COLORADO

Center of Excellence for Advanced Technology Aerial Firefighting

Division of Fire Prevention & Control

FS-01 Fire Suppressant Pile Burn Test Report

CoE-23-001.1

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Executive Summary

On October 10, 2022, the Center of Excellence (CoE) conducted a test burn of the fire suppressant agent FS-01 near our office at the Rifle-Garfield County Airport in Rifle, Colorado. The experiment aimed to evaluate the effectiveness of a new fire suppressant called FS01. The Center of Excellence for Advanced Technology Aerial Firefighting (CoE) performed the experiment with the assistance of the Colorado Division of Fire Prevention and Control Wildland Fire Management Section, the Colorado River Fire Protection District, Garfield County, the Rifle-Garfield County Airport, and the product manufacturer, Green Canyon Ventures.

For the FS01 Burn Test, two large piles, approximately 10 feet wide by 50 feet long, were created using sagebrush, juniper, and greasewood to mimic a dense stand/ jackpot representing natural fuels found on the Western Slope of Colorado. The piles were such that the fuel density was higher than would be naturally seen. The fuels were very dry. The burn was conducted using piles located on land owned by Garfield County on the east end of the Rifle-Garfield County Airport and south of the main taxiways and runway. The CoE documented the characteristics of the burning site, the fuels, the environmental conditions, the observed fire behavior, and the effectiveness of FS01.

Sections of the piles were pre-treated with the FS-01 product 1 hour and 2 hours before the burn. The burn was conducted during prescribed fuels and weather conditions. During the burn, the piles were monitored with a video camera, a thermal camera, and thermocouples connected to a data logger to collect temperature data. The intent was to assess the effectiveness of the product to reduce fire intensity, and extinguishing or halt the forward spread of the fire.

The piles were ignited using drip torches on the upwind end. The fire burned intensely through the untreated portion of the piles, then through the treated portion, and the CoE recorded the fire behavior and temperatures.

Results

The CoE observed a marked decrease in burn intensity and temperature as the fire moved from untreated fuel into treated fuel. The fire progression slowed significantly through the treated area; however, untreated sections beyond the treated area ignited from convective heating or embers. The fire then burned back into the treated area. An obvious cooling reaction occurred in the treated areas, but as the applied FS01 product was consumed, that reaction stopped, and eventually, the treated areas burned.

Summary Conclusions

The objective was to mimic dry, dense, natural fuels and test the performance of the FS-01 Fire Suppressant. Even though cooler temps and higher relative humidity prevailed, the fuels were very dry, so the fire burned intensely thermocouples recorded temperatures exceeding 900°C. No significant difference was noted between pile 1 and 2, so only pile 2 results are presented.

There was an obvious reduction in temperatures as fire impacted the treated fuels, with average temperatures dropping from about 788°C to about 108°C.

The fire did not extinguish fully in the treated fuels, however, had the section beyond the treated fuels also been treated, we expect the fire may have been extinguished.

Background information on FS-01 (Provided by Manufacturer)

FS-01 is a Fire Suppressant with an extinguishing effect for application by ground methods in wild & structural firefighting. It is supplied as a concentrated liquid that mixes readily with water by recirculation, agitation, or mechanical liquid mixing. According to the manufacturer, FS-01 suppresses the fire through an endothermic reaction triggered by heating. When heated, the FS-01 causes extreme cooling and gives off Nitrogen. These factors suppress the fire. When the product has been fully consumed, the reaction terminates, and if there is remaining fire and heat, the remaining fuel will burn.

FS-01 is biodegradable and non-toxic to humans, fauna, and flora. As it is non-toxic to fish, the product can be used close to rivers, lakes, seas, and water supplies. Test results for the product conducted in Europe were provided to the CoE by Green Canyon before conducting our test. A list of the tests performed previously in Europe are included in Appendix A.

Application

FS-01 is provided as a concentrate and stored in a concentrated form. For application, FS-01 is diluted and mixed with water as it is transferred/charged to the delivery system. The product is mixed with water at 15% for wildfires and 10% for structural fires. It is important to homogenize the concentrated product before mixing it with water.

Application of FS-01 to test burn pile.

Site and Fuel Characteristics

The CoE worked closely with the local Fire Department (Colorado River Fire Rescue) and the Airport Manager at the Rifle-Garfield County Airport to locate a safe and easily accessible site where burning could be conducted safely.

A good site was located on the east end of the airport property on a gravel pad with very little vegetation growing, excellent access, and well away from any active operations areas.

The CoE developed a prescribed fire participating agreement to allow the CoE to conduct prescribed fire activities on Garfield County-owned lands and to establish the respective responsibilities of each party for conducting the burns, specifically on the airport property.

Google Earth Image showing Rifle-Garfield County Airport with test site.

Fuels:

The fuels utilized for the fuel beds came from nearby lands managed by the airport. Each pile was composed of a continuous formation of sagebrush, greasewood, and juniper. Actual percentages of each species contained in each pile are not precisely documented, but in general, greasewood (Sarcobatus vermiculatus) was plentiful in our collection sites and probably represented the largest percentage of fuel by volume in our piles, around 50%, big sagebrush (Artemisia tridentata) was less plentiful and likely represented approximately 40% and juniper (Juniperus scopulorum) 10%.

Source areas showing brush used for the burn piles.

Fuel Bed Construction

The CoE Project Manager scheduled various crews from the DFPC and local Fire Departments to assist the CoE with cutting and hauling materials needed to construct the piles (fuel beds) that would be burned during the fire suppressant tests.

Crews began cutting and hauling in late May and early June. Some additional cutting took place in mid-August and fuels were added to achieve the final dimensions.

The result was two rectangular piles and an approximate size of 50’ long x 10’ wide and 6’ high. The piles were oriented from west to east to align with the predominantly WSW winds desired for the burn test.

Crews loading harvested fuels.

Crews cutting and hauling fuels.

Completed fuel bed.

Meteorological Conditions and Fuel Moistures

Weather conditions for the project were forecasted by the National Weather Service in Grand Junction, CO. A site-specific "Spot Weather Forecast was obtained on the afternoon of October 9 at 1550 hrs. This forecast indicated that conditions on-site would be favorable for burning with sunny skies and westerly winds (desired wind direction) with 20 ft. wind speeds from 5-10 mph. Inset: An additional Spot weather forecast was obtained at 0816 hrs on October 10. (See appendix).

This forecast indicated that the wind direction would be from the NE at 5 mph (not desired) in the morning, then shifting to the west at 8-12 mph in the afternoon with some gusts possible up to around 20 mph. The Burn Boss and Project Manager decided to proceed, and crews and equipment proceeded to the site to prepare for the burn.

Weather observations were taken on-site by a designated weather observer and an automated weather station on the airport.

Note: a westerly wind was desired for this test to help drive the fire from the east end of the piles to the west.

Fuel Moisture

Burn Parameters		
	Pile One	*Pile Two:*
Ignited at	*11:55*	*12:43*
Burn Time	*11:55 to 12:09*	*12:43 to 13:05*
Air Temperature (˚F)	*64*	*66*
Relative Humidity (%)	*35*	*32*
Solar Radiation (watts/m²)	*453*	
Wind Speed (2m height)	*3-5 with gusts to 5*	*3-5 with gusts to 5*
Range of Wind Speeds (mph)	*1-5*	*1-5*
Wind Direction (from)	*WNW (320˚)*	*WNW (320˚)*

Fuel moisture was calculated by collecting samples of the different fuels found in each pile which were brought in sealed containers to the laboratory and dried in a fuel moisture oven at 100 ˚C. Samples were weighed on a scale, and weights were recorded. The samples were then dried in the oven for 24 hours, removed, and weighed again. Fuel moistures were calculated using a worksheet provided and as shown below.

$$\%\ Moisture\ Content = \frac{wet\ weight\ of\ sample - dry\ weight\ of\ sample}{dry\ weight\ of\ sample - container\ tare\ weight}\ X\ 100$$

On the day of the burn, fuels were considered to be dead, with a fine dead fuel moisture content of 4-5% throughout the day.

Application of FS-01 and Pretreatment of Fuel beds

The FS-01 product was applied one hour and 30 minutes before ignition on Pile #1 and two hours and 13 minutes before ignition on Pile #2. The product was applied with a concentration of 6 gallons of FS-01 for every 40 gallons of water (15% mix ratio), Twenty gallons of FS-01 was applied on each pile and was applied to both sides of the pile in the area between marker 4 and 5.

Container Number	Species	Wet	Dry	Tare Weight	Water Weight	Dry Weight	Percent Moisture
304 (Pile #1)	Sage	85.1	84.4	72.2	0.7	12.2	5.7
305 (Pile #1)	Greasewood	84.0	83.3	72.4	0.7	10.9	6.4
307 (Pile #1)	Juniper	101.7	91.6	73.0	10.1	18.6	54.3
308 (Pile #2)	Sage	84.2	83.3	72.8	0.9	10.4	8.6
309 (Pile #2)	Greasewood	82.4	81.9	72.4	0.5	9.5	5.2
310 (Pile #2)	Juniper	102.8	4.2	71.7	8.6	22.5	38.2

Measured Fuel Moistures.

Preparations for burning included mixing the product in a UTV with a 40-gallon tank and pump (slip-on unit). The prepared product “ready to use” is made with 1 part of FS-01 to 5 parts of water.

A firefighter applied FS-01 to Pile # 1 to treat the area between markers 4 and 5.

Instrumentation

Fire behavior was characterized by setting up five, 5-foot high posts at five feet spacing along the pile, thus creating a visual reference for both the propagation speed of the fire front and the flame height.

Temperatures were recorded during the burn using ten type K thermocouples installed on the posts along the edge of each pile, two on each post. The thermocouples were placed at about 1 ft and 4 ft height above the ground and situated to be about 1 ft in toward the pile from the pole. Due to variations in the fuel bed loading and arrangement, the actual relative position of the thermocouple with respect to the fuel varies; however, since temperature trends and relative temperatures were the key factors, absolute temperature accuracy was not considered critical. The posts were located with a 5-foot separation from each other, extending from about 5 feet from the ignition point to about 5 ft before the end of the fuel. The area treated by the extinguishing agent was between stations 4 and 5. The rest was untreated. The temperature of each thermocouple was recorded every second using a Keysight DAQ970A data logger equipped with two 20-channel DAQ901MA Data Multiplexers. The thermocouples were custom-built from bulk-type K thermocouple wire with braided fiberglass insulation.

Photo showing steel post marker with Thermocouple installed at 4 feet above the ground surface

Fire Behavior

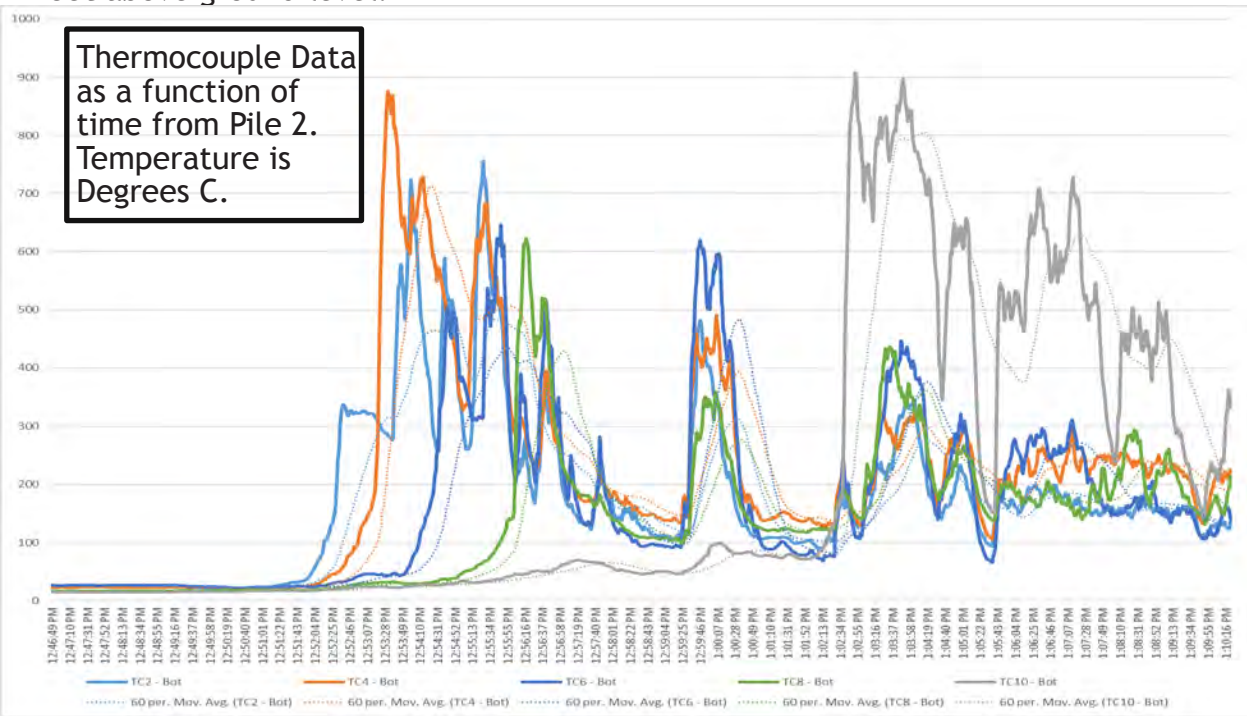
Fire behavior was characterized by using the posts as a visual reference for estimating rate of spread and flame length. This was used to estimate fireline intensity.

Fireline intensity is the rate of heat transfer per unit length of the fireline is a widely used measure of fire intensity. It represents the radiant energy released in the flaming front. fireline intensity is seldom actually measured, but is inferred from flame length. This has been found to correlate with fireline intensity.

	Range	Average
Estimated Rate of Spread of fire (Ch/hr)	4.10 to 5.60	
Length of flame (ft)	6.5 to 24	20
Fireline Intensity of fire front (BTU/ft/s)	1000-4200	3900

Thermocouple Data

Thermocouple temperatures collected were processed using Excel to calculate a 60-second running average. The results show temperatures in the untreated area ranging from 788˚C to 625˚C on average, dropping to 130˚C to 90˚C once the fire interacted with the suppressant. The temperatures remained low within the treated area for approximately two minutes from 1301 until 1302. After this time period, the fire burned through the treated area, and temperatures climbed back to between 175˚C and 200˚C and then lowered from 175˚C down to 94˚C between 1303 and 1309. Burning was complete, and the pile was consumed at 1310. The graph below shows the raw and 60-second running averages (dotted line) for the thermocouples installed 4 feet above ground level.



Conclusions

The objective to mimic dry, dense, natural fuels and test the FS-01 Fire Suppressant was achieved. The product was applied as instructed by the manufacturer, and the fuels were dead and very dry at the time of the test. The burn was carried out according to the burn plan prepared by the DFPC, and the conditions were well within the prescription parameters.

Even though the burns were conducted during a period of cooler temps and higher relative humidity conditions, the fuels were very dry, so the fire burned intensely; thermocouples recorded temperatures exceeding 920°C.

There was a significant reduction in fire intensity when the fire came into contact with the fuels in the treated area. We observed the reduction visually and measured an obvious reduction in temperatures as recorded by the thermocouples.

The visually observed reduction in fire behavior corresponded to a reduction in the temperatures measured by the thermocouples. Average temperatures dropped from about 788°C to about 108°C at the point of interaction with the FS-01.

Images and Burn Chronology on Pile 2.

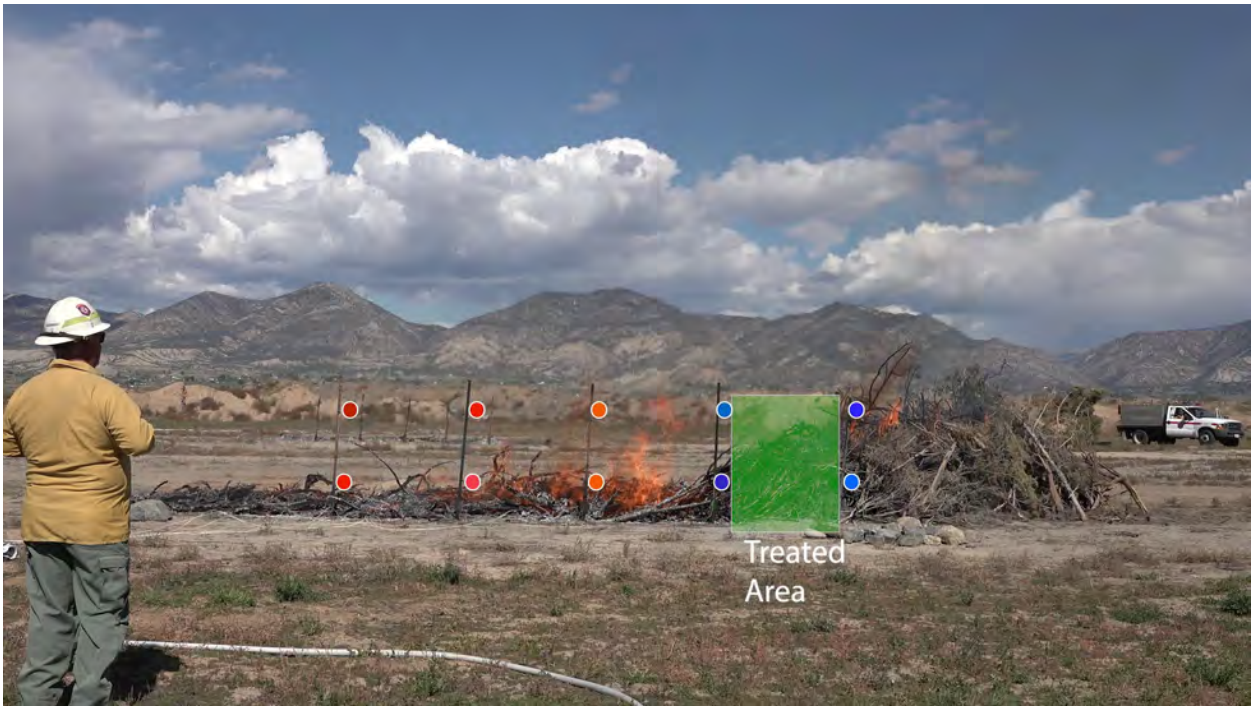
Time 1248: Ignition of South Pile (Pile # 2).

Time 1252: Fire has traveled from point ignition and well established at marker 1 and burning to marker 2. Flame lengths are approximately 18-20’ and is burning intensely with little to no wind. The silver item in the foreground is a Wildland FireShelter being used to protect the data logger from radiant heat during the burn. Thermocouple wires run directly from the test locations to the data logger.

Time 1254: Fire has spread from the ignition point at far left and has reached high intensity with 20-25 ft. flame lengths and is well established from marker 3, burning into marker 4.

Time: 1254. Fire is just entering the treated area between marker 4 and 5 which is where the FS-01 was applied.

Time: 1256: Fire has burned into the treated area. Note reduced fire spread and intensity with reduced flame lengths between marker 4 and 5. Also evident is the white/grayish smoke which indicates interaction with the FS-01.



Time 1258: Photo shows effects of fire interaction with the suppressant. Fire is spreading past marker 5 into untreated fuels, but note the remaining large amount of unconsumed fuel between marker 4 and 5.

Time 1259: Fire has spread beyond the treated area and past marker 5. Forward spread and intensity are becoming re-established due to radiant heat and spotting in the untreated fuel past marker 5. You can still see the white/grey smoke as the FS-02 interacts with the fire.

Time 1302: Fire has re-established in the untreated fuels and continues to spread throughout the remaining fuels.

Time 1310: Fire spread has ceased but has completely consumed the remaining fuels. Fuels in the treated area were consumed after the FS-01 appeared to be consumed.

Appendix A
Testing completed on FS-01 in Europe, provided by the manufacturer.

FS-01 has undergone a five-year testing phase, during which the product has been used in other tests as well as on actual wildland fires by authorities in Spain, Portugal, Brazil, Chile and Australia.

Currently Green Canyon Ventures has test results and certificates from:

- Professor Vega, Galicia Center for Forestry Studies (Centro de Estudios Forestales de Galicia).
- Government of Galicia, Spain.
- Military Emergency Unit (Unidad Militar de Emergencias), Spain.
- Portuguese Center for Forest Fire Studies (Centro de Estudios de Incendio Florestais de Portugal).
- Association for the Development of Industrial Aerodynamics (Associaçâo para o Desenvolvimento da Aerodinámica Industrial), Portugal.
- Associated Energy, Transportation, and Aeronautic Laboratory (Laboratório Associado de Energia, Transporte e Aeronáutica), Portugal.
- Municipal Fire and Civil Protection Department (Municipal de Bombeiros e Protecçâo Civil), Vila Nova de Gaia, Portugal.
- Brazilian Institute for the Environment and Renewable Natural Resources (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturaisnováveis), Brazil.
- Approval by the Center for Emergencies of the European Union.

FS-01 is approved for use by the European Union and is registered under the REACH regulation with the European Chemicals Agency.

Appendix B: Weather Forecast

CoE FS-01 Broadcast Burn

National Weather Service Grand Junction

2022-10-10 8:16 AM MDT

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Spot Forecast for CoE FS-01 Broadcast Burn...DFPC
National Weather Service Grand Junction CO
815 AM MDT Mon Oct 10 2022

Forecast is based on ignition time of 0800 MDT on October 10.
If conditions become unrepresentative, contact the National Weather
Service.

.DISCUSSION...

Sunny skies and westerly winds are still expected today and
tomorrow. Winds will pick up this afternoon with a few gusts to 20
mph. Winds will subside this evening and return again tomorrow
with stronger gusts ahead of an approaching front.

.REST OF TODAY...

Sky/weather.........Sunny (10-20 percent).
Max temperature.....69-74.
Min humidity........22-27 percent.
Wind (20 ft)........Northeast winds 5 mph shifting to the west 8-12
                    mph with gusts up to 20 in the afternoon.
Smoke dispersal.....Poor (4000 knot-ft) increasing to good in the
                    afternoon.
LAL.................1.
Mixing height.......7700 ft AGL.
Transport winds.....West 5 mph increasing to 13-15 mph in the
                    afternoon.

.TONIGHT...

Sky/weather.........Mostly clear (5-15 percent).
Min temperature.....37-42.
Max humidity........61-66 percent.
Wind (20 ft)........South winds 5-10 mph.
Smoke dispersal.....Poor (1000-15000 knot-ft).
LAL.................1.
Mixing height.......1700 ft AGL.
Transport winds.....West 10 mph shifting to the south 5 mph
                    overnight.

.TUESDAY...

Sky/weather.........Sunny (20-30 percent).
Max temperature.....70-75.
Min humidity........16-21 percent.
Wind (20 ft)........South winds 5 mph increasing to west 15-20 mph
                    with gusts to 30 mph in the afternoon.
Smoke dispersal.....Poor (22000 knot-ft) increasing to excellent in
                    the afternoon.
LAL.................1.
Mixing height.......8800 ft AGL.
Transport winds.....West 5-10 mph increasing to 18-22 mph in the
                    afternoon.

$$
Forecaster...Lucas Boyer
Requested by...Ryan McCulley
Type of request...PRESCRIBED
.TAG 2219341.0/GJT
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Good