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Evaluation of Alternative Chemical Strippers on Wood Furniture Coatings

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Abstract: Alternative chemical strippers have been evaluated to determine the potential effects on air emissions resulting from solvent changes in the furniture repair and refinishing industry. Alternative chemical strippers used to remove both traditional and emerging low-VOC (volatile organic compound) wood coatings were evaluated. Phase 1 was a laboratory evaluation of five chemical stripper combinations on three types of coatings. Phase 2 was the assessment of the best performing alternative stripper from the laboratory evaluation in a furniture repair and refinishing facility. This paper discusses both phases of research. Screening and assessment results will be presented at this conference.

Introduction

Chemical strippers employ a variety of chemical mechanisms and may be designed for specific functions. Solvents that cause physical and chemical reactions are often involved in chemical stripping applications. Chemical stripper removal processes encompass cold solvent (acid or alkaline activated), hot alkaline removal, and molten salt baths. These stripping solvents are designed to degrade coating films or destroy adhesion of the film from the substrate to which it is attached (Hahn). In the original equipment and furniture manufacturing markets, chemical strippers are used to remove defective coatings from items that do not pass inspection. They are also used to clean spray booths and coating application equipment. In this study, five alternative cold solvent chemical strippers were used to remove three coating types of wood furniture coatings from wooden surfaces. Following coating removal, the effectiveness of each chemical stripper to remove the coatings from the wooden surfaces was evaluated.

Methylene chloride (CH_2Cl_2) is a halogenated solvent and a suspected carcinogen; however, it is not defined as a volatile organic compound (VOC) by the Environmental Protection Agency's (EPA's) definition. CH_2Cl_2 has been a primary component formulated in chemical strippers. The effectiveness of CH_2Cl_2 is due to its small molecular size, which promotes rapid penetration into the coating film, and to its intermediated solvency for various polymer coatings. As CH_2Cl_2 penetrates to the substrate, the coating film swells to several times its original volume. The swelling causes an increase in internal pressure at the interface with the coating relieved in a direction away from the substrate. Thus the film wrinkles, blisters, buckles, and bubbles, resulting in its release from the substrate. CH_2Cl_2 has been used in nearly all chemical stripping applications because it can effectively strip a broad range of cured coatings from a substantial variety of substrates (Sizelove, Wollbrinck). Annual estimates for CH_2Cl_2 usage in paint stripping have ranged from approximately 50 million kilograms to 70 million kilograms.

Other solvents and chemicals that are often found in chemical stripper formulations may include: alcohols, xylene, toluene, amines, glycol ethers, mineral spirits, methyl ethyl ketone, acetone, phenol, and benzene (Sizelove, Wollbrinck). These additional components, several of which are VOCs and some of which are hazardous air pollutants (HAPs), are often used to enhance the properties and performance of primary components. In some cases, solvent blends that dissolve the coating film are favored over other types of chemical strippers. Some solvent chemical strippers that employ ketones and aromatic hydrocarbon blends are used primarily where other chemical strippers fail such as on low intrinsic strength films or sharply angled surfaces (Sizelove, Wollbrinck). Annual VOC emission estimates for all U.S. furniture stripping firms have been reported to be as high as 1.1 million kilograms. Alternative chemical strippers have been evaluated to determine the potential effects on air emissions resulting from solvent changes in the furniture repair and refinishing industry.

Project Description

The purpose of this research was to evaluate the feasibility of using alternatives to high VOC/HAP solvent-based chemical strippers that are currently used in the furniture repair and refinishing industry to remove both traditional high VOC lacquer and emerging, low-VOC, wood furniture coatings. Research Triangle Institute (RTI), under a cooperative agreement with the U.S. EPA's Air and Energy Engineering Research Laboratory, screened five alternative chemical strippers, consisting of one industrial and four retail chemical strippers. Alternative chemical strippers were evaluated based on their stripping effectiveness compared to a CH_2Cl_2-based stripper. A panel of individuals experienced in the area of chemical stripping evaluated the samples and selected the most effective chemical stripper for further evaluation. An on-site assessment of the best performing alternative chemical stripper from the screening evaluation took place at a local furniture refinishing facility. The EPA, RTI, several coating suppliers, one chemical stripper supplier, and two local furniture refinishing facilities participated in this project.

Project Objectives

This project was undertaken to identify chemical strippers that could serve as alternatives to CH_2Cl_2-based chemical strippers and to evaluate their effectiveness for the removal of furniture coatings typically used on wooden substrates encountered in furniture refinishing industries. The specific objectives of this research were to:

1. Conduct a laboratory evaluation of the performance of five alternative chemical stripper formulations and compare their performance to the performance of a traditional solvent-based chemical stripper formulation on three coating types found on wood furniture substrates.

2. Assess, in a furniture refinishing facility, the use of the best performing alternative stripper on traditional furniture coatings and new emerging low-VOC furniture coatings.

This project was limited to conducting a screening study and assessing of one industrial and four retail chemical strippers following the recommendations of the manufacturer or supplier of the material. No provisions were made for extending the experiments to cover the modifications of the five chemical strippers, or for the formulations of the chemical strippers. Refinement in the formulation of effective chemical strippers, and a thorough evaluation of the health and environmental effects, were beyond the scope of work for this project.

Project Activities

The laboratory evaluation, the first objective, involved cold, solvent strippers; no thermal methods were used. Solvent strippers work solely by dissolving the coating film. Their dissolving mechanism causes them to become rapidly saturated with dissolved coating. Care must be taken to prevent redeposition of the film on the substrate. Cold strippers act best when they are not true solvents of the film, but are absorbed by the film. This action is similar to the actions of CH_2Cl_2-based strippers. Five chemical strippers and three coating types were selected cooperatively by the EPA and RTI. The selected strippers consist of a combination of one or more of the following constituents: CH_2Cl_2, dibasic ester (DBE), n-methylpyrrolidone (NMP), and d-limonene. A CH_2Cl_2-based chemical stripper was used as the standard. The other chemical strippers did not contain CH_2Cl_2. DBE is a mixture consisting of refined dimethyl esters of adipic, glutaric, and succinic acids. The chemical strippers are identified as a number with at least one formulation constituent in parentheses. Individual constituents of each chemical stripper are listed in Table 1.

Coating types included traditional furniture coatings, which are often solvent-based nitrocellulose coatings, and new emerging coating types, which included waterborne and high solids coating types from four major wood furniture coating suppliers. Screening was performed in a laboratory hood at RTI by RTI's laboratory staff. Selected strippers were applied to remove the cured coatings from a 30 cm × 30 cm area of oak, pine, and maple wood substrates. The manufacturers' directions for the strippers were observed. Coating removal quality achieved by each of the alternative strippers was compared to the removal quality using a CH_2Cl_2-based stripper.

A panel of three non-RTI reviewers qualitatively evaluated the performance of the alternative chemical strippers. Each panelist ranked the quality of coating removal from zero to 10 based upon the percentage of coating removed. A score of 10 represented 100 percent removal while a score of zero represented no activity by the stripper on the coating. The final ranking represented the consensus of the panel. Ranking results are presented in Table 2.

The second objective was to assess the best performing chemical stripper, as found from the laboratory phase, in a furniture repair and refinishing facility. A facility representative applied the stripper and evaluated the quality and ease of coating removal for the alternative stripper selected for on-site assessments. The representative then compared the removal quality and ease of the alternative stripper to the removal quality and ease of the stripper routinely used at the evaluation facility.

RTI personnel estimated the emissions that result from the use of each stripper based upon the quantity of chemical stripper used. Using the information provided by material safety data sheets (MSDSs), RTI personnel estimated VOC and CH_2Cl_2 emissions of the investigated chemical strippers. Emission estimates for the alternative strippers were compared with emission estimates for the currently used products to learn the potential for emission reduction and pollution prevention.

Performance and Materials

The stripping performance of five chemical stripper formulations versus the performance of a CH_2Cl_2-based formulation was measured on furniture quality finished 30 cm × 30 cm solid wood coupons. Wood coupons were prepared according to methods typically used by coating manufacturers to market their coatings to the furniture industry. Three coating types (clear topcoats) from four unnamed coating suppliers were applied to oak, maple, and poplar wood coupons. Of the three wood types, the emphasis of this study was placed on oak. Wood types representation in this study were: porous hardwood, oak; nonporous hardwood, maple; and softwood, poplar. The clear topcoat types were: traditional nitrocellulose lacquer, high-solids, and waterborne coatings. Each of the clear topcoats was applied to the wood substrate using spray and oven curing applications similar to those typically used in a furniture manufacturing facility.

Each wood coupon was treated using a process of three coating steps that consisted of at least a stain, sealer, and clear topcoat. Once received from the coating suppliers the coupons were allowed to cure further for 10 days under ambient conditions. Individual constituents of each chemical stripper used for this test are listed in Table 1.

Application and Removal

All laboratory chemical stripper application and removal tests were conducted under a laboratory hood at approximately 22.4°C (72.3°F). For four cases, the chemical strippers were applied using 2-inch natural bristle brushes following the manufacturer's directions. For the single case where the chemical stripper was not applied using a brush, a heavy paper towel was saturated with the less viscous chemical stripper and applied to the wooden substrate, as the manufacturer suggested.

The area covered by each coating application was approximately 930 cm^2 (1 ft^2). The total coverage area for each of the five chemical strippers was approximately 6.1 m^2 (20 ft^2). The total volume of each chemical stripper used for the total area is presented in Table 3.

Treated coatings were removed with a disposable putty knife that had a blade about 1.3 cm (0.5 in.) wide. Table 4 lists the general ease of removal for the three coating types during the actual removal. Chemical strippers are identified above each column, and the coating types are listed beside each row in Table 4. Once the coatings were removed from the wooden coupons with the putty knife, the surface was wiped with a cloth and received no further treatment.

Stripper Evaluation

Laboratory Evaluation. Following stripper application and removal, a panel of individuals experienced in the area of chemical stripping visually evaluated the performance effectiveness of each chemical stripper on each coating type. Each chemical stripper test was ranked on a scale from zero to 10 (where, zero represented no activity by the stripper to remove the coating, and 10 represented 100 percent coating removal). The ranking results of the visual evaluation are presented in Table 2.

Figures 1 and 2 are photos of the test coupons with coatings removed using Chemical Stripper 4 (d-Limonene) and Chemical Stripper 5 (H_2O), respectively. Below each photo is the chemical stripper used in the screening evaluation. The chemical strippers ranked in order of best to worst are: Chemical Stripper 4 (d-Limonene), Chemical Stripper 5 (H_2O), Chemical Stripper 3 (NMP, DBE), Chemical Stripper 1 (Standard), and Chemical Stripper 2 (NMP, DBE). The top three performing chemical strippers from this study were closely ranked, Chemical Stripper 4 (d-Limonene) at 7.9, Chemical Stripper 5 (H_2O) at 7.5, and Chemical Stripper 3 (NMP, DBE) at 7.3. According to the panel, Chemical Stripper 4 (d-Limonene) was the most effective chemical stripper in the group. Figures 3 and 4 are photos of test coupons with coatings removed using Chemical Stripper 4 (d-Limonene). Because of its low vapor pressure, chemical stripper 5 (H_2O) can be left on the paint for extended periods without loss of solvents, allowing more flexibility in working time. However, this DBE chemical stripper is waterborne and can raise the grain of wooden substrates. Material cost for chemical strippers at the time of this study is presented in Table 5. The relative cost of the chemical strippers for the area treated in this study is listed in Table 6.

Furniture Repair and Refinishing Facility Evaluation. A local refinisher demonstrated the stripping effectiveness of Chemical Stripper 4 (d-Limonene) in his facility on a chair seat, a square table top, and circular table top. The participating refinisher was not aware of the specific coating types on the substrates; however, he took the liberty to speculate on the general coating type based on appearance, removal ease, and his experience. The coatings removed from the square table surface consisted of several layers of paint covering the original varnished surface with a removal time of approximately 45 minutes. Coatings removed from the chair seat were layers of lacquer-type finishes with a removal time of approximately 10 minutes. Removal time for coatings removed from the circular table top was approximately 6 minutes, and the coatings removed consisted of a traditional lacquer furniture coating system. All furniture pieces were presumed to have been solid wood. The area of coating removed was roughly 930 cm^2 (1 ft^2) from each surface.

Chemical Stripper 4 (d-Limonene) successfully removed the topcoats from the lacquer-type surfaces of the chair and circular table top without disturbing the appearance of the stain. However, it left a film on the lacquer-type surface that was removed by wiping the surface with an unsoiled cloth moistened with Chemical Stripper 4 (d-Limonene). Roughly three layers of paint and one layer of varnish were removed from the square table top leaving a raw wood surface. The refinisher said that the product was reliable. However, he was concerned with the cost.

Conclusions

Results from this evaluation included: (1) the subjective determination of a viable substitute for solvent-based chemical strippers based upon the effectiveness of the evaluated alternative chemical strippers, (2) the potential effect of the alternative chemical stripper on air emissions, and (3) the cost associated with the use of the alternative chemical stripper. Implementing the use of the alternative chemical stripper as a viable substitute was at the discretion of the host facility.

The VOC and CH_2Cl_2 emission estimates resulting from the use of alternative chemical strippers and currently used solvent-based chemical strippers were calculated using the available information provided from the MSDSs of each chemical and the amount of chemical stripper used. A cost assessment was generated from usage information provided by the host facility and cost information provided by the vendor for chemical strippers only. Relative costs and emission estimates are presented in Tables 6 and 7, respectively. Waste management, other cost associated with using the alternative chemical stripper, and handling and safety were not directly related to the objectives of this study and should be included in future work.

References

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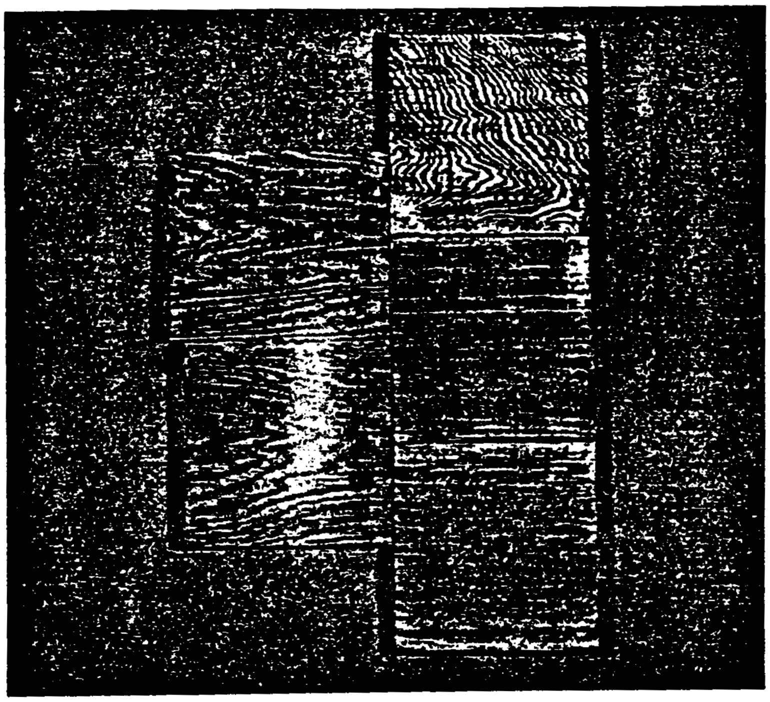

FIGURE 1. PHOTO OF TEST COUPONS FINISHED WITH VARIOUS FURNITURE COATINGS AND THEN STRIPPED USING CHEMICAL STRIPPER 4 (D-LIMONENE).[1]

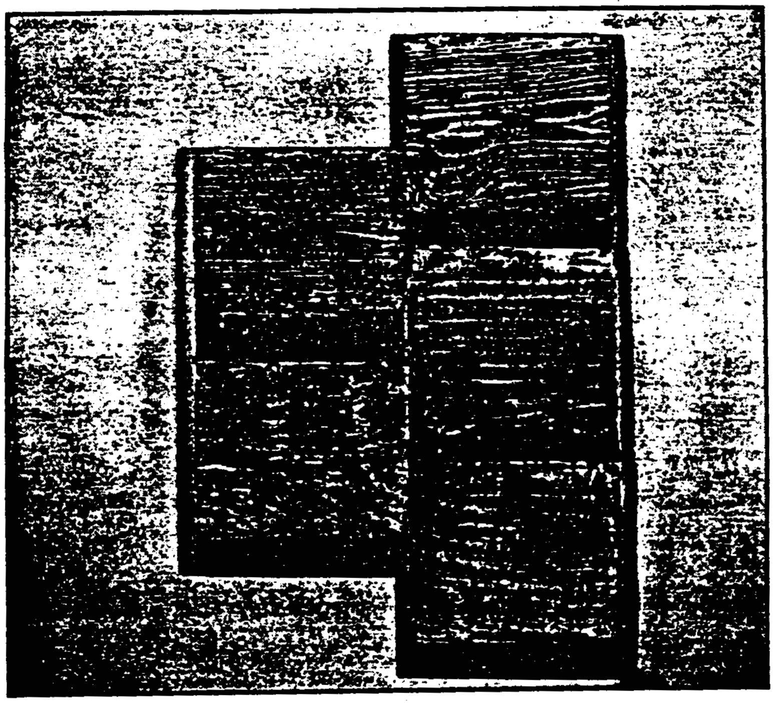

FIGURE 2. PHOTO OF TEST COUPONS FINISHED WITH VARIOUS FURNITURE COATINGS AND STRIPPED USING CHEMICAL STRIPPER 5 (H_2O).[1]

1 Coatings and wood types from top-to-bottom and left-to-right in figure are: waterborne on oak, high-solids on oak, and nitrocellulose lacquer on oak, poplar, and maple.

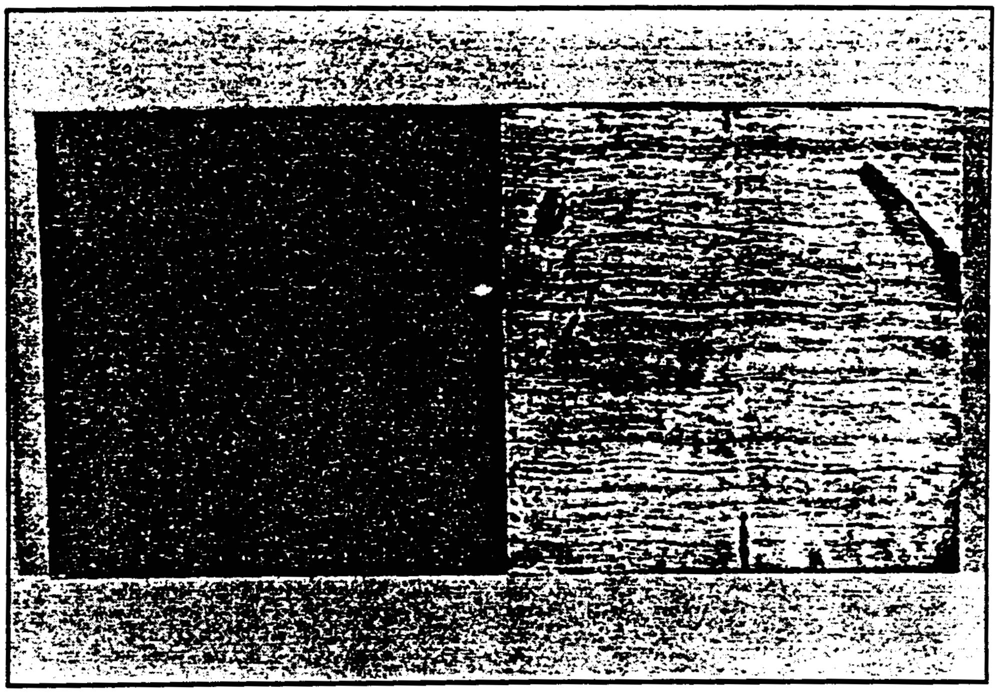

FIGURE 3. PHOTO OF TEST COUPONS FINISHED WITH A LACQUER SYSTEM ON MAPLE BEFORE AMD AFTER TREATMEMT USING CHEMICAL STRIPPER 4 (D-LIMONENE).

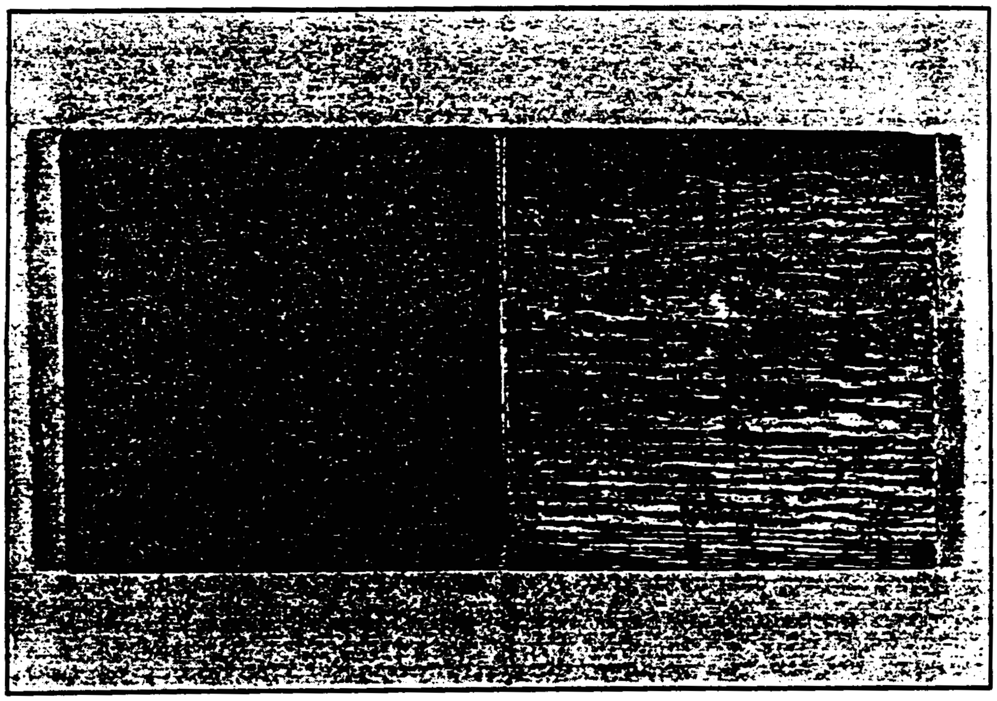

FIGURE 4. PHOTO OF TEST COUPONS FINISHED WITH A HIGH-SOLIDS SYSTEM ON OAK BEFORE AND AFTER TREATMENT USING CHEMICAL STRIPPER 4 (D-LIMONENE).

TABLE 1. CONSTITUENTS OF CHEMICAL STRIPPERS

CHEMICAL STRIPPER	CONSTITUENT	WEIGHT %
1 (Standard)	Methylene Chloride *	> 10
	Methanol *	< 25
	Toluene *	> 35
	Acetone	< 25
	Paraffin Wax	< 5
2 (NMP, DBE)	N-Methyl-2-Pyrrolidone	†
	Dimethyl Glutarate	†
	Dimethyl Adipate	†
	Dimethyl Succinate	†
3 (NMP, DBE)	1-Methyl-2-Pyrrolidone	†
	Dimethyl Glutarate	†
	Dimethyl Adipate	†
	Dimethyl Succinate	†
4 (d-Limonene)	n-Methyl Pyrrolidone	50 - 75
	d-Limonene	25 - 50
5 (H_2O)	Water	65 - 75
	Dimethyl Adipate	20 - 30
	Dimethyl Glutarate	1 - 5
	Hydrated Magnesium Aluminum Silicate	0 - 2
	Hydrated Aluminosilicate	0 - 2

* Hazardous Air Pollutants

† Constituent weight percent undisclosed on Material Safety Data Sheets (MSDSs); therefore, primary constituent can not be identified.

TABLE 2. AVERAGE RANKING FROM STRIPPING EVALUATIONS *

	1 (Standard)	2 (NMP, DBE)	3 (NMP, DBE)	4 (d-Limonene)	5 (H_2O)
Panelist 1	5.6	3.9	6.8	8.0	7.9
Panelist 2	7.6	6.2	8.1	8.2	8.0
Panelist 3	4.3	4.0	7.1	7.4	6.8
Average	5.8	4.7	7.3	7.9	7.5

* All significant figures are not shown. Numbers are rounded to the nearest one hundredth.

TABLE 3. USAGE ESTIMATES

CHEMICAL STRIPPER	VOLUME/COVERAGE AREA, (m^3/m^2)
1 (Standard)	1.22×10^{-4}
2 (NMP, DBE)	1.74×10^{-4}
3 (NMP, DBE)	2.67×10^{-4}
4 (d-Limonene)	3.23×10^{-4}
5 (H_2O)	6.47×10^{-4}

TABLE 4. REMOVAL EASE FOR COATINGS

Coating Types	1 (Standard)	2 (NMP, DBE)	3 (NMP, DBE)	4 (d-Limonene)	5 (H_2O)
Nitrocellulose	VE	VE	VE	VE	VE
Waterborne	RE	RE	RE	D	RE
High Solids	RE	RE	RE	D	VE

VE = VERY EASY RE = RELATIVELY EASY D = DIFFICULT

TABLE 5. MATERIAL COST (U.S. DOLLARS)

CHEMICAL STRIPPER	QUART	GALLON
1 (Standard)	4.03	10.17
2 (NMP, DBE)	7.95	21.94
3 (NMP, DBE)	9.22	25.16
5 (H_2O)	6.79	16.37
4 (d-Limonene)	11.73*	46.93*
	9.73†	38.93†

* 4 (d-Limonene) is only available for purchase in 5- and 55-gallon quantities, this is an estimate using the 5-gallon quantity.

† 4 (d-Limonene) is only available for purchase in 5- and 55-gallon quantities, this is an estimate using the 55-gallon quantity.

TABLE 6. RELATIVE MATERIAL COST FOR STRIPPING A FIXED AREA **
(U.S. DOLLARS)

CHEMICAL STRIPPER	COST/AREA, ($/m^2)	RELATIVE COST
1 (Standard)	0.52	1.0
2 (NMP, DBE)	1.46	2.8
3 (NMP, DBE)	2.61	5.0
5 (H_2O)	4.65	9.0
4 (d-Limonene)	3.40†	6.6†
	2.82*	5.4*

* All significant figures are not shown. Numbers are rounded to the nearest one hundredth.

† 4 (d-Limonene) is only available for purchase in 5- and 55-gallon quantities, this is an estimate using the 5-gallon quantity.

** 4 (d-Limonene) is only available for purchase in 5- and 55-gallon quantities, this is an estimate using the 55-gallon quantity.

TABLE 7. EMISSION ESTIMATES

CHEMICAL STRIPPER	VOC	CH_2Cl_2
	MASS/AREA, (g/m²)	
1 (Standard)	85.85	9.54
2 (NMP, DBE)	160.90	-
3 (NMP, DBE)	263.74	-
4 (d-Limonene)	158.94	-
5 (H_2O)	139.86	-