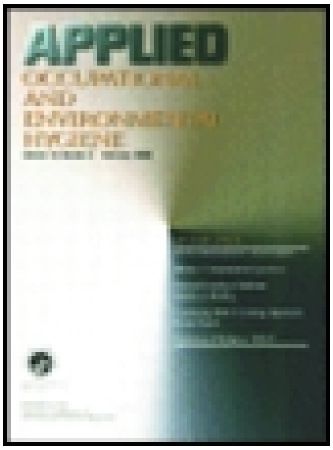

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Workstation Design Improvements for the Reduction of Dust Exposures During Weighing of Chemical Powders

Michael G. Gressel [a] & Thomas J. Fischbach [a]

[a] National Institute for Occupational Safety and Health, Division of Physical Sciences and Engineering , 4676 Columbia Parkway, Cincinnati, Ohio, 45226, USA

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Michael G. Gressel and Thomas J. Fischbach
National Institute for Occupational Safety and Health, Division of Physical Sciences and Engineering, 4676 Columbia Parkway, Cincinnati, Ohio 45226

Ventilated booth workstations often do not provide complete dust control during the manual transfer and weigh out of chemical powders. In a typical process, a worker removes powder from the bulk material drum with a scoop, weighs the powder into a paper bag, and then places the full bag into a second drum. A previous study identified points of exposure in a ventilated weigh-out operation at a plastics manufacturing plant. Eddies in front of the worker and inside the weigh-out drum hindered dust control. The depth of the powder in the weigh-out drum also contributed to increased exposures. This follow-up study sought to apply and evaluate three different control modifications of the weigh-out station. The first control was the modification of the worktable to streamline the process. The second control was a local exhaust hood placed at the lip of the bulk material drum. This hood controlled the eddy in the bulk material drum. The last control was an air shower, i.e., a low-velocity, fresh air supply located above the worker. This control counteracted the eddy in front of the worker. In addition to the new controls, the booth air flow rates were varied at one-third and two-thirds of the original flow and full (original) flow. The study design tested the effectiveness of the controls both singly and in combination using real time instrumentation and filter samples. Nine different workers participating in the study performed a total of 77 runs.

The results of this study showed some of the tested controls reduced worker dust exposures. The air shower and the local exhaust ventilation resulted in a reduction of exposures. The modified worktable had no significant effect on exposures. Further, this study showed that with the air shower installed, booth flow rates of one-third flow can control worker dust exposures. A recommended configuration would include the air shower, the local exhaust ventilation, and one-third booth flow. An economic analysis showed that the cost savings incurred by this configuration would result in a payback period of about 4.5 years. The recommended configuration, while reducing costs, will result in a reduction of worker dust exposures. Gressel, M.G.; Fischbach, T.J.: Workstation Design Improvements for the Reduction of Dust Exposures During Weighing of Chemical Powders. Appl. Ind. Hyg. 4:227–233; 1989.

Introduction

Manual weigh out and transfer of powders at a ventilated booth is common in many industries. Researchers at the National Institute for Occupational Safety and Health (NIOSH) previously conducted a study of such an operation at a Midwestern plastics manufacturing plant which identified sources of worker dust exposures.[1] A second study, reported here, was conducted at the same plant. This study's objectives were to determine control factors affecting worker dust exposures and to determine the optimum control configuration.[2]

The initial study identified several sources of worker dust exposures. First, scooping the powder from a nearly empty drum resulted in significantly higher dust exposures than scooping from a full drum. The booth air flow induced two eddies which reduced the effective control of exposures. The first eddy, located in front of the worker, transported dust generated at the work table into his breathing zone. The second eddy, created inside the weigh out drum, transported dust from inside the drum into the work environment.

Several modifications of the manual weigh out workstation were tested. First, the layout of the worktable was evaluated and redesigned to improve process flow and, hopefully, reduce dust exposures. Next, a local ventilation hood was added atop the bulk material drum. This hood controlled the eddy in the drum, preventing the dust from escaping from the drum into the work environment. Finally, an air shower was installed above the worker to control the eddy in front of the worker. This study evaluated these controls along with varied booth air flow rates to determine the most effective control scheme. In addition, a cost analysis determined the installation and operating costs of the modified controls.

Process Description

This plant receives many powdered raw materials in 23-kg

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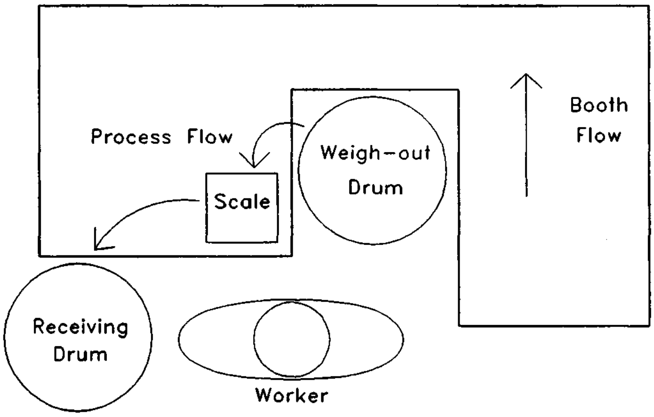

FIGURE 1. Original worktable design.

(50-lb) bags. Workers weigh small quantities of the materials (i.e., less than a full bag) at a ventilated booth. Large bags of raw materials, dumped into a drum, are weighed into small paper bags. These small bags of powder are placed into a bin or a second drum for storage.

Control Design

As a result of the initial study at this plant, bulk powder was weighed from half-height drums for all tests.[1] Standard drums were cut in half and placed on a platform to raise the top to the original 0.84-m (33-in) height above the floor. This provided a comfortable working level for most of the workers. The half-height drums assured that the workers would not have to reach deep into the drum to scoop the powder and may reduce dust exposures by up to 66 percent versus the full-height drums.[2]

The various control designs evaluated in this study complemented the ventilated booth presently installed at the plant. The average face velocity of the booth, as measured with a hot wire anemometer, was about 0.32 m/s (64 ft/min). With a booth face area of 2.78 m^2 (29.9 ft^2), this velocity results in an exhaust volume of 54 m^3/min (1920 ft^3/min). A blast gate in the ventilation duct leading from the booth was adjusted to allow evaluations at two other flow rates. Two-thirds flow, 36.3 m^3/min (1280 ft^3/min), produced a face velocity of 0.22 m/s (43 ft/min). One-third flow, 18.1 m^3/min (640 ft^3/min), produced a 0.11 m/s (21 ft/min) face velocity.

Figure 1 is a drawing of this workstation in its original configuration. The hood originally contained a metal table with a platform which folded down to cover the area where the weigh-out drum normally sits. When the drum is inside the booth, the platform folds up and rests on the back of the booth. However, the initial study of this work station showed the platform to adversely affect the air flowing around the drum.[1] For this study, a wood replica of the metal table was constructed to ease the switching of the different configurations. The wooden table did not include the platform.

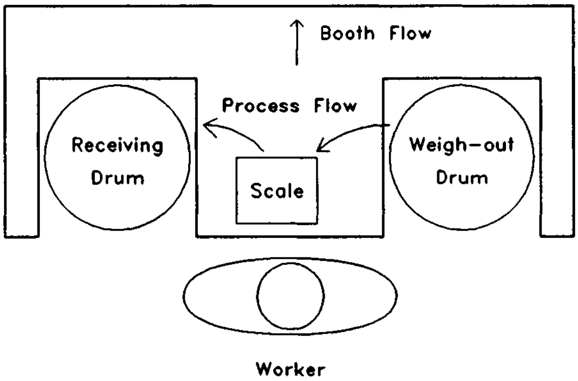

FIGURE 2. Modified worktable design.

Figure 2 shows the redesigned worktable, also constructed out of wood.[3,4] The design of this table streamlined the weigh-out operation. In addition, the design placed the material-receiving drum inside the hood, hopefully reducing dust exposures. The

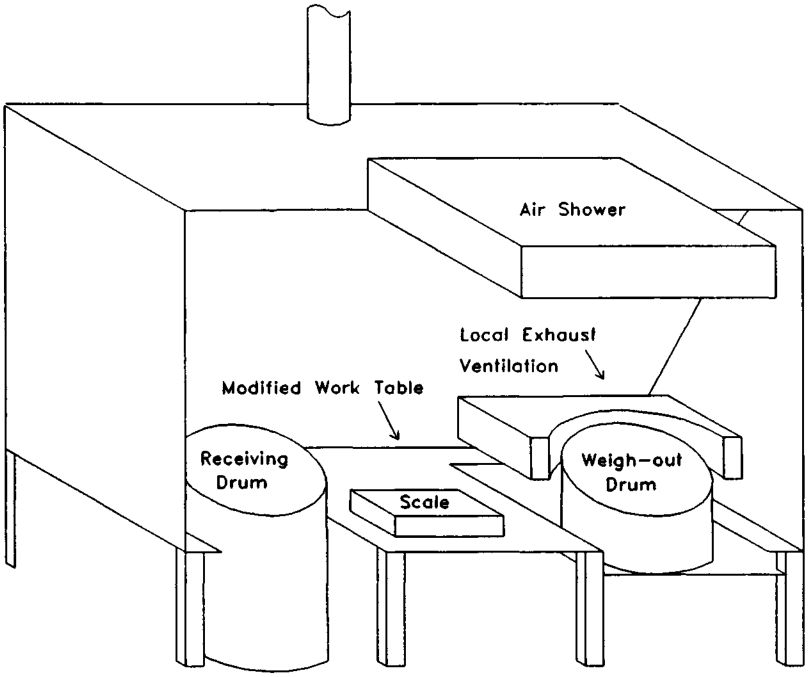

FIGURE 3. Modified table with air shower and local exhaust ventilation.

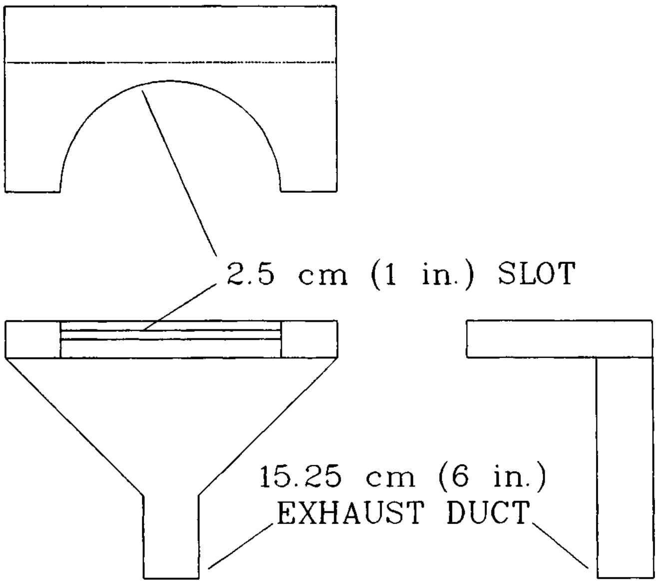

FIGURE 4. Local exhaust ventilation design.

two wooden worktables were interchanged as required by the study design. The modified worktable was evaluated in conjunction with the different booth air flow rates, local exhaust ventilation, and the air shower. Figure 3 shows the modified worktable as installed at the ventilated booth.

The local exhaust ventilation (Figure 4) consisted of a slot hood positioned behind the material weigh out drum. This hood provided exhaust ventilation near the dust source. The slot velocity was about 7.6 m/s (1500 ft/min) with a resulting flow of 14.2 m^3/min (500 ft^3/min).[5]

This hood was built of wood and sheet metal and was designed for easy removal from the workstation when necessary. A small fan exhausted the air from the local ventilation hood into a hood located elsewhere in the plant. The local exhaust hood design was intended to control the eddy inside the drum, thereby reducing the potential for the drum to be a source of dust exposure. Figure 3 shows the location of the local exhaust ventilation hood.

The air shower, pictured in Figure 5, consisted of a 0.91-m × 0.91-m × 0.25-m (3-ft × 3-ft × 0.83-ft) wooden plenum chamber with a pegboard face which served as the distribution plate. The holed area of the distribution plate was less than one-half of the sectional area of the plenum chamber. An air purifying unit supplied clean air into the plenum providing 0.25 m/s (50 ft/min) air velocity at the worker's breathing zone. The clean air from the air shower would force any dusty air down, away from the worker's breathing zone. The air shower unit was mounted 2.1 m (6.9 ft) above the floor in the area the worker normally occupied when weighing out materials. Figure 3 shows the relative location of the air shower.

Cost Analysis

The cost analysis for the various control configurations covered three basic areas: make-up air, fabrication, and air cleaning. The air cleaning cost analysis applies mainly to new installations. This analysis made several assumptions. Actual costs will depend upon site location and other installed equipment.

The cost of the make-up air will be dependent upon the volume of air exhausted. Depending upon the climate and operation, this air may require heating. The type and cost of the fuel and the temperature of the incoming air also affect the cost of the make-up air. The following equation was used to calculate the cost of the make-up air.[5]

$$\text{Annual cost} = \frac{10325\ QD\ dg}{q} \times c$$

where:

Q = air volume, m^3/min
D = operating time, hrs/week
dg = Annual Heating Degree Days, °C·days
q = heating value/unit of fuel, J/fuel unit
c = cost of fuel, \$/fuel unit

This cost analysis used several assumptions. The operating time of the weigh-out workstation was 120 hours/week. The Annual Heating Degree Days for the location of the plant were not readily available; data for Pittsburgh, Pennsylvania, located about 165 km (103 mi) away, was used. The plant was assumed to be maintained at 18°C (65°F) with a natural gas heat exchanger system operating at 80 percent efficiency. This heating system had an available heat of 2.98×10^{-7} J/m^3 (800 Btu/ft^3). The estimated cost of the gas was \$0.148/m^3 (\$0.0042/ft^3).[6]

The costs of building the various configurations are dependent upon the materials and labor required for construction. This estimate made several assumptions. The air shower was constructed of 18 gauge galvanized steel. The local exhaust ventilation hood was built of 16 gauge galvanized steel, heavier than the air shower due to the abrasive nature of the powder. The modified worktable frame was made of 7.6 cm × 7.6 cm × 0.64 cm (3 in. × 3 in. × 0.25 in.) angle iron with a gray iron plate of 0.48 cm (0.19 in.) thickness for the table top. Cost estimates came from price quotes submitted by a metal fabricating contractor.[7] Installation costs were estimated at 25 percent of the fabrication costs.[8] Cost estimates for duct work are available from a number of sources.[8,9] The air shower supply required 30 m (100 ft.) of 0.20-m (8-in.) diameter round galvanized ductwork. The local exhaust hood needed 9.1 m (30 ft) of 0.15-m (6-in.) diameter round galvanized ducts. The analysis also assumed the air cleaning device was a shaker-type baghouse with a capacity of 283 m^3/min (10,000 ft^3/min) and a filter fabric cost of \$61.87/m^3/min (\$1.75/ft^3/min).[10,11] The calculated cost of a typical shaker-type baghouse installation was \$184.13/m^3/min (\$5.21/ft^3/min).[2]

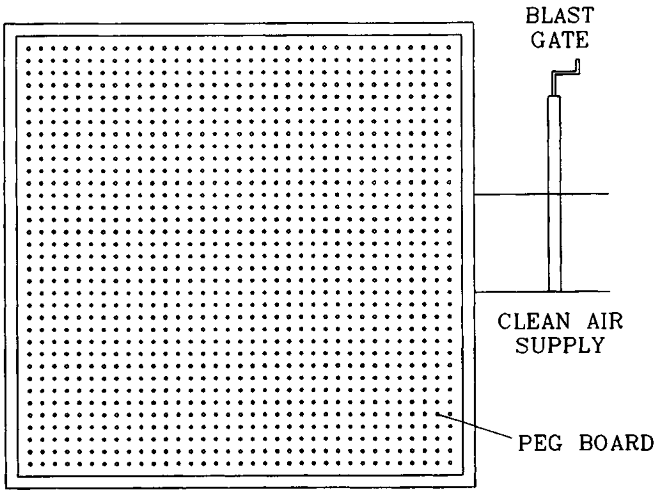

FIGURE 5. Air shower design.

Statistical Design

The study objective was to evaluate various workstation configurations for controlling worker dust exposures. The evaluation of each workstation configuration required a worker to transfer material to the bags for a specific period. The worker used either the original or the redesigned worktable. The redesigned worktable also had one of twelve possible variations of booth air flow, air shower, and local exhaust ventilation. To reduce variability, the workers weighed out the same polymethyl methacrylate powder (mean particle diameter of 90 microns with a geometric standard deviation of 2) during the entire study. Because of time limitations, the study used a nested half-fraction factorial design. This design included the two worktable designs, booth air flow rate, air shower, and local exhaust ventilation.[12,13] The design resulted in each worker completing one run in the original workstation configuration and six runs from the half-fraction factorial experiment. Workers in groups were randomly assigned to the six setups or half fractions. This randomized the order of the six possible sets. Seven workers completed a single sequence, while two workers completed two sequences each. The total was treated as if 11 workers participated. This resulted in the use of all three pairs of replicates, with all but one represented twice. For each worker, the order of the seven runs was randomized. The NIOSH researchers did not know the configuration assigned to a worker or the order or runs until the worker began.

Each run in this study lasted 15 minutes and started with a filled half-height drum. The worker weighed 0.49 kg (1.08 lbs) of the powder into the small paper bags. He then placed the filled bags into the full-height receiving drum for use at a later time. The worker filled three half-height drums with powder before starting a run. Each worker typically emptied one or two of the half-height bulk material drums. Members of the NIOSH survey team changed the bulk material drums when empty. All sampling ended after 15 minutes, and a different workstation configuration was put into place.

Sampling Methods

In this study, gravimetric filter sampling (mg/m^3) and real time instrument sampling were performed simultaneously. The filter samples provided average dust concentrations for the entire run and the real time sampling gave concentrations at a specific time.

TABLE I. Summary of Individual Factors' Effects on Dust Exposures

Factor	Effect on Dust Exposures
Worker	Statistically significant. Worker differences were responsible for most of the dust exposure variation.
Worktable Design	Not statistically significant.
Booth Air Flow*	Not statistically significant for the three different booth air flows tested.
Air Shower*	Statistically significant. The air shower reduced dust exposures. Air shower was second only to worker differences in its effect upon dust exposure.
Local Ventilation*	Statistically significant depending upon analysis. Local exhaust ventilation decreased exposures.
Booth Flow–Air Shower Interaction*	Statistically significant depending upon analysis. When the air shower was not operating, exposures tended to increase as the booth flow decreased.
All Other Interactions	Not statistically significant.

*Factor tested only with modified work table.

TABLE II. Groupings from the Bonferroni Multiple Comparison Tests

Configuration^A	Grouping^B
Full booth air flow, air shower, local exhaust ventilation	A
⅓ Booth air flow, air shower	AB
⅔ Booth air flow, air shower	AB
⅓ Booth air flow, air shower, local exhaust ventilation	AB
⅔ Booth air flow, air shower, local exhaust ventilation	ABC
⅓ Booth air flow, local exhaust ventilation	ABC
Full booth air flow	ABC
⅔ Booth air flow, local exhaust ventilation	ABC
Full booth air flow, air shower	ABC
Full booth air flow, local exhaust ventilation	BC
⅔ Booth air flow	BC
⅓ Booth air flow	C

^{A} Configurations are listed from lowest exposure to highest.
^{B} Configurations with the same grouping letter are not significantly different from each other.

Four filter samples were taken during each run. There were two personal samples (right and left lapel) and two background samples. The background sample locations were about 9 m (30 ft) from the weigh-out booth. The filters used were MSA type FWSB 37- mm with 5-micron pore size mounted in a closed-faced cassette. Carbon vane pumps with critical orifices, calibrated at 13–14 L/min, drew air through the filters. The total sample volume for each run was 195–210 L of air.

A hand-held aerosol monitor (HAM, Inc., Knoxville, TN), operating in an active mode, measured the dust exposures in real time. In the active mode, air is drawn through the sampling chamber by a sampling pump operating at 4–5 L/min. A Rustrak Ranger Datalogger (Gulton, Inc., East Greenwich, RI) collected the data from the HAM. The data logger transferred the data to a personal computer and into a spreadsheet for data analysis. A video camera recorded all activities. The clocks in the camera and the data logger were synchronized to aid in the identification of activities causing changes in dust exposures. The real time data also provided a second means for measuring the effectiveness of the various control configurations.

Comments were elicited from the workers concerning the various workstation configurations. This included the likes and dislikes of the different control devices, perceptions about the effectiveness of the controls evaluated, and suggestions for improvements to the controls.

Results

The study was proposed to determine which of the workstation configurations affected worker dust exposures. The dependent variable for filter data analysis was the exposure calculated from the weight of the dust collected on the personal filter samples. For the real time data, the dependent variable was the average of the 1-second readings over the 15-minute run. The analysis developed a regression equation to determine if the various control measures affected dust exposures. The analysis also accounted for the interactions of these terms. The worker differences term described all effects that could not be attributed to the controls listed. The data were analyzed in several different ways, each giving slightly different results. These differences, however, did not effect the overall conclusions.[2]

Table I is a summary of the individual factors and their associated effect on worker dust exposures. Statistical effect is at the 0.05 level.

Statistical analyses also determined which specific configurations resulted in the lowest worker dust exposures. These analyses used only the filter data from the modified workstation configurations. There were two types of analyses performed. The first was a standard multiple comparison test like the Least Significant Difference (LSD), Scheffe's Method, and the Bonferroni or Dunn t-test.[14] Table II lists the results of the multiple comparison tests.

The second method for identifying the configuration resulting in the lowest dust exposure used a fitted regression equation to estimate the exposures. Like the multiple comparison tests, this analysis only used the modified workstation configuration data. While these estimates identified the configuration resulting in the lowest exposures, there was no analysis determining statistically significant differences between the estimates. Table III gives the exposure estimates from this method.

The major operating cost involved with all of the tested configurations is heating the required make-up air. Table IV shows the results of the cost analysis for the make-up air on an annual basis. Both the volume of make-up air needed and the heating costs are shown. The make-up air volume equals the exhaust air volume for each configuration. Table V shows the construction and installation costs of the air shower, the local exhaust ventilation, and the modified worktable. Table VI lists the costs of the air cleaning equipment for each of the configurations. All costs given are estimates since actual costs will vary with the application.

Discussion

Analyses of both the filter data and the real time data gave similar results. There were some differences between the two sets of analyses, but the interpretation and conclusions were basically the same. Comments from participants in the study showed acceptance of the controls by the workers and identified areas requiring additional work. In addition, the cost analysis indicated possible cost or savings which may be incurred by installing a particular control configuration.

Worker differences had the most significant effect upon dust exposures for both the real time and filter data. These differences may include work practices and anthropometry. Since the emphasis of this study was to identify an effective ventilated workstation configuration, the worker factor was not investigated further.

TABLE III. Predicted Worker Dust Exposures (mg/m³) from General Linear Models Procedure

Configuration	Exposure (mg/m³)
⅓ Booth air flow, air shower, local exhaust ventilation	1.4
Full booth air flow, air shower, local exhaust ventilation	1.7
⅓ Booth air flow, air shower	2.0
⅔ Booth air flow, air shower	2.0
Full booth air flow, air shower	2.6
⅔ Booth air flow, air shower, local exhaust ventilation	2.7
Full booth air flow, local exhaust ventilation	3.1
⅔ Booth air flow, local exhaust ventilation	4.9
⅓ Booth air flow, local exhaust ventilation	5.3
Full booth view	5.5
⅔ Booth air flow	6.4
⅓ Booth air flow	8.2

TABLE IV. Annual Contribution of Make-up Air Cost by Workstation Configuration

Workstation Configuration	Make-up Air (m³)	Cost, Gas Heat Exchanger
Original, full flow	54.4	1115
Modified, full flow	54.4	1115
Modified, ⅔ flow	36.3	743
Modified, ⅓ flow	18.1	372
Modified, full flow, air shower	54.4	1115
Modified, ⅔ flow, air shower	36.3	743
Modified, ⅓ flow, air shower	18.1	372
Modified, full flow, local ventilation	68.5	1405
Modified, ⅔ flow, local ventilation	50.4	1033
Modified, ⅓ flow, local ventilation	32.3	662
Modified, full flow, air shower, local ventilation	68.5	1405
Modified, ⅔ flow, air shower, local ventilation	50.4	1033
Modified, ⅓ flow, air shower, local ventilation	32.3	662

TABLE V. Fabrication Cost (in dollars) of Modified Worktable, Air Shower, and Local Exhaust Ventilation

Control Item	Cost, $
Modified Worktable	
Worktable	660
Worktable Installation	165
Total	825
Air Shower	
Air shower supply unit	210
Air shower supply unit installation	53
Ducts, installed	483
Total	746
Local Exhaust Ventilation	
Local exhaust hood	245
Local exhaust hood installation	61
Ducts	145
Total	451

TABLE VI. Contribution of Air Cleaning Cost by Workstation Configuration

Work Station Configuration	Air to be Cleaned (m³)	Cost, Air Cleaning Equipment
Original, full flow	54.36	$10,009
Modified, full flow	54.36	10,009
Modified ⅔ flow	36.25	6,675
Modified, ⅓ flow	18.12	3,336
Modified, full flow, air shower	54.36	10,009
Modified, ⅔ flow, air shower	36.25	6,675
Modified, ⅓ flow, air shower	18.12	3,336
Modified, full flow, local ventilation	68.53	12,618
Modified, ⅔ flow, local ventilation	50.40	9,280
Modified, ⅓ flow, local ventilation	32.28	5,944
Modified, full flow, air shower, local ventilation	68.53	12,618
Modified, ⅔ flow, air shower, local ventilation	50.40	9,280
Modified, ⅓ flow, air shower, local ventilation	32.28	5,944

Both real time and filter data results showed no significant dust exposure differences between the original and the modified worktables. While the modified worktable did not decrease the exposures, the workers perceived it as an improvement in the process flow; most liked the modified layout. One negative comment was that the modified table did not have as much usable area as the original. Another worker noted that the modified table with local ventilation should be able to accommodate a left-handed worker.

The most significant *control* effect on the workers' dust exposures was the air shower. There were two limitations upon the workstation configurations using the air shower. Because of plant obstructions, the air shower was located slightly behind the worker. Locating the air shower directly above the worker would have provided better control of the eddy in front of the worker. The other limitation was the quantity of air to the air shower unit. Little is known about the effects of air showers at ventilated booths. This study used an air shower velocity of 0.25 m/s (50 ft/min) at the worker's face which may not have been optimum. A literature citation has reported air shower velocities of 1.9 m/s (375 ft/min).(15) This latter study did not use the air shower in conjunction with a ventilated booth. Neither one of these limitations may have been significant in this study. Furthermore, this study used filtered plant air as the supply to the air shower. Normally, fresh make-up air could supply the air shower in an actual plant installation.

The filter and real time sampling results for the local exhaust ventilation were inconsistent. For the real time analysis, the presence of the local exhaust ventilation significantly reduced the worker dust exposures. The filter data results, though, were not as clear. Depending upon the analysis, the local ventilation significantly reduced workers' dust exposures. The local ventilation also appeared to control dust generated when emptying the large bags of powder into the drum. Although not measured during this particular operation, visual observation showed the dust being drawn into the exhaust hood. Like the modified worktable, most of the workers perceived the local exhaust ventilation as effective and a work environment improvement. Several workers also used the top of the hood as a place to store empty bags into which they weighed the powder. This extra work space may compensate for part of the space lost by using the modified worktable. One worker felt that rotating the hood would give better access to the drum when scooping.

The analyses to determine which configurations resulted in the lowest exposures showed several trends. First, as shown in Tables II and III, the configurations using the air shower resulted in the lowest exposure. The configuration with one-third booth air flow, no air shower, and no local exhaust ventilation had the highest predicted exposures. Two-thirds booth air flow, no air shower, and no local exhaust ventilation was also among the configurations with the highest predicted exposures. Local exhaust ventilation configurations did not exhibit any distinguishable order. Although there were just three groupings, the multiple comparison tests did show some patterns between configurations. It also confirmed some of the other analyses performed to determine the effects of the different controls.

Conclusions and Recommendations

Several conclusions resulted from this study. First, with additional controls, a basic ventilated booth can reduce dust exposures if configured correctly. Further, by adding an air shower, reduction of booth exhaust can result in lower operating costs. With lower exhaust volumes, less make-up air is needed. Make-up air is an expense since it must be heated in the winter. Lower exhaust volumes also result in lower air cleaning capacity requirements. In new facilities, this will result in savings on the size of the air cleaning systems needed. In existing facilities, lower weigh-out air cleaning requirements will provide greater capacity to other areas of the plant. The major point is that the air shower in conjunction with the ventilated booth can reduce worker dust exposures while reducing costs. From the analysis of the data, the air shower was the most significant control factor tested. Furthermore, outside air must enter the plant as make-up air. Therefore, supplying the air shower with the make-up air should result in relatively low operating costs for the air shower system.

The study results showed that installation of the modified worktable with the local exhaust ventilation and air shower is desirable. Both controls were perceived by the workers participating in the study to improve the work environment. Also, the local exhaust ventilation appeared to control the dust exposures during filling of the material weigh-out drum. While the study did not focus on bag dumping, the local exhaust ventilation would be a good addition to the current controls. However, the local exhaust ventilation needs additional evaluation to determine its effectiveness at controlling dust exposures during drum filling. While worker comments about the modified work station were positive, one noted the worktable area reduction from the original workstation. This should be considered in the modification of the table at the workstation.

The recommended configuration for this plant is the modified worktable, air shower, local exhaust ventilation, and one-third booth air flow. Figure 3 shows this configuration. In the rank ordering analyses, this configuration was consistently among the configurations with the lowest exposures. The predicted exposures showed this configuration results in up to a 70 percent reduction in dust exposures versus the currently installed configuration. The analyses also showed that the booth flows tested had no significant effect on worker dust exposures (Table I). Therefore, the booth flow reductions will not increase the dust exposures. However, the configuration ranks showed the modified workstation with one-third booth air flow and no other controls had the highest exposures. Although these exposures were not significantly different from many of the other configurations, it consistently resulted in the highest exposures. It would not be prudent to reduce the booth air flow without implementing additional controls, namely the air shower.

Besides reducing exposures, the recommended configuration can reduce costs as well. As shown in Table VII, this configuration had an installed fabrication cost of $2022. Annual make-up air costs were $662 and air cleaning equipment costs were $5944. This assumed a natural gas heat exchanger operating at 80 percent efficiency. This particular plant would realize little cost saving due to reduction of air cleaning equipment costs. It would gain an important savings due to a reduction of make-up air. The current workstation has an estimated make-up air cost of $1115 per year. The recommended configuration would result in an annual savings of $453. Based upon the fabrication and make-up air costs, the recommended configuration would have a payback period of about 4.5 years. Although this is not a high rate of return, the major benefit derived from installing the controls would be a significant reduction of dust exposures.

Previous studies have shown that a ventilated booth will not

TABLE VII. Summary of Costs of Recommended Workstation Configuration

Item	Cost
Fabrication and installation	$2022
Air cleaning equipment	5944
Make-up air cost, annual	1115

adequately control dust exposures during the manual powder handling operation.[1] This study has demonstrated that exposure reductions are possible with the addition of several simple controls. Furthermore, cost savings can be incurred by installing these controls. Worker acceptance of the new controls, always important in the use of new systems, was favorable. The recommended workstation with its combination of controls, can improve the work environment while reducing operating costs.

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