American Industrial Hygiene Association Journal
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/aiha20

A Comparison of Conventional and High Volume-Low Pressure Spray-Painting Guns

William A. Heitbrink [a], Robert H. Verb [b], Thomas J. Fischbach [a] & Marjorie E. Wallace [a]

[a] U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Division of Physical Sciences and Engineering, 4676 Columbia Parkway, Mailstop R5, Cincinnati, OH 45226

[b] DeVilbiss Automotive Refinishing Products, 1724 Indian Wood Circle, Suite G, Maumee, OH 43537-4051

Published online: 04 Jun 2010.

To cite this article: William A. Heitbrink, Robert H. Verb, Thomas J. Fischbach & Marjorie E. Wallace (1996) A Comparison of Conventional and High Volume-Low Pressure Spray-Painting Guns, American Industrial Hygiene Association Journal, 57:3, 304-310, DOI: 10.1080/15428119691015043

To link to this article: http://dx.doi.org/10.1080/15428119691015043

APPLIED STUDIES

A Comparison of Conventional and High Volume-Low Pressure Spray-Painting Guns

AUTHORS
William A. Heitbrink[a]
Robert H. Verb[b]
Thomas J. Fischbach[a]
Marjorie E. Wallace[a]

[a]U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Division of Physical Sciences and Engineering, 4676 Columbia Parkway, Mailstop R5, Cincinnati, OH 45226;
[b]DeVilbiss Automotive Refinishing Products, 1724 Indian Wood Circle, Suite G, Maumee, OH 43537–4051

The effect of spray-painting gun choice, high volume-low pressure (HVLP) or conventional, on solvent and particulate overspray concentrations was experimentally studied in a downdraft spray-painting booth. This experiment was conducted by repeatedly applying two coats of paint to a car body shell. The two spray-painting guns were a gravity-fed conventional and a gravity-fed HVLP gun. During each experimental run, particulate overspray concentrations, solvent vapor concentrations, film thickness on the autobody, and mass of paint were measured. The film thickness per mass of paint for the HVLP gun was 33% higher than that for the conventional spray-painting gun. This difference was statistically significant ($p = 0.0015$). Apparently, the HVLP spray-painting gun had a much higher transfer efficiency than the conventional spray-painting gun. Also, the particulate overspray concentration per unit of film thickness for the conventional spray-painting gun was twice that of the HVLP gun. Again, this difference was statistically significant ($p = 0.0009$). Finally, the HVLP spray-painting gun reduced the overall solvent vapor concentrations measured in the booth by 21%, which was not statistically significant. However, solvent vapor exposures measured on the worker were reduced by a factor of 2 when using the HVLP gun. This difference was statistically significant ($p = 0.02$).

Keywords: efficiency, film thickness, paint overspray, particulate exposure, solvent exposures, spray-painting

During autobody repainting operations, spray-painting guns are used that can be classified as either conventional or high volume-low pressure (HVLP). In conventional spray-painting guns, compressed air is accelerated through a nozzle, where a reduction in static pressure occurs. The reduced static pressure causes the paint to flow from a cup into an orifice where the atomization occurs. When this cup is below the atomization nozzle, air pressure at the gun cap is typically 450 kPa (65 psig). These guns are termed "suction" or "siphon cup" spray-painting guns. When this cup is above the atomization nozzle, the flow of paint is augmented by gravity, and such guns are commonly called "gravity-fed" spray-painting guns. In HVLP spray-painting guns, paint is atomized with air pressures of less than 69 kPa (10 psig) at this orifice. The cups of some HVLP guns are above the atomization nozzle, and gravity assists the flow of the paint into the atomization orifice. In other cases the cup is below the atomization nozzle, and a controlled air pressure is used to meter the flow of paint into the orifice where atomization occurs.

Reportedly, HVLP spray-painting guns are much more efficient at transferring the paint from the gun to the car than conventional spray-painting guns. HVLP guns are believed to have a transfer efficiency of at least 65%, while conventional spray-painting guns are commonly reported to have a transfer efficiency of 20 to 40%.[1–3] As a result, some air pollution control districts require spray-painting equipment to have a transfer efficiency of at least 65%.[4] If HVLP spray-painting guns have a

Presented at the American Industrial Hygiene Conference and Exposition, Kansas City, Mo., May 1995.

Mention of company names or products does not constitute endorsement by the Centers for Disease Control and Prevention.

transfer efficiency of 65%, most of the paint becomes a surface coating instead of a potentially harmful overspray. Overspray is the paint mist that does not coat the surface being painted. If conventional spray-painting guns have a transfer efficiency of only 20 to 40%, most of the paint becomes an overspray that may contaminate the air in the worker's breathing zone. Furthermore, this lower transfer efficiency increases the amount of paint needed to obtain the same paint film thickness. Thus, switching from a conventional to an HVLP spray-painting gun should reduce paint usage and worker exposure to paint overspray.

The regulatory and commercial literature indicates that substituting HVLP spray-painting guns for conventional spray-painting guns should reduce the paint overspray generation.[1,4] However, there is little scientific literature to indicate whether the claimed improvements in transfer efficiency actually occur. One experimental study conducted in the wood finishing industry indicates that HVLP spray-painting guns do not have a higher transfer efficiency than other types of spray-painting guns.[5] This suggests a need to evaluate whether HVLP spray-painting guns can actually reduce worker exposure to paint overspray.

THEORETICAL CONSIDERATIONS

The following analysis explores the relationship between transfer efficiency and air contaminant concentrations in some perfectly mixed volume. Transfer efficiency, η, can be defined as the fraction of paint solids that coats the surface being painted:

$$\eta = \frac{m}{M} \quad (1)$$

where M = mass of paint solids used, and m = mass of paint solids deposited on the car.

The ventilation rate (Q), the mass of paint solids used (M), the transfer efficiency (η), and the time (t) required to do the painting can be used to compute the expected concentration, C_p, of paint solids in the air.

$$C_p = \frac{M(1-\eta)}{Qt} \quad (2)$$

This equation assumes that the particulate overspray is being perfectly mixed in some volume. During a painting operation a specified thickness or mass of paint must be put on the surface that is being painted. To see more clearly the effect of transfer efficiency on the particulate overspray concentration, M is replaced by m/η to obtain this equation:

$$C_p = \frac{m}{Qt}\left(\frac{1-\eta}{\eta}\right) \quad (3)$$

In a well-mixed room all of the solvent evaporates, and the relationship between solvent concentration, C_s, and paint application rate can be stated:

$$C_s = \frac{km}{Qt\eta} \quad (4)$$

where k = the mass ratio of carrier solvents to paint solids.

To illustrate the effect of transfer efficiency on concentration clearly, Equations 3 and 4 can be rearranged to express the relationship between transfer efficiency and a dimensionless particulate concentration (C_{dp}) and a dimensionless solvent concentration (C_{ds}):

$$C_{dp} = \frac{C_pQt}{m} = \frac{(1-\eta)}{\eta} \quad (5)$$

$$C_{ds} = \frac{C_sQt}{km} = \frac{1}{\eta} \quad (6)$$

In Figure 1 dimensionless particulate and solvent concentrations are plotted as a function of transfer efficiency. Increasing transfer efficiency from 0.4 to 0.65 reduces the particulate overspray concentrations by a factor of 2.8 and solvent concentrations exposure by a factor of 1.6.

Improved transfer efficiency has a greater effect on particulate overspray concentrations than on solvent concentrations. This occurs because increased efficiency reduces paint usage and the amount of paint overspray generated per mass of paint sprayed. Particulate overspray emissions are greatly reduced and eliminated as η approaches 1. In contrast, increased efficiency reduces only the amount of carrier solvents sprayed. All of the paint's carrier solvents evaporate from either the car's surface or the paint overspray particles.

EXPERIMENTAL PROCEDURES

For conditions that reflect realistic conditions in the autobody repair industry, this experiment evaluated whether choice of spray-painting gun affects air contaminant concentrations and the film thickness per mass of paint applied. The testing was conducted by repeatedly painting a car body shell. Car bodies have curved surfaces and edges. During routine painting in autobody repair shops, as in this testing, some paint will be sprayed into the air when the edges of the car are painted and when the shape of the spray pattern is adjusted at the start of a painting job. Adjusting the spray patterns requires a few seconds.

This experiment involved 16 experimental runs. For each run, air contaminant concentration, mass of paint used, painting time, and paint film thickness were measured. During each run the painter applied two coats of a white base coat (Chromabase, DuPont, Wilmington, Del.) to a car body shell (Pontiac Grand Am), simulating a complete paint job in an autobody shop. During the data analysis,

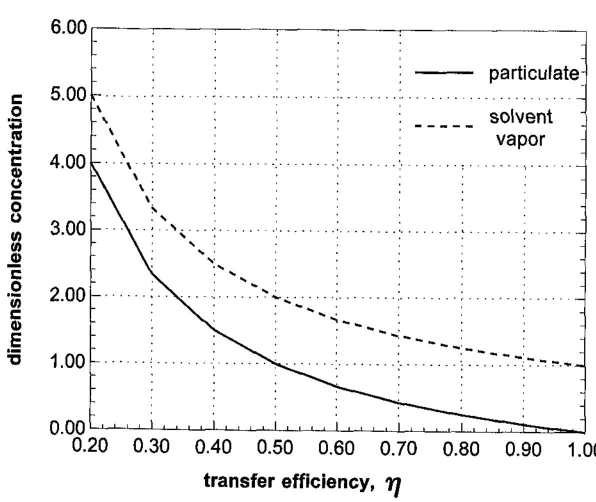

FIGURE 1. Effect of transfer efficiency on particulate overspray and solvent vapor concentrations assuming perfect mixing in a spray-painting booth

these two tints were treated as separate paints. To allow the paint to be removed at the end of the test, the car body shell was coated with a polyethylene film prior to the experiment. After each run the painter switched between two tints of a white base coat so that there was enough contrast to see the freshly applied paint. At the start of the even-numbered runs, the painter switched between a conventional gravity-fed spray-painting gun (model GFG-504–43-FF, DeVilbiss, Toledo, Ohio), and an HVLP gravity-fed spray-painting gun (model GFHV-501–57-DFW). This allowed each spray-painting gun to be used four times with each paint.

Air Contaminant Concentration Monitoring

Particulate overspray concentrations were measured as total dust concentrations using National Institute for Occupational Safety and Health (NIOSH) Method 0500.[6] Samples were collected on preweighed PVC filters at a flow rate of 5.0 L/min using personal sampling pumps (Aircheck Sampler, model 224–PCXR7, SKC Inc., Eighty Four, Pa). These pumps automatically terminate sampling when the flow rate drops by more than 5%. The time to apply the two paint coats was about 15 minutes. Therefore, the specified flow rate of 1–2 L/min specified in the method was increased to 5 L/min to collect a measurable mass of material on the filters. The weight gain of the filter was used to compute the milligrams of particulate overspray per cubic meter of air.

Filter samples were taken at four locations: on the worker, along the wall on the left side of booth, under the car door on the left side of the booth, and under the car door on the right side of the booth. All the filter samples were taken closed-face except that both an open-faced and a closed-faced sample were taken on the worker. The closed-face sample had an inlet diameter of 4 mm. The open-faced cassette, with the face cap removed, had an inlet diameter of 33 mm.

The comparison between open- and closed-faced filters was made to assess whether particulate concentrations might be affected by inlet conditions. As inlet sampling velocity of these samplers increases and particle size increases, the efficiency of the sampling inlet can decrease.[7,8] For particles with an aerodynamic diameter of 9 and 24 μm, sampling efficiencies of 62 and 9%, respectively, were reported when air samples were collected in closed-faced cassettes sampling at 2 L/min at an orientation of 90° with respect to an airflow of 60 m/min (180 ft/min).[9] The particle's inertia can prevent larger particles from following the fluid streamlines into the sampling cassette. These inertial losses could be minimized by using relatively large openings such as an open-faced cassette. However, the area samples were taken in a closed-faced cassette to protect the filter from paint spray blown directly into it. Because the sampling conditions were the same for both of the spray-painting guns, these area sampling results are useful as relative measures of total particulate concentration.

Air samples for solvent vapors were taken by placing charcoal tubes (SKC 100/50 mg, lot 120) in holders and using personal sampler pumps (model 200, DuPont Inc.) to draw air through the charcoal tubes at 200 cm^3/min. Bulk samples of the two paints used in this study were analyzed by gas chromatography and mass spectroscopy (GC/MS). Four solvents that had relatively large peaks during GC/MS were selected as analytes for the charcoal tube samples. The amount of toluene, xylene isomers, n-butyl acetate, and ethyl acetate on the charcoal tubes was quantitated using NIOSH Methods 1450 and 1501.[10] The concentrations of the four solvents were summed to compute a combined solvent concentration in terms of mg/m^3.

Charcoal tube samples were collected at the same sampling locations as the filters. However, two samples were taken under the left car door. One sample was a charcoal tube in a charcoal tube holder, the other a charcoal tube preceded by a 13-mm glass fiber filter (filter E133AG, Millipore, Bedford, Mass.). The filter was in a holder (part SX 00013000, Millipore) with an inlet diameter of 4 mm. This second sample was taken to evaluate whether the paint aerosol, which contained solvent, was penetrating the charcoal tubes.[11] The filter would provide a substrate to collect and evaporate the solvent.

Air samples for total particulate and solvent concentrations were taken at a variety of locations in the booth to assess whether the spray-painting guns affected the particulate and solvent emissions as well as the painter's exposure to paint overspray. The airflow patterns in a downdraft booth separate the worker from the paint overspray.[12] Quite possibly, the worker's exposure might be unaffected by the gun's transfer efficiency. The observed airflow patterns in the booth were such that much of the paint overspray flowed around the car and into the exhaust filters without entering the worker's breathing zone. Thus, air samples were taken in front of the exhaust filters to assess whether the spray-painting guns were affecting the generation of paint overspray.

Paint Film Thickness Measurements

Paint film thickness was measured at the car trunk, hood, roof, left door, and right door. At each location a strip of 302 stainless steel shim stock, 40 to 45 cm long, 3.75 cm wide, and 0.007 ±0.001 cm thick, was taped to the car body surface. After the experimental run was completed, the metal strip was removed and hung to dry. The paint film thicknesses were then measured with a Fischerscope Multi 650 (Helmut Fischer GMBH+CO, Sindelfingen, Germany). The instrument's magnetic probe (type GA 1.3) was placed on the surface of each metal test strip. In the probe a magnetic field was generated by sending an electrical current through an excitation coil. The paint film thickness affected the magnitude of the magnetic field. Changes in the magnetic field generated changes in an electrical current in a second electrical coil.[13] These changes in electrical current are related to film thickness through a calibration curve. The instrument was calibrated by placing films of known thickness on the metal test strip.

Paint Mass

The mass of paint used was obtained by pre- and post-weighing the spray gun on a balance (model GT 4000, Ohaus). The weight change was the amount of solid and liquid paint used.

Spray-Painting Booth Description

The autobody shell was painted in a modified DeVilbiss Concept II Downdraft Booth (Figure 2). To simulate a poorly operated spray-painting booth, the flow rates through the booth were deliberately reduced to produce measurable particulate overspray concentrations. In addition, this booth had a single exhaust trench covered by a metal grate (0.76 m × 7.3 m) in the floor instead of two exhaust trenches near the left and right sides of the car. The booth had a length of 7.3 m (24 ft), and it used two fans. One fan supplied air to the plenum above the filters in the ceiling. The ceiling filters measured 0.41 m × 1.1 m (16 in. × 46 in.) and were contained in 0.46 m × 1.22 m (18 in. × 48 in.) frames. The other fan exhausted air from the booth through the trench that ran the full length of the booth.

Ventilation Measurements

Ventilation measurements were made to document the booth's performance. An equal area, 36-point pitot tube traverse was made to measure the airflow into the spray-painting booth. The

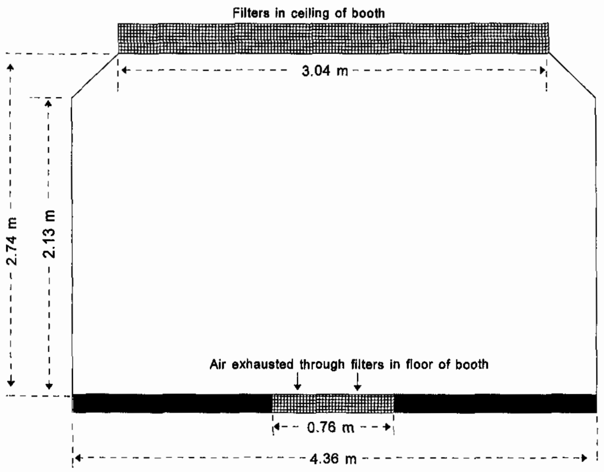

FIGURE 2. Cross-sectional view of the spray-painting booth. Instead of the normal two exhaust trenches, this booth has a single exhaust trench.

average air velocity coming out of the ceiling filters was measured with a Balometer® (Alnor, Niles, Ill.). The Balometer was held flush with the filters while the airflow through a 0.61 m × 0.61 m (2 ft × 2 ft) section was recorded. These measurements were used to compute an average inlet velocity and an inlet airflow rate. A velometer (model 1440, Kurz, Carmel, Calif.) was used to measure air velocities around the car body shell at a height of 0.9 m (3 ft) from the booth's floor and a horizonal distance of 0.3 m (12 in.) and 0.45 m (18 in.) from the car body shell. Smoke tubes and helium-filled bubbles from a generator (model 33, Sage Action, Ithaca, N.Y.) were used to trace airflow patterns in the booth.

RESULTS AND FINDINGS

Booth Characterization

Figure 3 summarizes ventilation measurements and observations about the airflow pattern in the booth. The pitot tube traverse in the supply air duct and the Balometer measurements in the ceiling resulted in measured airflows of 153 and 201 m^3/min (5400 and 7100 ft^3/min), respectively. The observed differences probably reflect experimental imprecision caused by measuring velocity pressures between 0 and 20 pascals (0.0 to 0.08 inches of water). The flow rate reported here was consistent with flow rates measured at some inadequately maintained spray-painting booths.[12] Based on these two measurements, the downward air velocity from the ceiling was between 6.7 and 8.8 m/min (22–29 ft/min). Airflow patterns were studied with a car in the booth. As the air flowed around the car, the airflow accelerated to 9.1–21 m/min (30–70 ft/min). Smoke and helium-filled bubbles released above the car stayed within 0.3–0.6 m (1–2 ft) of the car and exited the booth through the floor trench.

Effect of Spray-Painting Gun on Dependent Variables

To ferret out the differences in the dependent variables attributed solely to the spray-painting guns, the data analysis had to address the inconsistent paint usage. The painter did not tightly control the mass of paint used during each experimental run. He simply painted the car body so that the finish, in his professional opinion, looked good. As a result, different masses of paint were used, affecting film thicknesses and air contaminant concentrations.

To remove these mass-related effects, film thickness and air contaminant concentration data were normalized. The average film thickness during each run was divided by the mass of paint used. This quotient is directly proportional to the transfer efficiency because the average film thickness is directly proportional to the mass of paint on the car. Before statistical analysis was performed, air contaminant concentrations were divided by film thickness. Since film thickness is directly proportional to the mass of paint on the car body, differences in the air contaminant concentrations are evaluated on the basis of an equivalent paint job.

The time elapsed from when the worker started painting to when he stopped painting and left the booth was called the "painting time." This time was used to compute the concentrations. The mean painting times for the two spray-painting guns differed significantly ($p=0.03$); however, this difference was small. The mean painting times were 15.6 minutes for the conventional spray-painting gun and 14.1 minutes for the HVLP spray-painting gun. Because the authors were interested in studying the effect of gun choice on worker air contaminant concentrations, the data was not adjusted for the difference in painting times. Furthermore, the difference in painting times was small in relation to the variability in the concentration measurements and the observed differences in concentration.

The effects of paint, spray-painting gun, and the interaction term on film thickness per mass of paint were evaluated by an analysis of variance (ANOVA). For the data analysis, the two tints of the paint were treated as two different paints. The analysis was performed using the SAS General Linear Models (GLM) procedure (SAS Institute, Cary, N.C.).[14] Because air samples collected during the same experimental run may not be independent of each other, a repeated measures ANOVA was used for the concentration per film thickness data.[15,16] Before the data analysis was conducted, the concentration data were log-transformed.

In conducting the statistical analysis, the following variables were assumed to be normally distributed: (1) the average film thickness divided by the mass of paint used during a run, and (2) at each sampling location, the natural logarithm of the concentration

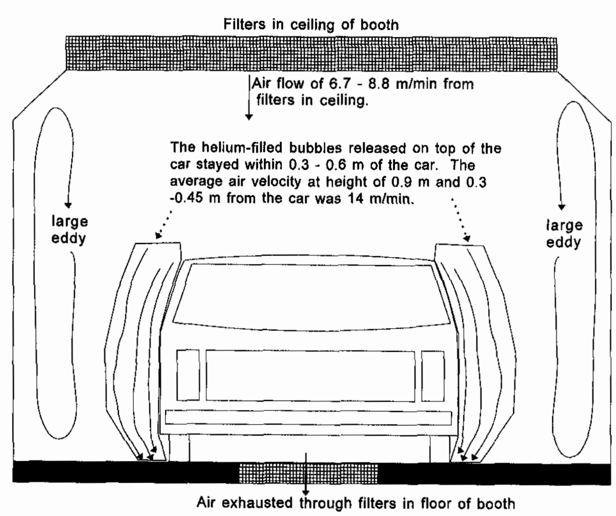

FIGURE 3. Schematic illustration of airflow patterns in booth. The airflow rates were reduced from 283 m^3/min to 153–201 m^3/min.

APPLIED STUDIES

divided by average film thickness during a run. This quotient was computed for both the total particulate and total solvent concentrations.

The assumption of normality was evaluated by computing the Shapiro-Wilk W statistic and its associated probability by using the SAS Univariate procedure. This W statistic was computed for the residual from an ANOVA involving the variables listed above. For the quotient of the average film thickness divided by the mass of paint used during a run, the residuals from the ANOVA were used to compute the W statistic and its probability. For the concentration/average film thickness data, the repeated measure analysis assumed that the normalized concentrations were lognormally distributed at each sampling location. For each sampling location an ANOVA was conducted that evaluated whether the concentration variable was affected by the paint, spray-painting gun, and the spray-painting gun-paint interaction. The W-statistic and its probability were computed for the residuals from each ANOVA by using SAS's Univariate procedure.[14] These probabilities were all between 0.05 and 0.95, indicating that there was no evidence for the significant departures from the assumption of normality.

Table I summarizes the ANOVA results. This table lists the probabilities that chance explains the observed differences in the dependent variables. It shows that the interaction between the independent variables, paint and spray-painting gun, significantly affected the film thickness per mass of paint. Figure 4 shows that the effect of spray-painting gun on film thickness per mass of paint varied with the paint. The film thicknesses presented in Figure 4 are the least squares estimates of the means for this experiment. Because the experiment was balanced, and there are no missing data, the least squares estimates of the means are the same as the average. For each paint the GLM procedure computed t-statistics and probabilities for testing the hypothesis that a spray-painting gun does not affect the film thickness per mass of paint. For Paint A the difference in spray-painting guns was not significant ($p=0.32$). For Paint B the difference in the film thickness per mass of paint between the two guns was statistically significant ($p=0.0005$).

The choice of spray-painting guns significantly affected the particulate overspray concentration/film thickness ($p=0.0009$) as presented in Table I (column 3). Because none of the interaction terms were statistically significant, the effect of the gun on the particulate overspray concentration did not vary with sampling location or paint to an extent large enough to be detected. The effect of spray-painting gun choice on particulate overspray concentrations is presented in Figure 5. Over all of the sampling locations the use of the HVLP spray-painting guns reduced the particulate overspray concentration by a factor of approximately 2. Another study found a similar reduction in particulate overspray concentrations when a conventional spray-painting gun was replaced with an HVLP spray-painting gun in a spray-painting room.[17]

In Table I under the column labeled "Combined Solvent Concentration/Film Thickness," the interaction between gun and sampling location was significant ($p=0.0002$). This indicates that the effect of the spray-painting gun varied with the sampling location. As shown in Figure 6, the combined-solvent breathing zone exposure measured on the worker varied significantly with the spray-painting gun ($p=0.02$). At the other locations the concentration difference was not significant. Furthermore, the gun-associated difference in the worker's exposure was much larger than the gun-associated difference in concentration at the other sampling locations ($p=0.006$).

DISCUSSION

Because most of the particulate sampling was conducted with closed-faced cassettes, it is possible that particle inertia caused inlet efficiency to decrease with increasing particle size, affecting the comparison between the two spray-painting guns. However, as shown in Figure 5, the difference between the open- and closed-face samples collected on the worker was small and statistically insignificant. Clearly the HVLP gravity-fed spray-painting gun produced less exposure to paint overspray than the conventional gravity-fed spray-painting gun. For both the sample taken around the worker and that collected near the wall, air velocities were less than 14 m/min. Apparently, the inertial effects for the closed-face samples collected on the worker did not bias sampling results. Because the air velocity around the area sample collected on the wall would be less than the air velocity around the worker, the sample collected near the wall is probably not biased by the particle inertia. The air velocities under the car were estimated to be 40 m/min, indicating that samples collected under the car could be affected by a reduction in inlet efficiency as particle size increased. However, the sampling conditions were the same for both of the spray-painting guns, so these measurements are useful as relative measures of concentration. Thus, the samples collected under the car indicate that the HVLP guns produce less particulate paint overspray than the gravity-fed conventional spray painting gun.

In this study the HVLP spray-painting gun was about 30% more efficient than the conventional spray-painting gun. Anecdotal reports indicate that switching from conventional to HVLP spray-painting guns reduces paint usage in autobody shops by

TABLE I. Probability that Chance Caused the Observed Differences in the Film Thickness per Mass of Paint Used and the Normalized Air Contaminant Concentrations

Independent Variables	Film Thickness/ Mass of Paint Used — Ordinary[A]	Combined Solvent Concentration/Film Thickness — Repeated Measures	Particulate Overspray Concentration/Film Thickness — Repeated Measures
	Probability of a Larger F, the Probability that Chance Could Have Caused the Observed Differences in the Dependent Variables		
	Dependent Variable/Type of ANOVA		
Paint	0.08	0.4639	0.6126
Gun	0.0015	0.1813	0.0009
Gun/paint	0.01	0.5299	0.5552
Location	NA	0.0001	0.0001
Gun/location	NA	0.0002	0.5734
Paint/location	NA	0.125	0.6334
Gun/paint/location	NA	0.1511	0.4501

[A] NA = not applicable

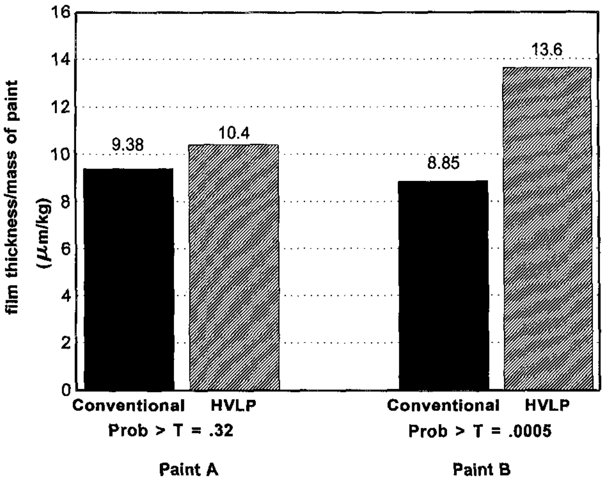

FIGURE 4. The effect of spray-painting guns on film thickness per mass of paint used varies with the paint tested.

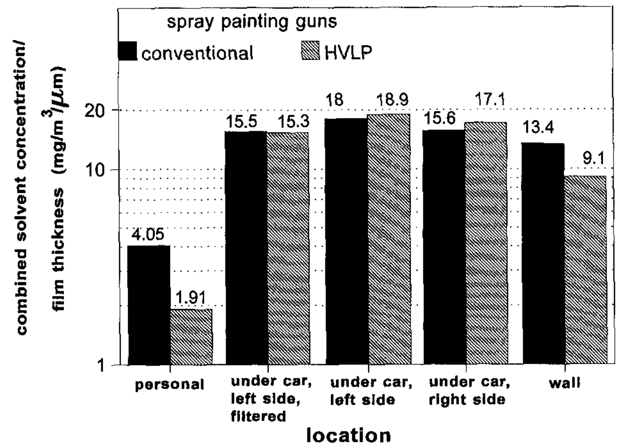

FIGURE 6. Effect of spray-painting guns and location on the geometric means of the combined solvent concentrations

about 25%.[18,19] Because a more efficient spray-painting gun places more of the paint on the car and uses less paint, increased transfer efficiency must cause a more than proportionate decrease in particulate overspray concentration. In this study a 30% improvement in transfer efficiency reduced particulate overspray concentration by approximately 50% averaged over all sampling locations. Clearly, minimizing the amount of overspray through gun selection is a useful option in conjunction with a spray-painting booth for controlling worker exposure to overspray. In addition to reducing the worker's exposure, the increased transfer efficiency acts to reduce emissions of particulate and volatile organic compounds into the environment.

As shown in Figure 6, use of the HVLP spray-painting gun appeared to reduce the painter's solvent exposure by a factor of 2. This difference was not observed at the other sampling locations or in the spray-painting room previously mentioned.[17] The airflow patterns presented in Figure 3 suggest that the downdraft spray-painting booth may be controlling the worker's exposure to solvent that is evaporating from the car. As a result, the painter is only exposed to solvents from the paint overspray aerosol, and the solvent exposure reduction is similar to the reduction in particulate overspray. The solvent concentrations measured under the car are the result of both paint overspray and solvent evaporation from the car body.

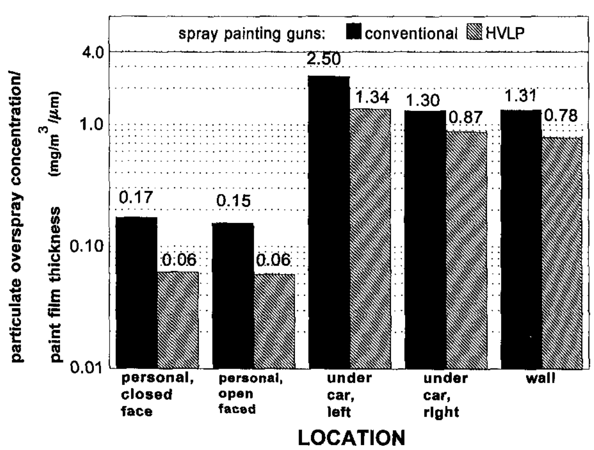

FIGURE 5. Effect of spray-painting guns on geometric mean particulate overspray concentration

According to claims in the commercial literature, conventional spray-painting guns have a transfer efficiency of less than 0.4, and HVLP spray-painting guns have a reported transfer efficiency of at least 0.65. Thus, the expected ratio of the film thicknesses per mass of paint sprayed for the conventional spray-painting gun to the result for the HVLP spray-painting gun is less than (0.4/0.65) or 0.62. In this study the observed geometric mean ratio was 0.76 with a 95% confidence interval of 0.66 to 0.88. Thus, the observed ratio differs significantly from the expected ratio estimated from claims in the commercial literature. This indicates that there is less improvement in transfer efficiency than one might expect based on such claims. However, the available commercial literature on spray-painting gun transfer efficiency did not provide or reference data to substantiate the reported transfer efficiencies.[1-3,18] Thus, one should not be surprised or alarmed by the smaller-than-expected difference between film thickness per mass of paint for the two spray-painting guns. These data suggest a need to develop a standardized test for measuring spray-painting gun transfer efficiency. In addition, fundamental knowledge about the effect of spray-painting parameters on transfer efficiency is needed to evaluate the appropriateness of transfer efficiency testing methodology.

CONCLUSIONS/RECOMMENDATIONS

The use of HVLP spray-painting guns needs to be encouraged. The possible benefit of using HVLP spray-painting guns compared to conventional guns needs to be considered along with other control options including ventilation and personal protective equipment.

A review of the literature showed an absence of information describing how an HVLP spray-painting gun minimizes overspray production. A physical model of overspray production would be very helpful. It would allow equipment designers and users to knowledgeably select operating conditions that would minimize paint overspray generation. Presently, such information is unavailable in the open scientific literature.

ACKNOWLEDGMENTS

The assistance of Mr. Michael Odum of DeVilbiss Automotive Products in conducting this testing is appreciated.

REFERENCES

1. **Johnson, B.W.:** "HVLP—Shoot for Profit." Paper presented at the National Autobody Congress and Exposition, New Orleans, LA, November 29–December 2, 1990.
2. **Marg, K.:** HVLP Spray Puts Into Compliance. *Met. Fin.: Prep., Electroplat., Coating 87(3)*:21–23 (1991).
3. **Dwyer, J.:** The VOC countdown on fleet finishes. *Fleet Owner 85(11)*:86–90 (1990).
4. **South Coast Air Quality Management District:** "Regulation XI Source Specific Standards, Rule 1107, Coatings of Metal Parts and Products." South Coast Air Quality Management District, 21865 Copley Dr., Diamond Bar, CA, 1991.
5. **Pacific Northwest Pollution Prevention Research Center:** "Transfer Efficiency and VOC Emissions of Spray Gun and Coatings Technologies in Wood Finishing." Pacific Northwest Pollution Prevention Research Center, 1218 Third Ave., Seattle, WA, 98101, 1992.
6. **National Institute for Occupational Safety and Health (NIOSH):** "Nuisance dust total: Method 0500 (issued 2/15/84)." In *NIOSH Manual of Analytical Methods*, 3rd ed., Suppl. 1–4. [DHHS (NIOSH) pub. no. 84–100] Cincinnati, OH: Centers for Disease Control, 1984.
7. **Chung K.Y.K., T.L. Ogden, and N.P. Vaughan:** Wind effects on personal dust samplers. *Aerosol Sci. 18(2)*:159–174 (1987).
8. **Grinshpun, S.A., G.N. Lipatov, and A.G. Sutugin:** Sampling errors in cylindrical nozzles. *Aerosol Sci. Technol. 12*:716–740 (1990).
9. **Buchan, R.M., S.C. Soderholm, and M.I. Tillery:** Aerosol sampling efficiency of 37-mm filter cassettes. *Am. Ind. Hyg. Assoc. J. 47*:825–831 (1986).
10. **National Institute for Occupational Safety and Health (NIOSH):** *NIOSH Manual of Analytical Methods*, 3rd ed. [DHHS (NIOSH) publication no. 84–100] Cincinnati, OH: Centers for Disease Control, 1984.
11. **Chen, B.S., L. Brosseau, C.P. Fang, A. Bowers, et al.:** Measurement of air concentrations of volatile aerosols in paint spray applications. *Appl. Occup. Environ. Hyg. 7(8)*:514–521 (1992).
12. **Heitbrink, W.A., M.E. Wallace, C.J. Bryant, and W.E. Ruch:** Control of paint overspray in autobody repair shops. *Am. Ind. Hyg. Assoc. J. 56*:1023–1032 (1995).
13. **Latter, T.D.T.:** Measurement and control of coating thickness. *Prod. Fin. 33(9)*:16–24 (1980).
14. **SAS Institute:** *SAS/STAT User's Guide, Release 6.03 Edition*. Cary, NC: SAS Institute, 1988.
15. **Winer, B.J.:** *Statistical Principles in Experimental Design*. 2nd ed. New York: McGraw-Hill, 1971.
16. **Keppel, G.:** *Design and Analysis—A Researchers Handbook*. Englewood Cliffs, NJ: Prentice Hall, 1991. pp. 344–500.
17. **Lingk, D.S.:** "Characterization of Paint Aerosol Exposure Using HVLP and Conventional Air-Atomization Techniques." MS thesis, Colorado State University, Fort Collins, CO, 1991.
18. **U.S. Environmental Protection Agency (EPA):** *Guides to Pollution Prevention—the Automotive Refinishing Industry*. [EPA/625/7–91/016] Washington, DC: EPA, Office of Research and Development, 1991.
19. **Mattson Spray Equipment Co.:** MAACO reviews HVLP. *MATTSON-ATOM-MISER Infor. Bull. 2*. Rice Lake, WI: Mattson Spray Equipment Co., 1991.