Development of a Nitrogen and Magnesium Oxide based Class A, B & D Suffocating Fire System (SFSS) for Gloveboxes

NSR&D

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Report Completed: February 18, 2021

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DEVELOPMENT OF A NITROGEN AND MAGNESIUM OXIDE BASED CLASS A, B & D FIRE SUFFOCATION SYSTEM FOR GLOVEBOXES

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02-19-2021

ABSTRACT

Testing related to the development and performance of a "Proof of Concept" Nitrogen/Magnesium Oxide Suffocating Fire System (SFSS) was conducted at Fire and Pump Service Group (FPSG) located in Rancho Dominguez, California. The SFSS Engineering Team (SFSSET), consisting of FPSG and Los Alamos National Laboratory (LANL) personnel researched, developed a prototype, and conducted testing to determine effective means to deliver magnesium oxide (MgO) sand into a glovebox (GB) in a class D fire event. The prototypes development also established the effective coverage area of a magnesium oxide suppression system as well as demonstrated that the GB inert atmosphere could be maintained during and after the release of the MgO sand to control Class A, B and D fires. Previous testing conducted on nitrogen based SFSS provided evidence that the nitrogen based SFSS controlled Class A and B fires (Ralph Clayton, Los Alamos National Laboratory, Brandon Troc and Frank Broidy, Fire and Pump Service Group 2020).

Final testing was conducted within a mock GB capable of simulating an inert glovebox atmosphere. Testing demonstrated that the inert atmosphere can be maintained during and after discharge of the MgO sand over a coverage area.

DISCUSSION

MgO sand is documented as an effective fire suppressant in plutonium and uranium metal fires (R.E Felt. 1967). There is currently no SFSS that will automatically deliver MgO sand as a fire suppressant. SFSSET members researched different methods of delivery, designed, and constructed prototype models, and tested the prototype Nitrogen/MgO based SFSS. Testing focused on defining and evaluating the MgO sand effective coverage area to a minimum depth of one inch (R.E Felt. 1967) and reestablishing and maintaining the inert atmosphere within the mock GB during and after the MgO sand discharge.

One principal concern was the anti-clumping additive in the MgO sand becoming airborne and plugging the GB ventilation exhaust HEPA filter, resulting in a loss of GB airflow and thus inability to maintain a negative atmosphere (in respect to the room). To evaluate potential changes in airflow magnehelic pressure gauges were installed up and down stream of the HEPA filter. Minimal difference in airflow was observed after numerous MgO discharges were conducted utilizing the same HEPA filter. Indicating that the anti-clogging agent plume is not sufficient to noticeably obstruct air flow through the 8" Flanders HEPA filter in use during all the discharge tests.

CONTAINMENT

The containment barrier during MgO sand discharge was a high level consideration of the SFSSET team. A double check valved nitrogen line provides positive pressure and inerting during discharge but also prevents contamination backflow into the hopper body. The stainless-steel hopper body also acts as a contamination barrier during a discharge event. Certain solutions that will need to be considered in concert with the client's needs i.e further containment barrier solutions.

Codes and standards considered:

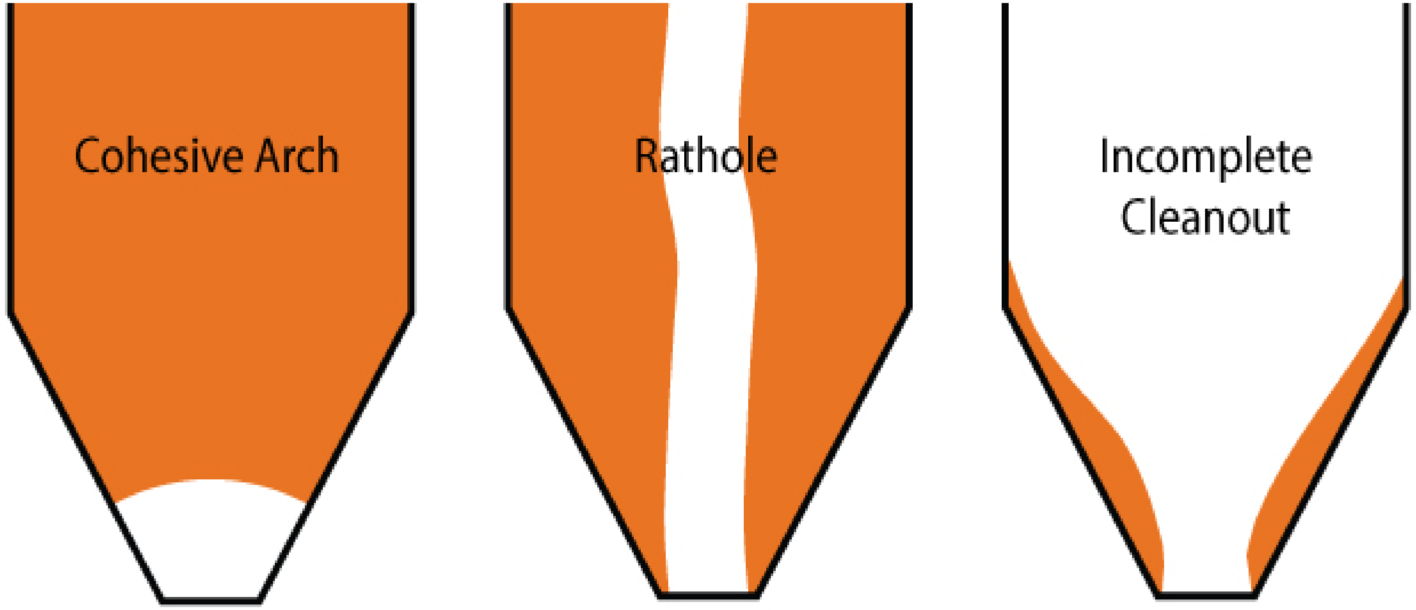
- NFPA 484 – Standard for Combustible Metals, (2019 Edition)
- NFPA 770 – Standard on Hybrid (Water and Inert Gas) Fire Extinguishing Systems, (2021 Edition)
- NFPA 2001 – Standard on Clean Agent Fire Extinguishing Systems, (2018 Edition)

DESIGN CONSIDERATIONS

The prototype SFSS design considered the following:

- Seismic moment;
- Space above/around glovebox;
- Glovebox design/operation;
- Preventing clumping of MgO sand while in the hopper;
- Helium leak testing of the system;
- Maintaining the glovebox containment throughout the discharge;
- Maintaining inert atmosphere during MgO sand discharge;
- Ensuring an even and predictable dispersal of MgO sand over the target area;
- Reliability, availability, maintainability, and inspect ability (RAMI);
- Disposal: Magnesium oxide sand used for fire suppressant at LANL is already covered in the CCP chemical compatibility evaluation document and therefore has a disposal path to WIPP as TRU waste;

HOPPER CONSIDERATIONS



Common hopper flow problems

The SFSSET assessed the condition of the MgO sand relative to being staged in the hopper over time. Sand materials are known to settle or increase in density while in storage. This can lead to ratholing, arching, bridging, and clinging. This condition was evaluated in Phase Two (B).

POTENTIAL APPLICATION METHODS

The SFSSET also researched multiple methods of applying the MgO sand to the affected area of the glove box:

- Specially designed discharge nozzles,
- Heat seeking robotic arm, to respond to flare ups
- Jet Venturi Ejectors
- Flexible discharge hose, A slinky like hose allowing personnel to control the MgO sand discharge and direct by hand.

The above potential applications were explored but were determined to be cost prohibitive and presented other design and performance drawbacks such as GB over-pressurization. The final design utilizes a commercially available stainless-steel hopper for “Proof of Concept” that contains the MgO sand installed outside the glovebox and a source of nitrogen. The SFSS operates control valves that disperse MgO sand and nitrogen through stainless steel piping onto the coverage area and into the glovebox atmosphere.

TEST PLAN

Testing consisted of several phases that were at times concurrent with SFSSET's design process. Phase one (A) of testing revolved around observing how MgO sand accumulates when dropped from various heights and in varying quantities, (exterior to an GB enclosure). This was an exploratory test using cups to pour the MgO sand and was the SFSSETs first look at how the material would behave. In all phases the area of effective coverage was calculated by measuring the radius of the MgO sand pile that had a depth greater than one inch.

Phase Two (B) testing focused on the flow and area of coverage characteristics of MgO sand while being discharged by our hopper. MgO Sand was dropped at predetermined quantities and heights to create sufficient data points to allow the SFSSET team to interpolate an Area of Effective Coverage (AoEC) at a specified glovebox height. Important to phase two was looking out for any of the potential common hopper flow problems (as previously indicated) during testing and simulating the material settling that takes place over time. To simulate settling the hopper was struck by the mallet 100 times prior to discharge. After 100 mallet taps the MgO sand in the hopper had leveled out and reduced in height by a quarter of an inch. Additional tapping did not result in further settling of the MgO sand therefore 100 hammer taps was deemed sufficient to relieve the gas pressure between the compacted sand granules simulating the settlement that will occur over time (T. Anthony Royal and Dr. John W. Carson. 1991).

Phase Three (C) Tested the “Y” shaped hopper configuration to see how different nozzle configurations effected AoEC. Phase three also included testing of the final Nitrogen/MgO sand SFSS configuration within a mock GB. This phase of testing looked to determine if dusting from the SFSS would impact the glovebox HEPA filter, compromising the GB negative pressure atmosphere. Pressure differential gauges across the HEPA filter and oxygen sampling were used to determine that the SFSS displaced the partial pressure of oxygen in the glovebox while maintaining a negative pressure difference across the HEPA filter.

TEST SETUP

Instrumentation

The following instruments and devices were used in the performance of the tests:

1. Oxygen Analyzer - AMI, Model 201RS, s/n 071025-2, the oxygen analyzer intake was located approximately 6 in. above the glovebox floor, 2 in. from the back wall, adjacent to the sealed pass thru located on the side wall.

2. Magnehelic Gauge 2x - Dwyer, Model 2304-AHU2, each magnehelic gauge was placed approximately 6 inches off the floor and two inches before or after the wooden separator holding the HEPA filter. For each gauge one probe was fed into the glovebox and sealed while the other remained outside subject to atmospheric pressure.

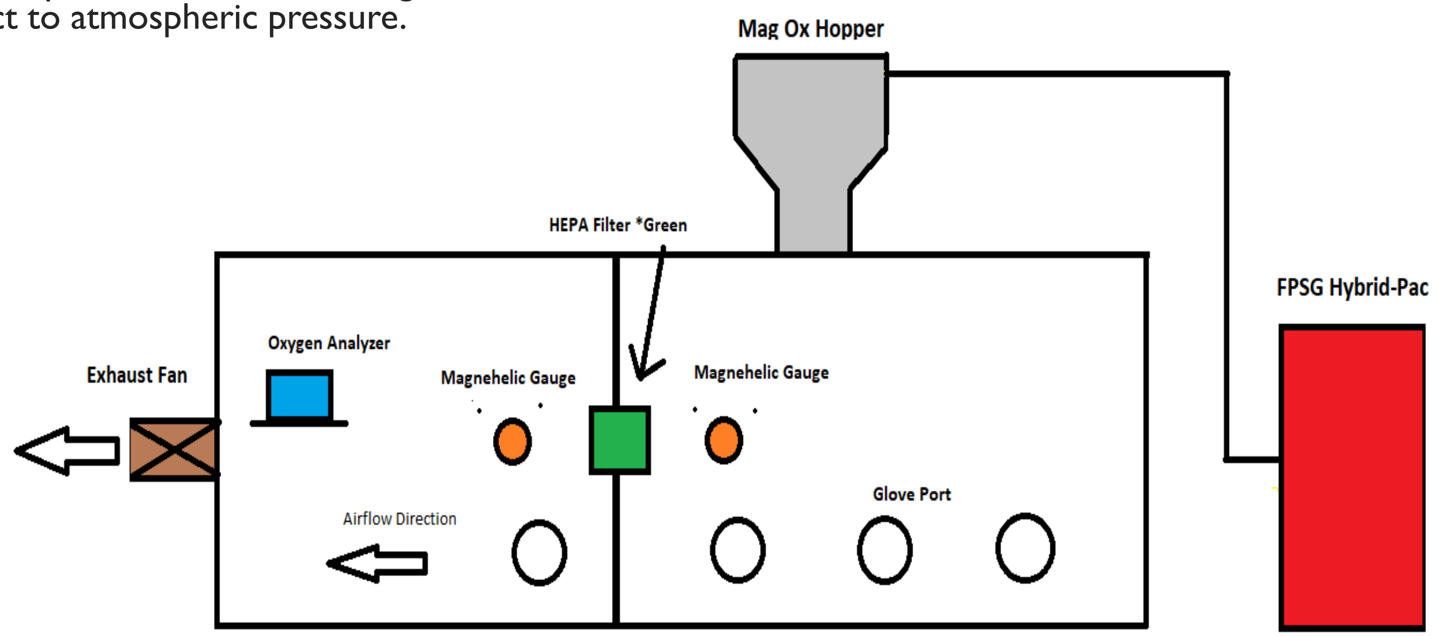
3. Video Camera – Panasonic DMC-LX5

4. Tape Measurer -Uncalibrated, Stanley Fatmax 25’

5. Vortex System HMI

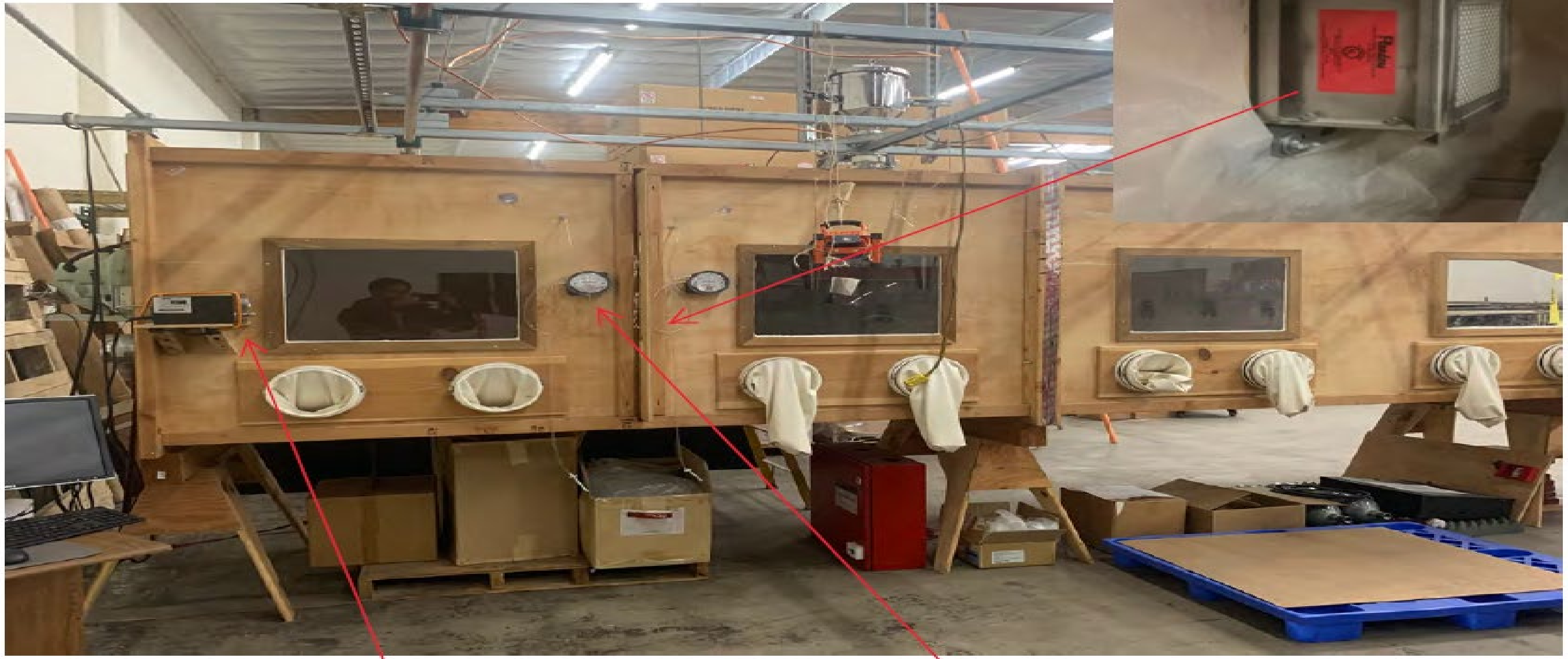
6. 8” HEPA Filter- Flanders, Model # F0620414

7. Rubber mallet – Uncalibrated



Test Setup

Photo 1. FPSG Mock Glovebox

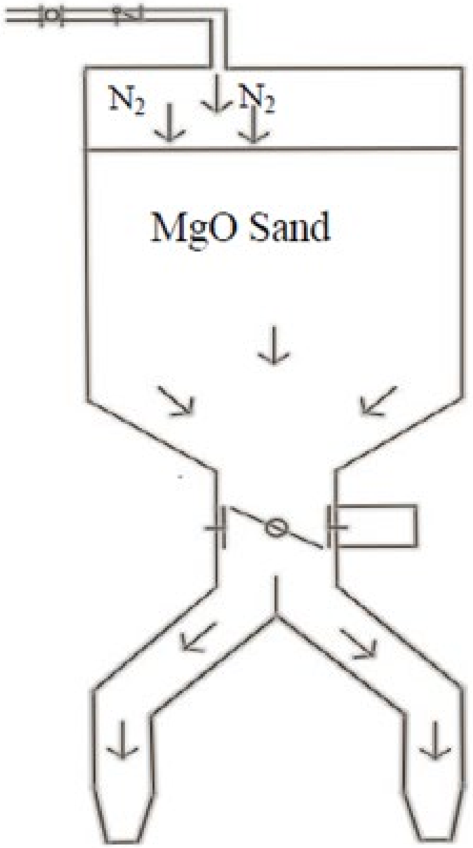


HEPA Filter

Oxygen Analyzer

Magnehelic Gauge

PROOF OF CONCEPT HOPPER



Hopper reduces in diameter from 4" to 2" at each nozzle

- Note: Prototype hopper was created from commercially available and sourced parts.

MagChem® P98 Dead Burned Milled Magnesium Oxide

DESCRIPTION

MagChem P98 products are high purity magnesium oxides produced from magnesium-rich brine and dolomitic lime. The products are fired in a shaft kiln to produce dead burned magnesium oxide with high density and low reactivity.

USES

MagChem P98 products are well suited for refractory and ceramic applications and other applications where a slow, controlled chemical reaction rate is required.

COMPOSITION

	Typical	Specification
Magnesium Oxide (MgO), %	98.0	97.7 min.
Silicon Oxide (SiO_2), %	0.7	0.8 max.
Calcium Oxide (CaO), %	0.95	1.1 max.
Iron Oxide (Fe_2O_3), %	0.15	0.3 max.
Aluminum Oxide (Al_2O_3), %	0.19	0.3 max.
Loss on Ignition, %	---	0.3 max

MagChem P98 grades are available in a variety of milled sizes from minus 1/8" to powder.

Typical Screen Sizes

% Passing	1/8"	-30 Mesh	Pulverized
4 Mesh	100		
6 Mesh	95		
8 Mesh	64	100	
16 Mesh	16	99.0	100
30 Mesh	2	88	99.8
50 Mesh			98
100 Mesh			91
200 Mesh		16	75
325 Mesh			60

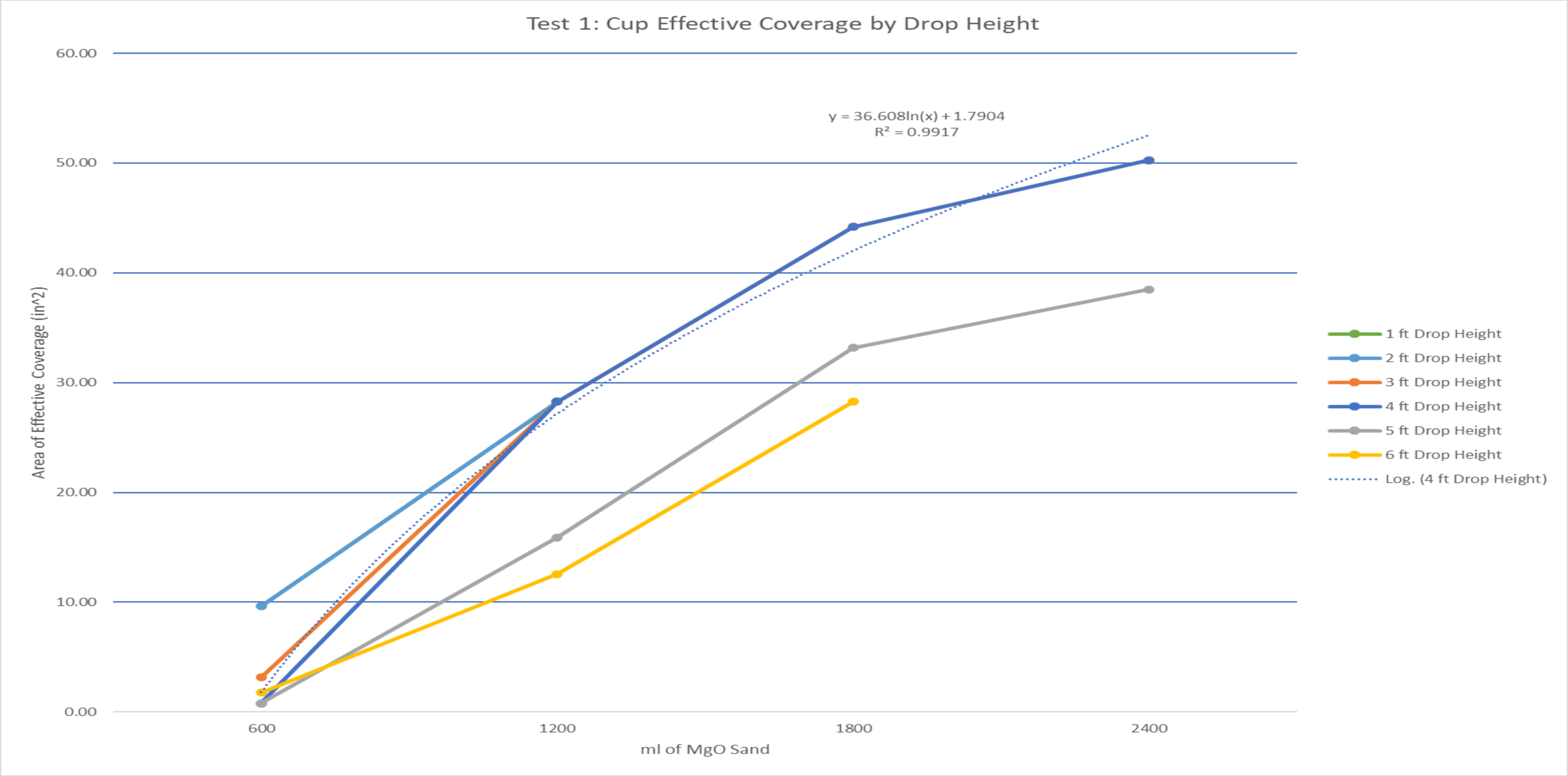
TEST ONE DATA AND ANALYSIS

Dropping MgO sand in 600 milliliter Increments							
Height of Drop in Feet	Milliliters of MgO	Radius of Effective Coverage in Inches	Area of Effective Coverage in Squared Inches	Height of Drop in Feet	Milliliters of MgO	Radius of Effective Coverage in Inches	Area of Effective Coverage in Squared Inches
1 ft	600	1-3/4”	9-10/16”	4 ft	600	½”	12/16”
	1200	3”	28-4/16”		1200	3”	28-4/16”
	N/A	N/A	N/A		1800	3-3/4”	44-3/16”
	N/A	N/A	N/A		2400	4”	50-4/16”
2 ft	600	1-3/4”	9-10/16”	5 ft	600	½”	12/16”
	1200	3”	28-4/16”		1200	2-1/4”	15-14/16”
	N/A	N/A	N/A		1800	3-1/4”	33-3/16
	N/A	N/A	N/A		2400	3-1/2”	38-7/16
3 ft	600	1”	3-2/16”	6 ft	600	¾”	1-12/16”
	1200	3”	28-4/16”		1200	2”	12-13/16”
	1800	3-3/4”	44-3/16”		1800	3”	28-4/16”
	2400	4”	50-4/16”		2400	4-1/2”	N/A

Test 1: (A) MgO Sand at Various Drop Heights

In this first preliminary test MgO sand was dropped from a 600 ml cup at various heights to give the SFSSET a general idea of the piling properties of the material. Testing data revealed that the area of effective coverage (AoEC) formed a logarithmic line. At around 2400ml of MgO sand the AoEC stopped growing in linear fashion with the addition of more MgO sand. This was a result of the MgO sand present on the ground dampening the impact of additional MgO sand. Testing also revealed that AoEC began to reduce from above four feet off the ground. Observed dusting was minimal.

TEST ONE GRAPH



TEST TWO DATA AND ANALYSIS

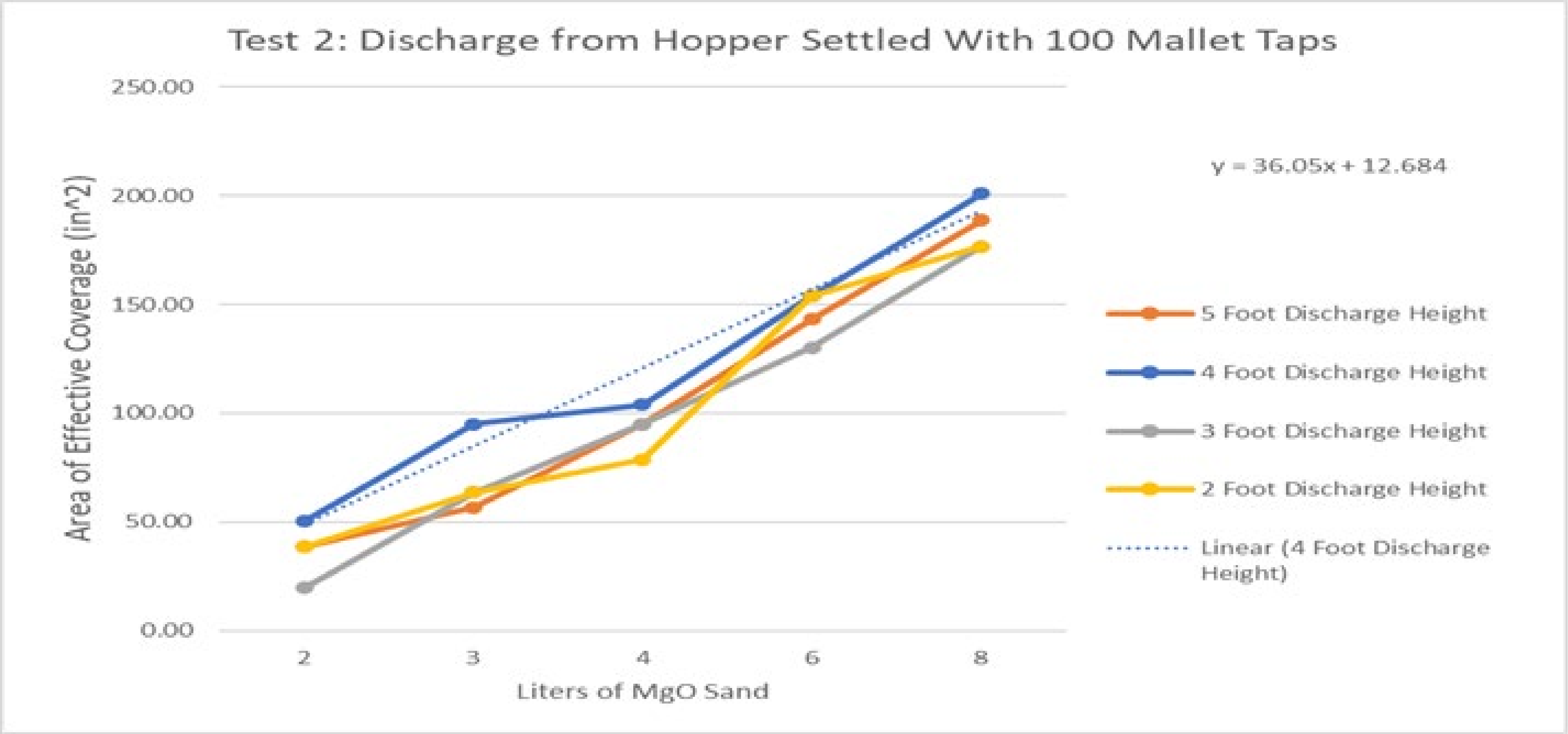
Area of Effective Coverage Test Settled MgO Sand 100x Mallet taps Hopper No Reducer							
Height to Drop	Liters of Mag Ox	Radius of Effective Coverage (in)	Area of Effective Coverage (in^2)	Height to Drop	Liters of Mag Ox	Radius of Effective Coverage (in)	Area of Effective Coverage (in^2)
2 ft	2	3-1/2”	38”-7/16”	4ft	2	4”	50-4/16”
	3	4-1/2”	63-10/16”		3	5-1/2”	95-1/16”
	4	5”	78-7/16”		4	5-3/4”	103-14/16”
	6	7”	153-15/16”		6	7”	153-15/16”
	8	7-1/2”	176-11/16”		8	8”	201-1/16”
3 ft	2	2-1/2”	19-10/16”	5ft	2	3-1/2”	38-7/16”
	3	4-1/2”	63-10/16”		3	4-1/2”	56-3/4”
	4	5-1/2”	95-1/16”		4	5-1/2”	95-1/16”
	6	6-7/16”	130-3/16”		6	6-3/4”	146-1/8”
	8	7-1/2”	176-11/16”		8	7-3/4”	188-11/16”
4ft	2	4”	50-4/16”	N/A	N/A	N/A	N/A
	3	5-1/2”	95-1/16”		N/A	N/A	N/A
	4	5-3/4”	103-14/16”		N/A	N/A	N/A
	6	7”	153-15/16”		N/A	N/A	N/A
	8	8”	201-1/16”		N/A	N/A	N/A

Test 2: (B) Discharge Through Hopper.

MgO sand was placed inside the hopper and mechanically settled by tapping the hopper wall 100 times with a rubber mallet. Settling from hammer taps dropped the height of the MgO sand by approximately ¼ inch each time. MgO sand completely flowed through the hopper each time and the hopper did not cause any observable detrimental effects to the MgO sand dispersal pattern. MgO sand flowed out of a 4” diameter 4-inch-long coupling attached to the hopper. AoEC continued to grow as the hopper height increased until the hopper opening was four feet off the ground. Above this height the AoEC began to decrease at all quantaties of MgO sand. The AoEC tended linearly to the equation y=36.05x+12.684 for applications of 2-8 liters of MgO sand."

Equation; y = 36.05x + 12.684

TEST TWO GRAPH



TEST THREE DATA AND ANALYSIS

Test 3: (C) Hopper with Dual Coverage Areas

Test three observed the AoEC with the tapered Y nozzle configuration attached to the hopper opening. The same configuration to be used in the simulated glove box testing. The nozzles are 16.5” apart (center to center). With the hopper diameter reducing from four inches to two inches at each nozzle. In these tests clumping in the MgO sand was observed in the supplied 25kg bags of MgO sand. It appears that the MgO sand was compressed while stored under other pallets of MgO sand weighing hundreds of pounds. Physical agitation or mixing to prevent clumping was explored but not tested in this report.

Area of Effective Coverage Test Wye configured with Tapered Nozzles, 16.5" Center to Center Outside Glovebox				
Height to Drop	Liters of Mag Ox Sand	Average Radius of Effective Coverage 1 (in)	Average Radius of Effective Coverage 2 (in)	Total Area of Effective Coverage (in^2)
2 ft	6.5	6-1/8”	6-1/8”	235-11/16”
	6.5	8”	8”	402-2/16”
	6.5	7-3/8”	7-1/8”	341-3/4”

TEST FOUR ANALYSIS

Test 4: (C) Dual Coverage Hopper Test with Nitrogen flow through hopper (tested within Glovebox).

In test four the hopper with the Y nozzle configuration was mounted on top of the mock glovebox to create a sealed environment with a negative pressure differential across the HEPA filter. A ¼" Line was attached to the hopper lid to introduce nitrogen to the hopper. The nitrogen is used to prevent backflow of contaminated gasses into the hopper as well as prevent any ratholing or arching through additional positive pressure. This test was primarily concerned with the clogging effects on the installed HEPA filter and if a negative pressure differential could be maintained despite any HEPA filter clogging that may occur. While some anti-clumping additive was observed, the negative pressure differential was never compromised as can be observed in the data below. It should be noted that in these tests the N2 line was placed closer to the nozzle associated with pile two, as a result that pile was constantly slightly larger than pile one. Future designs will split the introduced N2 over each nozzle. See photo two for anti-clumping additive cloud and photo four for the DeltaP observed while discharging the MgO sand.

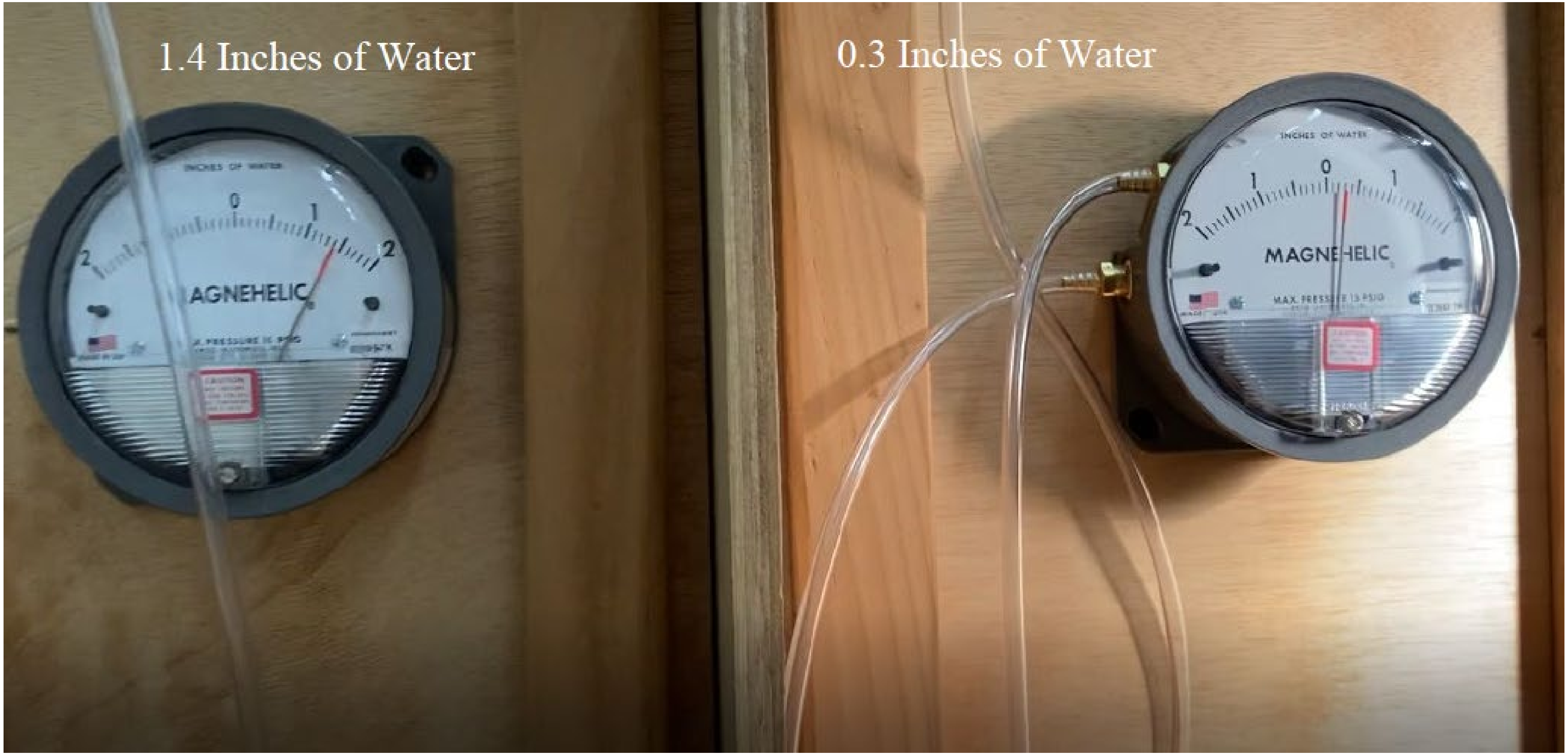
TEST FOUR DATA

Area of Effective Coverage Test Y configured with Tapered Nozzles, 16.5" Center to Center Inside Glovebox with 40 CFM Nitrogen Flow Through Hopper								
Height to Drop	Liters of MgO Sand	Average Radius of Effective Coverage pile 1	Average Radius of Effective Coverage Pile 2	Area of Effective Coverage (in^2)		Pressure Before HEPA Filter (inches of H20)	Pressure Before HEPA Filter (inches of H20)	Partial Pressure of Oxygen
17-3/4"	6.5	6-3/4"	7"1/16	297-1/16"	Before Discharge	1.4"	.3"	N/A
					MgO Discharge	1.4"	.2"	N/A
					30 Seconds After Discharge	1.4"	.3"	N/A
	6.5	6-5/8"	7-1/8"	297-6/16"	Before Discharge	1.7"	.3"	N/A
					MgO Discharge	1.7"	.3"	N/A
					30 Seconds After Discharge	1.7"	.3"	N/A
	6.5	6-1/8"	6-3/8"	260-6/16"	Before Discharge	1.7"	.35"	N/A
					MgO Discharge	1.7"	.3"	N/A
					30 Seconds After Discharge	1.65"	.3"	N/A
Area of Effective Coverage Test Y configured with Tapered Nozzles, 16.5" Center to Center Inside Glovebox with 40 CFM Nitrogen Flow Through Hopper and Victaulic Emitter @30psi								
17-3/4"	6.5	7"	7"	307-7/8"	Before Discharge	1.65"	.3"	20.5%
					MgO Discharge	1.6"	.05"	19.75%
					30 Seconds After Discharge	1.65"	.3"	17.30%

TEST FOUR PHOTOS

TEST FOUR PHOTOS

TEST FOUR PHOTOS



TESTING PHOTOS

Measurement taken from center line to 1" of depth

TEST FIVE DATA AND ANALYSIS

Test 5. (C) Negative Pressure Differential Test, Nitrogen inerting through Victaulic emitter

These tests were designed to determine the maximum nitrogen emitting rate that the negative pressure differential across the HEPA filter could be maintained at. Two different flowrates of nitrogen were tested: 40 and 30 Psi of Nitrogen, set at the Hybrid-Pac. Testing demonstrated that even though the HRPA filter had been through several discharge events and the associated dust, a negative pressure differential across the HEPA filter was maintained up to 40 psi. No MgO sand was discharged during these tests.

Maintain pressure differential across HEPA filter while inerting Glovebox with N2					
Pounds of N_2		Pressure Before HEPA Filter (inches of H20)	Pressure Before HEPA Filter (inches of H20)	Partial Pressure of Oxygen	Notes:
40	Before Discharge	1.65”	.3”	20.20%	
	60 Seconds into Discharge	1.6”	.0"	18.65%	Partial pressure of oxygen continued to rapidly drop until flow of N2 was stopped
30	Before Discharge	1.6”	.3”	20.50%	
	60 Seconds into Discharge	1.6”	.1"	18.50%	Partial pressure of oxygen continued to rapidly drop until flow of N2 was stopped

DATA AND RESULTS

The developed Nitrogen/MgO sand prototype SFSS consistently placed a metered volume of MgO sand that when combined with the nitrogen gas discharge would effectively control Class A and B fires within a GB and Class D fires within the defined coverage area(s).

Minimal pressure changes across the HEPA filter were observed during each test and no cumulative measurable degradation of HEPA filter performance was noted after conducting all tests using the same HEPA filter.

Accelerated clumping and compression evaluations utilizing mechanical vibration resulted in no detectable adverse conditions to MgO Sand flow. To prevent clumping of the MgO sand and to establish and maintain a dry atmosphere in the hopper the use of desiccants is recommended. The testing of desiccant application was not within the scope of these experiments but can be researched later.

Implementation of this GB SFSS into commercial use requires the SFSS to be engineered for the specific GB application(s). This is presently a performance based design.

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