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Project Summary

Iron and Steel Plant Open Source Fugitive Emission Control Evaluation

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Open dust sources in the iron and steel industry were estimated to emit 88,800 tons/year suspended particulate in 1978 based on a 10 plant survey. Of this, 70, 13, and 12% were emitted by vehicular traffic on unpaved roads, vehicular traffic on paved roads, and storage pile wind erosion, respectively. Emission measurements, utilizing the exposure profile technique, indicate a 17% solution of a petroleum resin (Coherex^R) in water on an unpaved road reduced heavy-duty vehicle emissions by 95.7% for total particulate, 94.5% for particulate <15 μm, and 94.1% for particulate <2.5 μm (averaged over the first 48 hours after application). Plain water reduced emissions 95% for all particle sizes half an hour after application. Four hours later, efficiency of watering had dropped to 55% (total), 49.6% (<15 μm), and 61.1% (<2.5 μm). Coherex^R on an unpaved road travelled by light-duty vehicles reduced emissions by 99.5% (total), 98.6% (<15 μm), and 97.4% (<2.5 μm), 25 hours after application. Control efficiency decayed to 93.7% (total), 91.4% (<15 μm), and 93.7% (<2.5 μm), 51 hours after application.

On paved roads, vacuum sweeping reduced emissions 69.8% (total), 50.9% (<15 μm), and 49.2% (<2.5 μm), 2.8 hours after vacuuming. Forty minutes after water flushing, emissions were reduced by 54.1% (total), 48.8% (<15 μm), and 68.1% (<2.5 μm). Combined flushing and broom sweeping reduced emissions by 69.3% (total), 78.0% (<15 μm), and 71.8% (<2.5 μm), 40 minutes after application.

Control of emissions from coal storage piles varied from 90% to almost zero depending on the type of treatment, length of time since treatment was applied, and windspeed. Tests were performed using a portable wind tunnel.

Relationships were developed to determine relative cost effectiveness of open source emission controls.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Previous studies of open dust particulate emissions from integrated iron and steel plants provided strong evidence that open dust sources (e.g., vehicular traffic on unpaved and paved roads, aggregate material handling, and wind erosion) should occupy a prime position in control strategy development. These conclusions were based on comparability between industry-wide uncontrolled emissions from open dust sources and typically controlled fugitive emissions from major process sources such as steelmaking furnaces, blast furnaces, coke ovens, and sinter machines. Moreover, preliminary cost-effectiveness analysis of promising control options for open dust sources indicated that control of open dust sources might result in significantly improved air quality at a lower cost in relation to control of process sources. (Cost-effectiveness is defined as dollars expended per unit mass of particulate emissions prevented by control.) These preliminary conclusions warranted gathering more definitive data on control performance and costs for open dust sources in the steel industry.

The cost reduction potential of open dust sources has not been missed by the iron and steel industry. With the advent of the Bubble Policy (Alternative Emissions Reduction Options) on December 11, 1979 (revised April 7, 1982), the industry recognized the economics of controlling open dust sources as compared to implementing more costly controls on stack and process fugitive sources of particulate emissions. However, the Bubble Policy requires the demonstration of no net gain in emissions from an imaginary bubble surrounding the plant.

To demonstrate no net gain in emissions as a result of a proposed controlled trading scenario, the controlled emission rate for an open dust source must be estimated using the equation:

$$R = Me(1-C)/2{,}000$$

where: R = mass emission rate, tons*/year
M = annual source extent
e = uncontrolled emission factor (i.e., pounds of uncontrolled emissions per unit of source extent)
C = overall control efficiency, expressed as a fraction.

Values for uncontrolled emission factor, e, can be calculated using the predictive emission factor equations shown in Table 1. These predictive equations are the outcomes of numerous prior MRI field tests. Parameters (e.g., moisture and silt contents of the emitting material, or equipment characteristics) which may affect particulate emission levels from open sources were identified and measured

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(*)Although EPA policy requires using metric units, certain nonmetric units are used in this summary for clarity. Readers more familiar with metric units may use the conversion factors at the end of this summary

Table 1. Open Dust Emission Factors Experimentally Determined by MRI

Source Category	*Measure of Extent*	*Emission Factor[a] lb/unit of source extent*	*Correction Parameters*
Unpaved roads	*Vehicle-miles traveled*	$5.9 \left(\frac{s}{12}\right)\left(\frac{S}{30}\right)\left(\frac{W}{3}\right)^{0.7}\left(\frac{w}{4}\right)^{0.5}\left(\frac{d}{365}\right)$	*s = Silt content of aggregate or road surface material, %* *S = Average vehicle speed, mph*
Paved roads	*Vehicle-miles traveled*	$0.09\ I \left(\frac{4}{N}\right)\left(\frac{s}{10}\right)\left(\frac{L}{1{,}000}\right)\left(\frac{W}{3}\right)^{0.7}$	*W = Average vehicle weight, tons* *L = Surface dust loading on traveled portion of road, lb/mile*
Batch load-in (e.g., front-end loader, railcar dump)	*Tons of material loaded in*	$0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{h}{5}\right)}{\left(\frac{M}{2}\right)^{2}\left(\frac{Y}{6}\right)^{0.33}}$	*U = Mean wind speed at 4 m above ground, mph* *M = Unbound moisture content of aggregate or road surface material, %*
Continuous load-in (e.g., stacker, transfer station)	*Tons of material loaded in*	$0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{h}{10}\right)}{\left(\frac{M}{2}\right)^{2}}$	*Y = Dumping device capacity, yd*^{3} *K = Activity factor[b]* *d = Number of dry days per year* *f = Percentage of time wind speed exceeds 12 mph at 1 ft above the ground*
Active storage pile maintenance and traffic	*Tons of material put through storage*	$0.10\ K \left(\frac{s}{1.5}\right)\left(\frac{d}{235}\right)$	*D = Duration of material storage, days*
Active storage pile wind erosion	*Tons of material put through storage*	$0.05 \left(\frac{s}{1.5}\right)\left(\frac{d}{235}\right)\left(\frac{F}{15}\right)\left(\frac{D}{90}\right)$	*e = Surface erodibility, tons/acre/year* *P-E = Thornthwaite's Precipitation-Evaporation Index*
Batch load-out (e.g., front-end loader, railcar dump)	*Tons of material loaded out*	$0.0018 \frac{\left(\frac{s}{5}\right)\left(\frac{U}{5}\right)\left(\frac{h}{5}\right)}{\left(\frac{M}{2}\right)^{2}\left(\frac{Y}{6}\right)^{0.33}}$	*N = Number of active travel lanes* *I = Industrial road augmentation fator[c]*
Wind erosion of exposed areas	*Acre-years of exposed land*	$3{,}400 \frac{\left(\frac{e}{50}\right)\left(\frac{s}{15}\right)\left(\frac{f}{25}\right)}{\left(\frac{P\text{-}E}{50}\right)^{2}}$	*w = Average number of vehicle wheels* *h = Drop height, ft* *F = Percentage of time unobstructed wind speed exceeds 12 mph at mean pile height*

[a] *Particulate smaller than 30 μm in diameter based on particle density of 2.5 g/cm*^{3}*.*

[b] *Equals 1.0 for front-end loader maintaining pile tidiness and 50 round trips of customer trucks per day in the storage area.*

[c] *Equals 7.0 for trucks coming from unpaved to paved roads and releasing dust from vehicle underbodies;*
Equals 3.5 when 20% of the vehicles are forced to travel temporarily with one set of wheels on an unpaved road berm while passing on narrow roads;
Equals 1.0 for traffic entirely on paved surface.

during the testing process. For sources with a sufficient number of tests, multiple linear regression formed the basis upon which significant variables were identified and then used in developing the predictive equation.

The annual source extent can be estimated by plant management from plant records and discussions with operating personnel. The variable with the least accurate data to support an estimate of controlled emissions is the control efficiency. Table 2 summarizes open dust source controls that are or have been used in the iron and steel industry. Control efficiency values are needed for all the techniques shown in Table 2.

Table 2. *Summary of Potential Open Dust Source Control Techniques*

Source	*Control technique*
Unpaved roads and parking lots.	*A. Watering* *B. Chemical treatment*[a] *C. Paving* *D. Oiling*
Paved roads and parking lots.	*A. Sweeping* *1. Broom* *a. Wet* *b. Dry* *2. Vacuum* *B. Flushing*
Material handling and storage pile wind erosion	*A. Watering* *B. Chemical treatment*[a]
Conveyor transfer stations.	*A. Enclosures* *B. Water sprays* *C. Chemical sprays*[a]
Exposed area wind erosion.	*A. Watering* *B. Chemical treatment*[a] *C. Vegetation* *D. Oiling*

[a] *For example: salts, lignin sulfonates, petroleum resins, wetting agents, and latex binders.*

Variables Affecting Control Efficiency

Open dust source control efficiency values can be affected by four broad categories of variables: time-related variables, control application variables, equipment characteristics, and characteristics of surface to be treated.

Time-Related Variables

Because of the finite durability of all surface-treatment control techniques, ranging from hours (watering) to years (paving), it is essential to tie an efficiency value to a frequency of application (or maintenance). For measures of lengthy durability, the maintenance program required to sustain control effectiveness should be indicated. One likely pitfall to be avoided is the use of field data on a freshly applied control measure to represent the lifetime of the measure.

The climate, for the most part, accelerates the decay of control performance adversely through weathering. For example, freeze/thaw cycles break up the crust formed by binding agents; precipitation washes away water-soluble chemical treatments like lignin sulfonates, and solar radiation dries out watered surfaces. On the other hand, light precipitation might improve the efficiency of water extenders and hygroscopic chemicals like calcium chloride, and will definitely improve efficiency of watering.

Control Application Variables

The control application variables affecting control performance are: application intensity, application frequency, dilution ratio, and application procedure. Application intensity is the volume of solution placed on the surface per unit area of surface: the higher the intensity, the better the expected control efficiency. However, this relationship applies only to a point, because too intense an application will begin to run off the surface. The point where runoff occurs depends on the slope and porosity of the surface.

Equipment Characteristics

Equipment characteristics that affect control efficiency values are those involved in imparting energy to the treated surface which might break the adhesive bonds keeping fine particulate composing the surface from becoming airborne. For example, vehicle weight and speed can affect the control efficiency for chemical treatment of unpaved roads. An increase in either variable accelerates the decay in efficiency. Figure 1 is a general plot portraying the change in rate of decay of the control efficiency for a chemical suppressant applied to an unpaved road as a function of vehicle speed, weight, and traffic volume.

Characteristics of Surface to be Treated

Surface characteristics that contribute to the breaking of a surface crust will affect control efficiency. For example, for unpaved road controls, road structure characteristics affect control efficiency. These characteristics are: combined subgrade and base bearing strength, amount of fine material (silt and clay) on the surface of the road, and the friability of the road surface material. Unacceptable values for these variables mainly affect the performance of chemical controls. Low bearing strength causes the road to flex and rut in spots with the passage of heavy trucks; this destroys the compacted surface enhanced by the chemical treatment. A lack of fine material in the wearing surface deprives the chemical treatment of the increased particle surface area necessary for interparticle bonding. Finally, the larger particles of a friable wearing surface material simply break up under the weight of the vehicles and cover the treated road with a layer of untreated dust.

Project Objectives

The overall objective of this project was to provide data that will document quantities of particulates generated from controlled open dust sources at steel plants and the cost-effectiveness of control procedures for eliminating or reducing emissions. Required to achieve the above objective were:

- Field tests to measure emissions from open dust sources to determine the efficiency of selected control procedures.
- Evaluation of data obtained in the test program to determine the change in efficiency over time.

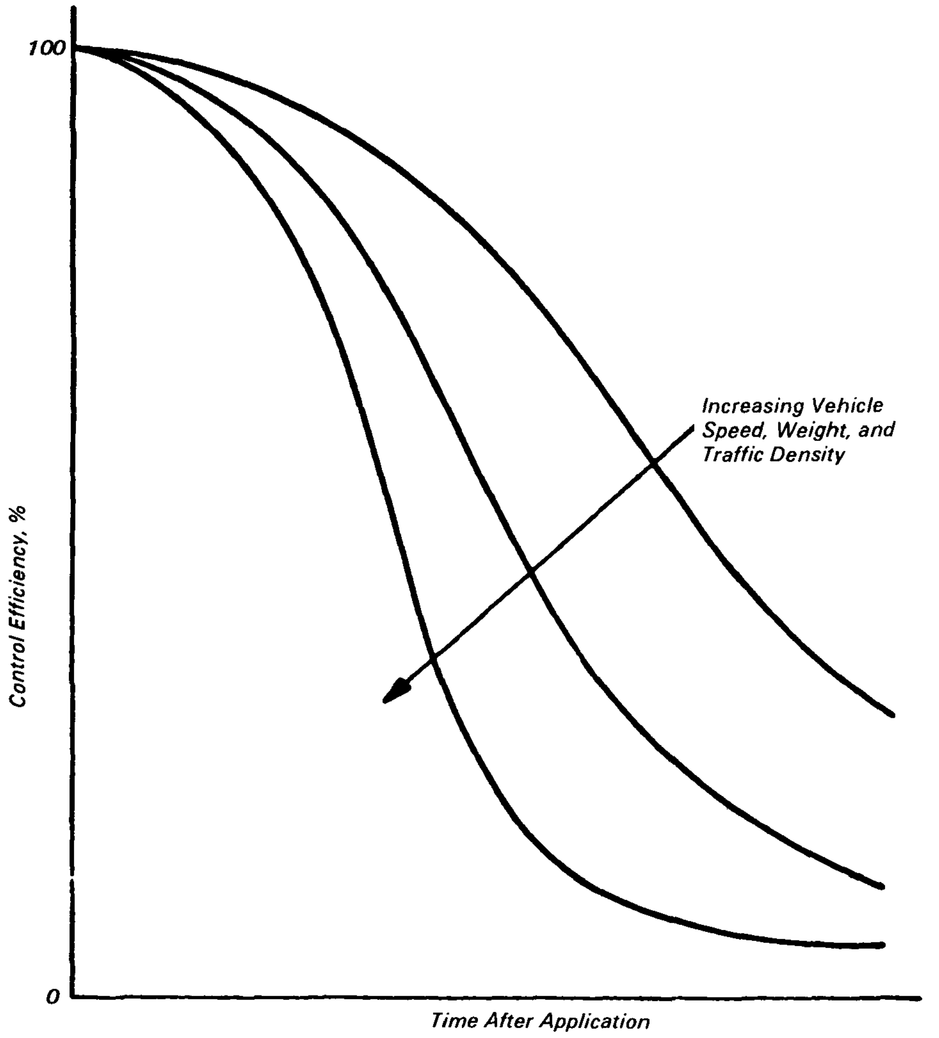

Figure 1. *Effect of vehicle speed, weight, and traffic density on control performance.*

- Development of design and operating information on all control procedures evaluated, including optimum operating procedures; operator and material requirements; design parameters; capital, operating, and maintenance costs; and energy requirements.

Report Structure

The report is structured as follows: Section 2.0 gives results of a 10-plant survey to determine the extent of open dust sources and controls in the iron and steel industry; Section 3.0 contains the methodology and results of source testing via exposure profiling; Section 4.0 contains the methodology and result of wind erosion testing via a portable wind tunnel; Section 5.0 presents cost, design, and operating information related to control techniques; and Sections 6.0 through 8.0 present references, a glossary, and English-to-metric conversion units, respectively.

Numbers in the report are generally rounded to three significant figures; therefore, columns of numbers may not add to the exact totals listed. Rounding to three significant figures produces a rounding error of less than 0.5%.

Summary and Conclusions

The purpose of this study was to measure the control efficiency of various techniques used to mitigate emissions from open dust sources in the iron and steel industry, such as vehicular traffic on unpaved and paved roads and wind erosion of storage piles and exposed areas. The control efficiency was determined not only for total particulate (TP), but also for inhalable particulate (IP)—particles less than 15 μm in aerodynamic diameter, and for fine particulate (FP)—particles less than 2.5 μm in aerodynamic diameter. In addition to control efficiency measurement, parameters defining control design, operation, and cost were quantified.

The methodology for achieving the above goals involved the measurement of uncontrolled and controlled emission factors for emissions from vehicular traffic on unpaved roads, vehicular traffic on paved roads, and storage pile wind erosion. These sources were selected based on an open dust source emission inventory for the iron and steel industry which showed the above three sources to contribute 70.4%, 12.7%, and 11.5%, respectively, of the 88,800 T/yr of suspended particulate emitted by the industry.

The exposure profiling method developed by MRI was the technique utilized to measure uncontrolled and controlled emission factors from vehicular traffic on paved and unpaved roads. Exposure profiling of roadway emissions involves direct isokinetic measurement of the total passage of open dust emissions approximately 5 m downwind of the edge of the road by simultaneous sampling at four or five points distributed vertically over the effective height of the dust plume. Size distributions were measured at 1 and 3 m heights downwind utilizing cyclone precollectors followed by parallel slot cascade impactors. During selected tests, size selective inlets mounted on high volume samplers were also deployed downwind.

Nineteen tests of controlled and uncontrolled emissions from vehicular traffic on unpaved roads were performed. Ten tests were of heavy-duty traffic (greater than 30 tons) and nine were of light-duty traffic (less than 3 tons).

In calculating the efficiency of a control technique from emission factor measurements collected during controlled and uncontrolled tests, the effect of testing during different periods in the lifetime of the control was taken into account. The decay of control efficiency with time after application has a number of causes, such as track-on from surrounding integrated surfaces and mechanical abrasion of the treated road surface. Accordingly, each value of control efficiency contained in this report includes the time after application that the measurement was taken.

Two control techniques utilized to reduce emissions from heavy-duty traffic on unpaved roads were tested: (1) a 17%

solution of Coherex® in water applied at an intensity of 0.86 l/m^2 (0.19 gal./yd^2), and (2) water applied at an intensity of 0.59 l/m^2 (0.13 gal./yd^2). The control efficiency for Coherex®, at the above application intensity, averaged over the first 48 hr after application, was 95.7% for TP, 94.5% for IP, and 94.1% for FP. The control efficiency for watering at the above application intensity, 4.4 hr after application, was 55.0% for TP, 49.6% for IP, and 61.1% for FP. The control efficiency of watering at the above application intensity was above 95% for all particle sizes half an hour after application.

Only one control technique for emissions from light-duty vehicles travelling on unpaved roads was tested. The control measure was a 17% solution of Coherex® in water at an application intensity of 0.86 l/m^2 (0.19 gal./yd^2). The control efficiency of Coherex® at the above application intensity, 25 hr after application, was 99.5% for TP, 98.6% for IP, and 97.4% for FP. This road had been closed to traffic for a day. Fifty-one hours after application, these efficiencies had decayed to 93.7% for TP, 91.4% for IP, and 93.7% for FP.

Three control techniques for mitigation of emissions from vehicles travelling on paved roads were tested: vacuum sweeping, water flushing, and flushing with broom sweeping. The highest measured values for the control efficiency of vacuum sweeping, occurring 2.8 hr after vacuuming, were 69.8% for TP, 50.9% for IP, and 49.2% for FP. The control efficiency for water flushing at 2.2 l/m^2 (0.48 gal./yd^2), about 40 min after application, was 54.1% for TP, 48.8% for IP, and 68.1% for FP. The control efficiency for flushing and broom sweeping, about 40 min after application with water applied at 2.2 l/m^2 (0.48 gal./yd^2), was 69.3% for TP, 78.0% for IP, and 71.8% for FP.

Earlier MRI studies of open dust sources in the iron and steel industry produced data bases which were used to develop predictive emission factor equations. The precision factors for the paved and unpaved road equations were 2.20 and 1.48, respectively. When the results of the 18 tests of uncontrolled particulate emissions from vehicular traffic on roads performed during this study were added to the data bases, the precision factors increased to 3.95 and 1.98, respectively. These increases indicate the need for possible refinement of the paved and unpaved road equations based on the larger data bases now available.

A portable wind tunnel was used to measure uncontrolled and controlled emission factors from storage pile wind erosion. The wind tunnel involves measuring the amount of emissions eroded from a given surface under a known wind speed. MRI's portable open-floored wind tunnel was placed directly on the surface to be tested, and its wind flow adjusted to predetermined centerline speeds. The emissions eroded from the surface were measured isokinetically at a single point in the sampling section of the tunnel with a sampling train consisting of a tapered probe, cyclone precollector, parallel slot cascade impactor, backup filter, and high volume sampler.

Wind erosion from storage piles was quantified during 29 tests of uncontrolled and controlled emission factors. Nearly all of the tests were on coal surfaces with two control techniques studied separately: (1) a 17% solution of Coherex® in water applied at an intensity of 3.4 l/m^2 (0.74 gal./yd^2), and (2) a 2.8% solution of Dow Chemical M-167 latex binder in water applied at an average intensity of 6.8 l/m^2 (1.5 gal./yd^2). The control efficiency of Coherex® applied at the above intensity to an undisturbed steam coal surface approximately 60 days before the test, under a wind of 15.0 m/s (33.8 mph) at 15.2 cm (6 in.) above the ground, was 89.6% for TP and about 62% for IP and FP. The control efficiency of the latex binder on a low volatility coking coal 2 days after application, under a 14.3 m/s (32.0 mph) wind speed at 15.2 cm (6 in.) above the ground, was 37.0% for TP and near zero for IP and FP. However, when the wind speed was increased to 17.2 m/s (38.5 mph), the control efficiency increased to 90.0% for TP, 68.8% for IP, and 14.7% for FP. The efficiency under the same wind speed, 17.2 m/s, decayed 4 days after application to 43.2% for TP, 48.1% for IP, and 30.4% for FP.

Three iron and steel plants were surveyed to determine open source emission control design, operation, and cost parameters. Design and operation parameters included application intensity and frequency, life expectancy, applicator equipment manufacturer, normal operating speed, capacity, fuel consumption, vehicle weight, number and capacity of nozzles at a specified pressure, and maintenance problems. Cost data included operating, maintenance, and capital investment costs. The operating and maintenance costs were further divided into labor, gasoline and oil, maintenance and repair, and depreciation costs. The capital investment costs included purchase and installation of primary and ancillary equipment.

Conclusions from this study are:

1. Open dust emissions from the entire integrated iron and steel industry for 1978 were estimated at 88,800 T/yr of suspended particulate. The total can be subdivided into general categories:

Category	*Percent Contribution*
Vehicular traffic on unpaved roads	*70.4*
Wind erosion	*15.0*
Vehicular traffic on paved roads	*12.7*
Continuous raw material handling operations	*1.6*
Batch raw material handling operations	*0.3*

2. A decay in control efficiency with time after application was measured for most of the control techniques tested. This means that a reported efficiency value has meaning only when given in conjunction with a time after a specified application. Within 5 hr of application, the control efficiency afforded by watering of unpaved roads decayed from nearly 100% to about 60%, but the control efficiency of Coherex® remained above 90% over the first 2 days after application. The decay rates of control measures applied to paved roads (which were much less effective than those applied to unpaved roads) were high; i.e., comparable to the rate observed for watering of unpaved roads.
3. There is some indication that short-term control efficiency varies as a function of particle size, especially for the paved road control techniques tested. For example, vacuuming is less effective in controlling fine particle emissions, but the opposite is indicated for water flushing.
4. Wind erosion from the coarse aggregate storage piles tested and observed at iron and steel plants is probably much less than previously thought. Tests show that, for typical storage pile surfaces, 10 m wind speeds in excess of 14.8 m/s (33.2 mph) are necessary for wind erosion to even begin. Also, crusts on piles and exposed surfaces are very effective inhibitors of wind erosion as long as the crust remains unbroken. Current thinking suggests that the major wind erosion problem exists on unencrusted areas (e.g., surrounding the piles, exposed areas, and road shoulders) and unpaved roads. Also, piles which have dozer or scraper traffic on them (atypical in the

iron and steel industry) are susceptible to wind erosion. Finally, as would be expected, uncrusted piles of fine dry material are also susceptible to wind erosion.

5. The control efficiency of the latex binder tested for effectiveness in reducing wind erosion increased with increasing wind speeds. This may apply to other wind erosion dust suppressants and to a broader range of wind speeds than those tested, but the data are still too sparse to support that inference.
6. The optimal cost-effective technique for applying open dust controls is to make the application and then reapply only after the initial application has decayed to zero control efficiency. However, this will yield only about 50% control efficiency, assuming the technique started at 100%. In controlled emissions trading (such as offsets, banking, and bubbles), much more than 50% reduction in open dust source emissions may be needed. Thus, optimization of cost-effectiveness in the control of open dust source emissions must always be considered in the context of a minimally acceptable level of control.

   There is no clear-cut definition of "best" control strategy for open dust source emissions. Two possible definitions are:
   a. That strategy which achieves the constraint of an acceptable level of emissions reduction at the least cost; and
   b. That strategy which achieves the minimally acceptable level of control and is the least expensive per unit mass of emissions reduced.

   Although the cost of (b) cannot be less than that of (a), (b) may indeed prove to be more desirable in the long term because greater offsets are possible and thus represents the most efficient use of funds.
7. Evaluation of the emission reduction effectiveness of an open dust source control measure requires the acquisition of detailed performance data on the control measure. The performance data gathered to date on open dust sources in the iron and steel industry have focused on the efficiences of freshly applied control measures for given sets of application parameters. Additional field tests would be required to determine the long term efficiency decay.
8. As with the initial control efficiency, the decay rate of a control measure should depend in part on the application parameters. Taking unpaved roads as an example, the frequency of application, the application intensity, and the dilution ratio of the chemical suppressant are of paramount importance. Also, there may be a residual effect of previous control applications which changes the shape of the decay curve, although this residual effect may become less important after repeated reapplication/decay cycles. Theoretically, a mathematical relationship could be developed which expresses mean control efficiency (during the period between applications) as a function of the application parameters and the frequency of application once a sufficiently large emissions data base has been obtained.
9. As part of the emission trading process, a calculated emission reduction requires information on the uncontrolled emission factor and the performance of the proposed control measure. Except for unpaved roads, the current uncontrolled open source emission factor equations listed in Table 1 are based on a limited number of tests. The control efficiency data base for these sources is even more limited, both in the small number of control efficiency values measured and the lack of data on the long-term efficiency of controls. This situation leads to corresponding levels of uncertainty when implementing emission trades.

Metric Conversion Factors

Readers more familiar with metric units may use the factors below to convert the English units used in this summary.

English	*Multiplied by*	*Metric*
acre	*0.00405*	*km^2*
ft	*0.305*	*m*
gal./yd^2	*4.53*	*liters/m^2*
lb	*0.454*	*kg*
lb/acre year	*112*	*kg/km^2 year*
lb/ton	*0.500*	*kg/tonne*
lb/vehicle mile	*0.282*	*kg/vehicle km*
mile	*1.61*	*km*
mph	*0.447*	*m/s*
ton	*0.907*	*tonne*
yd^3	*0.765*	*m^3*

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The complete report, entitled "Iron and Steel Plant Open Source Fugitive Emission Control Evaluation," (Order No. PB 84-110 568; Cost: $17.50, subject to change) will be available only from:

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