Fire Hazard Evaluation for Removal Products on a Test Surface

Raymond T. Ranellone Jr., Nicholas A Dembsey, PhD
Worcester Polytechnic Institute, Department of Fire Protection Engineering
August 30, 2018

Disclosures

This work was completed under contract with the Toxics Use Reduction Institute (TURI) located at the University of Massachusetts Lowell. The test protocol was developed jointly between TURI and WPI. The glovebox test enclosure design and construction as well as product fire testing was completed by WPI at the WPI FPE Fire Science Laboratory. TURI also provided the coating removal products for the fire testing, and descriptions of the coating removal products. The evaporation testing was conducted by TURI at the University of Massachusetts Lowell during April and May 2018. The manufacturer recommendations for coating removal product usage in Appendix A were obtained by TURI.

1 Introduction

Three components must be present for a fire to occur: 1) a fuel source (e.g. solvent vapors), 2) oxygen (which may be from the air, or another source), and 3) a source of ignition. When the vapor of a flammable liquid solvent is mixed with air in certain concentrations, and in the presence of a source of ignition, a rapid combustion can occur. The specific vapor/air concentration which can support combustion is called the "flammable range". In the flammable range, a flash will occur or a flame will spread if the air/fuel mixture is ignited. The borders of the flammable range are called Lower Flammability Limit (LFL) and Upper Flammability Limit (UFL). The LFL is the lowest concentration of vapor in air at which the vapor/air mixture will burn and the UFL is the highest concentration of vapor in air at which the vapor/air mixture will burn. LFL/UFL are usually expressed in terms of percentage by volume of vapor in air. Below the LFL the mixture is "too lean" to burn and above the UFL the mixture is "too rich" to burn. (ACC, 2011) Since it is the vapor of the liquid, not the liquid itself that burns, vapor generation becomes the primary factor in determining the fire hazard. (OSHA)

"Flash point" is defined by U.S. Occupational, Safety and Health Administration (OSHA) and the U.S. Department of Transportation (DOT) in the U.S. Code of Federal Regulations (CFR) as: "The minimum temperature at which a liquid gives off vapor within a test vessel in sufficient concentration to form an ignitable mixture with air near the surface of the liquid." (DOT, 2009, OSHA, 2009)

There are several flash point testing methods. Two common flash point testing methods used for paint stripping products are:

1) ASTM Standard D93 Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester

2) ASTM Standard D3278 Standard Test Methods for Flash Point of Liquids by Small Scale Closed-Cup Apparatus

The Pensky-Martens Closed Cup method is conducted in a closed vessel while the coating removal product is continually stirred. The stirring is accomplished by operating two bladed metal propellers within the test vessel. The propellers are operated between 90 r/min to 250 r/min depending upon the procedure selected. (ASTM D93) Coating removal products are not stirred during their use for paint stripping. Instead, they are applied to painted surface in a manner that precludes stirring. Coating removal product manufacturers recommend that coating removal products are applied in one direction with a single brush stroke. The continual stirring of sample during flash point testing disrupts the evaporation barrier from forming and consequently enables the evaporation of significant amounts of solvent vapor from the coating removal sample resulting in a low flash point measurement for coating removal products with evaporation barriers.

The Small Scale Closed-Cup method is also conducted within a closed vessel, and the coating removal product is not stirred. The sample is injected into the closed vessel via a syringe and then tested after one minute has elapsed after the sample was inserted into the vessel. (ASTM D3278) However, the

evaporation barrier is disrupted as the sample passes through the syringe into the closed vessel. The evaporation barrier typically takes about one to two minutes to fully be re-established. Due to the setup time of the barrier a flash point test conducted one minute after a sample is inserted is executed before the evaporation barrier is fully in place, and consequently enables the evaporation of significant amounts of solvent vapor from the coating removal sample resulting in a low flash point measurement for coating removal products with evaporation barriers.

Coating removal products work best when they remain in liquid form, therefore they typically have evaporation barrier additives that greatly diminish the evaporation rate of the solvents to keep the product in a liquid form during use. Other types of flammable products typically do not have evaporation retardant additives since they are designed to release the solvents as fast as possible so that they can be "fast drying". These "fast drying" flammable products include nail polish, windshield washer fluid, PVC cement, contact adhesives, denatured alcohol, various aerosols, spray paint, primer, brush cleaners, lacquer thinner, and many other product categories. In general, these "fast drying" products pose a significant fire hazard since the solvent vapors are rapidly entering the surrounding environment.

The use of flammable products creates a significant fire hazard for the users of the product that are not aware that they have exceeded the LFL in the surrounding area where the product has been used. The following is a list of the many different types of ignition sources that can cause a combustion event if the LFL is exceeded: (ACC, 2011)

Flames: includes open flames such as welding torches, matches, and gas burners

Smoldering: includes materials such as cigarettes

Hot surfaces: includes ovens, furnaces, electrical equipment, and heating pipes

Friction and Impact: hot spots and incandescent sparks may arise from friction

Electric Discharges: includes electrical power and electrostatic discharge

2 Test Design

The fire hazard test was designed to answer the following question:

> "Does the use of evaporation barrier additives within a flammable solvent based product reduce the risk of exceeding the LFL in the surrounding area that the product is used?"

The tests were conducted to determine if the Lower Flammability Level (LFL) for the solvent vapors was exceeded within the glove box. Exceeding the LFL of the solvent vapor is assumed if a combustion event is possible since there would need to sufficient fuel and oxygen, in the right amounts present, to allow for ignition of the solvent vapor.

The intent was to create a challenging test environment to evaluate the fire hazard of various coating removal products. The evaluation was conducted under the following challenging conditions:

- Confined working area (glove box)

- Working area with no forced ventilation
- Use of the maximum dwell time recommended by manufacturers of methylene chloride based coating removals (30 minutes – See Appendix A)
- Use of the maximum thickness of the coating removal product as recommended by manufacturers of methylene chloride based coating removals (1 gallon per 50 square feet – See Appendix A)
- Included two test cycles (2 applications, 2 dwell times, and 2 extractions)

The test design did not include an investigation of combustion events at the immediate surface area of the coating removal products.

2.1 Test Materials

The tests were conducted within a glove box to simulate a small confined working space. (See Figure 1) The glove box walls were made of clear polycarbonate so that the all events within the glove box were clearly visible from outside the glove box while providing an impact and shatter resistant safety barrier between the combustion event and the operator and observers. The internal dimensions of the glove box were 3 feet wide by 3 feet long by 3 feet high (0.91m x 0.91m x 0.91m) resulting in a volume of 27 ft^3 (765 liter). The glove box was completely enclosed and all seams were sealed with silicone such that there was no air entering or leaving the glove box during testing. In addition, there was no fan or any other type of forced ventilation present within the glove box during the testing. An opening that was 28" high and 28" wide (0.71m x 0.71m) was used to introduce and remove the test materials from the glove box. Drybox gloves were installed onto a hinged panel cover and used by the operator during testing.

The glove box had a movable ignitor arm to accommodate varying the location of the ignition source. The ignition source was a 0.126" – 0.189" diameter diffusion propane flame. This is the size of the test flame specified in ASTM D93 "Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester", Section 11.1.2.

There was a 10 inch (0.25m) diameter vent area at the top of the glove box. The vent was sealed with saran wrap to prevent air exchange between the surrounding and the glove box during a test. However, the vent covering was designed as the failure point in the glove box to provide pressure relief for combustion events. In addition, there were two gas lines plumbed with on/off valves attached to the glove box: 1) nitrogen which was used to assist in suppressing a combustion event within the glove box, and 2) ambient air which was used to refresh the inside of the glove box at the conclusion of each test.

Figure 1: Glove Box with test materials

The testing surface was an aluminum tray with a one inch high raised edge so that the coating removal product did not spill over the edge. The outside dimensions of the aluminum tray were 17.75 inches wide and 25.75 inches long (0.45m x 0.65m). The inside dimensions of the aluminum tray that was the actual test surface area was 17 inches wide by 25 inches long (0.43m x 0.64m), resulting in a test area of 2.95 ft^2 (0.27m^2). For the tests, a coating removal product thickness of 1 gallon per 50 square feet was used (3.79L per 4.65m^2). This resulted in a volume of 223 ml for the first application, and 223 ml for the second application of each test. For the two application cycles, a total of 446 ml of coating removal product was used. The test surface was placed in center of the floor of the glove box for the testing. The testing surface was removed from the glove box after each test and cleaned before conducting the next test.

3 Experimental Methods

The fire hazard testing of the coating removal products included the following nine steps:

1) Introduce Materials: The operator opened the glove box door and inserted the clean test surface, a 2" paint brush, a closed glass container with 446 ml of removal product, cloth rags, a 6" plastic scraper, and a one gallon plastic disposal bucket without a lid. The disposal bucket was sealed and placed in the rear of the glove box so that it would not interfere with the application of the coating removal products. The glove box door was then closed and remained closed for steps 2 through 8.

2) First Application: The operator placed his arms into the glove box arms, grasped the glass container with the coating removal product, unscrewed the container lid, tipped the container, poured a half of the removal product (approximately 223 ml) from the container onto the test surface, and screwed the

lid back onto the container. The operator then spread the removal product evenly onto the test area surface with a 2" paint brush, while brushing in one direction only. The operator then removed his arms from the glove box arms. The average time for the operator to conduct this step was approximately 3 minutes.

3) First Dwell: A thirty minute dwell time was conducted with the coating removal product residing undisturbed on the surface of the test area. An ignition source was applied inside the glove box at 5 minute intervals.

4) First Extraction: The operator placed his arms into the glove box arms, grasped the 6" plastic scraper, and extracted the coating removal product from the test area surface with the 6" plastic scraper onto cloth rags, and then deposited the cloth rags into the disposal bucket. The disposal bucket did not have a lid and remained open for the duration of the test. The average time for the operator to conduct this step was approximately 3 minutes.

5) Second Application: The operator then grasped the glass container with the coating removal product, unscrewed the container lid, tipped the container, poured the remaining half of the removal product (approximately 223 ml) from the container onto the test surface, and screwed the lid back onto the container. The operator then spread the removal product evenly onto the test area surface with a 2" paint brush, while brushing in one direction only. The operator then removed his arms from the glove box arms. The average time for the operator to conduct this step was approximately 3 minutes.

6) Second Dwell: A thirty minute dwell time was conducted with the coating removal product residing undisturbed on the surface of the test area. An ignition source was applied inside the glove box at 5 minute intervals.

7) Second Extraction: The operator placed his arms into the glove box arms, grasped the 6" plastic scraper, and extracted the coating removal product from the test area surface with the 6" plastic scraper onto cloth rags, and then deposited the cloth rags into the disposal bucket. The disposal bucket did not have a lid and remained open for the duration of the test. The operator then removed his arms from the glove box arms. The average time for the operator to conduct this step was approximately 3 minutes.

8) Final Ignition: Conducted one final ignition sequence.

9) Take Out Materials: The operator opened the glove box door and took out the test surface, 2" paint brush, empty container of removal product, remaining cloth rags, 6" plastic scraper, and disposal bucket. The glove box inside air environment was thoroughly flushed at the conclusion of each test until the air environment was returned to ambient conditions. The glove box door and top vent were opened and the glove box was purged by turning on the air nozzle attached to the glove box. The glove box was located under a 53,000 cfm hood and exhaust unit.

The total duration to conduct steps 2 through 8 was approximately 72 minutes.

The ignition source was provided at the following two locations within the glove box: 1) approximately 2 feet above the surface of the coating removal product near the center of the test area, and 2) approximately 6 inches above the surface of the coating removal product near the center of the test area.

The purpose of introducing a flame at these two locations was to determine if there were sufficient solvent vapors within the glove box to exceed the lower flammability limit and support a combustion event away from the test surface.

The following is the ignition sequence that was repeated every five minutes during the dwell time portion of the test:

- Flame ignited at 24 inches above test surface for 3 second duration
- Flame moved to next location while the flame remained ignited
- Flame located at 6 inches above test surface for 3 second duration

Table 1: Ignition Sequence

Step	Flame Ignition
1) Introduce Materials	None during this step
2) First Application (average time 3 minutes)	None during this step
3) First Dwell (30 minutes) Commences once operator removes arms from glove box	Repeated the ignition sequence every 5 minutes during the 30 minute dwell time.
4) First Extraction (average time 3 minutes)	None during this step
5) Second Application (average time 3 minutes)	None during this step
6) Second Dwell (30 minutes) Commences once operator removes arms from glove box	Repeated the ignition sequence every 5 minutes during the 30 minute dwell time.
7) Second Extraction (average time3 minutes)	None during this step
8) Final Ignition (average time 15 seconds)	Conducted one final ignition sequence
9) Take Out Materials	None during this step

If there was a combustion event the testing was stopped for that product. For example, a combustion event occurred for the Minwax Antique Furniture Remover coating removal product at 15 minutes

during the first dwell. Therefore, the Minwax Antique Furniture Remover coating removal product test was concluded at 15 minutes.

Paint remover coverage specified by methylene chloride based coating removal manufacturers ranged from 50 to 100 square feet per gallon (See Appendix A). The amount of coating removal product required for the 2.95 square foot test surface applied at the rate of 100 square feet per gallon is calculated as follows:

$17 \text{ in} \times 25 \text{ in} = 425 \text{ in}^2$

$425 \text{ in}^2 \times 1 \text{ ft}^2/144 \text{ in}^2 = 2.95 \text{ ft}^2$

$(2.95 \text{ ft}^2 / 100 \text{ ft}^2) * (3{,}785 \text{ ml per 1 gallon}) = 112 \text{ ml}$

The amount of coating removal product required for the 2.95 square foot test surface applied at the rate of 50 square feet per gallon is calculated as follows:

$(2.95 \text{ ft}^2 / 50 \text{ ft}^2) * (3{,}785 \text{ ml per 1 gallon}) = 223 \text{ ml}$

For the 2.95 ft^2 test surface, coverage at the rate of 100 square feet per gallon requires 112 ml, while coverage at the rate of 50 square feet per gallon requires 223 ml. The coverage rate of 50 square feet per gallon was selected for the fire hazard test since it requires the most coating removal product to be applied to the test surface. This creates a more challenging situation for the fire hazard evaluation since more quantity of coating removal product is used for the same test area.

The overall dwell time ranges specified by methylene chloride based coating removal manufacturers was from 2 minutes to 30 minutes (see Appendix A). For the purpose of the fire hazard evaluation testing, we took a conservative approach to represent a challenging scenario and selected the highest recommended dwell time of 30 minutes. For the 2 test cycles, the dwell time was exactly 30 minutes for each cycle. However, there were minor variations in the application and extraction time due to variability in the operator's handling of the different coating removal products.

In general, coating removal application instructions by the manufacturers recommend to apply by brush in a single direction, and for a single stroke if possible. The intent was to minimize disruption to the evaporation barriers within the paint stripping product. Therefore, for the purposes of this test, a similar application approach was used where the operator brushed the coating removal product in one direction only to cover the entire test surface.

3.1 Coating Removal Products

The following five coating removal products were included in the fire hazard evaluation:

Table 2: Coating Removal Products

Product	Supplier	Solvents	Flash Point	Flammability Rating	Thickener and Evaporation Barrier
Formulation LO3	UMass Lowell	methyl acetate, DMSO, 1, 3 dioxolane	23 F	Flammable	Yes
Similar solvents and ratios as Formulation LO3 with no additives	UMass Lowell	methyl acetate, DMSO, thiophene	Not available	Not available	No
Strypeeze	Savogran	acetone, methanol, methylene chloride, toluene	<20 F (SDS 3/10/15)	Extremely Flammable	Yes
Similar solvents and ratios as Strypeeze with no additives	UMass Lowell	acetone, methanol, methylene chloride, toluene	Not available	Not available	No
Antique Furniture Refinisher	Minwax	acetone, methanol, polyethylene glycol, rosin ester, toluene	19.4 F (SDS 9/7/17)	Extremely Flammable	No

3.1.1 Formulation LO3:

Formulation LO3 is a paint stripping formulation developed by the University of Massachusetts Lowell and is comprised of a blend of three solvents as well as thickener and evaporation barrier additives. To provide a direct comparison for a coating removal product with and without thickener and evaporation barrier additives, a test sample without thickeners or evaporation barriers was created by UMass Lowell for a similar formulation based on the same three solvents and concentration levels used in Formulation LO3.

3.1.2 Strypeeze

The Strypeeze product sold commercially is comprised of a blend of five solvents as well as thickener and evaporation barrier additives. The concentration range listed in the Styrpeeze safety data sheet for the five solvents used in the Strypeeze product are provided in the table below. To provide a direct

comparison for a coating removal product with and without thickener and evaporation barrier additives, UMass Lowell created a test sample for a similar coating removal product based on the five solvents used in the Strypeeze product. The test sample used the concentration levels for the five solvents as specified in the table below. The concentrations used were within the concentration ranges outlined in the Strypeeze safety data sheet.

Table 3: Strypeeze Solvents

Solvent	CAS #	Concentration Range in SDS Version 3/10/15 (% Wt)	Concentration Used in Test Sample Without Additives (% Wt)
Methylene chloride	75-09-2	25 – 30%	29%
Methanol	67-56-1	25 – 30%	29%
Toluene	108-88-3	15 - 20%	19%
Acetone	67-64-1	15 - 20%	19%
Stoddard solvent	8052-41-3	0 - 5%	4%

3.1.3 Minwax Antique Furniture Refinisher

The Minwax Antique Furniture Refinisher safety data sheet states that this coating removal product contains the following chemicals: acetone, methanol, polyethylene glycol, rosin ester, and toluene. The Minwax Antique Furniture Refinisher product does not contain any thickener or evaporation barrier additives.

3.1.4 Evaporation Testing

Evaporation testing of the coating removal products was conducted at the Toxics Use Reduction Institute laboratory at the University of Massachusetts Lowell during April and May 2018. The evaporation testing was conducted inside a Labconco fume hood with internal dimensions of approximately 2 feet deep, 5 feet wide, and 4 feet high resulting in a volume of approximately 40 cubic feet. The coating removal products were poured into a glass petri dish and spread to cover the entire surface of the petri dish with a paint brush. The brushing was done in one direction. The petri dish was placed on a Mettler Toledo PG802-S scale inside of the fume hood. The fume hood blower was turned off and the fume hood door was closed for the duration of the 60 minute evaporation test. After the 60 minute evaporation test was concluded, the fume hood blower was turned on to clear the fume hood of the evaporated solvent vapors before opening the fume hood door to then remove the petri dish. The petri dish used for the evaporation test had an inside diameter of 3.8125 inches resulting in a surface area of approximately 11.4 in^2.

11.4 in^2 x 1ft^2 per 144 in2 = 0.0792 ft^2

The amount of coating removal product used for the evaporation test represented a coverage of 50 square feet per gallon. The amount of coating removal product used in the petri dish is calculated as follows:

$(0.0792\ ft^2 / 50\ ft^2)$ * (3,785 ml per 1 gallon) = 6.0 ml

The weight of the coating removal products was slightly different for each of the different coating removal products due to: 1) differences in density for the various coating removal products, and 2) the difficulty of leaving a precise amount of coating removal product in the petri dish after spreading it with a paintbrush.

For Formulation LO3, the initial weight of the coating removal product with an evaporation barrier was 6.40 g and the weight at the end of the 60 minute evaporation test was 6.34 g, resulting in an evaporation loss of 0.9%. The initial weight of the similar coating removal product without an evaporation barrier was 6.44 g and the weight at the end of the 60 minute evaporation test was 1.65 g, resulting in a evaporation loss of 74.4%. The table below shows the evaporation loss at 5 minute intervals throughout the duration of the 60 minute evaporation test. Formulation LO3 is comprised of methyl acetate, DMSO, and 1,3 dioxolane. Methyl acetate and 1,3 dioxolane are solvents that quickly evaporate, while DMSO is a slow evaporating solvent. As a result only 67% of formulation LO3 evaporated after a 60 minutes due to the presence of a slow evaporating solvent within the overall formulation.

The estimated time for Formulation LO3 without an evaporation barrier to exceed the lower flammability limit within the glove box is calculated as follows:

The mass of Formulation LO3 gas in one cubic foot at 100% concentration:

74.94 g per mole x 1 mole per 22.4 L x 1 lb per 454 grams x 1 L per 0.0353 ft^3 = 0.209 lb/ft^3

The amount of Formulation LO3 to exceed the lower flammability limit inside the glove box:

29,000/1,000,000 ppm x 0.209 lb/ft^3 x 27 ft^3 = 0.162 lbs

The amount of Formulation LO3 for each application during the fire hazard test:

223 ml x 0.998 g/ml x 1 lb per 454 grams = 0.490 lb

The percent of Formulation LO3 evaporated needed to exceed the lower flammability limit:

0.162 lb / 0.490 lb = 33.0%

According to the Formulation LO3 Evaporation chart, this level of evaporation required to exceed the LFL of the glove box will occur before 10 minutes of the first dwell time of the Formulation LO3 coating removal product without the evaporation barrier. The Formulation LO3 coating removal product with the evaporation barrier will not exceed the LFL at any time during the entire fire hazard test procedure.

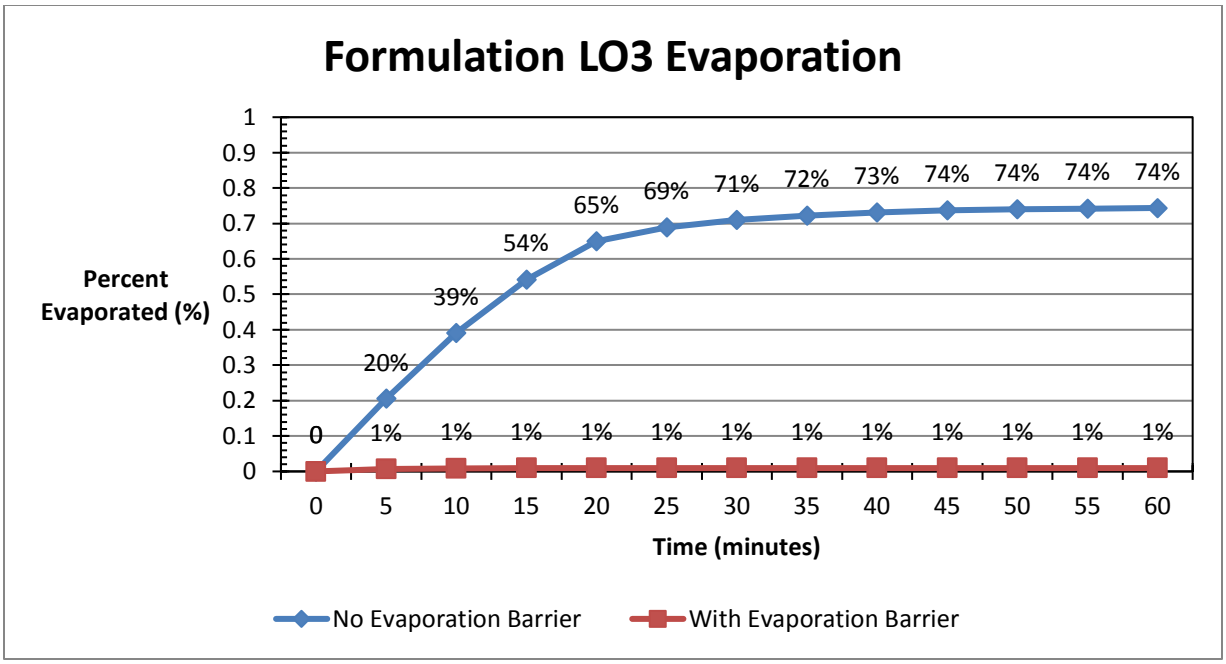

Figure 2: Evaporation testing results for formulation LO3 and solvents similar to Strypeeze without evaporation barrier

For the Strypeeze product, the initial weight of the coating removal product with an evaporation barrier was 5.91 g and the weight at the end of the 60 minute evaporation test was 5.81 g, resulting in an evaporation loss of 1.7%. The initial weight of the similar coating removal product without an evaporation barrier was 5.77 g and the weight at the end of the 60 minute evaporation test was 0.34 g, resulting in a evaporation loss of 94.1%. The table below shows the evaporation loss at 5 minute intervals throughout the duration of the 60 minute evaporation test.

The estimated time for Strypeeze without an evaporation barrier to exceed the lower flammability limit within the glove box is calculated as follows:

The mass of Strypeeze gas in one cubic foot at 100% concentration:

55.62 g per mole x 1 mole per 22.4 L x 1 lb per 454 grams x 1 L per 0.0353 ft^3 = 0.155 lb/ft^3

The amount of Strypeeze to exceed the lower flammability limit inside the glove box:

35,000/1,000,000 ppm x 0.155 lb/ft^3 x 27 ft^3 = 0.147 lbs

The amount of Strypeeze for each application during the fire hazard test:

223 ml x 0.912 g/ml x 1 lb per 454 grams = 0.448 lb

The percent of Strypeeze evaporated needed to exceed the lower flammability limit:

0.147 lb / 0.448 lb = 32.8%

According to the Strypeeze Evaporation chart, the level of evaporation required to exceed the LFL will occur before 10 minutes of the first dwell time of the solvent blend similar to the Strypeeze coating removal product but without any thickener or evaporation barrier. The Strypeeze coating removal product with the evaporation barrier will not exceed the LFL at any time during the entire fire hazard test procedure.

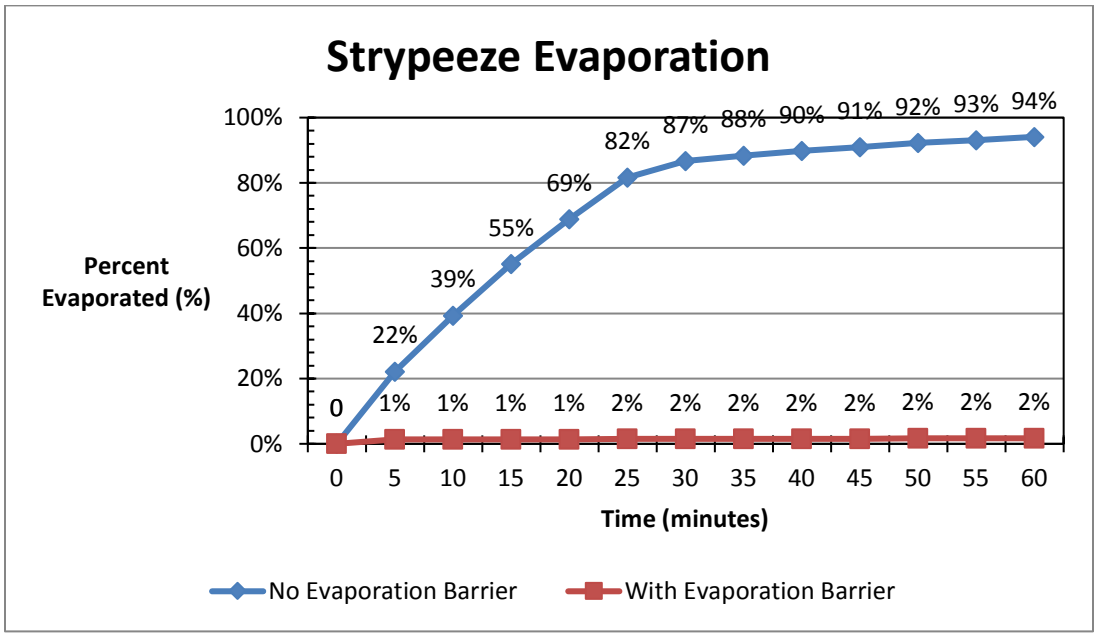

Figure 3: Evaporation testing results for Strypeeze and solvents similar to Strypeeze without evaporation barrier

For the Minwax Antique Furniture Refinisher product, the initial weight of the coating removal product without an evaporation barrier was 5.29 g and the weight at the end of the 60 minute evaporation test was 0.13 g, resulting in a evaporation loss of 97.5%. The table below shows the evaporation loss at 5 minute intervals throughout the duration of the 60 minute evaporation test.

The estimated time for the Minwax without an evaporation barrier to exceed the lower flammability limit within the glove box is calculated as follows:

The mass of Minwax gas in one cubic foot at 100% concentration:

57.87 g per mole x 1 mole per 22.4 L x 1 lb per 454 grams x 1 L per 0.0353 ft^3 = 0.161 lb/ft^3

The amount of Minwax to exceed the lower flammability limit inside the glove box:

10,000/1,000,000 ppm x 0.161 lb/ft^3 x 27 ft^3 = 0.044 lbs

The amount of Minwax for each application during the fire hazard test:

223 ml x 0.81 g/ml x 1 lb per 454 grams = 0.398 lb

The percent of Minwax evaporated needed to exceed the lower flammability limit:

0.044 lb / 0.398 lb = 11.1%

According to the Minwax Evaporation chart, this level of evaporation required to exceed the LFL will occur before 5 minutes of the first dwell time for the Minwax Antique Furniture Refinisher coating removal product that does not contain an evaporation barrier.

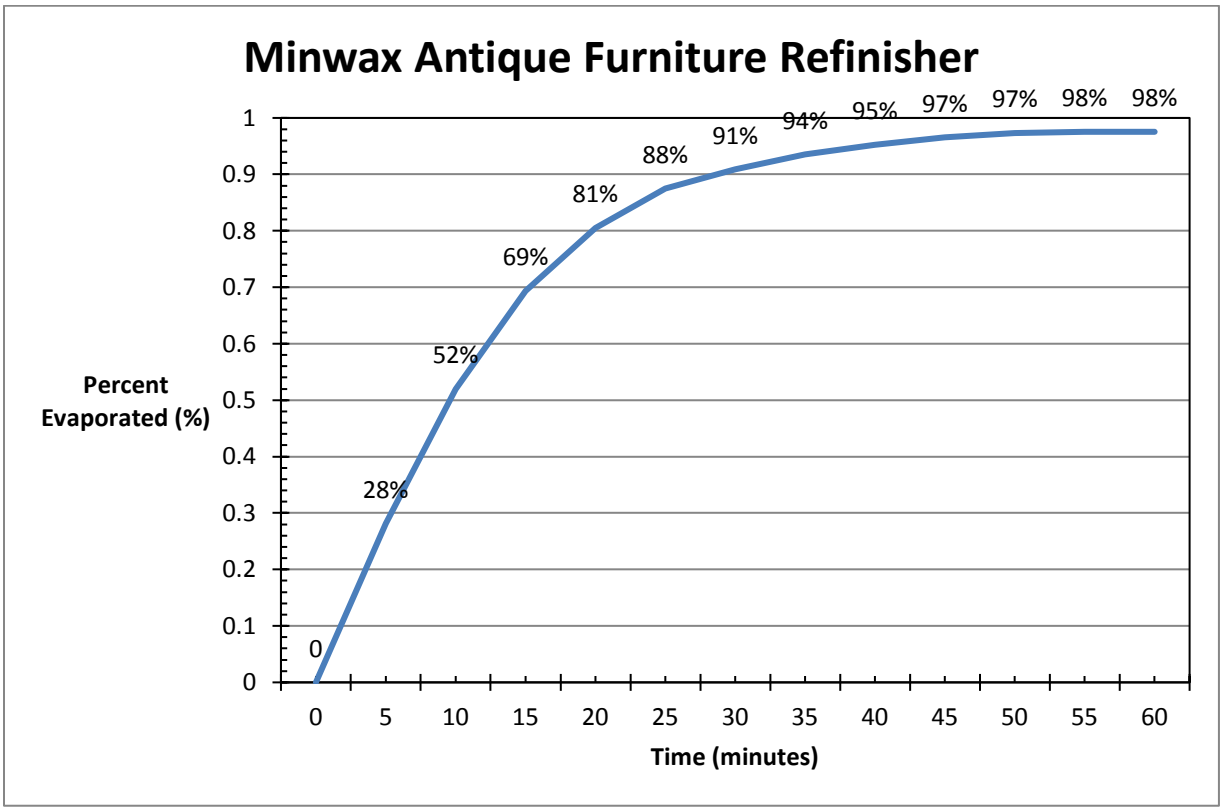

Figure 4: Evaporation testing results for Minwax antique furniture refinisher

4 Results: Fire Hazard Testing

The following table summarizes the results of the fire hazard testing conducted for the five coating removal products. This table shows at which stage during testing a fire event occurred. Note that if a fire occurred during any dwell periods subsequent ignitions were not tested.

Table 4: Fire Hazard Testing Results

Coating Removal Product	Ignition During 1st 30 Minute Dwell	Ignition During 2nd 30 Minute Dwell	Final Ignition After 2nd Extraction
Formulation LO3 with evaporation barrier	No combustion event at each 5 minute interval	No combustion event at each 5 minute interval	No combustion event
Solvents similar to Formulation LO3 without evaporation barrier	Combustion event at 15 minutes. Test concluded at this time.	Not applicable	Not applicable
Strypeeze with evaporation barrier	No combustion event at each 5 minute interval	No combustion event at each 5 minute interval	No combustion event
Solvents similar to Strypeeze without evaporation barrier	Combustion event at 15 minutes. Test concluded at this time.	Not applicable	Not applicable
Minwax Antique Furniture Refinisher with no evaporation barrier	Combustion event at 15 minutes. Test concluded at this time.	Not applicable	Not applicable

For each combustion event observed (See Figure 5), the event occurred when the ignition device was at the 6" level above the surface and not at the 24" level. This is due to the solvents evaporating from the coating removal products were significantly more dense than air. For example, 1,3 dioxolane (2.6), methyl acetate (2.6), methylene chloride (2.9), acetone (2.0), and toluene (3.2) all have vapor densities much higher than air. Consequently, the LFL would first be exceeded at the bottom of the glove box and slowly rise as the solvent vapors diffused to higher locations within the glove box.

Figure 5: Combustion event inside the glove box

The two products with an evaporation barrier did not exceed the LFL within the glove box and cause a combustion event, and all three products without evaporation barriers did cause a combustion event at the 15 minute timeframe for the first dwell period. For the LO3 and Strypeeze coating removal products, the only difference between the test samples was the presence or lack of thickener and evaporation barrier additives. For the coating removal product with solvents similar to Strypeeze without evaporation barrier, there was a combustion event at 15 minutes even though the solvent blend contained methylene chloride – a non-flammable substance. This combustion event occurred due to the presence of flammable solvents (i.e. acetone and toluene) that were also part of this solvent blend.

Based on the results of the evaporation testing and the fire hazard testing, it appears that the presence of the evaporation barrier within the coating removal products tested accomplishes the following:

- Significantly inhibits the generation of solvent vapors from evaporation during the application, dwell, and extraction of the coating removal products
- Prevents the exceeding of the LFL at a distance of 6” or greater from the surface of the coating removal application within a confined work space with no forced ventilation
- Greatly reduces the risk of a combustion event caused by exceeding the LFL in the area surrounding the use of the tested coating removal products

Sources:

ASTM Standard D93 – 16a, Standard Test Methods for Flash Point by Pensky-Martens Closed Cup Tester

ASTM Standard D3278 – 96 (Reapproved 2011), Standard Test Methods for Flash Point of Liquids by Small Scale Closed-Cup Apparatus

Occupational Safety and Health Administration, OSHA "Flammable Liquids 29 CFR 1910.106", https://www.osha.gov/dte/library/TrngandMatlsLib_FlammableLiquids.pdf.

Occupational Safety and Health Administration, OSHA 29 CFR 1910.106; Flammable and Combustible Liquids (7-1-09 Edition).

U.S. Department of Transportation, 49 CFR 173.120; Class 3- Definitions (10-1-09 Edition)

American Chemistry Council Solvents Industry Group, "WORKING WITH MODERN HYDROCARBON AND OXYGENATED SOLVENTS: A GUIDE to FLAMMABILITY and STATIC ELECTRICITY", 2011

Appendix A: Manufacturer Recommendations for Coating Removal Product Usage

The following table provides application methods, anticipated coverage, and recommended dwell times for use of methylene chloride based paint stripping products.

Manufacturer	Source	Application Method	Coverage	Dwell Time
Packaging Services	http://www.packserv.com/products/crown/faqs/	"Use a brush to apply a generous amount of stripper in a single brush stroke, if possible." "Give the product about 10-15 minutes to work before disturbing it in any way."	Not mentioned	10-15 minutes
Savogran	http://www.savogran.com/materials.html and http://www.savogran.com/procedure.html	"Don't apply the remover as you would paint. In fact, don't "brush" on the remover in the usual sense; rather "lay" it on in much the same way as you would icing on a cake. Working in one direction, preferably on a flat surface, apply the remover"	"One gallon of remover will strip 50 to 100 square feet".	"In general, removal time is from 15 to 20 minutes."
W.M. Barr (Goof Off)	https://goofoffproducts.com/pro-stripper/	"In a thick coat with a single brush stroke. Strippers contain ingredients to retard evaporation. Excess brushing causes loss of the active ingredients, causing the stripper to dry out."	Not mentioned.	"Give the stripper time to work, at least 15 minutes, before test scraping it."
W.M. Barr (Strip-X)	http://www.kleanstrip.com/product/strip-x-stripper	"Brush in one direction only. Leave the area and let the stripper do the work." "In a thick coat with a single brush stroke. Strippers contain ingredients to retard evaporation. Excess brushing causes loss of the active ingredients, causing the stripper to dry out."	"Typically, up to 80 sq. ft. per gallon"	"After 15-30 minutes, test scrape a small area to see if finish is ready for removal."

Manufacturer	Source	Application Method	Coverage	Dwell Time
W.M. Barr (Premium Stripper)	http://www.kleanstrip.com/product/premium-stripper	"Brush in one direction only. Leave the area and let the stripper do the work."	"Typically, up to 80 sq. ft. per gallon"	"After 15 minutes, test scrape a small area to see if finish is ready for removal."
W.M. Barr (Jasco Paint & Epoxy Remover)	http://www.jasco-help.com/product/premium-paint-epoxy-remover	"Brush in one direction only. Leave the area and let the stripper do the work."	"Approximately 80 sq. ft. per gallon"	"After 15 minutes, test scrape a small area to see if finish is ready for removal."
Formby's	https://www.formbys.com/products/paint_poly_remover/	"Lay a thick coat of Paint & Poly Remover on the surface, brushing in only one direction. Do not brush back & forth."	Not mentioned	"At least 15 - 20 minutes. Let the product work for you!"
Sunnyside (Pro Solutions)	http://www.sunnysidecorp.com/pdfs/Label_639G1P.pdf	"Apply a generous amount to area no larger than two feet by two feet at a time. Do not brush back and forth like paint. Allow the remover to stand undisturbed until the old finish softens"	Not mentioned	Not mentioned
Sunnyside (2 Minute Remover)	http://www.sunnysidecorp.com/pdfs/Label_639G1.pdf	"Apply a generous amount to area no larger than two feet by two feet at a time. Do not brush back and forth like paint. Allow the remover to stand undisturbed until the old finish softens"	Up to 100 square feet	2 to 5 minutes