Transfer Efficiency and VOC Emissions of Spray Gun and Coating Technologies in Wood Finishing

Pacific Northwest
Pollution Prevention Research Center

Table of Contents

Figures

Appendices

Transfer Efficiency and VOC Emissions of Spray Gun and Coating Technologies in Wood Finishing

Lesley Snowden-Swan, Battelle Pacific Northwest Laboratories

Summary

The objective of this study was to determine which factors most strongly influence net volatile organic compound (VOC) emissions and transfer efficiency (TE) of a spray coating operation in a "real-life" wood finishing environment. The factors that were tested included spray equipment types and coating types, as well as painter skill level and target size and shape. Transfer efficiency and coating usage were measured to rate the overall system performance (coating type plus application method) in an operating wood finishing shop. The equipment was designed to be representative of small- to medium-sized businesses in the wood finishing industry. The study was not designed to determine the maximum achievable transfer efficiency for the various spray guns, but rather to provide a non-biased test of "off-the-shelf' equipment not optimized with variable tips. Spray time was included in the data in order to aid in the analysis of possible effects of the variables on production rate. The study showed that water-borne coatings hold the greatest long-term potential for VOC reductions in wood finishing, and that painter skill level also exerts a strong influence.

Introduction

Because spray painting permits fast and even coverage with significantly lower labor costs than other application methods, it is used to apply coatings in many industries, including auto refinishing, wood finishing, and building construction. From an environmental perspective, the major drawback of spray painting is the release of smog-producing VOCs into the atmosphere from the coating materials, plus the generation of solid waste in the form of sprayed material that misses the target.

A useful measure of coating usage is transfer efficiency (TE). TE is defined as the ratio of mass or volume of solid coating deposited on a surface to the total mass or volume used in a coating application step, expressed as a percentage. For example, if one gallon of coating is used to finish a target, and only half of the material sprayed actually lands on the target, the system is said to be 50 percent transfer efficient. While more direct methods ofcoating application, such as brush, roller, dip and flow methods, are typically over 90% transfer efficient, spray application can result in transfer efficiencies as low as 20 percent. This increases both solid waste and solvent emissions, and represents hazards to the worker and to the environment.

VOCs are of extreme concern environmentally because they react photochemically with nitrogen oxides and sulfur oxides (auto emissions) to create low altitude ozone or "photochemical smog":

$$\text{VOC} + \text{NOx/SOx} + \text{Sunlight} = \text{Photochemical Smog}$$

Photochemical smog can cause health problems such as inflammation of breathing passages, decreased lung function, coughing, and chest pain. It is estimated that solvent evaporation from spray coating operations accounts for five to seven percent of the total VOCs contributing to low altitude ozone in the Puget Sound area.

Improving transfer efficiency in spray coating operations would reduce coating waste and VOC emissions, cut hazardous waste disposal fees and coating costs, and lessen worker exposure to potentially hazardous materials. Changing from 30 percent transfer-efficient equipment to 65 percent transfer-efficient equipment would reduce materials usage by approximately 50 percent[1]. Many factors affect achievable TE, including spray equipment type, size and geometry of the target, coating type, skill level of the spray operator, air velocity, atomizing air pressure, fluid flow rate, and fan size.

In this study, the impact of several factors which can affect achievable TE were investigated, including spray equipment type, size and geometry of the target, solids content of the coating, and skill level of the operator. Transfer efficiency and VOC emissions were calculated for each of these factors. Other factors which may affect TE, such as air velocity, atomizing air pressure, and fluid flow were monitored and kept as stable as possible for the duration of the spraying procedures. Environmental impact is clearly shown by the data on net VOC emissions, expressed in pounds of VOC per pound of solid applied, since those figures reflect both transfer efficiency and VOC content of the coating.

Methodology

Testing environment. Spraying was conducted inside a concrete dry filter spray booth of dimensions 14' x 43'x9'4" at a wood finishing facility in the Puget Sound area. Fresh dry filters were installed in the booth prior to testing. The average temperature, percent humidity and air velocity in the booth for the duration of testing were 70°F, 65%, and 180 ft/min, respectively. Air temperature and humidity were monitored using a Taylor 5565 meter. Air velocity was measured periodically using an Alnor Velometer Jr. air flow meter.

Operator skill level. To determine the importance of the "human application factor" on spray efficiency, the tests were performed with both a very experienced painter (over ten years' spray painting experience) and a painter with limited experience (less than one year). The experienced sprayer had substantial experience with all of the spray guns tested. The novice sprayer had used all of the guns at least once; however, the bulk of his experience was with the HVLP air-assisted and HVLP equipment.

Target size and geometry. To investigate the effects of target configuration on transfer efficiency, two types of targets-door panels and cabinet face frames-were sprayed for each set of equipment and coating type used. The door panels provided a large flat target surface, while the frames offered a more complex shape. The door panels used were standard sized mahogany doors (dimensions 28" x 80", with a thickness of 13/8"). The simulated cabinet face frames were approximately 18" by 30", constructed from 2 l/4" x l/2" hemlock door casings.

For each test, a set of three doors and three face frames for each sprayer were leaned against one side wall of the booth approximately 4-6 inches apart. The targets were then sprayed and set aside to dry until the next coating was to be applied. After the complete finish was applied (stain, sealer, and topcoat), the targets were allowed to dry approximately 12 hours for solvent-based coatings and 4.5 days for the water-borne finishes before mass measurements were taken.

Coating type. The physical properties of each coating type are listed in Appendix A, Table A. 1. Each coating type consisted of a stain, a sealer, and a topcoat. A single brand of stain was used for all tests. Stain usage was measured for the initial tests. However, because the weight of stain used was negligible compared to the weight of the sealer and topcoat, stain usage was found to have no measurable effect on the calculated TE of the total coating system. Therefore, although stain was applied in the remainder of the tests, stain usage was not included in the transfer efficiency determination.

---

[1] Lee, Abigail C. "Compliance Guidance for Autobody Repair and Refinishing Industry Spray Coating Operations," Puget Sound Air Pollution Control Agency, 1991.

The 25 percent solids and 30 percent solids alkyd modified nitrocellulose lacquer are solvent-based coatings which are cured through the normal evaporative process to remove the solvent. This type of coating is generally not available in a low-VOC materia1[2]. Spraying was also conducted with the 30 percent solids sealer combined with a 40 percent solids alkyd/urea conversion varnish for the topcoat. This latter material contains a catalyst which promotes curing through a polymer crosslinking process. Though this type of coating is generally available in high solids (low VOC) content, the shelf life of the final mixed material (catalyst plus varnish) is less than one day, and thus good planning and management is required to avoid wasting material.

The third type of coating investigated is a self-seal acrylic emulsion water-borne lacquer (32 percent solids). While the use of water-borne coatings substantially reduces VOC emissions, these coatings generally require longer drying times compared to solvent-reducible materials, and generally require a heated environment, such as a curing oven. Despite these difficulties, water-borne coatings can be applicable to the wood finishing industry with some procedural modifications.

<u>Spray equipment type</u>. The spraying procedure used was modeled after regular production procedures used in the shop. Complete equipment specifications for the technologies chosen for testing is provided in Appendix A, Table A-2. The equipment tested was selected by spray gun and coating manufacturers representatives participating in the study and are considered to be representative of technology available to small- to mid-sized wood finishing businesses. Although electrostatic application, a highly transfer efficient method of spray coating, is also applicable to the wood finishing industry, this technology was not included in the study as it is not considered to be affordableto this sector of the industry.

The actual guns used in the study were newly purchased. In addition, the guns were used with the tips which were packaged with them, and no attempt to optimize gun performance by using variable tips was made. The guns were intentionally used in this manner to provide a flat comparison of “off-the-shelf’ equipment. The following paragraphs provide a description of the spray guns listed in Table A.2.

Still in wide use today, the conventional air atomizing spray gun was the first tool to be used for spray application of paints and coatings. Conventional equipment uses a high velocity air stream to disperse and propel the coating onto a target in the form of small droplets. Although this system is easy to use, its high air velocity causes paint droplets to dry before reaching the surface and increases paint bounce-back and overspray. This results in excessive overspray fog and low TE.

The high-volume, low-pressure (HVLP) spray gun is defined by the Puget Sound Air Pollution Control Agency (Reg. II, Section 3.04) as a spray application system which uses between 0.1 to 10 psig air pressure for atomization. HVLP guns do not require compressed air, but instead generate high volumes of air with a high-speed turbine. This high volume of air allows atomization of the coating at low air pressure and consequently, decreases the overspray cloud. HVLP guns made by two different manufacturers were used in this study (HVLP-1 and HVLP-2).

The air-assisted airless spray system combines compressed air with hydraulic pressure to atomize the coating material. This combination results in finer droplets of coating than produced by airless spray and also allows for a reduction in hydraulic pressure, providing better operator control. Air-assisted HVLP application is obtained by attaching an HVLP fluid cap to the existing air-assisted configuration, allowing both compressed air and a high volume of air to atomize the fluid material.

The airless spray technology uses high fluid pressure applied by hydraulic pumps to atomize the coating material, rather than using high pressure air or high volumes of air, as with conventional and HVLP systems, respectively. Airless spray application is fast and considered by many to be ideal for large surfaces or heavy viscous coatings. However, this system generally does not produce a high-quality appearance, and it can cause injuries to the operator due to the extremely high fluid pressures used.

---

[2] Joseph, Ron. “Getting into Compliance with Environmental Regulations for Paints, Coatings, and Printing Facilities,” International Coating Seminars, October, 1991, Session 3-180, p.4.

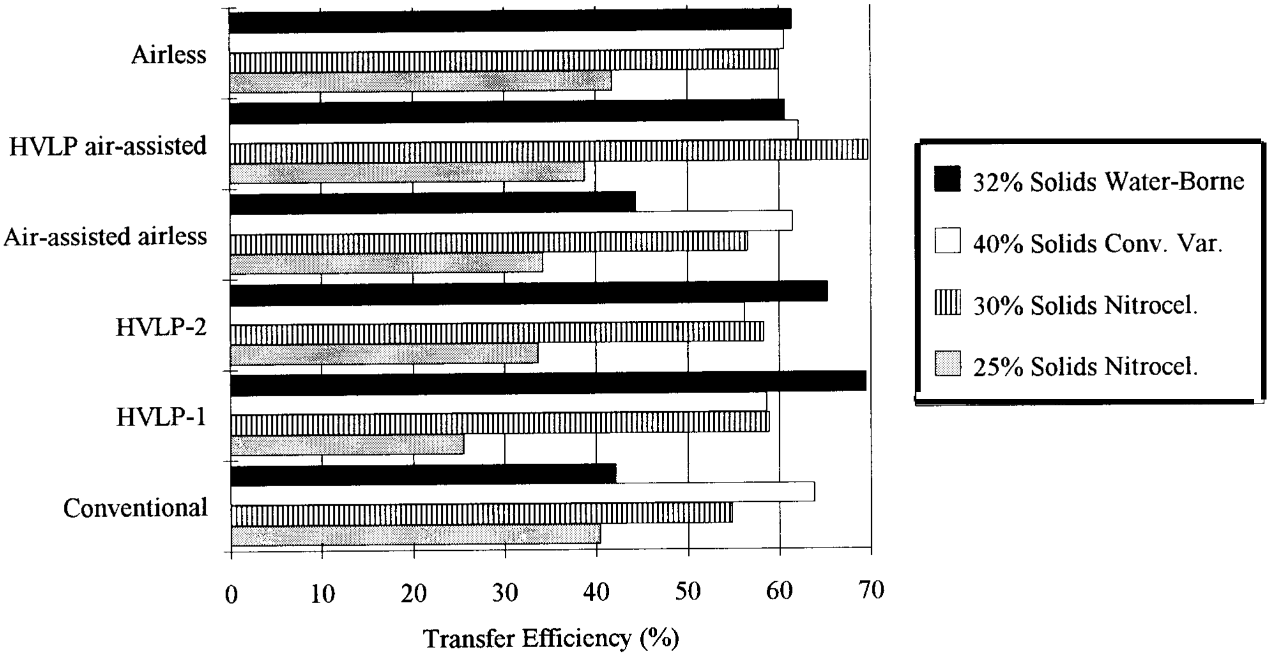
Volume and mass measurement. Several measurements were necessary for the calculation of TE (see Appendix B, Equation B-l), including volume of coating used, mass of solids deposited on the target, weight percent solids, and density of the coating. The latter two measurements were also necessary for calculation of VOC content (see Appendix B, Equations B.2 and B.3). The volume of coating material sprayed was measured using a fluid flow meter in conjunction with a pro-pulse receiver module. The mass of solids deposited on each target was determined by weighing the target before and after the coating system was applied using a Toledo SM30000 precision platform scale (+/- 0.1 gram).

Physical properties measurement. Coating samples were taken at the time of spraying and stored in sealed cans for later analysis in the laboratory. Percent solids, density, and viscosity were measured in a coatings laboratory. Weight percent solids was determined by weighing a designated quantity ofcoating specimen into an aluminum foil dish and heating at 200 degrees F to constant weight (approximately two hours). Density and viscosity measurements were made at the coating temperatures used for spraying using a weight-per-gallon cup and a Zahn #2 cup, respectively.

Results

Transfer efficiency. The transfer efficiency results vary widely. The maximum TE achieved in any of the tests approached 70 percent for the experienced sprayer and 60 percent for the novice sprayer, achieved both in spraying doors with the HVLP air-assisted gun and 30 percent solids coating system, and in spraying doors with the HVLP gun and water-borne system configurations (see Figure 1). The minimum TE achieved was 23 percent for the experienced sprayer when spraying frames with the conventional gun and 30 percent solids system, and 18 percent for the novice spraying frames with the HVLP- 1 gun and 25% solids system. Due to the number of tests performed, it is difficult to determine immediately from these results the influence of individual factors such as gun type or coating on TE. It is most useful to consider each factor separately, as follows.

Figure 1. Transfer efficiency for all equipment types and coating systems (using data from expert painter spraying doors).



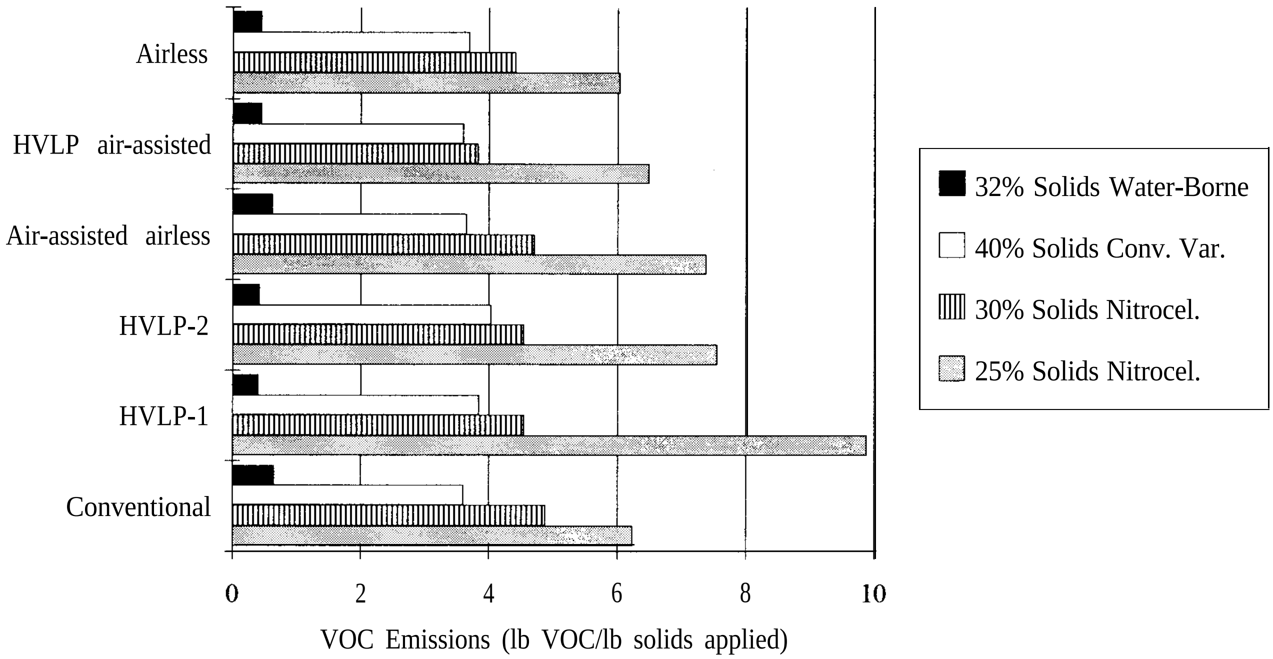
There is much concern and controversy within industry and the regulatory community regarding which spray gun technology gives the highest transfer efficiency. The EPA assumes a TE of 25 percent for conventional airspray, 40 percent for air-assisted airless, and 40 percent for airless spray (for the coating of metal parts). Although there is no universal TE assigned to HVLP, EPA region IX (San Francisco) assumes TE for HVLP to be greater than 65 percent (equivalent to electrostatic spray). Results from this study do not indicate a direct correlation between TE and spray gun type. Although individual guns did vary in TE , no one gun consistently outperformed another with all of the coatings used. In addition, the TE achieved by one gun varied by as much as 50 percent depending on the specific test configuration. Again, it should be noted that the spray equipment was not set up to give the optimum TE (i.e., with variable fluid tips and air caps), but rather were used "off-the-shelf' as received from the manufacturer. Pressures of fluid and air were, however, adjusted at the start of each test to ensure the best performance possible with the existing equipment.

The influence of coating type on TE is shown on the left side of the graphs in Figures 3-6. Although transfer efficiency does appear to be affected by coating type, there is no clear trend regarding the relationship between percent solids and TE.

Effects of target geometry and size on achievable TE are seen by comparing results shown for spraying doors with those for spraying face frames. It is evident from the results that TE achieved for door finishing is consistently higher than that achieved for frame finishing. The difference in transfer efficiency between the two targets varied by as much as 32 percent for the expert sprayer and 29 percent for the novice (both for 30 percent solids coating). As might be expected, the open geometry of the face frames allows much more overspray than does the solid surface of the doors.

Perhaps the most consistent factor seen to exert an influence on transfer efficiency is painter skill level. In 90% of the combinations tested, the expert sprayer achieved higher transfer efficiency than the novice. In fact, the differences in transfer efficiency due to painter skill level with a single gun type were often larger than differences between gun types. It is evident from these results that painter training and experience is a crucial factor in achieving optimal TE performance for spray coating operations.

Figure 2. VOC emissions for all equipment configurations and coating systems (using data from expert painter spraying doors).



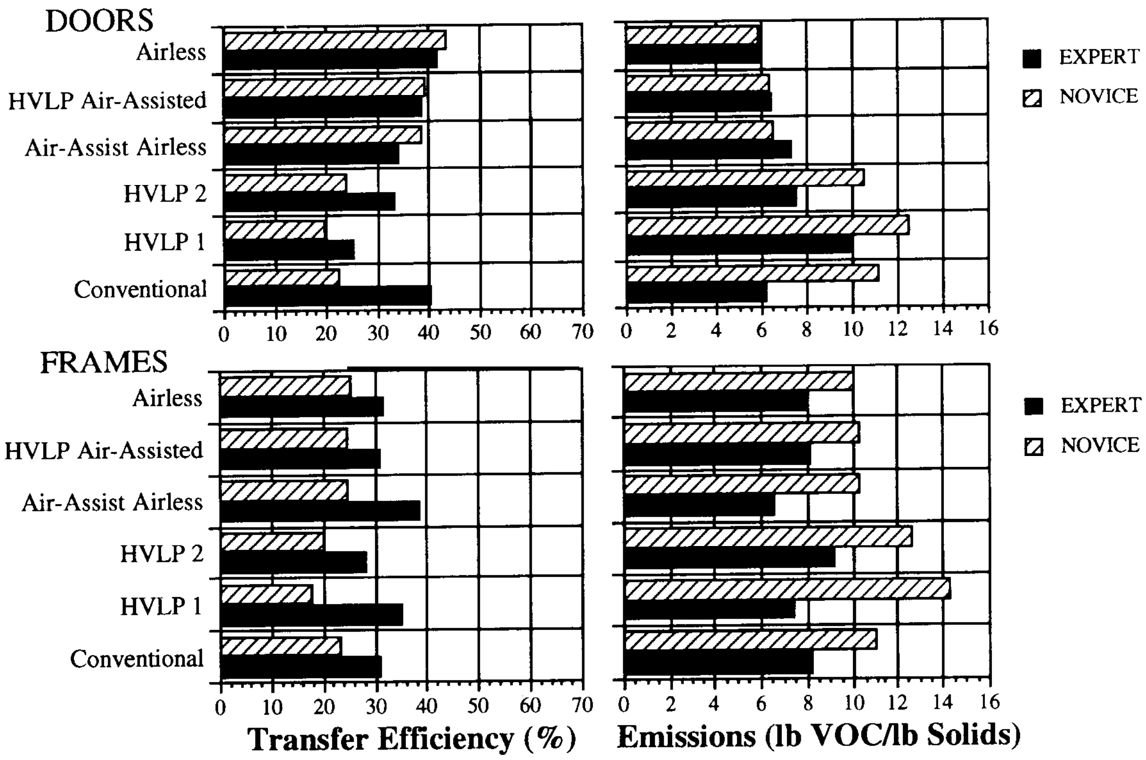


Figure 3. Transfer efficiency and VOC emissions for 25% solids nitrocellulose sealer and topcoat system.

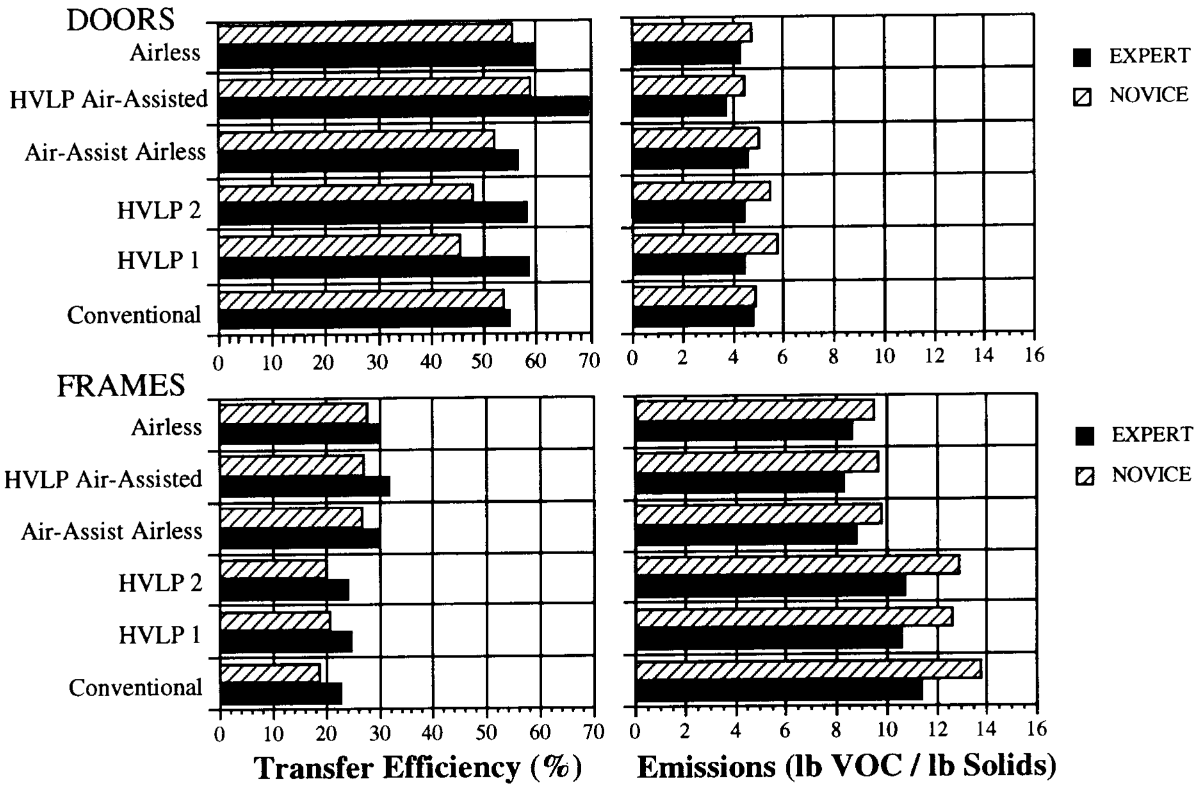


Figure 4. Transfer efficiency and VOC emissions for 30% solids nitrocellulose sealer and topcoat system.

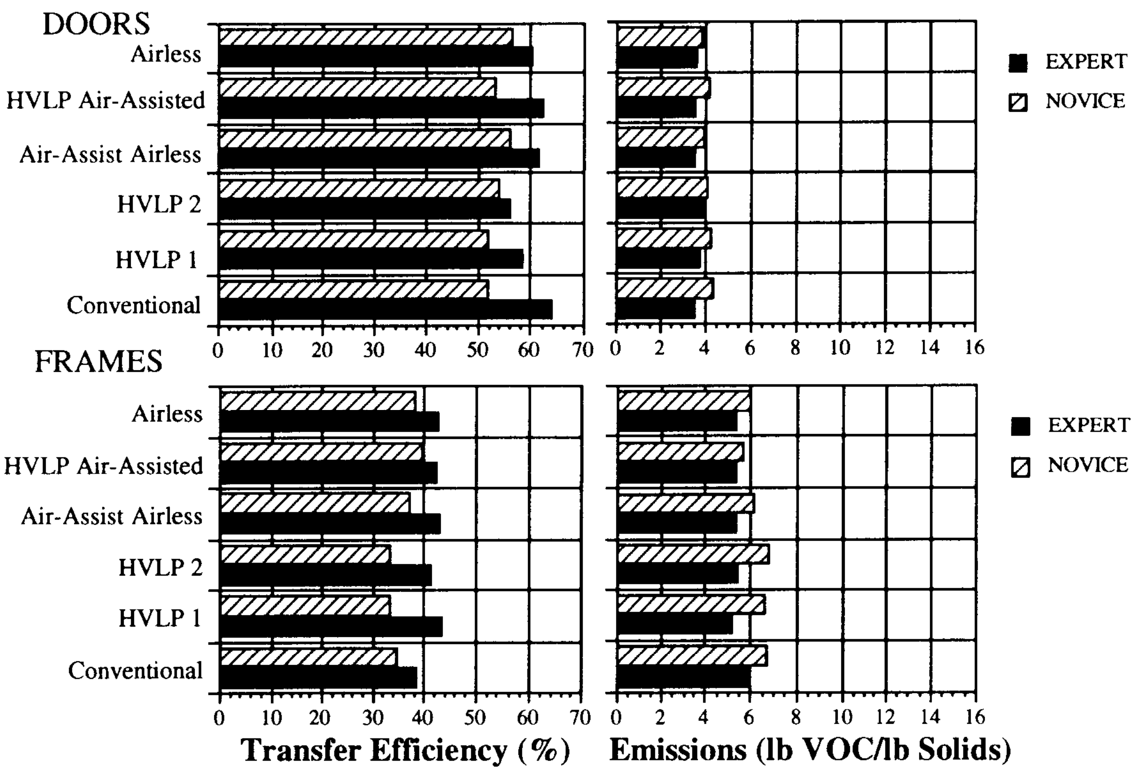


Figure 5. Transfer efficiency and VOC emissions for 30% solids nitrocellulose sealer/40% sol conversion varnish topcoat system.

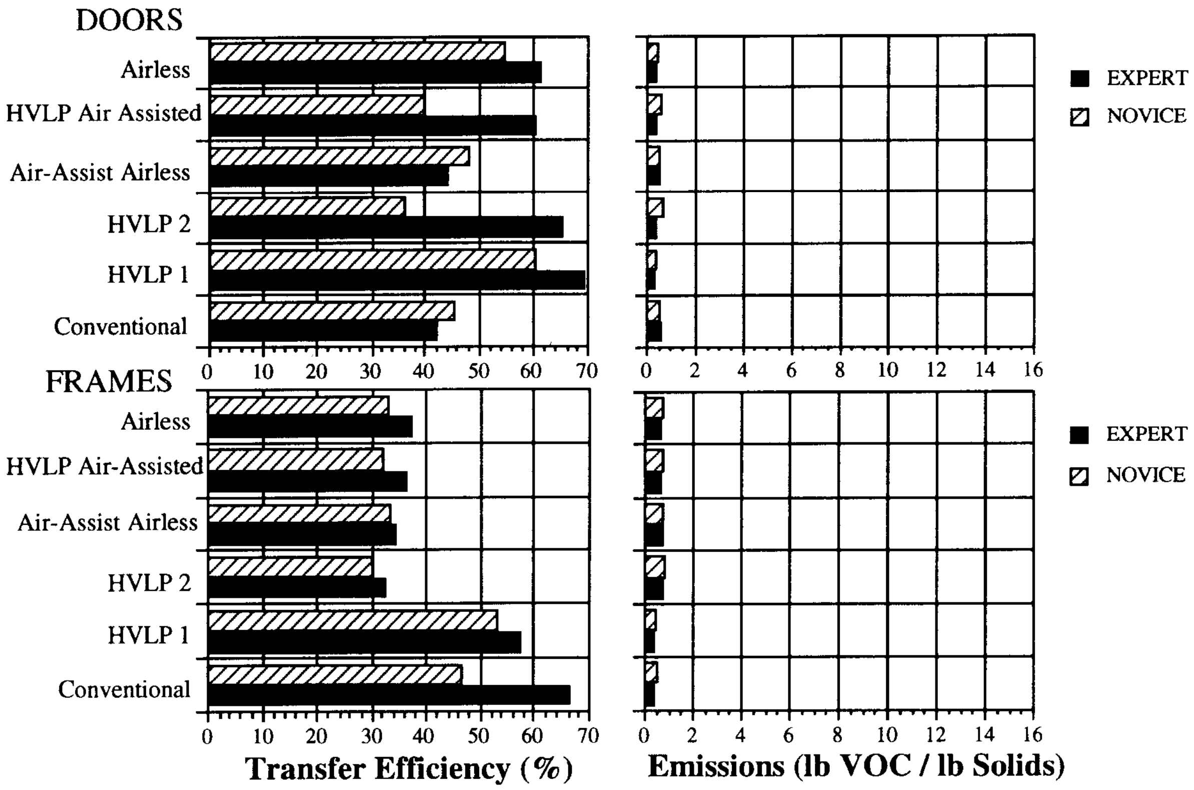


Figure 6. Transfer efficiency and VOC emissions for 32% solids water-borne sealer and topcoat syste

<u>Volatile organic compound (VOC) emissions.</u> A useful parameter for incorporating both the TE and VOC content of a coating application system is emissions (E). Emissions were calculated in this study as lb VOC/lb solids applied to the target (see Appendix B, Equation B.4). The results are presented in graphs on the right side of Figures 3-6. It is important to first notice the inverse relationship between TE and VOC emissions, i.e., with an increase in TE comes a decrease in VOC emissions. For example, spraying frames results in higher VOC emissions and lower TE, and the experienced sprayer consistently achieved lower emissions and higher TE than the novice.

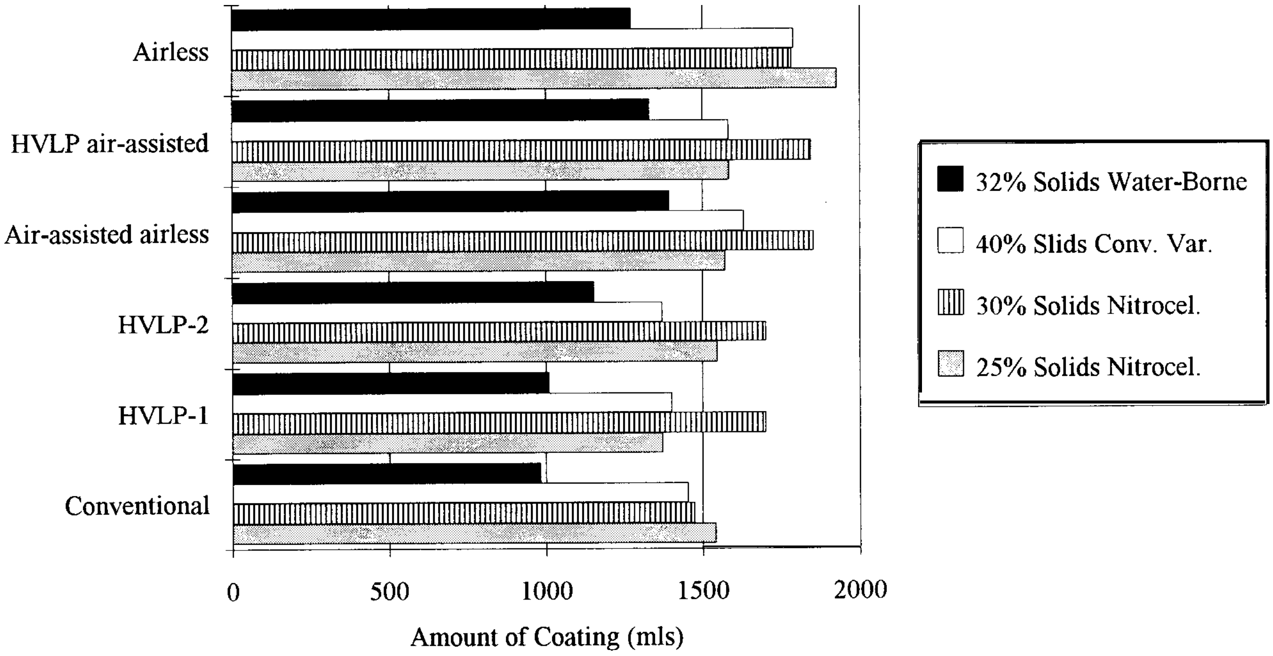
The most significant influence on emissions, however, appears to be the actual VOC content of the coating material. As shown in Figure 2, emissions appear to consistently decrease from the lower solids solvent-borne material to the higher solids material. In addition, tests run with water-borne coating show significantly lower emissions than all of the solvent-borne coatings.

Measurements of the amount of material of each coating type used to perform the spray operation were also taken. The results of these measurements, shown in Figure 7, demonstrate that, for each equipment configuration, the amount of water-borne coating material used was consistently lower than the solvent-based coating types. Obviously, reducing the amount of material used reduces the environmental impact of that material.

<u>Spray time.</u> Although TE and VOC releases are perhaps the most important factors determining environmental performance of a spray painting system, an equally important consideration from an economics standpoint is production rate. If, for example, a particular spray gun technology offers high TE but decreases production, material cost benefits due to increased TE may suffer.

In order to provide insight into the possible effects of gun type on production rate, spray times were measured for each combination of spray gun and coating system. The average results of these times are shown in Figure 8 (for data, see Appendix E). With regard to gun performance, airless application proved to be the quickest application method, while HVLP was the most time consuming. Once again, differences between the experienced and novice spray times clearly show the advantages of using a trained painter.

Figure 7. Coating materials usage by equipment and coating type (using data from expert painter spraying doors).



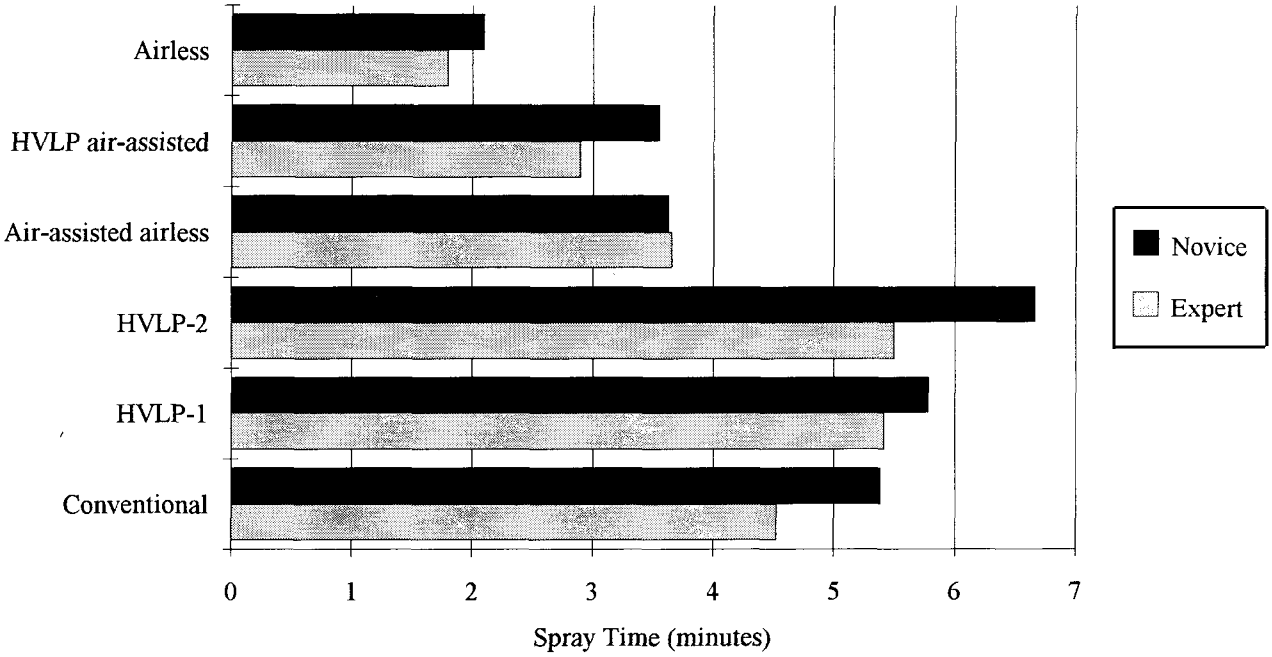


Figure 8. Spray time for expert and novice painters, with all equipment types (using average data from all coating systems, spraying doors).

Conclusions

Solid conclusions regarding the effects of gun type on transfer efficiency or VOC emissions are difficult to draw from the data. However, a few important points regarding environmental effects in wood finishing operations are clear:

Waterborne coatings hold the greatest long-term potential for VOC reductions in wood finishing Although water-borne coatings can cause complications in wood finishing operations, their use is highly advantageous from an air quality standpoint. As this study demonstrates, water-borne coatings provide significantly less VOC emissions as well as reduced materials usage, irrespective of spray equipment used. Operators are urged to request information on the latest in water-based materials from their vendors. (If water-borne coatings are not applicable, solvent-borne coatings with higher solids also offer potential reductions in VOC emissions.)

Painter skill level has a strong influence on achievable TE, VOC emissions. and spray time. This element of the system is a direct and simple measure for improving environmental performance. Training, both introductory and on-going, should include spray techniques, coating content, equipment set-up, and optimization (i.e., knowledge of the optimum fluid tip and/or air tip for any given configuration).

Several factors work as a system to affect environmentalperformance. These include painter skill level, spray equipment type, and coating type, as well as uncontrollable factors, such as the geometry and size of the target. Solutions should be situation-specific, and all of the factors discussed above should be adjusted to optimize performance.

Appendix A
Material and Equipment Specifications

Table A. 1. Physical Properties of Coatings

Coating	Weight (% solids)	VOC (lb/gal)	Density (lb/gal)	Viscosity (Zahn, #2)
Sealer (25% solids)	26.07	5.73	7.74	33
Topcoat (25% solids)	29.72	5.36	7.62	45
Sealer (30% solids)	25.81	5.67	7.62	37
Topcoat (30% solids)	28.07	5.52	7.67	28
Conv. Varnish (40% solids)	35.79	5.17	8.06	33
Water-Borne (32% solids)	30.86	1.76	8.24	30

Table A.2. Spray Equipment Specifications

Gun Type	Conventional Airspray	HVLP-1	HVLP-2	Air-Assisted Airless	HVLP Air-Assisted	Airless
Manufacturer	Binks	Devilbiss	Accuspray	Graco	Graco	Graco
Model No.	2001	JGHV-530	#10	AA2000	AA2000	Silver
Serial No.	------	-----	3610155	------	------	-----
Air Cap	63PB	#28	#11	(standard)	222608	-----
Fluid Tip	63B	0.0425 inch	0.051 inch	215/417*	215/417*	415/417*
Needle	563A	JGA402FX	0.051 inch	(standard)	(standard)	(standard)

* First number represents fluid tip used for spraying face framses; second number is the tip used for doors

In addition to the spray guns and coatings described above, other equipment was needed to perform the tests. Pumps were used with the air-assisted airless and airless configurations (Graco, Model 10: 1 Monark with l/4 inch fluid and 3/8 inch air hoses and Model 30:1 president with l/4 inch fluid hose, respectively). The fluid flow meter (Graco, CSA & FM approved; Class 1, Division 1, Model 224-222, Series F91A, Serial #C148) was used with a 200 mAmp power generator and a ,pro-pulse receiver module. The fluid pressure pot (5 gallon ASME) included 1.4 inch fluid line and a 5/16 inch air line. Fluid temperature was measured with a thermometer (VWR Scientific Inc., 61014-020).

Appendix B
Calculations

Transfer Efficiency. Transfer efficiency was determined on a mass basis using guidelines from ASTM Method D5009-89:

Equation B. 1 $TE = (100\ x\ P)\ x\ 100 / (F\ x\ d\ x\ S)$
where:
TE = transfer efficiency (%)
P = mass of coating solids deposited on target (g)
F = volume of fluid delivered (ml)
d = density of coating (g/ml)
S = wt% solids of coating

Volatile Organic Compound (VOC) Content. VOC content was calculated using guidelines from ASTM Method D3960-90:

For solvent-borne coatings,

Equation B. 2: $V = (100 - (S + X))\ x\ d\ x\ 10$
where
V_s = total VOC content (g/l) (organic volatiles)
S = wt% solids of coating
X = wt% exempt solvent of coating
d = density of coating (g/ml)

For water-borne coatings,

Equation B. 3: $V_{nw}=(V_w x\ \ 100xdW)/(100-(dxW))$
where
V_{nw} = total VOC content (g/l), based on coating excluding water
V_w = total VOC content (g/l), determined from calculation B.2
d_w = 0.997 g/ml (density of water at 25°C)
d = density of coating (g/ml)
W = wt% water of coating

Coating density (d) and percent solids (S) were determined in the laboratory (see Appendix A, Table A. l), while water content (W) was taken from manufacturers' coating specifications.

VOC Emissions. Emissions for each sealer + topcoat system were calculated with variables used in the above equations (assumes 100% of VOC content in coating material is dispersed into air):

Equation B. 4: $E = [(V_{ss}\ x\ VOL_s) + (V_{st}\ x\ VOL_t)] / P$
where
E = VOC emissions for sealer + topcoat (g VOC/g solids applied)
V_{ss} = VOC content of sealer (g/l)
V_{st} = VOC content of topcoat (g/l)
VOL_s = total volume of sealer used to finish target (1)
VOL_t = total volume of topcoat used to finish target (1)
P = mass of coating solids deposited on target (g).

Appendix C
Transfer Efficiency Data

Transfer Efficiency (%)

	25% Solids Nitrocellulose Coating		30% Solids Nitrocellulose Coating		40% Solids Conversion Varnish Coating		32% Solids Water-Borne Coating	
	Door	Frame	Door	Frame	Door	Frame	Door	Frame
Conventional Airspray								
Expert	40.47	31.19	54.90	23.14	63.91	38.85	42.21	66.45
Novice	22.63	23.66	54.04	19.17	52.16	35.16	45.74	46.80
HVLP- 1								
Expert	25.59	35.40	58.96	25.02	58.67	43.59	69.54	57.90
Novice	20.12	18.01	45.99	21.16	52.04	33.64	60.47	53.64
HVLP-2								
Expert	33.72	28.45	58.41	24.54	56.27	41.72	65.36	33.03
Novice	24.22	20.51	48.30	20.42	54.23	33.62	36.56	30.31
Air-Assisted Airless								
Expert	34.29	38.76	56.67	30.16	61.59	43.37	44.38	34.69
Novice	38.78	24.93	52.16	27.24	56.43	37.61	48.40	33.72
HVLP Air-Assisted								
Expert	38.89	31.21	69.77	32.28	62.17	42.68	60.70	36.58
Novice	39.49	25.01	59.02	27.49	53.43	40.07	40.38	32.70
Airless								
Expert	41.90	31.71	60.10	30.24	60.65	42.92	61.53	37.89
Novice	43.61	25.80	55.71	28.08	56.64	38.37	54.93	33.25

Appendix D
VOC Emissions Data

VOC Emissions (lb VOC/lb solids applied)

	25% Solids Nitrocellulose Coating		30% Solids Nitrocellulose Coating		40% Solids Conversion Varnish Coating		32% Solids Water-Borne Coating	
	Door	Frame	Door	Frame	Door	Frame	Door	Frame
Conventional Airspray								
Expert	6.24	8.29	4.88	11.49	3.61	5.94	0.65	0.42
Novice	11.2	11.04	4.98	13.82	4.39	6.79	0.60	0.59
HVLP- 1								
Expert	9.89	7.46	4.55	10.67	3.85	5.23	0.40	0.48
Novice	12.55	14.36	5.86	12.68	4.35	6.68	0.46	0.51
HVLP-2								
Expert	7.56	9.20	4.55	10.81	4.04	5.49	0.42	0.84
Novice	10.52	12.75	5.76	12.98	4.17	6.88	0.75	0.91
Air-Assisted Airless								
Expert	7.39	6.62	4.71	8.84	3.65	5.41	0.62	0.80
Novice	6.58	10.31	5.15	9.84	3.99	6.22	0.57	0.82
HVLP Air-Assisted								
Expert	6.50	8.21	3.83	8.33	3.60	5.41	0.45	0.75
Novice	6.40	10.29	4.55	9.70	4.24	5.75	0.68	0.84
Airless								
Expert	6.04	8.12	4.42	8.74	3.70	5.43	0.45	0.73
Novice	5.89	10.03	4.84	9.58	3.93	6.08	0.50	0.83

Appendix E
Spray Time Data

Spray Time (minutes)

	25% Solids Nitrocellulose Coating		30% Solids Nitrocellulose Coating		40% Solids Conversion Varnish Coating		32% Solids Water-Borne Coating	
	Door	Frame	Door	Frame	Door	Frame	Door	Frame
Conventional Airspray								
Expert	3.82	1.47	5.45	0.93	4.57	0.87	4.28	0.80
Novice	4.87	1.70	6.48	1.10	5.27	0.92	4.95	0.97
HVLP-1								
Expert	4.13	0.83	6.25	1.00	5.68	0.98	5.63	1.00
Novice	4.45	1.00	5.75	1.18	7.17	1.15	x	1.15
HVLP-2								
Expert	4.57	0.90	6.27	1.00	6.30	1.02	4.87	0.85
Novice	5.9	1.05	7.73	1.20	8.12	1.18	4.93	1.00
Air-Assisted Airless								
Expert	6.17	0.67	3.20	0.82	2.83	0.80	2.43	0.73
Novice	4.00	0.97	3.75	0.98	3.83	0.95	2.92	0.88
HVLP Air-Assisted								
Expert	3.20	0.87	3.28	0.75	2.77	0.73	2.37	0.72
Novice	3.83	0.93	3.83	0.98	3.63	0.82	2.90	0.82
Airless								
Expert	2.02	0.68	1.80	0.65	1.78	0.60	1.63	0.50
Novice	2.62	0.87	1.60	0.75	2.27	0.65	1.93	0.68

Appendix F
Participants and Recommended Reading

This study was a joint project carried out with contributions from the Pacific Northwest Pollution Prevention Research Center, Tiz's Doors wood finishing company, and several equipment manufacturers: Air-Tech, Akzo Reliance, Dickenson Equipment , and Guardsman Products. These and other key participants are listed below:

Greg Tisdel
Tiz's Door Sales, Inc.
P.O. Box 1078
Everett, WA 98206

Chuck Gillette
Air-Tech
5055 4th Ave. S.
Seattle, WA 98134

Les Sanders and Lyn Daunheimer
Akzo Reliance
1660 Cross St. S.E.
P.O. Box 12336
Salem, OR 97309

Rick Smith
Dickenson Equipment
120 NW 36th
Seattle, WA 98107

John Duignan and Brent Miller
Guardsman Products, Inc.
13535 Monster Road S
Seattle, WA 98178

Lesley Snowden-Swan
Battelle-Pacific Northwest
Laboratory
PO Box 999, P8-48
Richland, WA 99352

Scott Butner
Battelle-Pacific Northwest
Laboratory
PO Box 999, P8-48
Richland. WA 99352

Abigail Lee
Puget Sound Air Pollution Control
Agency
110 Union Street, Suite 500
Seattle, WA 98101

Chuck Darvin
U.S. EPA
Air and Energy Engineering
Research Laboratory
Research Triangle Park, NC

Claus Staalner
675 Progress Center Ave NE,
Suite A
Lawrenceville, GA 30243

Bob Stone
Washington State Department of
Ecology
Northwest Regional Office
3190 160th Avenue SE
Bellevue, WA 98008-5452

Madeline Grulich, Dara O'Rourke
Pacific Northwest Pollution
Prevention Research Center
1218 Third Ave, Suite 105
Seattle, WA 98101

The following are some further readings on this topic:

Allison, Melissa, Teresa Summers, and Cathy Troutman. *Final Report for High Volume/Low Pressure Spray Gun Evaluation.* Thomson Crown Wood Products. Mocksville, NC: 1992.

Dambek, Paul J., Kevin D. Kelly, Joshua M. Heltzer, Maria L'Annunziata, and Thomas M. Smith. *A Guide to Pollution Prevention for Wood Furniture Finishing.* Prepared for US EPA Region I, Capstone Project, Tufts University. Medford, MA: 1992.

EPA Guides to Pollution Prevention: The Paint Manufacturing Industry. US EPA Risk Reduction Engineering Laboratory, Center for Environmental Research Information, EPA/625/7-90/005. Cincinnati, OH: June, 1990.

Evaluation of High Volume/Low Pressure Spray Coating Equipment. Hackney & Sons, Inc. Washington, NC: 1990.

Kennedy, K.C. *US EPA Research & Development: Transfer Efficiency of Improperly Maintained or Operated Spray Painting Equipment, Sensitivity Studies.* US EPA Air & Engineering Research Laboratory, EPA-600/2-85-107. Research Triangle Park, NC: Sept, 1985.

Randall, Paul M. "Pollution prevention methods in the surface coating industry." *Journal of Hazardous Materials, 29* (1992), pp. 275-295. Amsterdam: Elsevier Science Publishers B.V., 1992.