Supplementing your dust control equipment with whole-plant ventilation

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While various types of equipment are used in bulk material processing plants to control respirable dust, the equipment often doesn't adequately protect workers. One cost-effective way to supplement your existing dust control equipment is to install a whole-plant ventilation system. This article outlines research by the National Institute of Occupational Safety and Health (NIOSH) on using whole-plant ventilation in two mineral processing operations to reduce respirable dust levels. Information also covers how to design a ventilation system for any bulk material processing plant.

The most common dust control equipment in bulk material processing plants is a baghouse dust collector. The collector usually controls dust at processes such as milling, screening, drying, and bagging. Although dust collectors and other equipment can control these major dust sources in your plant, have you thought about controlling dust from minor sources? These sources typically include:

- Leakage from chutes, transfer points, and dust collectors.
- Material falling from conveyor belts and rollers.
- Dust released when workers remove lids or covers to inspect screeners, mills, or other equipment.
- Dust falling from beams, walls, and equipment due to vibration.
- Dust released from steps and walkways as workers move through the plant.
- Dust generated by improper housekeeping practices.

Over a work shift, dust from these sources can gradually increase to unacceptable concentrations for workers. While training your workers to minimize such dust sources is an important first step in controlling the dust, a good way to supplement these efforts is to install a whole-plant ventilation system. The ventilation system provides a general purging of the plant air, thus keeping dust levels down while ensuring worker exposure levels comply with government regulations.

Principles of whole-plant ventilation

Most bulk materials processing plants can be considered closed systems. This means that any uncontrolled dust in the plant, including that from minor sources, will contribute to a gradual increase in respirable dust concentrations over a shift. The dust can exit the plant through open doors and windows and contaminate outdoor workers. The dust can also recirculate back into the plant, further increasing dust concentrations.

A whole-plant ventilation system can help solve this problem by using exhaust fans to draw clean makeup air into the plant through inlets near the plant's ground floor. The fans then draw the dust-laden air within the plant upward to exhaust at or near the structure's top. The whole-plant ventilation provides a general air purging, clearing dust-laden areas throughout the plant. The size and number of fans determine the total ventilation volume.

Ventilation is aided by the heat from plant equipment. The heat produces thermodynamic effects that provide a chimney-like flow to promote ventilation. Because the exhaust air velocity and dust concentration are relatively low, the air doesn't present any environmental concerns.

Study goals

While published sources[1] suggest that a whole-plant ventilation system can reduce respirable dust levels, the sources don't provide information about designing and installing such a system. This lack of published information led National Institute of Occupational Safety and Health (NIOSH) researchers to conduct a study that would determine guidelines and design criteria for ventilation systems. Although the study was conducted in mineral processing plants, the results can be applied to plants processing other dry bulk materials.

Research equipment and procedures

In the study,[2] whole-plant ventilation systems were installed in two mineral processing plants. At both plants, the researchers used respirable-dust-monitoring instruments to measure dust concentrations with and without the ventilation system operating.

The respirable dust measurements were taken with two instruments — a gravimetric dust sampler and real-time aerosol dust monitor (RAM-1). Both were used with a 10-millimeter-diameter cyclone to classify the respirable portion of dust (particles with *aerodynamic diameters* of 10 microns or less, which can deposit in a worker's lungs).

Gravimetric dust sampler. The gravimetric dust sampler includes a sampling pump and filter. The pump deposits the respirable dust sample on the filter, which is then removed for weighing.

Two sets of gravimetric dust samplers were used at most sampling locations in the tests. Two or three samplers were operated side by side in each set so the average concentration could be calculated. At each location, one sampler set was operated when the ventilation system was on, and the other set was operated when the system was off.

The researchers weighed the filter from each gravimetric dust sampler before and after each use. This allowed them to determine the average respirable dust concentration over the entire time the sampler was operated. Each sampler provided one dust concentration value for each day of testing.

RAM-1. The RAM-1 includes a sampling pump and internal sensing chamber. It determines instantaneous respirable dust concentrations by the light scatter of particles drawn through the internal sensing chamber by the sampling pump.

A RAM-1 was located at each sampling location. The unit sent data to a datalogger; after testing was completed each day, the datalogger information was dumped to a computer. The RAM-1 let the researchers determine the respirable dust concentration over short periods.

Plant 1 tests

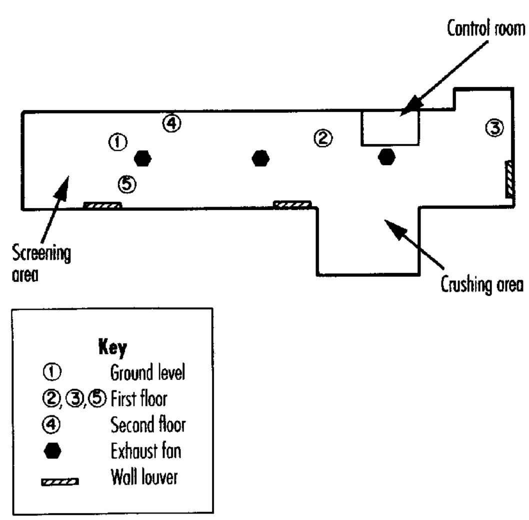
The first tests were at a clay processing plant in New York state. The three-story, 130- by 32-foot plant had crushing and screening equipment on every floor and a 150,000-cubic-foot volumetric capacity.

The researchers designed a whole-plant ventilation system that would provide 25,500 cfm of ventilation air to the plant, which equalled about 10 air changes per hour. The ventilation was provided by three 8,500-cfm exhaust fans that were evenly spaced across the plant roof. Each fan was wired separately to permit the repair of one unit without turning off the other two. This also allowed one or two fans to be turned off during the winter months when outdoor air temperatures are low and could further promote freeze-up of the plant's processing equipment. The system's makeup air inlet consisted of three wall louvers that were installed at ground level, where they would provide clean air and a good air distribution pattern for the entire plant.

Procedure. Figure 1 shows where the researchers installed gravimetric dust samplers and RAM-1s in the plant. These

Figure 1

Sampling locations in plant 1



sampling locations were chosen to provide a good dust profile of the plant.

- Locations 1, 4, and 5 were near the plant's screening areas on all three floors because the respirable dust concentrations fluctuated here.
- Location 2 was at a central walkway.
- Location 3 was away from the screening areas to round out the plant's entire dust profile.

Two test series were run in the plant. The first was in winter, when outdoor temperatures ranged from 10°F to 40°F. Testing was permitted on only 2 days because of extremely high winds and process equipment freeze-up problems; windchill factors as each shift started were as low as -30°F to -40°F. The second test series occurred over 3 days in spring, when outdoor temperatures ranged from 50°F to 80°F.

In both series, the dust-monitoring instruments were in the same sampling locations, except for location 5. The instruments located here in winter had to be moved to another nearby spot for the second series because in spring a door was opened near the original location to allow cleaning. Although the open door wouldn't affect the ventilation system, it would bias dust concentration data for this area. For both series, the researchers switched the ventilation system on and off during alternating periods of about 1 hour.

Results. Both series verified that the ventilation system effectively reduced respirable dust concentrations throughout the entire plant. In winter, the gravimetric dust samplers measured respirable dust concentrations from 0.22 to 2.39 mg/m^3 when the ventilation system was off and from 0.13 to 1.55 mg/m^3 when the system was on. In spring, the samplers measured concentrations from 0.29 to 4.84 mg/m^3 with the system off and from 0.21 to 2.37 mg/m^3 with the system on. In both test series, the ventilation system also improved visibility throughout the plant, which confirmed that dust concentrations had dropped.

Figure 2 shows the dust concentration measured by the RAM-1 at location 5 during a 3-hour period on day 2 of the winter test. The ventilation system was off, on, and then off again. When the system was switched on, the dust concentration typically reduced to a stable level in about 8 to 10 minutes.

Figure 2

RAM-1 results at sampling location 5, plant 1

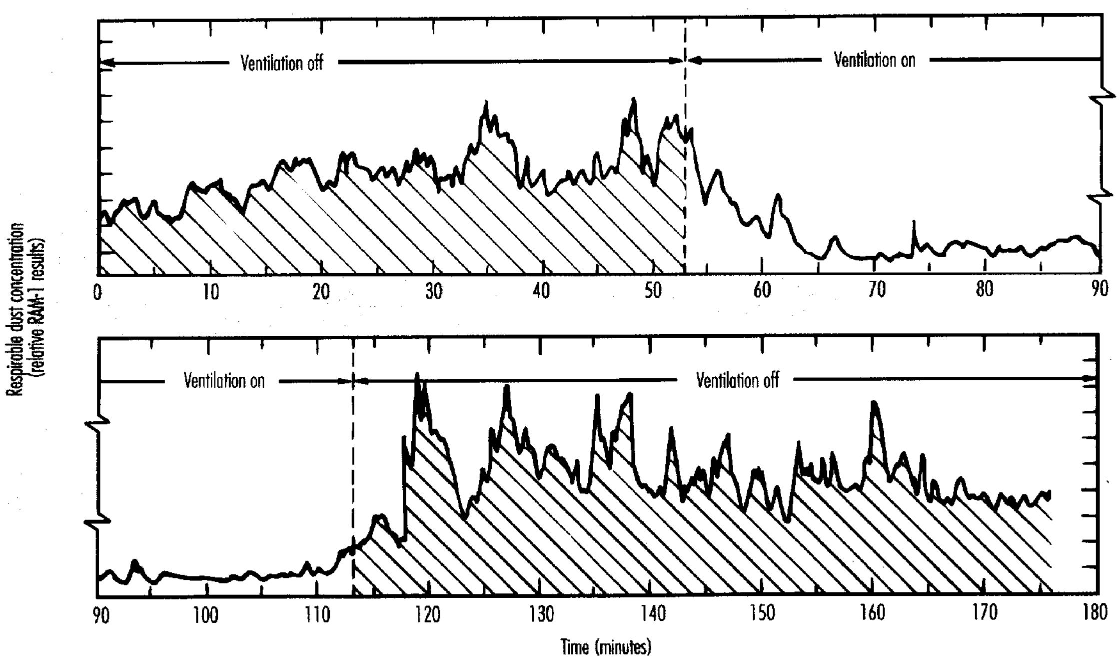


Table I lists dust concentration reductions determined by both the gravimetric dust samplers and RAM-1s at each location. The results are based on comparing average dust concentrations when the ventilation system was on with those when it was off. The overall average reduction for the five locations was about 40 percent (although the correlation between the two instruments at each location was less than expected).

Plant 2 tests

A silica sand plant in Texas was the setting for the other tests. The six-story, 79-foot-high structure was located above several three-story storage silos, as shown in Figure 3, and had a base measuring 66 by 34 feet. The plant had a 177,000-cubic-foot volumetric capacity.

The researchers designed a larger ventilation system for this plant than for plant 1 to see if there was an optimal system size and if the system could achieve greater dust concentration reductions. The system included four 25,000-cfm exhaust fans, which provided 100,000 cfm of total ventilation volume. This corresponded to about 34 air changes per hour (with four fans operating) or about 17 air changes (with two fans operating). One fan was installed on each of the plant's four outside walls, and the fans were wired separately to a control room to permit either two or four fans to operate at a time. (Two fans are shown in Figure 3.)

Large doors already present in the plant's base supplied enough makeup air, so no additional inlets were installed. The doors remained open during all tests. A bank of windows between levels A and B (Figure 3), typically left open during plant operation, were closed for the tests except during one test sequence to show how opening the windows affected the results.

Figure 3

Sampling locations in plant 2

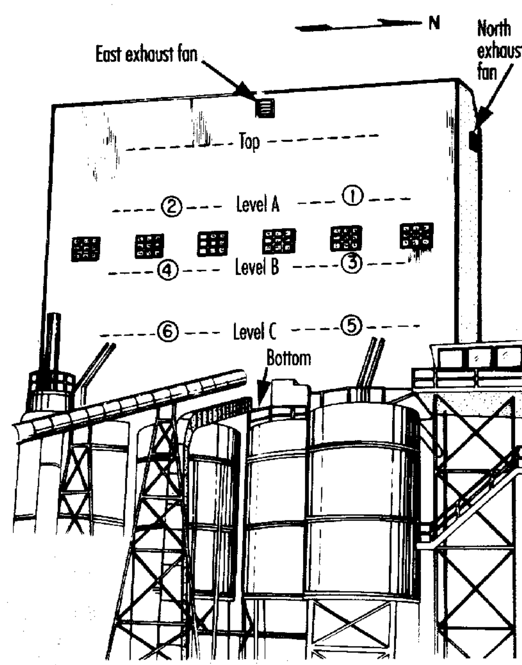


Table I

Respirable dust concentration reductions for plant 1 (in percent)

	Sampling location									
	1		2		3		4		5	
Day	Gravimetric	RAM-1	Gravimetric	RAM-1	Gravimetric	RAM-1	Gravimetric	RAM-1	Gravimetric	RAM-1
					Winter					
1	64.9	54.8	33.3	18.5	40.7	55.0	55.0	53.4	33.5	*
2	49.0	18.4	54.2	43.8	40.9	35.0	67.4	55.3	*	72.5
					Spring					
3	37.4	20.1	66.7	53.5	14.6	22.7	48.7	38.2	53.4	12.1
4	63.3	44.3	27.7	46.3	0	33.3	27.6	37.2	44.8	29.5
5	48.3	16.8	63.5	56.9	27.3	26.2	39.5	35.9	19.2	9.9

*Note: Equipment malfunctioned.

Procedure. Dust-monitoring instruments were installed at six locations in the plant (Figure 3):

- Gravimetric dust samplers were mounted at locations 2 (level A), 4 (level B), and 6 (level C) on the plant's south wall.
- RAM-1s were installed at all six locations.

Continuously monitoring digital thermometers were also installed on levels A, B, and C in the plant to determine whether the ventilation system could cool the plant, which would be an additional benefit. High plant temperatures were a problem because of hot summers here and heat generated by the equipment.

The tests were run over two 14-hour days in the beginning of summer. On day 1, results were recorded with the ventilation system off, and then with two or four fans operating in alternating periods; in all the tests, the windows were closed. On day 2, results were also recorded when the system was off and with either two or four fans operating, but during 1 hour of testing with four fans, the windows were open.

Results. The tests showed that the ventilation system reduced the plant's respirable dust concentrations and slightly cooled the plant air. The results also showed that when the windows were opened, ventilation was less effective in the plant's bottom portion.

Table II lists the gravimetric dust sampler results for both days. These results show that the overall average respirable dust concentration dropped between about 25 and 78 percent with two fans operating. It dropped between about 60 and 86 percent when four fans were operating.

Table III shows the RAM-1 results for both days. (The unit at location 5 malfunctioned, so no results for this area were obtained.) They show that the plant's overall respirable

Table II

Gravimetric dust sampler results for plant 2 (respirable dust concentration reduction in percent)

Number of fans operating	Level A, sampling location 2	Level B, sampling location 4	Level C, sampling location 6
Day 1			
2	24.8	56.4	45.6
4	70.5	72.6	59.5
Day 2			
2	54.9	52.4	77.5
4	76.9	80.5	86.4

Table III

RAM-1 results for plant 2

Sampling location	Fans off (concentration mg/m³)	Two fans		Four fans		Four fans, windows open	
		Concentration (mg/m³)	Reduction (%)	Concentration (mg/m³)	Reduction (%)	Concentration (mg/m³)	Reduction (%)
Day 1							
1	2.17	1.17	46.08	0.88	59.45	*	*
2	2.53	2.39	5.53	1.35	46.64	*	*
3	2.36	1.43	39.41	0.85	63.98	*	*
4	2.04	0.92	54.90	0.71	65.20	*	*
6	1.92	1.16	39.58	0.89	53.65	*	*
Day 2							
1	2.59	1.69	34.75	1.06	59.07	1.02	60.62
2	3.67	2.10	42.78	1.18	67.85	1.18	67.85
3	3.31	2.13	35.65	0.97	70.70	1.35	59.22
4	3.68	2.46	33.15	1.02	72.28	1.68	54.35
6	2.32	1.58	31.90	0.61	73.71	1.48	36.21

*Note: No testing performed.

dust concentration averaged 2.66 mg/m³ before the ventilation system was operated. With only two fans operating, the average concentration dropped to 1.7 mg/m³ — a 36.1 percent average reduction. With four fans operating, the average concentration was 0.95 mg/m³, representing a 64.3 percent average drop.

Figure 4 shows temperatures recorded at three levels in the plant on day 1. With the system off, the temperature rose; with the system on, the temperature fell.

When the windows were opened for 1 hour on day 2 with four fans operating (Table III), the ventilation was less effective in the plant's bottom portion, as indicated by the high dust concentration and temperature (location 6). At location 6, the RAM-1 recorded an average respirable dust concentration of 0.61 mg/m³ with the windows closed, compared with 1.48 mg/m³ with the windows open. And the only time level C's temperature exceeded the level A and B temperatures was when the windows were opened. At this time most of the system's makeup air was coming through the windows and prevented effective ventilation in the plant's bottom portion.

Efforts to estimate optimal ventilation volume

The researchers expected plant 2's ventilation system, which provided up to 34 air changes per hour, to allow them to estimate an approximate optimal operating point for ventilation systems. They planned to predict this by plotting a curve showing dust concentration reduction versus ventilation volume at several operating points. The theoretical curve would be linear up to an area — the optimal ventilation volume — where it would start to flatten out. The researchers theorized that as the ventilation volume continued to increase past this point, the curve would flatten, showing reduced efficiency as the system began to overpower the plant's other dust control equipment. But the ventilation profile plotted with the plant 2 test results for four fans (maximum ventilation volume) was still in the curve's linear portion; that is, the curve continued to rise instead of flattening out.

The researchers also noted a substantial difference in efficiency between plant 2's east and west fans and north and south fans due to the region's prevailing winds, as indicated in tracer gas tests they also performed at the plant.[3] The researchers determined it would have been better to install two fans each on the east and west walls to avoid working against the prevailing winds.

The researchers concluded that the optimal ventilation volume can vary substantially from one plant to another and can be higher than expected for some applications. But they did develop practical design criteria for an effective whole-plant ventilation system.

System design criteria

To be effective, a whole-plant ventilation system must meet three design criteria:

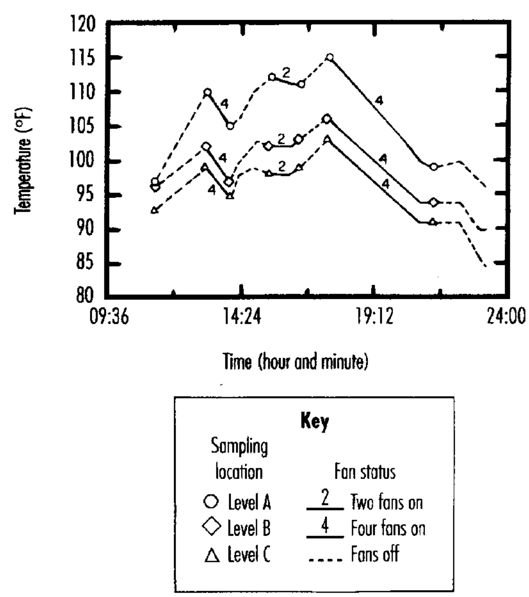
1. Clean makeup air. The system must supply clean makeup air at the plant's base. Contaminated makeup air will increase dust concentrations and worker exposure, as shown in a previous study.[4] You can ensure the intake air is clean by controlling the air's entry through inlets such as wall louvers at strategic locations, plant doors, or other openings.

2. Effective airflow pattern. The system should provide an effective airflow pattern that ventilates the entire plant and also sweeps through dust sources and work areas. You can achieve this by properly locating the exhaust fans and makeup air inlets. The latter must be located not only to provide clean makeup air but to create the most effective airflow pattern for purging the entire plant.

3. Well-sealed plant shell. Because the ventilation system draws makeup air through the points of least resistance, the plant's outer shell should be intact — that is, without open or broken windows, wall or roof cracks or holes, or openings near the fans. Any openings can short-circuit the ventilation system's designed airflow pattern and reduce its effectiveness. This happened in the plant 2 test when

Figure 4

Day 1 temperature readings for plant 2



the windows were opened and only the plant's upper floors were well-ventilated.

Other design considerations

Consider several other factors when designing a ventilation system, including your region's prevailing winds, potential freeze-up problems, environmental effects, and cost.

Prevailing winds. The direction of prevailing winds around your plant can affect your ventilation system. With roof exhaust fans, the effect can be minor, as in plant 1. But with wall fans, as in plant 2, the winds can reduce your system's effectiveness. Avoid placing wall fans where the prevailing winds can work against them; instead, mount the fans where the exhaust air can flow with the wind. This also minimizes dust recirculation into the plant via the makeup air.

Potential freeze-up problems. In some cases, the whole-plant ventilation system may increase freeze-up problems with process equipment in a climate with extremely low winter temperatures. To avoid the problem, you can heat the makeup air, but this will increase the system's operating costs. You can also turn off some of the fans in the system to reduce the intake air volume.

But in many cases the ventilation system doesn't contribute to freeze-up problems. For instance, the plant 1 ventilation system seemed to have no effect on freeze-up problems during extremely cold weather. The plant had no heating system, and the only heat source during winter was from the process equipment. Temperatures were similar inside and outside the plant whether or not the ventilation system was operating. Most freeze-up problems occurred during the night, when both the plant and ventilation system were shut down. Since the ventilation system's installation, the system hasn't increased freeze-up problems in the plant.

Environmental effects. Consider how the ventilation system will affect outdoor air quality. Make sure the system complies with your state's EPA Clean Air Act regulations.

Plants 1 and 2 complied with EPA regulations. No dust plume was visible at any exhaust point. The exhausted dust was quickly diluted by atmospheric air, reducing its potential for contaminating the environment or outdoor workers. The researchers periodically measured dust concentrations outside each plant's base with handheld instruments, which also indicated no dust increase.

Cost. The whole-plant ventilation system is probably the most cost-effective method for reducing respirable dust levels. At plant 1, the system equipment and installation by an outside contractor cost about $10,000. At plant 2, the total system cost was only about $6,000 because the fans were wall-mounted, permitting installation by maintenance workers. Maintaining the system is also easy and low-cost because the fans are the only moving parts.

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References

1. American Conference of Governmental Industrial Hygienists, *Industrial Ventilation: A Manual of Recommended Practice* (20th edition), 1988; P.S. Eshelman, "Correcting OSHA's citations with ventilation," *Proceedings of the Symposium on Silica,* Industrial Health Foundation, 1975, pages 105-120.

2. Tests conducted by the dust and toxic substance control branch, NIOSH, Pittsburgh.

3. More information on the tracer gas study at plant 2 is available from the author.

4. Andrew B. Cecala and Edward D. Thimons, "Impact of background sources on dust exposure of bag machine operators," US Bureau of Mines Information Circular 9089, 1986.

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