HR		96349.54	77114.78	61889.36	40201.10	56375.25	43397.55	34188.17	6136.86
CO GR/HR		146.37	170.16	222.22	229.80	72.44	63.76	60.43	222.44
VENTILLATION RATES									
PART 7, SUBPART E CATEGORY B									
NO CFM	25 ppm	6157	6590	5282	2534	3129	3986	4279	367
NO2 CFM	5 ppm	1044	1535	3151	2115	687	1808	1747	671
CO2 CFM	5000 ppm	6070	4858	3899	2533	3552	2734	2154	387
CO CFM	50 ppm	1455	1691	2208	2284	720	634	601	2211
NOX ppm - wet EURO, EPA, ISO		500.83	555.13	480.63	240.00	384.36	522.74	560.90	127.71
NOX ppm(corr) EURO,EPA,ISO		501.40	543.84	464.30	228.86	383.35	508.92	539.12	118.59
NOX GR/HR EURO, EPA, ISO		525.74	569.58	488.26	244.25	269.74	359.07	382.25	41.43
NOX cfm EURO, EPA, ISO		6361	6891	5907	2955	3263	4344	4625	501
PARTICULATE EMISSIONS									
Modal Particulate emission (gr/hr)		23.46	28.13	36.64	48.37	16.10	7.78	9.16	3.05
	weight factor	0.15	0.15	0.15	0.10	0.10	0.10	0.10	0.15
Weighted Particulate (gr/hr)		3.52	4.22	5.50	4.84	1.61	0.78	0.92	0.46
Weighted HP		19.969	15.028	9.984	1.469	10.441	7.824	5.232	0.253
Weighted Average HP		70.201	HP						
Weighted Average PARTICULATE		21.834	GR/HR						
		0.311	**(GR/HP-HR)**						
PARTICULATE INDEX (PI) CFM		12849.151							

Figure B. 2. 8-mode emissions test on CAT 3306 PCNA #23C994.

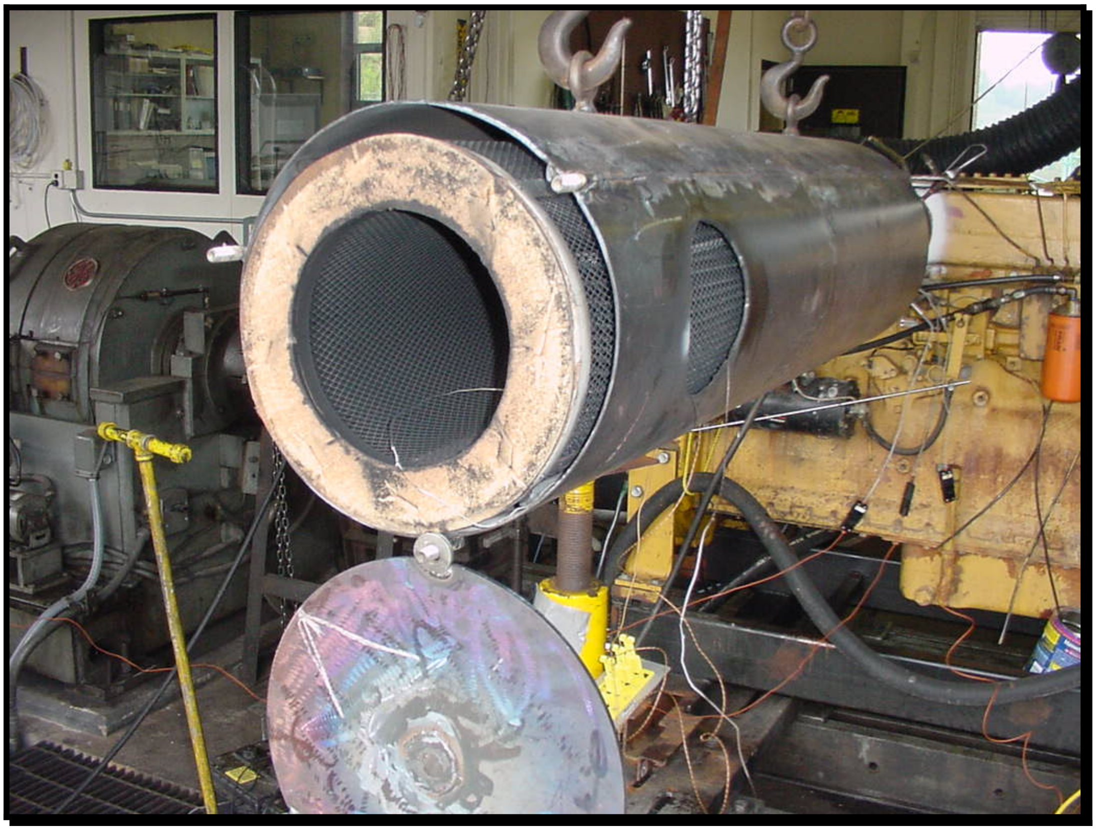

Figure B. 3. Installation of a set of test filters.

Tests were run in basic accordance with the goal of the original test protocol and the test method written in the body of the report. Any deviations are noted in the data sheets.

If data was recorded by computer on exhaust and filter temperatures, these are included with the test record. The temperature charts label the temperatures as follows:

1. Raw Exhaust: this was the exhaust temperature as measured by a thermocouple installed in the exhaust pipe just prior to entering the filter canister.
2. Filter #1: this was the temperature of a thermocouple embedded in the filter media of filter #1 (1st filer in canister) approximately mid-way along the filter's length, embedded in the outer media surface.
3. Filter #2A: this was the temperature of a thermocouple embedded in the filter media of filter #2 (2nd filter in canister) approximately mid-way along the filter's length, embedded in the out media surface.
4. Filter #2B: this was the temperature of a thermocouple embedded in the filter media of filter #2, embedded on the inner media surface of the portion of the filter exposed by the canister exhaust hole.

If ignition events were recorded on videotape, then a representative image from the tape is also be included.

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FILTER IGNITION TESTING — TEST DATA AND OBSERVATIONS

Test No:	1	**Date:**	8/3/04
Filter ID:	Donaldson P604516 “special” (ceramic potting)		
Filter Condition:	New, loading up as testing		
Engine:	Caterpillar 3306 PCNA #23C994		
Filter Canister:	Dual Element (2 filter) inline canister with 4” pipe inlet diameter and 6 5/8” diameter outlet hole aligned with #2 filter		
Startup	14:50		
TEST GOAL:	To load up a set of new filters with limited amount of DPM and determine if anything inherent in a new filter promotes ignition. Secondary goal to experiment with test method(s)		
Time:	**Condition:**		
14:50-15:00	1250rpm no engine load – warm-up and dirtying filter		
15:00-15:10	1400rpm 250ft-lb – buildup of DPM, exhaust temperature ~520F		
15:10-15:25	2200rpm, full load – 30” intake restriction, 0.5% CH4, exhaust temp 1066F		
15:25-15:30	1290rpm no load – no observed effects at canister outlet		
15:30-15:55	Engine idle		
15:55-16:05	2200rpm full load 1% CH4 exhaust temp 1060-1075F no observed effects at canister outlet		
16:05-16:15	Engine idle – filters held heat long after engine exhaust had cooled to 200F and below, no other observed effects.		
After Test Observations:	No damage to ceramic potting compound observed – end caps tight. No noticeable changes in media or pleats. Wire mesh on pleats appears clean with no clinging DPM. DPM on pleats has a brownish/gray appearance instead of dark black (burning / regeneration effect?). Filter media graying on outer surface.		
Figures:	NA		

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FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No:	2	**Date:**	8/4/04
Filter ID:	Donaldson P604516 "special" (ceramic potting)		
Filter Condition:	Same set as test 1, loading up further and testing		
Engine:	Caterpillar 3306 PCNA #23C994		
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter		
Startup	09:30		
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Secondary goal to experiment with test method(s)		
Time:	**Condition:**		
9:30-9:40	1250 rpm no engine load		
9:40-9:50	1400rpm, 250ft-lb – exhaust temperature ~520F		
9:50-9:52	2200rpm full load		
9:52-9:55	2200rpm full load, 1%CH4 exhaust temperature ~1000F		
9:55-10:55	2200rpm, 45 ft-lb (Mode 4) depositing DPM (~44g/hr) at exhaust temperature ~450F		
10:55-11:30	Engine idle, shutdown		
13:20-14:00	Engine idle		
14:00-14:04	2200rpm full load, 1%CH4 exhaust temperature 959F, heavy smoke from filter as temperature rose		
14:04-14:06	Engine idle, no observed effects on filter		
14:06-14:11	2200rpm full load 1.2%CH4		
14:12-14:30	Engine idle, no observed effects		
14:30-14:35	1400rpm full load with 1%CH4		
14:35-14:55	1400rpm, 210ft-lb (Mode 7)		
14:55-15:05	2200rpm full load, 1%CH4 – small particles blown out of canister exit – probably ceramic potting material and not sparks		
15:05-15:25	2200rpm, 45 ft-lb (Mode 4) - no observed effects		
15:25-15:55	Engine idle		
15:55-1600	2200rpm full load, 1% CH4 – heavy smoke as filters heat up with occasional particles blowing out of canister hole		
16:00-16:15	Engine idle, shutdown – no observed effects		
After Test Observations:	None		
Figures:	NA		

FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No:	3	**Date:**	8/5/04
Filter ID:	Donaldson P604516 "special" (ceramic potting)		
Filter Condition:	Same set as test 1 and 2, loading up further and testing		
Engine:	Caterpillar 3306 PCNA #23C994		
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter		
Startup			
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Secondary goal to experiment with test method(s)		
Time:	**Condition:**		
After Test Observations:	None		
Figures:	NA		

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FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No:	4	**Date:**	8/6/04
Filter ID:	Donaldson P604516 “special” (ceramic potting)		
Filter Condition:	Same set as test 1, 2 and 3, loading up further and testing		
Engine:	Caterpillar 3306 PCNA #23C994		
Filter Canister:	Dual Element (2 filter) inline canister with 4” pipe inlet diameter and 6 5/8” diameter outlet hole aligned with #2 filter		
Startup			
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Secondary goal to experiment with test method(s)		
Time:	**Condition:**		
After Test Observations:	None		
Figures:	NA		

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FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No:	5	**Date:**	8/9/04
Filter ID:	FSATC high temperature filter		
Filter Condition:	Used, received from field (Sim Bundersen)		
Engine:	Caterpillar 3306 PCNA #23C994		
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter		
Startup	10:00		
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Secondary goal to experiment with test method(s)		
Time:	**Condition:**		
10:00-10:30	Engine Idle		
10:30-11:00	2200rpm, 36ft-lb (Mode 4)		
11:00-11:35	Engine Idle		
11:35	Shutdown		
13:05-13:45	Engine Idle		
13:45-13:48	Ramp Engine to 2200rpm full load, add 1%CH4 to intake, and when exhaust temp reaches 1000F, ramp back to idle: RESULT: Filter Ignition of #2 Filter, observable parts of filter consumed in fire.		
13:48-13:50	Engine idle, shutdown		
After Test Observations:	Filter #2 had large area around canister exit hole consumed by fire. Smaller burn-throughs around end caps. Filter #1 also had ignited on same side of canister as #2 filter and was burned through along its length.		
Figures:	B.4 – B.9		

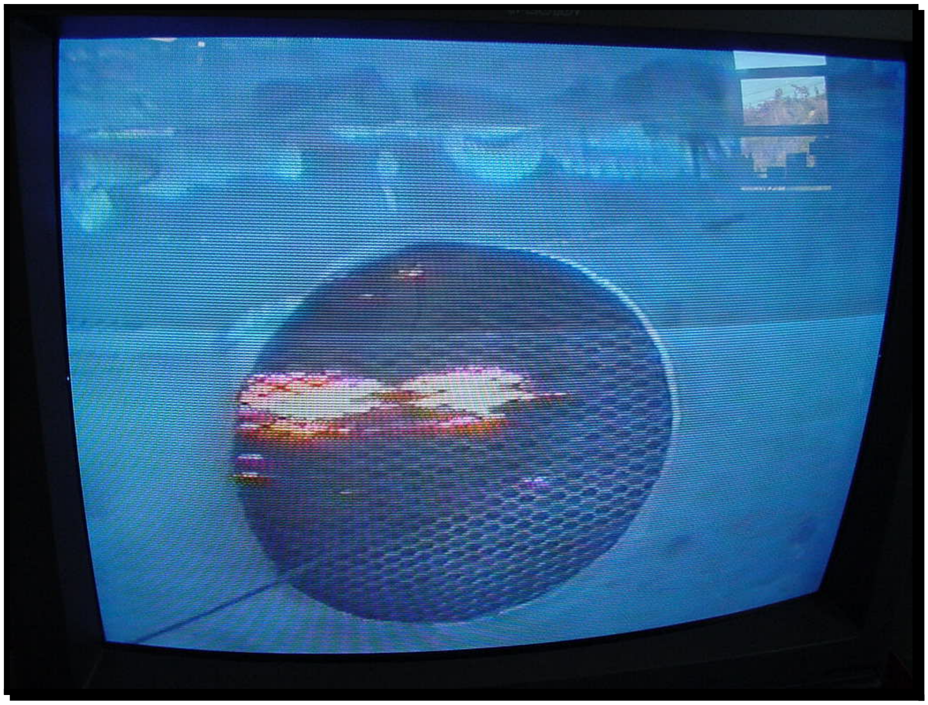

Figure B. 4. Test #5; Video view of filter Ignition.

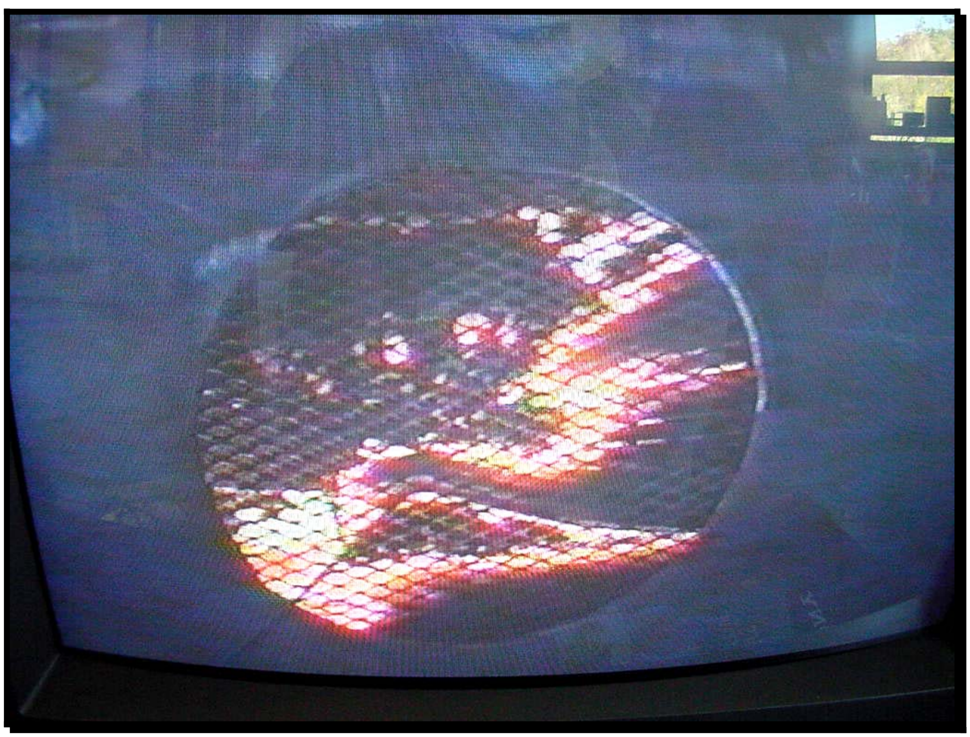

Figure B. 5. Test #5, Video view of filter burning.

Figure B. 6. Test #5; Burn Damage to Filter #2 aligned with filter canister hole.

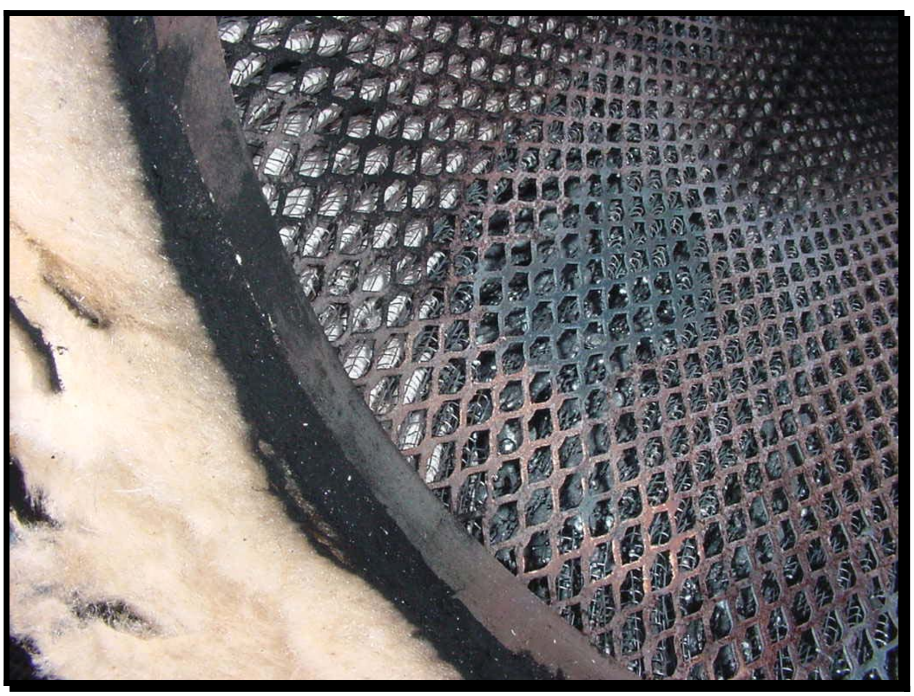

Figure B. 7. Test #5; Small burn through near end cap of Filter #2.

Figure B. 8. Test #5; Burn damage to both filters, Filter #1 on left.

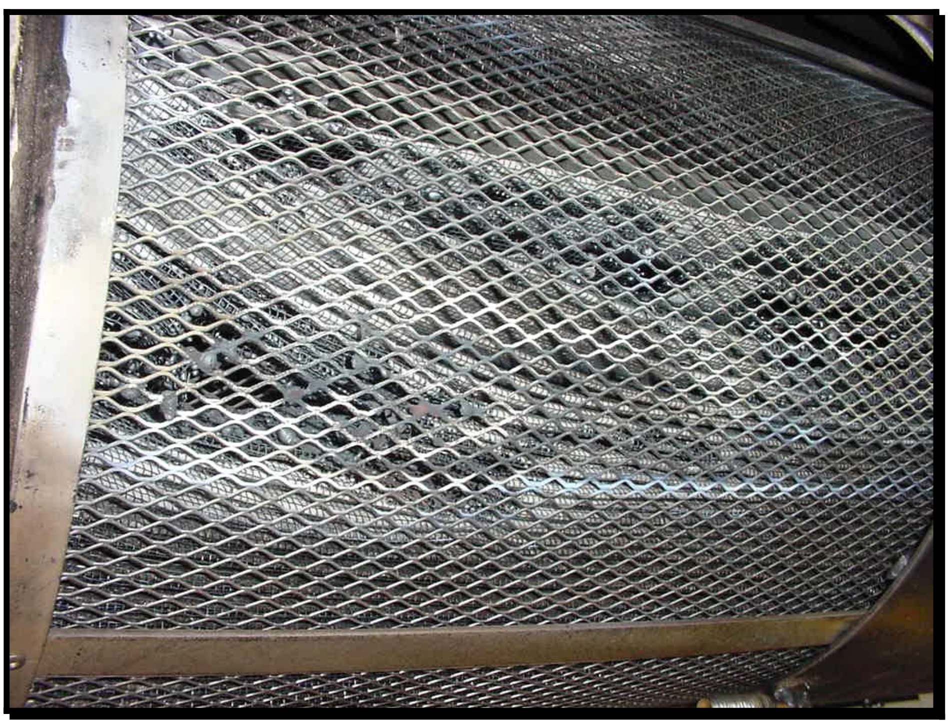

Figure B. 9. Test #5; Burn damage to Filter #1.

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FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No:	6 (STEP1)		**Date:**	8/10/04	
Filter ID:	FSATC high temperature filter				
Filter Condition:	Used, received from field (Sim Bundersen)				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup	10:25				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Secondary goal to experiment with test method(s): progressive step test from 500F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
10:25-10:35	Idle	-	200	-	
10:35-10:38	2200	100	495	48	Some smoke, particles exiting canister
10:38-10:48	Idle	-	200	-	
10:48-10:54	2200	130	538	46	Some smoke, particles exiting canister
10:54-11:04	Idle	-	200	-	
11:04-11:08	2200	160	620	65	Some smoke, particles exiting canister
11:08-11:18	Idle	-	200	-	
11:18-11:20[1]	2200	No load	425	-	
11:20-11:30	Idle	-	200	-	
11:30-11:35	2200	190	644	50	
11:35-11:45	Idle	-	200	-	
11:45-11:50	2200	220	704	57	Particles
11:50-12:00	Idle	-	200	-	
12:00-12:04	2200	250	780	55	Shower of sparks exiting canister as engine idled down, Filter #1.
12:04	Engine idle, shutdown				
After Test Observations:	Filter #1 had ignited in quadrant aligned with the canister exit hole. Significant damage to filter media and screens in a line between filter end caps. Filter #2 showed no damage or signs of ignition. Shower of sparks caused by breakup of filter media and screen as dpm burns.				
Figures:	NA				

[1] Dyno Control lost, could not control torque – system reset.

RR 1, Box 251
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FILTER IGNITION TESTING TEST DATA AND OBSERVATIONS

Test No:	7 (STEP2)			**Date:**	8/10/04
Filter ID:	FSATC high temperature filter				
Filter Condition:	Used, received from field (Sim Bundersen). Filter placed in #2 position very heavily loaded with rust on screen covering media and outer cage. Filter placed in #1 position not rusted.				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup	14:10				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
14:10-14:25	Idle	-	200	-	
14:25-14:29	2200	190	650	45	Very heavy smoking from filters, Ignition of Filter #2 before reached maximum temperature, open flames, sparks and filter melting as throttled back to idle.
14:29-14:33	Idle	-	200	-	Filter continuing to burn
14:33	Engine idle, shutdown				
After Test Observations:	Filter #2 had ignited and burned in the area align with the canister exit. Several other areas of Filter #2 showed signs of ignition. Media, media screen and outer cage all severely damaged. Filter continued to smolder, smoke and glow after engine was stopped and filter removed from canister. Filter #1 appeared undamaged.				
Figures:	B.10, B.11, B.12				

Figure B. 10. Test #7, Initiation of Fire in Filter #2, (haze is smoke from filter).

Figure B. 11. Test #7; Filter Burning.

Figure B. 12. Test #7; Filter continuing to burn, hole in outer cage can be seen (3 o'clock position).

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FILTER IGNITION TESTING TEST DATA AND OBSERVATIONS

Test No:	8 (STEP3)			**Date:**	8/10/04
Filter ID:	FSATC high temperature filter				
Filter Condition:	Used, received from field (Sim Bundersen)				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4” pipe inlet diameter and 6 5/8” diameter outlet hole aligned with #2 filter				
Startup	15:00				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
15:00-15:15	Idle	-	200	-	
15:15-15:20	2200	190	651	65	Smoke
15:20-15:30	Idle	-	200	-	
15:30-15:35	2200	210	690	64	Smoke
15:35-15:45	Idle	-	200	-	
15:45-15:50	2200	225	730	51	Smoke
15:50-16:00	Idle	-	200	-	
16:00	****	****	****	****	TEST INTERUPTED[2]
16:05	Engine idle, shutdown				
After Test Observations:	No apparent filter damage or ignition events up to point test interrupted.				
Figures:	NA				

[2] Test stopped due to lightening strike on lab building and power surge in laboratory.

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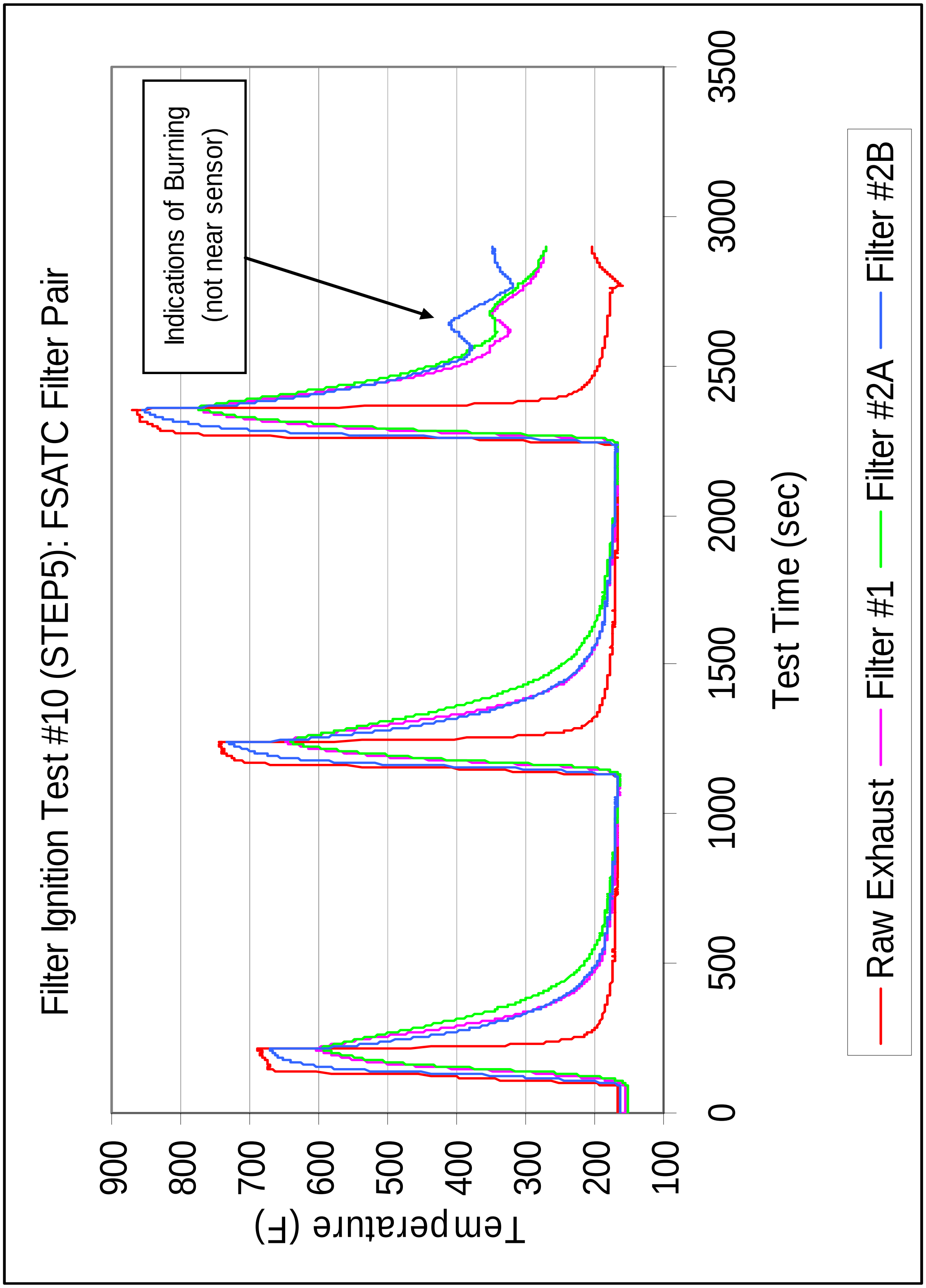
FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No:	9 (STEP4)			**Date:**	8/11/04
Filter ID:	FSATC high temperature filter, same pair as used in test 8				
Filter Condition:	Used, received from field (Sim Bundersen)				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup	14:55				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
14:55-15:25	Idle	-	200	-	
15:25-15:28	2200	200	640	65	Heavy smoke
15:28-15:38	Idle	-	200	-	
15:38-15:42	2200	220	680	60	Light smoke
15:42-15:52	Idle	-	200	-	
15:52-15:55	2200	240	725	60	
15:55-16:08	Idle	-	200	-	
16:08-16:11	2200	260	780	60	
16:11-16:15	Idle	-	200	-	
16:15	Engine idle, shutdown				
After Test Observations:	No apparent filter damage or ignition events.				
Figures:	NA				


Filter Ignition Test #9 (STEP4): FSATC Filter Pair
Temperature (F)
800
700
600
500
400
300
200
100
0
500
1000
1500
2000
2500
3000
3500
Test Time (sec)
Raw Exhaust
Filter #1
Filter #2A
Filter #2B

FILTER IGNITION TESTING TEST DATA AND OBSERVATIONS

Test No:	10 (STEP5)		**Date:**	8/12/04	
Filter ID:	FSATC high temperature filter, same pair as used in test 8, 9				
Filter Condition:	Used, received from field (Sim Bundersen)				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4” pipe inlet diameter and 6 5/8” diameter outlet hole aligned with #2 filter				
Startup	9:40				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
9:40-10:15	Idle	-	200	-	DPM Buildup
10:15-11:00	2200	45	450	-	DPM Buildup
11:00-11:20	Idle	-	200	-	DPM Buildup
11:20	-	-	-	-	Shutdown
13:00					Startup
13:00-13:15	Idle	-	200	-	
13:15-13:20	2200	200	680	60	Smoke
13:20-13:35	Idle	-	200	-	
13:35-13:38	2200	230	740	60	Light smoke
13:38-13:53	Idle	-	200	-	
13:53-13:55	2200	~275	845	60	Rated full load; sparks began a few seconds after ramp down to idle; Filter #2 ignited at bottom and side opposite of canister exit hole near end cap
13:55-14:00	Idle	-	200	-	Idle
14:00	Engine idle, shutdown				
After Test Observations:	Filter #2 burned along bottom of filter and around outboard end cap. Severe media damage. Globules of melted media and metal screen lying on bottom of filter canister. Filter #1 appeared undamaged.				
Figures:	B.13-B.17				


Filter Ignition Test #10 (STEP5): FSATC Filter Pair
Indications of Burning (not near sensor)
Temperature (F)
900
800
700
600
500
400
300
200
100
0
500
1000
1500
2000
2500
3000
3500
Test Time (sec)
Raw Exhaust
Filter #1
Filter #2A
Filter #2B

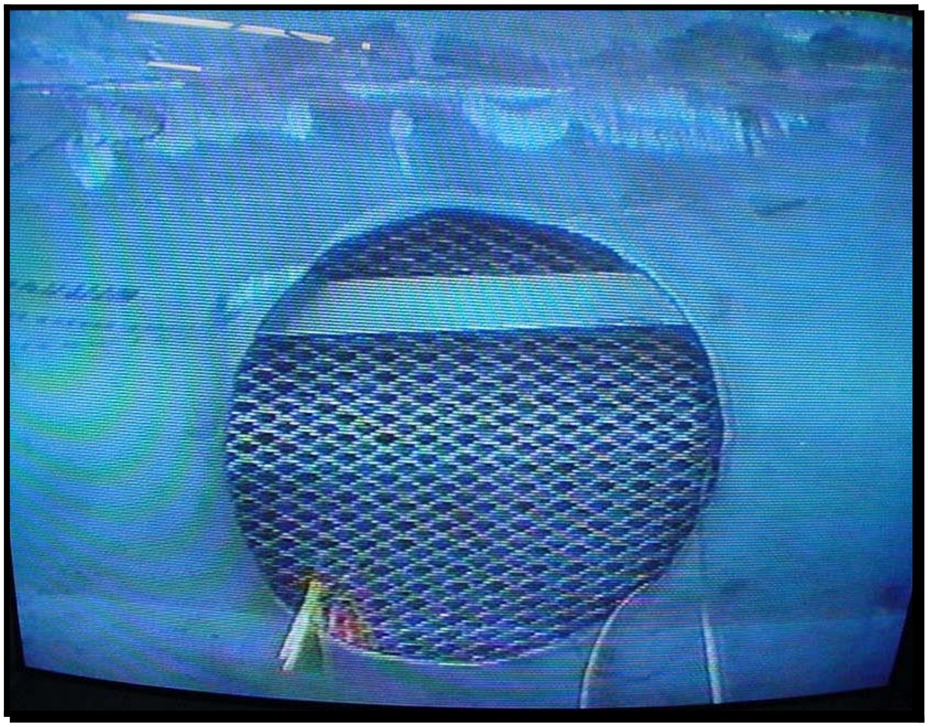


Figure B. 13. Test #10 Spark(s) exiting filter canister after Filter #2 ignition.

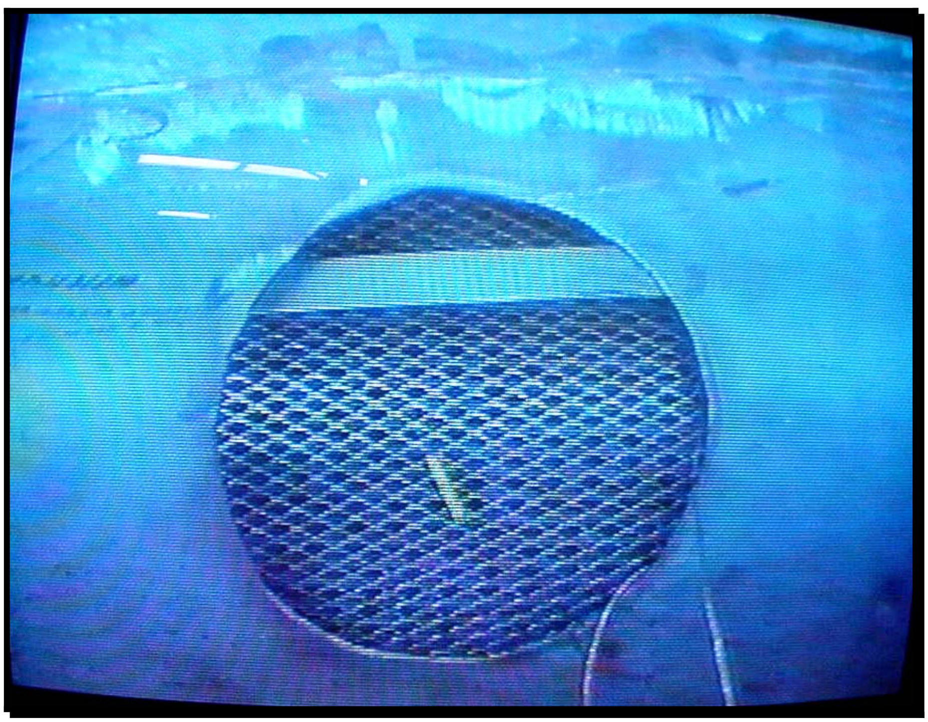


Figure B. 14. Test #10 Spark(s) exiting filter canister after Filter #2 ignition.

Figure B. 15. Test #10; damage to #2 filter with melted media and screen material.

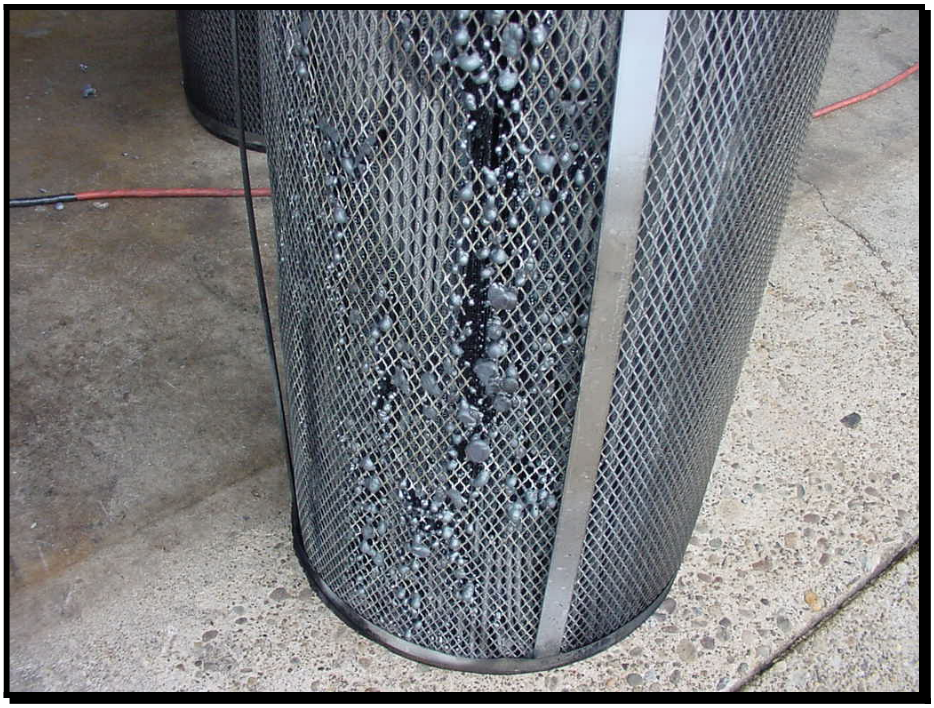


Figure B. 16. Test #10; close-up of damage to #2 filter.

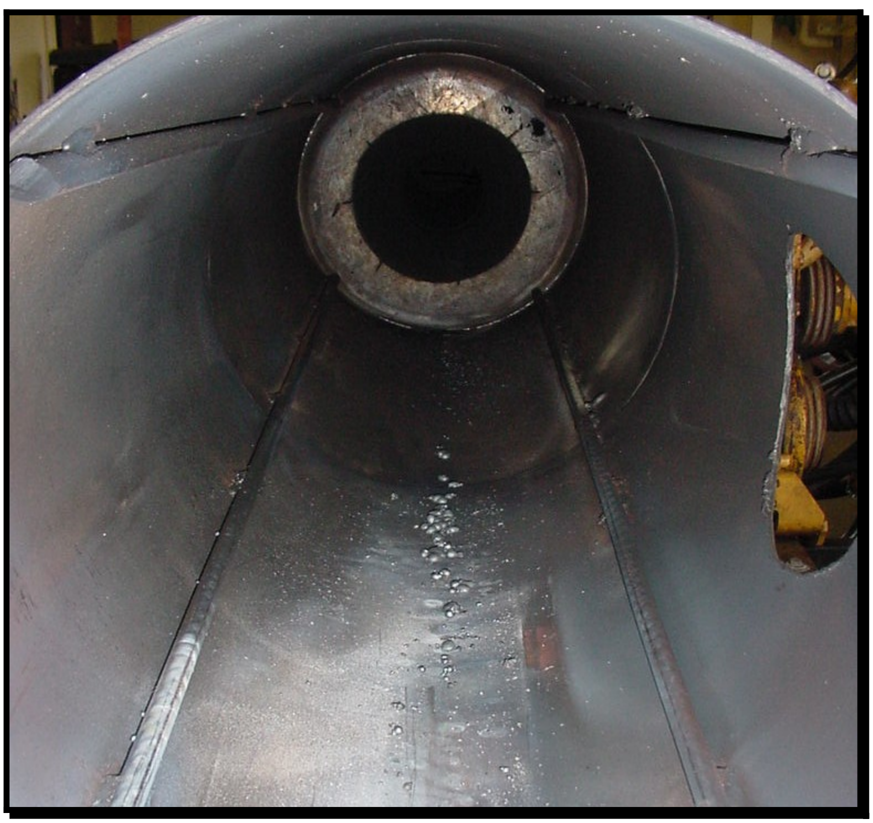


Figure B. 17. Test #10; Inside of filter canister showing burn marks and remains of burned filter.

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(304) 547-2051

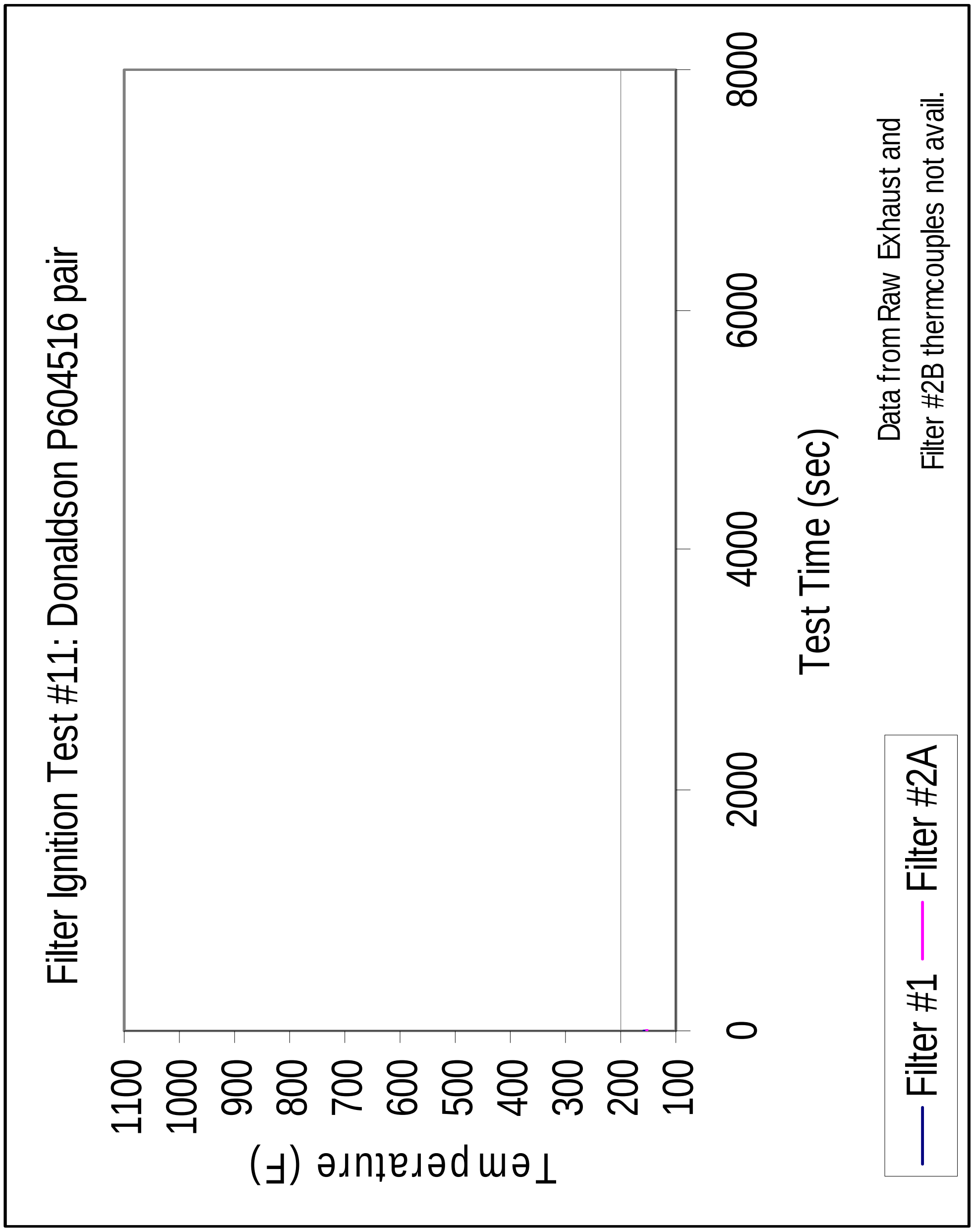
FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No:	11 (STEP6)			**Date:**	8/16/04
Filter ID:	Donaldson P604516 'special' high temperature filter				
Filter Condition:	Used, received from Steve Forbush of Canyon Fuels – run on Mercedes 906 engine (outby) for 25-35 hours, "SET 1"				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup	12:56				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
12:56-13:06	Idle	-	200	-	
13:06-13:09	2200	190	660	65	Some particles (not sparks), light smoke
13:09-13:19	Idle	-	200	-	
13:19-13:23	2200	210	690	65	Particles
13:23-13:33	Idle	-	200	-	
13:33-13:36	2200	230	745	60	Particles
13:36-13:46	Idle	-	200	-	
13:46-13:50	2200	250	790	65	Particles
13:50-14:00	Idle	-	200	-	
14:00-14:05	2200	270	840	70	particles (not sparks)
14:05-14:15	Idle	-	200	-	
14:15-14:20	2200	Full +0.5% CH4	940	75	particles (not sparks)
14:20-14:30	Idle	-	200	-	
14:30-14:36	2200	Full + 0.9% CH4	990	75	Lots of particles
14:36-14:46	Idle	-	200	-	
14:46-14:51	2200	Full + 1.2% CH4	1040	75	Lots of particles, small glowing spot of ignition near canister exit, self extinguished
14:51-14:56	2200	Full + 1.4% CH4	1077	75	Lots of particles, small glowing spot of ignition bottom of Filter #2, self extinguished
14:56-15:00	Engine idle, shutdown				

RR 1, Box 251
Triadelphia, WV 26059
(304) 547-2051

FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

After Test Observations:	Filter #1 was noticeably cleaner of DPM than when placed in the canister for testing – media lighter in color than when received and lighter than #2 filter. Wire mesh had not DPM clinging to it at all, unlike when received. Filter #2 did not show any observable damage from dpm ignitions during tests. Potting compound on end caps crumbling (source of particles during tests) and Filter #2 looked to be leaking DPM from end caps.
Figures:	NA



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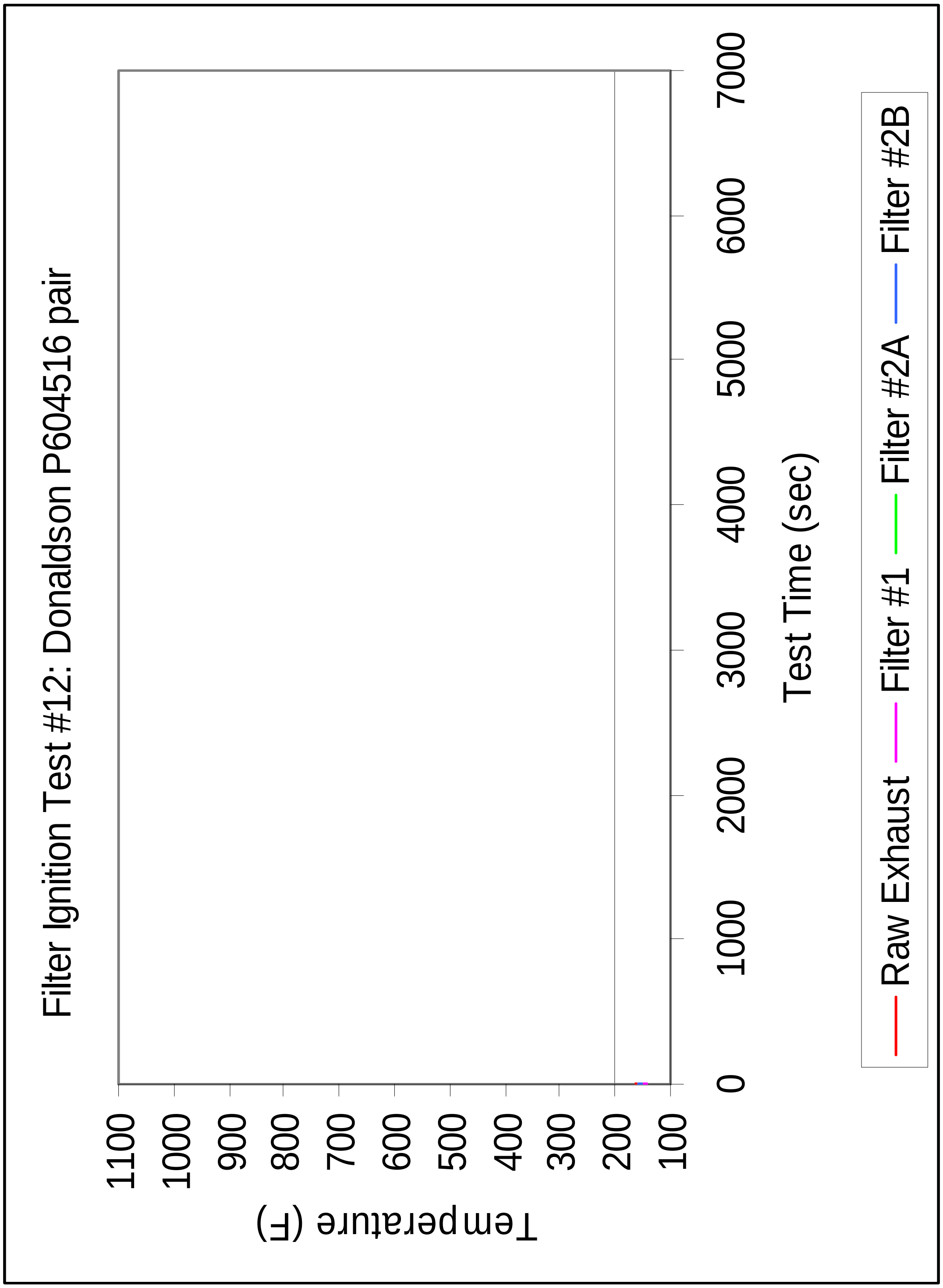
FILTER IGNITION TESTING TEST DATA AND OBSERVATIONS

Test No:	12 (STEP7)			**Date:**	8/17/04
Filter ID:	Donaldson P604516 'special' high temperature filter				
Filter Condition:	Used, received from Steve Forbush of Canyon Fuels – run on Mercedes 906 engine (outby) for 25-35 hours "SET 2"				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup	9:55				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
9:55-10:05	Idle	-	200	-	
10:05-10:10	2200	190	650	60	Potting particles, smoke
10:10-10:20	Idle	-	200	-	
10:20-10:30	2200	210	690	75	Smoke
10:30-10:40	Idle	-	200	-	
10:40-10:45	2200	230	740	65	No smoke
10:45-10:55	Idle	-	200	-	
10:55-11:00	2200	250	785	60	Light gray smoke
11:00-11:10	Idle	-	200	-	
11:10-11:15	2200	270	840	65	Light blue smoke
11:15-11:25	Idle	-	200	-	
11:25-11:30	2200	Full + 0.7% CH_4	980	75	
11:30-11:40	Idle	-	200	-	
11:40-11:45	2200	Full + 1.1% CH_4	1055	75	Potting particles
11:45-11:50	Idle, shutdown				
After Test Observations:	No physical damage to filters observed other than potting compound losses. Filter #1 showed same signs of cleaning / regeneration as shown in Test 11.				
Figures:	NA				


Filter Ignition Test #12: Donaldson P604516 pair
Temperature (F)
1100
1000
900
800
700
600
500
400
300
200
100
Test Time (sec)
0
1000
2000
3000
4000
5000
6000
7000
Raw Exhaust
Filter #1
Filter #2A
Filter #2B

RR 1, Box 251
Triadelphia, WV 26059
(304) 547-2051

FILTER IGNITION TESTING TEST DATA AND OBSERVATIONS

Test No:	13 (STEP8)			**Date:**	8/18/04
Filter ID:	Donaldson P604516 'special' high temperature filter				
Filter Condition:	Used, received from Steve Forbush of Canyon Fuels – run on Mercedes 906 engine (outby) for 25-35 hours "SET 2" : same set as used in test 12, continuing to build up new dpm				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup	14:05 on 8:17 and 08:40 on 8/18				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
8/17 14:05-15:05	Idle	-	200	-	DPM buildup
8/17 15:05-16:20	2200	45	450	-	DPM buildup, BP= 8.3mmHg @ 15:40 and 11.3mm @ 16:15
8/17 16:20-16:25	idle	-	200	-	DPM buildup, shutdown
8/18 08:40-09:00	Idle	-	200	-	DPM buildup
09:00-10:15	2200	45	450	-	DPM buildup, BP= 11.5mm @ 9:07 and 17.7mm @ 10:14
10:15-10:20	1400	150	-	-	DPM buildup
10:20-11:15	1400	100	350	-	DPM buildup
11:15-11:30	Idle	-	200	-	DPM buildup, shutdown
13:00-13:20	Idle	-	200	-	
13:20-13:25	2200	210	705	65	Heavy blue smoke, particles
13:25-13:35	idle	-	200	-	
13:35-13:40	2200	230	755	65	Smoke, particles
13:40-13:50	Idle	-	200	-	
13:50-13:55	2200	250	800	65	No smoke, BP=20.1mmHg particles
13:55-14:05	Idle	-	200	-	
14:05-14:10	2200	270	850	65	Particles
14:10-14:20	idle	-	200	-	
14:20-14:25	2200	Full + 0.6% CH4	950	75	Smoke, particles

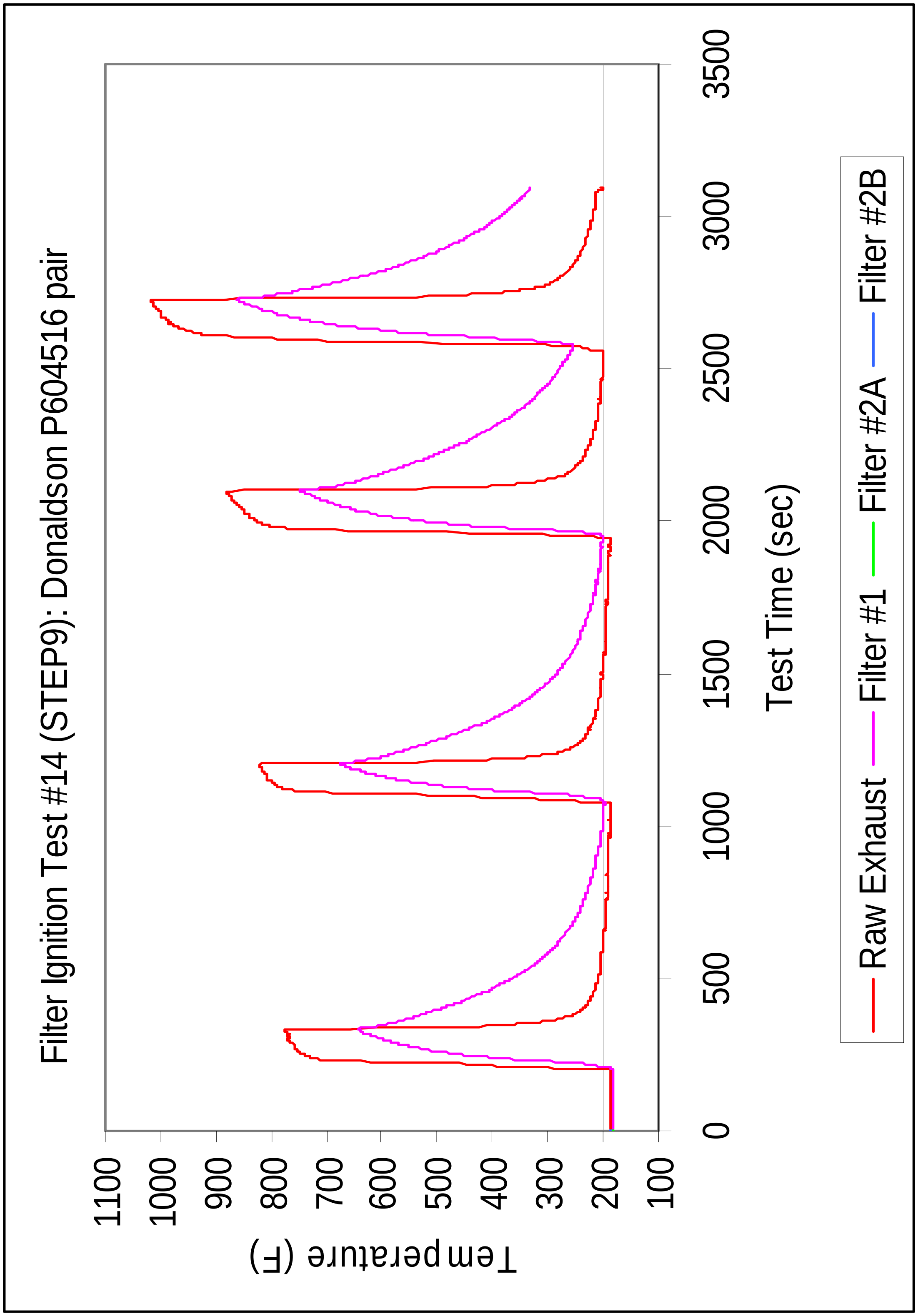
RR 1, Box 251
Triadelphia, WV 26059
(304) 547-2051

FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

14:25-14:45	Idle	-	200	-	
14:35-14:40	2200	Full + 1.35% CH4	1070	75	Particles
After Test Observations:	NA				
Figures:	NA				

FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No:	14 (STEP9)			**Date:**	8/19/04
Filter ID:	Donaldson P604516 'special' high temperature filter				
Filter Condition:	Used, received from Steve Forbush of Canyon Fuels – run on Mercedes 906 engine (outby) for 25-35 hours "SET 2"; same filters as used in test 12 and 13				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup	14:50 on 8/18 and 08:25 on 8/19/04				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
8/18 14:50-15:00	Idle	-	200	-	DPM buildup
8/18 15:00-15:55	2200	45	450	-	DPM buildup
8/18 15:55-16:25	Idle	-	200	-	DPM buildup
8/19 08:25-08:40	Idle	-	200	-	DPM buildup
08:40-15:00	2200	45	450	-	DPM buildup, BP=22mmHg @ 08:40 and 47.2mm @ 15:00
15:00-15:30	Idle	-	200	-	DPM buildup
15:30-15:35	2200	230	765	65	Heavy smoke
15:35-15:45	Idle	-	200	-	
15:45-15:48	2200	250	810	65	Smoke
15:48-15:58	Idle	-	200	-	
15:58-16:04	2200	Full, 265	870	65	A few sparks
16:04-16:09	Idle	-	200	-	
16:09-1614	2200	Full + 0.8% CH_4	1000	75	Several sparks as engine throttled down
16:14	Idle, shutdown				
After Test Observations:	Filter #1 appeared regenerated. Filter #2 showed heavy dpm buildup from the long period of running before test and did not show any regeneration signs. No physical damage to either filter observed other than potting losses.				
Figures:	B.18				


Filter Ignition Test #14 (STEP9): Donaldson P604516 pair
Temperature (F)
1100
1000
900
800
700
600
500
400
300
200
100
Test Time (sec)
0
500
1000
1500
2000
2500
3000
3500
Raw Exhaust
Filter #1
Filter #2A
Filter #2B

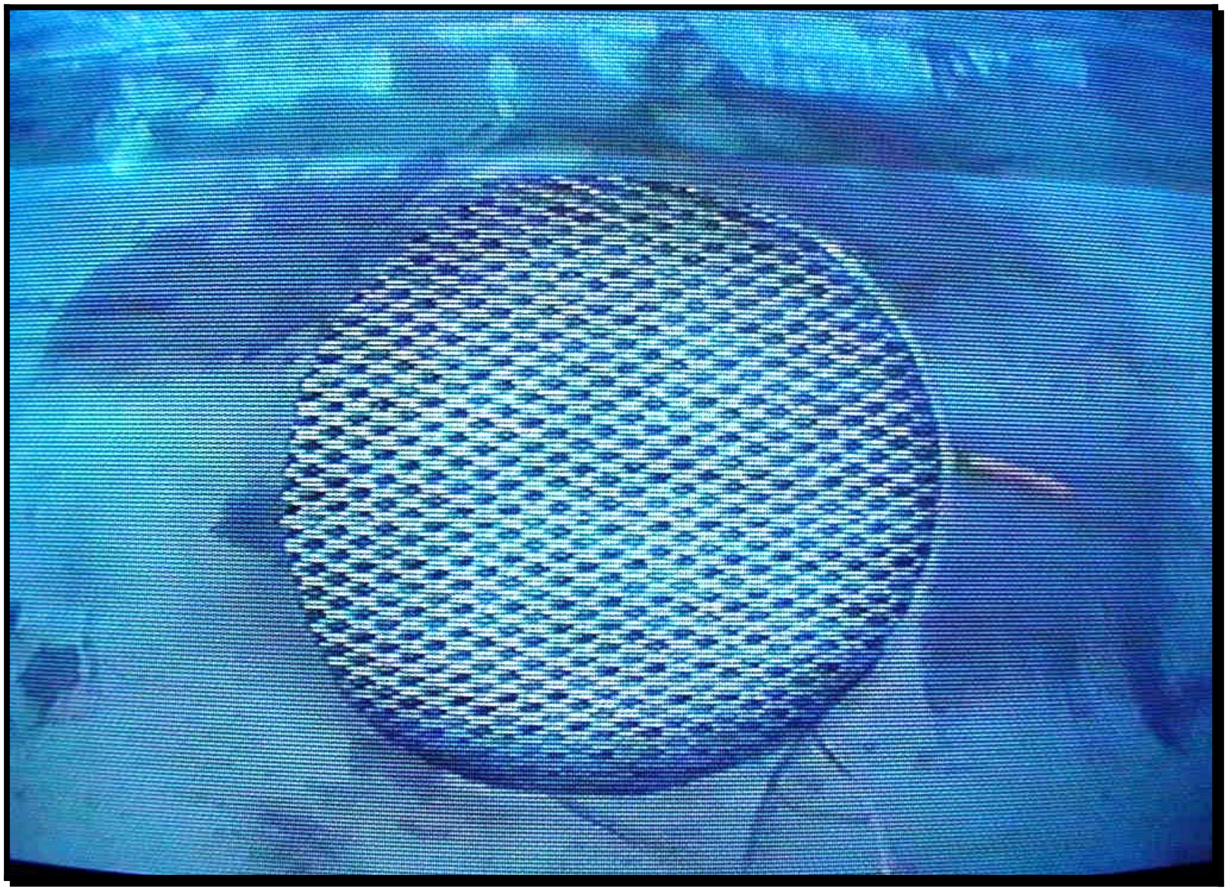
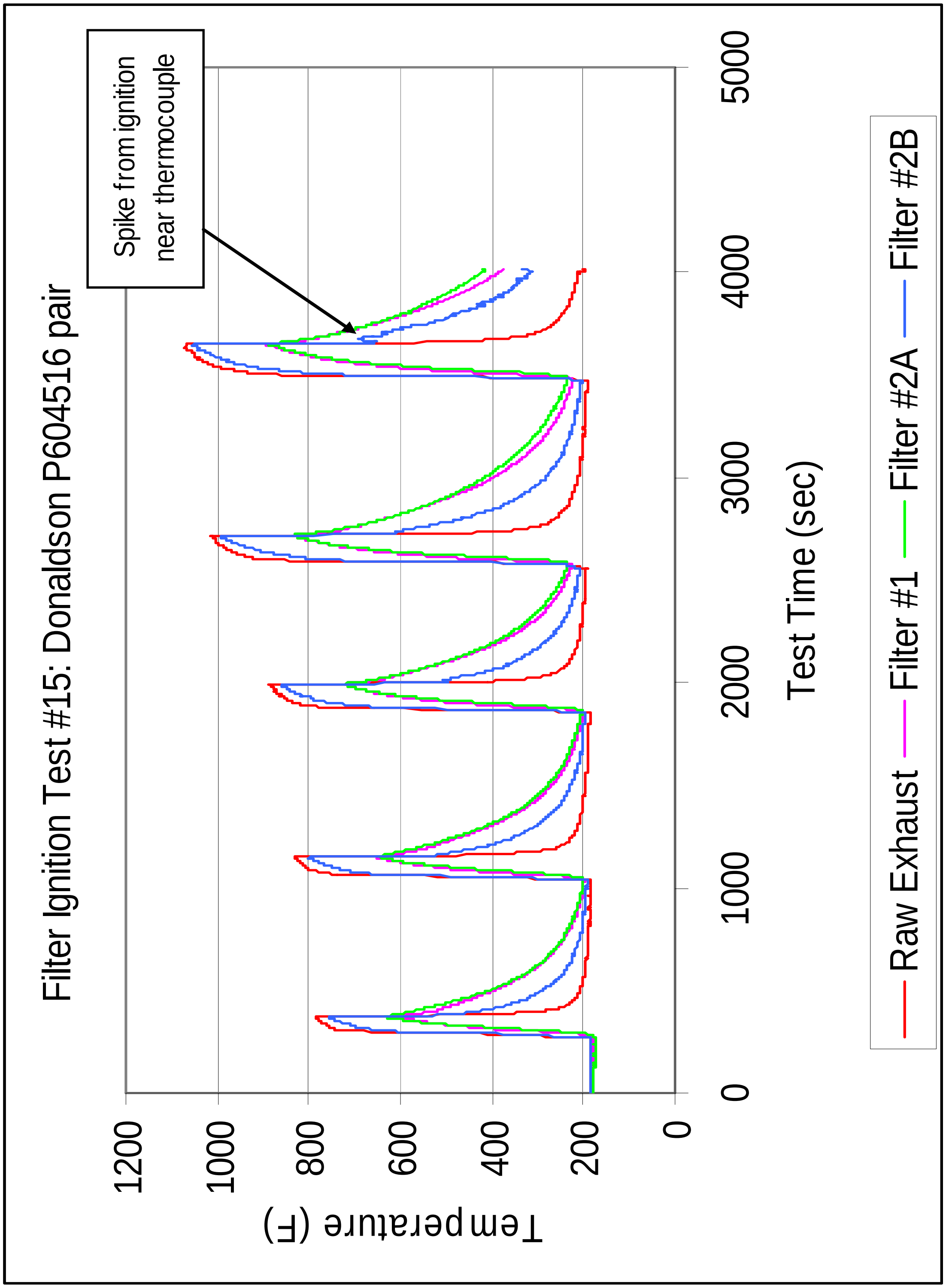


Figure B. 18. Test #14; example of spark exiting canister (right side of hole).

FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No.	15 (STEP10)			**Date:**	8/20/04
Filter ID:	Donaldson P604516 'special' high temperature filter				
Filter Condition:	Used, received from Steve Forbush of Canyon Fuels – run on Mercedes 906 engine (outby) for 25-35 hours "SET 2"; same filters as used in test 12, 13, and 14				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup	08:00				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
08:00-08:30	Idle	-	200	-	DPM Buildup
08:30-11:30	2200	45	450	-	DPM Buildup, BP=33.6mmHg @ 08:42 and 46.8mm @ 11:30
11:30-13:00	Idle	-	200	-	DPM Buildup
13:00-14:45	1400	100	350	-	DPM Buildup
14:45-15:15	Idle	-	200	-	DPM Buildup
15:15-15:20	2200	230	770	65	Heavy smoke
15:20-15:30	Idle	-	200	-	
15:30-15:33	2200	250	825	65	Light smoke
15:33-15:43	Idle	-	200	-	
15:43-15:45	2200	Full, 275	866	65	
15:45-15:55	Idle	-	200	-	
15:55-16:00	2200	Full + 0.75% CH4	990	75	Small glowing ignition and sparks at exit hole
16:00-16:10	Idle	-	200	-	
16:10-16:15	2200	Full + 1.2% CH4	1061		Small glowing ignition and sparks at exit hole
16:15-16:20	Idle, shutdown				
After Test Observations:	Filters appeared undamaged after testing. Areas of Filter #1 appeared regenerated and small spots of Filter #2 also appeared cleaned.				
Figures:	B.19, B.20				


Filter Ignition Test #15: Donaldson P604516 pair
Spike from ignition near thermocouple
Temperature (F)
1200
1000
800
600
400
200
0
Test Time (sec)
0
1000
2000
3000
4000
5000
Raw Exhaust
Filter #1
Filter #2A
Filter #2B

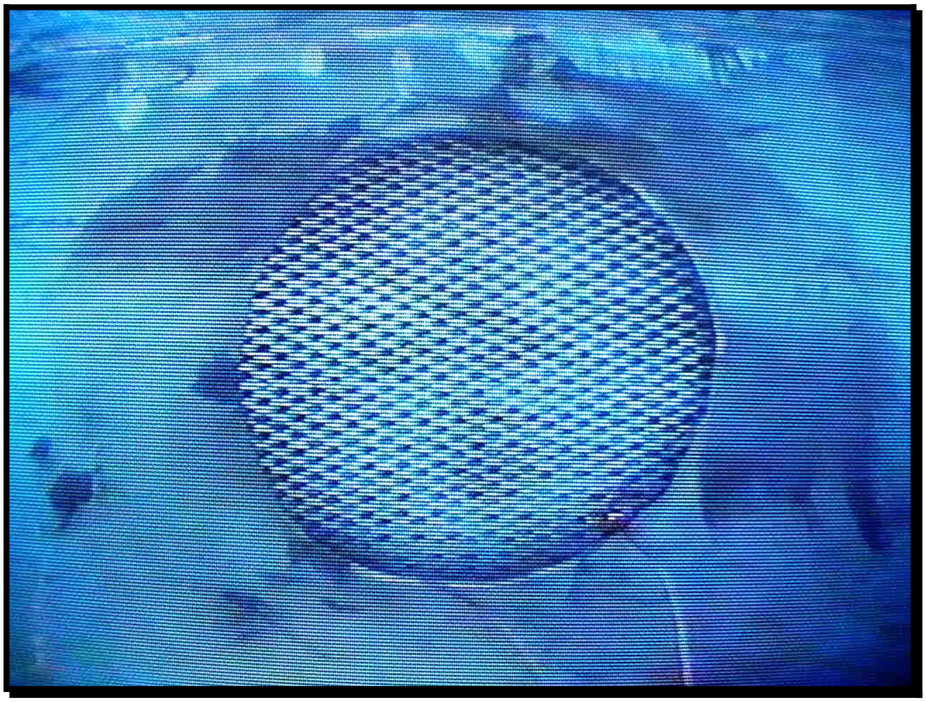


Figure B. 19. Test #15; small ignition on filter surface (5 o'clock position).

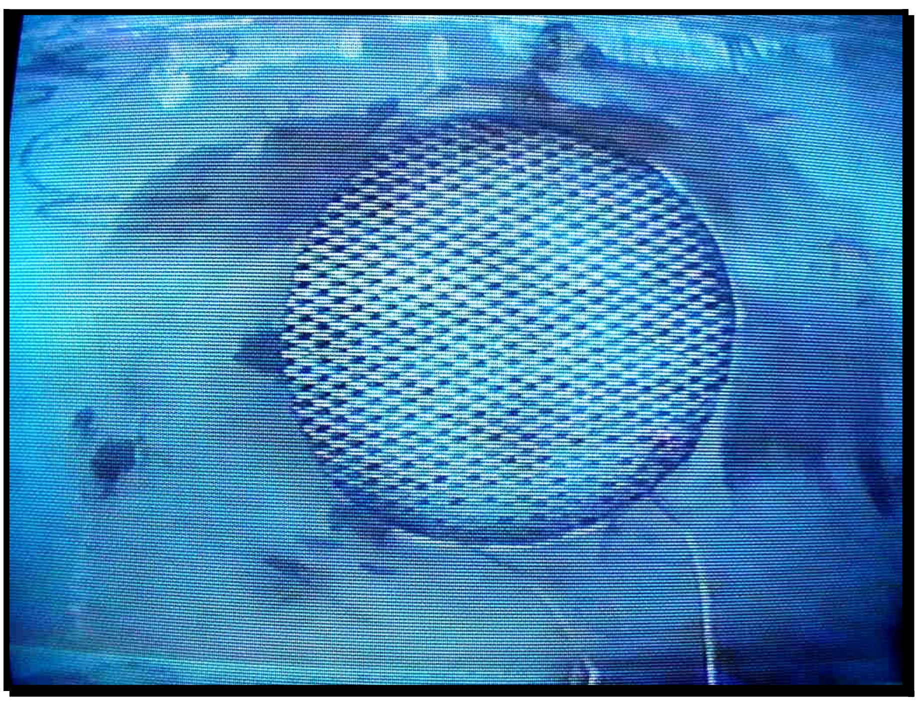


Figure B. 20. Test #15; small ignition on filter surface (5 o'clock position).

RR 1, Box 251
Triadelphia, WV 26059
(304) 547-2051

FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No.	16 (STEP11)		**Date:**	8/23/04	
Filter ID:	Donaldson P604516 'special' high temperature filter				
Filter Condition:	Used Inby on CAT3306 with water scrubber. Received from Energy West Mining. Filters heavily loaded, screens rusted and damaged				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup	12:40				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
12:40-12:55	Idle	-	200	-	
12:55-13:00	2200	190	645	65	Heavy Smoke, sparks and ignition of #2 filter. Filter had ignited before max temperature achieved.
13:00-13:05	Idle, shutdown				
After Test Observations:	Heavy Damage to Filter #2 in area aligned with canister exhaust hole. Several other areas on filter damaged. Heat indications on filter canister appeared to show filter #1 burning as well, but no visible damage apparent to filter.				
Figures:	B.21-B.24				

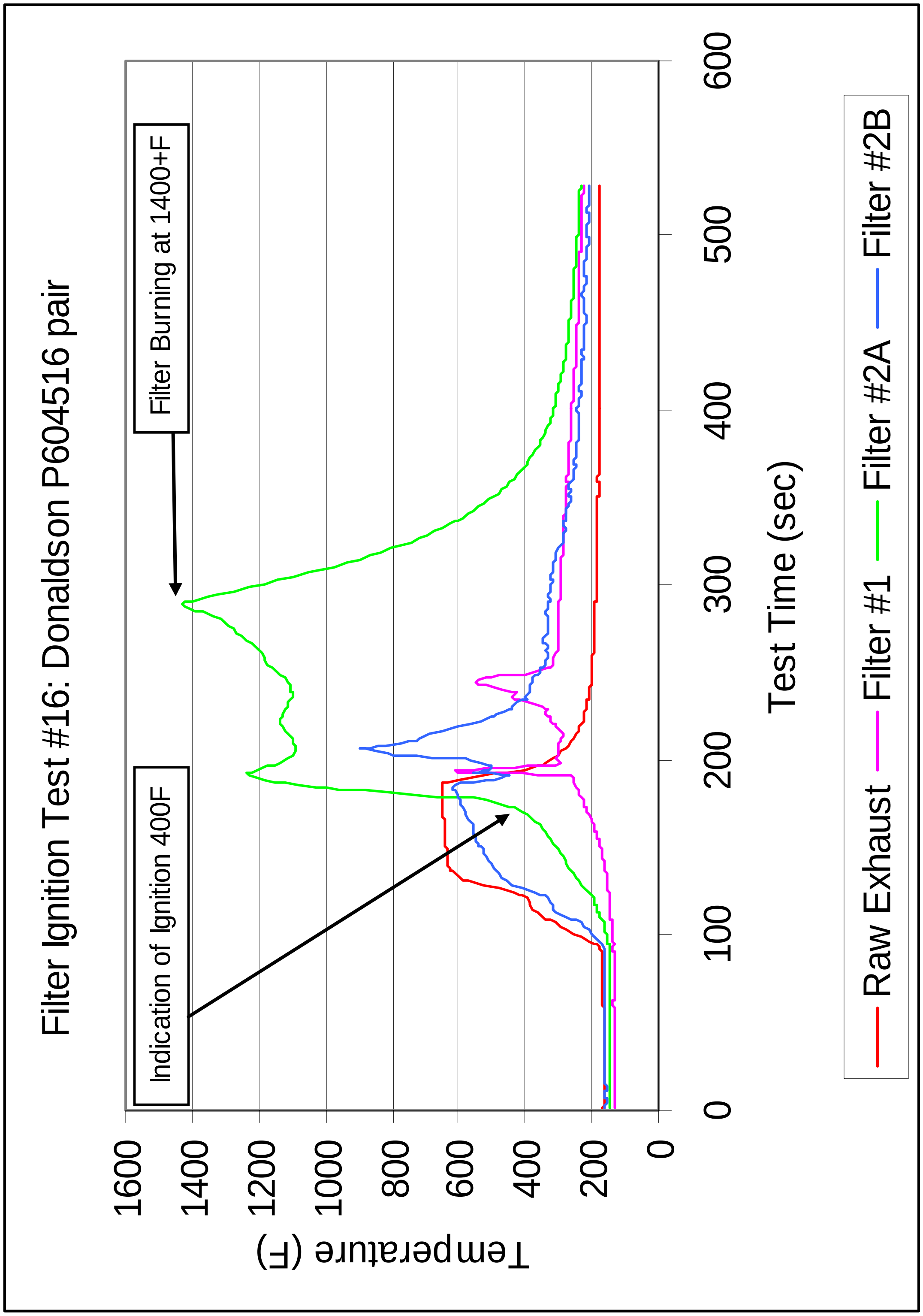

Filter Ignition Test #16: Donaldson P604516 pair
Filter Burning at 1400+F
Indication of Ignition 400F
Temperature (F)
1600
1400
1200
1000
800
600
400
200
0
Test Time (sec)
0
100
200
300
400
500
600
Raw Exhaust
Filter #1
Filter #2A
Filter #2B

Figure B. 21. Test #16; Ignition of Filter #2 (haze is due to smoke).

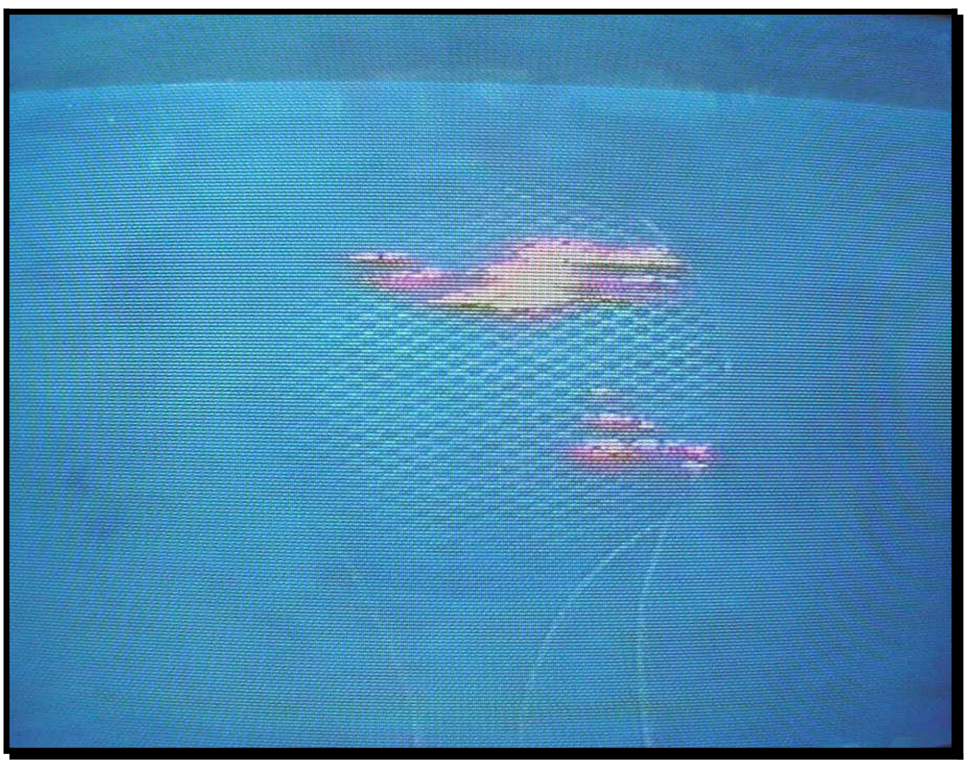


Figure B. 22. Test #16. Filter #2 continuing to burn (haze due to smoke).

Figure B. 23. Test #16; Damage to filter #2 from ignition.

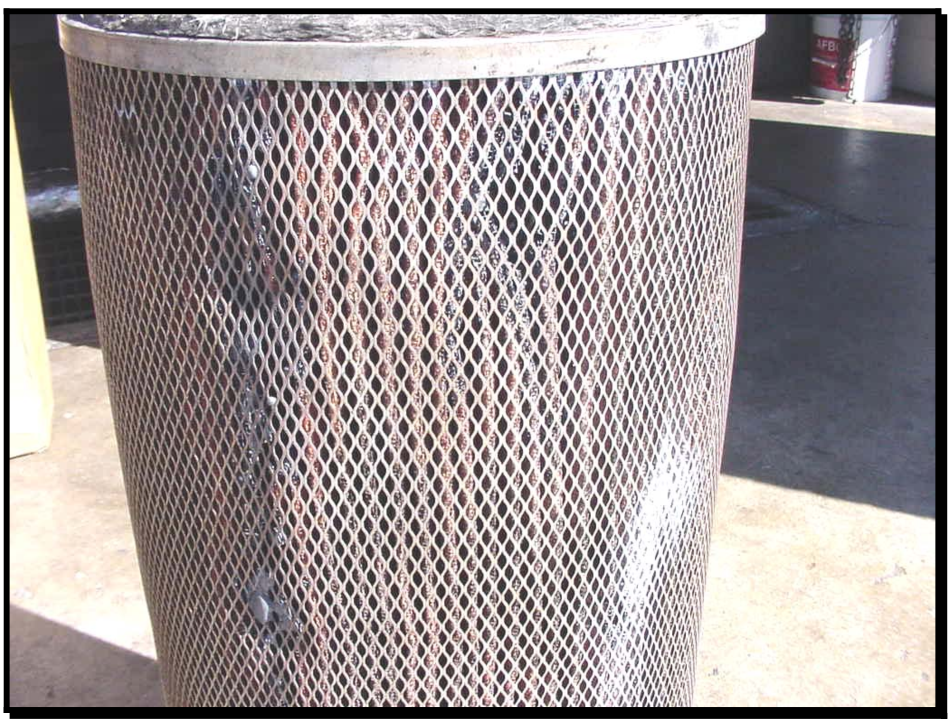
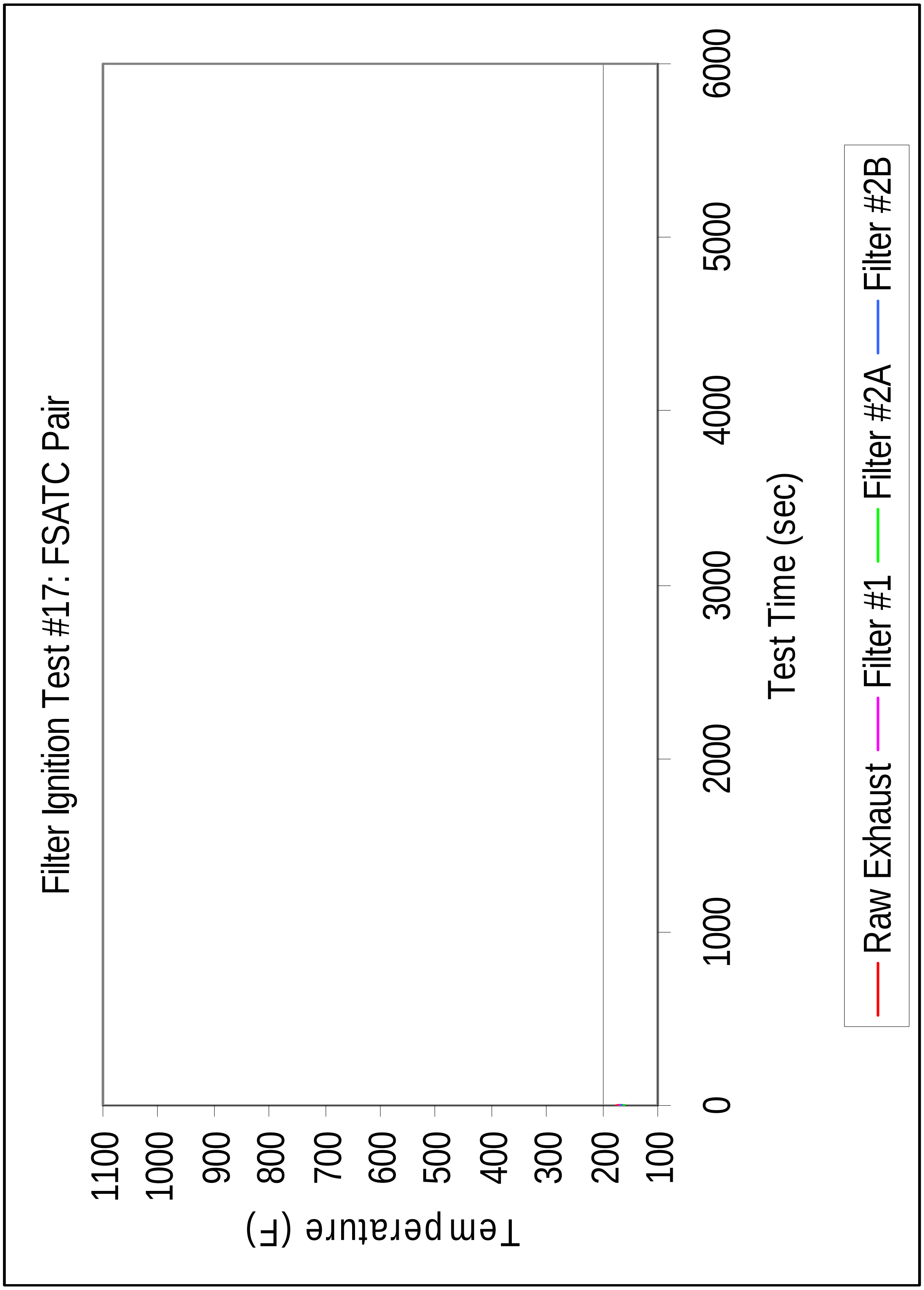


Figure B. 24. Test #16; Damage to #2 filter.

RR 1, Box 251
Triadelphia, WV 26059
(304) 547-2051

FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No.	17 (STEP12)		**Date:**	8/23/04	
Filter ID:	FSATC filter pair				
Filter Condition:	Used Inby on CAT3306 with water scrubber. Received from FSATC. Filters heavily loaded, screens rusted, rust coating media.				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4” pipe inlet diameter and 6 5/8” diameter outlet hole aligned with #2 filter				
Startup:	13:45				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
13:45-13:55	Idle	-	200	-	
13:55-14:00	2200	190	645	65	Very heavy smoke from filter, filter continued to smoke after engine idle
14:00-14:10	Idle	-	200	-	
14:10-14:15	2200	210	690	65	Heavy smoke
14:15-14:25	Idle	-	200	-	
14:25-14:30	2200	230	735	65	Lighter smoke
14:30-14:40	Idle	-	200	-	
14:40-14:45	2200	250	775	65	Light smoke
14:45-14:55	Idle	-	200	-	
14:55-15:00	2200	Full, 275	850	65	Small glowing ignition at exhaust hole. Sparks emitted from other parts of filter. Self extinguished.
15:00-15:10	Idle	-	200	-	
15:10-15:15	2200	Full + 0.85% CH4	1000	75	Sparks emitted as engine loaded up. More Ignitions on #2 filter at top of filter. Self extinguished.
15:15-15:20	Idle, shutdown				
After Test Observations:	Heavy Damage to Filter #2 along top of filter. A small burn thru was noted at the point on filter observed glowing at 850F step. Areas on #1 Filter appear regenerated.				
Figures:	B.25, B.26				


Filter Ignition Test #17: FSATC Pair
Temperature (F)
1100
1000
900
800
700
600
500
400
300
200
100
Test Time (sec)
0
1000
2000
3000
4000
5000
6000
Raw Exhaust
Filter #1
Filter #2A
Filter #2B

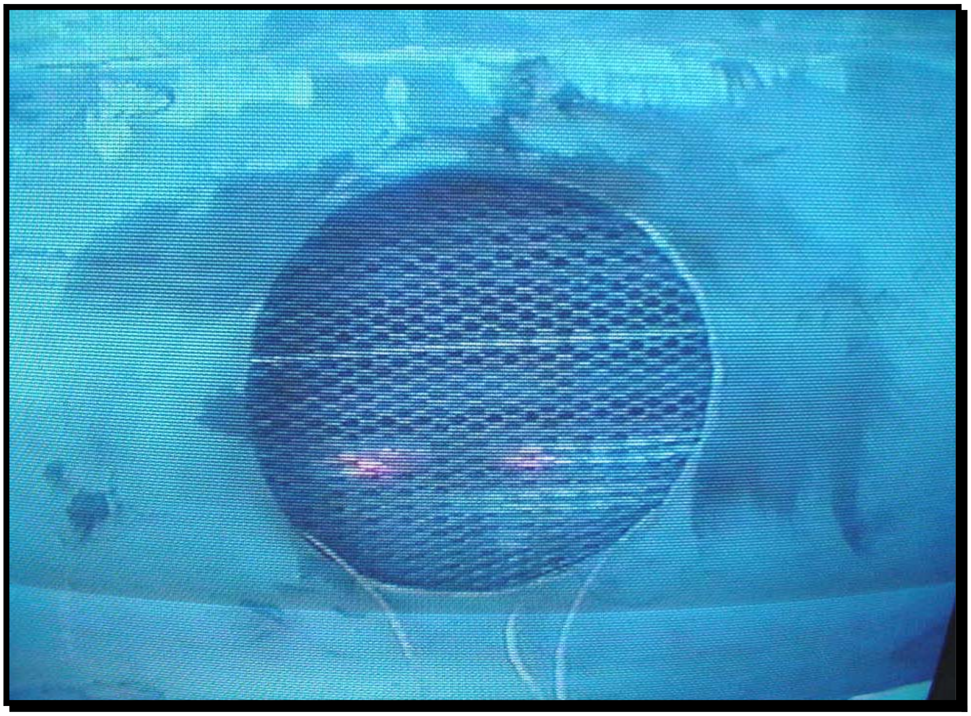


Figure B. 25. Test #17; Glowing ignition on Filter #2 at 850F.

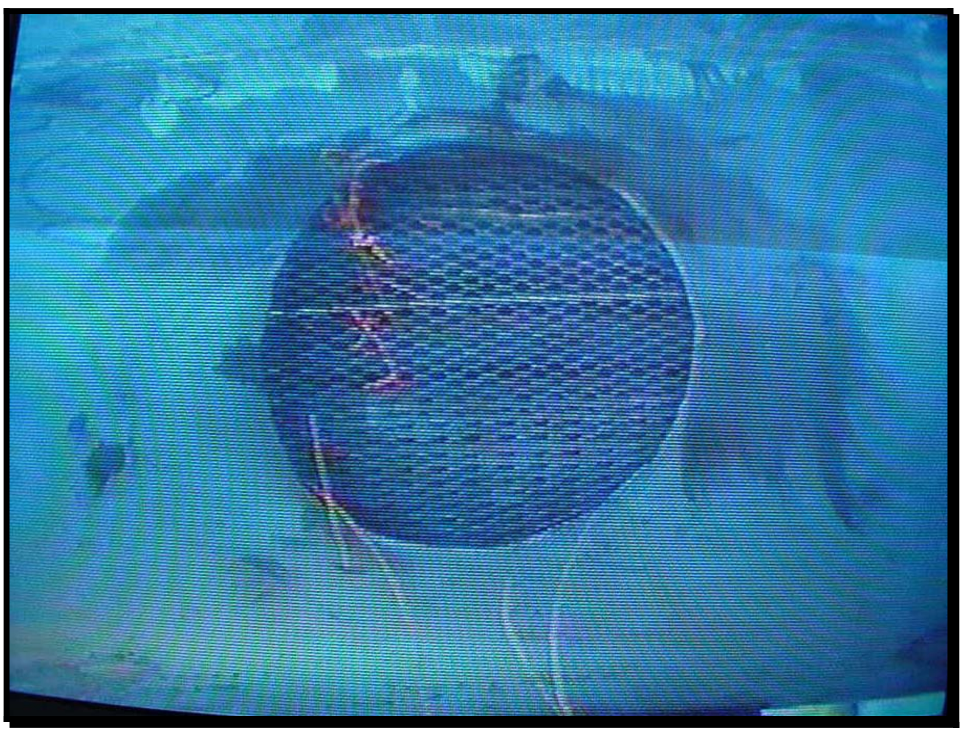
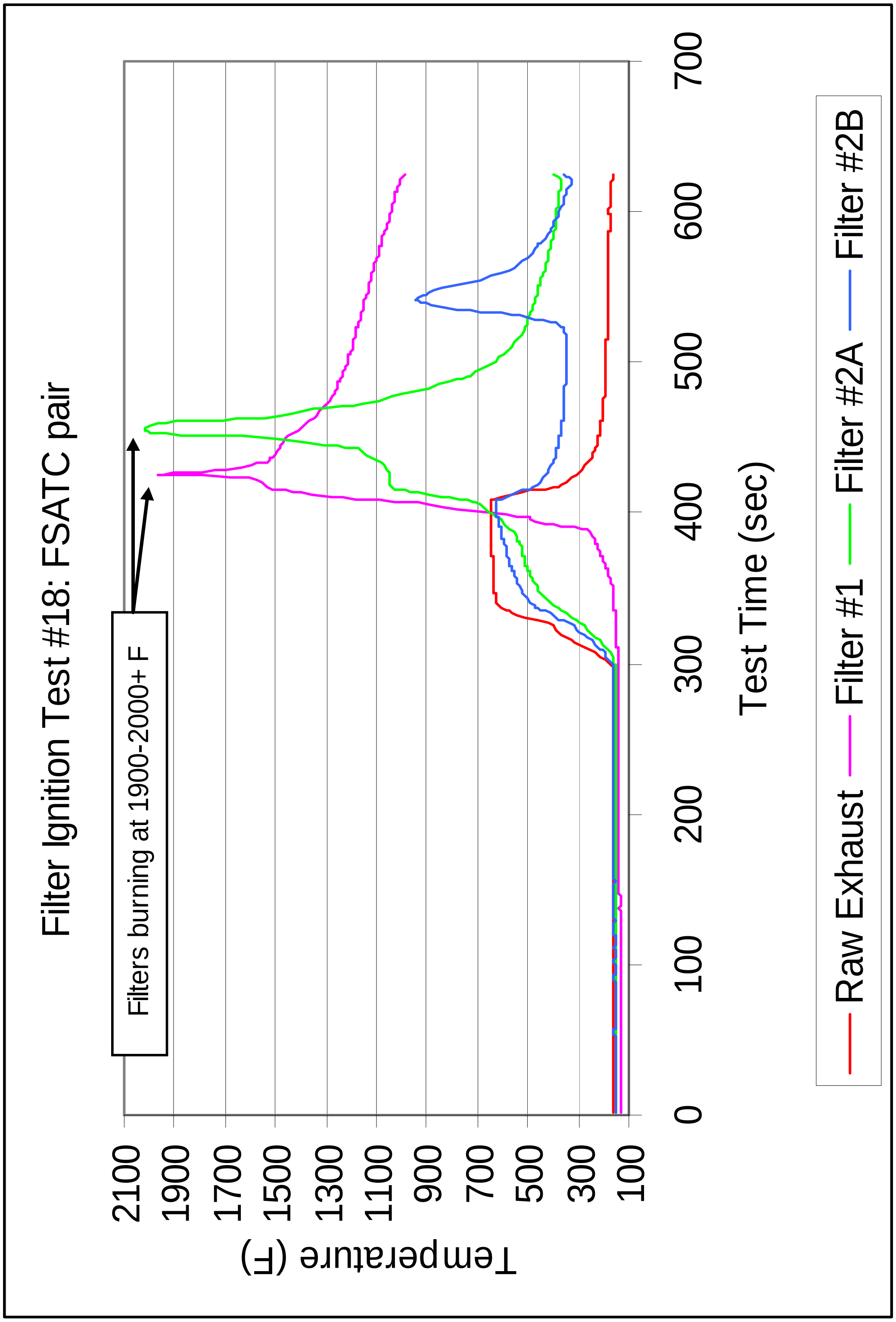


Figure B. 26. Test #17; Sparks from top of #2 filter at 1000F.

RR 1, Box 251
Triadelphia, WV 26059
(304) 547-2051

FILTER IGNITION TESTING TEST DATA AND OBSERVATIONS

Test No.	18 (STEP13)		**Date:**	8/24/04	
Filter ID:	FSATC filter pair				
Filter Condition:	Used on CAT3306. Received from FSATC. Filter #1 moderately dirty with light rust (Outby?), Filter #2 heavily loaded with moderate screen rust (Inby)				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4” pipe inlet diameter and 6 5/8” diameter outlet hole aligned with #2 filter				
Startup:	08:50				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
08:50-09:00	Idle	-	200	-	
09:00-09:05	2200	190	645	65	Heavy smoke at load, sparks and glow filter #2, ignition, burning of filter, heavy sparking
09:05-09:10	Idle, shutdown				
After Test Observations:	Filters continued to smoke and smolder after shutdown. Filters removed, still smoldering. Filter #2 showed extensive damage from rear of filter to exhaust hole. Filter #1 showed multiple small burned spots. Smoldering spots would re-ignite and burn if compressed air blown across spot or filter placed outside in wind.				
Figures:	B.27-B.30				


Filter Ignition Test #18: FSATC pair
Filters burning at 1900-2000+ F
Temperature (F)
2100
1900
1700
1500
1300
1100
900
700
500
300
100
Test Time (sec)
0
100
200
300
400
500
600
700
Raw Exhaust
Filter #1
Filter #2A
Filter #2B

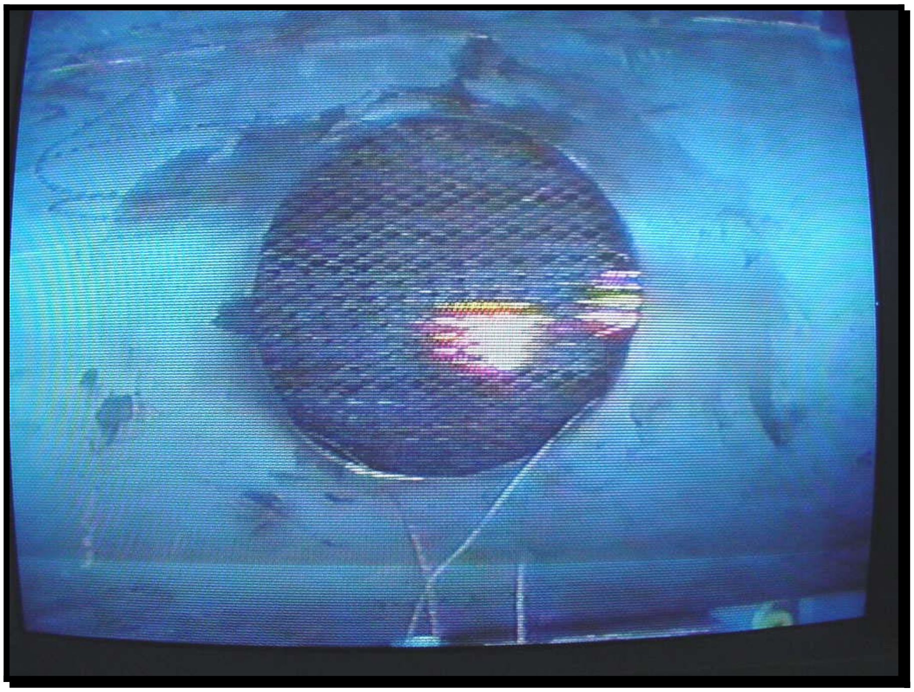


Figure B. 27. Test #18; Filter #2 ignition.

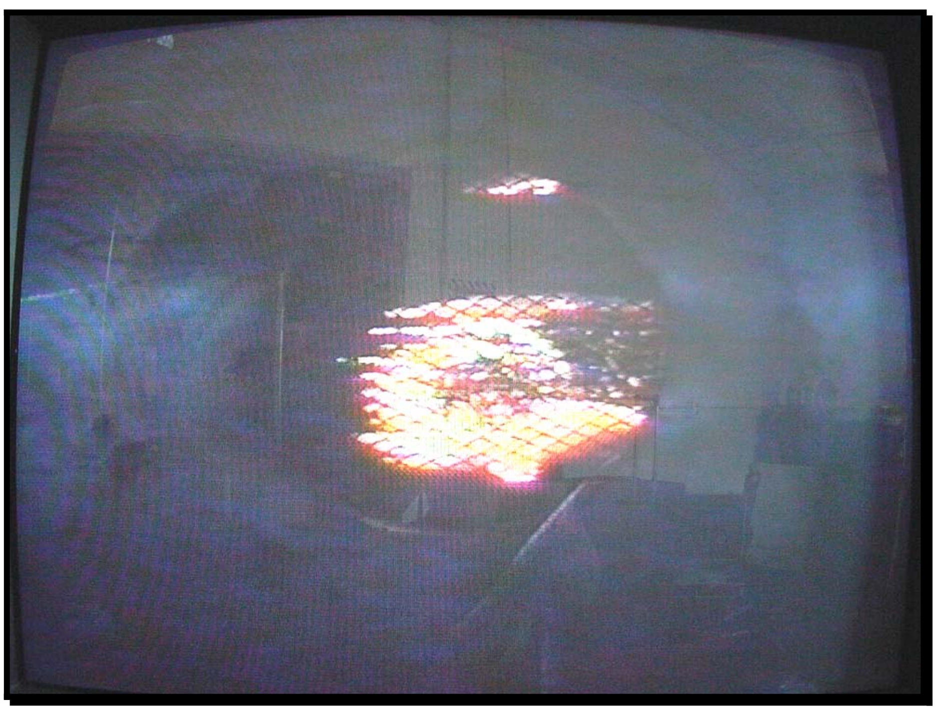


Figure B. 28. Test #18; Filter #2 burning.

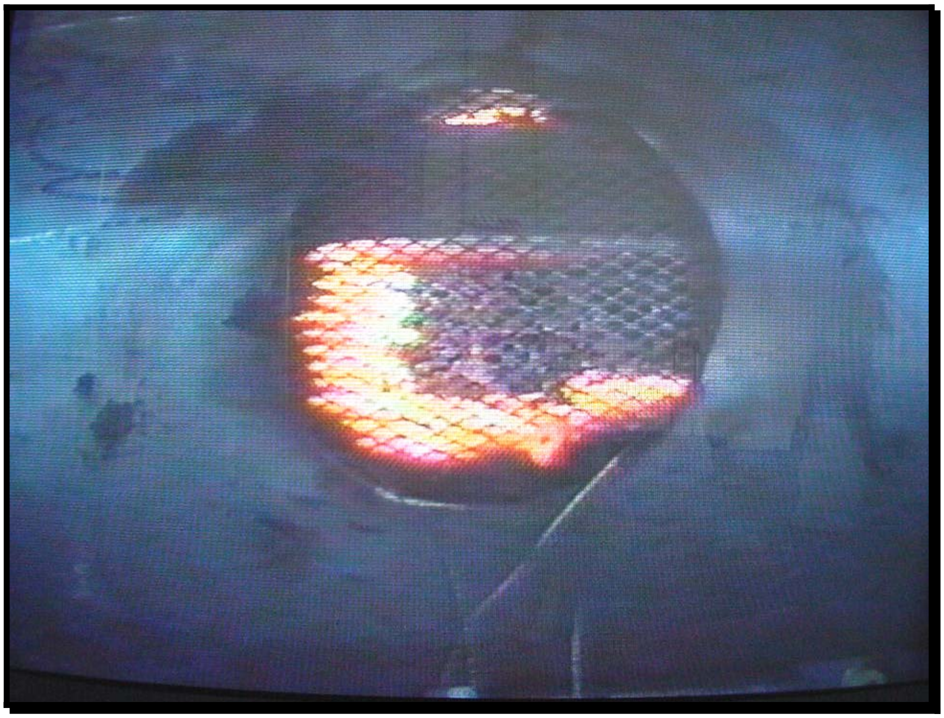
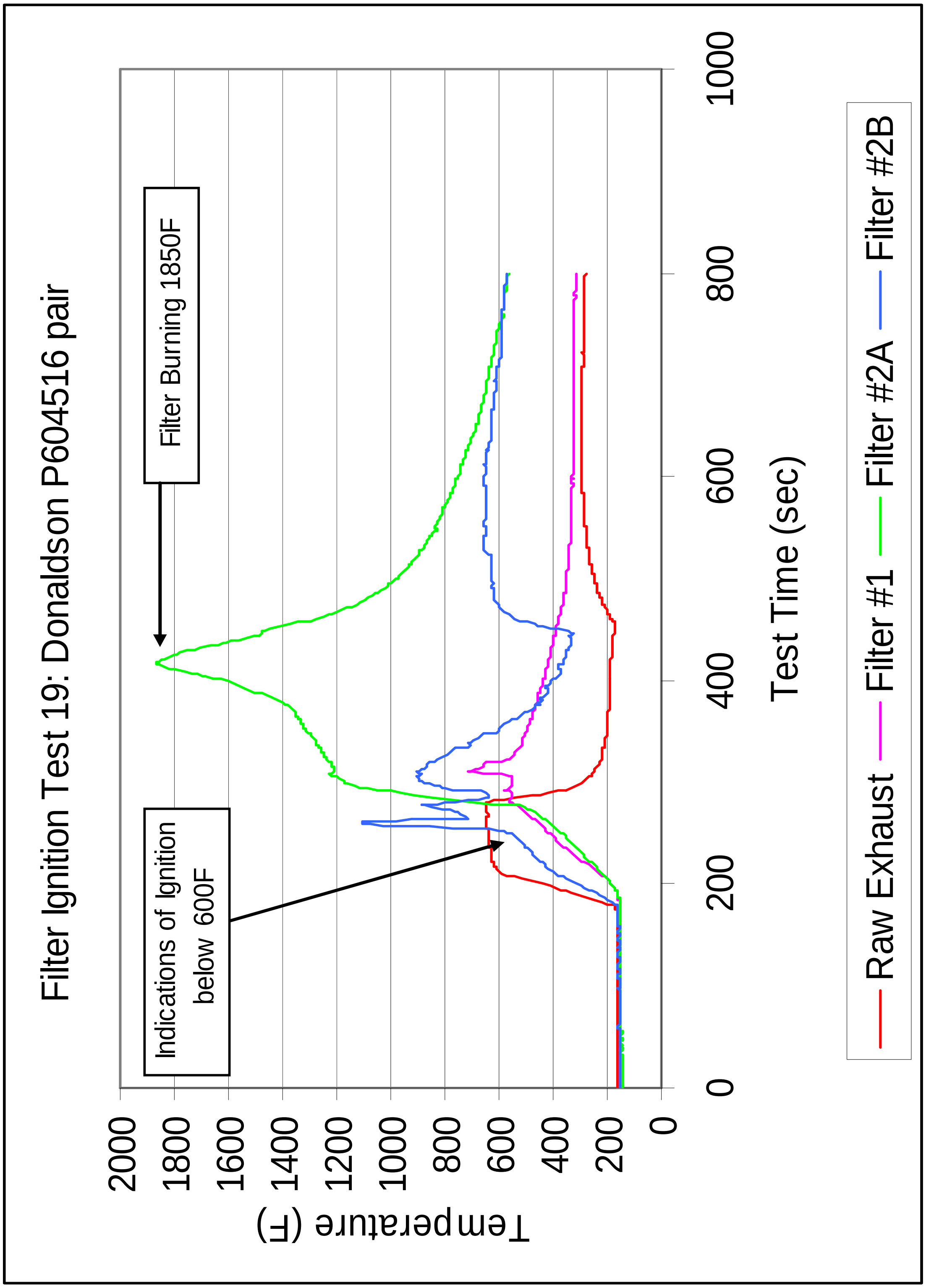


Figure B. 29. Test #18; Filter #2 burning, with hole apparent in center of burn.

Figure B. 30. Test #18; Damage to Filter #2.

FILTER IGNITION TESTING TEST DATA AND OBSERVATIONS

Test No.	19 (STEP14)		**Date:**	8/24/04	
Filter ID:	Donaldson P604516 'special'				
Filter Condition:	Used Inby on CAT3306 with water scrubber. Both filter look heavily loaded with light to moderate rust on screens.				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup:	10:00				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
10:00-10:10	Idle	-	200	-	
10:10-10:15	2200	190	645	65	Extreme smoke at load, sparks and glow filter #2, ignition, burning of filter, sparking, open flame exiting canister, white burn material accumulating on filter parts exposed to flame
10:15-10:20	Idle, shutdown				
After Test Observations:	Filter #2 continued to smoke and smolder after shutdown. Filters removed, #2 still smoldering and continued long after removal. Filter #2 showed extensive damage all along length and in areas around end caps. Filter #1 appeared undamaged.				
Figures:	B.31, B.32				


Filter Ignition Test 19: Donaldson P604516 pair
Filter Burning 1850F
Indications of Ignition below 600F
Temperature (F)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Test Time (sec)
0
200
400
600
800
1000
Raw Exhaust
Filter #1
Filter #2A
Filter #2B

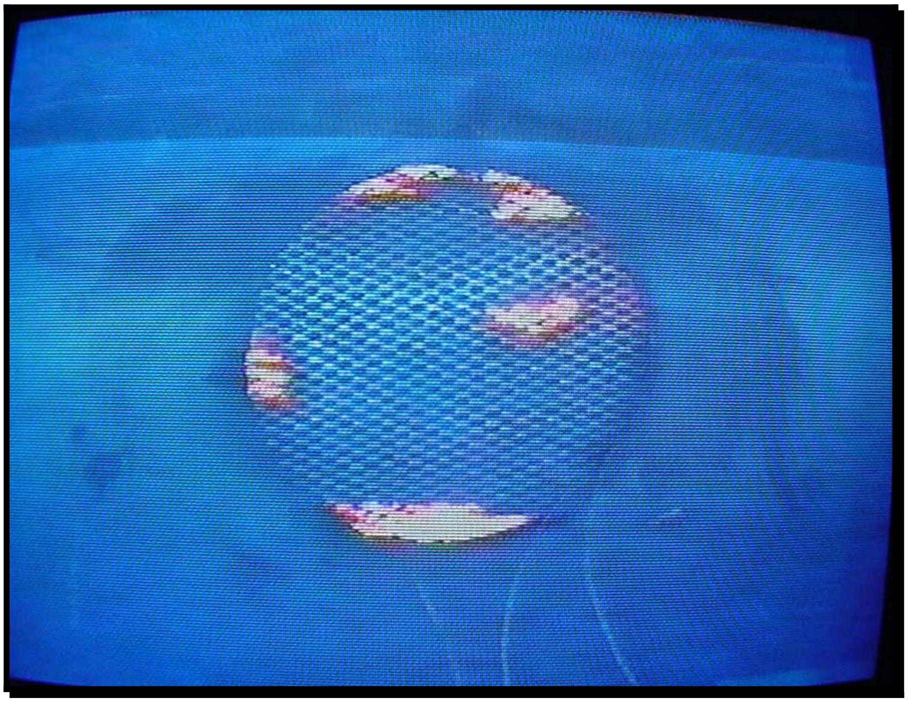


Figure B. 31. Test #19; Ignition and burning of filter #2.

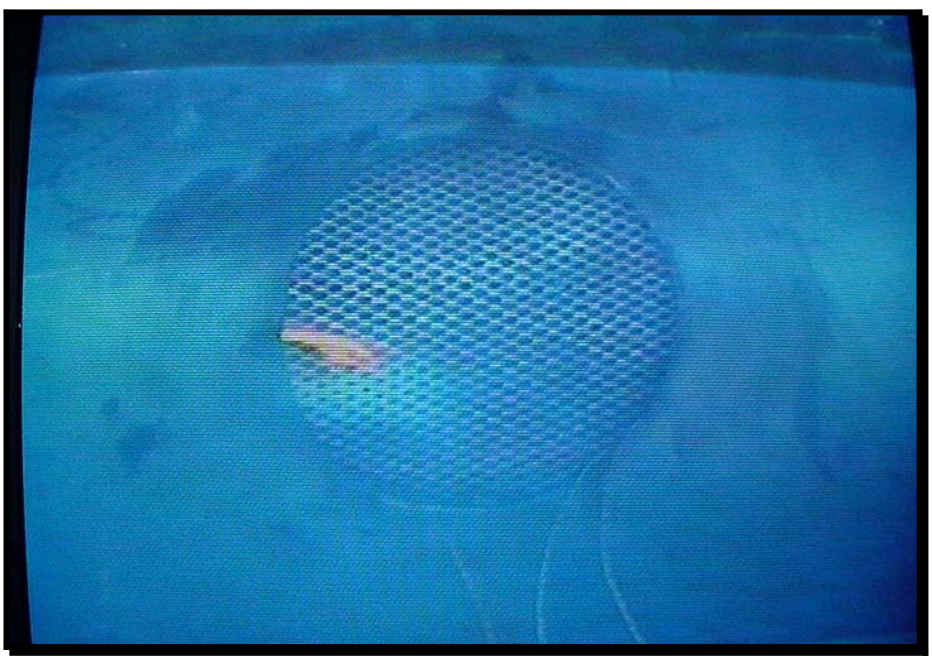
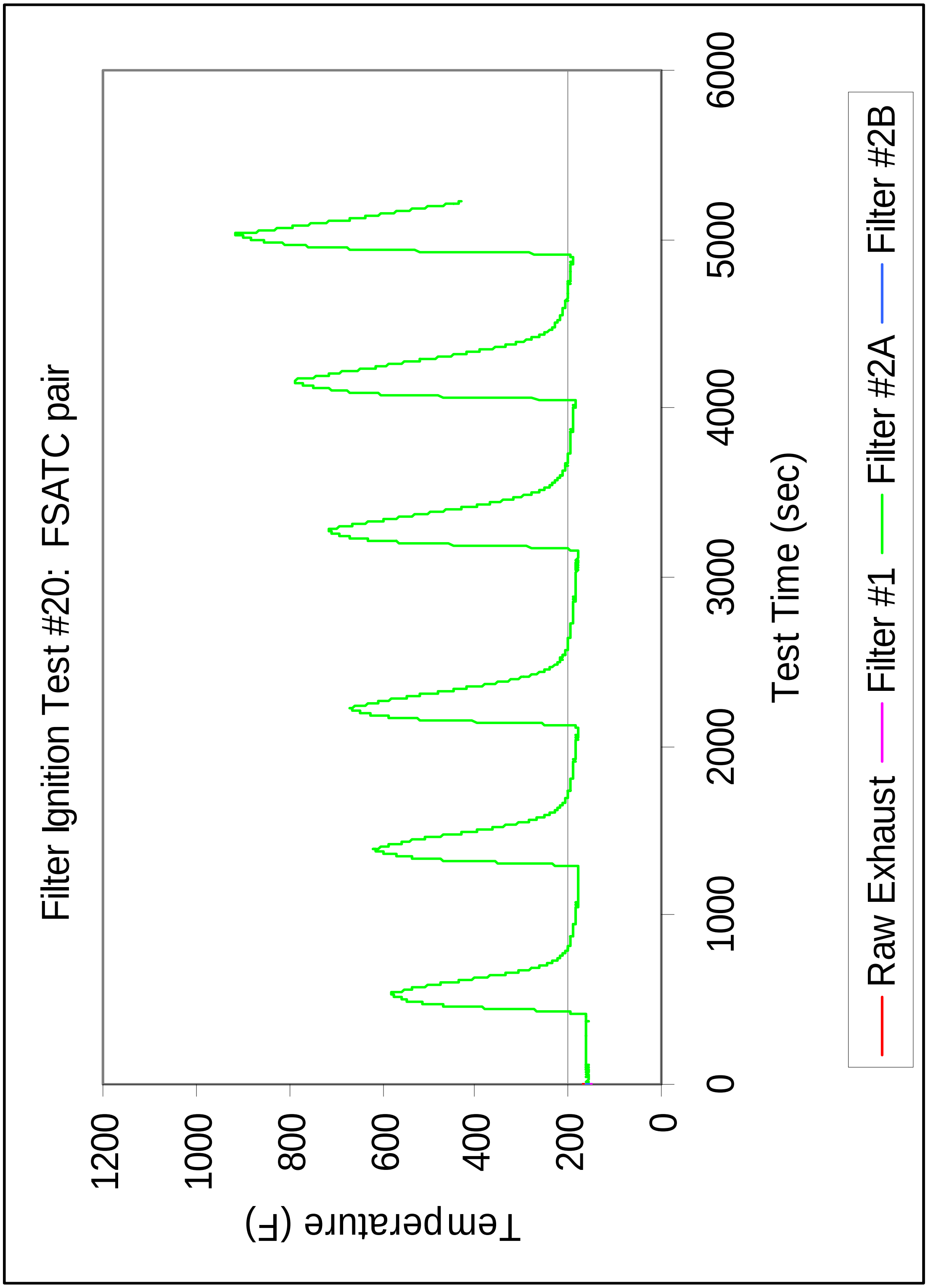


Figure B. 32. Test #19; Open fame exiting from canister hole.

FILTER IGNITION TESTING TEST DATA AND OBSERVATIONS

Test No.	20 (STEP15)			**Date:**	8/24/04
Filter ID:	FSATC filter pair				
Filter Condition:	Used Outby on CAT3306. Received from FSATC. Filters lightly to moderately loaded, no rust. Filters do not have metal screen on outside media pleats				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup:	10:55				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
10:55-11:05	Idle	-	200	-	
11:05-11:10	2200	190	645	65	Light smoke
11:10-11:20	Idle	-	200	-	
11:20-11:25	2200	210	688	65	Light smoke
11:25-11:35	Idle	-	200	-	
11:35-11:40	2200	230	732	65	Light smoke
11:40-11:50	idle	-	200	-	
11:50-11:55	2200	250	780	65	Light smoke, possible hole blown in media at canister exit hole
11:55-12:05	idle	-	200	-	
12:05-12:10	2200	Full (275)	860	65	Hole in media (enlarged)
12:10-12:20	Idle	-	200	-	
12:20-12:25	2200	Full + 0.8% CH_4	985	75	Hole in media (enlarged)
12:25-12:30	Idle, shutdown				
After Test Observations:	No signs of ignition detected, but hole in media had developed due to lack of screen support on the outside surface of the pleats. Pleats overall had deformed out of shape on both filters.				
Figures:	NA				


Filter Ignition Test #20: FSATC pair
Temperature (F)
0
200
400
600
800
1000
1200
Test Time (sec)
0
1000
2000
3000
4000
5000
6000
Raw Exhaust
Filter #1
Filter #2A
Filter #2B

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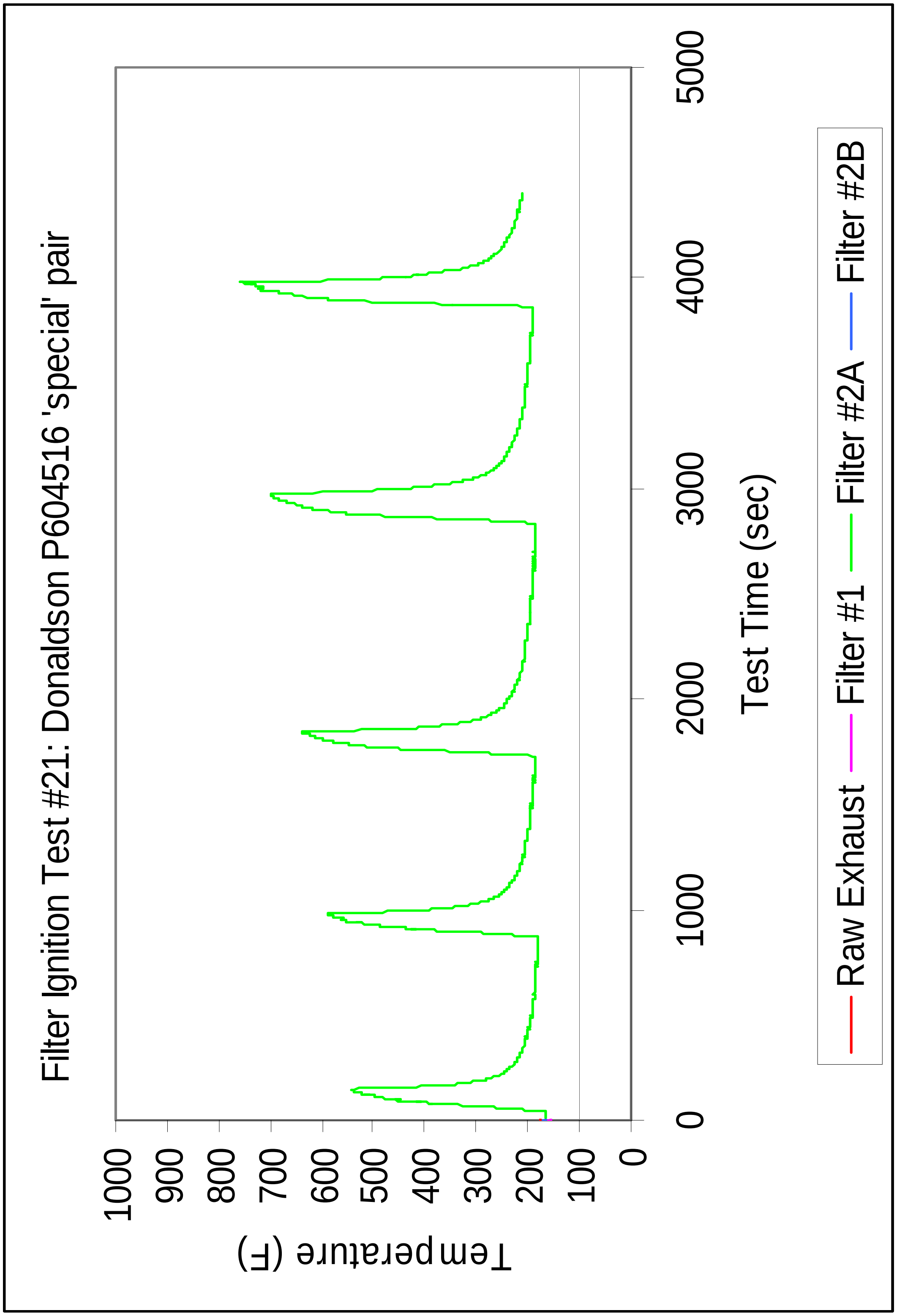
Diesel Laboratory

RR 1, Box 251
Triadelphia, WV 26059
(304) 547-2051

FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No.	21 (STEP16)			**Date:**	8/24/04
Filter ID:	Donaldson P604516 'special'				
Filter Condition:	Filters are used, from Mercedes 906 outby machine (25-35 hours run time), then laundered and shipped "clean" for testing (no signs of dpm left on filters)				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup:	13:50				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
13:50-14:05	Idle	-	200	-	
14:05-14:10	2200	190	652	65	Light smoke, potting particles
14:10-14:20	Idle	-	200	-	
14:20-14:25	2200	210	695	65	Light smoke, potting particles
14:25-14:35	Idle	-	200	-	
14:35-14:40	2200	230	740	65	Light smoke, potting particles
14:40-14:55	Idle	-	200	-	
14:55-15:00	2200	250	790	65	Light smoke, potting particles
15:00-15:10	Idle	-	200	-	
15:10-15:15	2200	Full (275)	870	65	potting particles
NA	Idle, shutdown				
After Test Observations:	No signs of ignition detected. Deterioration of end cap potting compound shown by particles exiting exhaust. No backpressure on filter (0.2-0.8mmHg during testing) to show media fused/damaged by cleaning or prior use.				
Figures:	NA				


Filter Ignition Test #21: Donaldson P604516 'special' pair
Temperature (F)
1000
900
800
700
600
500
400
300
200
100
0
0
1000
2000
3000
4000
5000
Test Time (sec)
Raw Exhaust
Filter #1
Filter #2A
Filter #2B

RR 1, Box 251
Triadelphia, WV 26059
(304) 547-2051

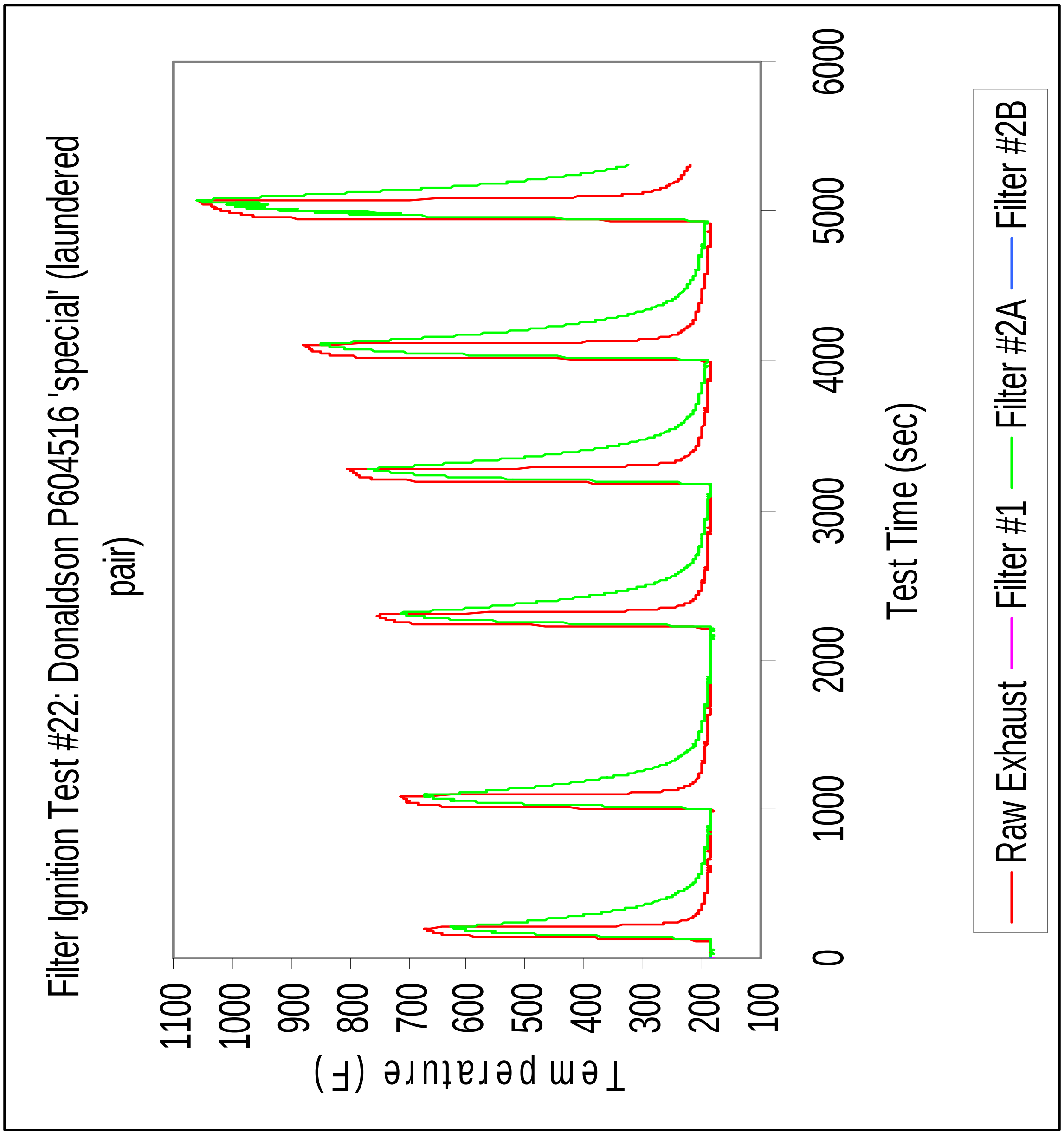
FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No.	22 (STEP17)		**Date:**	8/24/04 – 8/25/04	
Filter ID:	Donaldson P604516 'special'				
Filter Condition:	Filters are used, from Mercedes 906 outby machine (25-35 hours run time), then laundered and shipped "clean" for testing (no signs of dpm left on filters), build up dpm on filters and retest				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup:	07:35 on 8/25				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
8/24 15:15-15:20	Idle	-	200	-	DPM buildup
8/24 15:20-17:00	2200	45	450	-	DPM buildup
8/24 17:00-17:15	Idle	-	200	-	DPM buildup, shutdown
8/25 07:25-07:35	Idle	-	200	-	DPM buildup
07:35-11:30	2200	45	450		DPM buildup BP=7.66mmHg @ 8:25 = 25.2mmHg @ 11:30
11:30-15:00	1400	55	300	-	DPM buildup
15:00-15:20	Idle	-	200	-	DPM buildup
15:20-15:25	2200	190	663	65	Heavy smoke BP=20.2mm
15:25-15:35	Idle	-	200	-	
15:35-15:40	2200	210	705	65	Heavy smoke, sparks?? and potting particles
15:40-15:55	Idle	-	200	-	
15:55-16:00	2200	230	745	65	Moderate smoke, sparks?? and potting particles
16:00-16:10	Idle	-	200	-	
16:10-16:15	2200	250	790	65	Moderate smoke, sparks? and particles - during throttle-up and during steady state
16:15-16:25	Idle	-	200	-	
16:25-16:30	2200	Full (275)	870	65	Sparks?? and particles
16:30-16:40	Idle	-	200	-	
16:40-16:45	2200	Full + 1% CH_4	1035	75	

RR 1, Box 251
Triadelphia, WV 26059
(304) 547-2051

FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

16:15	Idle, shutdown
After Test Observations:	Examination of #2 filter showed one deformed pleat. A lot of ceramic potting compound debris in filter canister. #1 Filter showed cleaned areas indicating regeneration. No indications of ignition. Observers out by filter can thought some of the items exhausted were sparks. Examination of the video after test could not confirm sparks, too hard to differentiate potting particles from potential sparks.
Figures:	NA



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Diesel Laboratory

RR 1, Box 251
Triadelphia, WV 26059
(304) 547-2051

FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No.	23 (STEP18)		**Date:**	9/14/04	
Filter ID:	Donaldson P604516 'special'				
Filter Condition:	Filters are used, from Mercedes 906 outby machine loaded to backpressure limit (~70hrs). Filters had some very light rusting and 'clean spots' indicating some regeneration				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup:	10:20				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
10:20-10:40	Idle	-	200	-	
10:40-10:43	2200	190	642	65	Light smoke
10:43-10:55	Idle	-	200	-	
10:55-10:57	2200	210	676	65	
10:57-11:10	Idle	-	200	-	
11:10-11:13	2200	230	718	65	
11:13-11:25	Idle	-	200	-	
11:25-11:27	2200	250	773	65	
11:27-11:40	Idle	-	200	-	
11:40-11:43	2200	270	830	65	
11:43-12:00	Idle	-	200	-	
12:00-12:05	2200	Full + 0.6% CH_4	880	75	Ignition and Burning causing continuous shower of sparks
12:05-12:10	Idle, shutdown				
After Test Observations:	Extensive Damage to #2 filter. Damage around filter end near canister lid and damage to bottom of filter. Media and screen damage and also holes burned in outer mesh cage.				
Figures:	B33-B.35				

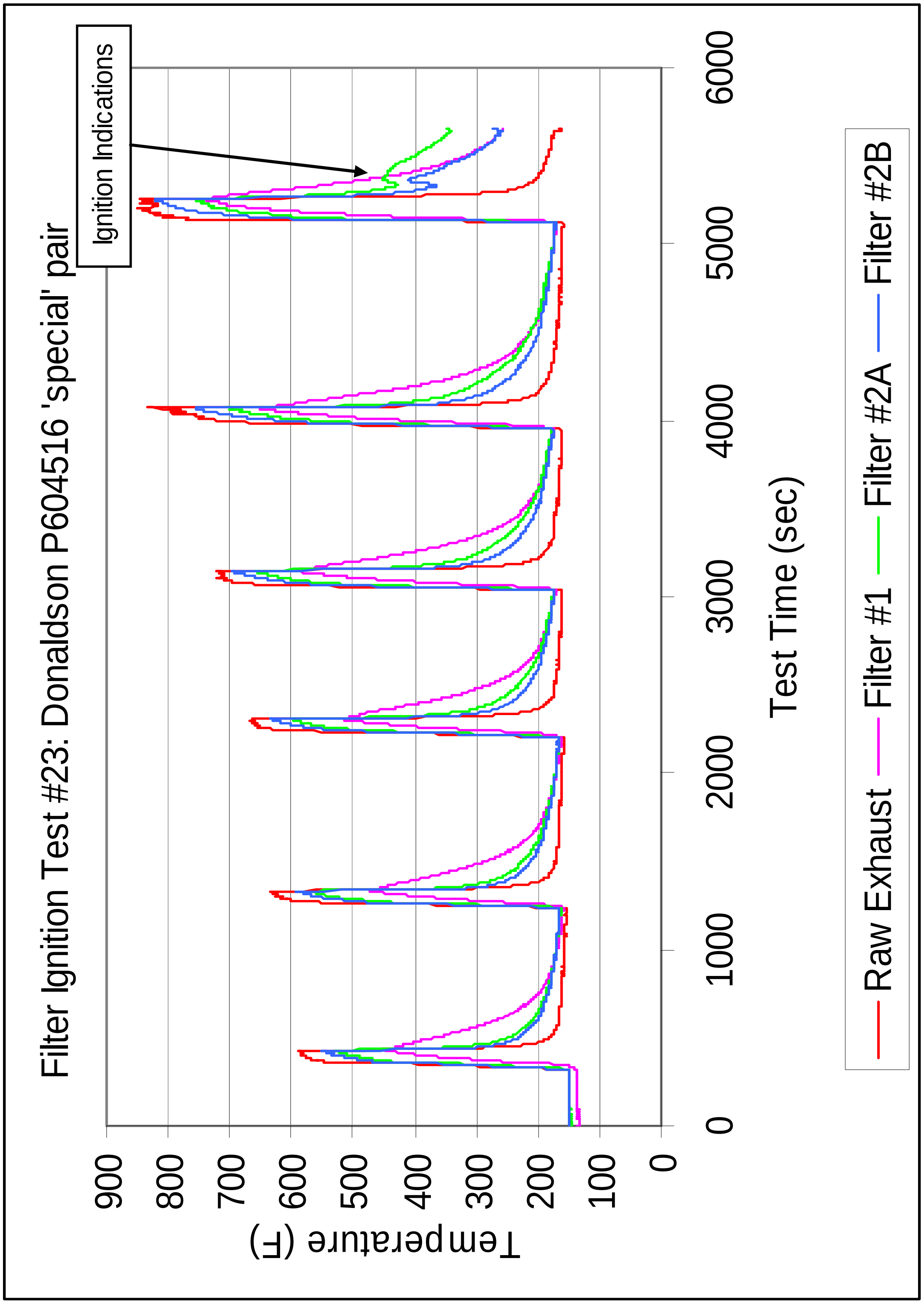

Filter Ignition Test #23: Donaldson P604516 'special' pair
Ignition Indications
Temperature (F)
900
800
700
600
500
400
300
200
100
0
Test Time (sec)
0
1000
2000
3000
4000
5000
6000
Raw Exhaust
Filter #1
Filter #2A
Filter #2B

Figure B. 33. Test #23; damage to filter #2 along bottom of filter.

Figure B. 34. Test #23; damage to filter #2 along bottom of filter.

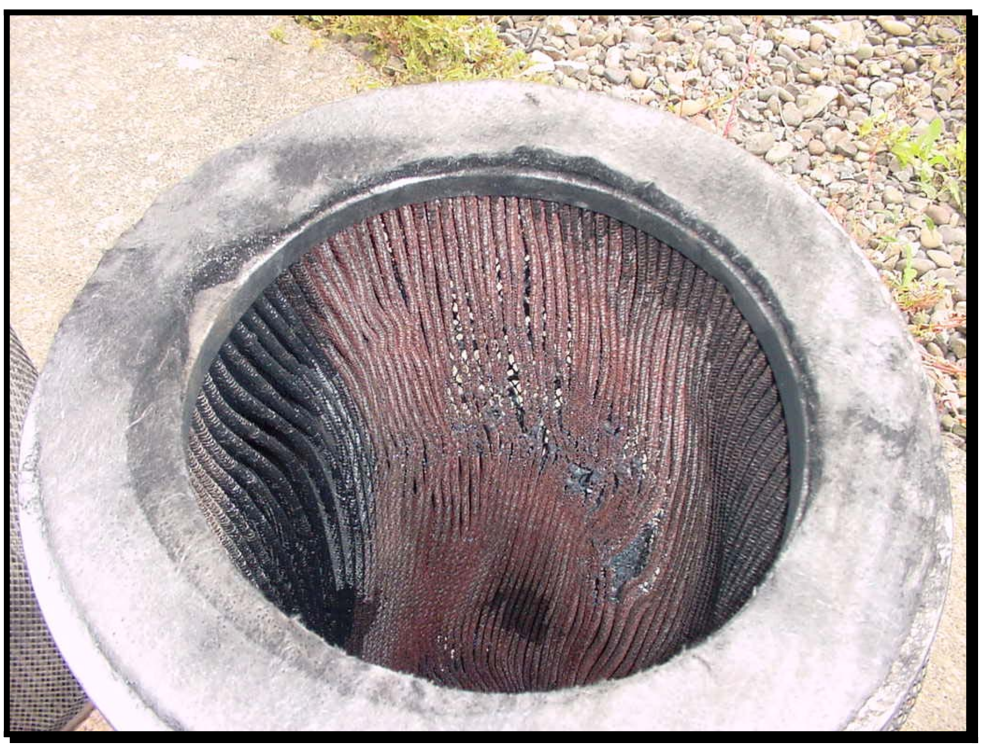
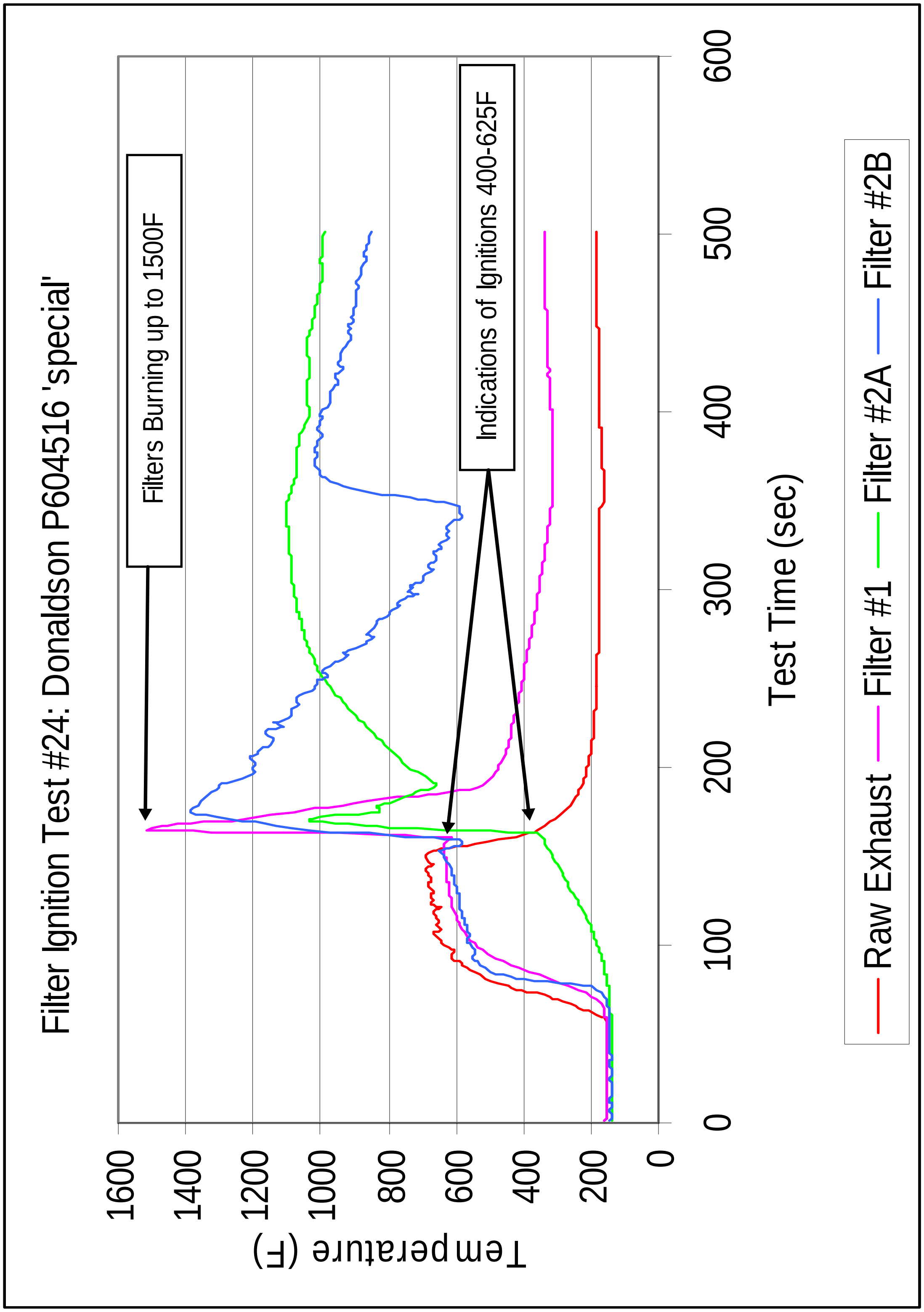


Figure B. 35. Test #23; damage to filter #2 along bottom of filter.

RR 1, Box 251
Triadelphia, WV 26059
(304) 547-2051

FILTER IGNITION TESTING TEST DATA AND OBSERVATIONS

Test No.	24 (STEP19)		**Date:**	9/14/04	
Filter ID:	Donaldson P604516 'special'				
Filter Condition:	#1 Filter used, from CAT 3306 inby water scrubber, loaded backpressure limit. Filter was heavily loaded with DPM with some rust. #1 Filter used at MSHA CAT 3306 (outby).				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup:	14:10				
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
14:10-14:25	Idle	-	200	-	
14:25-14:30	2200	190	649	65	Very heavy smoking, filter #2 ignition and burning
14:30-14:35	Idle, shutdown				
After Test Observations:	Extensive Damage to #2 filter. Filter was still smoldering upon removal from canister. #1 Filter showed no damage but was still smoking after removal from canister				
Figures:	B.36-B.				


Filter Ignition Test #24: Donaldson P604516 'special'
Filters Burning up to 1500F
Indications of Ignitions 400-625F
Temperature (F)
0
200
400
600
800
1000
1200
1400
1600
Test Time (sec)
0
100
200
300
400
500
600
Raw Exhaust
Filter #1
Filter #2A
Filter #2B

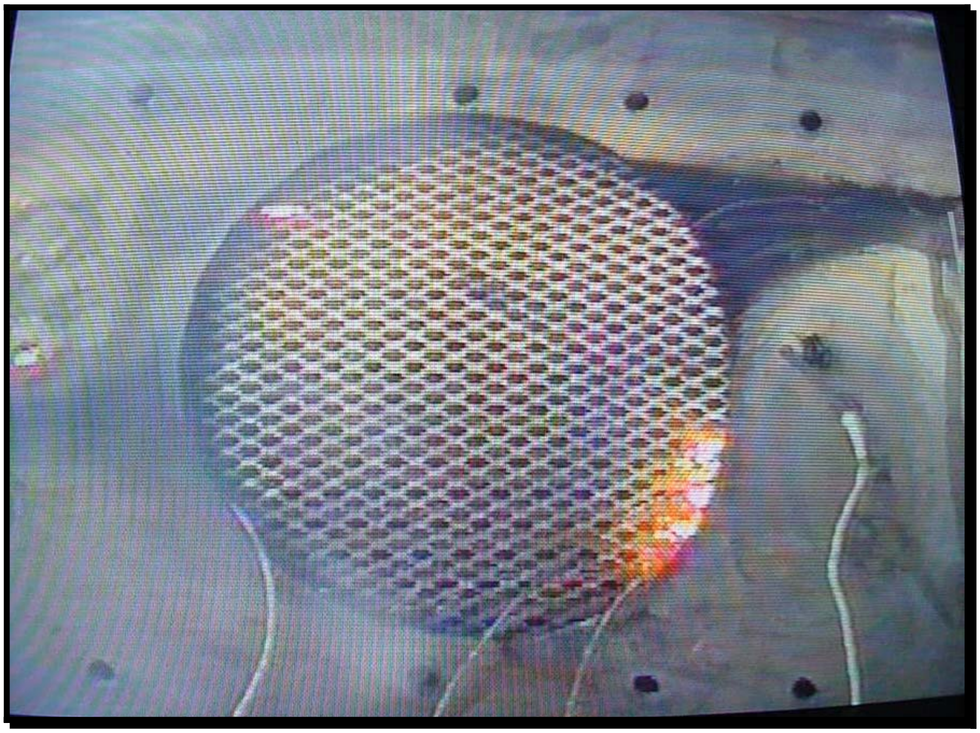


Figure B. 36. Test #24; initial #2 filter ignition.

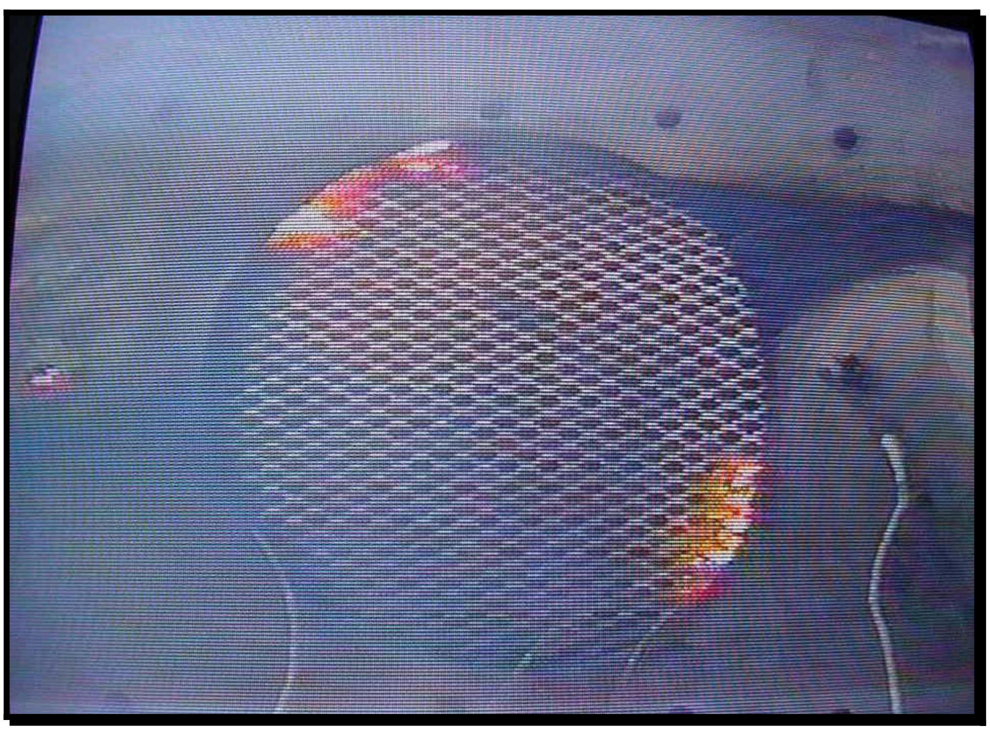


Figure B. 37. Test #24; second ignition on #2 filter.

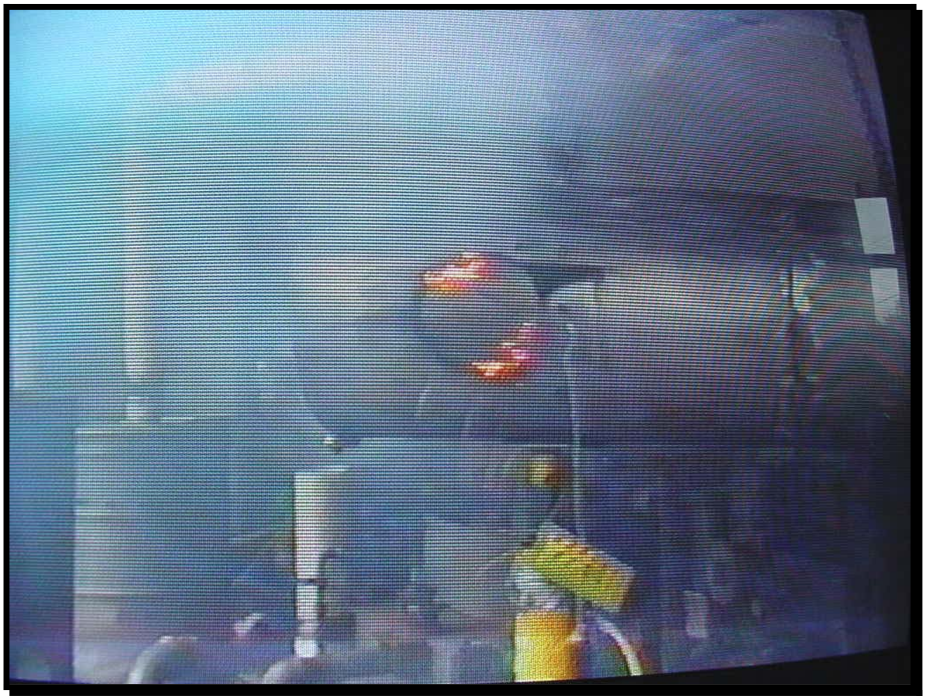


Figure B. 38. Test #24; filter burning with heavy smoke in lab.

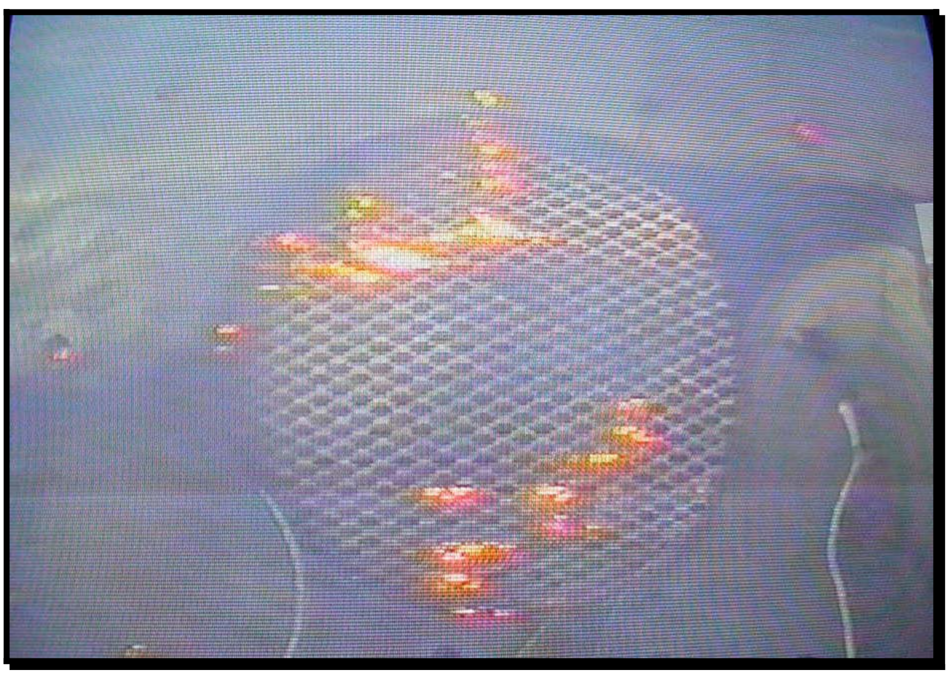


Figure B. 39. Test #24; filter #2 burning over large area of exposed surface.

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RR 1, Box 251
Triadelphia, WV 26059
(304) 547-2051

FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No.	25			**Date:**	9/28/04
Filter ID:	FSATC				
Filter Condition:	Filters used previously for efficiency tests. Trial using engine oil injected into exhaust pipe upstream of filter canister				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup:					
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F. Oil injected during short duration load test similar to previous step tests Short idle periods, 5min and under , between ramp periods				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
	2200	163	604	75	Massive smoking
	2200	190	663	75	Massive smoking
	2200	210	700	75	Massive smoking
	2200	235	754	75	Massive smoking
	2200	250	787	75	Massive smoking
	2200	275	870	75	Massive smoking
	Idle, shutdown				
After Test Observations:	No effects on filter. No ignitions noted.				
Figures:	NA				

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Mechanical Engineering and Safety Division
Diesel Laboratory

RR 1, Box 251
Triadelphia, WV 26059
(304) 547-2051

FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No.	26			**Date:**	9/28/04
Filter ID:	FSATC				
Filter Condition:	Filters pair loaded from new on MSHA 3306 engine. Trial using engine oil injected into exhaust pipe upstream of filter canister				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4” pipe inlet diameter and 6 5/8” diameter outlet hole aligned with #2 filter				
Startup:					
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F. Oil injected during short longer duration load so oil sprays on filters after heating. Short idle periods, 5min and under , between ramp periods				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
	2200	165	615	120	Massive smoking
	2200	190	664	120	Massive smoking
	2200	210	700	120	Massive smoking
	2200	235	760	120	Massive smoking, some sparks observed
	2200	250	807	120	Massive smoking
	2200	275	870	120	Massive smoking
	Idle, shutdown				
After Test Observations:	No effects on filter.				
Figures:	NA				

FILTER IGNITION TESTING TEST DATA AND OBSERVATIONS

Test No.	27		**Date:**	9/28/04	
Filter ID:	FSATC				
Filter Condition:	Filters pair loaded from new on MSHA 3306 engine (same pair as test 26). Trial using engine oil injected into exhaust pipe upstream of filter canister.				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup:					
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F. Oil injected during short longer duration load so oil sprays on filters after heating. Oil injector lengthened to inject oil at entrance to filter canister. Short idle periods, 5min and under , between ramp periods				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
	2200	163	618	120	Massive smoking
	2200	190	663	120	Massive smoking
	2200	210	712	120	Massive smoking
	2200	235	768	120	Massive smoking, some sparks observed
	2200	250	806	120	Massive smoking
	2200	275	864	120	Massive smoking
	2200	190	658	120	Massive smoking
	Idle, shutdown				
After Test Observations:	Small burn through on #1 Filter.				
Figures:	NA				

MSHA Approval and Certification Center
Mechanical Engineering and Safety Division
Diesel Laboratory

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FILTER IGNITION TESTING **TEST DATA AND OBSERVATIONS**

Test No.	28		**Date:**	9/29/04	
Filter ID:	FSATC				
Filter Condition:	Mixed filter pair from tests 26 and 27. Both coated with engine oil from previous tests.				
Engine:	Caterpillar 3306 PCNA #23C994				
Filter Canister:	Dual Element (2 filter) inline canister with 4" pipe inlet diameter and 6 5/8" diameter outlet hole aligned with #2 filter				
Startup:					
TEST GOAL:	To load up filters with DPM and expose to high exhaust temperatures. Test method(s): progressive step test from 650F to 1000+F. No Oil injected. Build up more DPM on oily filters and test using short duration step test. Short (<5min) idle periods between ramps.				
Time:	**Condition:**				
	Engine Speed	**Engine Torque ft-lb**	**Max Exhaust Temp F**	**Time at load (sec)**	**Observations**
10:00-10:30	Idle	-	200	-	DPM Buildup
10:30-11:30	2200	45	450	-	DPM Buildup, shutdown
13:20-13:30	Idle	-	200	-	DPM Buildup
13:30-15:25	1400	40	275	-	DPM Buildup
15:25-15:35	Idle	-	200	-	DPM Buildup
	2200	190	660	65	Smoke
	2200	210	720	65	Smoke
	2200	230	770	65	Smoke
	2200	250	815	65	Smoke
	2200	275	893	65	Smoke
	2200	Full (300)	965	75	A few sparks as throttled down
	Idle, shutdown				
After Test Observations:	No noticeable damage to filters.				
Figures:	NA				