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CONVEYOR BELT DUST CONTROL

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Martin Marietta Corporation
Martin Marietta Laboratories

BUREAU OF MINES
UNITED STATES DEPARTMENT OF THE INTERIOR

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The belt conveyor is one of the major pieces of equipment for transferring bulk material in mining operations. However, considerable amount of respirable dust may be generated whenever the bulk material is loaded, dumped, or transferred. This report identifies and evaluates various dust control technolgies applicable to belt conveyors, and describes how an integrated systems approach can reduce dust emissions at a transfer point.

Phase I of the program consisted of a literature search and a critical evaluation of various dust control technologies. The work established that a comprehensive approach to calculating exhaust volumes for dust collection system does not exist. The parameters that affect the wet dust suppression efficiency were also reviewed.

Based on the Phase I work, bulk material handling system and dry dust collection or wet dust suppression systems were designed and installed at a number of transfer points in a limestone processing facility, a surface mine selected as a field test site. Field test data were used to determine the validity of various exhaust volume calculations at the different transfer points. The field test data also formed the basis for the evaluations of the relative effectiveness of commercially available and wet dust suppression systems in controlling respirable dust emissions.

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*** FOREWORD

This report was prepared by the staff of the Center for Occupational Health Engineering, Martin Marietta Laboratories, Baltimore, Maryland, under U.S. Bureau of Mines Contract No. H0113007. Mr. Richard Wilson of the Twin Cities Mining Research Center was Technical Project Officer at the start of the contract and Mr. Sterling Anderson of the Twin Cities Center was Technical Project Officer at its completion. Mr. Doyne W. Teets was the contract administrator for the Bureau of Mines. The report is a summary of work for the period 9 February 1981 to 5 December 1983 and was first submitted by the authors in March 1984.

This project was conducted under the technical supervision of Mr. Vinit Mody, with Mr. Raj Jakhete as co-principal investigator; both are the authors of this report. Martin Marietta Laboratories staff who also participated on this project are: Messrs. Bill Harris, Kurt Holderied, Christopher Scheer, Douglas Farquar, and James Blackburn.

The authors are grateful for the cooperation of the staff of Genstar Corporation's Marriottsville, Maryland, facility. Special thanks are due Messrs. Carroll Geldmacher, Roy Wagner, and Price Hearst for their excellent cooperation, assistance, and direct field support during the design, installation, and field evaluation phases of the program.

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*** EXECUTIVE SUMMARY

The belt conveyor is one of the major pieces of equipment for transferring bulk material in mining operations. However, a considerable amount of dust may be generated whenever the material is loaded, dumped, or transferred, thus potentially exposing mine operating and maintenance personnel to harmful respirable dust. The Bureau of Mines, as part of its continuing efforts to reduce employee exposure to respirable dust, has funded the present program, "Conveyor Belt Dust Control," to identify existing dust control technologies and field test them for effectiveness, durability, and reliability over an extended period.

The program consisted of three major phases. In Phase I, the authors critically reviewed the state of the art in dust control technologies and selected two dust control techniques (dust collection and wet dust suppression) for field testing that are applicable to a wide range of belt conveyor installations in mining operations. From a number of candidate sites surveyed in Phase I, the Genstar Corporation's Marriottsville, Maryland, facility was selected for field testing. An interim report summarizing Phase I efforts was submitted in July 1981.

In Phase II, designs based on the selected dust control techniques were developed and installed at the field test site. In Phase III, the installed systems were field tested during an 18-month period.

Originally, the program called for design and testing of a dust collection and a wet dust suppression system at only two belt conveyor transfer points; however, Martin Marietta and Genstar, along with the Bureau of Mines, provided additional support to expand the scope to include the 10 most frequently encountered transfer points in a mining facility.

The dust control system elements installed at these transfer points consisted of:

1) Bulk material handling components to reduce dust generation and emissions and contain dust at the source, and
2) A dust collection system to capture airborne respirable dust or a wet dust suppression technique to control or prevent airborne dust.

The work performed under Phase I of the program indicated how an integrated systems approach could effectively reduce respirable dust emissions at a transfer point. Application of bulk material handling systems was cited as the first major step in combatting respirable dust emissions from transfer points. The use of known bulk material handling components, such as rockboxes, muckshelves, enclosures, and dust seals, at the selected in-mine test site appeared to reduce and control dust generation enough to substantially decrease the load on the dust collection or wet dust suppression systems. A particularly clear demonstration of the benefit achievable was seen during the field testing of a vibrating screen circuit, where we had installed Trellex dust seals on the vibrating screen and necessary enclosures and rubber seals at the associated transfer points. The exhaust volume computed based on literature approaches ranged from a total of 7,600 cfm to 11,600 cfm, while our data showed a dust control system effectiveness of about 65% for volumes between 1,250 cfm and 8,400 cfm at all the sampling locations. The high performance at the lower exhaust volume rates would probably not have been possible without the aid of a good bulk material handling system.

The Phase I work also established the absence of a comprehensive approach for calculating the proper exhaust volumes for applications of dust collection techniques. Various rules of-thumb or empirical formulas have been used by designers to calculate exhaust volumes, but our field evaluations of a dust collection system at various transfer points during an 18-month period confirmed the inadequacy of a number of presently recommended prediction methods. For example, at the primary crusher-to-belt conveyor and the secondary crusher-to-belt conveyor tranfer points, the exhaust volumes predicted by the Industrial Ventilation Manual were too low for dust control, whereas the exhaust volume predicted by the Anderson approach was adequate to control both respirable and total dust. At the vibrating screen circuit, as discussed earlier, both of these approaches predicted exhaust volumes far in excess of that actually needed.

For a typical conveyor belt transfer point, dust is emitted from three locations: "E" (the end of the settling box), "S" (the side of the conveyor), and "T" (the tail pulley). The nature of dust emissions at these points is different. The dust emitted from "S" and "T" locations puffs out through the gaps between the conveyor belt and the skirting rubber or seals and is generally relatively coarse (predominantly non-respirable); at "E" locations, however, emissions consist of dust carried by the air induced along with the material. These dust emissions are finer and are believed to be orders of magnitude times higher for a given material than those at the "S" and "T" locations, assuming a well-sealed system.

Our field evaluations of dust collection systems at the primary crusher-to-belt conveyor and secondary crusher-to-belt conveyor tranfer points led to the concept of a "critical exhaust volume" at the "E" location, which has not previously been reported in the literature. This finding, which was uncovered by data on system efficiency and supported by visual observations, points to the existence of an exhaust volume below which the efficiency of the control system decreases drastically and above which unnecessary ambient air is entrained into the system. The practical importance of this concept lies in the determination of design exhaust volume: it must exceed the "critical exhaust volume" to achieve adequate and reliable dust control, but beyond a certain point, additional exhaust volume (and therefore additional cost) produces no improvement in efficiency.

At the "S" location, on the other hand, the situation is somewhat different. For the secondary crusher-to-belt conveyor transfer point, we found a continuing increase in dust control efficiency with increasing exhaust volume. In other words, there was apparently no "critical exhaust volume" for the sides of the conveyor in the range of exhaust volumes of practical importance. The reason can be traced to the relatively large distance between the exhaust hood and the dust cloud;

at these distances, and in the range of practical exhaust volumes, the hood cannot provide enough driving force to reverse the direction of dust emissions.

During Phase I, we also reviewed wet dust suppression technology. A variety of wet dust suppression systems are currently in use, ranging from a simple homemade water spray system to sophisticated electrostatically charged fogs. Though wet dust suppression systems are widely used, we found that their performance is poorly characterized. Our communications with vendors of commercially available systems failed to elicit quantitative data on the efficiency of their systems: performance evaluation was largely based on "before" and "after" pictures.

Our field testing of wet dust suppression techniques at a hammermill crusher-to-belt conveyor transfer point indicated that respirable dust suppression efficiencies of over 75% can be achieved by simple, inexpensive water sprays. The efficiency of the commercial Sonic wet dust suppression system, on the other hand, ranged from 44% at the same transfer point to over 70% at a belt conveyor-to-belt conveyor transfer point. The high efficiencies obtained using simple water sprays indicate that good material-water mixing plays a significant role in reducing dust generation, and thus dust emissions, and that simple methods can be effective if applied properly.

Through actual field test data, the program has thus furthered the understanding of some of the critical elements and their relative roles in the design and/or selection of an effective dust control system. Moreover, we believe that the results have raised enough questions to warrant further research using our data as a building block.

*** 1. INTRODUCTION

The belt conveyor is one of the major pieces of equipment for accomplishing bulk material transfer between equipment used in mining operations such as chutes, crushers, elevators, vibrating screens, storage hoppers, feeders, kiln, and dryers. It is also one of the most prevalent dust emission sources, since dust is generated whenever material is dumped, loaded, or transferred. As a result, equipment operators, maintenance personnel, laborers, and truck drivers suffer harmful exposure to respirable dust.

Due to the diversity of belt conveyor applications, dust controls are not usually incorporated into conveyor systems at the time of manufacture. It is therefore necessary to employ retrofit techniques for older facilities or to allow for dust control systems when new facilities are in the design phase. Both of these applications are governed by similar objectives -- chiefly, to integrate an efficient and effective dust control system without sacrificing production.

The basic technology for controlling respirable dust emissions from belt conveyors is available, but has not previously been critically reviewed and field tested for application to the mining industry. The two types of systems in general use, wet dust suppression and dry dust collection, can both be ineffective if applied without sound knowledge of the processes and objectives involved.

Wet dust suppression systems are popular since they offer reasonable control at a relatively low capital expenditure. However, many wet systems that appear adequate for large particles may be ineffective in controlling respirable-sized airborne dust. Also, with wet systems, the effects of simply shifting the dust further downstream are seldom considered.

Dust collection systems, which are based on industrial ventilation principles, require much greater capital expenditure, and in general, provide better control of respirable dust by removing it from the process stream. However, in dust collection systems, the design of the capture elements is of utmost importance, and these elements are frequently ineffective in actual use.

The Bureau of Mines, as part of its continuing efforts to reduce respirable dust emissions, has funded the present program, "Conveyor Belt Dust Control," to identify existing dust control technologies that can be applied to most mining operations employing conveyors and to evaluate them for effectiveness, durability, and reliability over an extended period of time. The program consisted of three major phases:

1) Data collection and analysis of existing dust control technologies and site characterization
2) Design, fabrication, and installation of prototype dust control systems
3) Field evaluation of the prototype systems.

In Phase I, we assessed dust control technologies, as they existed in 1981, through an extensive literature search combined with site visits and personal communications. The technologies in three principal areas were assessed: bulk material handling to reduce dust generation and emissions, dust collection systems, and wet dust suppression systems to control dust emissions further. The bulk material handling systems were assessed to determine their effectiveness in reducing dust generation and in containing dust emissions at the source. Investigations of dust collection systems were primarily directed towards determining 1) how well respirable dust could be controlled at the source through the use of industrial ventilation principles in general, and 2) the exhaust volumes needed to control dust emissions effectively at various transfer points. Information on state-of-the-art wet dust suppression techniques and various commercially available systems was collected, and the systems were evaluated against a uniform set of criteria, such as: predicted effectiveness; capital, operating, and maintenance costs; and applicability to a wide range of belt conveyor installations.

An interim report summarizing Phase I efforts was submitted to the Bureau in July 1981, and Chapter 2 contains a major portion of this report. The purpose of including this information is to familiarize the reader with the various dust control techniques and their probable shortcomings, as well as the state of the art in dust control technologies in 1981.

In Phase II of the program, we designed and installed prototype dust control systems at the selected test site. The original scope of the program called for testing the dust collection and wet dust suppression systems at only two belt conveyor transfer points. However, through cost sharing by industry in general, and Martin Marietta and Genstar corporations in particular, the program scope was broadened to include a total of six transfer points involving belt conveyors and crushers. A subsequent contract modification expanded the program further to include a vibrating screen circuit consisting of belt conveyors, a vibrating screen, and storage bins. Thus, we designed and installed dust control systems at a total of 10 of the most commonly encountered transfer points. The description of our Phase II efforts, including the detailed design of dust control systems at each of these transfer points, is given in Chapter 3.

In Phase III, we evaluated the installed dust control systems to establish their effectiveness and reliability. Chapter 4 describes the sampling strategies adopted, and the statistical techniques used in data analysis. The detailed data analysis and performance evaluations of the dust control systems installed are contained in Chapter 5. Chapter 6 provides guidelines for designing an effective dust control system at some of the commonly encountered transfer points in a typical minerals processing plant.

Conclusions for the entire program effort are presented in Chapter 7. Based on our experience gained in the present program, we suggest certain areas for further research and development in Chapter 8.

*** 2. PHASE I REVIEW

2.1. BACKGROUND

Belt conveyors have often been dubbed the "workhorses" of bulk material handling systems. Over the years they have proven to be a dependable and low-cost method of moving bulk materials at high volume. However, they are also one of the major contributors to the ambient dust concentrations in a mining facility.

Belt conveyors emit dust almost exclusively from the tail pulley where material is received, the head pulley where material is discharged, and the return idlers due to the "carryback" of fine dust on the return belt. These dust particles become airborne during material transfer and, if small enough, can remain suspended in the air indefinitely. The amount of dust emitted at these transfer points (belt-to-belt, crusher-to-belt, etc.) depends upon the physical characteristics of the material and the manner in which the material is handled. Dust control at these transfer points can be accomplished by three major methods:

1) Preventive measures to control dust generation, emissions, and dispersion during bulk material handling
2) Dust collection using industrial ventilation
3) Wet dust suppression using water sprays with or without surfactants.

Design of a dust control system thus requires a thorough knowledge of the processes and principles involved in bulk material handling, as well as techniques to either capture the dust or prevent it from becoming airborne.

2.2. BULK MATERIAL HANDLING FOR CONTROL OF DUST

Total prevention of dust generation in bulk material handling operations is an impossible task; however, minimizing attrition, unnecessary ambient air entrainment, and impaction of bulk materials is not only possible but often desirable from the standpoint of product quality. The design of bulk material handling systems, therefore, plays an important role in dust control. The following factors should be considered in designing a belt-conveyor transfer point.

2.2.1. Belt Loading

The amount of dust generated at belt conveyor transfer points depends on how the material is initially loaded onto the belt. If the material is placed centrally on the belt so that its speed and direction of travel, as nearly as possible, are the same as that of the receiving belt itself, then the reduced turbulence of the material will decrease the dust generation at the transfer point.

2.2.2. Impact at the Loading Point

The considerable impact forces generated when material is loaded onto the belt deflect the belt between the adjoining idlers and cause dust leakage under the skirtboard rubber seals. However, if idlers are closely spaced under the loading point, the belt deflections and thus dust emissions can be reduced (fig. 1).

2.2.3. Loading Chutes

Properly designed loading chutes are important to reduce air entrainment and dust leakage through worn areas. Where lumps and fines are mixed, the Conveyor Equipment Manufacturer's Association (1) recommends a chute width at least twice the maximum lump size; for uniformly sized lumps with very few fines, the inside dimensions of the chute should be at least 2-1/2 to 3 times the largest dimension of the lump.

Wear and tear from loading a mixture of fines and lumps on the belt may be avoided either by arranging the chute to place a layer of fines on the belt ahead of the lumps, or by using a curved or perforated chute bottom or grizzly chutes (fig. 2). These measures will also reduce the dusting at a transfer point.

In the case of abrasive material, customarily the chute bottom is equipped with a "stone box" or "rockbox" which acts as a retaining box for some of the material. The retained material in the rockbox absorbs the impact of the incoming material and thus reduces the wear on the chute bottom (fig. 3). To aid in dust control, the rockbox can also be utilized to reduce the height of free fall of material which, in turn, reduces the amount of entrained air.

Underlined numbers in parentheses refer to items in the list of references at the end of this report.

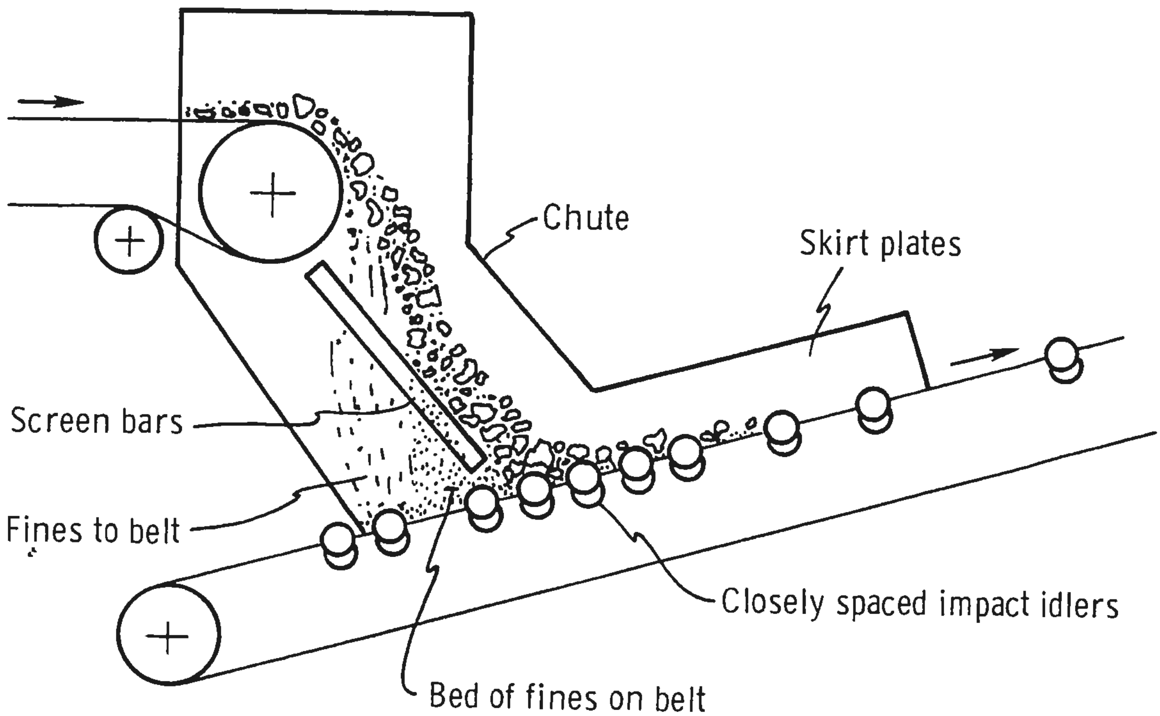


FIGURE 1. - Belt-to-belt transfer point equipped with closely spaced impact idlers.

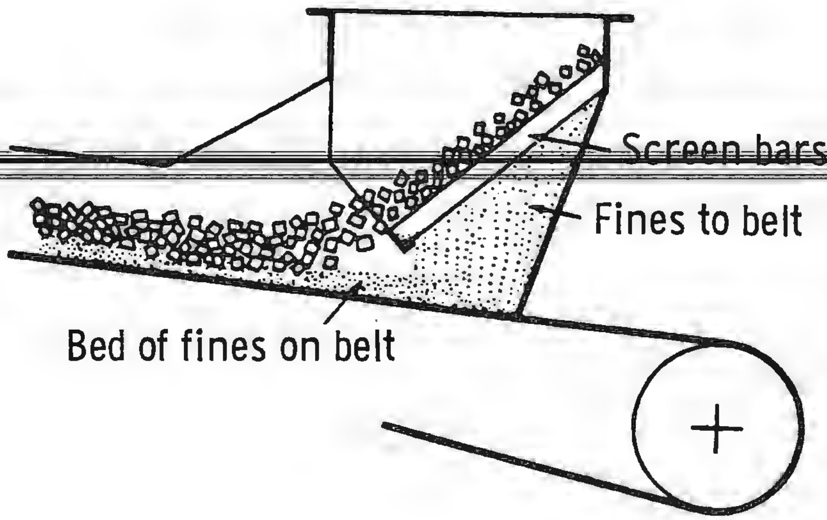


FIGURE 2. - Loading chute equipped with grizzly or screen bars to provide a layer of fine material ahead of impacting lumps. (Reproduced by permission of Conveyor Equipment Manufacturer's Association, Ref. 1.)

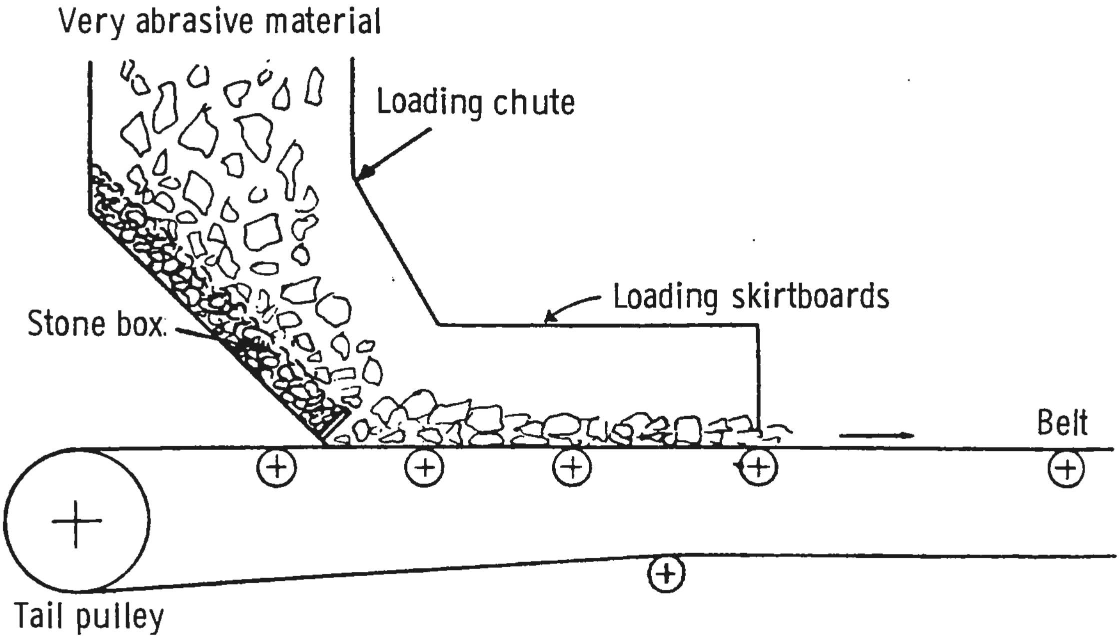


FIGURE 3. - Use of stone box at a transfer point to reduce impact, wear, and dust emissions.

2.2.4. Skirtboards

Traditionally, skirtboards are used to retain the material on the belt after it leaves the loading chute. A frequently recommended distance between skirtboards is two-thirds the width of a troughed belt (fig. 4), and a few inches less than the belt width for flat belts. Morrison (2) recommends that the skirtboards be high enough to contain not only the material volume as it is loaded, but also pressure surges caused by the inflowing material and ingress of induced air. Suppression of these pressure surges minimizes the "puffing" at the openings. The Conveyor Equipment Manufacturer's Association recommends a skirtboard length of 2 ft for each 100 fpm of belt speed but not less than 3 ft.

2.2.5. Skirtboard Rubber Seals

To prevent leakage of fines through the clearance between the lower edge of the skirtboards and the moving belt, seals, consisting of long flat strips of 1/4-in.- to 1/2-in.-thick solid rubber of 60-65 durometer hardness, are bolted to the skirtboards. Since they are usually installed vertically, they soon wear out against the moving belt, thus allowing dust to leak through the openings between the moving belt and skirtboard rubber seals.

2.2.6. Skirtboard Covers

Dust emissions can be reduced through the use of skirtboard covers fastened to the top edges of the skirtboards. Rubber gaskets at all bolted joints will reduce the dust emissions further.

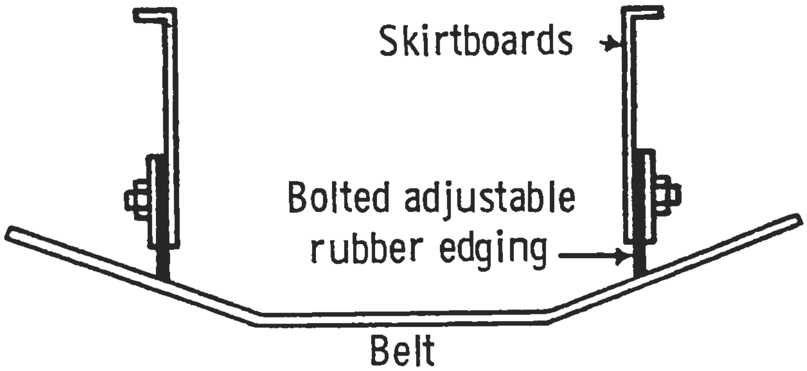


FIGURE 4. - Conventional skirtboards and skirt rubber seals. (Reproduced by permission of Conveyor Equipment Manufacturer's Association, Ref. 1.)

2.2.7. Conveyor Loading Capacity

Belt conveyors are frequently operated in excess of designed capacity. Excessive spillage and dust emissions can result when operating them much in excess of 75% of design capacity. The excessive loadings can also increase wear on skirting rubber seals.

2.2.8. Belt Cleaners

Most belt conveyors travel at high speed. The resulting return idler dribble, due to the "carryback" of the fine materials on the return belt, creates serious dust, as well as maintenance and cleanup, problems. This "carryback" phenomenon, occurring in most operations, is caused by various factors ranging from static electricity to sticky muck. Effective belt scrapers installed at head pulleys can provide a clean belt surface and reduce respirable emissions. Installation of a "scraping" chute for the fine material removed by the belt scrapers is also suggested.

2.2.9. Enclosing Dust Sources

Providing well-designed enclosures around belt conveyor transfer points is a major step towards the containment of dust at the source (fig. 5). A few simple rules, as suggested by Morrison and others, are stated below:

1) Be generous in sizing enclosures: Spacious enclosures permit internal recirculation of dust-laden air, reducing its escape through cracks and openings (fig. 6).

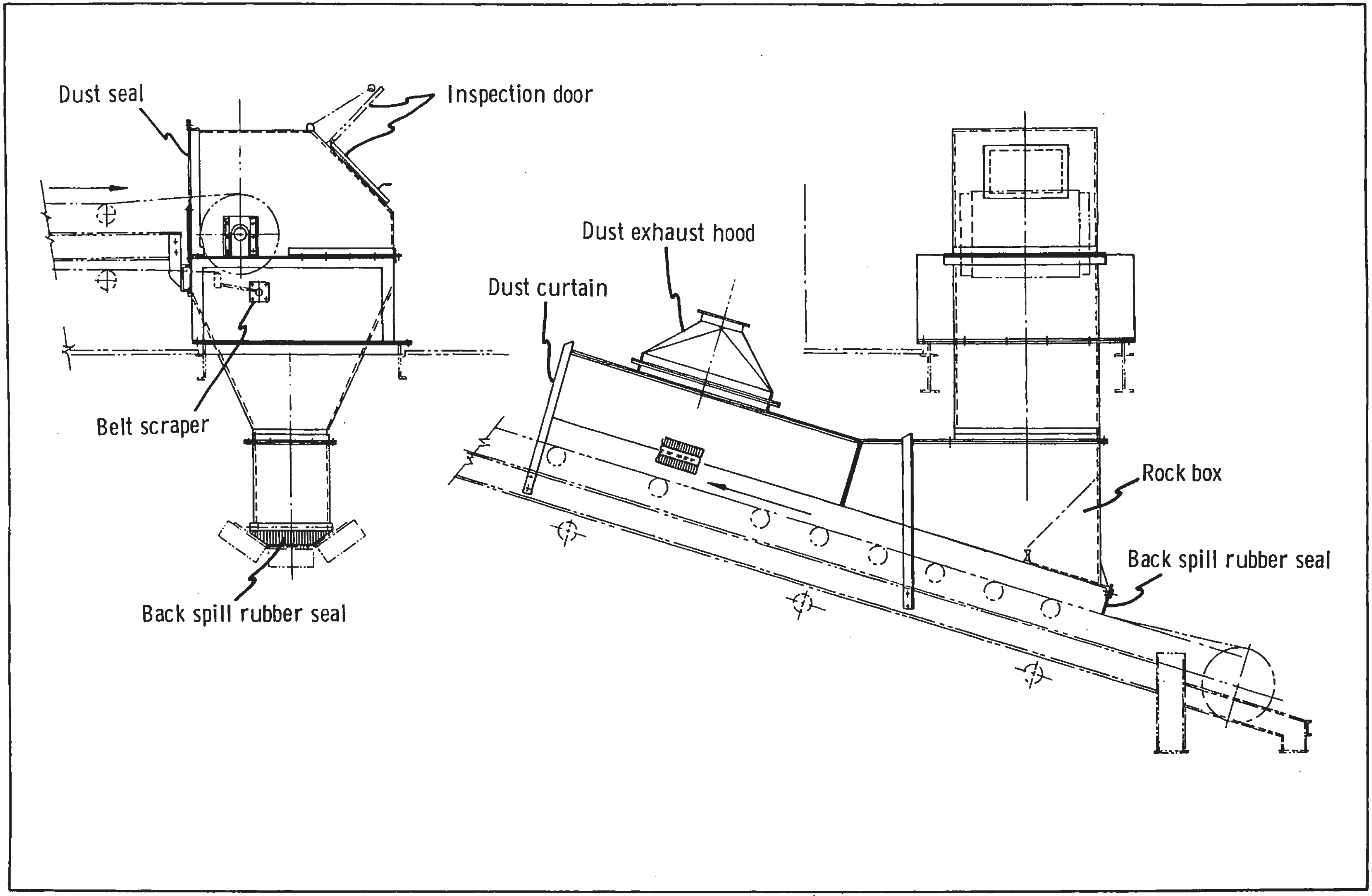


FIGURE 5. - Typical enclosures at the belt-to-belt conveyor transfer point.

EXHAUSTED ENCLOSURES

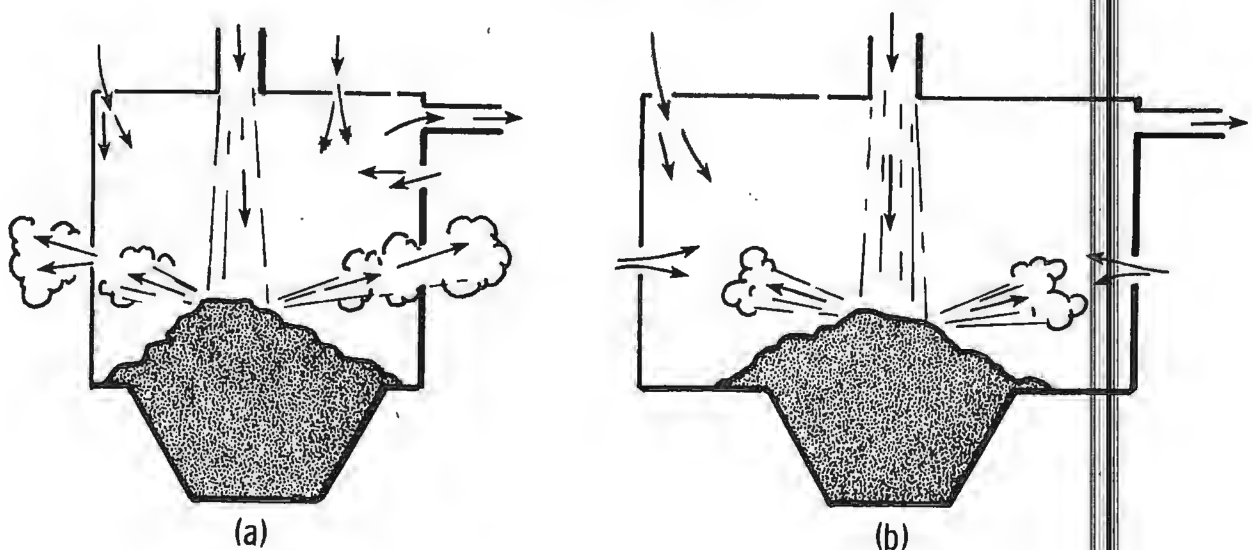


FIGURE 6. - a) In narrow enclosures, dust can escape through openings due to the "splash" effect;

b) Spacious enclosures permit internal air recirculation and prevent dust escape through openings due to "splash".

2) Arrange enclosures in easily removable sections: If enclosures are not built in easily manageable sections, they are regarded as a nuisance by the crew who must service them and may not receive proper maintenance.

3) Provide access doors on enclosures: Access doors facilitate routine inspections and maintenance. These should be hinged and preferably self-closing by gravity. Quick-disconnect clamps should be considered if hinged doors are not possible.

4) Install skirting and curtains at enclosure openings: Rubber curtains are recommended for the open ends of the enclosures (upstream and downstream) with vertical slits approximately 2 in. apart and with the bottom edges cut to conform to the cross-sectional profile of the material conveyed (fig.7). These curtains will contain the dust emissions at the downstream end and reduce the amount of air entrained into the system at the upstream end.

2.3. DUST COLLECTION SYSTEM

The use of local exhaust ventilation principles to control dust is more than half a century old. However, Federal and State concerns with occupational safety-and health-related hazards in the workplace have created an ever-increasing awareness of the need for effective dust control systems. An industrial ventilation system, commonly known as a dust collection system, can provide the desired control only when it is properly planned, designed, constructed, and maintained.

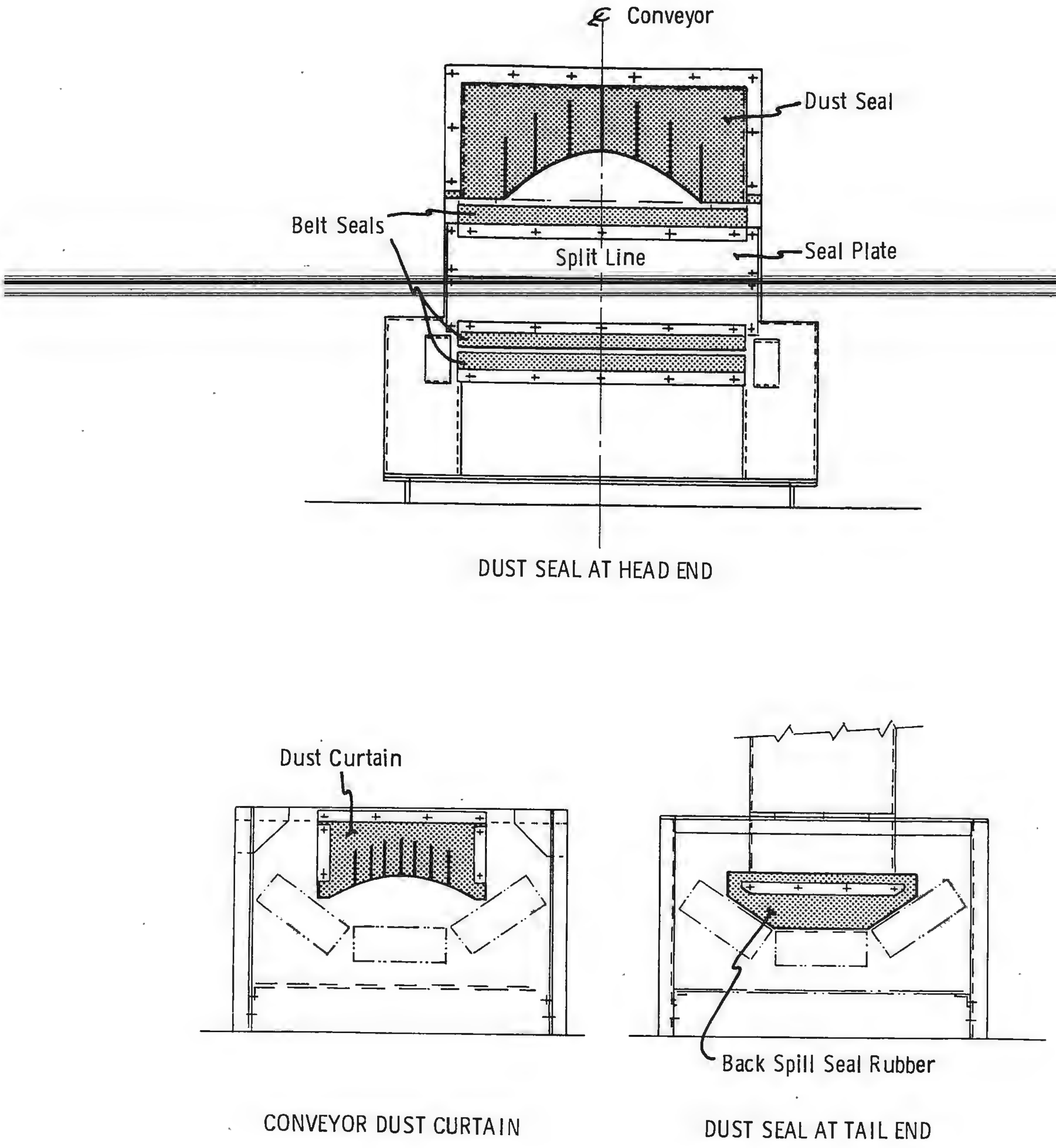


FIGURE 7. - Typical conveyor dust seals.

There are four major components of a dust collection system:

1) An exhaust hood to capture dust at the source
2) Ductwork to transport the captured dust to a dust collector
3) A dust collector to clean the dust-laden gases
4) A fan and motor to provide necessary exhaust air volumes.

2.3.1. Exhaust Hood

Of the four major components, the exhaust hood demands the most careful design because it is the capture efficiency of an exhaust hood that is important from occupational health considerations, not the collection efficiency of a dust collector. For instance, collection efficiencies in excess of 99% can be achieved by a dust collector, but will have no direct bearing on the capture efficiency of the exhaust hood installed at the source.

The capture efficiency of an exhaust hood depends primarily on the exhaust volumes through the hood; therefore, determination of adequate exhaust volumes is one of the most important steps in the design of an effective and reliable dust collection system.

To design an effective hood, sufficient knowledge of the process and operation is essential. The degree of control achieved depends upon:

1) Location and shape of the exhaust hood
2) Rate of airflow through the exhaust hood.

2.3.1.1. Location and Shape of an Exhaust Hood

Major amounts of dust form when the material falls through the transfer chute onto the receiving belt conveyor. At the impact point, however, most of the dust is coarse and settles quickly. If the exhaust hood is located suitably far downstream, it will capture only the finer, and predominantly respirable-sized, dust. This arrangement will reduce dust concentrations in the exhaust gas stream, prevent unnecessary transportation of coarser material within the ductwork and, most important of all, reduce the probabilities of dust settling in the horizontal duct runs.

2.3.1.2. Rate of Airflow Through the Hood

Adequate rate of airflow (i.e., exhaust volume) is the important parameter in the effective capture of dust emissions at the source. Over the years, many industrial standards, so-called rules-of-thumb, have evolved for calculating exhaust volume, based on empirical data for specific operations. However, because they do not have a theoretical basis, these standards are ineffective for many dust control applications. Depending on the specific operation, the exhaust volumes resulting from these rules can be far less than adequate or exceedingly high.

On a broad scale, there are two basic approaches used in the industry to calculate exhaust air volumes:

1) Control velocity
2) Air induction.

2.3.1.2.1 Control Velocity Approach

"Control velocities" are those velocities found through experience to provide sufficient exhaust volumes to counteract the volumes and pressures within the enclosure and thus to capture dust emissions.

Control velocity criteria are derived primarily from the New York State Labor Department code and are used by many vendors of dust control equipment. The exhaust volumes recommended by the Industrial Ventilation Manual (3), cited below, are almost identical to those in the New York State code.

The Industrial Ventilation Manual (IVM), published by the American Conference of Governmental Industrial Hygienists, recommends the following design criteria for determining exhaust volumes necessary to control dust emissions at a belt-to-belt transfer point (fig. 8).

1) Enclose to provide 150-200 fpm in-draft velocities at all openings.
2) Provide a minimum exhaust flow rate of Q = 350 cfm/ft belt width for belt speeds less than 200 fpm.
3) Provide Q = 500 cfm/ft belt width for belt speeds over 200 fpm.
4) For a material fall height of less than 3 ft, provide an exhaust hood at the upstream end.
5) For a fall greater than 3 ft, provide an additional exhaust hood at the downstream end.
6) In the material is dusty, use an additional exhaust at the tail end of the receiving conveyor, with Q = 700 cfm for belt widths of 12-36 in. and Q = 1000 cfm for belt widths over 36 in.
7) Dry and very dusty materials may require exhaust volumes 1.5 to 2.0 times greater than those calculated above.

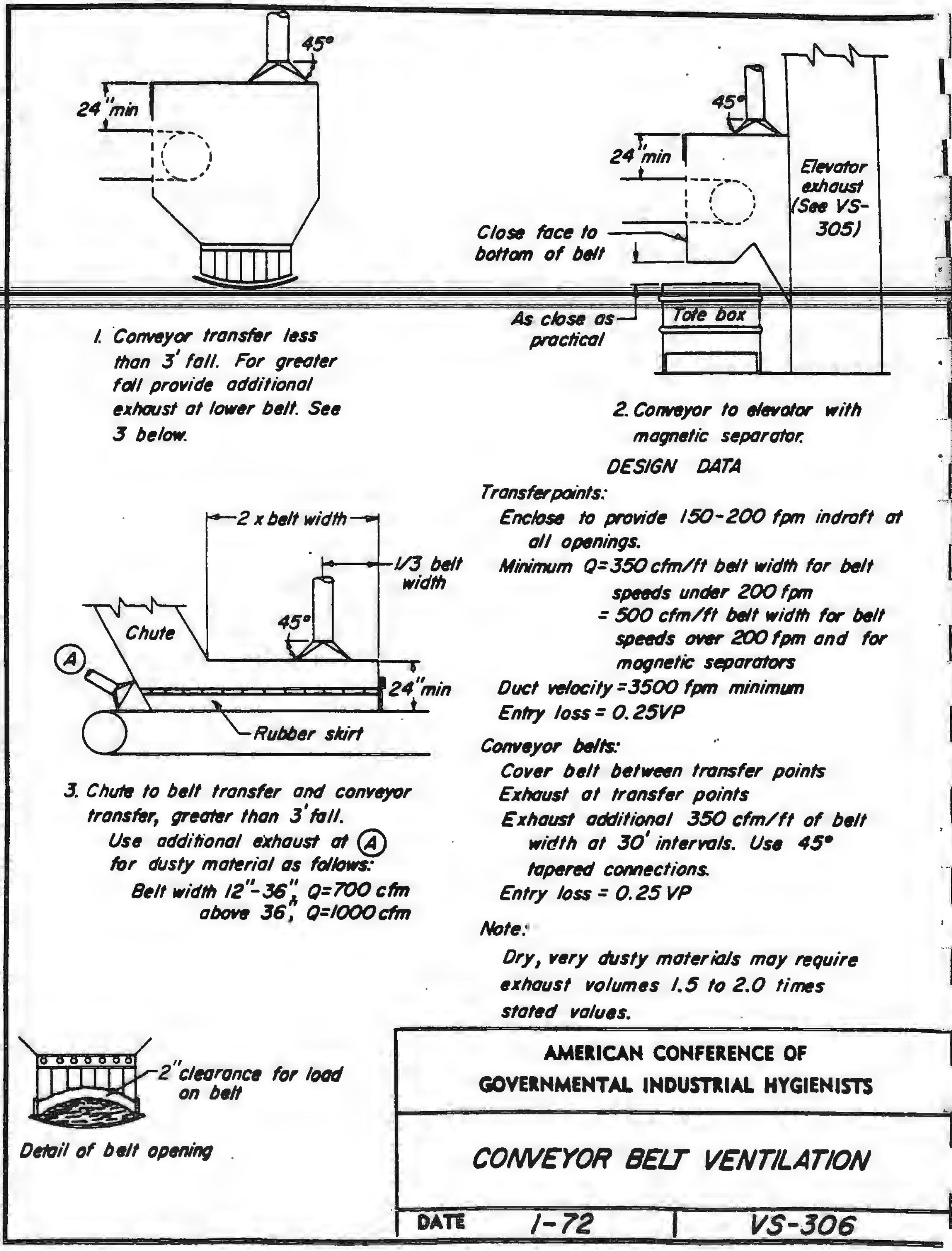


FIGURE 8. - Conveyor belt ventilation. (Reproduced by permission of American Conference of Governmental Industrial Hygienists, Ref. 3.)

These relationships, developed through testing and observation of bulk material handling operations, are entirely dependent on belt speeds. Therefore, their applicability to reduce dust emissions over a wide range of operations and parameters is questionable. This disparity was demonstrated by Pring (4) who compared recommended and experimentally determined exhaust volumes for a 54-in. belt conveyor moving at 350 fpm. The results were:

1) Exhaust volume calculated based on IVM approach = 2250 cfm.
2) Required exhaust volume determined experimentally = 9000 cfm.

Further evaluation of the IVM recommended criteria indicates the following:

1) Important variables, such as material flow rate, material bulk density, material lump (aggregate) size, cross-sectional area of material on the belt, and percentage of full loading on the belt are not considered in the criteria. For instance, at a given belt speed, the area of cross section of material, and hence the material flow rate, can vary depending upon the belt-carrying idlers used (i.e., flat, 15°, 20°, or 35°). An exploratory laboratory study on coal by Cheng (5) indicated that: (1) for heavy belt loads (bed thickness >> mean lump size), an increase in the coal bed reduces the specific formation of airborne respirable dust; and (2) for light belt loads (bed thickness = mean lump size), an increase in belt speed reduces dust formation.
2) When the height of fall is less than 3 ft, the recommended location of the exhaust hood is at the upstream end. This

design is effective only if the enclosure at the head pulley of the feed conveyor is large enough so that the dust plume generated at the receiving belt can rise countercurrent to the material flow and be captured by the exhaust hood. If the enclosure is not sufficiently large, then a "short circuit" may occur, i.e., only "clean" ambient air, which enters through the open area upstream, is exhausted by the hood.

3) For dry and very dusty materials, the IVM recommends higher exhaust volumes (1.5 to 2.0 times greater), but there is no convenient way for a designer to ascertain whether or not a material is dry and very dusty. The American Society for Testing and Materials (ASTM) has an approved method for determining an "Index of Dustiness" for coal and coke. However, using it as a routine design guideline is not only impractical but questionable. Moreover, the generation of dust depends on the hardness of the mined material, which may vary from stratum to stratum in the mine.

The Steel Mill Ventilation Manual (6) published by the Committee on Industrial Hygiene of the American Iron and Steel Institute, recommends another empirical approach, similar to that of the Industrial Ventilation Manual. Here, the exhaust volume is calculated by:

$$Q = SW\sqrt{H/3} \qquad (1)$$

where Q = exhaust air volume, cfm,

S = 350 for belt speeds less than 250 ft/min, 550 for belt speeds between 250-500 ft/min, and 750 for belt speeds greater than 500 ft/min,

W = belt width, ft,

and H = height of material fall, ft.

The use of this equation is qualified by the following design guidelines for enclosures and location of exhaust hoods, which play equally important roles in the successful operation of a dust control system.

1) Calculated exhaust volumes should provide an indraft velocity equal to that of the belt speed at all openings.
2) Enclosures at the downstream end should be at least 4-6 times the belt width in length and one belt width high to accommodate air surges.
3) Exhaust hoods should be located at least two belt widths from the point of impact to avoid pickup of coarser material.
4) Belt scrapers should be used on the return belt when practical.

This empirical relationship has the same drawback as that of the Industrial Ventilation Manual. Although height of fall is incorporated into the equation, this is only one of the major variables that determine needed exhaust volumes. Other variables, such as material flow rate, aggregate size, bulk density, etc., are not considered.

2.3.1.2.2 Air Induction Approach

The air induction approach is based on the theory that when granular material falls through a chute, each solid particle imparts some momentum to the surrounding air, and the aggregate effect is the induction of a stream of air traveling along with the material (fig. 9). This stream serves as a transport medium for the fine dust formed in the process. When the material reaches the belt, impact forces cause the airstream to disperse outward through all openings, carrying the fine dust particulates that became suspended in the process of falling.

Air induction is a function of the moving material and not the conveyor belt. A study by Kruse and Bianconi (7) suggested that no measureable air flow was obtained at transfer points with empty but moving belt conveyors. This phenomenon of air induction is of great significance in calculating exhaust air volumes. Following is a summary of various attempts that have been made to establish air induction rate as a function of material feed rate, height of fall, material stream cross-sectional area, aggregate size, bulk density, etc.

Pring, Knudsen, and Dennis (4)

One of the earliest studies performed to study the effect of various parameters on induced air flow of particles freely falling under gravity was conducted by Pring, Knudsen, and Dennis. These authors experimentally determined the exhaust capacity requirements for effective dust control.

Laboratory tests under controlled conditions showed that the air volume, Q_A, entrained by falling droplets of water, may be expressed as:

$$Q_A = K \ A_p^{0.5} \ (V_w - V_1) \ N \sqrt{A_s} \ (L/W)^{0.139} \qquad (2)$$

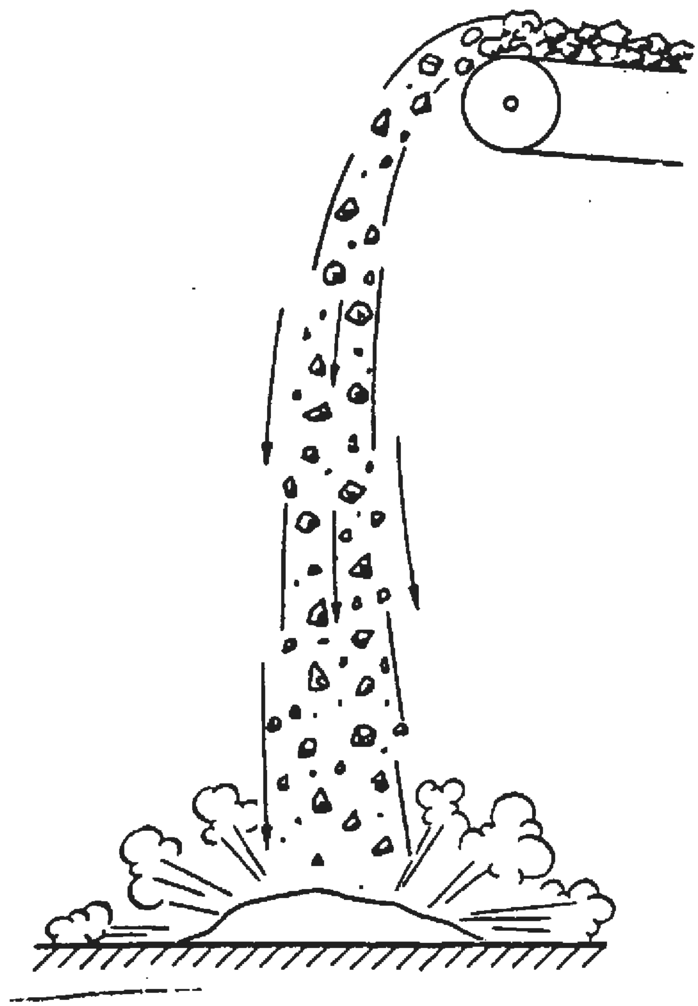


FIGURE 9. - Air entrainment along the column of material and "splash" effect at the impact.

where Q_A = air volume, cfm,

A_p = cross-sectional area of the product stream, ft^2,

V_w = maximum velocity attained by the falling droplets, ft/min,

V_I = velocity intercept at Q_A = 0, ft/min,

N = number of particles in a unit system of single successive drops falling in line,

A_s = projected area per droplet, ft^2,

L = length of droplet stream cross section, ft,

W = width of droplet stream cross section, ft,

and K = constant.

The following results were obtained:

1) The rate of induced air flow is a direct function of the velocity attained by the falling bodies.

2) In the larger particle size range, the square root of the height of fall may be used instead of the actual height. This parameter is incorporated in the velocity, V_w, attained by falling droplets.

3) The rate of air flow does not depend directly on the weight of material, but rather on total projected area of the falling material. This area, in turn, depends on the projected area per particle, the number of particles per unit area, and total cross-sectional area of the product stream.

4) For a system involving several columns of particles within the same stream, where the interference among adjoining particles is to be considered, the following relationship is found:

$$Q_A = f\ (n, A_s, N) \qquad (3)$$

where n = number of columns of particles within the stream.

Equation 2 is of little value for practical application because it requires determination of A_p and N, and the evaluation of factors for particle shape, surface roughness, relative enclosure, and particle crowding to determine K. However, the study defined the relative importance of various variables and has been widely used to arrive at an empirical relationship for the induced air phenomenon.

Hemeon (8)

In his book, Plant and Process Ventilation, Hemeon developed an expression based on the theory that every particle starting from rest and falling freely under gravity passes successively through three flow regions: streamline, intermediate, and turbulent, and imparts some momentum to the surrounding air. The energy transferred by these particles to the surrounding air can be converted into horsepower using the following simplified equation:

$$Q = \sqrt[3]{(HP) \cdot A^2 \cdot 10^{11}} \qquad (4)$$

where Q = induced air flow, cfm,

A = cross-sectional area of material stream, ft^2,

and HP = horsepower.

Moreover, Hemeon developed the following expressions for power generated by particles in each of the three flow regions - streamline, intermediate, and turbulent. Streamline motion is of little significance in a bulk material handling system and therefore is not discussed here.

1) Turbulent fall starting from rest:

$$HP = 0.22 \frac{R \cdot S^2}{Z \cdot d_m} \quad (5)$$

2) Intermediate fall starting from rest:

$$HP = 34 \frac{R \cdot S^{1.7}}{Z \cdot d_m^{1.6}} \quad (6)$$

3) Fall at terminal velocity:

$$HP = \frac{R \cdot S}{550} \quad (7)$$

where R = solid material flow rate, lb/s,

S = distance travelled by particles, ft,

Z = specific gravity of particle,

and d_m = particle diameter.

Examination of the above relationships indicates the following:

1) In bulk material handling operations, particles are of different sizes so that the particle diameter (d_m) is never a single value as the expression assumes. Therefore, some practical difficulties may arise in calculating induced air flow rates.

2) Air flow rates can be calculated from the various reference tables and charts developed by Hemeon, but this process is somewhat tedious when a designer is faced with a number of transfer points.

3) No method to determine the cross-sectional area of the falling material stream is presented. This is a major parameter in determining the air induction rate, and neglecting it could have a significant impact on the results achieved.

4) One limitation to this theory, as rightly pointed out by Hemeon, is that development of the power equations was based on the assumption that each particle acts independently and is completely separated from every other particle. Obviously, this is seldom true.

This approach is useful in one way however; if we assume that all of the energy is devoted to the acceleration of air from a state of rest to an average velocity, we can calculate the maximum possible induced air flow rate. This conservative value can then be used as a check against the values calculated by other methods to ensure an adequate exhaust volume margin.

Anderson (9)

Based on the results of a comprehensive laboratory study made by Dennis (10) at the Harvard School of Public Health, Anderson developed a single empirical equation relating the important variables for induced air flow, as follows:

$$Q_{ind} = 10.0\ A_u \sqrt[3]{RS^2/D} \tag{8}$$

where Q_{ind} = induced air flow, cfm,

A_u = enclosure open area at the upstream end (point where air is induced into the system by the action of the falling material), ft^2,

R = rate of material flow, ton/h

S = height of fall, ft,

and D = average particle diameter, ft.

The single most important parameter in the formula is A_u, the open area at the upstream end through which air is induced. Based on this formula, Anderson suggests values of A_u for various bulk material handling operations:

1) Belt-to-belt and chute-to-belt transfer: For belt-to-belt transfer, A_u = 0.5 times the belt width (ft) for a tight enclosure at both the head and tail pulleys of the feed and return belts , or, A_u = an appropriate value (measured or estimated) based on the tightness of the enclosure.

2) Chute-to-belt transfer: A_u = chute opening at the top instead of the open area around the head pulley.

3) Crusher-to-belt transfer: To achieve good dust control at crushers, ventilation must be applied at the top of the enclosure surrounding the upper portion of the crusher and also at the crusher feed chute-to-belt transfer point downstream. At the upstream location, A_u = enclosure open area at the crusher feed: for the chute-to-belt transfer at the downstream end, A_u = crusher throat opening, S = height from crusher throat to belt, D = average crushed material diameter, and $Q_{exhausted} = 1/3\ Q_{ind}$.

Anderson, in contrast to Morrison and others, claims that since the induction technique predicts conservative exhaust volumes, the designer may neglect the additional, comparatively small volume of 150 cfm per square foot of total openings at the upstream and downstream ends.

Evaluation of this method leads to the following conclusions:

1) The most important factor in the entire formula is "A_u," the opening through which the air induction occurs. Common sense supports this approach -- the tighter the enclosure, the smaller the volume of induced air. For this same reason, a bulk material handling operation equipped with "perfect" dust sealing requires significantly less exhaust volume, i.e., if the amount of induced air is kept to an absolute minimum, the only air that needs to be exhausted is the air volume displaced by the material.

2) Unlike Hemeon, Anderson suggests use of an average value for particle diameter to simplify the calculation process. This assumption has a minimal effect because:

$$Q_{ind} \propto \sqrt[3]{\frac{1}{D}} .$$

Therefore, a 50% reduction in particle diameter would amount to only a 26% increase in induced airflow rate.

Anderson's approach, although semi-empirical, seems to be of significant general value because it accounts for important process variables, such as material flow rate, particle diameter, height of fall, etc., in calculating exhaust volumes.

Kruse and Bianconi (7)

Kruse and Bianconi present a method for calculating induced air flow based on extensive measurements in coal handling systems at the Tennessee Valley Authority's power plants. Air flow measurements were made at

217 belt transfer points and at chutes discharging material from five Bradford breakers and nine hammermill installations. The authors have modified Hemeon's theoretical equation by adding an efficiency factor, $E^{1/3}$, representing the amount of energy transferred to the air, which actually induces air flow. The resulting expression is:

$$Q = 78 \left(\frac{ETA^2h^2}{d_i Z} \right)^{1/3} \tag{9}$$

where Q = rate of induced air flow, cfm,

T = rate of material flow, ton/h

A = cross-sectional area of falling particles, ft^2,

h = free fall distance, ft,

Z = density of material, g/cm^3,

and d_i = mass median diameter of material, in.

Using an assumed efficiency factor of 0.3 and the cross-sectional area of the chute as an estimate of the area enclosed by particles, the authors calculated the amount of air induction for each experimental condition and compared it with previous field measurements. The correlation coefficient between observed and calculated air flow rates was only 0.293. Hatch suggested that the wide differences between calculated and measured values should be expected since the induced air flow for material flow with limited free fall within enclosed inclined chutes may be influenced by factors not included in the fundamental equation.(8)

To overcome this shortcoming, the authors developed an expression that includes a transfer chute efficiency factor, K, and an empirically derived efficiency factor, $e^{-6.5K}$. The resulting expression is

$$Q = \left(\frac{10.5\ Th^{1/3}}{d_i{}^{0.5}Z}\right) e^{-6.5K} \qquad (10)$$

where $K = \frac{(\text{number of chute turns x } 90°)}{\theta \text{ x } h}$

and θ = slope of the chute to the horizontal in degrees.

In contrast to Equation 9, Equation 10 is independent of the cross-sectional area of the falling particles. The correlation coefficient between observed and calculated induced air flows using this expression was 0.728. However, the calculated values were significantly different from the observed values in many cases. Using this relationship requires an accurate estimation of d_i, especially ahead of crusher or breaker equipment. Moreover, high moisture content may affect the material flow through the chute and change the efficiency factor.

Morrison (11)

For effective dust control, Morrison suggests performing an air balance at a transfer point. The ultimate exhaust volume should reflect the following factors:

1) Induced air: an air flow equal to the rate of air induction
2) Displaced air: an air flow equal to the volumetric flow of material
3) Control air: a positive indraft of air at all openings.

Induced Air - Morrison used the Hemeon approach and developed an empirical expression for induced air in a turbulent accelerating velocity zone. Unlike Hemeon, he let particle diameter be the average lump size (instead of calculating air volumes for each particle size segment as suggested by Hemeon). Based on an in-house study, Morrison claimed that there was no significant difference between the exhaust air volumes by the two approaches. The suggested expression is:

$$Q_1 = 110 \sqrt[3]{TH^2A^2/GD} \qquad (11)$$

where Q_1 = induced flow rate, cfm,

T = material flow rate, ton/h

H = height of material drop, ft,

A = cross-sectional area of material stream, ft^2,

G = material density, lb/ft^3,

and D = average material lump size, in.

<u>Displaced air</u> – When material is introduced into an enclosure, an equal volume of air is displaced. To prevent this displaced air from seeking escape, Morrison suggests an additional exhaust air volume equivalent to

$$Q_2 = 33.3\frac{T}{G} ,$$

where Q_2 = displaced air volume, cfm. (12)

<u>Control air</u> – To create an indraft through all openings downstream, Morrison recommends an additional exhaust volume based on a minimum control velocity of 150 ft/min for belt speeds up to 150 ft/min; beyond this speed, the control velocity may be set equal to the belt speed. This relationship is expressed as

$$Q_3 = A_2S_2 \qquad (13)$$

where Q_3 = control air volume, cfm,

A_2 = tail pulley enclosure opening, ft^2,

and S_2 = belt speed, ft/min

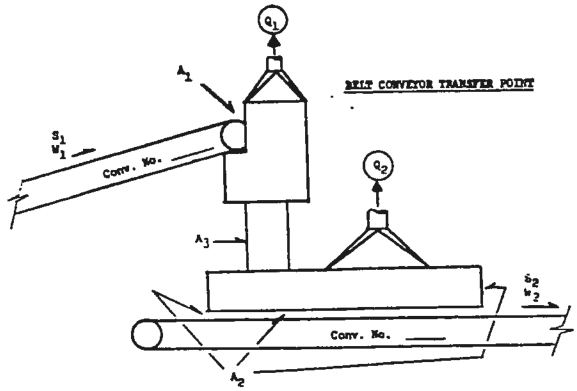
Morrison has prepared a standard calculation form (fig. 10) and made assumptions to simplify design procedures. Evaluation of his method leads to the following conclusions:

1) The value of A, the cross-sectional area of the material stream, is assumed to be equal to the cross-sectional area of the chute. This may not be true in all cases because the area of the chute may vary considerably depending upon the adopted design standards.

2) Under certain conditions, Morrison recommends locating an exhaust hood at the upstream end, similar to the Industrial Ventilation Manual's suggestion. However, with a proper enclosure (i.e., dust curtain), a sufficiently high control velocity can be attained through the openings at the head pulley enclosure to avoid the need for an exhaust hood at the conveyor head end.

3) For a transfer chute with a rockbox (to reduce height of free fall), Morrison, based on the empirical data, recommends a value for effective height equal to 50% of free fall height.

The calculation methods for transfer points suggested by Morrison appear to be more appropriate and practical for exhaust volume determinations than those typically recommended. However, these relationships are useful only for belt-to-belt transfer points, and their application to other transfer points, such as crusher-to-belt and screen-to-belt, has not been determined.



DESIGN DATA

Belt Widths

W_1 = ________ inches

W_2 = ________ inches

Belt Speeds

S_1 = ________ fpm (150 fpm minimum)

S_2 = ________ fpm (150 fpm minimum)

Head Pulley Enclosure Openings

A_1 = ________ sq. ft. (See TABLE 1

Tail Pulley Enclosure Openings

A_2 = ________ sq. ft. (See TABLE 1

Cross-Sectional Area of Material Stream

A_3 = ________ sq. ft. (See TABLE 1

Material Flow Rate

T = ________ tons per hour (1 ton = 2000 lbs.)

Material Bulk Density

G = ________ lbs. per cu. ft.

Average Material Lump Size

D = ________ inches (1/8 in. min.)

Height of Material Fall

H = ________ feet (See TABLE 2

Material Temperature

t = ________ °F

Ambient Air Temperature

t' = ________ °F

HEAD PULLEY EXHAUST RATE, Q_1

1. Induced air through head pulley enclosure openings caused by stream of falling material.

$$q_1 = 110 \sqrt[3]{\frac{TH^2A_3^2}{GD}}$$

$$= 110 \sqrt[3]{\frac{(\quad)(\quad)^2(\quad)^2}{(\quad)(\quad)}} \qquad = \_\_\_\_\_\_\_\_ \text{ acfm}$$

2. Control velocity at head pulley enclosure openings due to induced air in 1.

$$v_1 = \frac{q_1}{A_1} = \frac{(\quad)}{(\quad)} = \qquad = \_\_\_\_\_\_\_\_ \text{ fpm}$$

3. If v_1 is greater than belt speed S_1 required head pulley exhaust rate.

$Q_1 = 0$

4. If v_1 is less than belt speed S_1 required head pulley exhaust rate,

$Q_1 = A_1S_1 - q_1 = (\quad)(\quad) - (\quad)$ = ________ scfm

5. The appropriate Q_1 value from 3 and 4 is equal to the Minimum Required Head Pulley Exhaust Volume, (Q_1 = ________ scfm)

TAIL PULLEY EXHAUST RATE, Q_2

6. Induced air from falling material into tail pulley enclosure.

$q_1 - Q_1 = (\quad) - (\quad)$ = ________ scfm

7. Air displaced by material stream

$33.3 \frac{T}{G} = 33.3 \frac{(\quad)}{(\quad)}$ = ________ scfm

8. Required control volume through tail pulley enclosure openings

$A_2S_2 = (\quad) \times (\quad)$ = ________ scfm

9. The addition of air volumes in 6, 7 and 8 is equal to the Minimum Required Tail Pulley Exhaust Volume. (Q_2 = ________ scfm)

10. Estimating the actual temperature of the exhaust air volumes

$t'' = 0.7t' + 0.3t = 0.7(\quad) + 0.3(\quad)$ = ____________ °F

CONVERSION OF EXHAUST VOLUMES TO ACFM*

11. Head Pulley Exhaust Volume conversion to acfm.

$$Q_1 \text{ (in acfm)} = Q_1 \text{ (in scfm from line 5)} \times \frac{t'' + 460}{530}$$

$$= (\quad) \times \frac{(\quad) + 460}{530} \qquad (Q_1 = \_\_\_\_\_\_\_\_ \text{ acfm})$$

12. Tail Pulley Exhaust Volume conversion to acfm.

$$Q_2 \text{ (in acfm)} = Q_2 \text{ (in scfm from line 9)} \times \frac{t'' + 460}{530}$$

$$= (\quad) \times \frac{(\quad) + 460}{530} \qquad (Q_2 = \_\_\_\_\_\_\_\_ \text{ acfm})$$

*Standard conditions based on 29.92" Hg and 70° F.

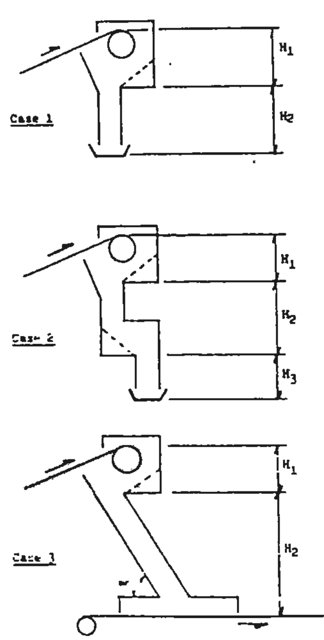
TABLE 1**

W_1 (inches)	A_1 (sq. ft.)	A_2 (sq. ft.)	A_3 (sq. ft.)
18	2.66	2.92	1.04
24	2.89	3.14	1.88
30	3.12	3.40	2.93
36	3.93	3.70	4.16
42	5.19	4.04	5.63
48	6.90	4.42	7.08
54	9.06	4.84	8.72
60	11.67	5.30	10.50

**Values in Table 1 are based on belt conveyor transfer point design according to Dravo mechanical design standards MS-15, MS-22, and MS-23.

TABLE 2

Height of material fall requires special consideration for transfer point arrangements which impose obstructions to the free fall of material. Obstructions commonly encountered are stoneboxes and sloped transfer chutes. Illustrated below are typical cases. Shown with each case is an empirical formula which estimates an "effective" height of material fall. A height (H) calculated by one of these formulas should be used in performing the calculations on Page 2.



Case 1: $H = 0.5H_1 + H_2$

Case 2: $H = 0.5H_1 + 0.5H_2 + H_3$

Case 3: $H = 0.5H_1 + (\sin\alpha) \cdot H_2$

FIGURE 10. - Standard calculation form for determining exhaust air volume. (Reproduced by permission of Society of Mining Engineers, AIME 11.

2.3.2. Ductwork

After the particulates are captured by the exhaust hood, the ductwork transports them to a dust collector. Proper design of ductwork is essential to:

1) Maintain adequate transport velocities so that particulates will not settle out in the ducts
2) Provide proper air distribution at various exhaust hoods and hence maintain the designed capture velocities
3) Reduce wear and abrasion on components such as elbows and "y" branches
4) Minimize friction losses and power consumption.

2.3.2.1. Transport Velocities

To prevent dust settling and plugging of ductwork, the Industrial Ventilation Manual(3) recommends transport velocities of 3,500 to 4,000 fpm for most industrial dust (i.e., granite, silica flour, limestone, coal, asbestos, clay, etc.). For heavier or moist dust, such as lead, cement, quick lime, etc. the recommended velocities are 4,000 to 5,000 fpm.

2.3.2.2. Distribution of Air Flow

Air always takes the path of least resistance. If the design does not provide for proper air distribution in a multiple-branch exhaust system, a natural balance of the air will occur, i.e., the exhaust volume will distribute itself automatically according to the resistance of the available flow paths -- the branch with the least resistance will carry the most volume, and transport velocities in other branches will be reduced. It is, therefore, essential to design a system that will provide a means of distributing proper air flow to maintain adequate capture and transport velocities. Two methods are used to achieve proper air distribution:

1) Air balance without blast gates

2) Air balance by blast gates.

2.3.2.2.1. Air Balance Without Blast Gates

In this method, pressure drops are calculated beginning at the branch of greatest resistance and proceeding up to the fan. At each junction, the static pressures necessary to achieve the desired flow in both streams are matched and the branches are brought into "balance." These static pressures can be balanced at the desired rate of flow by suitable choices of pipe sizes, exhaust hoods, elbows, etc.

2.3.2.2.2. Air Balance by Blast Gates

This method depends on the use of blast gates to achieve the desired air flow at each hood. Here also, the design calculation begins at the branch of greatest resistance, and pressure drops are calculated through each branch and through the various main sections up to the fan. However, no attempt is made to balance the static pressure in the joining air stream. The branches are merely sized to provide the minimum transport velocities. Care must be exercised in selecting the branch of greatest resistance. If the choice is incorrect, any branch or branches having higher resistance will fail to draw the desired air volume even though their blast gates are wide open.

2.3.2.2.3. Choice of Methods

The first method is normally selected where highly toxic materials are exhausted so that possible tampering with blast gates will not affect air flow. The second method provides some flexibility for correcting improperly estimated exhaust volumes. Whichever method is chosen, once a multiple hood layout is completed and balanced, additional hoods should not be added: they may alter the airflow and can make some other hoods totally ineffective. Table 1 compares both approaches.

2.3.2.3. Wear and Abrasion

Excessive air velocities may cause rapid abrasion of ductwork systems handling solid particulates. Although rate of abrasion also depends on other factors, such as size, shape, and hardness of the particulates, transport velocity is the major cause of wear and abrasion. For dust collection systems in bulk material handling operations, the *Industrial Ventilation Manual* recommends the following guidelines:

1) Ducts shall be constructed of black iron, welded, or galvanized sheet steel, riveted and soldered.
2) The recommended minimum wall thickness for a duct of a given diameter is:

TABLE 1

TABLE 1. - COMPARISON OF AIR FLOW DISTRIBUTION METHODS I AND II

Method I. Air Balance Without Blast Gates	Method II. Air Balance by Blast Gates
1. System cannot be tampered with by workmen or at the whim of the operator.	1. System is very sensitive to malfunction due to operator tampering.
2. Only a small degree of flexibility is available for future equipment changes or additions.	2. There is a degree of flexibility for future changes or additions with proper design.
3. Choice of exhaust volumes for a new, unknown operation may be incorrect; in such cases, some ductwork revision is necessary.	3. Improperly estimated exhaust volumes can be corrected easily, up to a certain limit.
4. There are no unusual erosion or accumulation problems.	4. Partially closed blast gates may cause erosion of sides, thereby changing the degree of restriction, or may cause accumulations, particularly linty material.
5. Ductwork will not plug if velocities are carefully chosen.	5. Ductwork may plug if the blast gates become maladjusted.
6. Although calculations are time consuming during design stages, there is no need to measure and balance airflow in the field.	6. Design calculations are fast, but considerable efforts are required in the field to measure the airflow and adjust the blast gates to achieve the desired airflow.
7. Total air volumes may be slightly greater than design air volumes due to additional air handled to achieve balance.	7. Balance can be achieved with designed air volumes.
8. Poor choice of "branch of greatest resistance" will show up in design calculations.	8. Poor choice of "branch of greatest resistance" may remain undiscovered. In such cases, the branch or branches of greatest resistance will be "starved."
9. System layout must be complete and detailed, with all obstructions cleared and length of runs accurately determined. Installations must exactly follow layout.	9. Leeway can be allowed for moderate variations in duct location to account for obstructions or interferences not known at time of layout.

Diameter of Straight Ducts	U.S. Standard Gauge for Steel Ducts
Up to 8 in.	20
Over 8 in. to 18 in.	18
Over 18 in. to 30 in.	16
Over 30 in.	14

3) Elbows and exhaust hoods shall be at least two gauges heavier than straight ducts.

4) Where abrasive material is exhausted, all 90° elbows should be flat back with removable wear plates.

2.3.2.4. Friction Losses and Power Consumption

Once proper exhaust volumes have been determined, and the connecting ductwork has been sized to convey the dust-laden gases at adequate transport velocities to the dust collector, frictional losses in the ductwork must still be overcome. The necessary power is supplied by the fan and the motor. The higher the frictional losses, the greater the motor horsepower requirements. The Industrial Ventilation Manual recommends the following guidelines for ductwork design to reduce friction:

1) All branches should enter the main at a 30° angle, and wherever possible, the air velocity should match that of the incoming gas stream.

2) Duct contractions and enlargements should be kept to a minimum. However, if needed, they should be gradual.

3) Wherever possible, a circular duct should be used instead of a rectangular duct to maintain uniform velocity distribution and, hence, prevent settling of material in the ductwork.

4) Hood entrance losses should be kept to a minimum, and wherever possible, flanges should be provided to minimize the losses.
5) The centerline radii of all elbows should be at least twice the diameter of the duct.

2.3.3. Dust Collector

Dust collectors are essential for removing the contaminants from the exhaust air stream. They are available with a wide range of designs, efficiencies, capital costs, operating and maintenance costs, space requirements, and construction materials. Following are five major categories of dust collectors:

1) Dry centrifugal collectors
2) Wet dust collectors
3) Fabric filters
4) Electrostatic precipitators
5) Unit collectors.

2.3.3.1. Dry Centrifugal Collectors

Dry centrifugal collectors separate solid particulates from the gas stream by rapidly spinning the dusty gases, i.e., by employing centrifugal forces. One of the most common and simplest of all industrial dust collectors, the "cyclone," belongs to this category.

Dry centrifugal collectors can be divided into the following two basic groups.

2.3.3.1.1. Conventional Cyclone Collector

Cyclones are commonly applied for the removal of coarse dust (>10 μ m from an air stream. Their principal advantages are low capital maintenance, and operating costs, and a low pressure drop, usually 0.75 in. to 1.5 in. of H_2O. However, their lower collection efficiency for particles less than 10 μm precludes their use in many applications.

2.3.3.1.2. High-Efficiency Centrifugal Collector

This device provides higher centrifugal forces than the conventional cyclone to improve the dust separation. The higher centrifugal forces can be obtained by:

1) Increasing the inlet velocities of the conventional cyclones
2) Using a number of small-diameter cyclones in parallel (multi-cyclones).

Although these collectors are able to attain higher collection efficiencies than the conventional cyclones, they are not as efficient as fabric filters and electrostatic precipitators for respirable dust (i.e., less than 10 μm.

Dry centrifugal collectors are not susceptible to freezing weather conditions, and are employed for the following general applications:

1) Collection of coarse dust particles (greater than 10 μm)
2) As a precleaner in series with high-efficiency collectors, such as a fabric filter, an electrostatic precipitator, etc., where particulate concentrations are high (greater than 3 gr/scf)

3) Classification of particles in the coarse size range

4) Where extremely high collection efficiency is not critical for industrial hygiene purposes (i.e., woodworking operations).

2.3.3.2. Wet Dust Collectors

Wet dust collectors, commonly known as "scrubbers," bring a scrubbing liquid (normally water) into intimate contact with a gas stream containing dust. The greater the contact of the gas and liquid streams, the higher the collection efficiency. Multitudes of contact mechanisms are used, e.g., spray contact, impingement, cyclone, and venturi. However, regardless of the contact mechanisms, all wet scrubbers perform three basic operations:

1) Gas humidification

2) Gas-liquid contacting

3) Gas-liquid separation.

Selection of the right scrubber for a particular application requires thorough understanding of the scrubber operation and its principles of collection. Some scrubbers are primarily designed for particulate collection (this is of importance for dust control), others for mass transfer. However, the prime requisite in both cases is still good liquid-gas contact. The collection efficiency of a scrubber and the associated cost determine the application of a particular scrubber.

Scrubbers are available in many designs and show a wide range of performances. The following are the most commonly used scrubbers in the mining industry.

2.3.3.2.1. Chamber or Spray Towers

These collectors consist mainly of a chamber in which finely atomized water droplets, formed by atomizing nozzles, are sprayed onto the incoming gas stream. Many variations of the design are available but the principal mechanism is the impaction of dust particles on the water droplets. These droplets are then separated from the airstream either by centrifugal force or by impingement.

Spray towers are generally used where extreme air cleaning is not required. They can achieve relatively high collection efficiency for particulates larger than 5 μm at pressure drops of 1 in. to 2 in. water gauge and 10 to 100 psi of water pressure. The operating costs are minimal due to the low pressure drop. Normal water requirements are up to 5 gpm per 1000 scfm of gas; for some fogging towers, the requirements could be as high as 10 gpm per 1000 scfm at 100 to 400 psi water pressure.

2.3.3.2.2. Packed Towers

Collectors in this group consist of beds of packing elements, such as rings, saddles, or other manufactured elements. The packing breaks down the liquid flow into a high-surface-area film, so that the gas stream passing through the bed achieves maximum contact with the liquid film. There are generally three types of packed bed towers: countercurrent, co-current, and cross-flow.

These kinds of scrubbers are primarily used for gas, vapor, and mist removal. Although they will capture solid particulates, they are not recommended because dust will plug the packing and thus result in excessive maintenance.

2.3.3.2.3. Wet Centrifugal Collectors

Wet centrifugal collectors constitute a large portion of the commercially available designs. They use centrifugal force to accelerate the dust particles, as with a dry cyclone, and impinge them upon a wetted collector surface.

These types of collectors are generally more efficient than the spray towers and they are available with different numbers of impingement sections. The fewer the sections, the lower the efficiency, cost, pressure drop, and space requirements. However, collectors with multiple collecting tubes offer high collection efficiencies.

The normal water flow rates are 2 to 60 gpm per 1000 scfm. The water flow can be generated by nozzles, gravity flow, or induced water pickup. Pressure drop is 2 in. to 6 in. water gauge.

2.3.3.2.4. Wet Dynamic Precipitators

This type uses water sprays within a fan housing to precipitate the dust particles on wetted surfaces of an impeller with a special fan blade shape. No internal pressure drop is involved, although the mechanical efficiency is somewhat reduced compared to the efficiency of a standard exhaust fan.

2.3.3.2.5. Orifice-Type Scrubbers

In wet dust collectors of this type, the air flow through the collector is brought into contact with a sheet of water in a restricted passage. The water flow may be as high as 20 gpm per 1000 scfm, and is induced by the velocity of the air stream or maintained by pumps or weirs. Most of the water can be recirculated. Pressure losses vary from 3 in. to 6 in. water gauge in most industrial collectors.

2.3.3.2.6. Venturi Scrubbers

The venturi-shaped inlet in these scrubbers provides much higher throat velocities than the orifice-type scrubbers. Typical gas velocities at the throat range from 15,000 to 20,000 fpm and the pressure drops range from 5 in. to 100 in. water gauge. Although the contact time is relatively short at these high velocities, the extreme turbulence in the venturi section promotes very intimate contact between gas and liquid and increases the impaction efficiency greatly. The wetted particles and droplets are then collected in a conventional wet centrifugal collector. The water flows rates are ~ 5 to 10 gpm per 1000 scfm of gas. Venturi scrubbers can achieve extremely high collection efficiencies for very fine (0.5 to 2 μm) particulates; however, their operating costs are considerably higher than for other wet collectors.

2.3.3.2.7. Advantages and Disadvantages of Wet Scrubbers

Advantages

1) Can withstand and handle high-temperature and high-moisture-content gases
2) Collect dust in a wetted form, thus eliminating a secondary dust problem on disposal. However, the disposal of the slurry without clarification or treatment may create water pollution problems.

3) Can eliminate, or at least reduce, fire or explosion hazards for some dry dust

4) Humidify the gas stream. If the gas stream is initially at an elevated temperature and not saturated, evaporation of the added moisture reduces the gas temperature and, hence, the volume of the gas leaving the collector, thus resulting in smaller fan and motor requirements.

Disadvantages

1) May promote corrosive conditions within the collector

2) Require freeze protection if collectors are located outside in the colder climates

3) May not be used for recovery of dry products. However, in cases where wet processing is employed, the scrubber can recycle the slurry back to the process.

2.3.3.3. Fabric Filters

Use of fabric filters to separate solid particulates from the gas stream is one of the most efficient and economical methods available today. Fabric filters, commonly known as "baghouses," have been widely used in mining and other industries.

A baghouse comprises a woven or felted filtering cloth, arranged in an envelope or tubular shape, through which the contaminated gas is passed to separate out the solid particulates. Basically, there are four mechanisms predominant in air filtration:

1) Inertial collection (the basic collection mechanism in woven media) - The particle, because of its inertia, does not change direction with the gas stream and impinges on a fiber placed perpendicular to the gas flow direction.

2) Interception - An inertialess particle (i.e., one which does not cross the fluid streamlines) comes in contact with a fiber solely because of the fiber's size.

3) Brownian movement - Submicron particles diffuse due to pressure fluctuations, thus increasing the probabilities of contact between the particles and collecting surfaces.

4) Electrostatic forces - Electrostatic charges of the particles and filter media create electrostatic forces that may help or impede the capture of particulates by filtering media.

Cursory observation of a fabric filter suggests that particulates are strained out by the filtering medium. However, in reality, very small particulates are actually filtered by a cake of the material, which builds up on the filtering medium. Since resistance to gas flow increases as the cake builds, the cake deposit must be removed periodically to ensure proper operation of the system. Based on the filter cleaning methods employed, three broad categories of baghouses are available:

1) Shaker-type
2) Reverse-air
3) Reverse-jet.

2.3.3.3.1. Shaker-Type Collectors

These were the most popular baghouses in the mining industry for several years. The filter bags are cleaned by manual, mechanical, or pneumatic shaking. The cleaning operation can be continuous or intermittent, and manual, semi-automatic, or automatic.

Single-compartment collectors are intermittent-duty types, i.e., the gas flow is interrupted at some predetermined interval so that the excess dust collected on the surface of the filtering medium can be shaken off. These types of collectors are designed so that a periodic cleaning, normally every 4 to 6 hours, is adequate to recondition the bags. However, the cleaning cycle could also be initiated at a preset pressure point.

Multiple-compartment collectors offer continuous-duty operation since each compartment has its own set of dampers and can be totally isolated during the cleaning cycle. They are used when it is not possible to shut down the process. Normally, they are cleaned by automatic shaking.

In all shaker-type collectors, there must be no positive pressure inside the bags during the shake cycle. Mumford(12) demonstrated that a pressure as little as 0.02 in. water gauge can interfere with cleaning.

The normal filtering velocity, commonly known as the "air-to-cloth ratio," is between 1.5 to 4 ft/min, and the pressure drop across the collector is 2 to 5 in. water gauge between the start and end of a cycle. Since the air-to-cloth ratio is relatively low, the space requirements for a shaker-type collector are quite high. However, because of the simplicity of the design, the maintenance needs are minimal. Collection efficiencies of more than 99% can be achieved for very fine particulates.

2.3.3.3.2. Reverse-Flow Collectors

Some envelope-type baghouses use reverse air flow for bag cleaning. Normally, the dust in this type of collector is collected on the outer surfaces of the bag, and during the cleaning cycle, a moving carriage or a valve seals off the outlet to one or more bags. Another valve permits outside air to be drawn through the bag in the reverse direction, so that the sides of the bag collapse and dust falls into the hopper below. With this type of cleaning, only a few bags need be out of service at any one time. Often, baghouses of this kind have multiple compartments, so that one compartment can be cleaned while the others handle the additional gas flow.

Normal filtering velocity for this kind of collector is 1 to 2 ft/min; the filtering medium is usually glass cloth, which is fragile and requires gentle cleaning. Reverse-flow glass cloth collectors are widely used for cement kilns, rotary driers, in the chemical industry, and for other high-temperature applications. Collection efficiency is normally greater than 99%, and space and maintenance needs are somewhat greater than for a shaker-type collector.

2.3.3.3.3. Reverse-Jet Collectors

This system employs compressed air to remove the filter cake from the fabric. The two most commonly used cleaning methods are as follows:

1) A pressure nozzle mounted at the top of each tubular bag releases a "bubble" of compressed air, normally at 80 to

100 psi. As the "bubble" travels downward, the bag surface flexes and releases the dust collected on the outer surface.

2) Travelling devices such as slotted rings, for tubular bags, or pipes which move across the surface, for envelope-type bags, distribute compressed air, which releases the dust collected inside the bag.

The reverse-jet method provides more complete cleaning and reconditioning than vibrating or shaking. Also, filtering velocities for these collectors are very high -- 6 to 12 ft/min -- because the short cleaning cycles reduce reentrainment and redeposition of "loose" dust. Normal pressure drops are 4 to 6 in. water gauge and efficiency does not vary significantly with air volume changes. With its high filtering velocity, i.e., high air-to-cloth ratio, the reverse-jet fabric filter requires less space than other types of fabric filters. However, fabric filters of this type are relatively expensive and have higher maintenance requirements than conventional shaker-type collectors. Collection efficiency is greater than 99% for very fine particulates.

2.3.3.3.4. Advantages and Disadvantages of Fabric Filters

Advantages

1) Can achieve collection efficiencies of greater than 99% for very fine particulates at a pressure drop of 3 to 6 in. water gauge, compared to 10 to 100 in. water gauge for a venturi scrubber

2) Can appreciably maintain collection efficiency with changes in air volume

3) Require moderate capital costs

4) Can be used for a wide range of temperatures, e.g., from 180°F for cotton fabrics to 550-600°F for fiberglass media

5) Can be used for a variety of processes in many industries

6) Allow recoverable product to be fed directly back into the process stream

7) Are little affected by freezing weather

8) Have moderate maintenance requirements

Disadvantages

1) Require more space than most other types, except electrostatic precipitators

2) May cause secondary emission problems during dry dust removal and disposal

3) Cannot be used for hygroscopic materials or for exhaust gases with high moisture content

4) May have to be insulated in subfreezing ambient temperatures because condensation in the exhaust gases may blind the bag

2.3.3.4. Electrostatic Precipitators

Electrostatic precipitators employ electrical forces to separate particles from the exhaust gases. Collection is achieved by imparting a negative charge to the particles in the gas stream, so that they are attracted to a grounded or positively charged plate. The collected material is then removed by rapping or vibrating the plates either continuously or at some predetermined interval. Cleaning usually takes place without interrupting the air flow.

Since the electrical forces are directly applied to the particulates themselves rather than to the entire gas stream -- as with mechanical methods such as fabric filters, cyclones, scrubbers, etc. -- the power requirements are moderate. Up to 99.9% collection efficiency can be achieved for all particulates.

The four main components of electrostatic precipitators are:

1) Power supply unit, to provide high-voltage, unidirectional current
2) Ionizing section to impart a charge to particulates in the gas stream.
3) A means of removing the collected particulates
4) A housing to enclose the precipitator zone.

Basically there are two main types of precipitators available: one-stage and two-stage.

2.3.3.4.1. <u>One-Stage Precipitator</u>

One-stage precipitators combine both an ionization and collection step. They are commonly referred to as Cottrell precipitators, and are the most widely used in industry.

2.3.3.4.2. <u>Two-Stage Precipitator</u>

The operating principle is similar to that for the single-stage precipitator; however, an ionizing section is followed by the collection plates. This type is used primarily where the particulate loading is low and ozone generation must be minimized.

2.3.3.4.3. <u>Advantages and Disadvantages of Electrostatic Precipitators</u>

Advantages

1) Can attain collection efficiencies up to 99.9% for all sizes of particulates
2) Produce negligible pressure drop, hence minimal operating power costs
3) Increase in efficiency with humidity of the air stream
4) Allow product recovery
5) Can be used for high-temperature applications as well as in colder climates

Disadvantages

1) Have relatively high capital costs for gas volumes up to 50,000 cfm due to the cost of high-voltage electrical equipment
2) Have relatively large space requirements
3) Are limited to non-explosive or non-combustible materials due to spark potential from the high voltage

2.3.3.5. Unit Collectors

Unit collectors, unlike central collectors are, as the name suggests, aimed at controlling contamination at the source itself. They are suitable for isolated, portable, or frequently relocated dust-producing operations and are normally intended for light dust loads and/or intermittent operations such as remote conveyor transfer points, tool room grinders, or packaging facilities. A number of designs are available with capacities ranging from 200 to 2000 cfm, but basically there are two types of unit collectors:

1) Fabric collectors using cloth envelopes with some manual means of vibration cleaning.
2) Fan filters equipped with an air filter, normally of the viscous impingement type.

Unit collectors, because of their small space requirements and their air recirculation design, are widely used in the metal working industry. However, dust holding and storage capacity, servicing facilities, and longer maintenance intervals have been sacrificed for small space requirements and low initial cost.

Use of unit collectors is questionable if the dust-producing operations are located in an area where central exhaust systems would be practical. Dust removal and servicing requirements for a number of unit collectors are expensive and are more likely to be neglected than those for a single large collector.

2.3.4. Fan and Motor

The fan and motor system is the fourth major element in an exhaust system. The fan converts electrical energy, supplied by the motor, into the mechanical energy that moves air and suspended particulates from the source to a final dust collector.

Fans are divided into two main categories:

1) Axial-flow or propeller-type

2) Radial-flow or centrifugal-type.

2.3.4.1. Axial-Flow Fans

Axial-flow fans move the air by the thrust effect of the inclined blades on the propellers. The air flow is essentially parallel to the axis of rotation, and the screw-like action of the propeller causes a helical-type flow pattern. Fans in this category include:

1) Propeller-type

2) Tube-axial

3) Vane-axial.

2.3.4.1.1. Propeller-Type Fans

Most propeller-type fans operate without a housing. As a result, the static pressure developed is low because there is little opportunity for the conversion of velocity pressure into static pressure. Propeller-type fans are used to move large quantities of air against very low static pressures.

2.3.4.1.2. Tube-Axial Fans

Tube-axial fans are similar to the propeller types except they are mounted in a tube or cylinder. Consequently, they are more efficient than the propeller types and can develop up to 3 to 4 in. of static pressure. They are best suited for moving air containing condensable fumes, pigments, etc.

2.3.4.1.3. Vane-Axial Fans

Vane-axial fans are similar to tube-axial fans except that air-straightening vanes are installed on the suction or discharge side of the rotor. Vane-axial fans are readily adaptable to multistaging and can develop static pressures as high as 14 to 16 in. water gauge. They are normally used for clean air only.

2.3.4.2. Centrifugal Fans

With centrifugal fans, the air flow is produced by the centrifugal forces generated in a rotating column of air and by the tangential velocity imparted to the air as it leaves the tip of the blades. The centrifugal force imparts static pressure to the air and the scroll-type casing gradually transforms the velocity pressure into static pressure.

Centrifugal fans are divided into three main categories:

1) Forward-curve blade type
2) Backward-curve blade type
3) Radial- or turbine-blade type.

2.3.4.2.1. Forward-Curve Blade Type

This fan is perhaps the most widely used in general ventilation work. It operates at slow speed and is quiet and inexpensive. It is slightly less efficient than other types and is somewhat unstable at the middle operating range.

This type of fan is usually suited for low-to-moderate static pressures, such as those encountered in heating and air conditioning work. It is not recommended for dusts or fumes that would adhere to the short curved blades, causing imbalance and subsequent damage to the fan.

2.3.4.2.2. Backward-Curve Blade Type

This type of fan is usually larger than the forward-curve blade type. It also operates at higher speeds, provides higher efficiency, and has nonoverloading characteristics.

This fan is more suitable for higher static pressures. However, the blade shape is conducive to buildups of material and should not be used for air containing condensable fumes or vapors.

2.3.4.2.3. Radial- or Turbine-Blade Type

This design is a compromise between a forward-curve and a backward-curve blade centrifugal fan. The efficiency is not quite as high as for the backward-curve blade type; however, the fan is small and operates at a comparatively high speed, resulting in higher static pressures than for the backward-curve blade fan.

Radial-blade fans are frequently used for exhaust systems that handle materials likely to clog the fan wheel. The design of the blades and wheel lends itself to rugged construction and offers a minimum of ledges, etc., where dust or material could accumulate.

2.3.5. Advantages and Disadvantages of Dry Dust Collection Systems

The most effective method of reducing respirable dust emissions is to contain the dust where it is generated and then exhaust it from the process stream. The advantages of dry collection systems in performing this function include the following:

1) Dust is effectively extracted from the process stream.

2) Since the use of a dust collection system requires dust-emitting sources to be enclosed, the sources are under negative pressure, and emissions are greatly reduced.

3) Systems generally are reliable and can operate continuously under variable and extreme weather conditions.

Disadvantages of dry systems are:

1) Capital expenditure is much greater than for wet systems.

2) Specialized engineering design is required.

3) Maintenance needs are greater than for wet suppression systems.

4) The systems are bulky and require considerable space.

2.3.6. Selection of A Dust Collection System

The industrial ventilation system -- comprising an exhaust hood, ductwork, a dust collector, and a fan and motor -- is the only known dry method for controlling dust emissions in the mining industry. However, the approaches to designing the system have varied considerably, depending on available empirical data, theoretical formulas, and the experience and judgement of the individual designer. Principles of ductwork design, fan selection, etc., have long been established and understood, but the calculation of exhaust air volumes has been one of the major topics of debate.

Many designers consider determination of exhaust air volume to be a minor detail. Perhaps, that is the reason a reliable, effective, and economical industrial ventilation system to control dust emissions in the mining industry is rarely encountered.

Over the years, many approaches based on empirical or analytical methods have been suggested. Upon closer examination of the various relationships discussed, it seems that there does not exist a single comprehensive approach to determining the exhaust air volumes for effective control of dust emissions. Most of the analytical approaches either include constants and variables that are not easily available to a designer or are specific for a particular operation.

To compare various approaches, we used a graphic procedure. A hypothetical belt-to-belt transfer point was designed, incorporating a wide range of operating conditions encountered in the mining industry, as indicated in Table 2. Based on the recommendations in various approaches, exhaust volumes were calculated and plotted against the height of fall and belt speed (figs. 11 and 12). It is evident from the graphs that the Anderson and Morrison approaches lead to the low and high exhaust volumes, respectively. We discount the Hemeon approach since it is purely theoretical, and recommend it only as a check against other approaches. Although the Industrial Ventilation Manual and the Steel Mill Ventilation Manual approaches lead to values in the mid-range, their universal applicability is questionable because of their purely empirical nature.

The semi-empirical approaches suggested by Morrison and Anderson are similar. Both are practical and most of the variables are easily available to a designer. Morrison's approach (a modified version of Hemeon) is based on field experience and observations during an in-house study with a belt-to-belt transfer point designed in accordance with mechanical

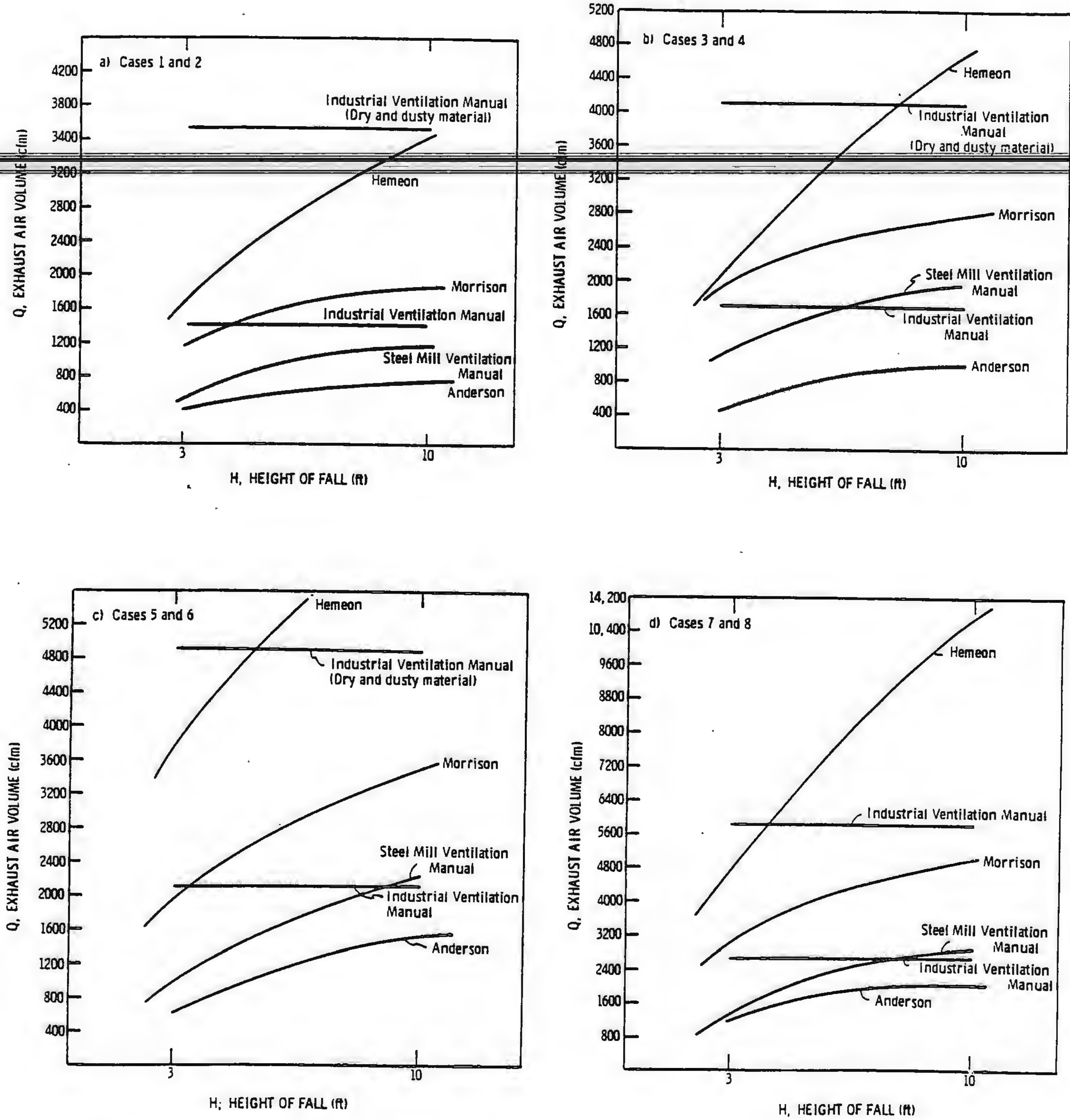


FIGURE 11. - Exhaust air volume vs height of fall, calculated using various approaches for cases listed in Table 2: (a) 1 and 2; (b) 3 and 4; (c) 5 and 6; (d) 7 and 8.

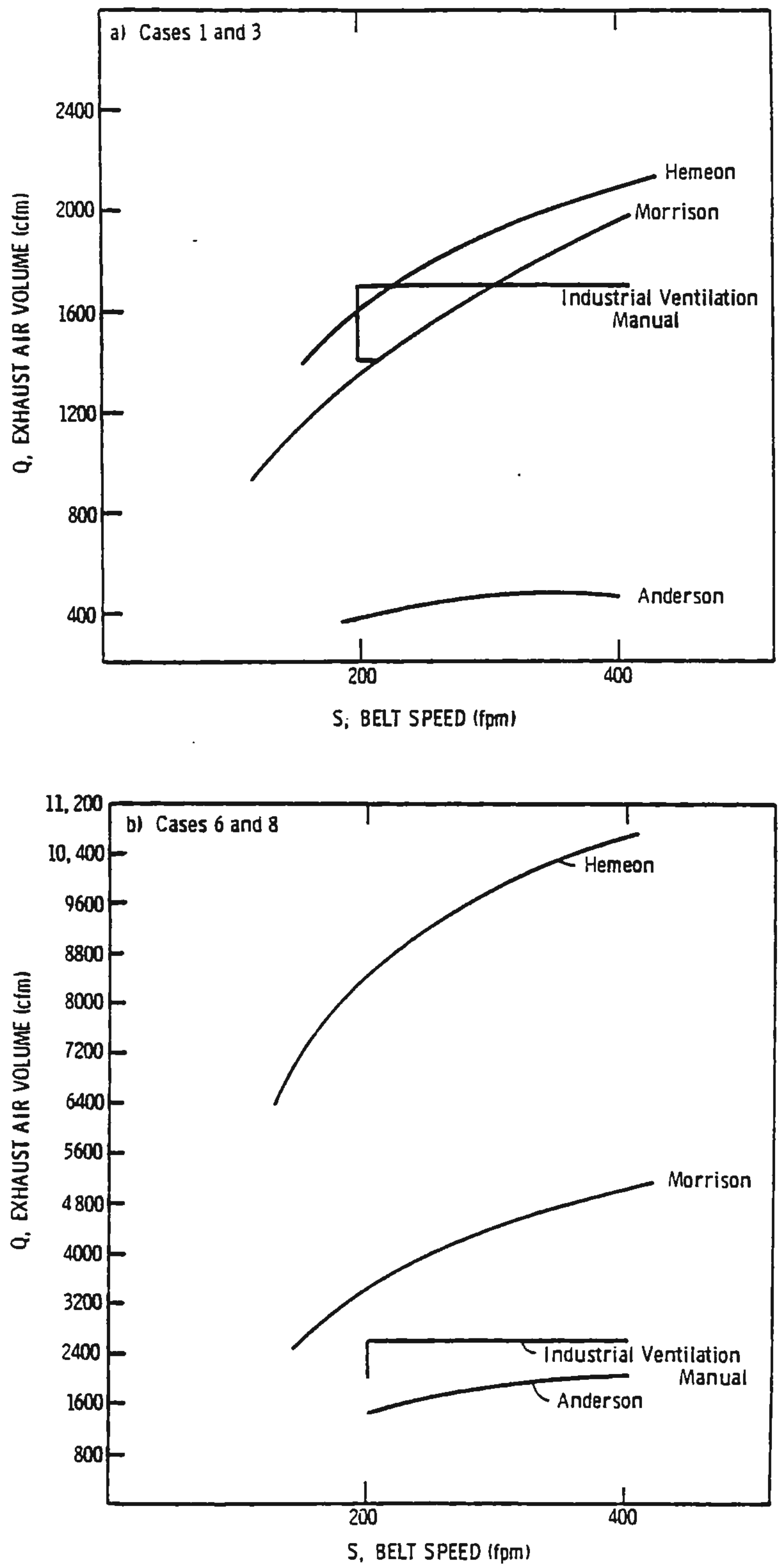


FIGURE 12. - Exhaust air volume vs height of fall, calculated using various approaches for cases listed in Table 2: (a) 1 and 3; (b) 6 and 8.

TABLE 2

TABLE 2. - DESCRIPTION OF HYPOTHETICAL BELT-TO-BELT TRANSFER POINT

Case No.	Belt Width (in.)	Belt Speed (fpm)	Capacity (ton/hr)*	Avg. Particle Diameter (in.)	Height of Fall (ft)
1	24	200	185	1/2	3
2	24	200	185	1/2	10
3	24	400	370	1/2	3
4	24	400	370	1/2	10
5	36	200	450	1/2	3
6	36	200	450	1/2	10
7	36	400	900	1/2	3
8	36	400	900	1/2	10

* Capacities are based on three equal 35° roll troughing idlers, a bulk density of 100 pounds per cubic feet, and a 5° surcharge angle.

standards adopted by Dravo Corporation. Its applicability to operations with different design standards, as well as to other transfer points, such as crusher-to-belt or screen-to-belt, is questionable. Anderson's approach is a simplified version of the results obtained in an experiment performed by Dennis at the Harvard School of Public Health.

Extensive literature search has disclosed that neither Anderson's nor Morrison's approach has been evaluated by quantitative studies of actual respirable dust reduction. We, therefore, designed the system based on Anderson's approach, allowing a sufficient reserve capacity to meet any foreseeable needs.

2.4. WET DUST SUPPRESSION SYSTEMS

2.4.1. Wet Dust Suppression Principles

The use of water sprays is a well-known means of controlling dust emissions. By definition, wet dust suppression systems use liquids (mainly water) to control dust emissions. Dust suppression is achieved primarily by one or both of the following approaches:

1) Control Approach: The dust particle collides with the water droplet and through agglomeration becomes too heavy to remain airborne, and thus settles.
2) Preventive Approach: The product is wetted so that it has a lower tendency to generate dust.

2.4.1.1. Control Approach

The control approach is based on the theory that fine droplets sprayed on dust particles initiate and enhance the agglomeration process until the agglomerates are too heavy to remain airborne and settle down. Particle capture by liquid droplets is a two-step process:

1) Collision of a particle with a droplet
2) Coalescence or adhesion after collision.

2.4.1.1.1. Particle-Droplet Collision

The collision between a particle and a droplet can occur by any of four fundamental mechanisms.

Impaction/Interception

Impaction/interception mechanisms are dominant in controlling particles above 1 μm with water sprays. As droplet and particle approach each other on a collision path, the particle tends to follow the fluid streamlines and be swept around larger droplets. Because of its inertia, however, the particle does not exactly follow the fluid path, but instead cuts across some streamlines. Depending on its initial trajectory and velocity, it may impact directly on the droplet, barely graze the droplet, or entirely miss the droplet (fig. 13).

Diffusion

Submicron particles collide with the droplet due to random bombardment by gas molecules. This collision mechanism depends on diffusion and becomes predominant with decreasing particle size.

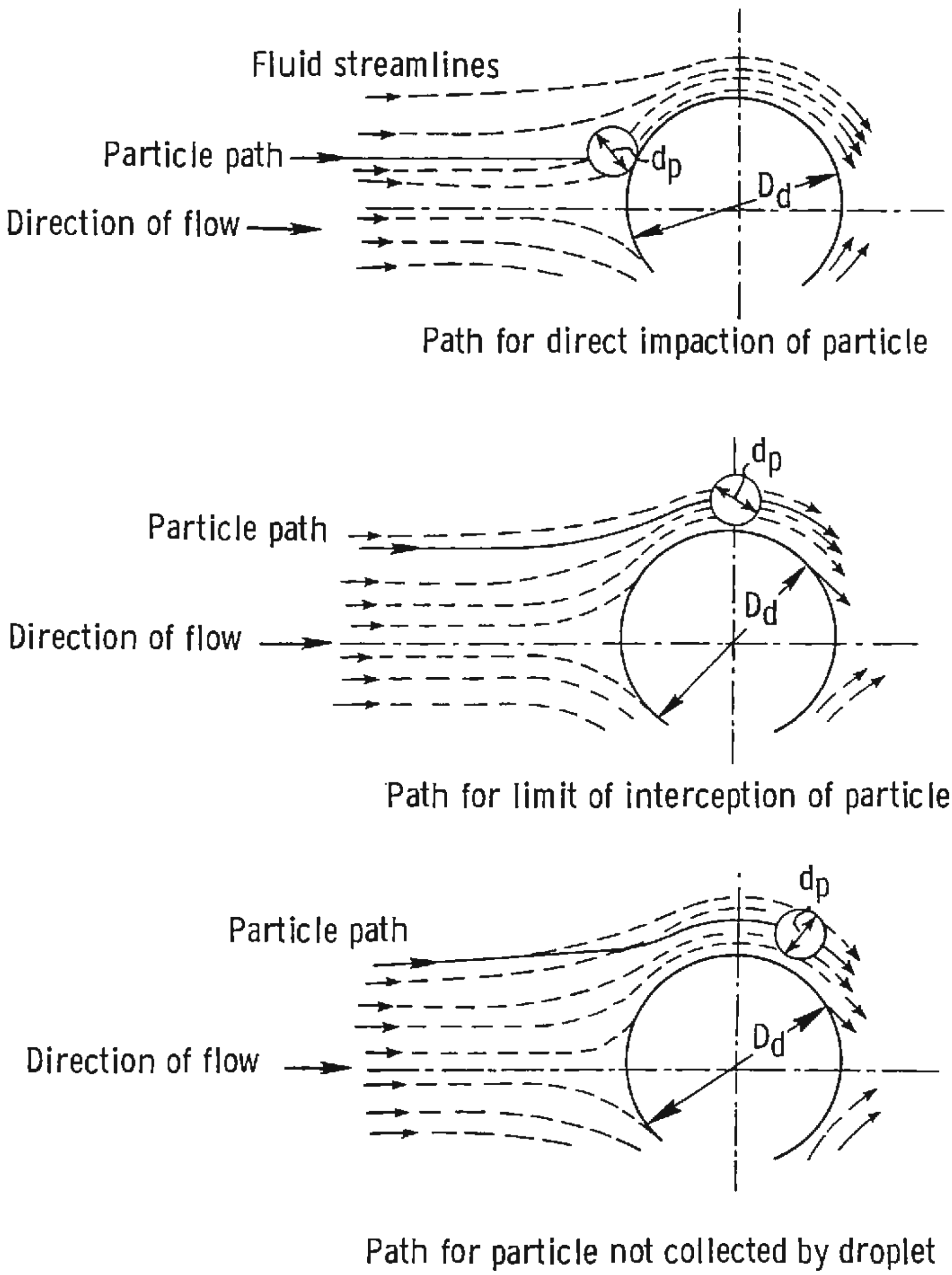


FIGURE 13. - Particle trajectories around a water droplet. (Reproduced from EPA Interagency Energy/Environment R&D Program Report, Ref. 13.)

Phoresis

Phoresis is a process in which particles move because they are subjected to a gradient in temperature (thermophoresis) or vapor pressure (diffusion phoresis). For particles larger than 2 μm, phoretic forces exert little effect.

Electrostatic Attraction

Practically all aerosols carry an electrical charge. The presence of a charge on a particle or a droplet (or both) affects the particle trajectory around the droplet and can improve (opposite charges) or reduce (like charges) the collision efficiency.

Factors Affecting Collision Efficiency

Several investigators have studied the collision process. The data obtained can be utilized to design or select an appropriate wet dust suppression system. They are described below.

Grover (14) determined the collision efficiency of a droplet/particle pair for water droplets falling at their terminal velocity. Efficiencies were calculated for various droplet properties, such as size, humidity, and electrical charge, and these data were used to calculate overall collision efficiency of a spray. Figure 14a shows that the collison efficiency is strongly dependent on the diameter of the water droplet. The minimum collision efficiency occurs at a particle diameter of about 2-5 μm, where several interaction mechanisms become ineffective.

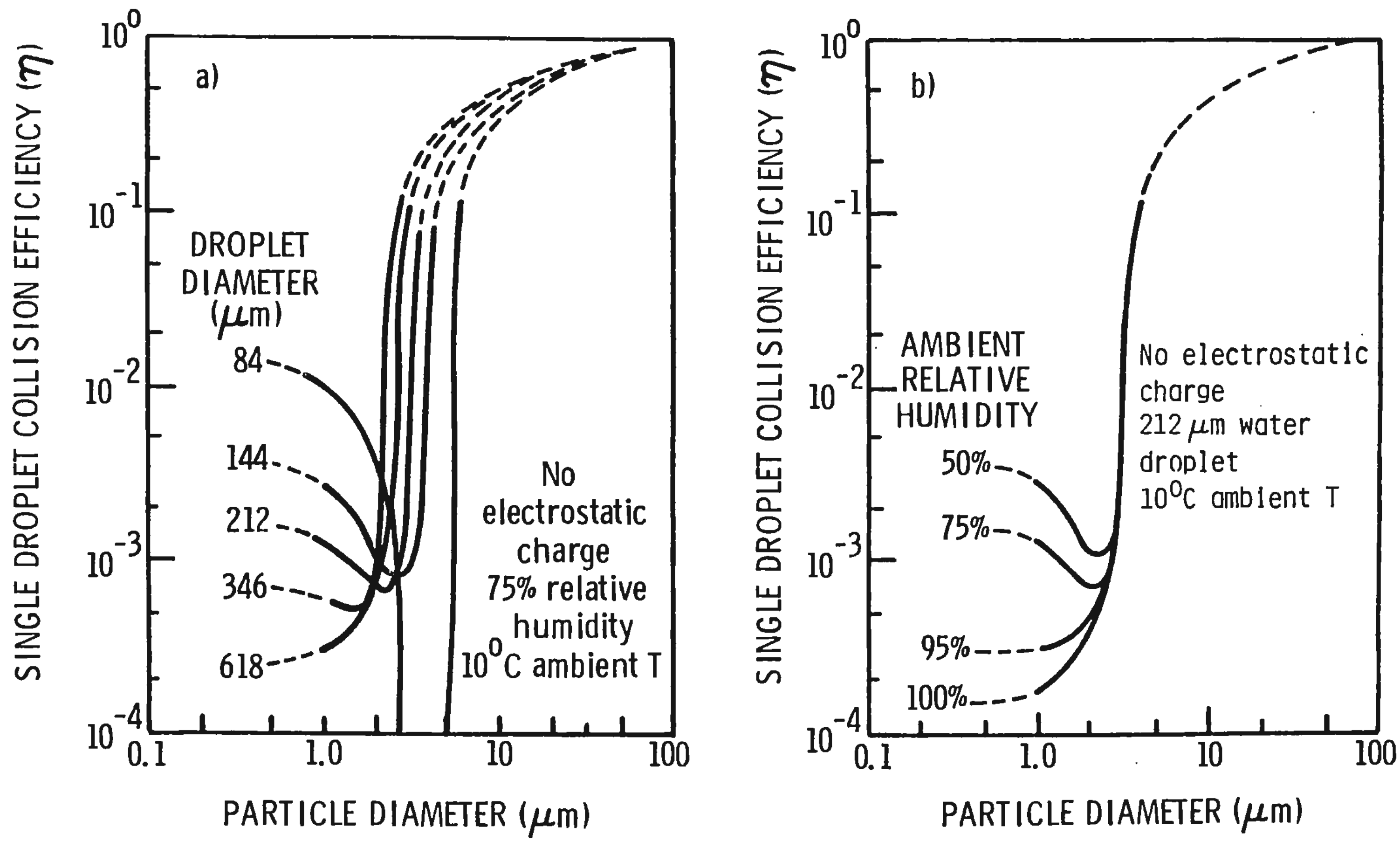


FIGURE 14. - a) Effect of droplet diameter on collision efficiency;
b) Effect of relative humidity on collision efficiency.
(Reproduced from the Journal of Atmospheric Environment (Ref. 14.)

The efficiency curve levels off as droplet size decreases. This effect is known as the "Greenfield effect." Figure 14b shows that the relative humidity (or tendency of the droplet to evaporate) affects the collision efficiency. Although collision efficiencies are higher in drier environments, the droplet lifetimes are shorter due to higher evaporation rates.

Daugherty (13) showed that a single droplet sweeping through the air will not necessarily capture a solid particle lying in its path; as the drop approaches the particle, the particle's inertia carries it across the streamlines surrounding the droplet (fig. 13). If the particle lies within a certain capture cross section about the axis of the droplet, it will strike the surface. The collision cross section of a fluid droplet can be interpreted as the fraction of the area swept by the droplet in which dust particles are captured. It has been related to a dimensionless parameter, K:

$$K = \frac{U \rho d^2}{9 \mu D} \tag{14}$$

where U = relative velocity between a particle and a droplet,

ρ = density of a particle,

μ = viscosity of air,

d = particle diameter,

and D = droplet diameter.

The relationship between K and the collision cross section depends on whether a viscous-flow or potential-flow model is used in computing the trajectory of the particle around the droplet. Figures 15 and 16 depict

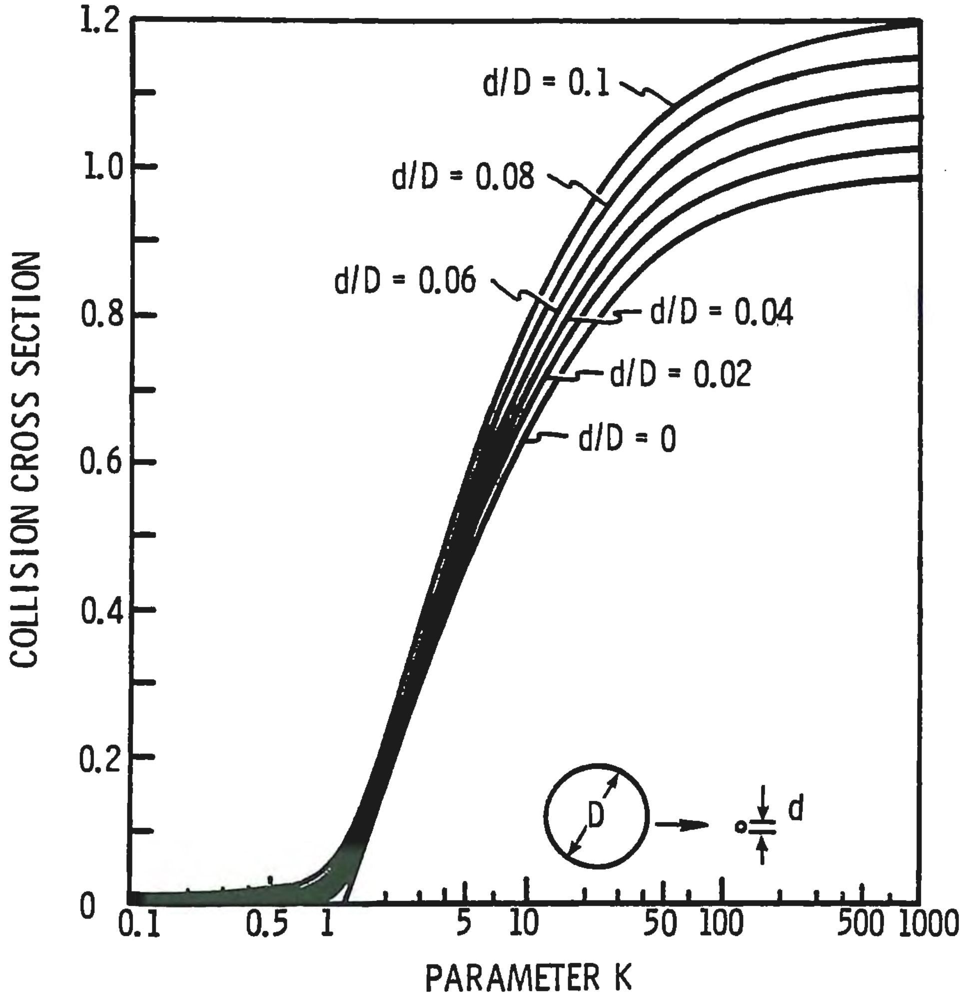


FIGURE 15. - Collision cross section of water droplet vs parameter K for viscous flow. (Reproduced from Ref. 15.)

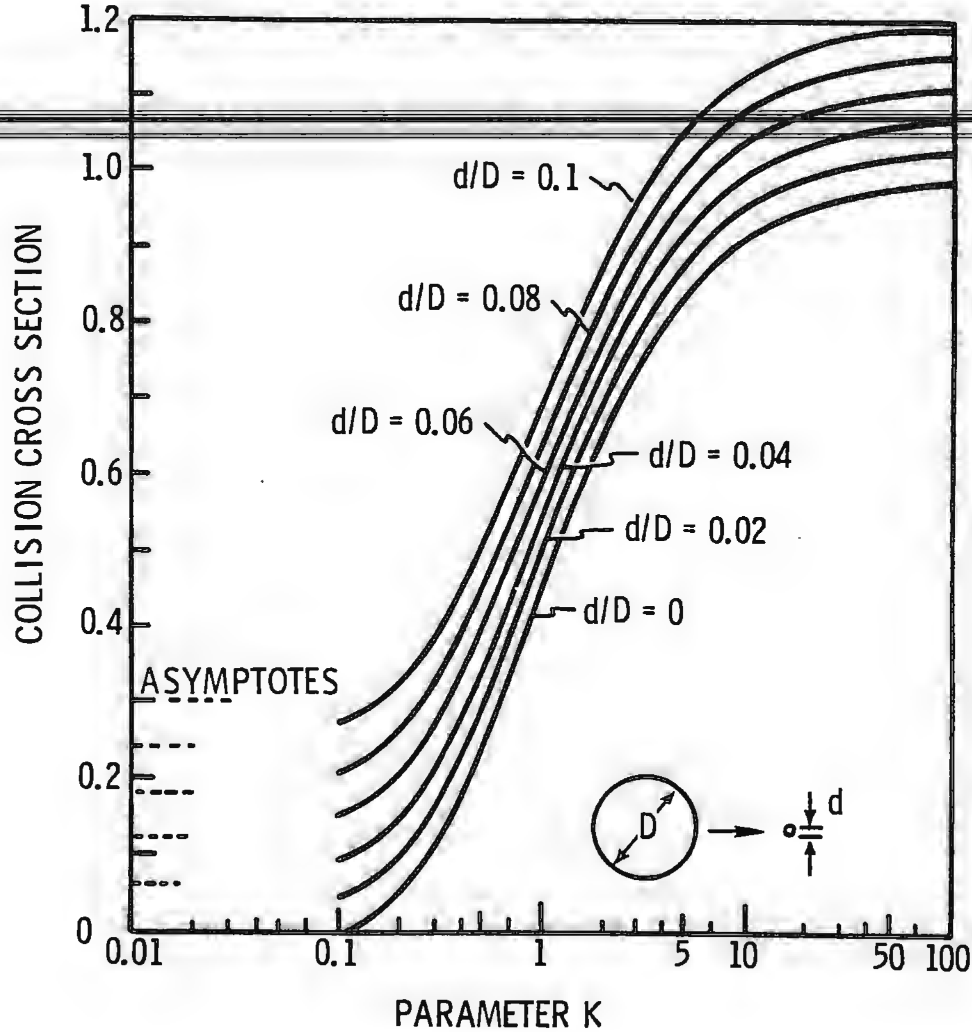


FIGURE 16. - Collision cross section of water droplet vs parameter K for potential flow. (Reproduced from Ref. 15.)

the result for both models. It is evident from the form of the parameter K that the collision cross section and single droplet collision efficiency improve with increasing relative velocity and decreasing droplet size.

Schowengerdt (16) has suggested that water droplets in the same size range as dust particles would tend to show high collision efficiencies (fig. 17). However, smaller droplets decelerate more rapidly than larger ones because of frictional drag. Thus, the relative velocity between the droplet and the particle decreases rapidly for smaller droplets and, as a result, the collision cross-section parameter K and single particle collision efficiency also decrease rapidly. Hence, there is an optimum droplet diameter for maximum collision efficiency.

Cheng (17) has developed a general theoretical model for calculating collection efficiency of airborne dust particles by water droplets. The model assumes an inertial impaction collection mechanism, and is based on a mean interdrop length and mean particle area. Figure 18 shows optimum diameters for several conditions.

The relationship between single particle collision efficiency and overall collision efficiency is given by Walton and Woolcock (18) and Cheng: (17)

$$E = 1 - \exp\left(- \frac{3}{2} \frac{\eta L Q}{D Q_a}\right) \tag{15}$$

where E = overall collision efficiency,

η = single particle collision efficiency,

L = characteristic length,

Q = volume flow rate of water,

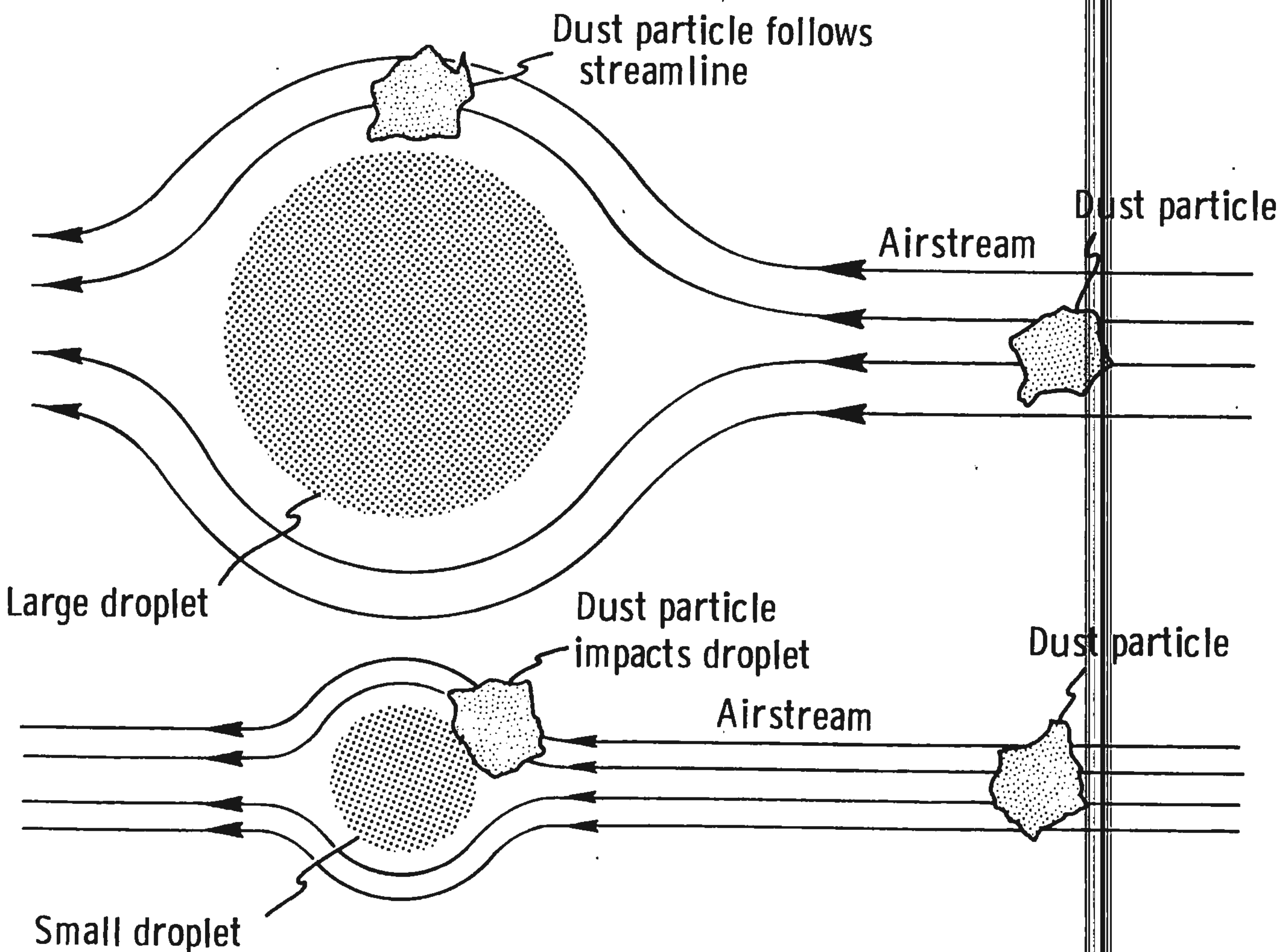


FIGURE 17. - Airflow around large water droplet (top) prevents coal dust particles from contacting the droplet. The dust particle, however, easily impacts a smaller droplet (bottom). (Reproduced from Ref. 16.)

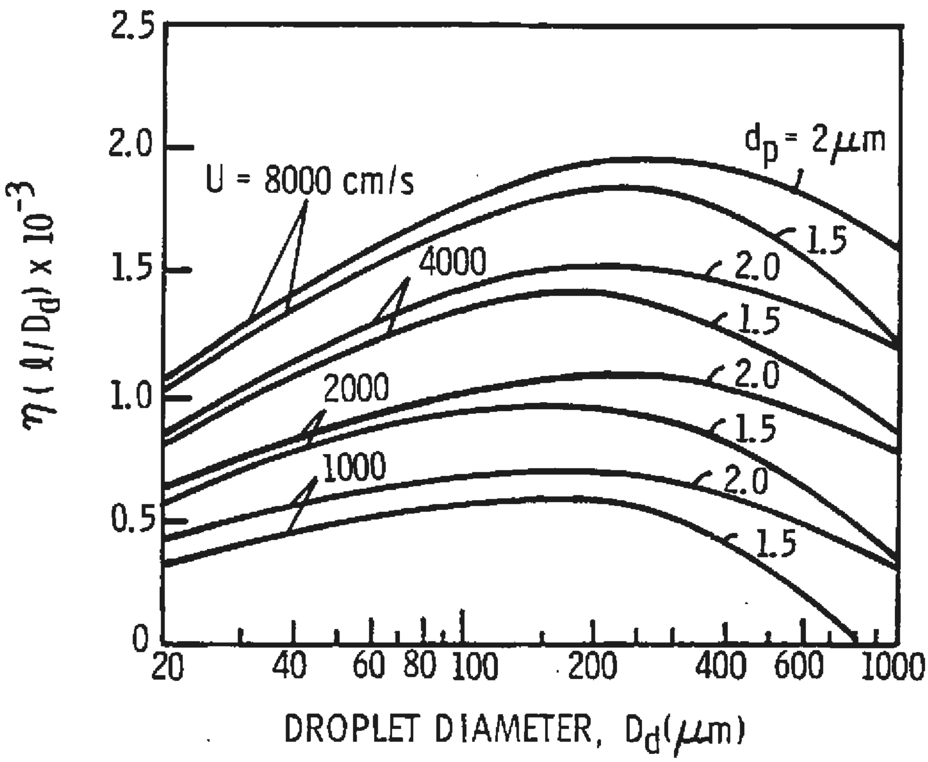


FIGURE 18. - Computed spray collision efficiency vs droplet diameter; U = relative velocity between the particle and the droplet, d = particle diameter. (Reproduced from Ref. 17.)

D = droplet diameter,

and Q_a = volume flow rate of air.

This equation is an idealized version of the complex interaction between a spray and a moving dust cloud, but the form of the equation is instructive. Walton and Woolcock and Cheng have assumed a coalescence efficiency equal to one; therefore, single particle collection efficiency is equal to overall collision efficiency. A more exact form for overall collection efficiency would be

$$E_o = 1 - \exp\left(-\frac{3}{2}\ \frac{\eta \psi L Q}{D Q_a}\right) \tag{16}$$

where E_o = overall collection efficiency

and ψ = single particle coalescence efficiency.

Thus, several parameters play an important role in controlling airborne particulates by water sprays. From the above discussion, the following can be concluded:

1) A reduction in droplet diameter increases the probabilities of collision between the droplet and dust particle.

2) Dust suppression efficiency increases with the increase in the relative velocity between a particle-droplet pair. However, due to frictional drag, the velocity of smaller droplets decreases more rapidly with distance than that for larger droplets; hence, there is an optimum droplet diameter for maximum dust suppression. Reducing droplet size below this optimum lowers the dust suppression efficiency.

2.4.1.1.2. Coalescence After Collision

After a particle and a droplet collide, they may either adhere or bounce apart. Adhesion requires attractive forces at the droplet/particle interface. Adhesive forces can be supplied by interfacial surface tension, other intermolecular forces (e.g., dipole or Van der Waals' forces), chemical bonds, or electrostatic forces. Of these, surface tension appears to be the most important.

The film thinning theory represents one model of the coalescence process. When a particle impacts a liquid droplet, the air film between them prevents immediate coalescence and the resistance due to surface tension and viscosity slows down the penetrating particle. The particle comes to rest and rebounds back if the separating air film remains intact. However, if the film becomes thinner than some critical thickness, it ruptures and coalescence takes place.

The coalescence phenomenon is not discussed in detail here because the coalescence efficiency for airborne dust is near unity. (13)

2.4.1.2. Preventive Approach

The preventive approach to dust suppression is based on the theory that adequately wetted material generates less dust. The effective wetting of the product depends on several factors, such as the type of product, its surface properties, droplet size, concentration of droplets on a given surface, interfacial properties of the droplet, and velocity of impaction.

Cheng (19) has suggested two mechanisms by which droplets wet or spread on a surface: static spreading and dynamic spreading.

2.4.1.2.1. Static Spreading

Static spreading is defined as wetting of the material under stationary conditions, i.e., at zero relative velocity between the material and spreading solution. For a stationary droplet on the surface of the product, the specific static spread, S_s (area of coverage by a sessile drop per unit mass of liquid), is given by:

$$S_s = 3/2 \left(\frac{4 \sin^3 \theta}{2-3 \cos \theta + \cos^3 \theta} \right)^{2/3} \frac{1}{\rho D} \qquad (17)$$

where ρ = droplet density,

D = droplet diameter,

and θ = contact angle.

Thus, reducing the droplet diameter or contact angle (same as reducing surface tension) increases the amount of surface coverage.

2.4.1.2.2. Dynamic Spreading

Dynamic spreading is defined as the wetting of the material under dynamic conditions, i.e., at non-zero relative velocities between the material and spreading solution. The specific dynamic spreading, S_d (area covered by an impacting droplet per unit mass of liquid), can be expressed as:

$$S_d = \frac{1}{(\rho d \sigma)^{1/2}} \quad \frac{C^2 V}{D^{1/2}} \qquad (18)$$

where σ = surface tension of a solution,

d = particle diameter,

C = spread coefficient = F (σ, V, D),

ρ = droplet density,

D = droplet diameter,

and V = impact velocity.

The specific dynamic spreading is increased by reducing the surface tension or increasing the impact velocity. Decreasing droplet size appears to increase specific dynamic spreading; however, because of frictional drag, impact velocity also decreases. Therefore, there exists an optimum diameter for maximum specific spreading.

Of these two spreading mechanisms, one can be emphasized at the expense of the other depending on the needs of the user. Therefore, proper selection and location of spray nozzles as well as selection of the wetting solution are of paramount concern for achieving desired efficiency.

2.4.2. Wet Dust Suppression Techniques

Thus far, we have briefly reviewed various mechanisms, principles, and parameters affecting the performance of wet suppression methods. Described below are the four major categories of wet suppression techniques:

1) Water sprays
2) Water sprays with additives
3) Electrostatically charged fog
4) Combination of water sprays and steam.

2.4.2.1. Water Sprays

The use of water sprays is a well-known and inexpensive means of suppressing airborne dust or preventing dust from becoming airborne. However, water, due to its high surface tension, wets most surfaces only with difficulty. Since large quantities of water are needed for adequate penetration, this method would not be suitable where additional moisture content could be detrimental.

2.4.2.2. Water Sprays with Additives

This concept of wet dust suppression relies on the use of chemicals to alter the surface properties of water. The chemicals used are blends of one or more surface active agents (surfactants) and polymers, which reduce the surface tension of water from the normal 72.6 dynes/cm to as low as 25-30 dynes/cm.

The two most appropriate uses for treated water appear to be:

1) Preventing dust from becoming airborne
2) Capturing airborne dust.

The treated water achieves these results by modifying the following factors:

1) Droplet size
2) Coalescence
3) Surface area
4) Contact angle.

2.4.2.2.1. Droplet Size

Treated water, because of its low surface tension, is more readily atomized. The relationship between the diameter of the drop and the surface tension is given by

$$D = c\sqrt{\sigma} \tag{19}$$

where D = droplet diameter,

c = nozzle constant,

and σ = surface tension of the solution.

Thus, when the surface tension is reduced by 50%, the droplet diameter is reduced by only 30%. However, there is then a corresponding 200% increase in the number of droplets and a 50% increase in surface area for the same volume. In general, the collision efficiency increases for treated water because of a reduction in droplet size. However, below a certain critical droplet size, the efficiency does not increase because several other parameters play a major role.

2.4.2.2.2. Coalescence

Reducing surface tension without changing any other parameters can increase coalescence. Reducing surface tension reduces resistance to penetration by a particle, thus allowing deeper penetration (18). In general, the coalescence efficiency increases thereby, but other conflicting forces may counteract this effect.

2.4.2.2.3. Surface Area

Another method which has been exploited for dust control is foaming. Certain surfactants, if used under suitable conditions, generate foam which contains significantly more surface area for a given volume of water than untreated water. The additional surface area, of course, greatly increases the collision efficiency of the spray.

The chief reason for using surfactants is to avoid the addition of excess moisture to the product. The application of surfactants is not recommended for a product which may not be contaminated, or one where a high moisture content interferes with a subsequent operation.

2.4.2.2.4. Contact Angle

Treated water, because of the decreased contact angle between the droplet and the particle, can wet readily and uniformly, spread farther, and penetrate deeper. This action cements the surface of the product stream and significantly reduces the tendency of dust to become airborne.

2.4.2.3. Electrostatically Charged Fogs

Practically all aerosols carry an electrical charge. The presence of charge on the particle or droplet (or both) affects the particle trajectory around the droplet and can improve (opposite charges) or reduce (alike charges) the collection efficiency. These interacting forces increase as the charge increases. Electrostatically charged fogs take advantage of this phenomenon to suppress dust. According to Hoenig, (20) the effectiveness of electrostatically charged fogs is highly dependent on the polarity and charge concentration, which, in turn, depend on several factors, such as particle size, type of material, impurities, processes to which the product is subjected (e.g., crushing, grinding), temperature, etc. Although the individual particles can be highly charged, the overall charge carried by the product may be neutral. For example, figure 19 shows the charge density for various sizes of quartz particles, and figure 20 gives elementary charges per particle for different minerals.(21) For respirable-sized dust, the polarity as well as the charge distribution may vary under different sets of conditions. Therefore, to achieve the optimum efficiency, actual in-field tests are essential before the final installation.

A water droplet in a spray may be electrostatically charged by several methods: (13) via induction from a metal ring surrounding the spray, via a needle in the spray, or by direct electrical contact with the water (fig. 21). All of the charging mechanisms have limitations. With ring induction charging, the outer layer of water receives a higher charge, and the charge distribution over all of the droplets is unknown. Similarly, with needle charging, it is again unlikely that all the droplets formed will have a uniform charge. With direct contact charging, the nozzle must be carefully insulated to prevent current leakage through the supporting structure and water feedline.

Hoenig (20) has reported insulating the nozzles up to 20 kV by injecting air into the plastic tubing feedline. The injected air breaks the continuous water column into segments and prevents electrical leakage via conduction through the water column. Hassler (21) has reported an autogenous charging method that does not require any voltage source. Droplet charge results from water-to-metal friction in a grounded spray nozzle, as shown in

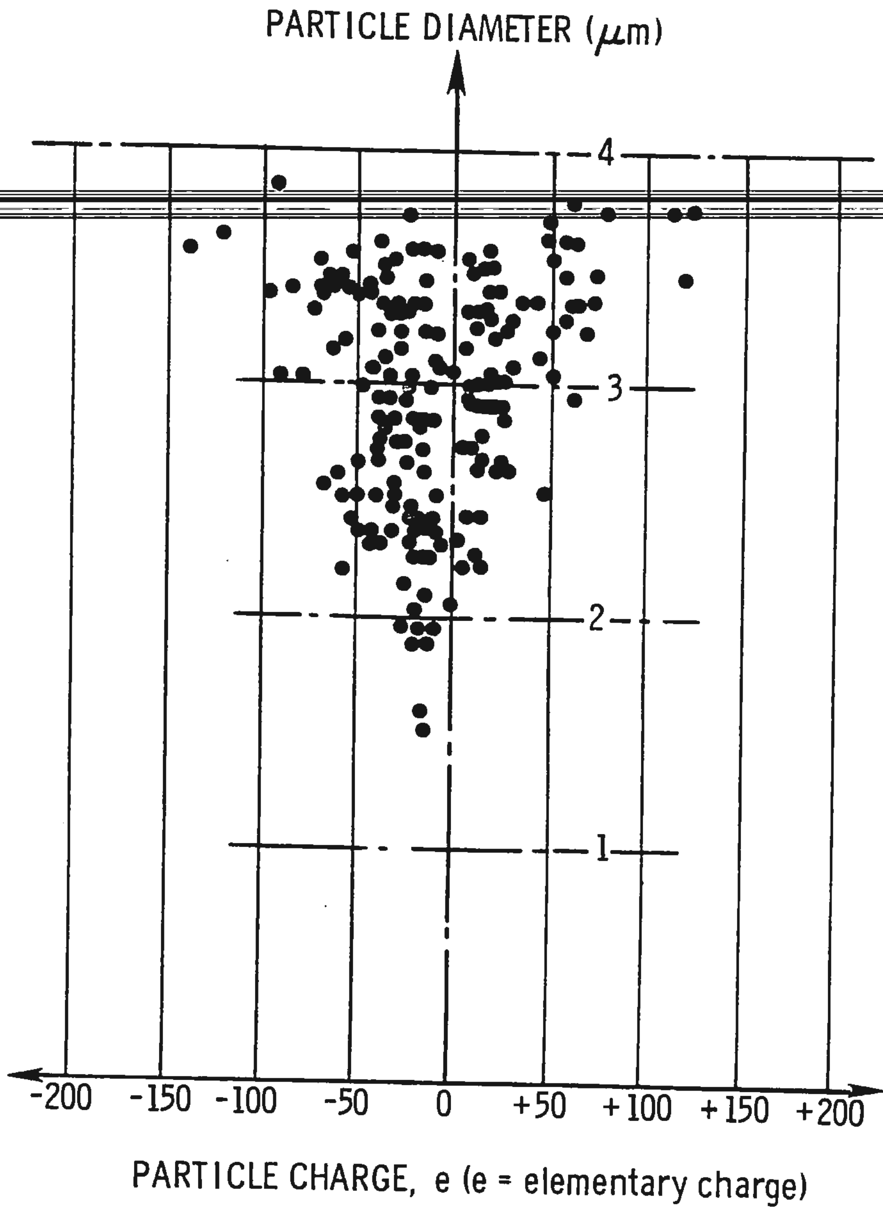


FIGURE 19. - Dust particle charges for quartz dust from disc crusher. (Reproduced from Ref. 21.)

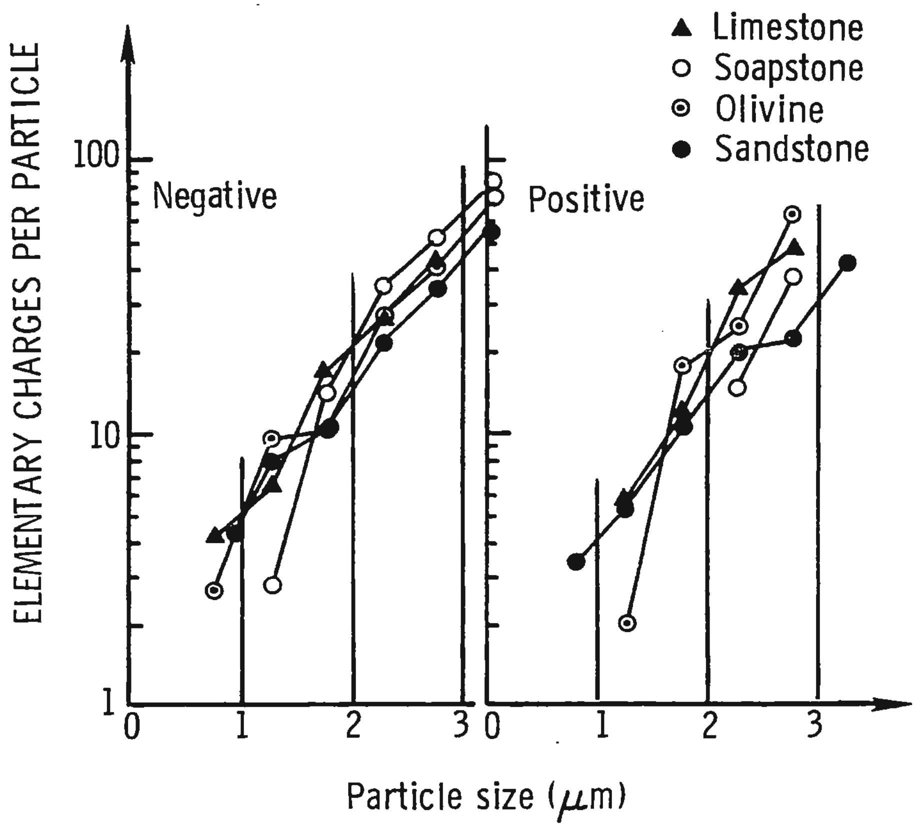


FIGURE 20. - Elementary charges per particle for different minerals crushed in a jaw crusher. (Reproduced from Ref. 21.)

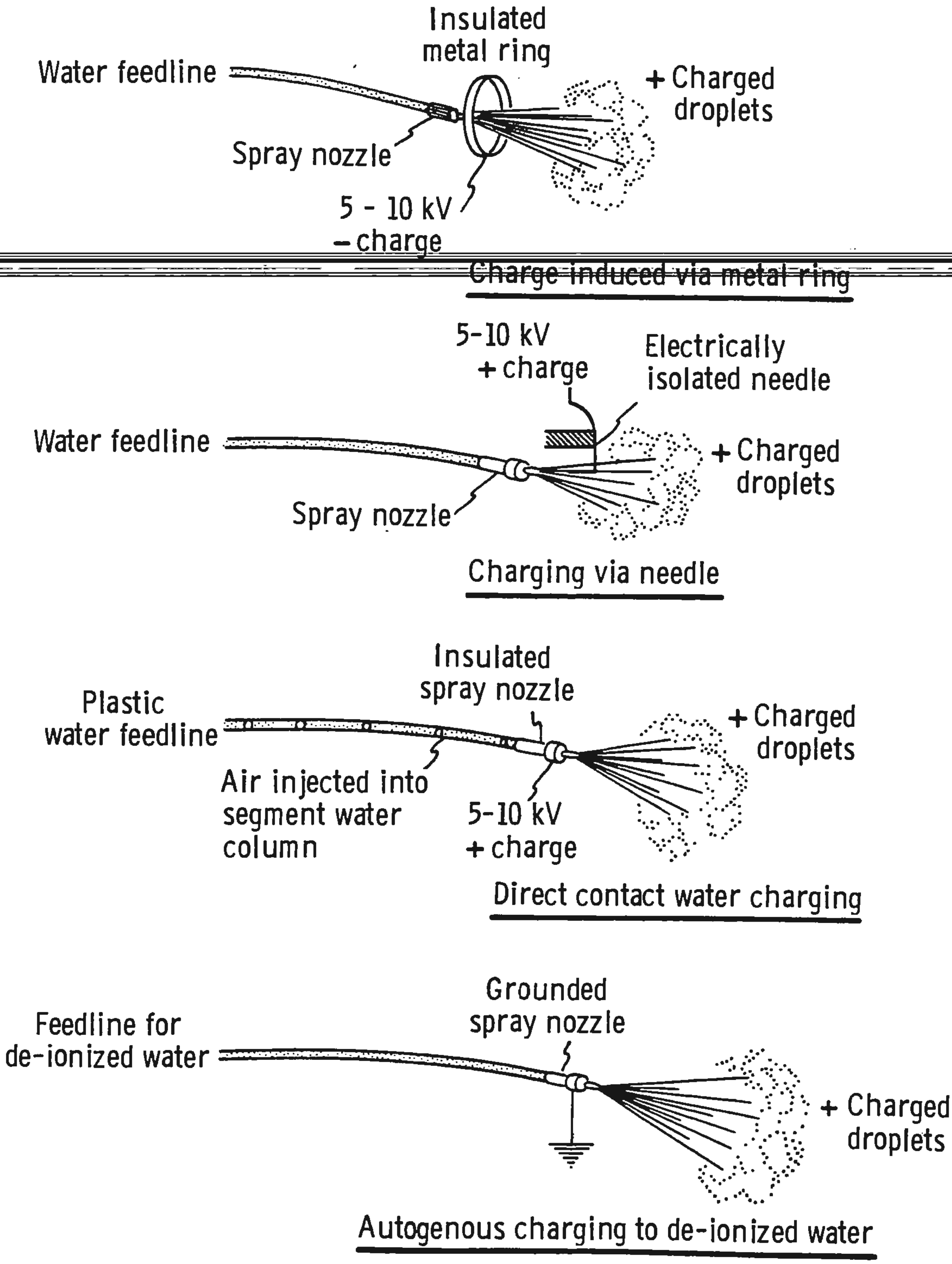


FIGURE 21. - Means of producing charged water sprays. (Reproduced from Ref. 13.)

figure 21 (bottom). Autogenous charging will work only if the nozzle is grounded and the water acts as an insulator (tap water or recycled water has a high conductivity due to impurities and thus cannot be charged by this method). The use of deionized water in a mining environment is not practical.

The effect of electrostatic charges on single droplet collision efficiency is illustrated in figure 22. The collection efficiency is significantly higher for particles less than 3µm.

Hoenig (20) conducted the first systematic study to evaluate the effect of electrostatically charged fog on the collection efficiency of airborne dust generated by various materials, such as granite, clay, foundry dust, cement, silica-sand, coal, etc. He experimentally showed that the charge distribution and polarity of various sizes of airborne dust were a function of factors such as type of product, processes applied, impurities present, climatic conditions, etc.

The typical suppression efficiencies obtained for foundry dust at various water flow rates are given in figure 23. Significant improvements in suppression efficiencies for positively charged fog were attributed to the presence of primarily negatively charged particles in the dust. Figure 24 compares the performance of an uncharged fog with positively charged and negatively charged fogs for trona dust. The results suggest that the dust contained both positively and negatively charged particles in approximately equal amounts.

It is evident from the foregoing discussion that the charge and size distribution of the particulates in the dust must be known before

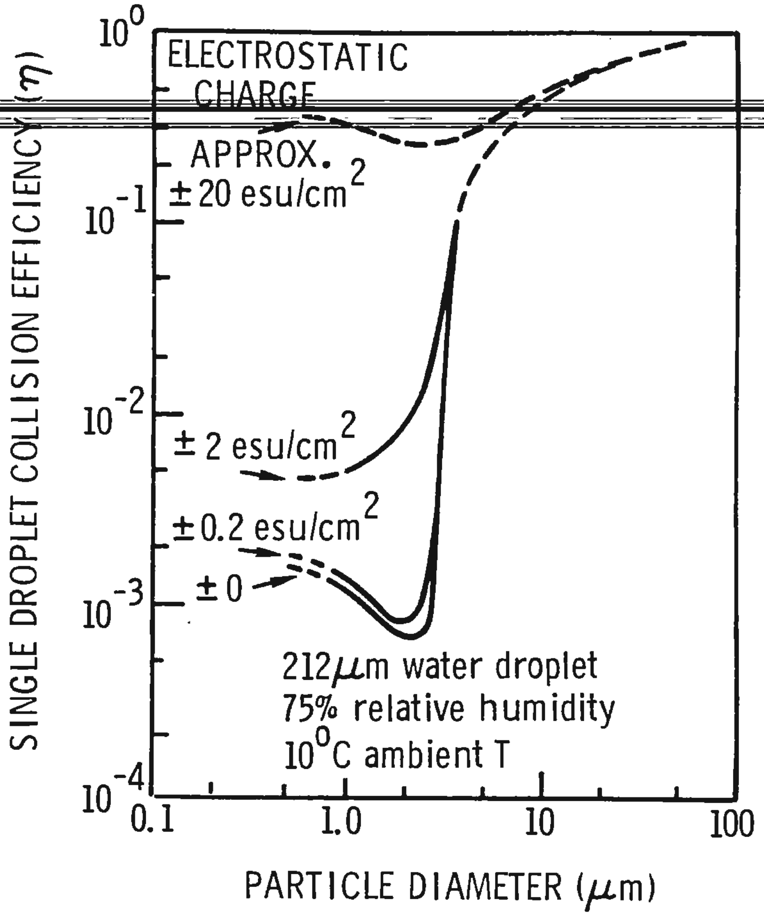


FIGURE 22. - Effect of electrostatic charge on collision efficiency. (Reproduced from Ref. 14.)

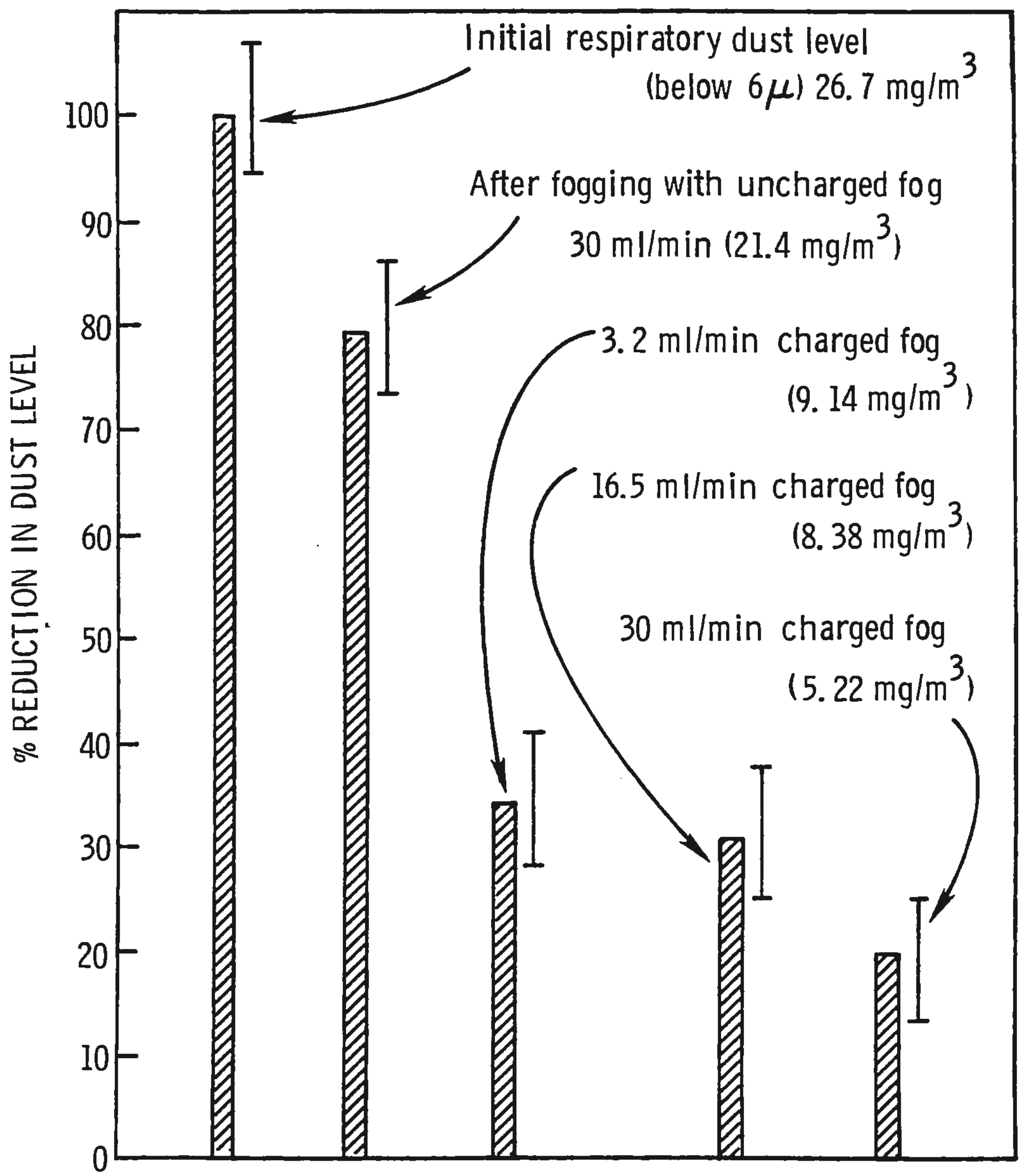


FIGURE 23. - Percentage reduction in dust levels at various water flow rates for foundry dust. (Reproduced from Ref. 20.)

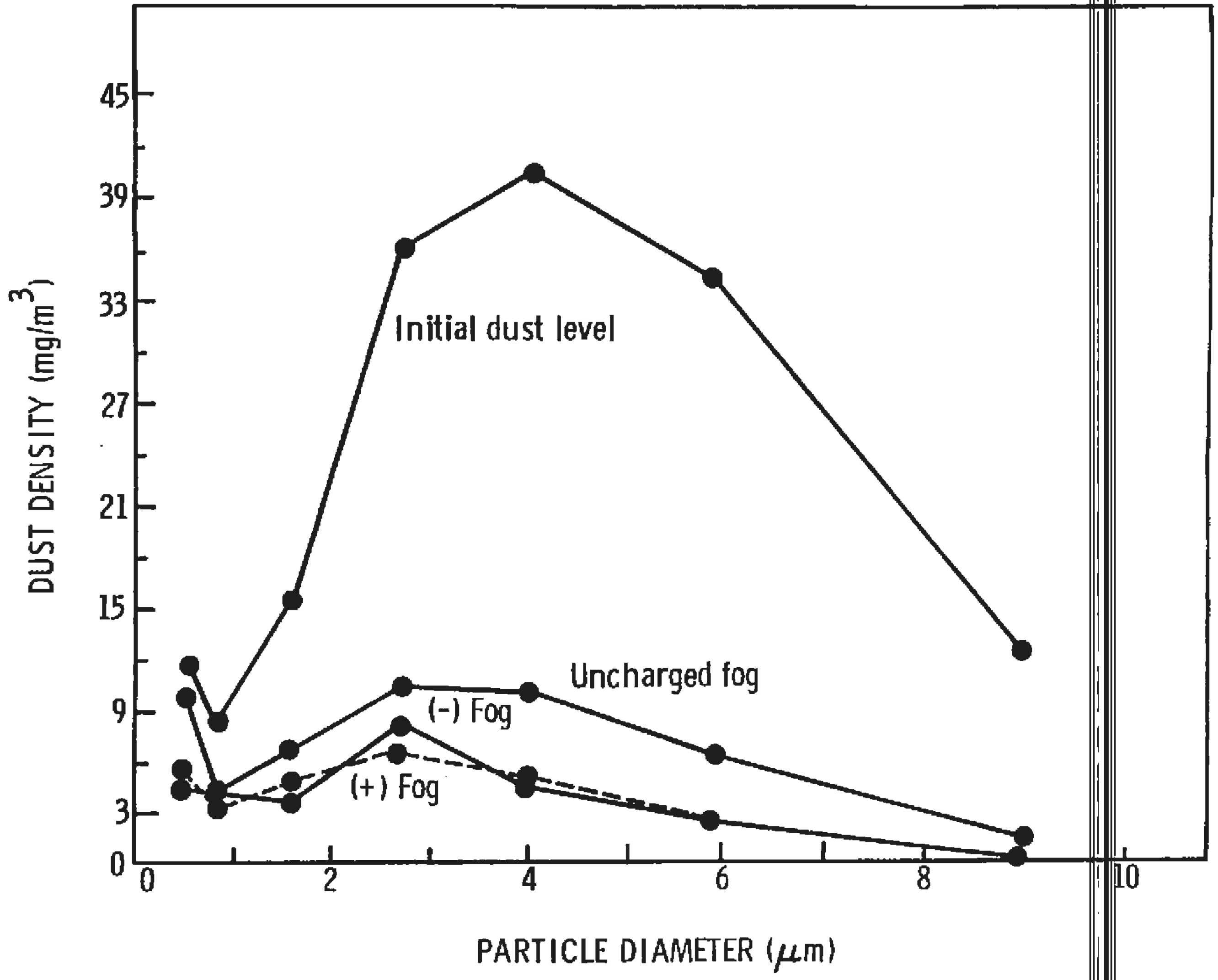


FIGURE 24. - Laboratory tests of trona dust control with charged fog. (Reproduced from Ref. 20.)

electrostatic fog generators can be considered for dust suppression. Electrostatic foggers are an ideal choice for a dust source that generates predominantly positive or negative polarity dust of 3μm or less. However, if the respirable dust fraction has an overall neutral charge, an auxiliary fogger (generating fog of opposite polarity to the primary fog) may be necessary to obtain the desired control. This alternative, however, is very expensive. The use of electrostatic fog may also be objectionable in some underground mining operations, such as for coal, because of potential explosion hazards due to static electricity or sparks.

2.4.2.4. Combination of Steam and Water Sprays

Another approach which has proven effective in dust suppression is the use of steam in conjunction with water. Schauer (22) has observed a 70% greater collection efficiency for submicron size particles with a steam pretreatment than with water alone. Lohs (23) has reported a collection efficiency of 75% for 0.4-μm hydrophilic (sodium sulfate) particulates with steam, compared to 40% without steam; for the same particle size, an efficiency of only 50% was obtained for hydrophobic (polyester) particles with steam, compared to 40% without steam.

Cheng (24) has shown that the wet collection mechanism for airborne coal particles involves condensation of steam on the coal particles and sedimentation of the resulting heavy, wet particles. Cooling is required to achieve condensation on the dust particles.

Figure 25 summarizes the collection efficiencies at various particle sizes for steam, a steam-water mixture, and water alone. It shows that, in general, the collection efficiencies with the steam-water treatment

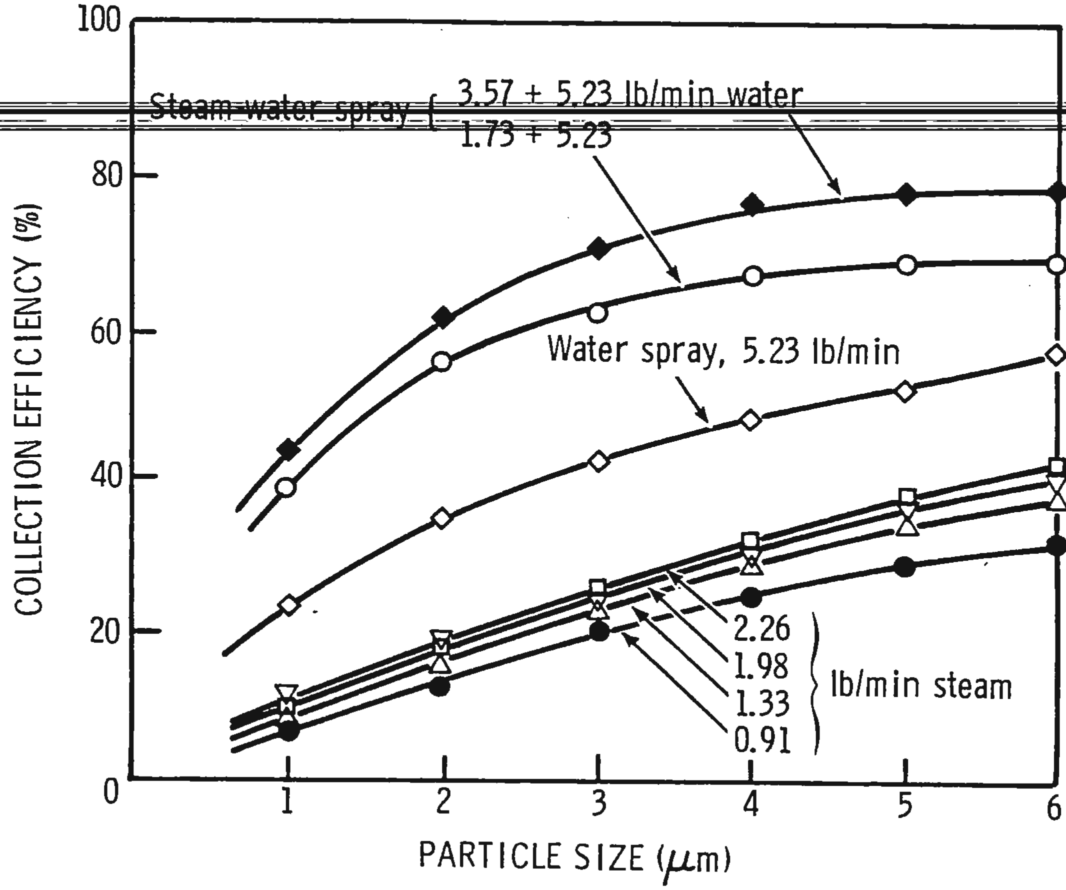


FIGURE 25. - Collection efficiencies of sprays of mixtures of steam-water, water alone, and steam alone. (Reproduced from Ref. 24.)

are 20% higher than with the water spray alone, for all particle sizes. The mixture is 100% more effective than the sprays alone for 1-μm particles and 40% more effective for 6-μm particles (fig. 26). However, on an overall gravimetric basis, steam-water mixtures are about 14% more effective than simple water sprays.

The results of using a steam-water mixture are encouraging; however, cost considerations -- for a continuous supply of steam, among other things -- preclude its application in the mining industry.

2.4.3. Advantages and Disadvantages of Wet Dust Suppression Methods

The simplest and least expensive means of controlling airborne dust at conveyor transfer points is through the use of wet dust suppression systems.

The chief advantages of wet suppression systems are:

1) They are relatively inexpensive and easy to install and operate.
2) They are effective in many applications.
3) No specialized maintenance is required.

The disadvantages of these systems include:

1) Water is often a scarce resource in summer months when it is most needed.
2) Wet systems are highly susceptible to freezing.
3) Nozzles can become clogged.
4) Dust is not extracted from the product stream and, hence, the same dust could become airborne downstream.
5) Wet material can blind screens.

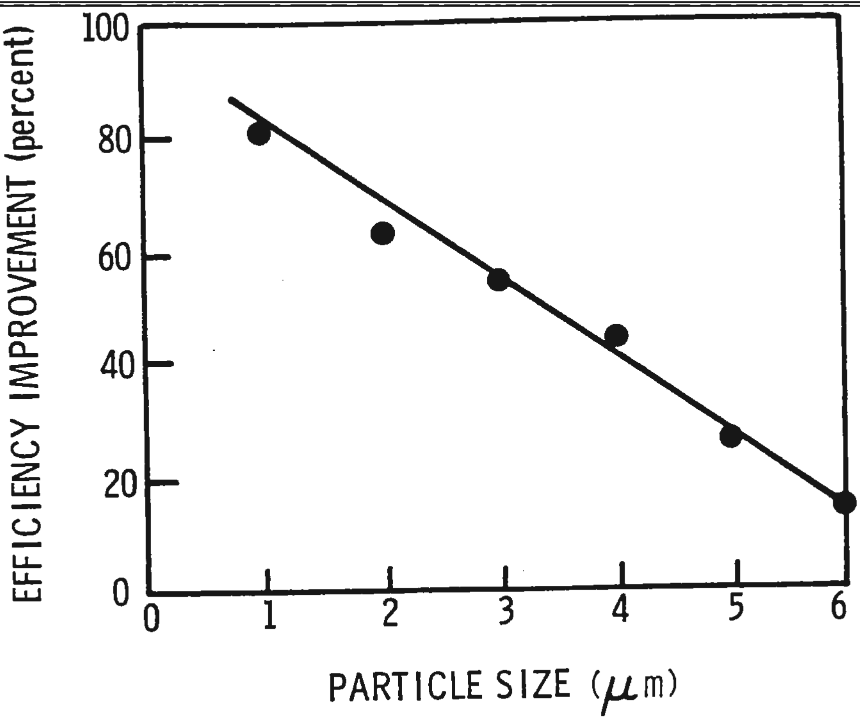


FIGURE 26. - Efficiency of mixture of steam-water sprays over water sprays alone. (Reproduced from Ref. 24.)

6) All wet systems may not be effective for respirable-sized dust.

7) Wet dust tends to cling to conveyor belting and is released during return runs, creating muck piles which may become an added source of fugitive dust and require additional maintenance.

2.4.4. Commercially Available Wet Dust Suppression Systems

The preceding sections described the principles, mechanisms, and techniques of wet dust suppression. Discussed below are various commercially available wet dust suppression systems based on one or more of the techniques described earlier. The main advantages and disadvantages of each are described.

2.4.4.1. Water Sprays

2.4.4.1.1. Sonic Dry Fog Dust Suppression System

The Sonic Dry Fog system is designed to control airborne dust by introducing droplets smaller than 20μm in the direction of the material stream flow. Since these droplets are in the same size range as respirable dust particles, according to Schowengerdt's (16) theory, the Sonic system should be efficient in controlling respirable dust emissions.

Advantages

1) Water requirements are 5-15 gph per nozzle at city water pressure (20 psig).
2) Air requirement is 7 scfm per nozzle at 60 psig.
3) Water droplet size can be varied from 1-10 μm to 200-600 μm.
4) Moisture addition usually amounts to less than 0.1% of product weight.

5) The product/material is not chemically contaminated.

6) The system is effective even in cold weather (claimed by Sonic Corp.).

Disadvantages

1) Tight enclosures are needed for effective system operation.

2) Resonator caps on the nozzles are fragile and susceptible to wear, requiring periodic inspection and maintenance.

3) System is not recommended by manufacturer when air velocities are in excess of 1 m/s, or under very turbulent conditions.

4) System effectiveness cannot be determined visually because fog and dust cannot be differentiated.

2.4.4.1.2. Homemade Water Sprays

Use of a homemade water spray is a popular way to prevent dust from becoming airborne where there are no restrictions on the addition of moisture to the product. However, other important factors -- how well the product mixes with water, nozzle location, spray patterns, and droplet sizes -- are often not considered. Therefore, effective homemade water sprays are rarely encountered in the mining industry. If properly applied, homemade water sprays can be effective in preventive dust control.

2.4.4.2. Water Sprays with Additives

This type of wet dust suppression relies on the use of surfactants and polymers to reduce the surface tension of water. The following two commercial systems are most frequently encountered in the mining industry.

2.4.4.2.1. Chem-Jet Dust Suppression System (Johnson-March)

The Chem-Jet dust suppression system is a preventive dust control method that uses surfactants to reduce water surface tension and decrease water-particle contact angle. The system meters and mixes a preset amount of specially formulated surfactants with water and sprays the mixture on the material through strategically located nozzles. Application usually begins at the truck or car dump at the primary crusher, and additional applications are normally made at all crushers where new surface is being created.

Advantages

1) Moisture added at the transfer point in the beginning of the process stream is claimed to have a "carryover effect" at subsequent transfer points.
2) Effective where surfactants are tolerated, but not excessive moisture.
3) Fixed costs are lower.

Disadvantages

1) Operating costs are higher.
2) Careful application is required at transfer points prior to the vibrating screen to prevent blinding.
3) The proportioning equipment, pump, etc., should be adequately protected against freezing.

2.4.4.2.2. Deter Microfoam System

The Deter microfoam system, as the name suggests, uses fine foam bubbles to control airborne dust. The foam is injected into free-falling aggregates, and since it consists of a thin film of water around air, a minimal amount of water produces a large surface area for dust suppression. Foam is produced by mixing air, water, and specially formulated surfactants under pressure. The metering unit automatically supplies a preset ratio of air, water, and surfactant through the mixer, which uses vortex action to produce many small foam bubbles (100-200 μm).

Advantages

1) Enclosure tightness is not critical.
2) A carryover effect is claimed by Deter.
3) Moisture addition amounts to usually less than 0.1% of product weight.

Disadvantages

1) Operating costs are higher.
2) The proportioning equipment, pump, piping, and compressor should be adequately protected against freezing.
3) Cautious application is required at transfer points prior to the screen to prevent blinding.

2.4.4.3. Electrostatically Charged Fogs

Dust suppression through electrostatically charged fogs is based on the principle that charged water droplets will attract dust particles, thus increasing collision probabilities. This approach is ideal for a dust source that generates particles that have predominantly positive or negative charges. However, charges are seldom uniforms; for example, the charge carried by a cloud of dust can be neutral, while the individual particle may be charged positively or negatively.

The use of electrostatic fogs must be ruled out for coal and other gassy mines because of the potential explosion hazards due to static electricity or sparks.

The following two systems were evaluated.

2.4.4.3.1 Aero-vironment Electrostatically Charged Fog Generator

The Aero-vironment Electrostatically Charged Fog Generator utilizes centrifugal forces and a high-velocity air stream to generate fine water droplets from water flowing into an atomizing cup. These droplets are charged by direct contact with a high-voltage power supply. The typical charge-to-mass ratio is as high as 1.2×10^6 C/g (coulombs per gram) with a mass median droplet diameter of 200 μm.

Advantages

1) The high charge density on the droplets makes them very efficient for suppressing oppositely charged particles under 3 μm -- a difficult problem to solve by any other technique.

2) Positive, negative, or neutral fogs may be generated.

3) There is no chemical contamination.

Disadvantages

1) Capital costs are high.

2) Electric insulation maintenance is critical.

3) This method is not recommended where static electricity can trigger an explosion.

2.4.4.3.2. Ritten Electrostatic Fogger (Sonic Development Corporation)

The Ritten Electrostatic Fogger charges atomized water droplets either positively or negatively via induction from a metal ring surrounding the spray. Since charging is indirect, the charge density on a given droplet is much lower than that produced by the direct contact charging method.

Advantages

1) Costs are lower than with the direct contact method of charging, but the charge density is also lower.

2) Effectiveness is high for oppositely charged particles smaller than 3 μm.

3) There is no chemical contamination.

4) Positive, negative, or neutral fogs can be generated.

Disadvantages

1) All droplets may not be charged by the induction ring method.

2) Electric insulation maintenance is essential.

3) The method is not recommended where static electricity can trigger an explosion.

2.4.5. Selection of a Wet Dust Suppression System

One of the goals of this program was to select a commercially available wet dust suppression system for rigorous field testing to determine its effectiveness in reducing respirable dust concentrations. The system selected had to meet the following criteria:

General applicability - The system should be applicable for all products, climatic conditions, processes, etc.

Efficiency - The system should be able to reduce respirable dust concentrations to permissible levels.

Cost - The system should be inexpensive to acquire, operate, and maintain.

Moisture addition - Mositure addition to the product should be minimal.

Product contamination - The system should not contaminate the product.

Maintenance requirements - The system should be as rugged as possible with minimal maintenance requirements.

The commercial systems reviewed for each method of wet suppression were:

Water sprays

Sonic Dry Fog Dust Suppression System

Homemade water sprays

Water sprays with additives

Deter Microfoam System

Chem-Jet Dust Suppression System by Johnson-March

Electrostatically charged fog

Ritten Electrostatic Fogger

Electrostatically Charged Fog Generator by Aero-vironment.

To evaluate these systems on a common reference scale, we formulated two hypothetical transfer points: crusher-to-belt and belt-to-belt, with characteristics commonly encountered in the mining industry (Appendix A). We then asked the various manufacturers for information regarding efficiencies achievable, cost, utility requirements, auxiliary equipment requirements, etc., for each application and evaluated each system based on the established criteria. These systems were chosen to illustrate basic concepts; the advantages and disadvantages of each were objectively evaluated only on the basis of their overall ability to effectively reduce respirable dust.

2.4.5.1. System Evaluations

2.4.5.1.1. General Applicability of the Systems

Water spray systems are potentially applicable to any product that can tolerate moisture. Conventional water sprays are unable to fully penetrate the product stream, and some materials cannot be "wetted" by water alone. Although a majority of the larger dust particles may be suppressed, the efficiency in controlling airborne respirable dust may be low, since it has been shown that coarser droplets cannot capture smaller dust particles.

The Sonic system (atomized water spray) introduces droplets smaller than 20 μm in the direction of the material stream flow. These small droplets have a much greater probability of colliding with a respirable-sized dust particle than the larger spray droplet.

The Chem-Jet and Deter systems rely on surfactants to thoroughly wet the product so that dust does not become airborne. These systems are preventive and are not effective for removing airborne respirable dust. Also, additional applications are needed whenever new surfaces are created or exposed, e.g., when the material is transferred, crushed, or screened. The Chem-Jet and Deter systems add a small amount of chemical contamination to the product. In addition, their use can cause screen blinding or create muck on the belt if adequate precautions are not taken.

The Ritten and Aero-vironment electrostatic foggers should be more efficient than water alone for respirable-sized particles that are either predominantly positively or negatively charged. However, the efficiency is highest for particles < 3 μm, and decreases for larger particles. Electrostatic sprays require a considerable amount of auxiliary equipment which may not be economically feasible for many mining applications. The use of electrostatic foggers is questionable in coal mines because of potential explosion hazards.

2.4.5.1.2. Efficiency

It is impossible to compare efficiencies of these systems because they were not tested under identical conditions. However, we can draw some general conclusions by comparing the basic mechanisms by which these methods control or prevent dust.

Electrostatic foggers are effective for controlling all dust particles < 3–5 μm that have predominantly one type of charge; however, for neutral or slightly charged dusts over the entire respirable and non-respirable range, they are unsuitable unless the user provides an auxiliary fog opposite in polarity to the primary fog.

The Deter foam system is a good choice for products that cannot tolerate additional moisture but can tolerate contamination; the use of foam generally reduces the amount of water required for control. However, since the relatively large foam bubbles produced (100–200 μm) have very low inertia (because of low weight), the relative velocity between the bubbles and a particle decreases much faster than for a water droplet, reducing the foam's effectiveness for particles below 3–5 μm. Foams are also displaced very easily by air movement. To use foam as a preventive measure, thorough mixing with the material is essential.

The application of surfactants, as in the Chem-Jet system, to prevent dust from becoming airborne is especially suitable where the effect carries over to subsequent operations. When a product goes through several processes, however, additional treatments may be needed. Surfactant systems are ineffective in reducing respirable dust that is already airborne.

The Sonic system seems particularly effective in capturing respirable-sized dust particles due to the small droplet size. It must be used within an enclosure (settlement chamber) to facilitate thorough mixing of the spray and air and to allow larger particles ample time to settle out.

2.4.5.1.3. Cost

Capital, operating, and maintenance costs for primary and auxiliary equipment are clearly important in evaluating a system. Generally, systems with central units are most economical when they can be used to treat more than one point.

Cost estimates for a dust control system can vary significantly depending upon the plant layout, location, material processed, severity of the problem, degree of control required, climatic conditions, number of transfer points treated, etc.

Homemade water spray systems are the least expensive wet suppression system. The Sonic system is relatively inexpensive to install, utilizes low air pressure and water volume, and requires no additives.

The Chem-Jet and Deter systems are relatively inexpensive, but require the continued purchase of costly proprietary surfactants.

The Ritten and Aero-vironment systems require auxiliary equipment to produce a high electric potential. In addition, the Ritten fogger may require a fan to impart sufficient velocity to the droplets. Furthermore, neither of these electrostatic systems is readily available commercially.

2.4.5.1.4. Moisture Addition

Most of the systems examined here claim to add less than about 1% moisture by weight. However, wet suppression systems are not recommended for moisture-sensitive products such as hydrated lime, cement, etc.

2.4.5.1.5. Product Contamination

The Chem-Jet and Deter systems require additives that may contaminate certain products, such as certain limestone aggregates used for construction and road building, cement, silica sand used for glass mixing, or certain types of coal used in power generators.

2.4.5.1.6. Maintenance Requirements

All the systems seem to need routine maintenance, but, relatively speaking, the systems with the least number of moving parts are expected to have the lowest maintenance needs.

The Chem-Jet and Deter systems have nozzles that may clog occasionally, and require filtered water. These systems also require additional metering systems for adding the surfactants.

The Sonic nozzle is designed to minimize clogging, but, as with other systems, filtered water is still required. The resonator cap is a fragile component and will wear out. However, the replacement cap is inexpensive and "snaps" into place. The Sonic, Deter, and Ritten systems require an air compressor, which adds to the maintenance requirements.

The electrostatic systems have nozzle maintenance requirements similar to those of other systems, but also need effective electrical insulation, covers or partial enclosures, and an electrical source.

All the systems reviewed have some difficulty operating under winter conditions, and heat tracing of the water lines is required. Deter Company claims that foam, due to its low heat conductivity, is only marginally affected by cold, even after it leaves the nozzle. Sonic Development Corporation advertises the effectiveness of their system under freezing conditions, and attributes it to the production of droplets too light to freeze. However, the relatively drier atmosphere during winter would increase evaporation losses so that it would be necessary to change the air pressure under such conditions.

2.4.5.2. Recommended System for In- Mine Testing

Upon our recommendation, the Bureau approved the Sonic Dry Fog system for in-mine testing. The advantages of the system are:

1) Installation and operation are simple.
2) Smaller droplets (1-20 μm) are produced at much lower pressure than with other commercially available nozzles.
3) High flexibility and turndown ratios of 1:30 are possible.
4) Fewer problems are likely during winter operation.
5) Total water consumption is very low.
6) It is relatively inexpensive.
7) Since there are no moving parts in the system itself, less maintenance is expected.
8) Nozzles are self-cleaning.
9) No wetting agents are required.

Its disadvantages are:

1) Enclosures must be tight.
2) Wet systems are not recommended where excessive air turbulence is expected.

3) Evaporation losses in drier environments may reduce efficiencies and require additional water or somewhat coarser droplets.

4) Faulty resonator caps will allow coarser droplets to enter the system, with resulting decreased efficiency.

5) Since it is difficult to visually differentiate between fog and dust, elaborate sampling is needed to determine the efficiency of the system.

*** 3. DESIGN AND FABRICATION

3.1. BACKGROUND

Chapter 2 is a revised version of the Phase I report as submitted in July, 1981. Phase I also required a survey to establish typical characteristics of belt conveyor installations in the mining industry, and to select a site for detailed testing of dust control technology in subsequent phases of our study. To accomplish this task, we visited a number of mining facilities and collected appropriate information, such as physical layout and designs of conveyor belt transfer points, location of dust sources and their expected airborne respirable dust concentrations, and control techniques in use and their effectiveness.

This chapter will describe our Phase II efforts. We first used the collected information to develop criteria for selecting an in-mine test site. Based on these considerations, we selected Genstar Corporation's Marriottsville, Maryland, facility, a surface limestone mine producing crushed limestone at an average rate of 700 ton/h year-round.

Next, on the basis of the information collected during field trips, the literature search in Phase I, and our experience, we designed prototype bulk material handling, dust collection, and wet dust suppression systems appropriate to this site. These were then installed at the selected test facilities.

Our approach to reducing respirable dust emissions from belt conveyor transfer points was two-tiered: first, to reduce dust generation and emissions through the use of effective and reliable bulk material handling components, such as rockboxes, enclosures, skirtings, dust curtains, and belt scrapers; and second, to apply either dust collection or wet dust suppression techniques to control the generated dust emissions from the belt conveyor transfer points included in the study. The following sections describe our program efforts during Phase II.

3.2. DESCRIPTION OF OVERALL PROCESS FLOWSHEET

As described in Chapter 2, the design of an efficient, effective, and reliable dust control system requires a thorough knowledge of the equipment and processes involved. A process flow sheet of the test facility, including the bulk material flow and equipment characteristics (types of crushers and vibrating screens; belt conveyor size, speed, capacity, etc.), was developed at the outset of Phase II. Using the flow sheet, we then selected the critical transfer points for applying the prototype dust control systems. Figure 27 schematically shows the overall process flow of the test facility and the transfer points selected in the study.

To determine the applicability of dust control systems under a variety of operating and process conditions, we selected transfer points from each segment of the test facility, i.e., the primary crushing circuit, secondary crushing circuit, and tertiary crushing circuit. Moreover, the transfer points chosen included several different

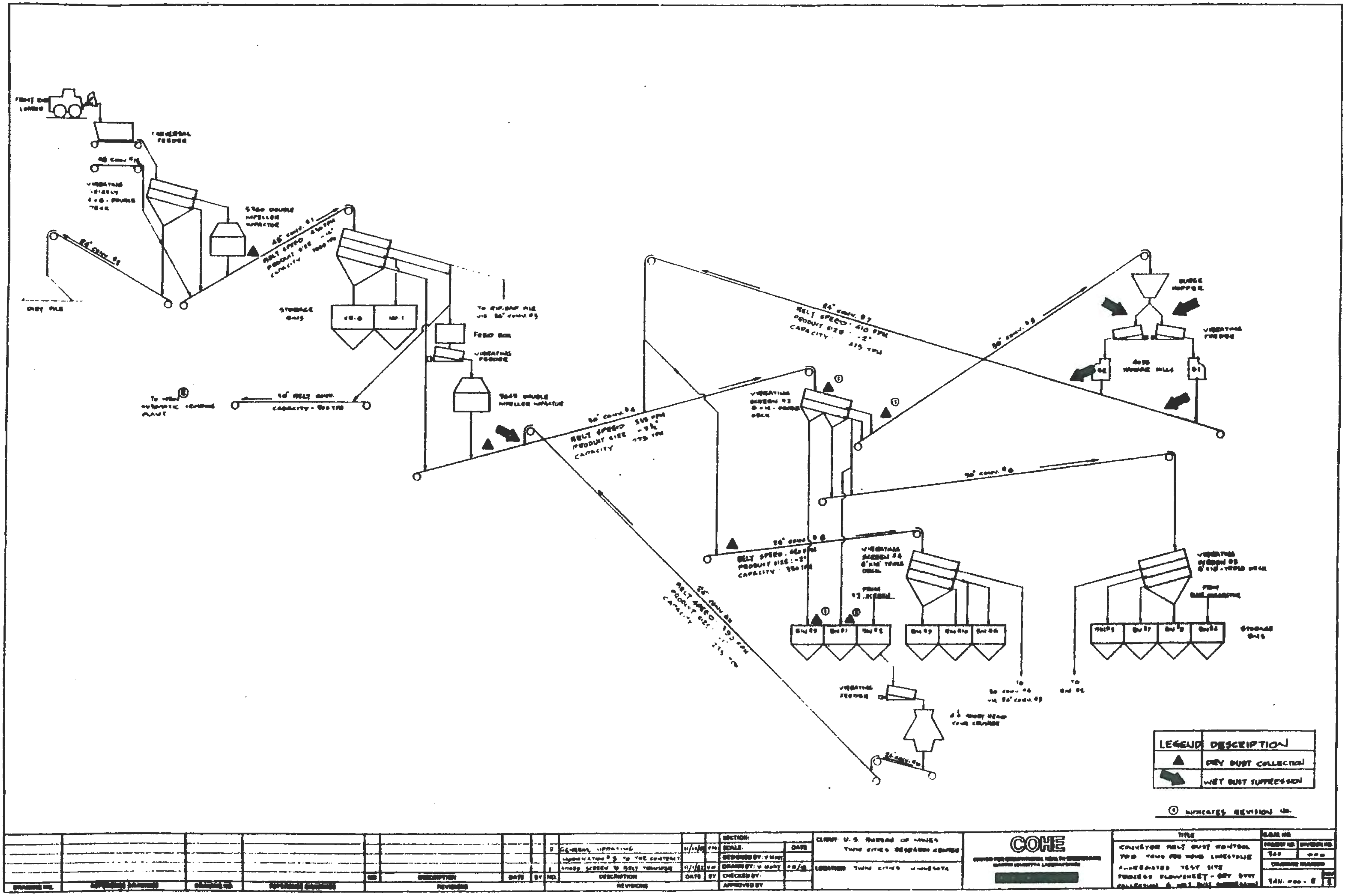


FIGURE 27. - Process flow sheet for the test facility.

types of mineral processing equipment, such as belt conveyors of various sizes, speeds, and designs; crushers of different designs (e.g., double impeller impactor, hammermills); and the vibrating screen. As a result, 10 of the most commonly encountered transfer points in the mining industry were retrofitted in this study: seven were equipped with dust collection systems using industrial ventilation principles, and the remaining three were equipped with a wet dust suppression system. The selected points for each system were:

Dust Collection System

Primary crusher-to-belt conveyor #1

Secondary crusher-to-belt conveyor #4

Belt conveyor #7-to-belt conveyor #8

Belt conveyor #4-to-vibrating screen #2

Vibrating screen #2-to-belt conveyor #5

Vibrating screen #2-to-storage bin #1

Vibrating screen #2-to-storage bin #5

Wet Dust Suppression System

Hammermill #1-to-belt conveyor #7

Hammermill #2-to-belt conveyor #7

Belt conveyor #11-to-belt conveyor #4

The following sections describe in detail the condition of the test facilities before modifications; the installed bulk material handling, dust collection, and wet dust suppression systems; and the problems encountered and solutions adopted at each transfer point.

3.3. EXISTING INSTALLATIONS AT IN-MINE TEST SITE

The in-mine test site, approximately 30 years old, was originally equipped with state-of-the-art dust control technology, reflecting an attitude of genuine concern for the working environment of plant personnel. The same concern continues to this day, as evidenced by the complete cooperation of the local management throughout the present program.

Over the years, unavoidable changes and additions made to the facility to accommodate new processes and product lines have resulted in less than optimum dust control system efficiencies compared to those in more recent plants. Visits to eight other mining facilities during Phase I of the program indicated similar trends. Hence, conditions at the selected test facility were representative of the mining industry.

The existing systems for bulk material handling, dust collection, and wet dust suppression at the various transfer points prior to any modifications are described below.

3.3.1. Bulk Material Handling System

Most of the bulk material at the test site was handled by belt conveyors and transfer chutes. Before our modifications, many belt conveyors were running at speeds which resulted in some spillage at certain transfer points. Some transfer chutes were without the covers needed to facilitate easy access in case of material jam-up.

At some chutes, covers were present originally, but were not reinstalled after maintenance or production-related work because they required bolting.

The skirting on all of the belt conveyors had shorter and narrower settling boxes than we would now recommend. These created higher air velocities within the enclosure that promoted dust escape. Moreover, the skirting rubber, fastened with nuts and bolts, was worn out at a number of locations, resulting in considerable material spillage and dust emissions.

We also found that bolted dust curtains and rubber seals to contain dust emissions were not consistently in place. The head chutes of most of the conveyors were equipped with rockboxes and access doors, and no wear was apparent on these. However, some transfer chutes without the rockboxes were worn out in places. Belt cleaners were found at only a few transfer points.

3.3.2. Dust Collection System

The existing dust collection system consisted of three reverse jet baghouses. One large central baghouse with 40,000-cfm capacity exhausted most of the transfer points, while two 7,000-cfm dust collectors exhausted the primary crusher and screen house transfer points. The dust collection system was, most likely, designed based on approaches described in the Industrial Ventilation Manual. (We will show in Chapter 5 that for some of the transfer points, the Industrial Ventilation Manual estimates lead to less than adequate exhaust volume.) Observations at individual points, and conversations with operating personnel at the test facility, revealed that several exhaust hoods had been added to counteract losses in efficiency. However, this unbalanced ductwork resulted in further losses of efficiency. For example, two exhaust hoods were operating at the end of the settling box at the secondary crusher-to-belt conveyor transfer point, but dust emissions were still visible. Moreover, to control the dust emissions from the sides of the conveyor, two additional 10-ft-long exhaust manifolds had been installed on either side of the conveyor. These suffered from poor air distribution, and were sometimes plugged. The dust collector at the primary crusher was located directly above belt conveyor #1, and discharged the collected dust back onto the same belt to avoid its subsequent handling. However, this resulted in shifting the problem from one area of the belt conveyor to another. On a windy day, much of this dust became airborne again, increasing ambient dust levels.

The dust control system at vibrating screen #2 consisted of an exhaust manifold mounted on top of the screen enclosure. Three 10-in.-diameter ducts connected to an exhaust manifold created an in-draft through a 1-in. opening between the vibrating screen body and the stationary enclosure. To avoid material spillage, the rear of the vibrating screen was equipped with rubber seals.

The storage bins receiving the material from the vibrating screen circuit were without covers and significant dust emissions were visible.

3.3.3. Wet Dust Suppression System

Wet dust suppression systems were in use at two locations: at the receiving hopper feeding the primary crusher, and on the discharge chute from vibrating screen #2 feeding belt conveyor #5. At the primary crusher receiving hopper, water was sprayed onto the material through a number of nozzles connected to a common manifold. The effectiveness of the spray could not be determined because the transfer point was also equipped with a dust collection system. The wet dust suppression system at the vibrating screen discharge chute consisted of a simple garden hose nozzle, spraying approximately 4 gpm water on the material. This appeared to be highly effective; sizable reductions in airborne dust emissions were observed at the subsequent hammermill crushers-to-belt conveyor transfer point. In addition, a number of spray nozzles were present at the end of the settling boxes for some of the transfer points. These were not very effective in controlling dust emissions at the end of the settling boxes but appeared to help reduce dust emissions at the subsequent transfer points.

3.4. TEST INSTALLATIONS - GENERAL DESCRIPTION

The test installations at various transfer points consisted of some common dust control system elements. Elements common to all the systems are described in Sections 3.4; details specific to each system are discussed in Section 3.5.

3.4.1. Bulk Material Handling System

The analysis of the data collected during our Phase I field visits revealed that a transfer point involving a belt conveyor emits dust from three locations: at the tail pulley where material is received (location "T"), through the sides of the conveyor skirting rubber (location "S"), and from the end of the settling box through which the material exits (location "E"). Our observations indicated that dust emissions from "S" and "T" locations could be reduced by containing them through the use of bulk material handling components such as spacious enclosures, proper dust seals, etc.; the emissions from "E" locations could be controlled either by dust collection or wet dust suppression. Accordingly, we placed great emphasis on designing a bulk material handling system to reduce not only dust generation and emissions at a transfer point, but also to contain dust at the source. Our typical transfer point included bulk material handling components such as rockboxes, inclined conveyor skirting, spacious enclosures, dust curtains and seals, belt scrapers, and V-plows, etc. (fig. 28).

3.4.1.1. Rockboxes

Rockboxes were strategically placed in the transfer chutes to reduce the height of free fall of the material and also to absorb the impact of incoming material, thus reducing chute wear and abrasion. Rockboxes placed in the bypass chutes of primary and secondary crushers reduced the impact of incoming material on the belt and deflected the material in the direction of belt travel, thus reducing turbulence, dust generation, and emissions enough to obviate the need for an exhaust hood at the tail pulleys of the respective conveyors.

3.4.1.2. Skirting

The conventional straight edge skirting design was replaced with inclined conveyor skirting. This design provided a greater wear area

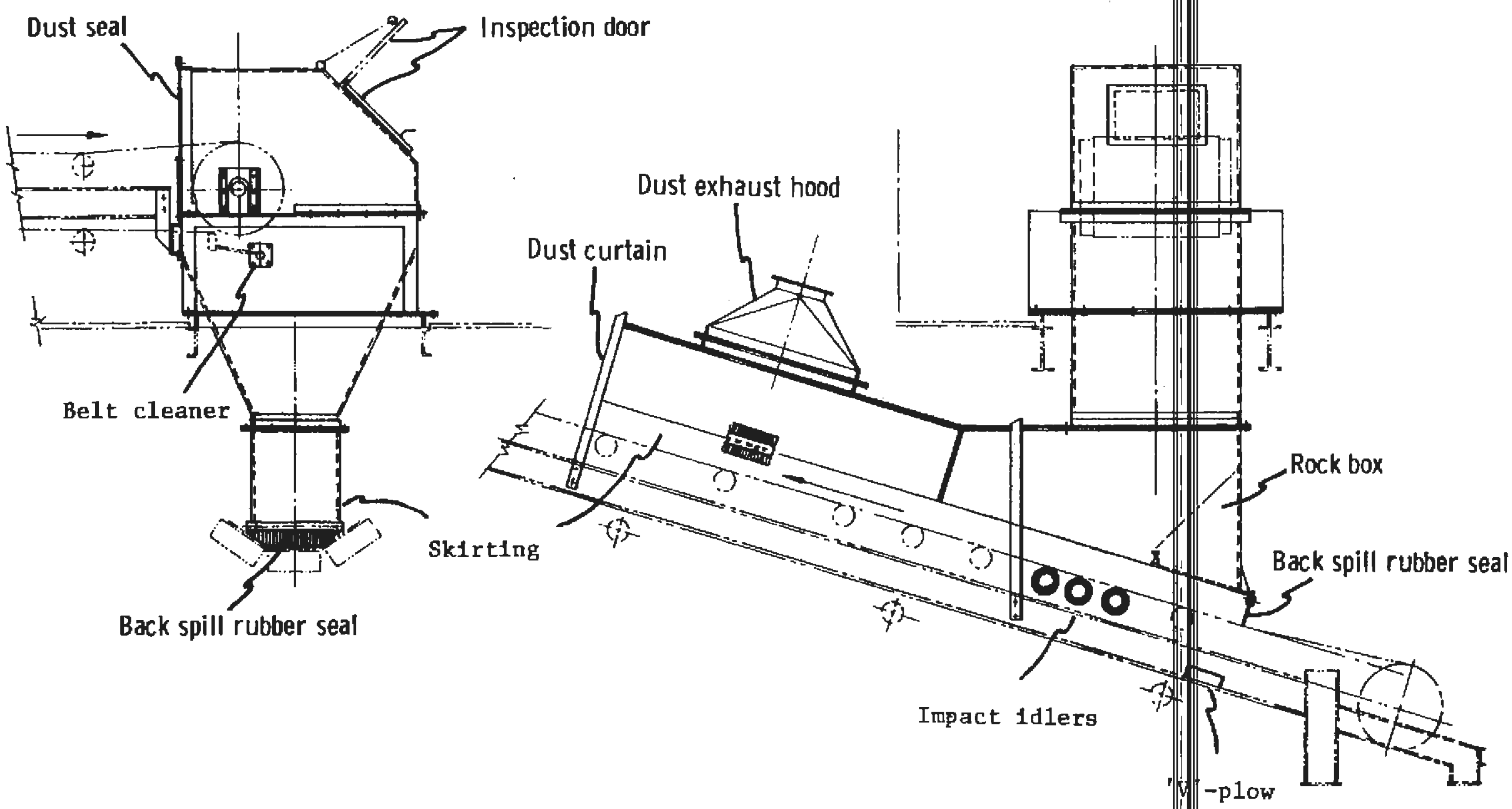


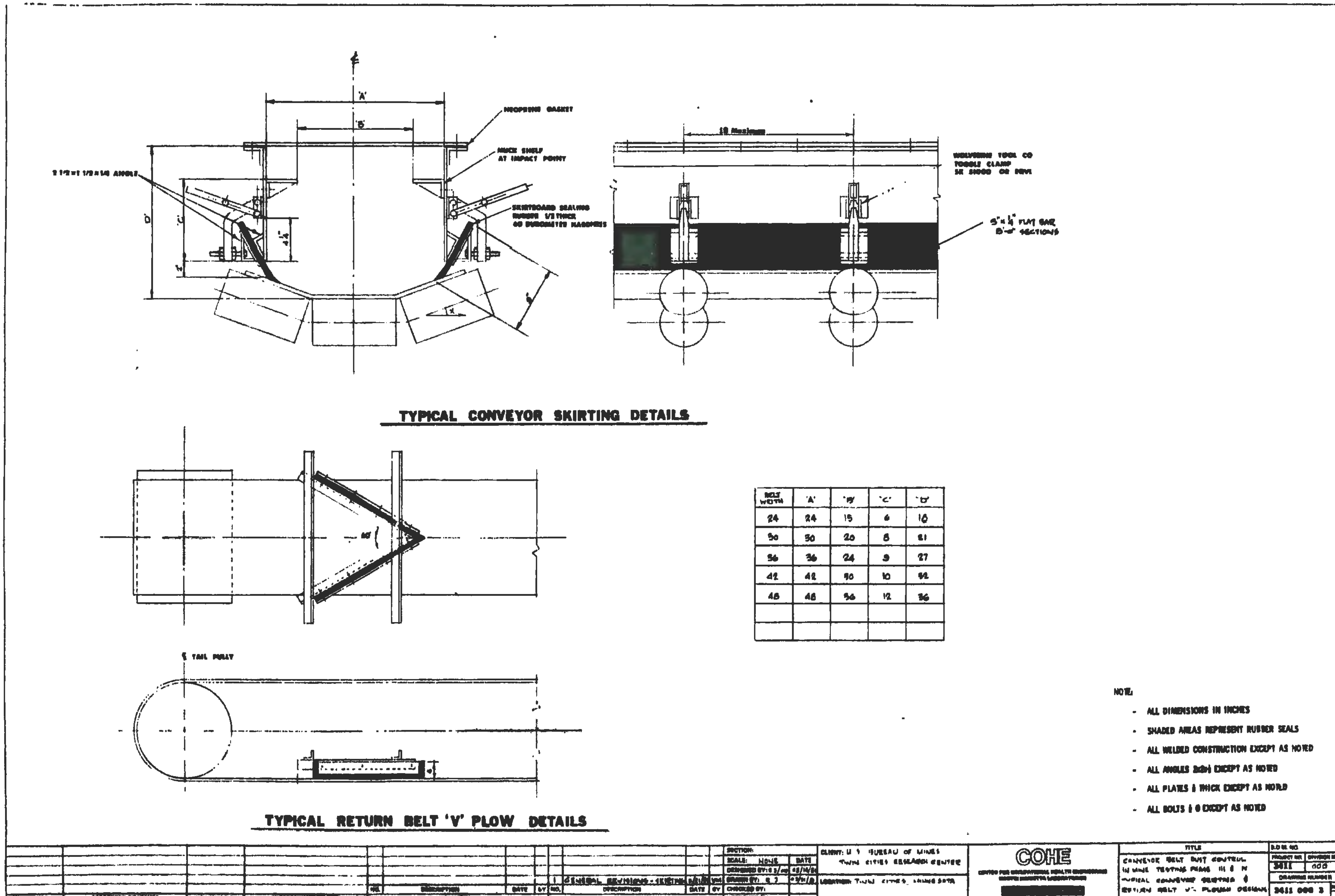
FIGURE 28. - A typical belt conveyor transfer point.

for the skirting rubber seals, and maintained a proper seal with the moving belt at all times, even when the belt was momentarily depressed between the adjacent idlers due to the impact of the incoming material. The skirting rubber, 1/2-in. thick and of 55-60 durometer hardness, was attached with quick-disconnect clamps (Wolverine Tool Company, Model SK-51000) for fast and easy adjustment. The design did not require frequent adjustments, and whatever adjustments were necessary could be performed in significantly less time than before. The original skirting design was based on the premise that the belt conveyors would not be operated much in excess of 75% of design capacity. However, in practice this was seldom true. Indeed, our initial installation of the skirting on belt conveyor #4 caused material jam-ups due to insufficient belt surface area. The skirting configuration was modified as described in figure 29.

Muckshelves installed in the material impact zone of the transfer chutes reduced the direct impact of some of the incoming material onto the conveyor skirting rubber. Moreover, they also helped to place material centrally on the belt, thus keeping the belt properly aligned.

3.4.1.3. Enclosures, Dust Seals, Idlers, Belt Cleaners, "V"-Plows

To reduce the air velocities and pressure surges that cause dust leakage at conveyor transfer points, long and spacious enclosures, known as settling boxes, were installed at each transfer point (fig. 30). The purpose of such enclosures is to allow settling of coarser dust on the belt so that an exhaust hood located far downstream can collect



BELT WIDTH	'A'	'B'	'C'	'D'
24	24	15	6	18
30	30	20	8	21
36	36	24	9	27
42	42	30	10	32
48	48	36	12	36

NOTE:

- ALL DIMENSIONS IN INCHES
- SHADED AREAS REPRESENT RUBBER SEALS
- ALL WELDED CONSTRUCTION EXCEPT AS NOTED
- ALL ANGLES 2x2x¼ EXCEPT AS NOTED
- ALL PLATES ¼ THICK EXCEPT AS NOTED
- ALL BOLTS ½ Ø EXCEPT AS NOTED

FIGURE 29. - Typical conveyor skirting and return belt "V"-plow designs.

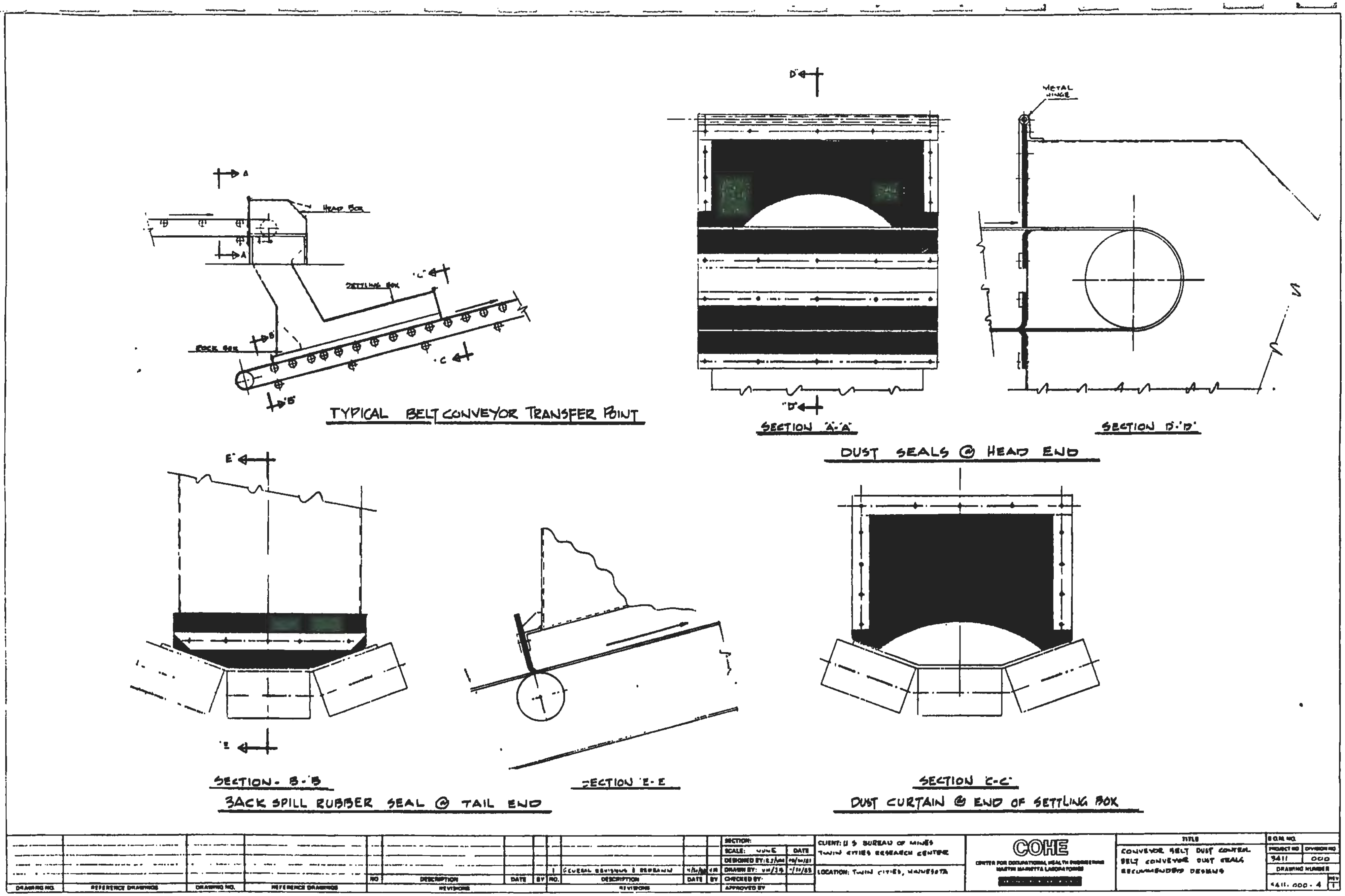


FIGURE 30.- Belt conveyor dust seals - recommended designs.

primarily the finer dust fraction, which stays airborne. This technique is particularly useful in ore concentrating or other operations where dust could be a useful product. The enclosures were equipped with hinged access doors instead of the conventional bolted construction to facilitate easy access. Dust curtains and dust seals were installed at the open ends of the enclosures to contain dust emissions and reduce the amount of air entrained (fig. 30).

On some belt conveyors, additional impact idlers were installed in the material impact zone to reduce the amount of unsupported span and prevent belt deflection. The maximum distance between the impact idlers was maintained at 1 ft wherever possible. Martin Engineering Torsion Arm Belt Cleaners were installed at the head pulley of all conveyors to dislodge the fine dust carryback on the return belt surfaces. The stainless steel blades initially fitted on the belt cleaners wore out within a month of operation and were replaced with tungsten carbide tip blades. Since then, all the belt cleaners have performed satisfactorily. "V"-plows (fig. 29) were also installed near the tail pulleys of the conveyors to clean the non-carrying side of the belt and thus prevent material and dust buildup on the tail pulley that could cause lateral movement of the belt.

3.4.2. Dust Collection System

A total of seven transfer points was equipped with dust collection systems. As discussed in Chapter 2, the determination of adequate exhaust volume is one of the most important steps in designing an efficient and economical dust collection system; however, a comprehensive approach to calculating exhaust volume is not available. As a result, at the conclusion of Phase I, we recommended that the dust collection system be designed initially based on Anderson's approach to calculating exhaust volumes, allowing a sufficient reserve capacity to meet any foreseeable needs. A subsequent contract modification expanded the program scope to include field validation of various estimates of exhaust volumes.

Variable exhaust volumes were obtained by providing air bleed-in ducts and control dampers in the ductwork near each exhaust hood. When air flows were low, ambient air was introduced through the air bleed-in ducts to maintain adequate particulate transport velocities and thus prevented dust settling in the ductwork. The ductwork was designed and constructed as per criteria established in the <u>Industrial Ventilation Manual</u>.

The exhaust volume calculations using the approaches most commonly recommended in the literature are given in Appendix B and summarized in Table B-1. The maximum design exhaust volumes at various transfer points were:

Primary crusher-to-belt conveyor #1 - 6700 cfm

Secondary crusher-to-belt conveyor #4 - 8800 cfm

Belt conveyor #7-to-belt conveyor #8 - 2400 cfm

Vibrating screen #2 - 2500 cfm

Storage bins #1 and 5 - 1700 cfm each

Storage bin #5 - 1700 cfm

Belt conveyor #5 - 2500 cfm.

Due to the physical location of the transfer points, three separate dust collection systems were designed, as follows.

3.4.2.1. Primary Crusher

The dust collection system at the primary crusher-to-belt conveyor #1 transfer point consisted of an exhaust hood mounted on the top of the settling box to capture fine airborne dust particulates. The collected dust was then transported through the ductwork to the existing dust collector for the primary crusher.

The existing dust collector was also relocated so that the collected dust could be discharged into a storage bin provided underneath. A haul truck periodically emptied the hopper and carried away the collected dust to a mine dump site.

3.4.2.2. Secondary Crushing Circuit

The dust collection system at the secondary crusher-to-belt conveyor #4 and belt conveyor #7-to-belt conveyor #8 transfer points was connected to the existing ductwork leading to a central 40,000-cfm baghouse. The general layout of the ductwork including the bypass and bleed-in ducts is shown in figure 31.

3.4.2.3. Vibrating Screen #2 Circuit

A central dust collection system connecting all the transfer points included in the vibrating screen circuit was added onto the existing test facility ductwork. A number of control dampers were provided to

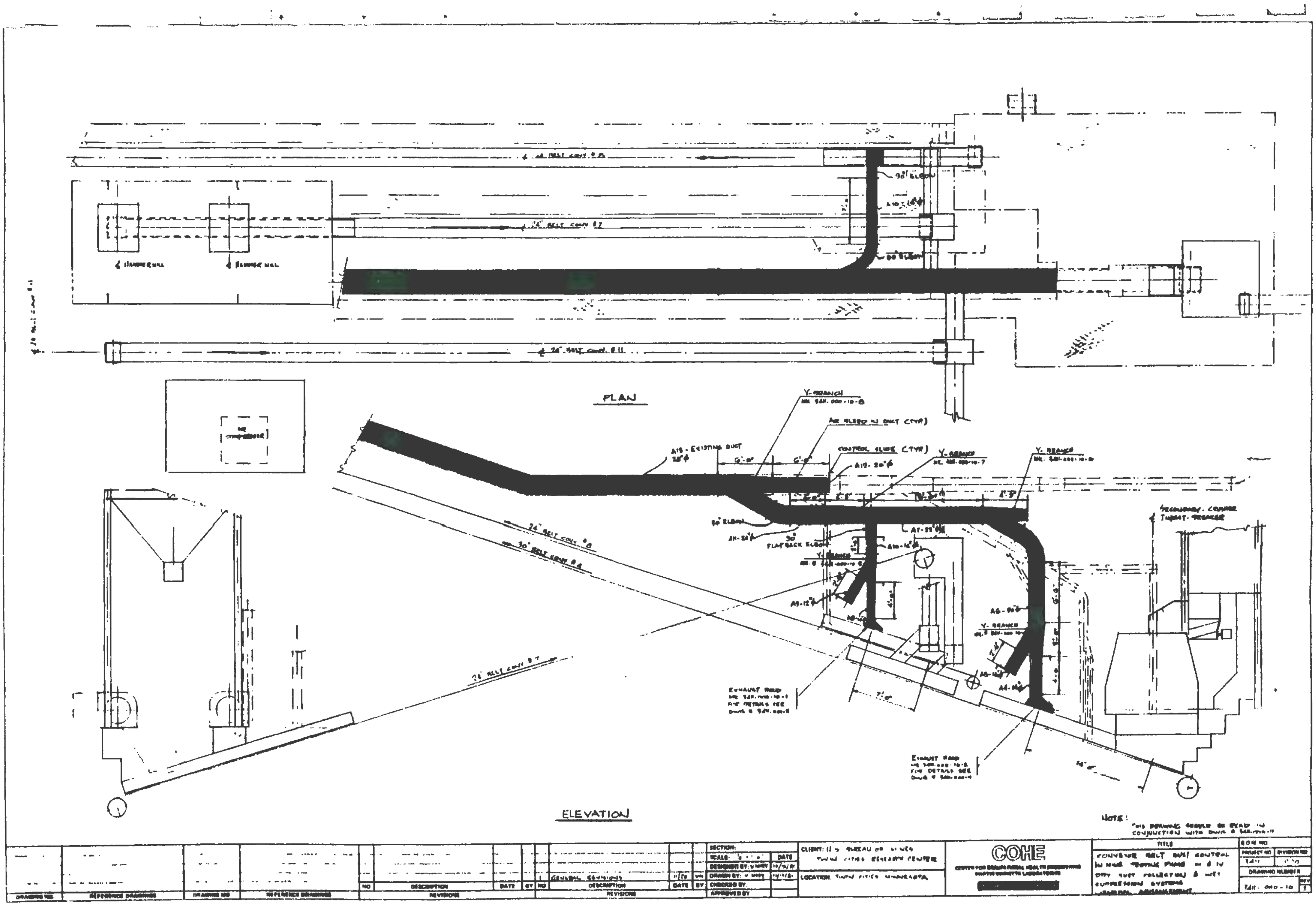


FIGURE 31.- Dust collection system at the secondary crusher-to-belt conveyor #1 and belt conveyor #7-to-belt conveyor #8 transfer points - general arrangement.

vary the exhaust volumes as required in testing. Figure 32 shows the general arrangement of the ductwork at all the transfer points in the vibrating screen #2 circuit.

3.4.3. Wet Suppression System

At the conclusion of Phase I, we recommended the Sonic system to the Bureau of Mines as our choice for field testing and evaluation. Our selection was approved by the Bureau, and this system was installed at the following three transfer points:

Hammermill #1-to-belt conveyor #7

Hammermill #2-to-belt conveyor #7

Belt conveyor #11-to-belt conveyor #4.

In consultation with the Sonic Development Corporation, the system was initially installed as shown in figure 33. At the hammermills-to-belt conveyor #7 transfer point, two spray bars, each containing two Sonic nozzles, were installed. The first spray bar, was located at the tail end of hammermill #1, and injected water in the direction of the material flow. The second spray bar was located on top of the settling box after hammermill #2, and injected water countercurrent to the material flow. Because of some problems with this arrangement at the hammermills-to-belt conveyor #7 transfer point, we eventually relocated the spray bars. The details of these modifications are given in Section 3.5.4. At the conveyor belt #11-to-conveyor belt #4 transfer point, one spray bar containing two nozzles was installed before the material impact zone.

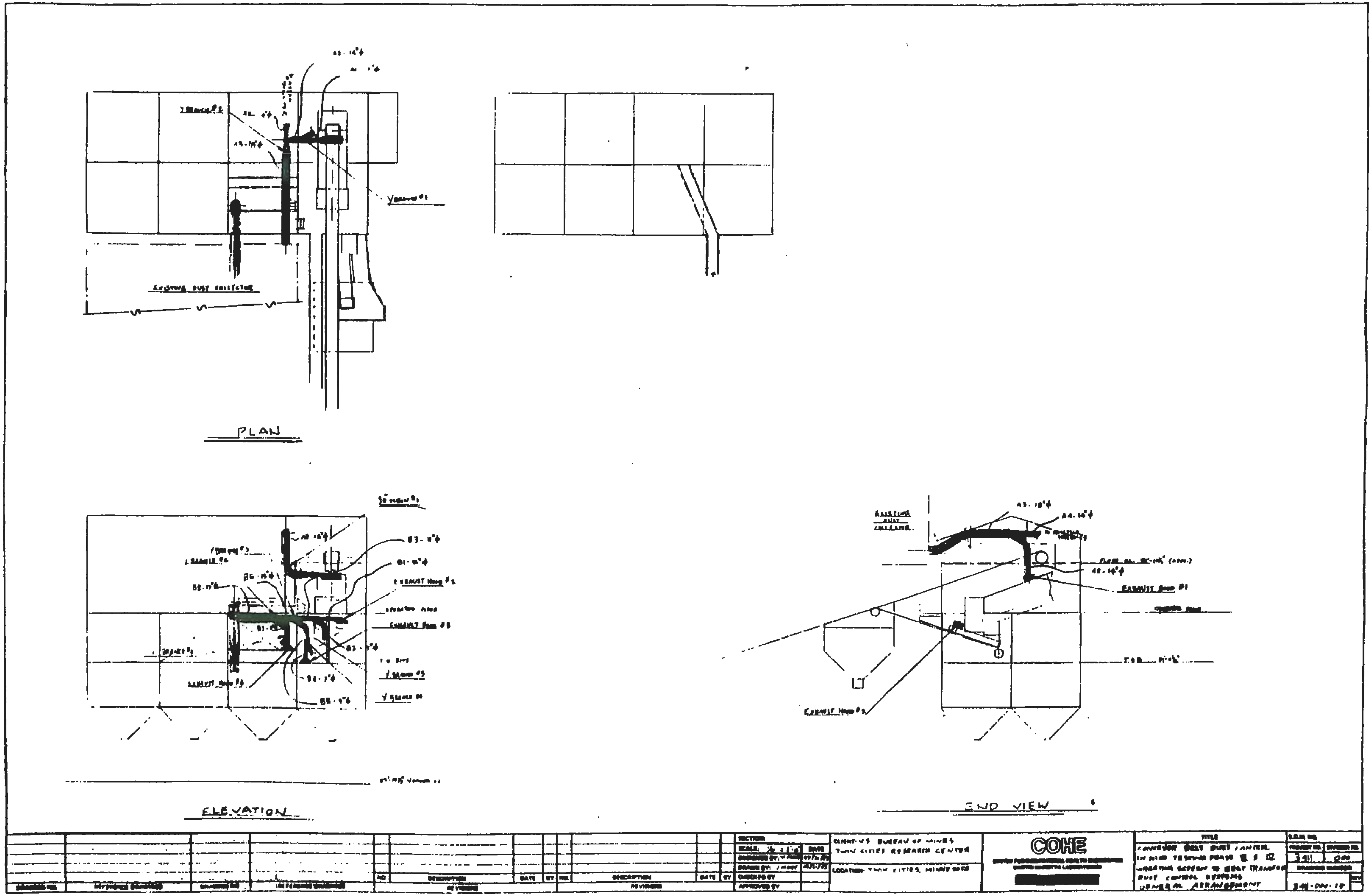


FIGURE 32.- Dust collection system at the vibrating screen #2 circuit general arrangement.

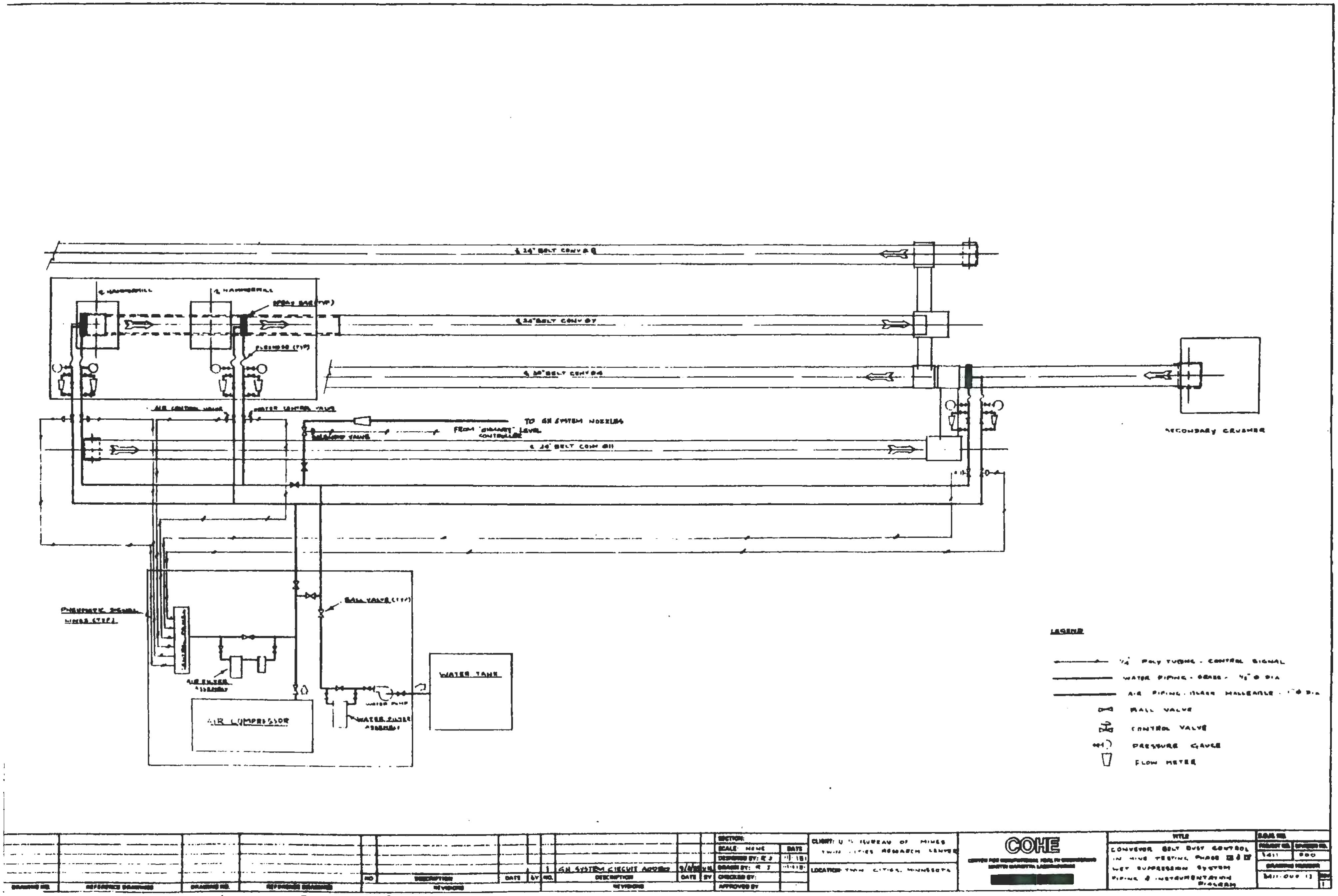


FIGURE 33 - Wet suppression system piping and instrumentation diagram.

The Sonic control panel (figure 34) was equipped with a set of air and water pressure gauges for each spray bar that read instrument air pressure. However, instrument air pressure has no direct relationship to operating pressure or flow rates of air and water near each spray bar. To measure actual air and water pressures as well as flow rates, we installed the following instruments near each spray bar in a separate control box:

1) Compressed air pressure gauge

   Make: Span Instruments

   Type: Oil-filled

   Range: 0-100 psig

   Accuracy: ± 2% on full scale

2) Compressed air flow meter

   Make: Wallace and Tiernan

   Range: 0-24 scfm

   Accuracy: ± 2% on full scale

   Pressure: Up to 100 psig

3) Water pressure gauge

   Make: Span Instruments

   Type: Oil-filled

   Range: 0-30 psig

   Accuracy: ± 2% on full scale

4) Water flow meter

   Make: Dwyer Instruments

   Range: 0-20 gph

   Accuracy: ± 2% on full scale.

These instruments were equipped with adjustment knobs so that we could regulate and monitor individual variables.

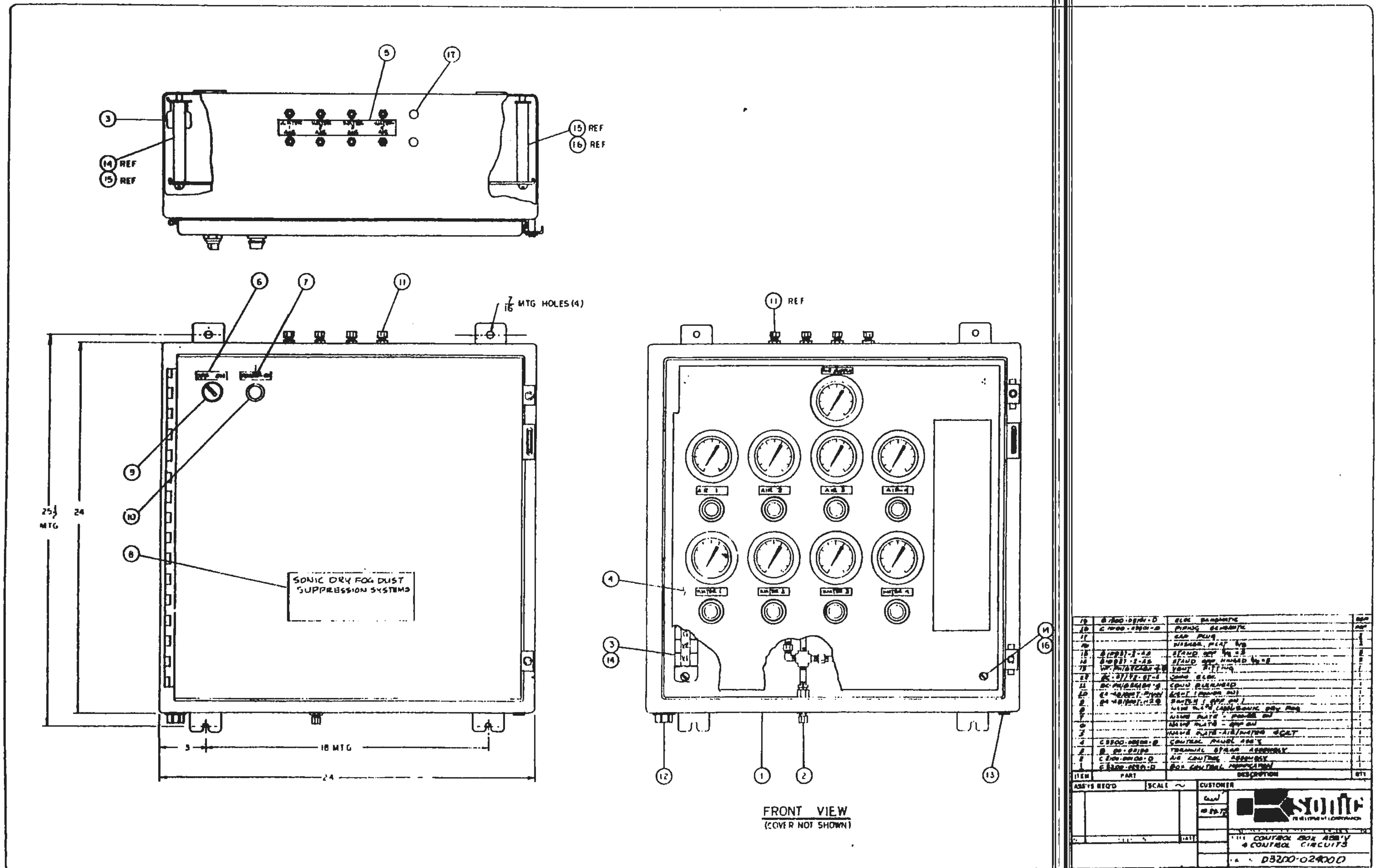


FIGURE 34.- Sonic control panel.

To ensure reliable system operation during winter, the compressed air and water supply lines and field control boxes were heat traced and insulated. In addition, a number of drain valves were also installed at strategic locations in both lines to drain off water when required. The air and water lines were interconnected through a common valve so that the water supply line could be flushed with compressed air at the end of the day to avoid freezing problems at nighttime.

Later in the program, the solenoid valve in the Sonic control panel malfunctioned during colder weather. Since we could monitor individual spray bars via the field control instruments we had installed, we removed the Sonic control panel and control valves and instrument air lines.

The tests of the Sonic system at the hammermills-to-belt conveyor transfer point revealed that it was not fully able to reduce dust emissions to acceptable levels. The problem was particularly severe at the side and tail of the conveyor belt. Therefore, a separate water spray system, consisting of two garden hose nozzles (GH system) was installed to augment the Sonic system. The details of the water spray are given in Section 3.5.4.4.

3.5. TEST INSTALLATION - SPECIFIC TRANSFER POINTS

3.5.1. Primary Crusher-to-Belt Conveyor #1

3.5.1.1. Process Description

The mined material is hauled from the quarry via trucks and dumped onto a surge pile. A front-end loader equipped a 9-yd^3-capacity bucket dumps the material into the primary crusher surge hopper, from which it is fed through the apron feeder and vibrating grizzly into the primary crusher -- a 5360 double-impeller impactor. As the name suggests, the impactor breaks the material into smaller fractions by impact forces, generating considerable dust. The crusher discharges the crushed material onto the 48-in.-wide belt conveyor #1. The finer fraction of the material (-6 in.) from the vibrating grizzly bypasses the primary crusher and is discharged directly onto belt conveyor #1.

3.5.1.2. Equipment Characteristics

Primary Crusher:	Cedar Rapids, 5360 double-impeller impactor
	Speed: 400 rpm
	Capacity: 700 ton/h (average)
	1000 ton/h (peak)
	Material size at inlet: -60 in.
	Material size at discharge: -14 in.
Belt Conveyor #1:	Size: 48 in.; 20° idlers
	Speed: 430 ft/min
	Theoretical capacity[1]: 1700 ton/h

3.5.1.3 Test Installation

Figure 35 shows the primary crusher-to-belt conveyor #1 transfer point; existing bulk material handling is indicated by dotted lines and new installations by shaded areas. A single exhaust hood located downstream

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1 Calculated based on Ref. (<u>1</u>) approach assuming:
Surcharge angle = 25°
Angle of repose = 38°
Bulk density = 85 lb/ft^3

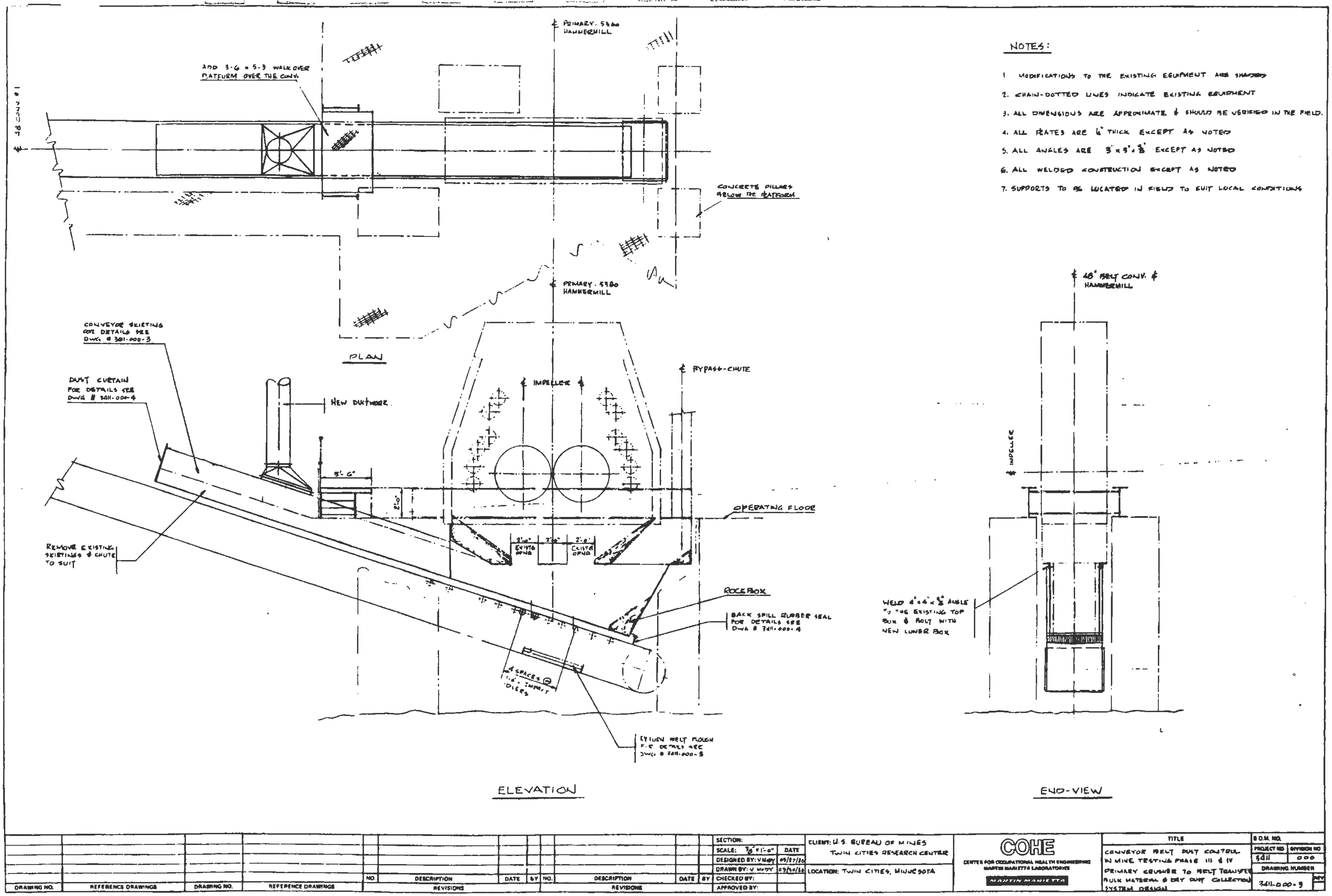


FIGURE 35. - Primary crusher-to-belt transfer point - bulk material handling and dust collection system design.

of the primary crusher was installed to control the dust emissions. The dust collection system was designed to operate at a maximum exhaust volume of 6700 cfm.

3.5.1.4. Problems Encountered and Solutions Adopted

During the installation of the new bulk material handling system, we noticed that belt conveyor #1 was skewed with respect to the primary crusher, i.e., the centerlines of the belt conveyor and crusher did not coincide. The result was uneven loading of the belt. The situation was partially corrected through the installation of muckshelves in the impact zone, but not totally eliminated. As a result, the skirting rubber on one side of the conveyor continued to tear away due to rock impact, and had to be replaced. This situation was partially corrected by extending the muckshelf on that side. The conveyor skirting on the other side lasted through a normal wear-and-tear cycle of approximately 8 months.

3.5.2. Secondary Crusher-to-Belt Conveyor #4

3.5.2.1. Process Description

Belt conveyor #1 discharges -14 in. material onto a 6 x 14-ft triple deck vibrating screen. The oversize material (-14 in., + 7 in.) is discharged through a feedbox and a vibrating feeder into the secondary crusher -- a 3645 double-impeller impactor.

The secondary crusher discharges -3-1/2-in. rocks onto the 30-in.-wide belt conveyor #4. The smaller fraction (-3-1/2 in., +1-1/2 in.) from the screen bypasses the secondary crusher and is discharged directly onto belt conveyor #4 through a transfer chute.

3.5.2.2. Equipment Characteristics

Secondary Crusher: Cedar Rapids, 3645 double-impeller impactor

Speed: 500-700 rpm

Capacity: 800 ton/h

Material size at inlet: -14 in., +3-1/2 in.

Material size at discharge: -3-1/2 in.

Belt Conveyor #4: Size: 30 in.

Speed: 535 ft/min

Theoretical capacity: 790 ton/h

Material size: -3-1/2 in.

3.5.2.3. Test Installation

Figure 36 shows the secondary crusher-to-belt conveyor #4 transfer point. Existing bulk material handling and dust collection systems are shown by dotted lines; new installations are shown by shaded portions. Two muckshelves, approximately 10 ft long and projecting 4 in., were installed in the material impact zone to reduce skirting rubber wear due to direct impact of the oncoming material. Two rockboxes, one for each impeller drum of the impactor, were also installed to reduce height of free fall and to absorb the impact of the incoming material. A single exhaust hood (replacing two exhaust hoods), located downstream of the secondary crusher, was installed to control dust emissions. The dust collection system was designed to operate at a maximum of 8800 cfm. To vary the exhaust volumes, a bypass duct was used to bleed ambient

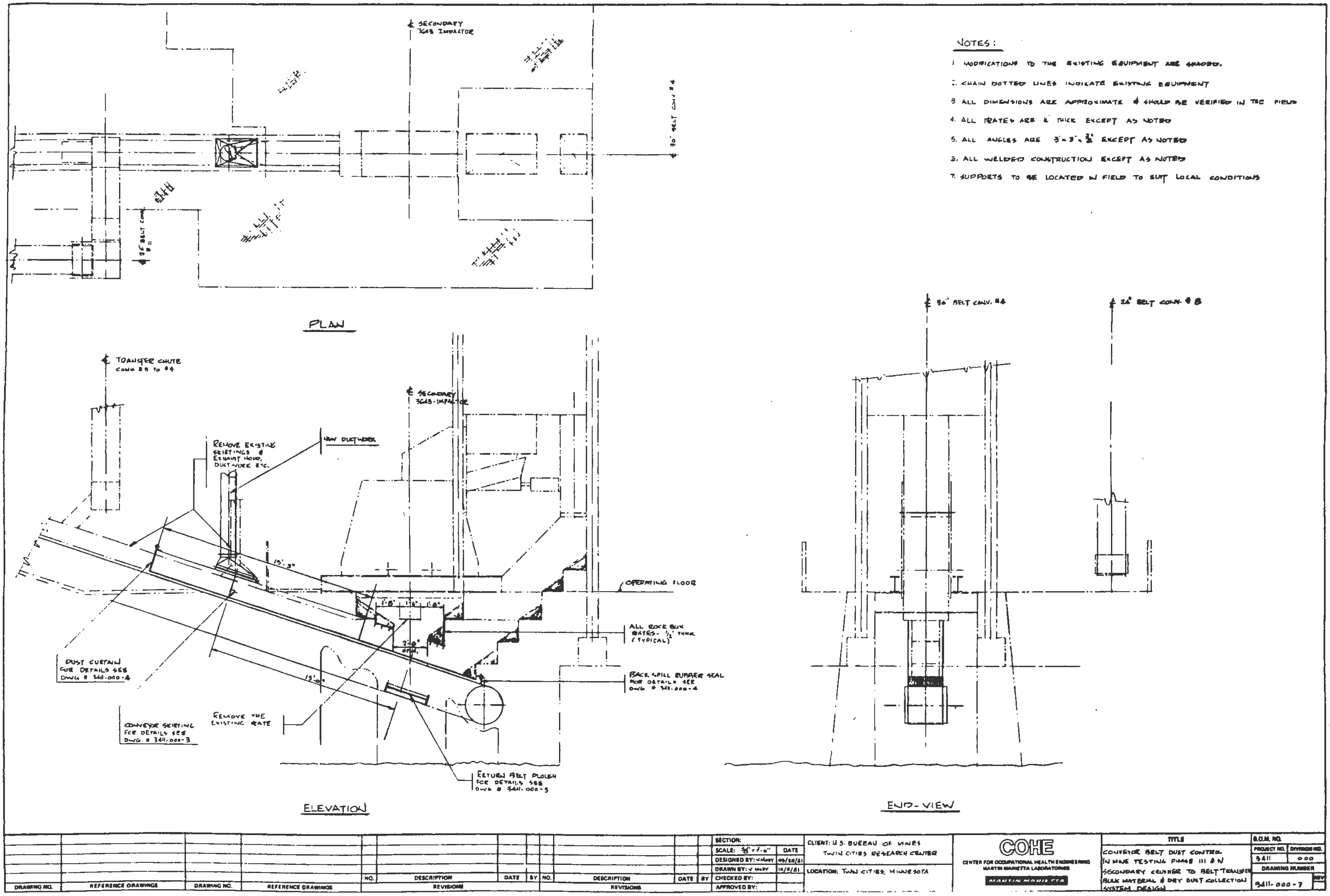


FIGURE 36. - Secondary crusher-to-belt transfer point - Bulk material handling and dust collection system design.

air into the system, thus maintaining adequate transport velocities. Control dampers were also provided in the ductwork to regulate the air flows.

3.5.2.4. Problems Encountered and Solutions Adopted

The new skirting installation caused plugging of the secondary crusher. Further investigation revealed that the peak throughput of the secondary crusher exceeded the theoretical capacity of belt conveyor #4. Thus, the crusher became plugged because of insufficient belt surface area. The expanded skirting design shown in figure 29 and described in Section 3.4.1.2. eliminated the plugging.

3.5.3. Belt Conveyor #7-to-Belt Conveyor #8

3.5.3.1. Process Description

The 24-in.-wide belt conveyor #7 carries 2-in. material from two tertiary crushers (hammermills) and discharges onto the 24-in.-wide belt conveyor #8. Belt conveyor #8 discharges the material onto the triple deck vibrating screen #4 for size classification.

3.5.3.2. Equipment Characteristics

Belt Conveyor #7: Size: 24 in. wide

Speed: 410 ft/min

Theoretical capacity: 390 ton/h

Material size: -2 in.

Belt Conveyor #8: Size: 24 in. wide

Speed: 420 ft/min

Theoretical capacity: 320 ton/h

Material size: -2 in.

3.5.3.3. Test Installation

Figure 37 shows the existing bulk material handling and dust collection systems as dotted lines and the new installations as shaded portions.

The bottom surface of the transfer chute was lined with a number of steel angles to create mini-rockboxes, which reduced abrasion of the chute and prevented dust and material leakage. The small amount of airborne dust generated as a result of the bulk material transfer was contained in the spacious enclosure, where, due to the low air velocities most of the coarser dust settled out. A single exhaust hood was installed approximately 8 ft from the impact point to capture airborne dust. Dust seals at the head chute of belt conveyor #7 replaced the exhaust hood located at the head pulley.

The dust collection system was designed to operate at a maximum of 2400 cfm. To vary the airflow and still maintain sufficient transport velocities, a bypass duct was used to bleed ambient air into the

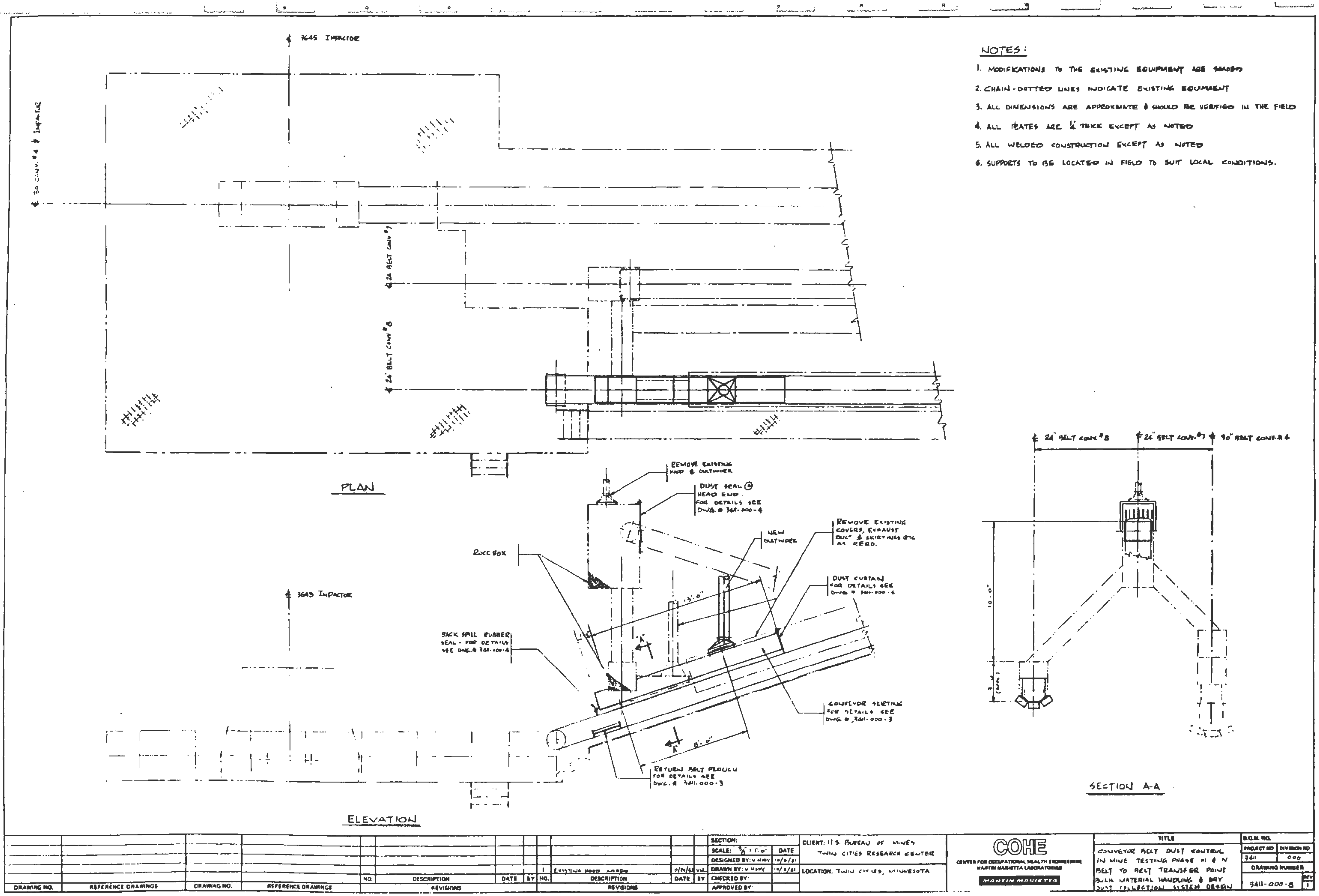


FIGURE 37. - Belt conveyor #7-to-belt conveyor #8 transfer point - bulk material handling and dust collection system design.

system when required. Control dampers were also installed in the ductwork to regulate the airflows.

3.5.3.4. Problems Encountered and Solutions Adopted

The new bulk material handling and dust collection systems have been working satisfactorily. No maintenance or other problems have arisen since their installation was completed.

3.5.4. Tertiary Crushers-to-Belt Conveyor #7

3.5.4.1. Process Description

The oversize material (-3-1/2 in.) from vibrating screen #2 is fed to the 30-in. belt conveyor #5, which in turn dumps it into a storage hopper. Two vibrating feeders located underneath the storage hopper feed both the hammermill crushers. In these crushers, considerable fine dust is generated as the material is broken up by a number of rotating hammer bars. Moreover, the hammermills act as fans and induce high air velocities in the enclosure. The crushed material (-2 in.) from both the hammermills is discharged onto the common 24-in. belt conveyor #7, located underneath.

3.5.4.2. Equipment Characteristics

Hammermills #1 and #2: Type: Cedar Rapids, 4033 hammermill
Speed: 900 rpm
Capacity: 200 ton/h each

	Material size at inlet: -3-1/2 in.	
	Material size at discharge: -2 in.	
Belt Conveyor #7:	Size: 24 in.	
	Speed: 410 ft/min	
	Capacity: 375 ton/h	
	Material Size: -2 in.	

3.5.4.3. Test Installation

Figure 38 shows the tertiary crushers-to-belt conveyor transfer point. The existing bulk material handling and dust collection systems are shown by dotted lines; new installations are shown by shaded portions.

A number of rockboxes were installed on the transfer chutes from the hammermills to reduce belt wear and the height of material free fall. Muckshelves projecting approximately 3 in. were also installed in the material impact zone to reduce skirting rubber wear from the direct impact of the incoming material. A hinged dust curtain was installed at the end of the settling box to increase the residence time for water droplets and dust particles.

The wet dust suppression installation included two Sonic spray bars, each equipped with two nozzles, at the transfer point (fig. 39). A typical spray bar is shown in figure 40. Spray bar #1 (SB1), initially installed behind the impact point of hammermill #1, delivered water in the direction of the material flow on the belt; spray bar #2 (SB2), installed after the impact point of hammermill #2, delivered water against the material flow.

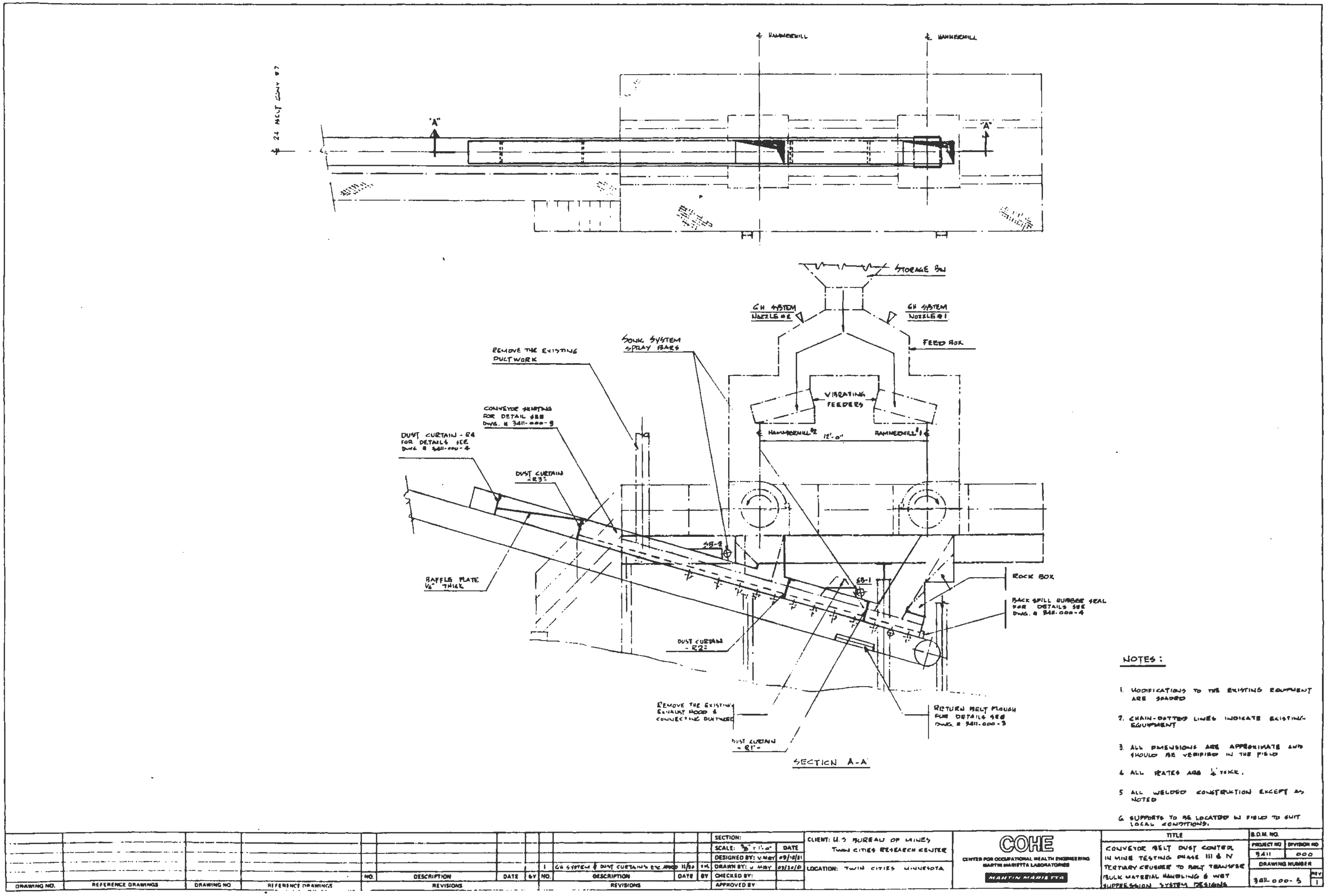


FIGURE 38. - Hammermills-to-belt transfer point - bulk material handling and wet suppression system designs.

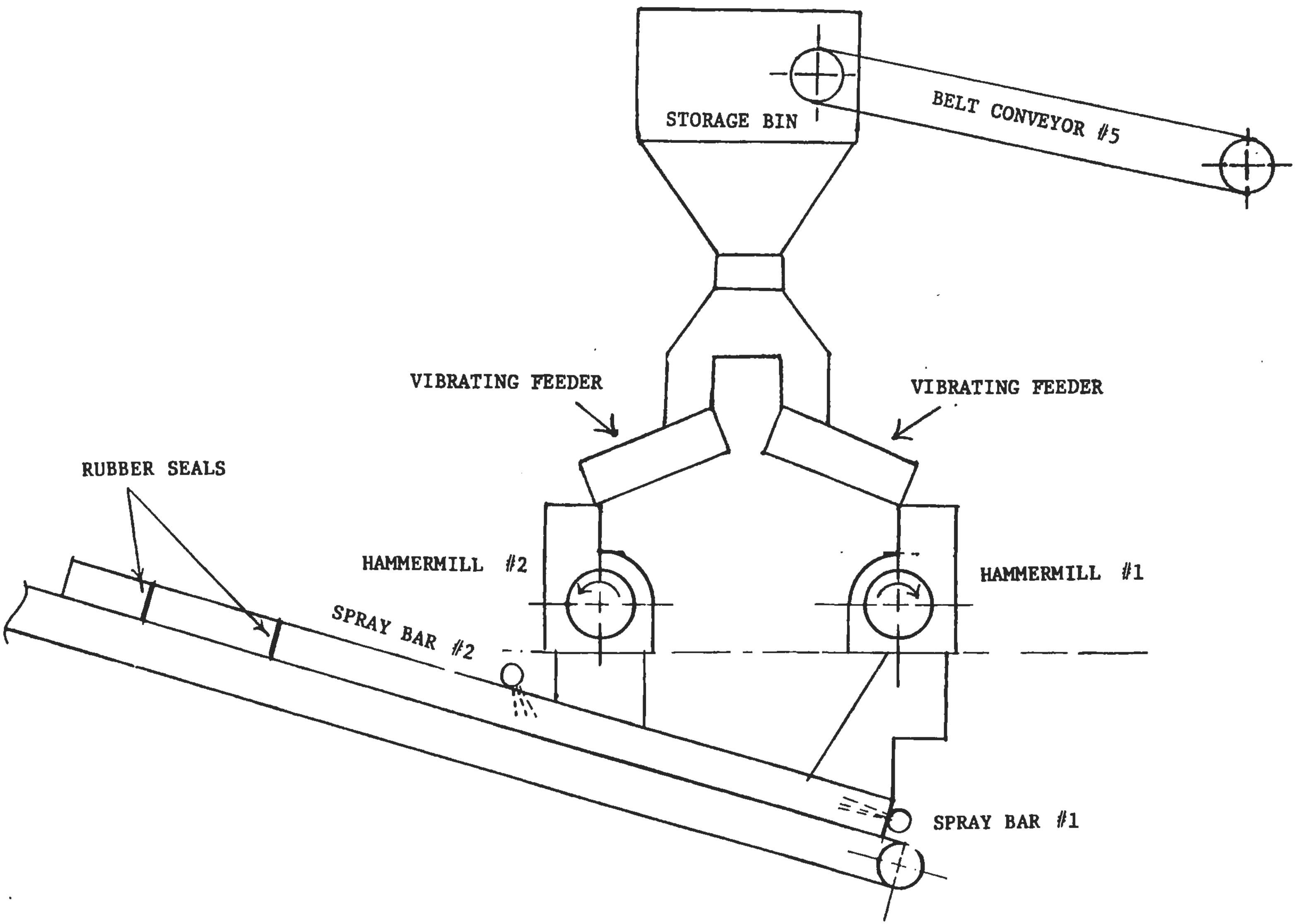


FIGURE 39. - Original location of Sonic spray bars.

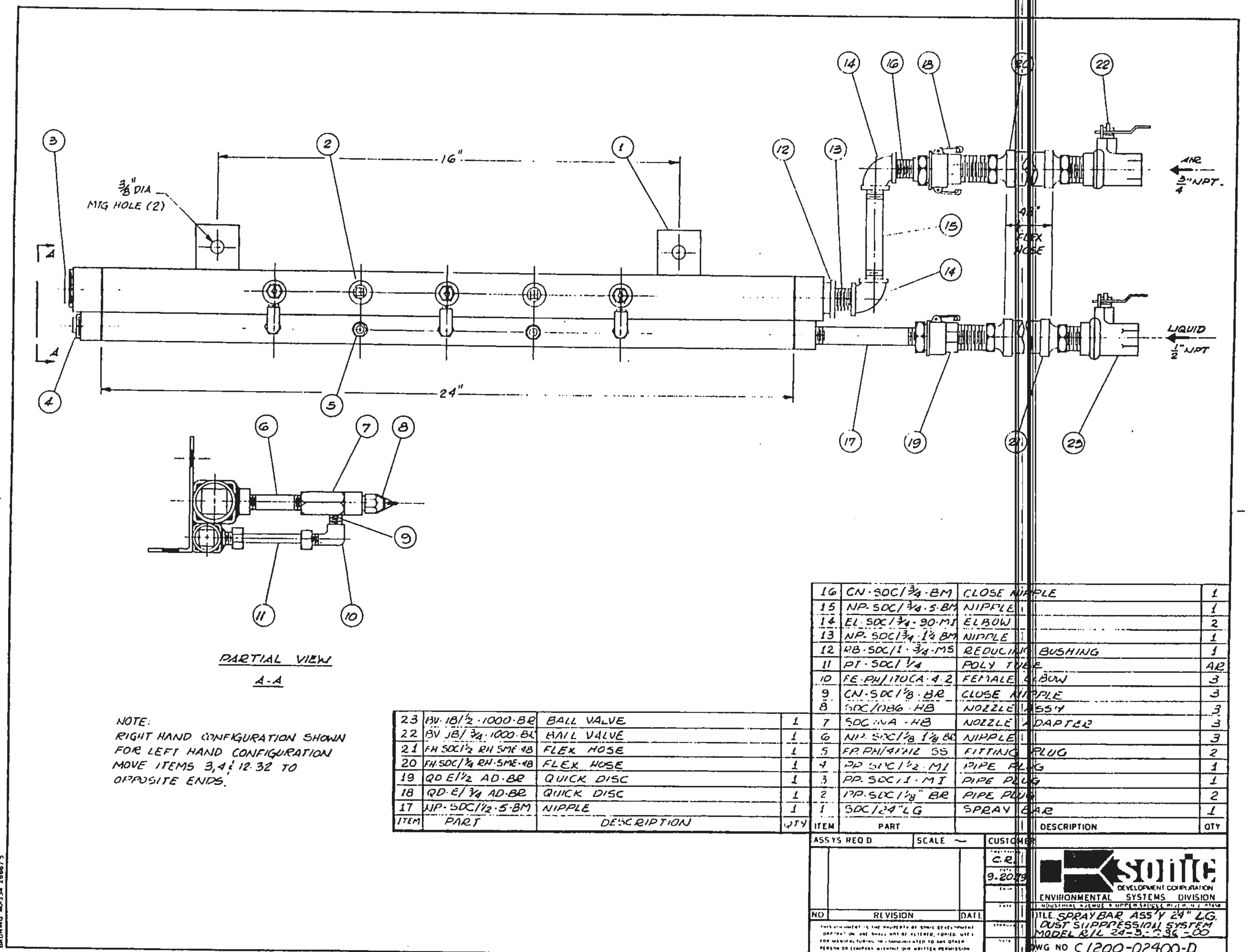


FIGURE 40.- Typical Sonic spray bar.

3.5.4.4. Problems Encountered and Solutions Adopted

The resonators on the nozzles on SB1 repeatedly either wore out or were damaged due to the violent motion of rocks near the impact point of the #1 hammermill. To reduce the nozzle damage, a rockbox was added in the transfer chute to shift the bulk material impact point forward by approximately 1 ft. Also, the regular Sonic nozzles were replaced with shielded Sonic nozzles to reduce resonator wear. However, resonator wear was still not considered satisfactory. The SB2 installed after the impact point of the hammermill #2 showed no excess resonator wear. Subsequently, after consultation with an engineer from Sonic Development Corporation, we relocated both spray bars as shown in figure 38. Rubber seals R1 and R2 were also installed to further reduce resonator wear and damage on SB1.

High velocities inside the settling box carried not only the water droplets, but also the agglomerated dust particulates out of the settling box. Rubber curtains R3 and R4 were installed to further increase the residence time for the water droplets produced by the Sonic system, and to enhance the interaction of water droplets and airborne dust particulates. Due to the higher air velocities, however, the agglomerated dust did not settle out and interfered with the operation of the sampling apparatus. The problem was solved by installing an inclined baffle plate between rubber seals R3 and R4. The plate gradually deflected the agglomerated dust down and facilitated its adhesion to the material pile on the belt conveyor.

The skirting rubber near the impact zone for the hammermill #2 continued to wear out due to direct impact of the incoming material. This problem was corrected by installing double skirting in the impact zone (fig. 41).

It was evident that the Sonic fog system alone was not adequate to control the dust emissions at "E" locations, and the problem was much more severe at "S" and "T" locations. To improve the overall system efficiency, we added a separate wet dust suppression system at each vibrating feeder, consisting of two garden hose nozzles (GH system) set to deliver 1 gpm of water to the material prior to the hammermills. The continuous spray of water through the nozzles in winter created freezing conditions at belt conveyor #7, as well as subsequent transfer points. The problem was solved by coupling the water flow to the bin feed. The storage bin feeding the hammermills was equipped with a level controller which automatically shut off the vibrating feeders when the stone level fell below a predetermined level. We installed an electrical solenoid valve in the water line that was activated by the bin level controller to stop and start water flow in concert with the vibrating feeders.

3.5.5. Belt Conveyor #11-to-Belt Conveyor #4

3.5.5.1. Process Description

The cone crusher discharges -1 in. material onto the 24-in. belt conveyor #11, which, in turn, discharges material onto the 30-in. belt conveyor #4 through a transfer chute.

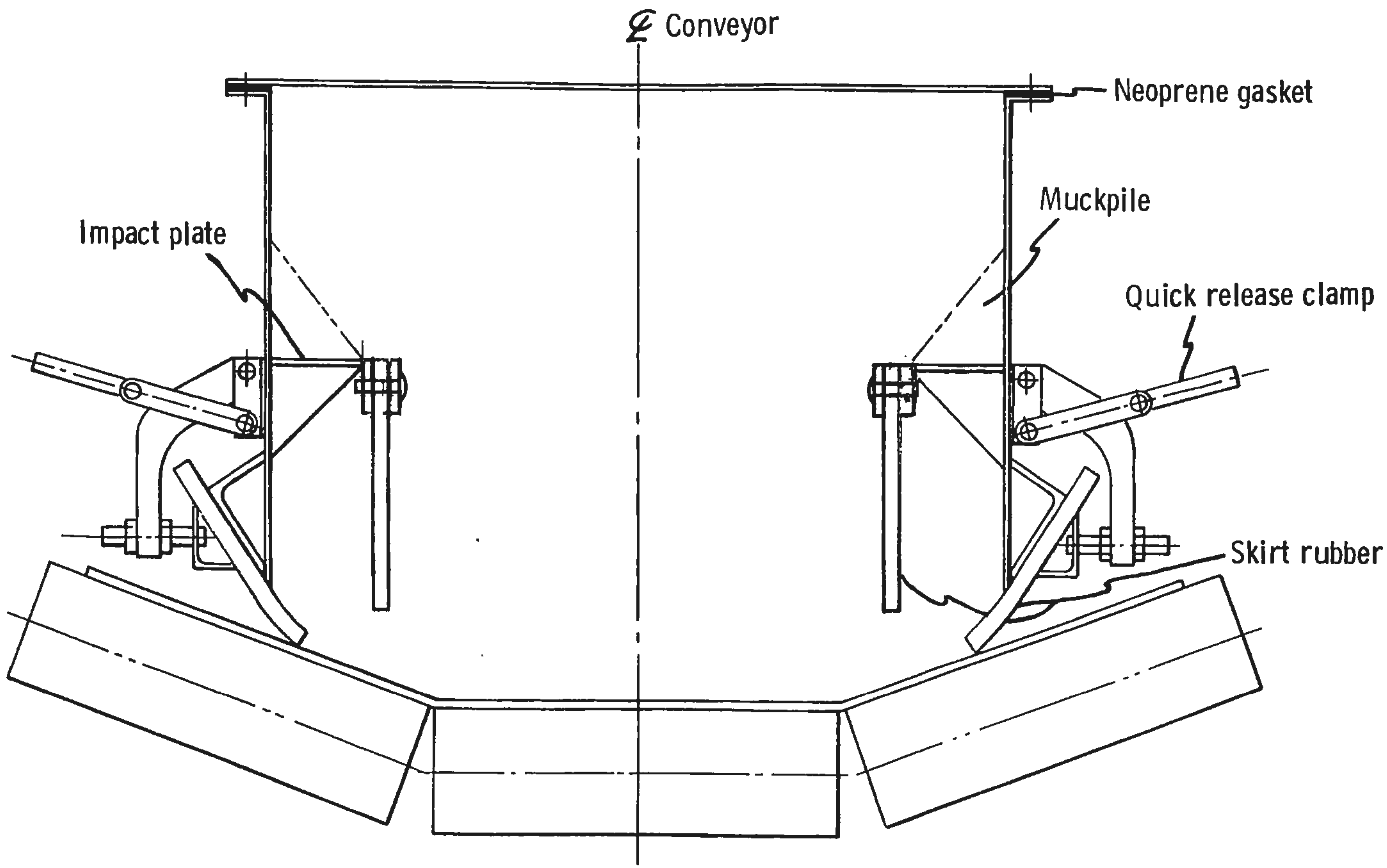


FIGURE 41. - Typical double skirting design.

3.5.5.2. Equipment Characteristics

Belt Conveyor #11: Size: 24 in.

Speed: 390 ft/min

Theoretical capacity: 350 ton/h

Material size: -1 in.

Belt Conveyor #4: Size: 30 in.

Speed: 535 ft/min

Theoretical capacity: 790 ton/h

Material size: -1 in.

3.5.5.3. Test Installation

Figure 42 shows the belt conveyor #11-to-belt conveyor #4 transfer point. The old bulk material handling and dust collection systems are shown by dotted lines; new installations are shown by shaded portions.

This transfer point was equippped with the Sonic wet dust suppression system. The position of the Sonic spray bar is shown in figure 42.

Two hinged dust curtains on either end of the settling box, as well as a dust curtain at the head chute of conveyor #11, were placed as shown in figure 30 to reduce the ambient air entrainment and increase the residence time for interaction of water droplets and airborne dust particulates.

3.5.5.4. Problems Encountered and Solutions Adopted

The resonators on the spray bar lasted through a normal wear-and-tear cycle of approximately 6 months. No problems were encountered with the system.

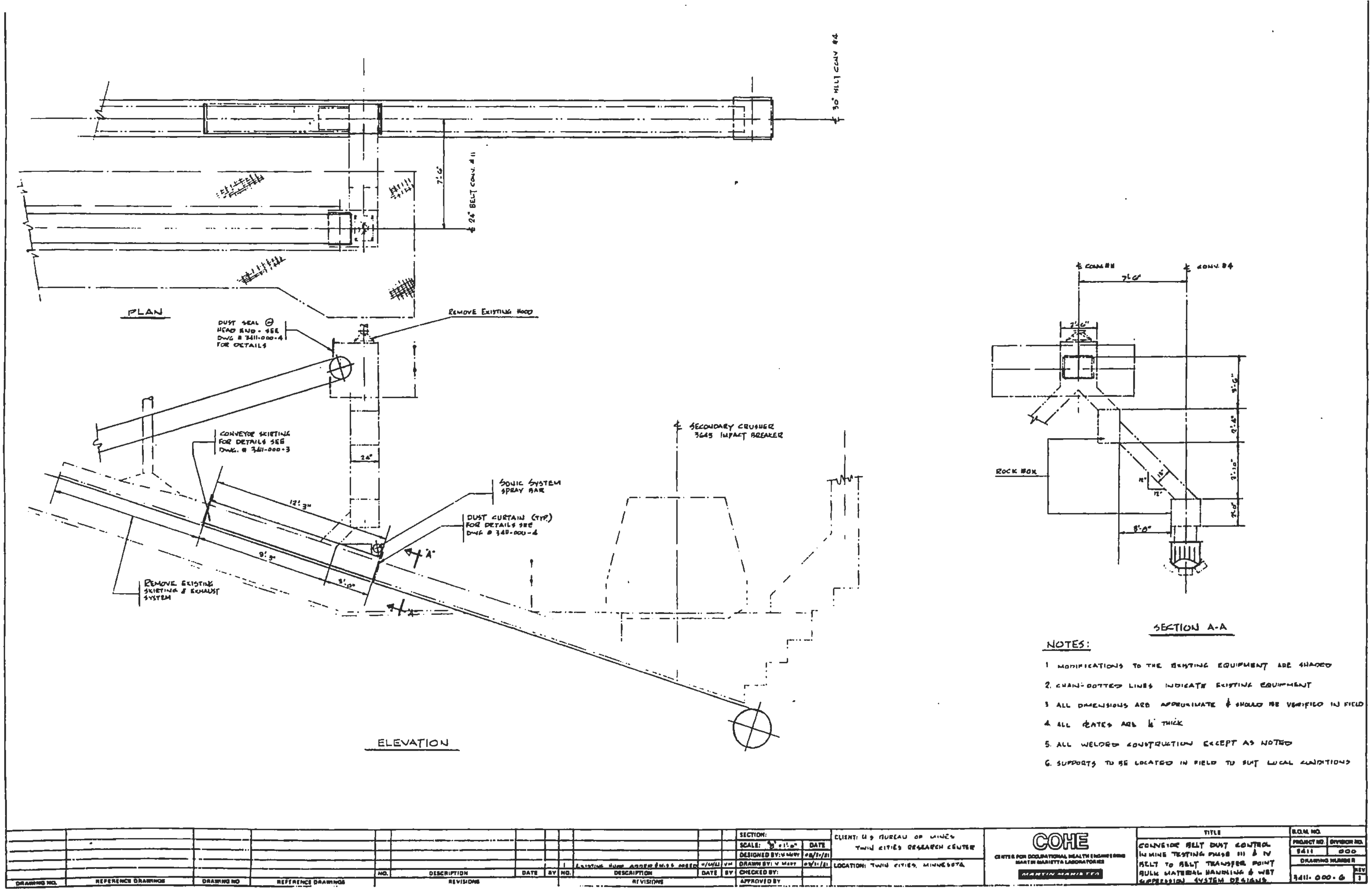


FIGURE 42.- Belt conveyor #11-to-belt conveyor #4 transfer point - bulk material handling and wet suppression system design.

3.5.6. Vibrating Screen #2 Circuit

3.5.6.1. Process Description

Belt conveyor #4 discharges material onto the 6 x 14-ft double deck vibrating screen #2. The vibrating screen classifies the material into three primary size fractions: oversize material (+3-1/2 in.) which is discharged onto belt conveyor #5; -3-1/2 in. and +2 in. material, which is discharged either onto belt conveyor #6 or into storage bin #1; and -1/4 in. material, which is discharged either onto the 30-in. belt conveyor #5 or into storage bin #5.

3.5.6.2. Equipment Characteristics

Belt Conveyor #4:	Size: 30 in. wide
	Speed: 535 ft/min
	Capacity: 790 ton/h
	Material size: -3-1/2 in.
Vibrating Screen #2:	Type: Tyler, double deck
	Size: 6 x 14 ft
	Material size at inlet: -3-1/2 in.
	Material size at discharge: -3-1/2 in., -2 in., -1/4 in.

3.5.6.3. Test Installation

Figure 43 depicts the belt conveyor #4-to-vibrating screen #2 transfer point, including the existing bulk material handling (shown by dotted lines) and the new installation (shown by shaded portions).

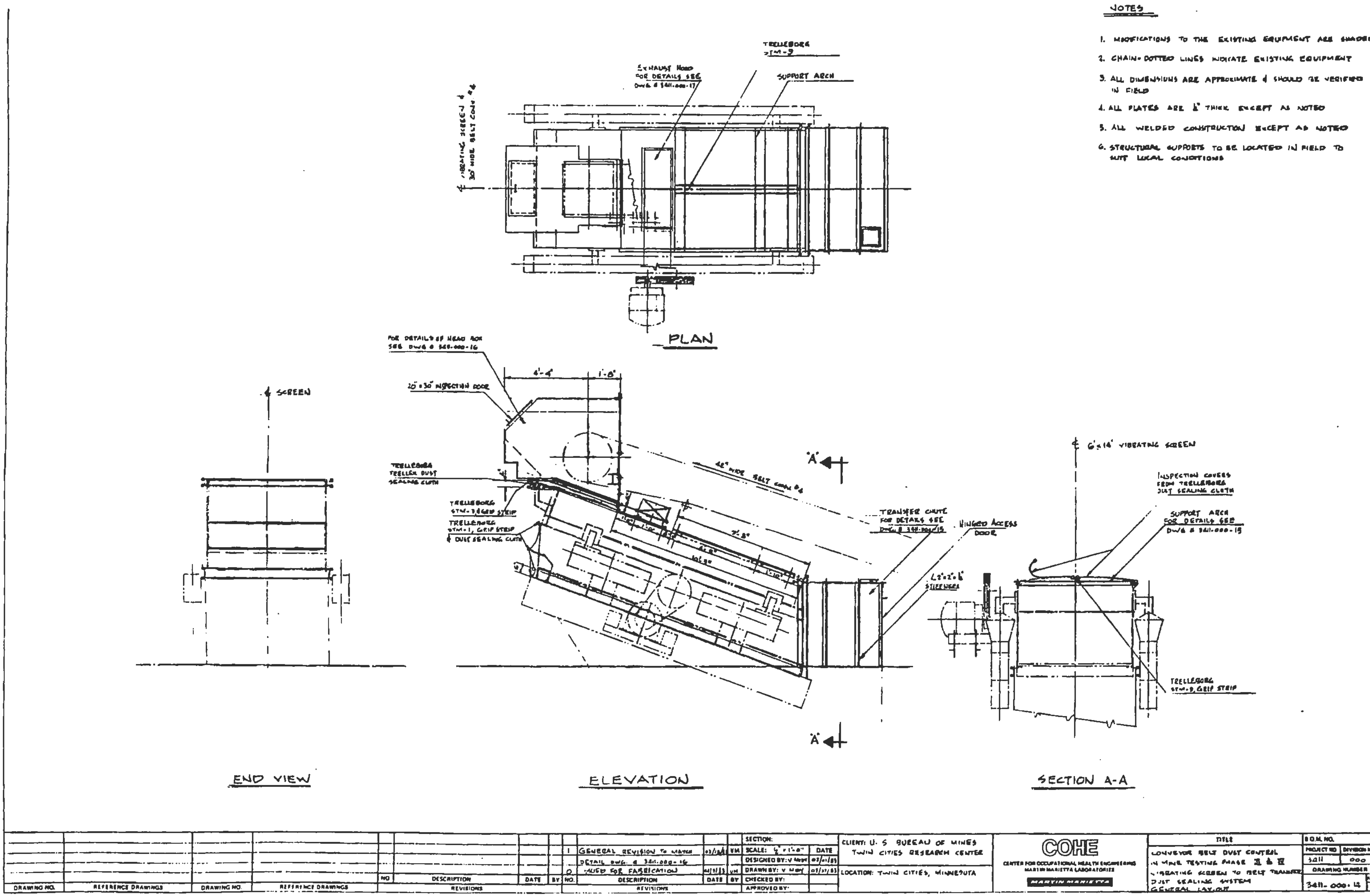


FIGURE 43. - Vibrating screen #2 circuit - dust sealing system - general layout.

The head box of belt conveyor #4 was made wider and longer and a hinged inspection door was provided for easy access. The need for an exhaust hood at the head pulley was eliminated by installing dust curtains and dust seals to contain the dust at the source and reduce ambient air entrainment.

Vibrating screen #2 was equipped with a Trellex dust sealing system, which contained the dust and reduced the amount of air entrained at the source. The Trellex system consists of a rubber cloth cover clamped to metal hardware by a special rubber molding. The covers made out of Trellex rubber cloth replaced the conventional metal covers used to enclose the screen and provided an almost perfect seal between the vibrating and stationary parts of the screen. Moreover, removing these lightweight covers required considerably less effort and time than before during operations such as screen changing or routine inspection. The Trellex dust sealing system provided a totally enclosed system which not only reduced the dust emissions considerably but also kept the amount of entrained air to an absolute minimum. The dust collection system for the vibrating screen consisted of a single exhaust hood on top of the screen to collect the dust resulting from the bulk material transfer. The maximum design exhaust volume was 2500 cfm.

To contain the dust at the source and reduce ambient air entrainment further, storage bins #1 and 5 and the connecting transfer chutes were enclosed by metal covers. The dust collection system was designed to exhaust 1750 cfm per bin.

The vibrating screen-to-belt #5 transfer point was modified as shown in figure 44, and an exhaust hood was installed on top of the settling box to exhaust a maximum of 2500 cfm.

3.5.6.4. Problems Encountered and Solutions Adopted

The first batch of Trellex rubber seals installed between the stationary and vibrating components lasted only about 2 months, primarily because of inadequate slack in the rubber cloth. New rubber cloth installed with proper slack has been performing satisfactorily over an 8-month period and shows no signs of wear.

The belt cleaner scraped off the majority of dust sticking to the return belt. However, the remaining dust was dislodged either at the rubber seal or at the conveyor return rollers, and accumulated on the screen covers. Installation of a second belt scraper and a scraping chute to transfer the dislodged material back into the process stream would probably eliminate this problem.

Two cracks developed on the side plates of the vibrating screen, probably as a result of welding the Trellex hardware. A 1/4-in. plate was welded on the cracked surface to stop the cracks from propagating further. This problem can be prevented by bolting on the Trellex hardware in future installations.

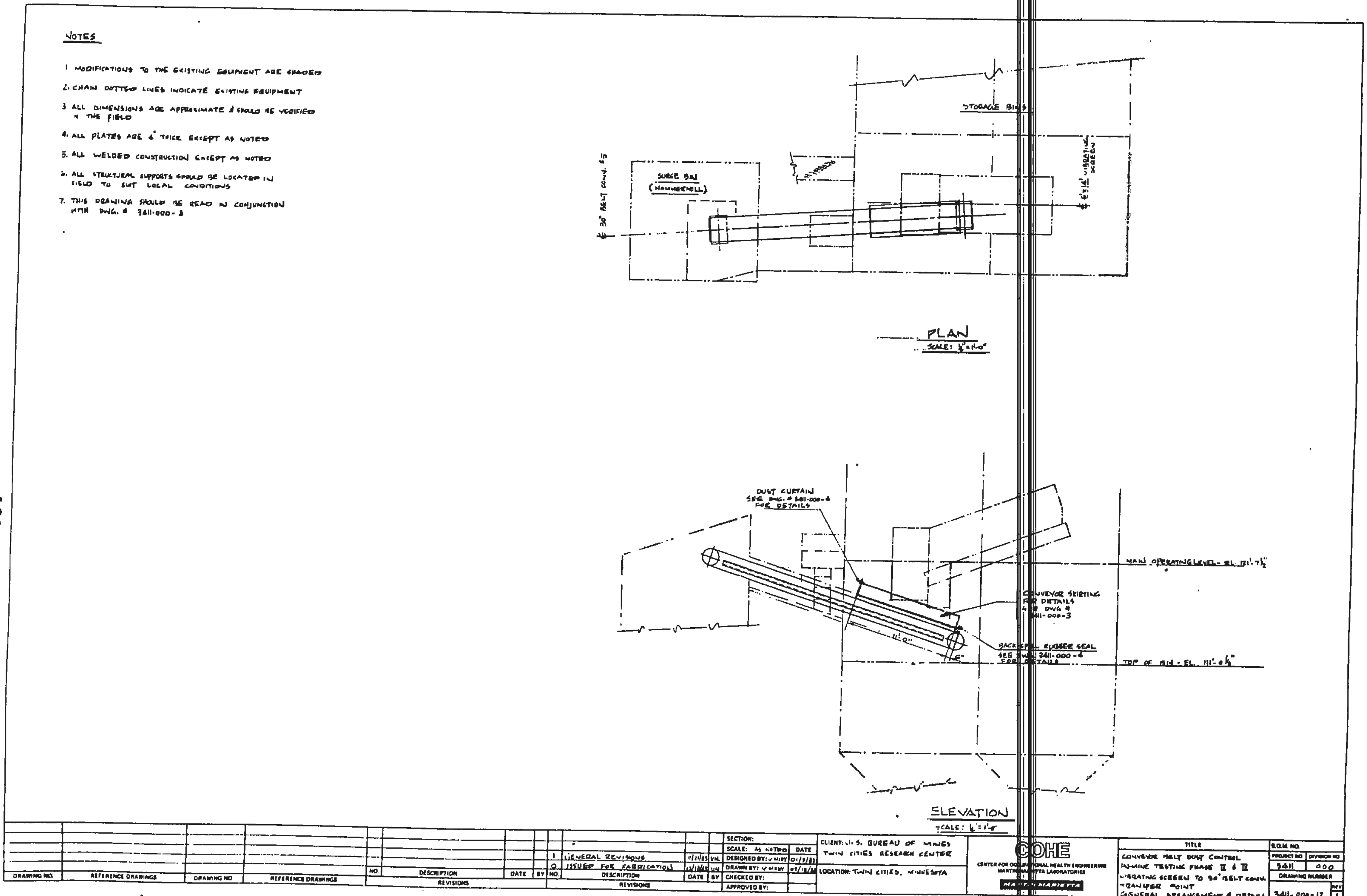


FIGURE 44. - Vibrating screen #2-to-belt conveyor #5 transfer point - details.

*** 4. SAMPLING AND DATA ANALYSIS PROCEDURES

4.1. BACKGROUND

The following sections describe the sampling strategies and data analysis techniques used to evaluate the performance of the installed dust control systems at the various transfer points.

4.2. SAMPLING STRATEGIES

4.2.1. General Description

To ensure that the samples collected were representative of actual local dust emissions, we established a number of sampling locations around each transfer point, close enough to the source to minimize interference from other dust sources. Samples of airborne respirable dust and total dust were then collected around each transfer point with the new control systems "on" and "off."

To evaluate the systems' performance under various test conditions, respirable dust sampling was repeated for a number of days. Each set of samples was collected at the same locations to avoid spatial variation and, whenever possible, on the same day to minimize the effect of uncontrollable variables such as production rate, aggregate size, material moisture content, ambient temperature, and weather conditions. To account for possible fluctuations at a sampling location, more than one sample was collected at each site.

Sampling duration, as well as the specific sampling sites, at each of the transfer points was selected on the basis of trial data obtained prior to actual sampling. Since both the processing equipment and dust emissions varied from transfer point to transfer point, sampling times were selected to ensure that:

1) Enough dust sample was collected for reliable and accurate gravimetric analysis.
2) Dust loadings in the sampling device were low enough to prevent caking and possible loss of sample during handling and transport.
3) Sampling pumps maintained the required steady flow of 1.7 L/min under heavier dust loadings (see Section 4.2.3).

Though not required in the scope of work, we collected a limited number of total dust samples at various transfer points prior to any modifications. These samples established the total dust emission levels with the old dust control systems operating in "as is" condition. (Comparison between the "as is" and new system data showed remarkable reductions in dust emissions at the various transfer points -- see Appendix C.)

4.2.2 Sampling Locations

Based on the trial data, the following sampling locations were established. The number of samples taken at each is also indicated.

4.2.2.1 Primary Crusher-to-Belt Conveyor #1 (fig. 45)

3 - End of the settling box (E)

3 - Side of the conveyor (S)

2 - Tail end of the conveyor (T)

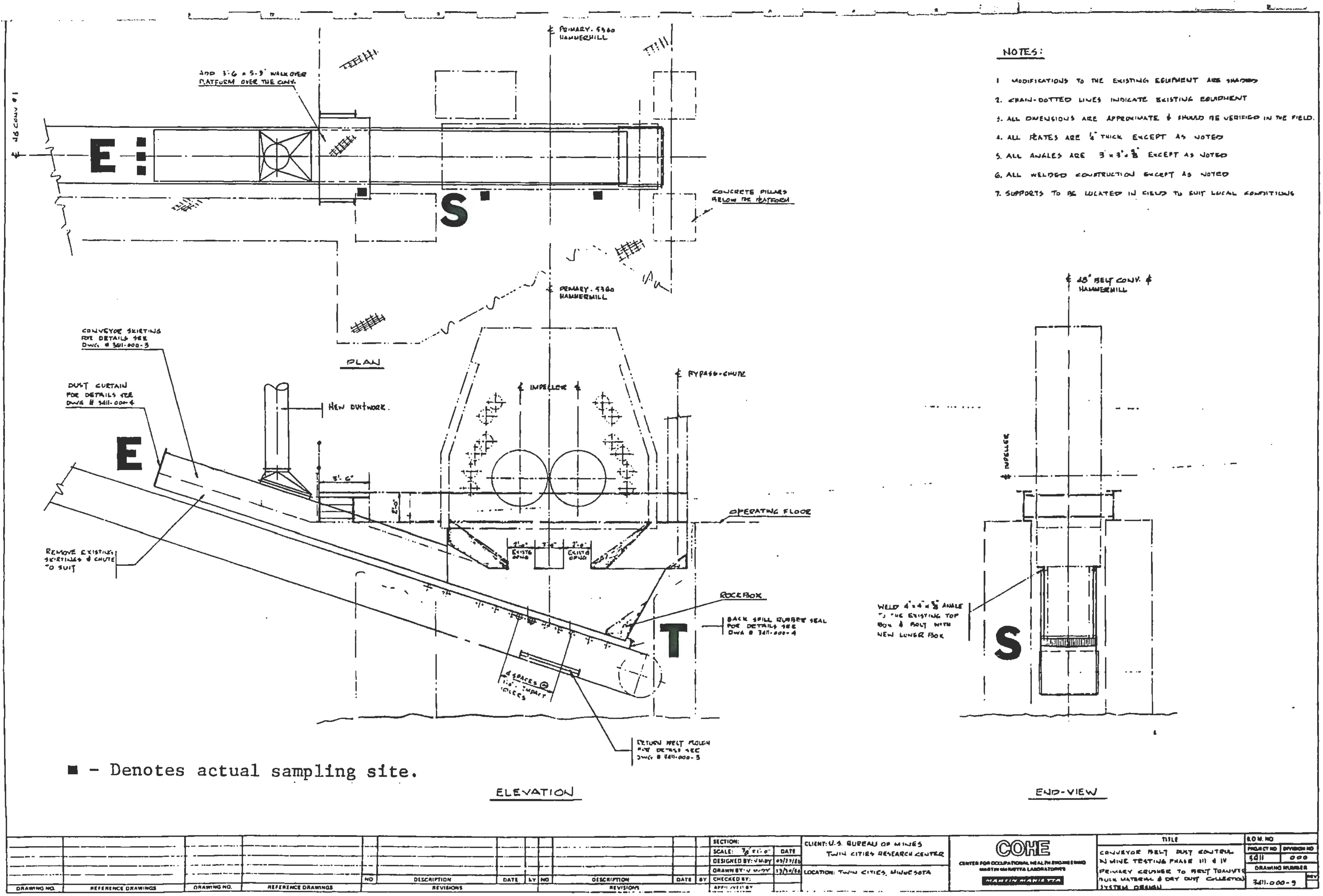


FIGURE 45. - Sampling locations at the primary crusher-to-belt conveyor #1 transfer point.

4.2.2.2. Secondary Crusher-to-Belt Conveyor #4 (fig. 46)

3 - End of the settling box (E)

3 - Side of the conveyor (S)

2 - Tail end of the conveyor (T)

4.2.2.3. Hammermills-to-Belt Conveyor #7 (fig. 47)

3 - End of the settling box (E)

3 - Side of the conveyor (S)

2 - Tail end of the conveyor (T)

4.2.2.4. Vibrating Screen #2 Circuit (fig. 48)

3 - Head chute, belt conveyor #4 (H)

3 - Rear of the vibrating screen #2 (R)

3 - Side of the vibrating screen #2 (D)

3 - End of settling box, belt conveyor #5 (E)

2 - Side of the belt conveyor #5 (S)

4.2.2.5. Belt Conveyor #7-to-Belt Conveyor #8 (fig. 49)

3 - End of the settling box (E)

3 - Side of the conveyor (S)

2 - Tail end of the settling box (T)

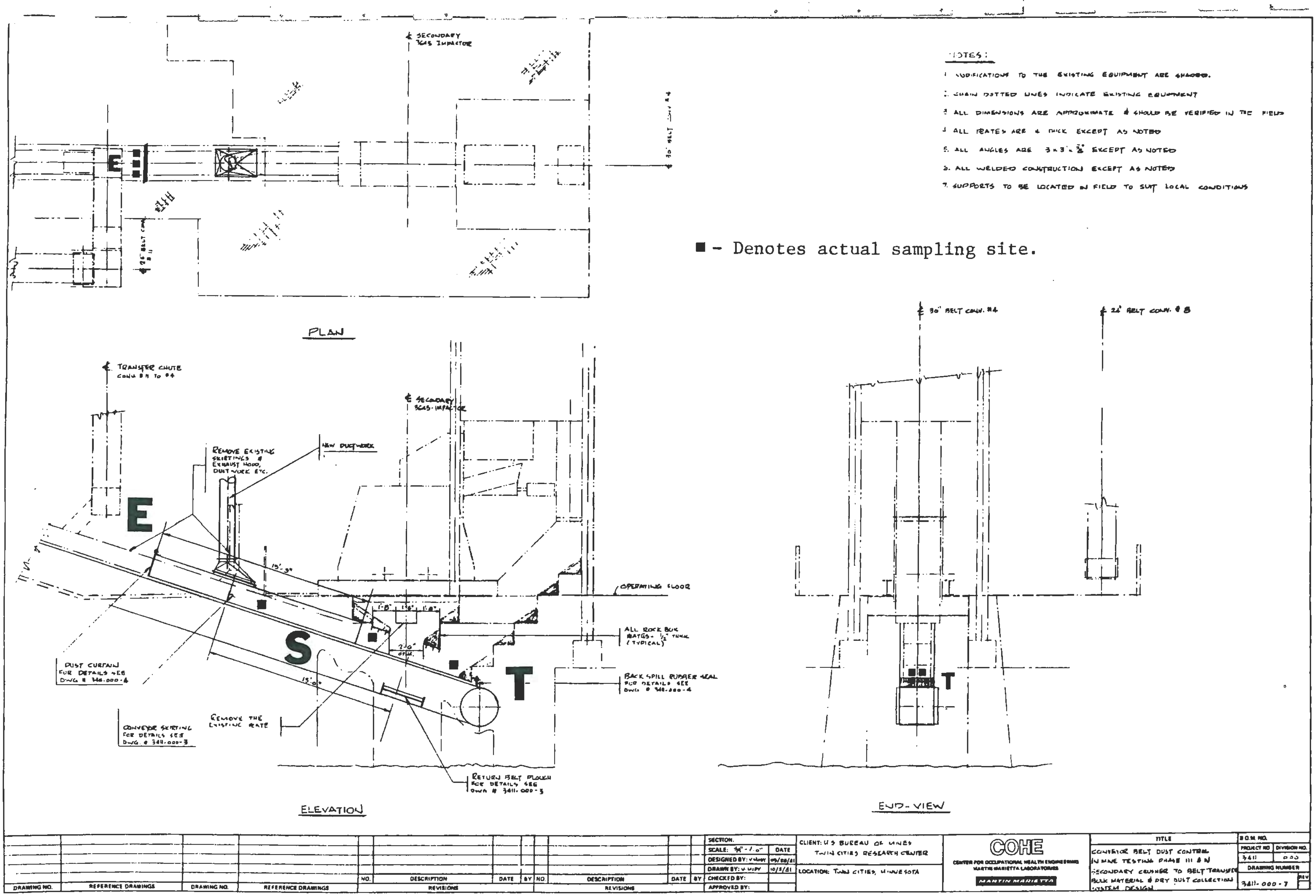
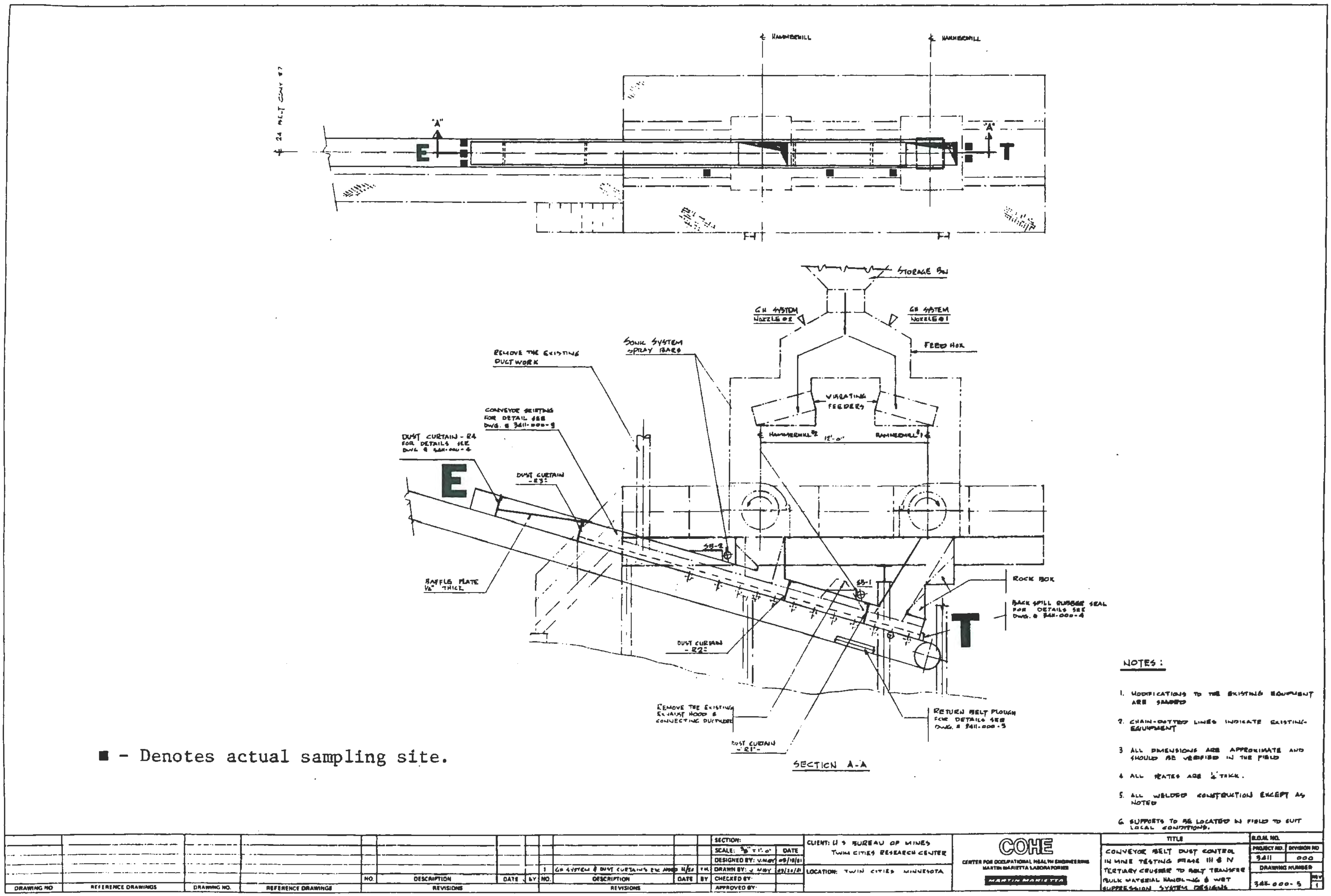


FIGURE 46. - Sampling locations at the secondary crusher-to-belt conveyor #4 transfer point.



■ - Denotes actual sampling site.

FIGURE 47. - Sampling locations at the hammermills-to-belt conveyor #7 transfer point.

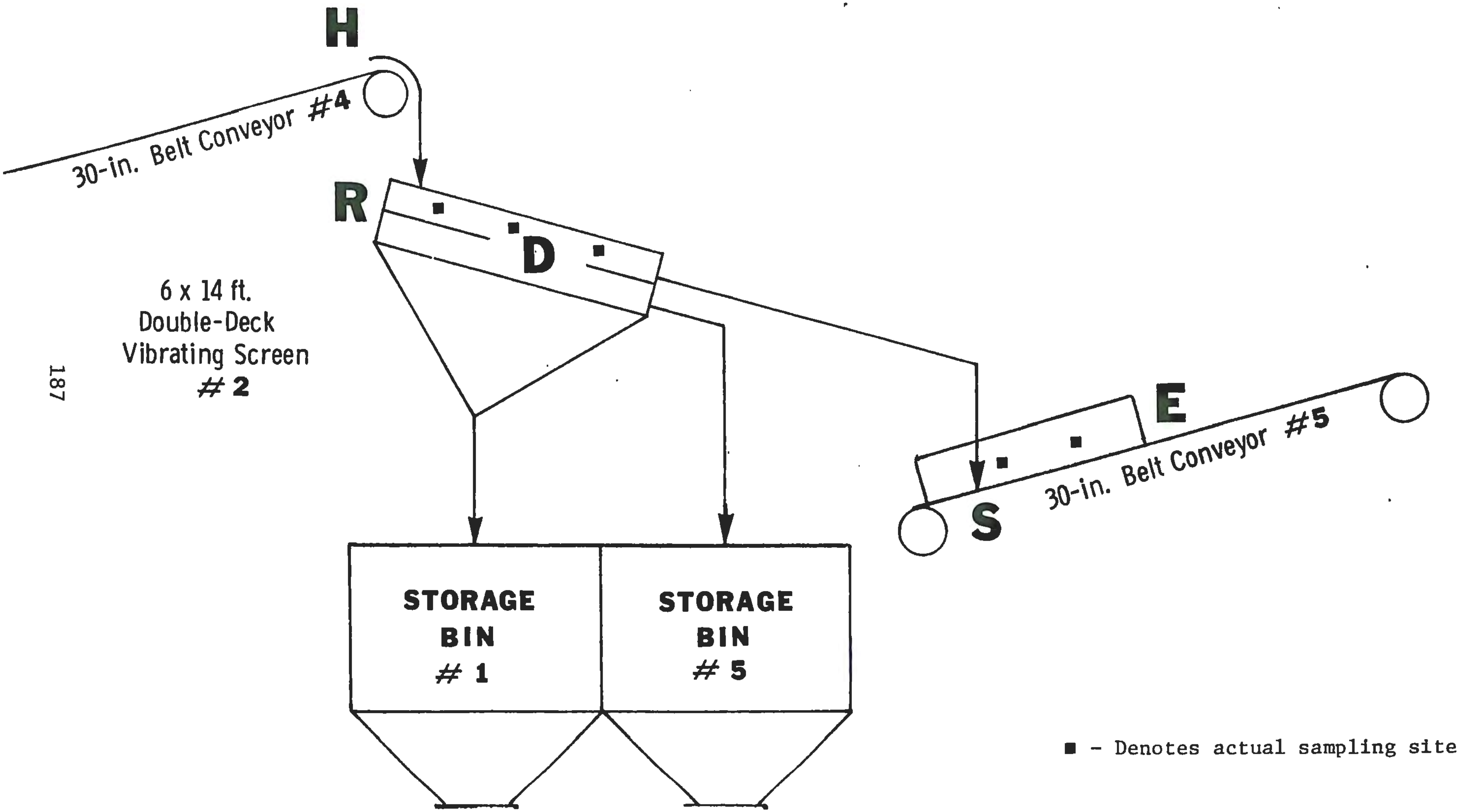


FIGURE 48. - Sampling locations for vibrating screen #2 circuit.

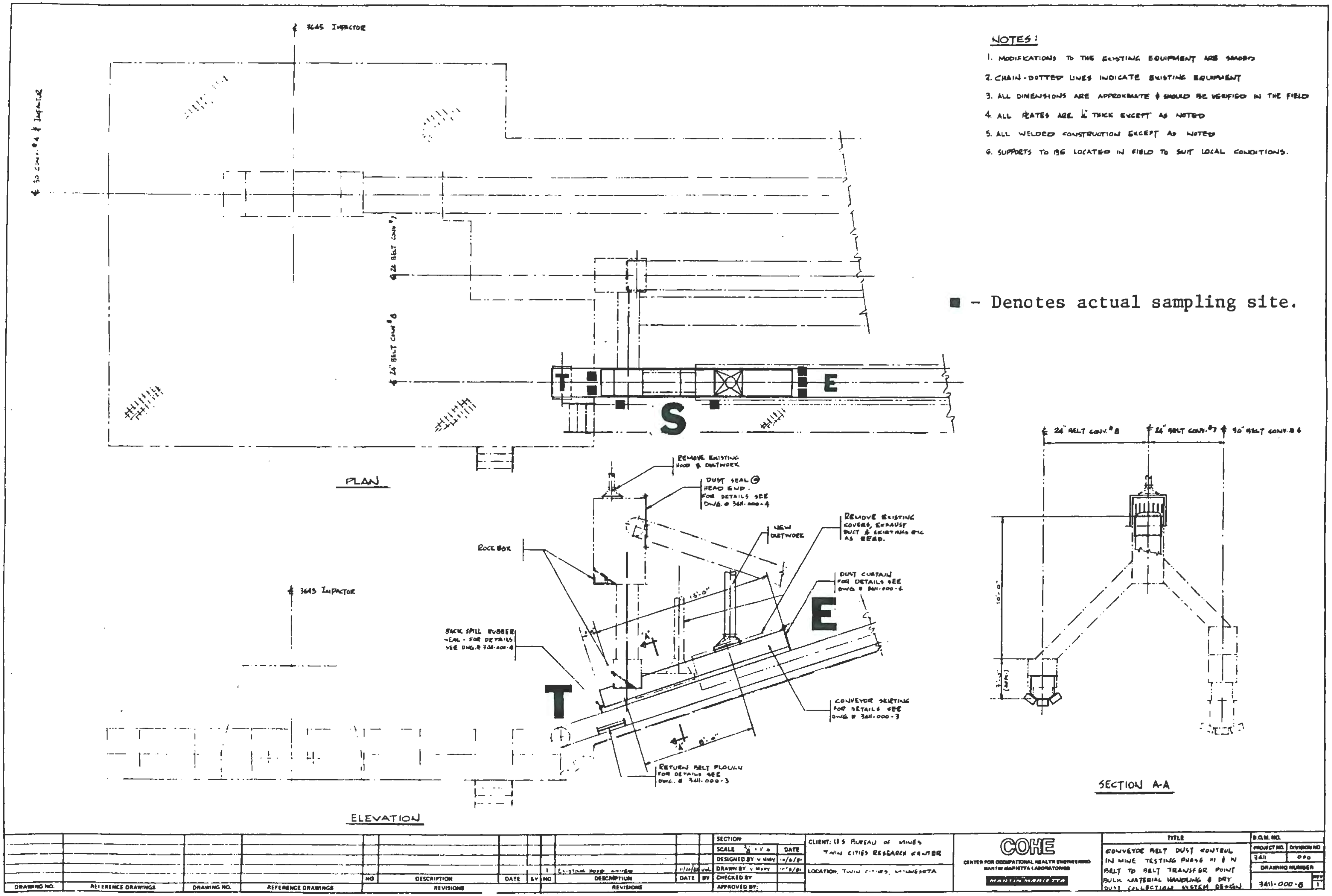


FIGURE 49. - Sampling locations at the belt conveyor #7-to-belt conveyor #8 transfer point.

4.2.2.6. Belt Conveyor #11-to-Belt Conveyor #4 (fig. 50)

3 - End of the settling box (E)

3 - Side of the conveyor (S)

4.2.3. Sampling Hardware

Respirable dust samples were collected, using standard MSHA procedures, with Bendix BDX-44 or MSA sampling pumps and a 10-mm nylon cyclone preceding a 37-mm-diameter, 5-μm pore size PVC filter. The total dust samples were collected with a "closed face cassette." In addition, numerous instantaneous samples were collected during startup and fine tuning of the control systems using GCA Corporation RDM-101 and RAM-1 respirable dust monitors. The pumps were calibrated regularly with a bubble meter at 1.7 L/min to ensure uniform flow rates during the sampling.

4.2.4. Sample Analysis and Quality Control

Respirable and total dust concentrations were determined by gravimetric analysis using a Mettler ME-22 electronic balance system. The balance has an internal standard, traceable to the National Bureau of Standards (NBS), which is checked and calibrated daily. Weighing accuracy is further ensured by a special quality control procedure conducted by our laboratory, which is accredited by the American Industrial Hygiene Association (AIHA); the laboratory weighs six reference filters at specified dates each month to detect possible variations caused by the weighing system or procedure.

As an additional quality control measure, two blank (unexposed) samples were processed on each sampling day to ensure accuracy in sample preparation and analysis.

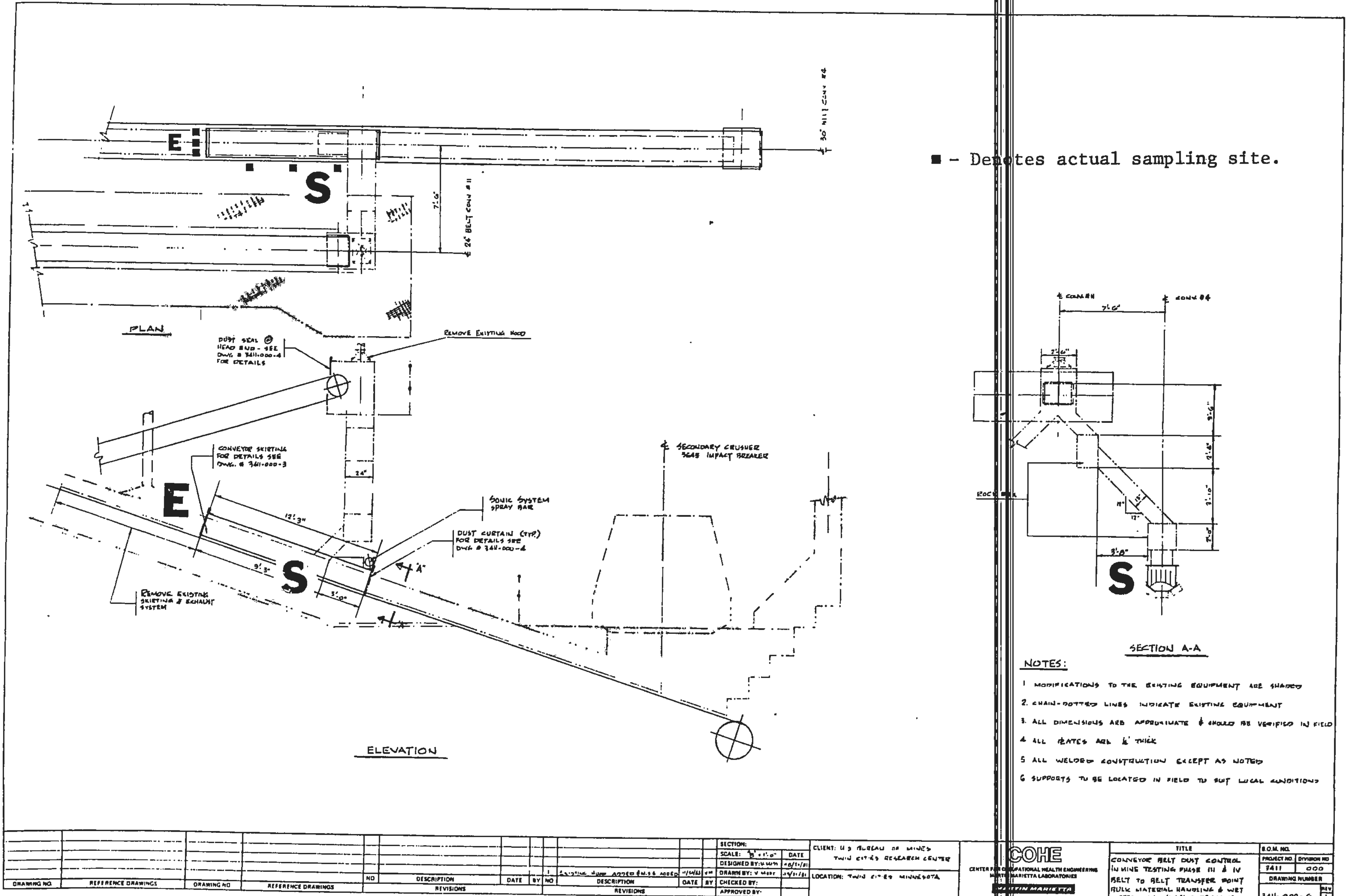


FIGURE 50. - Sampling locations at the belt conveyor #11-to-belt conveyor #4 transfer point.

A typical field sampling sheet and laboratory analysis sheet are given in Appendix D.

4.2.5. Data Analysis

The performance of the control systems on an individual sampling day was evaluated by collecting respirable or total dust samples with the control system "off" and "on." Performance was then calculated using the following equations:

$$n_j = \frac{C_j - C_j'}{C_j} \times 100\% \tag{20}$$

where

n_j = control system efficiency on jth day,

C_j = geometric mean dust concentration with control system "off" on jth day

$$\sqrt[n]{\sum_{i=1}^{n} x_{ij}} \tag{21}$$

and C_j' = geometric mean dust concentration with control system "on" on jth day.

$$\sqrt[p]{\prod_{i=1}^{p} y_{ij}} \tag{22}$$

where x_{ij} = dust concentration with control system "off" on jth day at ith position

y_{ij} = dust concentration with control system "on" on jth day at ith position.

and n and p = number of samples in a given set.

Notes: 1) An individual sample at a specific sampling location (i.e., "E," "S," or "T") was rejected if its value differed by an order of magnitude from the median.

2) When both "on" and "off" data were not available for the same day, the performance of the control system on that day was not computed.

3) When more than one set of samples was obtained on the same day, the "arithmetic" mean of the "geometric mean dust concentration" was used as the basis for the efficiency calculation.

4) In some cases, concentrations with the control system "on" were higher than with the control system "off," i.e., the efficiency of the control system was negative. These data are reported as question marks in the appropriate tables (Chapter 5). The causes for such discrepancies are not known.

Mean values were calculated as follows.

4.2.5.1. Dust Control System "Off"

Arithmetic mean dust concentration ($\overline{X}$) = arithmetic mean of dust concentrations with system "off."

$$\overline{X} = \frac{\sum_{i=1}^{n} \left(\sum_{j=1}^{m} x_{ij} \right)}{N} \tag{23}$$

where N = total number of samples with control system "off"

and m = number of sets with control system "off."

Standard deviation =

$$\sigma_x = \sqrt{\frac{\sum_{i=1}^{n} \sum_{j=1}^{m} (x_{ij} - \overline{X})^2}{N}} \tag{24}$$

Standard error =

$$SE_{\overline{X}} = \sqrt{\frac{\sum_{i=1}^{n} \sum_{j=1}^{m} (x_{ij} - \overline{X})^2}{N\ (N - 1)}} \qquad (25)$$

4.2.5.2. Dust Control System "On"

Arithmetic mean dust concentration ($\overline{Y}$) = arithmetic mean of dust concentrations with control system "on."

$$\overline{Y} = \frac{\sum_{i=1}^{p} (\sum_{j=1}^{q} y_{ij})}{K} \qquad (26)$$

where K = total number of samples with control system "on."

and q = number of sets with control system "on."

Standard deviation =

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^{p} \sum_{j=1}^{q} (y_{ij} - \overline{Y})^2}{K}} \qquad (27)$$

Standard error =

$$SE_{\overline{Y}} = \sqrt{\frac{\sum_{i=1}^{p} \sum_{j=1}^{q} (y_{ij} - \overline{Y})}{K\ (K - 1)}} \qquad (28)$$

4.2.5.3. Dust Control System Performance

Mean dust control efficiency =

$$\overline{E} = \frac{\overline{X} - \overline{Y}}{\overline{X}} \times 100\% \qquad (29)$$

Standard error in mean dust control efficiency =

$$SE_{\overline{E}} = \sqrt{\left[\frac{(SE_{\overline{Y}})^2}{\overline{X}^2} + \frac{\overline{Y}^2 (SE_{\overline{X}})^2}{\overline{X}^4}\right]} \qquad (30)$$

The approximate 95% confidence limits were computed using Student's "t" distribution:

1) Control system "off" concentration (X)

$$X = \overline{X} \pm (SE_{\overline{X}}) \cdot t_{(.025,N-1)} \qquad (31)$$

2) Control system "on" concentration (Y)

$$Y = \overline{Y} \pm (SE_{\overline{Y}}) \cdot t_{(.025,K-1)} \qquad (32)$$

3) Efficiency of the control system (E)

$$E = \overline{E} \pm (SE_{\overline{E}}) \cdot t_{(.025,N+K-2)} \qquad (33)$$

where $t_{(.025,N-1)}$, $t_{(.025,K-1)}$ and $t_{(.025,N+K-2)}$ are "t" values from statistical tables.

4.2.5.4. Significance of Standard Deviations and Standard Errors

The use of standard deviation and standard error in statistical analysis to describe the degree of variation of the data is fairly common. These terms are described briefly here for reference.

Standard deviation is simply the square root of population variance, where population variance is defined as the average of the squared deviations from the average of the distribution. Thus, the standard deviation is a measure of variability or dispersion of population.

The standard error of the mean, on the other hand, is defined as the square root of sampling variance. This is a statistical expression of the well-known fact that a large number of samples represents a population more accurately than a small one. Therefore, the standard error is a measure of precision in the estimated mean of the distribution. The standard deviation and the standard error for dust concentrations with the control systems "on" and "off" reported here thus indicate the reproducibility of mean dust concentrations and the dispersion of the concentrations around the mean. We have reported the standard error in the mean efficiency of the control system as a measure of the precision in the estimate of performance of the control system.

4.2.6. Sampling Problems Encountered and Solutions Adopted

4.2.6.1. Ambient Dust Samples

Due to the physical constraints of the test facilities and the limited scope of the program, individual transfer points could not be completely isolated from other dust sources in the vicinity. We attempted to account and correct for the contribution of these other dust sources in the sampling strategy by collecting numerous ambient samples. The ambient sampling was discontinued within a few months of testing.

Some of the ambient sampling data and the detailed reasons for discontinuing ambient dust sampling are presented in Appendix E.

4.2.6.2. Wet Dust Suppression System Testing

As with all the transfer points, the actual sampling locations and duration at the hammermills-to-belt conveyor #7 transfer point selected for evaluating the Sonic system were based on the initial trial data. Field observations at "E" locations indicated

1) Partial clogging of the cyclone inlet

2) Partial-to-complete clogging of the cyclone discharge opening.

These problems were seen only during testing of the Sonic wet dust suppression system and were attributed to the following causes:

1) A portion of the fog/fine mist produced by the Sonic system escaped the settling box and impacted on the sampling cyclones, thus wetting them.

2) Rotating at 900 rpm, the two hammermills acted as fans and created high air velocities (approx. 400 ft/min) within the settling box that prevented the agglomerated dust particulates from settling out. Hence, the airstream exiting from the settling box consisted of fine droplets/mist, fine untreated dust, and agglomerated coarser dust particulates that adhered to the wetted exteriors of the cyclone and clogged the cyclone inlet.

3) Some of the fine droplets/mist produced also entered the cyclones, wetting their inner walls and eventually clogging the discharge opening.

Reducing sampling duration minimized the problem somewhat but did not eliminate it completely. Therefore, sampling was discontinued until a proper sampling procedure could be formulated. After discussions with Bureau of Mines personnel, we changed the orientation of the cyclone inlet from a facing "in" to a facing "out" position (the facing "out" position was at 180° to the direction of the airstream), so that water droplets and agglomerated wet dust would not impact directly on it. This approach, coupled with a shorter sampling duration, eliminated the clogging problems.

The effect of cyclone orientation on actual dust emissions was evaluated by Cecala (26), who showed that there is a difference in recorded concentrations with the cyclone facing "in" and cyclone facing "out." We would expect the dust emissions recorded with the cyclone "out" to be lower than the actual control system "on" and "off." However, since efficiency is defined as the ratio of concentrations ($E = 1 - Y/X$), relative efficiency can still be obtained. With the concurrence of the Bureau of Mines, we modified our sampling strategy accordingly for evaluating efficiency of the wet dust suppression system at the "E" location. The samples for the "S" location were not subject to the same problems; hence, sampling at that location was conducted with the cyclone facing "in." Some of the trial data comparing dust emissions with the cyclone facing "in" and "out" at the "E" location are presented in Appendix F.

*** 5. PERFORMANCE EVALUATION AND DATA ANALYSIS

To evaluate the dust control systems installed in Phase II, we collected respirable dust samples over a period of 18 months both with and without the control systems operating.

The primary independent variable for the dust collection system was exhaust volume, which we varied systematically. In the tests of the wet dust suppression system, the test parameters were kept constant.

As noted in Section 4.2.1., a comparison of limited data from the old ("as is") and new systems indicated that the new systems were far superior to the old.

The following sections describe the performance evaluation of the dust collection and wet dust suppression systems installed at various transfer points.

5.1. TRANSFER POINTS EQUIPPED WITH DUST COLLECTION SYSTEMS

5.1.1. Primary Crusher-to-Belt Conveyor #1

The following two approaches were used to establish the upper and lower limits of the exhaust volume in the design of the dust collection system.[2]

1) Anderson — 6700 cfm

2) Industrial Ventilation Manual (IVM)
   - Non-dusty material — 2000 cfm
   - Dusty material — 5000 cfm.

---

2 Detailed calculations are shown in Appendix B.

Although the dust collection system was designed to operate in the above range, the field tests were conducted only between 4000 to 6700 cfm because no dust control was apparent visually below 4000 cfm.

A new crushing circuit, added to the existing facilities in September 1983, increased the primary crusher throughput to 1000 ton/h from an average of 700 ton/h. Table 3 summarizes the test data under various conditions while Tables 4 through 13 show summaries of test data for individual test conditions. The following discussions are based on Table 3 unless otherwise noted:

1) The mean dust control efficiencies for respirable as well as total dust emissions under similar test conditions were higher at "E" locations than at "S" and "T" locations.

2) The scatter in dust control efficiencies at "S" and "T" locations was much wider than at "E" locations because the exhaust hood had a greater effect on dust emissions at "E" locations. In other words, the performance of the dust control system was more sensitive to changes in dust concentrations at "S" and "T" locations than at "E" locations.

3) Compared to "S" and "T" locations, the dust control system at "E" locations, was more reliable and efficient on a day-to-day basis (fig. 51, Table 4), as well as over a period of 6 months (fig. 52, Tables 5 & 7). At "E" locations, the control efficiencies for total dust were higher than those for respirable dust. This was epecially true at lower exhaust volumes.

4) Comparison of July 1982 and June 1983 data indicated that the mean dust concentrations at "E" locations with the control

TABLE 3. - SUMMARY OF TEST RESULTS AT PRIMARY CRUSHER-TO-BELT CONVEYOR #1

CONTROL SYSTEM: Dust Collection

TEST CONDITION	TIME PERIOD	SAMPLING LOCATIONS (1): E — ARITH. MEAN DUST CONC.(2) SYS. OFF mg/m³	E — EFFICIENCY MEAN %	E — EFFICIENCY STANDARD ERROR %	T — ARITH. MEAN DUST CONC.(2) SYS. OFF mg/m³	T — EFFICIENCY MEAN %	T — EFFICIENCY STANDARD ERROR %	S — ARITH. MEAN DUST CONC.(2) SYS. OFF mg/m³	S — EFFICIENCY MEAN %	S — EFFICIENCY STANDARD ERROR %	REFERENCE TABLES
RESPIRABLE DUST											
Crusher throughput: 700 tph											
6700 cfm	07/82	109.0	98.7	0.4	32.5	77.6	7.2	43.6	72.3	11.6	4
6000 cfm	06/83	163.0	97.4	0.7	--	--	--	47.0	54.6	11.7	5
5000 cfm	06/83	163.0	66.0	5.3	--	--	--	47.0	36.0	15.6	6
Crusher throughput: 1000 tph											
6000 cfm	11/83	105.7	98.3	0.4	--	--	--	13.3	17.4	26.8	7
5400 cfm	11/83	105.7	69.1	8.9	--	--	--	13.3	?(2)	?	8
4500 cfm	11/83	105.7	60.2	9.4	--	--	--	13.3	?	?	9
4000 cfm	11/83	105.7	?	?	--	--	--	13.3	?	?	10
TOTAL DUST											
Crusher throughput: 700 tph											
6700 cfm	08/82	772.7	99.5	0.1	126.1	55.0	20.9	603.5	45.0	17.3	11
6000 cfm	06/83	1638.2	99.7	0.1	--	--	--	220.2	60.3	29.5	12
5000 cfm	06/83	1638.2	92.4	2.1	--	--	--	220.2	?	?	13

(1) E - End of the settling box.
T - Tail end of the conveyor.
S - Side of the conveyor.

(2) [illegible] to [illegible]on 4[illegible], fo[illegible]lana[illegible]

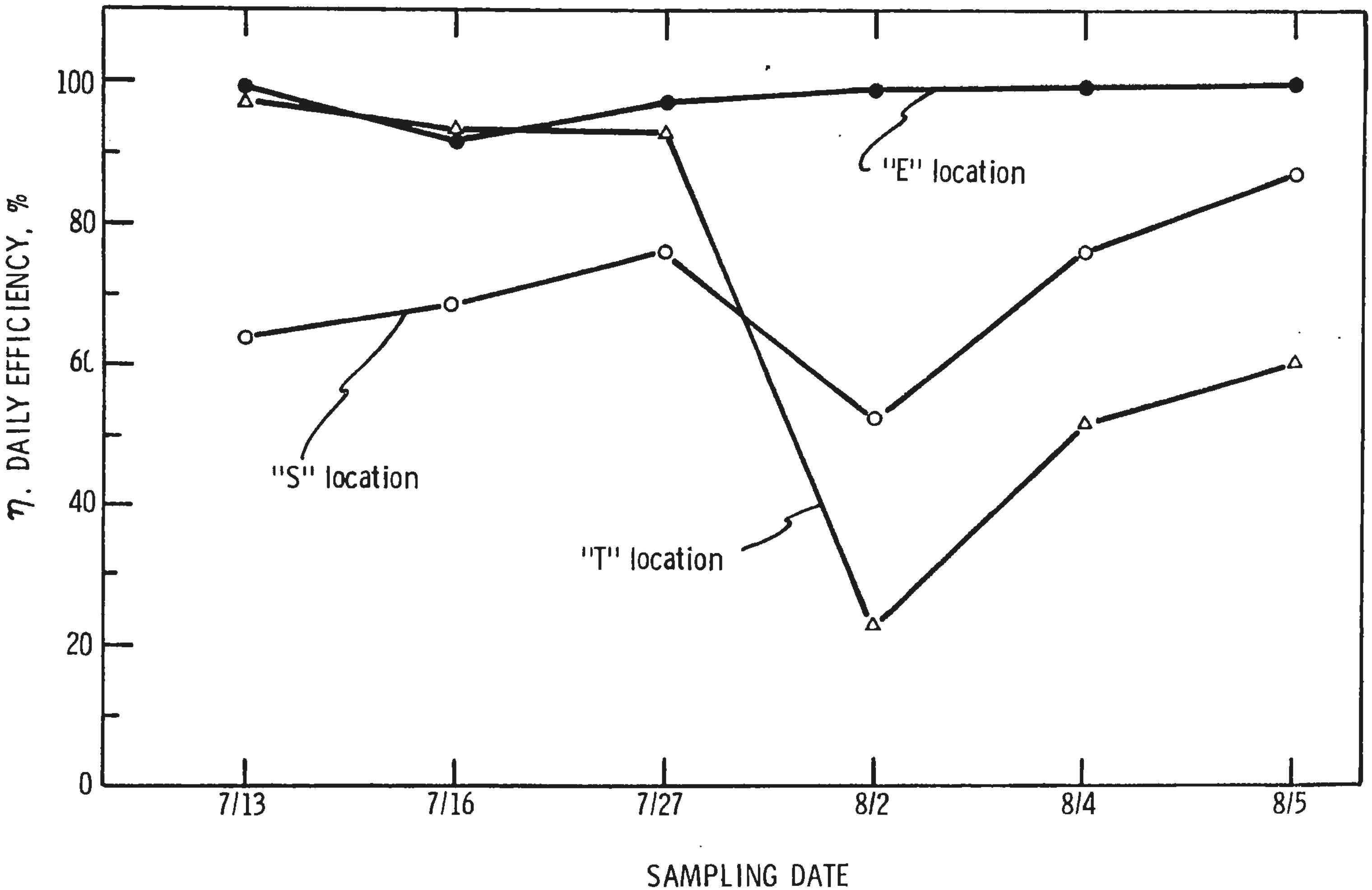


FIGURE 51.- Day-to-day variations in efficiency of dust control system at the primary crusher-to-belt conveyor #1 transfer point. Testing condition - 6700 cfm; type of sampling - respirable dust.

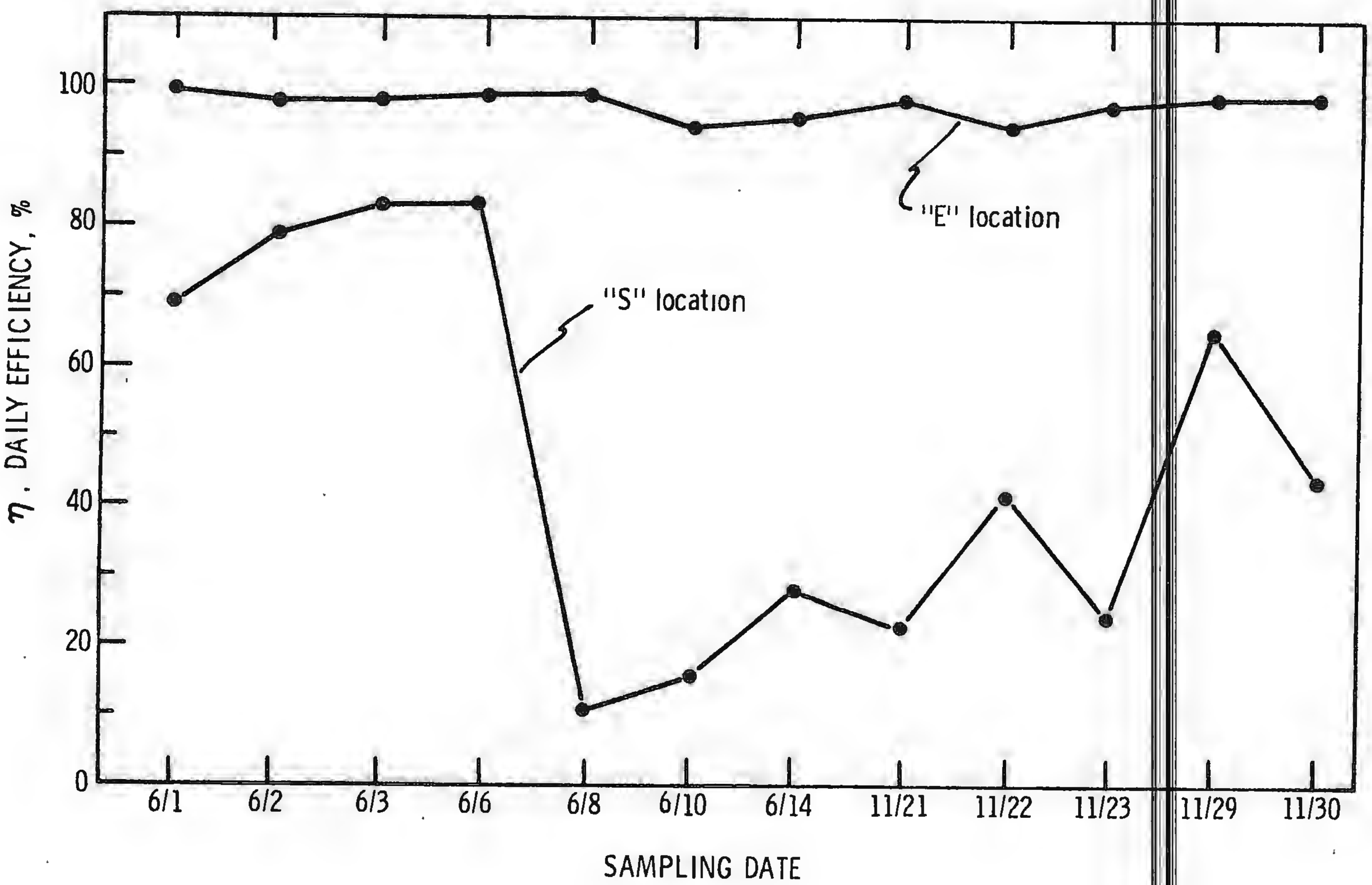


FIGURE 52.- Long-term reliability of dust control system at the primary crusher-to-belt conveyor #1 transfer point.
Testing condition - 6000 cfm, type of sampling - respirable dust.

system "off" increased from 109.0 mg/m^3 to 163.0 mg/m^3 for respirable dust (Tables 4 and 5) and from 772.7 mg/m^3 to 1638.2 mg/m^3 for total dust (Tables 11 and 12). These increases could be attributed to several factors such as changes in the moisture content of the material, type of rock, rock hardness, etc. However, at "S" locations, the mean respirable dust concentrations with the system "off" were essentially the same, indicating that the bulk material handling components at this location were functioning as in July 1982. It is also interesting to note that the total dust emissions at "S" locations during the same time period decreased from 603.5 to 220.2 mg/m^3.

5) The mean respirable dust control efficiency at "E" locations remained unchanged between 6700 cfm and 6000 cfm exhaust volumes, but dropped to 66% at 5000 cfm. Figure 53 illustrates this result. It can be concluded that the Anderson approach predicts adequate exhaust volumes at this location whereas the Industrial Ventilation Manual does not. We interpret the curve in figure 53 to mean that there exists a exhaust volume below which the effectiveness of the dust control system at "E" locations decreases sharply. We call that exhaust volume the "critical exhaust volume" (refer to Section 5.1.1.2. for further discussion).

6) The respirable dust control efficiency at "S" locations fell from 72.3% at 6700 cfm to 54.6% at 6000 cfm, and to 36.0% at 5000 cfm. The decrease in system performance between 6700 cfm

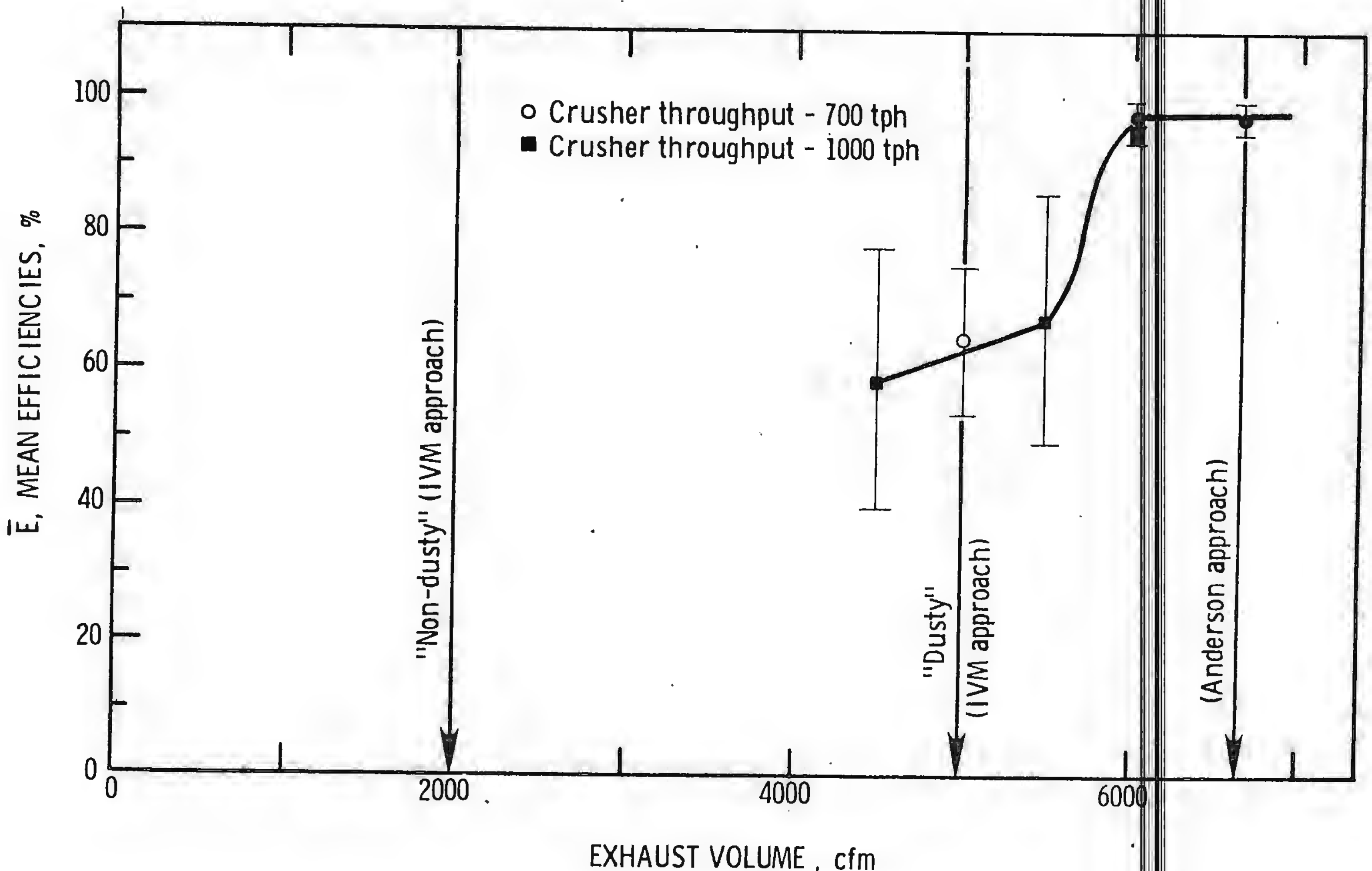


FIGURE 53.- Effect of exhaust volume on dust control efficiency at "E" locations for the primary crusher-to-belt conveyor #1 transfer point. Type of sampling - respirable dust.

and 5000 cfm was relatively smooth, without an obvious sharp drop (fig. 54). Therefore, it appears that at "S" locations, there is no critical exhaust volume in the range of testing.

7) The control efficiency for total dust at "E" locations followed the same trend as that for respirable dust, i.e., there was a drastic drop in effectiveness of the dust control system between 5000 cfm and 6000 cfm. Thus, the "critical exhaust volume," as defined earlier, is valid for both the respirable and total dust emissions.
8) The total dust data at "S" locations were inconclusive.
9) At the increased production rate (from 700 ton/h to 1000 ton/h), mean respirable dust concentrations with the system "off" decreased from 163.0 mg/m^3 to 105.7 mg/m^3 at "E" locations, and from 47.0 mg/m^3 to 13.3 mg/m^3 at "S" locations. This reduction may be attributed to the fact that at a higher production rate the size of the opening through which air (i.e., induced air) can enter into the circuit is smaller and, therefore, results in lower airborne dust concentrations.
10) At 6000 cfm, the mean dust control efficiency for "E" locations remained unchanged with increased production rates. However, the mean efficiency at "S" locations decreased from 54.6% to 17.4%, indicating that the dust collection efficiency at "S" and "T" locations was more sensitive to changes in production rate than at "E" locations.
11) At higher production rates, the mean respirable dust control efficiency at "E" locations decreased sharply from 98.3% at 6000

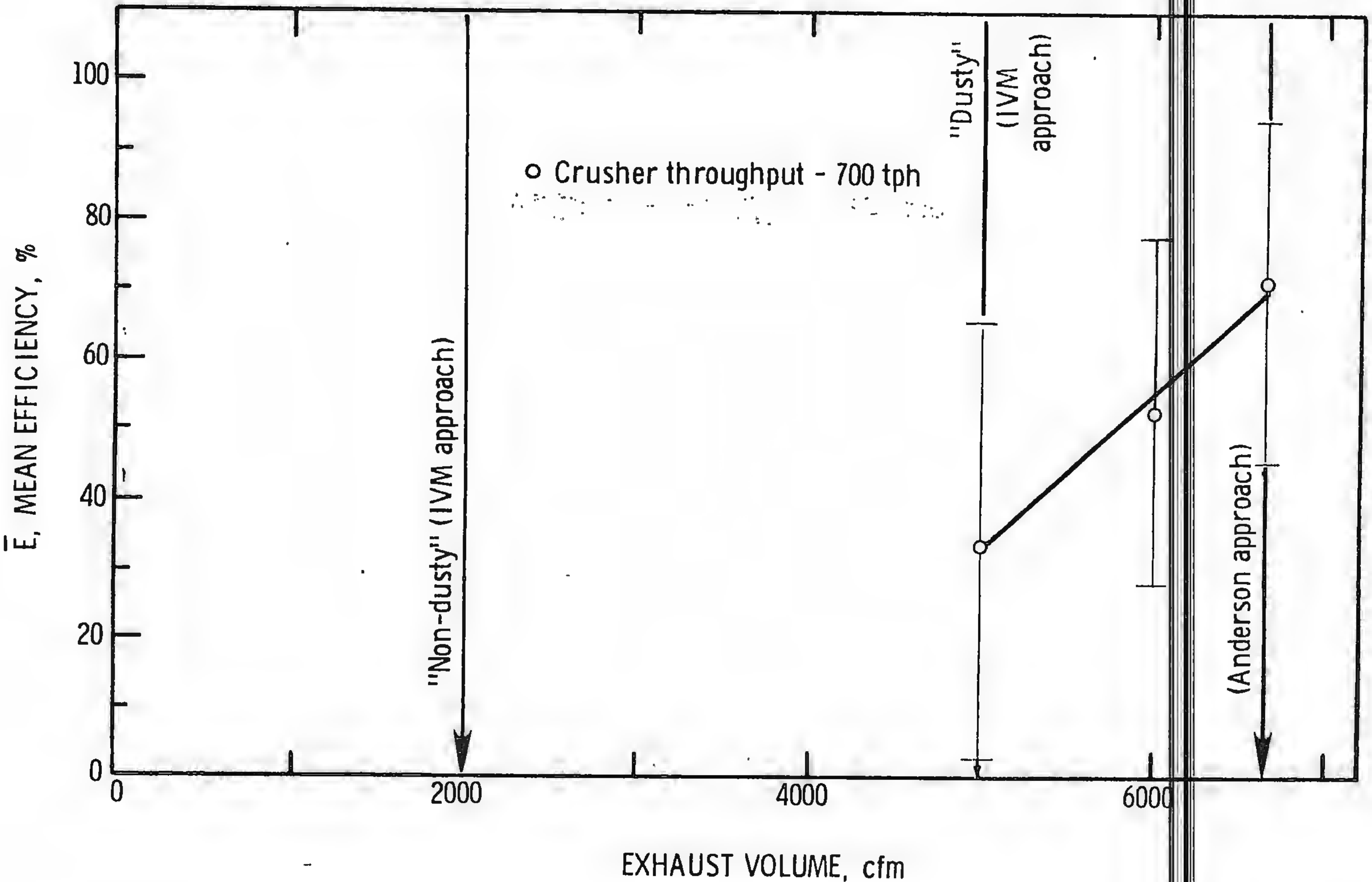


FIGURE 54.- Effect of exhaust volume on dust control efficiency at "S" locations for the primary crusher-to-belt conveyor #1 transfer point. Type of sampling - respirable dust.

cfm to 69.1% at 5400 cfm. However, between 5400 cfm and 4500 cfm, the drop in efficiency was more gradual --- from 69.1% to 60.2%.

5.1.1.2. Explanation of "Critical Exhaust Volume" Phenomenon

Figures 53 and 54 show the mean efficiency data for respirable dust at "E" and "S" locations, respectively. A close examination of figure 53 indicates that there exists a "critical exhaust volume" at "E" locations below which the dust control efficiency decreases drastically. We observed during field testing that when the exhaust system was turned "off," dust-laden air emerged continuously from the settling box at high velocity (fig. 55). When the dust collection system was turned "on" and exhaust volume was gradually increased, the velocity of this dust-laden airstream decreased continuously until there was a reversal in the direction of air flow from the settling box (the point at which no dust was emitted - fig. 56). The point at which flow reversal occurred coincides with the "critical exhaust volume," defined earlier.

At "S" locations, however, the nature of dust emissions is different. Here, the dust emissions are chiefly due to puffing through the gaps between the conveyor belt and skirting rubber or through imperfections such as holes or cracks in the rubber. Since the exhaust hood normally is installed far from the dust source, it is less effective in reducing dust emissions at the sides. Within the testing range for the primary crusher-to-belt conveyor #1 transfer point, no flow reversal trend was observed at "S" locations. (Figures 57 and 58 show a "S" location with

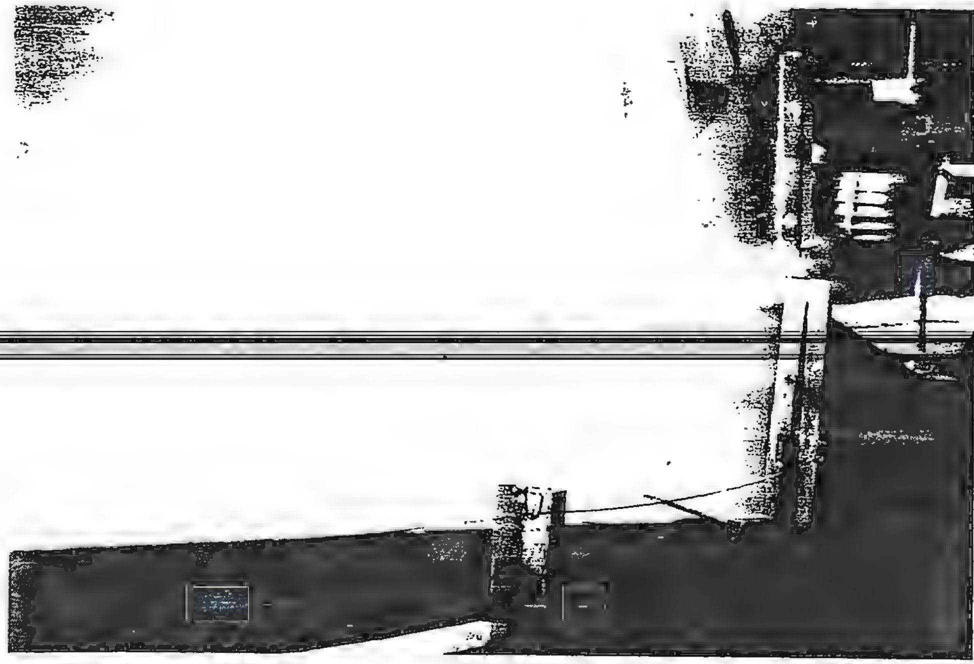


FIGURE 55.- "E" location at the primary crusher-to-belt conveyor #1 transfer point. Dust collection system "off."

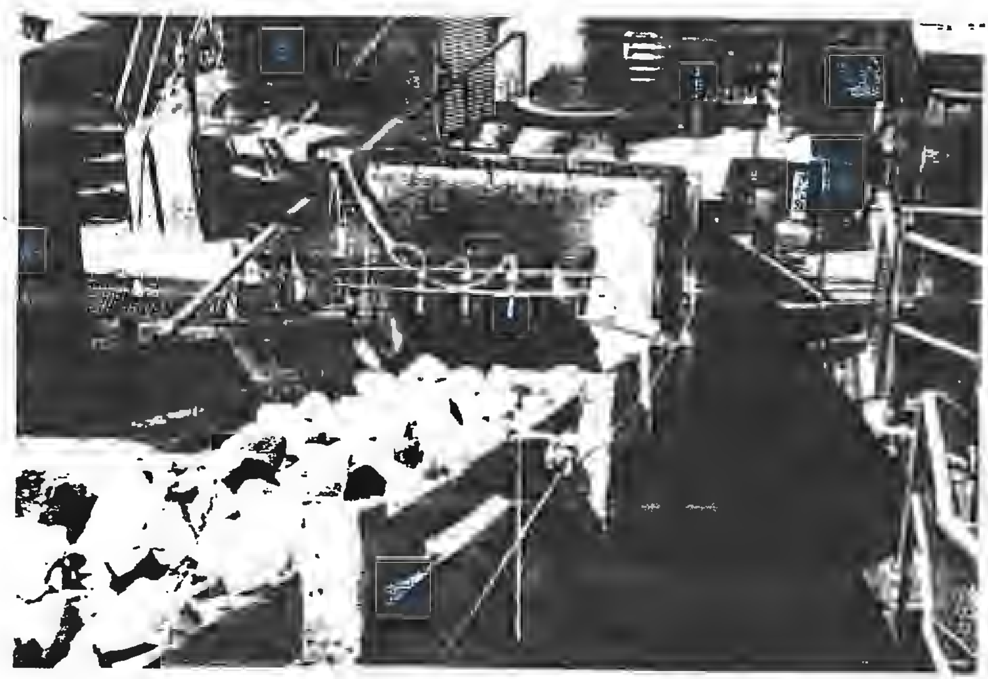


FIGURE 56.- "E" location at the primary crusher-to-belt conveyor transfer point. Dust collection system "on."

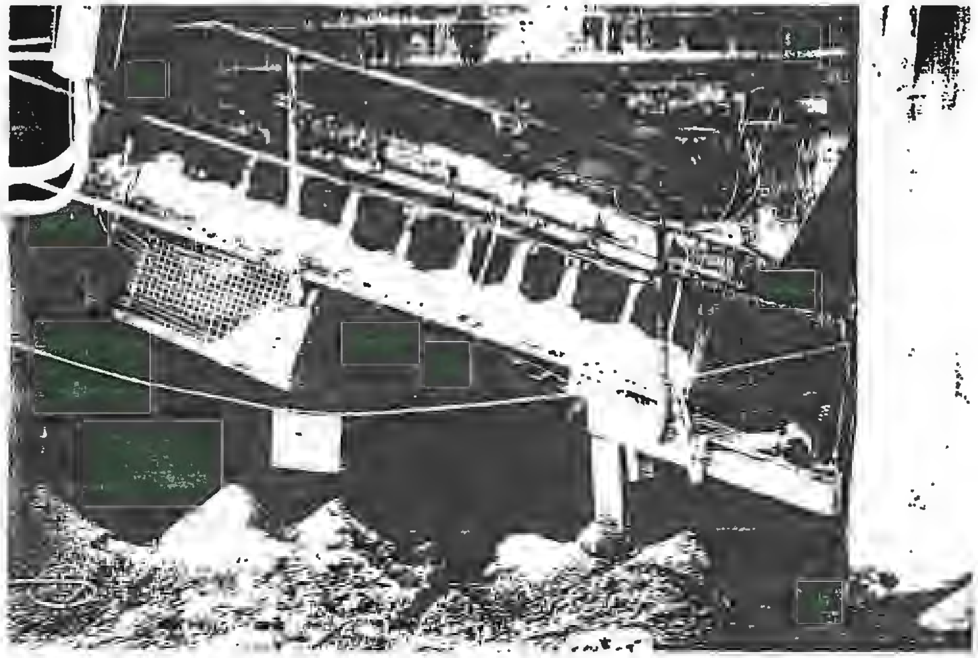


FIGURE 57.- "S" location at the primary crusher-to-belt conveyor #1 transfer point. Dust collection system "on."

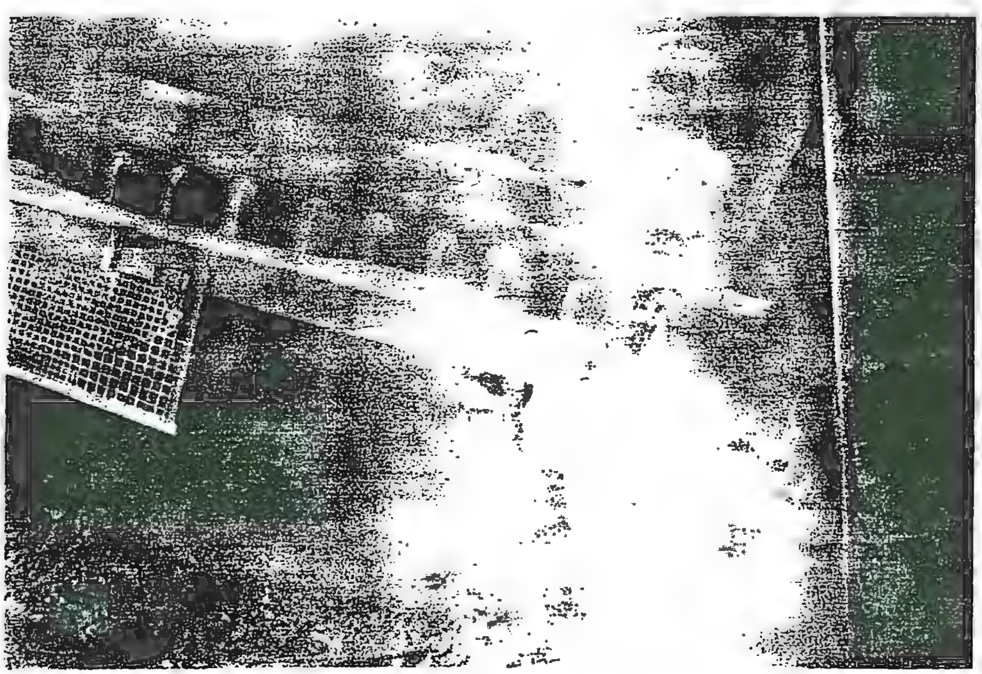


FIGURE 58.- "S" location at the primary crusher-to-belt conveyor #1 transfer point. Dust collection system "off."

and without the dust collection system operating.) Figure 54 shows the test data; they are not definitive, but the "critical exhaust volume" phenomenon does not seem to exist on the sides. Testing could not be conducted at higher exhaust volumes at this #1 transfer point due to limitations on the dust collector's capacity. However, at the secondary crusher to belt conveyor #4 transfer point, discussed next, collector capacity was adequate to explore this phenomenon at much higher exhaust volumes.

5.1.1.3. Results

Based on the detailed discussion so far, the following conclusions can be drawn concerning dust control for the primary crusher-to-belt conveyor #1 transfer point.

1) Reducing exhaust volume below a "critical exhaust volume" drastically reduces dust control efficiency at "E" locations.
2) The efficiency at "S" locations increases smoothly as the exhaust volume increases and a "critical exhaust volume" does not appear to exist in the range of testing.
3) The exhaust volume calculated based on the Anderson approach was adequate for controlling both respirable and total dust emissions at "E" locations (fig. 53).
4) The exhaust volume calculated based on The Industrial Ventilation Manual was inadequate for controlling both the respirable and total dust emissions at "E" locations (fig. 53).

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TABLE 4. - RESPIRABLE DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 6700 cfm, 700 ton/h

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Exhaust Volume - 6700 cfm
Crusher Throughput: 700 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m^3		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System Off	System On	%	°F	%		
7/13/82	E	63.0	0.6	99.0	89	92	7/13/82	
	T	27.4	0.5	98.0				
	S	30.0	10.8	64.0				
7/16/82	E	53.6	3.4	93.6	84	88	7/15/82	
	T	30.2	1.6	94.6				
	S	24.1	7.5	68.9				
7/27/82	E	66.6	1.7	97.5	94	62	7/23/82	
	T	32.3	2.1	93.5				
	S	23.5	5.5	76.6				
8/2/82	E	84.3	0.7	99.2	90	72	7/31/82	Water spray system upstrea of primary crusher off.
	T	8.5	6.5	23.5				
	S	15.4	7.3	52.6				
8/4/82	E	259.9	0.4	99.8	91	60	8/2/82	Same as above
	T	46.3	22.1	52.3				
	S	104.0	24.7	76.2				
8/5/82	E	117.0	0.3	99.7	88	62	8/4/82	Same as above
	T	19.4	7.6	60.8				
	S	63.1	8.4	86.7				

TABLE 4. - RESPIRABLE DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 6700 cfm, 700 ton/h (Con'd)

	SAMPLING LOCATION(1)		
	E	T	S
DUST CONTROL SYSTEM "OFF"			
Arith. Mean Dust Concentration (mg/m^3)(2):	109.0	32.5	43.6
Standard Deviation:	82.2	19.3	39.4
Standard Error:	20.5	5.0	10.9
DUST CONTROL SYSTEM "ON"			
Arith. Mean Dust Concentration (mg/m^3)(2):	1.4	7.3	12.1
Standard Deviation:	1.4	8.5	14.7
Standard Error:	0.4	2.1	4.1
DUST CONTROL SYSTEM PERFORMANCE			
Mean Control System Efficiency (%):	98.7	77.6	72.3
Standard Error:	0.4	7.2	11.6
95% CONFIDENCE LEVELS (APPROXIMATE)			
Control System Off Concentration (X) (mg/m^3):	$65.4 < X < 152.5$	$21.8 < X < 43.1$	$20.0 < X < 67.1$
Control System On Concentration (Y) (mg/m^3):	$0.6 < Y < 2.2$	$2.9 < Y < 11.6$	$3.3 < Y < 20.9$
Control System Performance (E) (mg/m^3):	$97.9 < E < 99.6$	$62.9 < E < 92.4$	$48.3 < E < 96.2$

(1) E - End of the settling box.
T - Tail end of the conveyor.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

TABLE 5. - RESPIRABLE DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 -

6000 cfm, 700 ton/h

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Exhaust Volume - 6000 cfm.
Crusher Throughput: 700 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
6/1/83	E S	78.5 22.3	0.6 6.8	99.2 69.6	71	49	5/29/83	
6/2/83	E S	164.0 74.2	3.6 15.8	97.8 78.7	71	43	5/29/83	Hole in the rubber skirting.
6/3/83	E S	120.5 39.5	2.6 6.6	97.8 83.3	77	47	5/29/83	
6/6/83	E S	135.4 37.9	1.2 6.4	99.1 83.1	81	72	6/5/83	
6/8/83	E S	196.8 32.5	1.6 29.2	99.2 10.2	77	40	6/5/83	
6/10/83	E S	309.6 42.9	14.9 35.7	95.2 16.8	74	45	6/5/83	
6/14/83	E S	84.8 28.5	3.6 20.4	95.7 28.1	90	37	6/5/83	

TABLE 5. - RESPIRABLE DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 6000 cfm, 700 ton/h (Con'd)

	SAMPLING LOCATION[1]	
	E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	163.0	47.0
Standard Deviation:	80.6	31.4
Standard Error:	18.0	7.0
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	4.2	21.3
Standard Deviation:	4.9	19.6
Standard Error:	1.1	4.5
DUST CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	97.4	54.6
Standard Error:	0.7	11.7
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	$125.4 < X < 200.6$	$32.3 < X < 61.6$
Control System On Concentration (Y) (mg/m^3):	$1.9 < Y < 6.5$	$11.9 < Y < 30.7$
Control System Performance (E) (mg/m^3):	$95.9 < E < 98.9$	$30.9 < E < 78.4$

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

TABLE 6. - RESPIRABLE DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 5000 cfm, 700 ton/h

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Exhaust Volume - 5000 cfm
Crusher Throughput: 700 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m^3 System off	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m^3 System on	SYSTEM EFFICIENCY %	TEMP. °F	RELATIVE HUMIDITY %	DATE OF LAST PRECIPITATION	COMMENTS
6/1/83	E	78.5	27.8	64.6	71	49	5/29/83	
	S	22.3	32.5	?(3)				
6/2/83	E	164.0	54.7	66.7	71	43	5/29/83	
	S	74.2	9.7	86.9				
6/3/83	E	120.5	72.5	39.8	77	47	5/29/83	
	S	39.5	16.1	59.5				
6/6/83	E	135.4	19.6	85.5	81	72	6/5/83	
	S	37.9	10.7	71.7				
6/8/83	E	196.8	67.9	65.5	77	40	6/5/83	
	S	32.5	44.4	?				
6/10/83	E	309.6	67.6	78.2	74	45	6/5/83	
	S	42.9	36.4	15.2				
6/14/83	E	84.8	46.6	45.0	90	37	6/5/83	
	S	28.5	25.8	9.2				

TABLE 6. - RESPIRABLE DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 5000 cfm, 700 ton/h (Con'd)

	SAMPLING LOCATION[1]	
	E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	163.0	47.0
Standard Deviation:	80.6	31.4
Standard Error:	18.0	7.0
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	55.4	30.0
Standard Deviation:	26.8	25.4
Standard Error:	6.0	5.8
DUST CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	66.0	36.0
Standard Error:	5.3	15.6
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	$125.4 < X < 200.6$	$32.3 < X < 61.6$
Control System On Concentration (Y) (mg/m^3):	$42.9 < Y < 67.9$	$17.9 < Y < 42.2$
Control System Performance (E) (mg/m^3):	$55.4 < E < 76.6$	$4.4 < E < 67.7$

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

(3) Control System efficiency is not computed because mean concentration with Control System 'off' was lower than mean concentration with Control System 'on'.

TABLE 7. - RESPIRABLE DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 6000 cfm, 1000 ton/h

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Exhaust Volume - 6000 cfm
Crusher Throughput: 1000 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
11/21/83	E	125.8	1.7	98.6	53	65	11/20/83	
	S	18.2	14.0	22.9				
11/22/83	E	43.0	2.1	95.0	50	81	11/20/83	
	S	16.1	9.2	42.8				
11/23/83	E	177.8	3.1	98.3	60	76	11/20/83	Water spray system up-stream of crusher not operating.
	S	15.5	17.1	?(3)				
11/29/83	E	51.0	0.5	99.2	50	67	11/28/83	Same as above
	S	5.4	2.5	53.7				
11/30/83	E	70.8	0.7	99.0	40	75	11/28/83	Same as above
	S	7.8	5.4	30.8				

TABLE 7. - RESPIRABLE DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 6000 cfm, 1000 ton/h (Con'd)

	SAMPLING LOCATION[1]	
	E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	105	13.3
Standard Deviation:	85.2	11.4
Standard Error:	17.8	3.0
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	1.7	11.0
Standard Deviation:	1.1	7.8
Standard Error:	0.3	2.6
DUST CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	98.3	17.4
Standard Error:	0.4	26.8
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	$68.9 < X < 142.4$	$7.0 < X < 19.6$
Control System On Concentration (Y) (mg/m^3):	$1.1 < Y < 2.4$	$5.1 < Y < 16.9$
Control System Performance (E) (mg/m^3):	$97.5 < E < 99.2$	$0.1 < E < 72.7$

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

(3) Control System efficiency is not computed because mean concentration with Control System 'off' was lower than mean concentration with Control System 'on'.

TABLE 8. - RESPIRABLE DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 5400 cfm, 1000 ton/h

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Exhaust Volume - 5400 cfm
Crusher Throughput: 1000 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³ System off	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³ System on	SYSTEM EFFICIENCY %	TEMP. °F	RELATIVE HUMIDITY %	DATE OF LAST PRECIPITATION	COMMENTS
11/21/83	E S	125.8 18.2	57.3 26.0	54.4 ?(3)	53	65	11/20/83	
11/22/83	E S	43.0 16.1	34.8 12.2	19.0 24.2	50	81	11/20/83	
11/23/83	E S	177.8 15.5	58.0 24.9	67.7 ?	60	76	11/20/83	Water spray system upstrea of crusher not operating.
11/29/83	E S	51.0 5.4	4.6 7.2	91.0 ?	50	67	11/28/83	Same as above.
11/30/83	E S	70.8 7.8	8.7 3.9	87.7 50.0	40	75	11/28/83	Same as above.

TABLE 8. - RESPIRABLE DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 5400 cfm, 1000 ton/h (Con'd)

	SAMPLING LOCATION[1]	
	E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	105.7	13.3
Standard Deviation:	85.2	11.4
Standard Error:	17.8	3.0
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	32.7	18.5
Standard Deviation:	27.3	15.7
Standard Error:	7.6	5.5
DUST CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	69.1	?[3]
Standard Error:	8.9	?
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	$68.9 < X < 142.4$	$7.0 < X < 19.6$
Control System On Concentration (Y) (mg/m^3):	$16.3 < Y < 49.1$	$5.7 < Y < 31.2$
Control System Performance (E) (mg/m^3):	$51.1 < E < 87.0$	- < E < -

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

(3) Control System efficiency is not computed because mean concentration with Control System 'off' was lower than the mean concentration with Control System 'on'.

TABLE 9. - RESPIRABLE DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 -

4500 cfm, 1000 ton/h

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Exhaust Volume - 4500 cfm
Crusher Throughput: 1000 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m^3		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
11/21/83	E S	125.8 18.2	65.7 14.0	47.8 23.3	60	54	11/20/83	
11/22/83	E S	43.0 16.1	42.0 11.1	2.2 31.1	64	55	11/20/83	
11/23/83	E S	177.8 15.5	52.5 23.1	70.4 ?(3)	60	67	11/20/83	Water spray system up-stream of crusher not operating.
11/29/83	E S	51.0 5.4	26.8 2.4	47.7 55.6	47	65	11/28/83	Same as above
11/30/83	E S	70.8 7.8	11.1 12.0	84.3 ?	46	60	11/28/83	Same as above

TABLE 9. - RESPIRABLE DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 4500 cfm, 1000 ton/h (Con'd)

	SAMPLING LOCATION[1]	
	E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	105.7	13.3
Standard Deviation:	85.2	11.4
Standard Error:	17.8	3.0
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	42.1	14.2
Standard Deviation:	25.9	9.1
Standard Error:	6.9	3.0
DUST CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	60.2	?[3]
Standard Error:	9.4	?
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	68.9 < X < 142.4	7.0 < X < 19.6
Control System On Concentration (Y) (mg/m^3):	27.2 < Y < 56.9	7.3 < Y < 21.0
Control System Performance (E) (mg/m^3):	41.2 < E < 79.2	- < E < -

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

(3) Control System efficiency is not computed because mean concentration with Control System 'off' was lower than the mean concentration with Control System 'on'.

TABLE 10. - RESPIRABLE DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 4000 cfm, 1000 ton/h

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Exhaust Volume - 4000 cfm.
Crusher Throughput: 1000 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
11/21/83	E	125.8	236.7	?(3)	60	54	11/20/83	
	S	18.2	27.7	?				
11/23/83	E	177.8	106.7	40.0	60	67	11/20/83	Water spray system upstrea of crusher not operating.
	S	15.5	12.7	18.0				
11/29/83	E	51.0	64.3	?	47	65	11/28/83	Same as above
	S	5.4	10.6	?				
11/30/83	E	70.8	23.1	67.4	46	60	11/28/83	Same as above
	S	7.8	3.0	61.5				

TABLE 10. - RESPIRABLE DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 4000 cfm, 1000 ton/h (Con'd)

	SAMPLING LOCATION[1]	
	E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	105.7	13.3
Standard Deviation:	85.2	11.4
Standard Error:	17.8	3.0
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	111.0	14.1
Standard Deviation:	85.8	9.9
Standard Error:	25.9	3.8
DUST CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	?[3]	?
Standard Error:	?	?
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	$68.9 < X < 142.4$	$7.0 < X < 19.6$
Control System On Concentration (Y) (mg/m^3):	$54.0 < Y < 167.9$	$5.3 < Y < 23.0$
Control System Performance (E) (mg/m^3):	- < E < -	- < E < -

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

(3) Control System efficiency is not computed because mean concentration with Control System 'off' was lower than the mean concentration with Control System 'on'.

TABLE 11. - TOTAL DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 -

6700 cfm, 700 ton/h

Control System: Dust Collection
Type of Sampling: Total Dust
Testing Condition: Exhaust Volume - 6700 cfm.
Crusher Throughput: 700 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m^3		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
8/18/82	E	534.1	3.9	99.3	81	42	8/17/82	
	T	61.6	18.2	70.5				
	S	260.9	251.4	3.6				
8/25/82	E	867.6	3.7	99.6	82	78	8/25/82	
	T	143.4	84.7	40.9				
	S	755.5	391.0	48.2				

TABLE 11. - TOTAL DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 6700 cfm, 700 ton/h (Con'd)

	SAMPLING LOCATION(1)		
	E	T	S
DUST CONTROL SYSTEM "OFF"			
Arith. Mean Dust Concentration (mg/m^3)(2):	772.7	126.1	603.5
Standard Deviation:	290.4	92.8	313.6
Standard Error:	129.9	46.4	156.8
DUST CONTROL SYSTEM "ON"			
Arith. Mean Dust Concentration (mg/m^3)(2):	3.9	56.8	332.0
Standard Deviation:	1.0	35.8	102.6
Standard Error:	0.4	16.0	59.2
DUST CONTROL SYSTEM PERFORMANCE			
Mean Control System Efficiency (%):	99.5	55.0	45.0
Standard Error:	0.1	20.9	17.3
95% CONFIDENCE LEVELS (APPROXIMATE)			
Control System Off Concentration (X) (mg/m^3):	$438.4 < X < 1106.7$	$0.1 < X < 254.9$	$168.2 < X < 1038.7$
Control System On Concentration (Y) (mg/m^3):	$2.8 < Y < 5.0$	$15.7 < Y < 97.9$	$143.4 < Y < 520.5$
Control System Performance (E) (mg/m^3):	$99.3 < E < 99.7$	$7.8 < E < 99.9$	$4.0 < E < 86.0$

(1) E - End of the settling box.
T - Tail end of the conveyor.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

TABLE 12. - TOTAL DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 6000 cfm, 700 ton/h

Control System: Dust Collection
Type of Sampling: Total Dust
Testing Condition: Exhaust Volume - 6000 cfm.
Crusher Throughput: 700 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
6/21/83	E	1192.0	1.7	99.9	69	100	6/21/83	System 'off' and System 'on' data are average of two sets.
	S	67.2	30.7	54.3				
6/22/83	E	1870.3	6.3	99.7	79	54	6/21/83	System 'off' and System 'on' data are average of two sets.
	S	231.6	109.6	52.7				

TABLE 12. - TOTAL DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 6000 cfm, 700 ton/h (Con'd)

	SAMPLING LOCATION(1)	
	E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)(2):	1638.2	220.2
Standard Deviation:	787.9	367.6
Standard Error:	237.6	139.0
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)(2):	4.8	87.5
Standard Deviation:	4.3	107.8
Standard Error:	1.3	34.1
DUST CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	99.7	60.3
Standard Error:	0.1	29.5
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	$1115.3 < X < 2161.1$	$0.1 < X < 548.9$
Control System On Concentration (Y) (mg/m^3):	$1.9 < Y < 7.7$	$11.6 < Y < 163.5$
Control System Performance (E) (mg/m^3):	$99.5 < E < 99.9$	$0.1 < E < 99.9$

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

TABLE 13. - TOTAL DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 -

5000 cfm, 700 ton/h

Control System: Dust Collection
Type of Sampling: Total Dust
Testing Condition: Exhaust Volume - 5000 cfm.
Crusher Throughput: 700 tph

DATE	SAMPLING LOCATION[1]	GEOMETRIC MEAN CONCENTRATIONS[2] mg/m^3		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
6/21/83	E S	1192.0 67.2	134.6 242.8	88.7 ?[3]	69	100	6/21/83	System 'off' and System 'on' dat are average of two sets.
6/21/83	E S	1870.3 231.6	72.6 430.0	96.1 ?	79	54	6/21/83	System 'off' and System 'on' data are average of two sets.

TABLE 13. - TOTAL DUST RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 - 5000 cfm, 700 ton/h (Con'd)

	SAMPLING LOCATION(1) E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)(2):	1638.2	220.2
Standard Deviation:	787.9	367.6
Standard Error:	237.6	139.0
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)(2):	125.3	426.0
Standard Deviation:	95.7	322.9
Standard Error:	28.9	107.6
DUST CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	92.4	?(3)
Standard Error:	2.1	?
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	$1115.3 < X < 2161.1$	$0.1 < X < 548.9$
Control System On Concentration (Y) (mg/m^3):	$61.7 < Y < 188.8$	$182.6 < Y < 669.4$
Control System Performance (E) (mg/m^3):	$88.0 < E < 96.7$	$- < E < -$

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

(3) Control System efficiency is not computed because mean concentration with Control System 'off' was lower than the mean concentration with Control System 'on'.

5) Increasing production rate does not necessarily increase dust emissions. In fact, at this transfer point, the dust emissions decreased at a higher production rate.

5.1.2. Secondary Crusher-to-Belt Conveyor #4

The following two approaches were used to establish the upper and lower limits of the exhaust volume in the design of the dust collection system.[3]

1) Anderson 3000 cfm

2) Industrial Ventilation Manual (IVM)

- Non-dusty material 1250 cfm
- Dusty material 3000 cfm

Although the established range of exhaust volumes was between 1250 and 3000 cfm, the dust collection system was designed to operate up to a maximum of 8800 cfm to test the effect of very high exhaust volumes on control at "S" and "T" locations. No testing was conducted at exhaust volumes below 2500 cfm because dust emissions below that exhaust volume did not appear visually to be controlled.

The average secondary crusher throughput until September 1983 was approximately 675 ton/h. A new crushing circuit added to the existing facilities in September 1983 decreased the secondary crusher throughput to approximately 300 ton/h. To determine the control system's performance under the new throughput, additional respirable dust sampling was conducted. Table 14 summarizes the test data under various conditions while Tables 15 through 22 show summaries of test data for individual

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3 Detailed calculations are shown in Appendix B.

TABLE 14. - SUMMARY OF TEST RESULTS AT SECONDARY CRUSHER-TO-BELT CONVEYOR #4

CONTROL SYSTEM: Dust Collection

TEST CONDITION	TIME PERIOD	SAMPLING LOCATIONS (1)									REFERENCE TABLES
		E			T			S			
		ARITH. MEAN DUST CONC.(2) SYS. OFF	EFFICIENCY MEAN	EFFICIENCY STANDARD ERROR	ARITH. MEAN DUST CONC.(2) SYS. OFF	EFFICIENCY MEAN	EFFICIENCY STANDARD ERROR	ARITH. MEAN DUST CONC.(2) SYS. OFF	EFFICIENCY MEAN	EFFICIENCY STANDARD ERROR	
		mg/m^3	%	%	mg/m^3	%	%	mg/m^3	%	%	
RESPIRABLE DUST											
Crusher throughput: 675 tph											
8800 cfm	08/82	592.3	98.8	0.4	75.2	91.5	3.7	74.5	89.1	4.9	15
6000 cfm	06/83	537.5	99.4	0.2	--	--	--	19.0	78.6	7.4	16
3000 cfm	06/83	537.5	99.3	0.2	--	--	--	19.0	68.3	10.4	18
Crusher throughput: 300 tph											
4500 cfm	12/83	62.7	96.9	0.9	--	--	--	7.9	58.4	14.8	17
2500 cfm	12/83	62.7	74.6	11.3	--	--	--	7.9	35.3	21.8	19
TOTAL DUST											
Crusher throughput: 675 tph											
8800 cfm	08/82	2043.6	86.8	4.8	676.4	90.7	3.7	1944.0	83.6	5.1	20
6000 cfm	06/83	5093.6	99.0	0.4	--	--	--	789.2	87.0	5.1	21
3000 cfm	06/83	5093.6	97.9	0.8	--	--	--	789.2	77.0	8.2	22

(1) E - End of the settling box.
T - Tail end of the conveyor.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

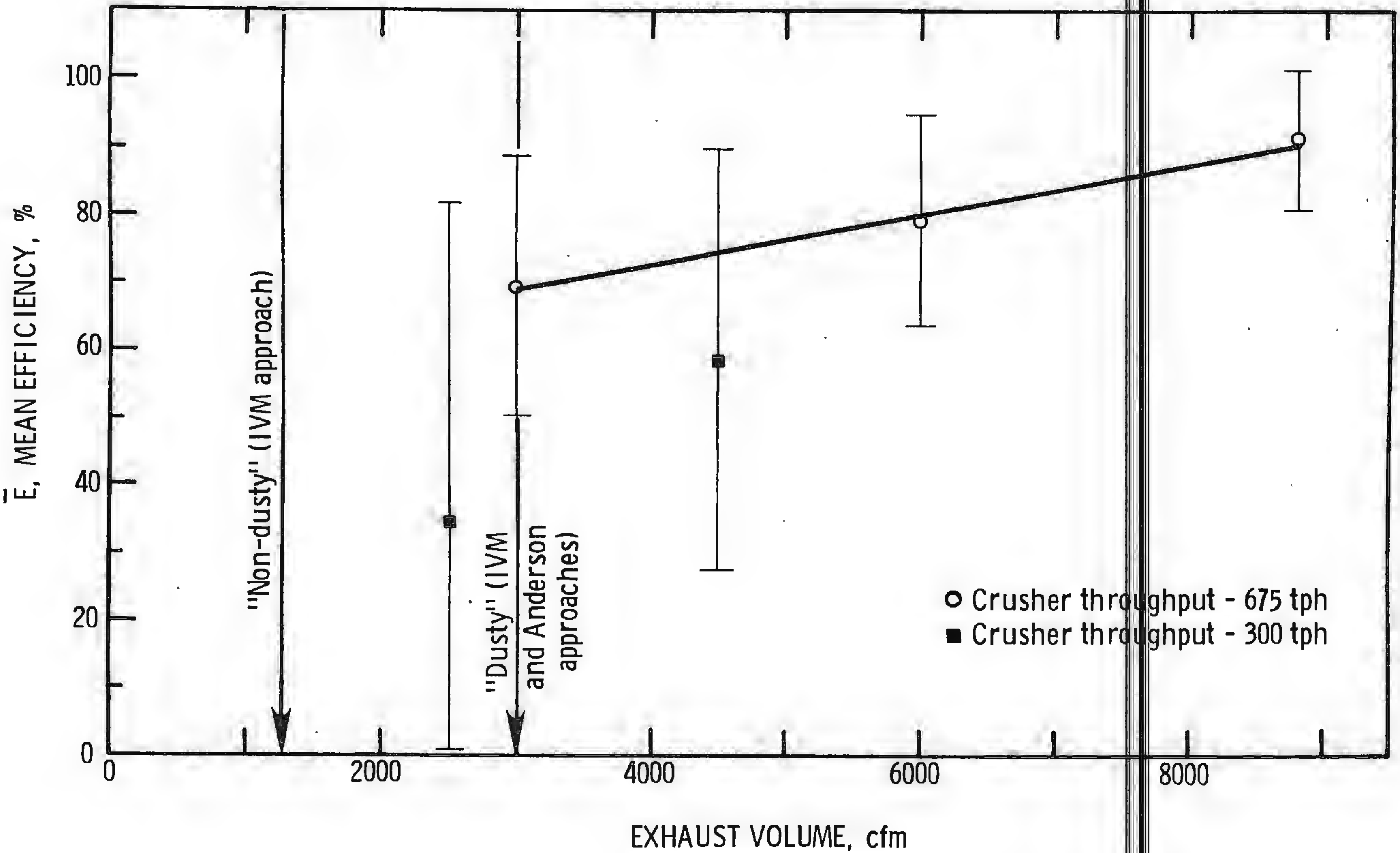

FIGURE 60.- Effect of exhaust volume on dust control efficiency at "S" locations for the secondary crusher-to-belt conveyor #4 transfer point. Type of sampling - respirable dust.

5) As indicated for the primary crusher-to-belt conveyor #1 transfer point, the scatter in dust control efficiencies at "S" and "T" locations was much greater than at "E" locations.

6) To indicate the reliability of the control system on a day-to-day basis, the data of Table 18 are plotted in figure 61. The figure shows that the control system is more reliable and efficient at "E" locations than at "S" locations.

7) With the control system "off," the mean dust concentrations for respirable as well as total dust were generally much higher than those for the primary crusher, at all locations. This may be due to the higher amount of new surface area produced per ton of material by the secondary crusher.

8) At "S" locations, the mean respirable and total dust concentrations with the control system "off" decreased from 74.5 mg/m^3 to 19.0 mg/m^3, and from 1944.0 mg/m^3 to 789.2 mg/m^3, respectively, between 1982 and 1983. We believe that such a drastic reduction in dust concentrations at these locations was due to the installation of rockboxes at the transfer point in December 1982.

9) At the higher production rate (675 tph) and a 3000-cfm exhaust volume, mean control efficiency was 99.3% while at the lower production rate (300 tph) and a higher exhaust volume (4500 cfm), the efficiency for respirable dust was 96.9%. This difference occurred because the control efficiency is a nonlinear function of uncontrolled dust emissions. This can be seen

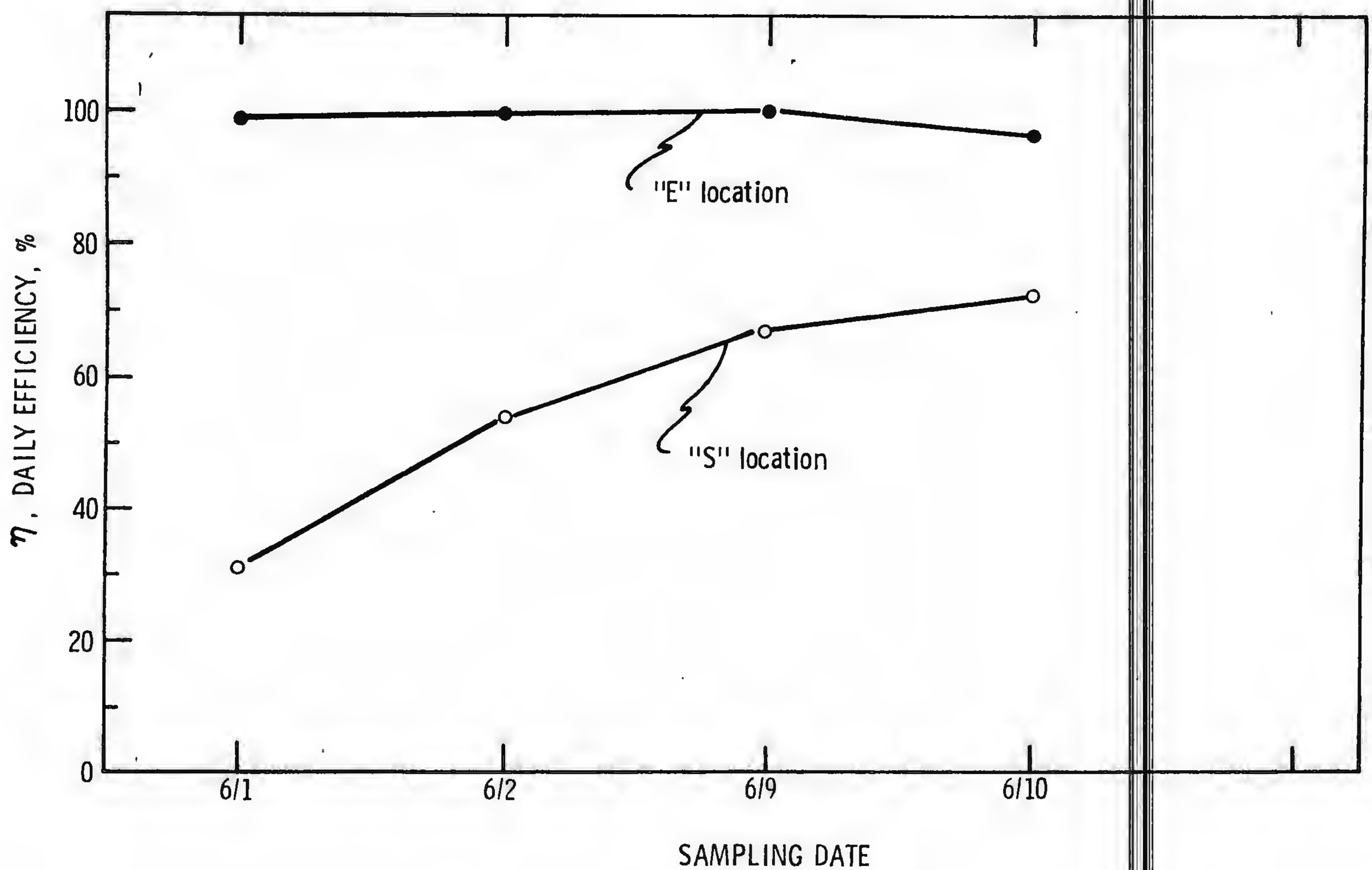

FIGURE 61.- Day-to-day variation in efficiency of dust control system at the secondary crusher-to-belt conveyor #4 transfer point. Testing condition - 3000 cfm, type of sampling - respirable dust.

from the data in summary Table 14: mean respirable dust concentrations at "E" locations with the dust collection system "off" were 62.7 mg/m^3 in December 1983, compared to 537.5 mg/m^3 6 months earlier.

5.1.2.1. Results

Based on the detailed discussion, the following conclusions can be drawn concerning dust control for the secondary crusher-to-belt conveyor #4 transfer point.

1) Reducing exhaust volume below a "critical exhaust volume" significantly reduces dust control efficiency at "E" locations.
2) The efficiency at "S" locations increases smoothly with exhaust volume up to 3 times that recommended by Anderson, indicating that there is no "critical exhaust volume" at "S" locations, at least in the range of practical importance.
3) The exhaust volumes calculated by the Anderson approach and by the Industrial Ventilation Manual for dusty material (identical in this case) are adequate to control both the respirable and total dust emissions.
4) The exhaust volume calculated by the Industrial Ventilation Manual approach for non-dusty material is inadequate to control both the respirable and total dust emissions.

TABLE 15. - RESPIRABLE DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT CONVEYOR #4 - 8800 cfm, 675 ton/h

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Exhaust Volume - 8800 cfm.
Crusher Throughput: 675 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m^3		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
7/12/82	E	313.2	2.4	99.3	82	89	7/9/82	
	T	6.5	0.9	86.2				
	S	1.9	1.4	26.3				
7/15/82	E	380.7	1.4	99.6	89	83	7/14/82	
	T	21.7	1.9	91.3				
	S	13.7	3.0	78.1				
7/21/82	E	-	3.8	-	76	65	7/20/82	
	T	-	2.2	-				
	S	-	6.7	-				
7/22/82	E	601.7	-	-	74	74	7/20/82	
	T	48.0	-	-				
	S	27.6	-	-				
7/26/82	E	2021.2	31.8	98.5	92	63	7/23/82	Primary dust collector as well as wet suppresion system down.
	T	202.9	9.1	95.5				
	S	65.7	4.8	92.7				
7/27/82	E	288.9	4.7	98.4	94	62	7/23/82	
	T	43.0	4.1	90.5				
	S	25.6	5.7	77.7				
8/2/82	E	59.3	1.8	97.0	90	72	7/31/82	Same as above
	T	12.0	2.3	80.8				
	S	-	-	-				
8/4/82	E	123.9	8.9	92.8	91	60	8/2/82	Same as above
	T	33.8	13.7	59.4				
	S	42.5	5.4	87.3				
8/5/82	E	983.3	1.1	99.9	88	62	8/4/82	Same as above
	T	132.6	1.9	98.6				
	S	77.3	4.1	94.7				
8/26/82	E	677.6	16.5	97.6	75	68	8/25/82	Same as above
	T	53.2	19.4	63.5				
	S	124.1	16.0	87.1				

TABLE 15. - RESPIRABLE DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT #4 - 8800 cfm, 675 ton/h (Con'd)

	SAMPLING LOCATION(1)		
	E	T	S
DUST CONTROL SYSTEM "OFF"			
Arith. Mean Dust Concentration (mg/m^3)(2):	592.3	75.2	74
Standard Deviation:	559.1	139.6	101.4
Standard Error:	119.2	29.1	26.2
DUST CONTROL SYSTEM "ON"			
Arith. Mean Dust Concentration (mg/m^3)(2):	7.4	6.4	8
Standard Deviation:	9.1	6.4	8.8
Standard Error:	1.9	1.2	2.3
DUST CONTROL SYSTEM PERFORMANCE			
Mean Control System Efficiency (%):	98.8	91.5	89.1
Standard Error:	0.4	3.7	4.9
95% CONFIDENCE LEVELS (APPROXIMATE)			
Control System Off Concentration (X) (mg/m^3):	$345.1 < X < 839.5$	$15.0 < X < 135.4$	$18.8 < X < 130.3$
Control System On Concentration (Y) (mg/m^3):	$3.5 < Y < 11.2$	$3.8 < Y < 8.9$	$3.3 < Y < 12.9$
Control System Performance (E) (mg/m^3):	$97.9 < E < 99.6$	$84.1 < E < 98.9$	$79.2 < E < 99.1$

(1) E - End of the settling box.
T - Tail end of the conveyor.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

TABLE 16. - RESPIRABLE DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT #4 -

6000 cfm, 675 ton/h

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Exhaust Volume - 6000 cfm
Crusher Throughput: 675 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m^3		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
6/1/83	E	458.4	0.7	99.8	85	46	5/29/83	
	S	4.4	1.9	56.8				
6/2/83	E	1006.1	6.6	99.3	71	49	5/29/83	
	S	13.1	2.6	80.4				
6/8/83	E	-	2.4	-	77	40	6/5/83	
	S	-	8.8	-				
6/9/83	E	561.2	1.7	99.7	71	57	6/5/83	High production rate. System 'off' data are average of two sets.
	S	28.6	3.2	88.8				
6/10/83	E	156.4	1.0	99.4	74	45	6/5/83	High production rate
	S	8.5	2.6	69.4				

TABLE 16. - RESPIRABLE DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT #4 - 6000 cfm, 675 ton/h (Con'd)

	SAMPLING LOCATION(1)	
	E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)(2):	537.5	19.0
Standard Deviation:	416.1	19.7
Standard Error:	115.4	5.3
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)(2):	3.0	4.1
Standard Deviation:	4.3	3.1
Standard Error:	1.1	0.8
DUST CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	99.4	78.6
Standard Error:	0.2	7.4
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	$288.2 < X < 786.7$	$7.7 < X < 30.3$
Control System On Concentration (Y) (mg/m^3):	$0.5 < Y < 5.4$	$2.3 < Y < 5.9$
Control System Performance (E) (%):	$98.9 < E < 99.9$	$63.5 < E < 93.8$

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

TABLE 17. - RESPIRABLE DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT CONVEYOR #4 - 4500 cfm, 300 ton/h

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Exhaust Volume - 4500 cfm.
Crusher Throughput: 300 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m^3		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
12/1/83	E	83.5	1.3	98.4	64	68	11/28/83	System 'off' and 'on' data are average of two sets.
	S	4.8	1.0	79.2				
12/2/83	E	40.4	1.6	96.0	39	69	11/28/83	System 'off' and 'on' data are average of two sets.
	S	4.0	1.5	62.5				
12/5/83	E	46.3	1.9	95.9	42	94	12/4/83	
	S	12.6	7.1	43.8				

TABLE 17. - RESPIRABLE DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT CONVEYOR #4 - 4500 cfm, 300 ton/h (Con'd)

	SAMPLING LOCATION(1)	
	E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)(2):	62.7	7.9
Standard Deviation:	40.2	6.1
Standard Error:	10.8	1.6
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)(2):	2.0	3.3
Standard Deviation:	1.5	3.3
Standard Error:	0.4	0.9
DUST CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	96.9	58.4
Standard Error:	0.9	14.8
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	$39.6 < X < 85.7$	$4.4 < X < 11.3$
Control System On Concentration (Y) (mg/m^3):	$1.0 < Y < 2.9$	$1.2 < Y < 5.3$
Control System Performance (E) (mg/m^3):	$95.1 < E < 98.6$	$28.1 < E < 88.8$

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

TABLE 18. - RESPIRABLE DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT CONVEYOR #4 - 3000 cfm, 675 ton/h

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Exhaust Volume - 3000 cfm.
Crusher Throughput: 675 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³ System off	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³ System on	SYSTEM EFFICIENCY %	TEMP. °F	RELATIVE HUMIDITY %	DATE OF LAST PRECIPITATION	COMMENTS
6/1/83	E	458.4	4.9	98.9	85	46	5/29/83	
	S	4.4	3.1	30.7				
6/2/83	E	1006.1	5.3	99.4	71	49	5/29/83	
	S	13.1	6.1	53.9				
6/8/83	E	-	2.4	-	77	40	6/5/83	
	S	-	6.1	-				
6/9/83	E	561.2	4.2	99.3	71	57	6/5/83	High production rate. System 'off' data are average of two sets.
	S	28.6	9.2	67.8				
6/10/83	E	156.4	2.6	98.3	74	45	6/5/83	High production rate
	S	8.5	2.3	72.9				

TABLE 18. - RESPIRABLE DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT CONVEYOR #4 - 3000 cfm, 675 ton/h (Con'd)

	SAMPLING LOCATION[1]	
	E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	537.5	19.0
Standard Deviation:	416.1	19.7
Standard Error:	115.4	5.3
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	4.0	6.0
Standard Deviation:	1.5	3.9
Standard Error:	0.4	1.0
DUST CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	99.3	68.3
Standard Error:	0.2	10.4
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	$288.2 < X < 786.7$	$7.7 < X < 30.3$
Control System On Concentration (Y) (mg/m^3):	$3.1 < Y < 4.9$	$3.8 < Y < 8.3$
Control System Performance (E) (mg/m^3):	$98.9 < E < 99.6$	$47.1 < E < 89.5$

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

TABLE 19. - RESPIRABLE DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT CONVEYOR #4 -

2500 cfm, 300 ton/h

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Exhaust Volume - 2500 cfm.
Crusher Throughput: 300 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m^3		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
12/1/83	E S	83.5 4.8	25.0 2.2	70.0 54.2	41	64	11/28/83	System 'off' an 'on' data are average of two sets.
12/2/83	E S	40.4 4.0	2.6 3.3	93.6 17.5	39	69	11/28/83	System 'off' an 'on' data are average of two sets.
12/5/83	E S	46.3 12.6	3.1 8.7	93.3 31.1	42	94	12/4/83	

TABLE 19. - RESPIRABLE DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT CONVEYOR #4 - 2500 cfm, 300 ton/h (Con'd)

	SAMPLING LOCATION(1)	
	E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)(2):	62.7	7.9
Standard Deviation:	40.2	6.1
Standard Error:	10.8	1.6
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)(2):	15.9	5.1
Standard Deviation:	23.5	5.1
Standard Error:	6.5	1.4
DUST CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	74.6	35.3
Standard Error:	11.3	21.8
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	$39.6 < X < 85.7$	$4.4 < X < 11.3$
Control System On Concentration (Y) (mg/m^3):	$1.9 < Y < 30.0$	$2.2 < Y < 8.0$
Control System Performance (E) (mg/m^3):	$51.4 < E < 97.7$	$0.1 < E < 80.1$

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

TABLE 20. - TOTAL DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT CONVEYOR #4 - 8800 cfm, 675 ton/h

Control System: Dust Collection
Type of Sampling: Total Dust
Testing Condition: Exhaust Volume - 8800 cfm.
Crusher Throughput: 675 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
8/18/82	E	1562.5	218.2	86.0	81	42	8/17/82	
	T	622.5	27.0	95.7				
	S	1356.2	321.0	76.3				
8/19/82	E	172.7	184.1	?(3)	77	48	8/17/82	Water spray system upstream of the primary crusher was off.
	T	246.6	19.4	92.1				
	S	759.4	224.3	70.5				
8/26/82	E	3888.6	323.4	91.7	74	68	8/25/82	Same as above
	T	1052.3	108.1	89.7				
	S	2991.4	318.0	89.4				

TABLE 20. - TOTAL DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT CONVEYOR #4 - 8800 cfm, 675 ton/h (Con'd)

	SAMPLING LOCATION(1) E	T	S
DUST CONTROL SYSTEM "OFF"			
Arith. Mean Dust Concentration (mg/m^3)(2):	2043.6	676.4	1944.0
Standard Deviation:	1761.4	415.4	1184.1
Standard Error:	622.7	146.9	483.4
DUST CONTROL SYSTEM "ON"			
Arith. Mean Dust Concentration (mg/m^3)(2):	269.0	62.8	317.9
Standard Deviation:	149.3	52.3	149.3
Standard Error:	52.8	21.4	60.9
DUST CONTROL SYSTEM PERFORMANCE			
Mean Control System Efficiency (%)"	86.8	90.7	83.6
Standard Error:	4.8	3.7	5.1
95% CONFIDENCE LEVELS (APPROXIMATE)			
Control System Off Concentration (X) (mg/m^3):	$607.9 < X < 3479.7$	$337.7 < X < 1015.1$	$761.2 < X < 3126.9$
Control System On Concentration (Y) (mg/m^3):	$147.2 < Y < 390.7$	$10.6 < Y < 115.1$	$168.8 < Y < 467.0$
Control System Performance (E) (mg/m^3):	$76.7 < E < 97.0$	$82.7 < E < 98.7$	$72.5 < E < 94.8$

(1) E - End of the settling box.
T - Tail end of the conveyor.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

(3) Control System efficiency is not computed because mean concentration with Control System 'off' was lower than mean concentration with Control System 'on'.

TABLE 21. - TOTAL DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT CONVEYOR #4 - 6000 cfm, 675 ton/h

Control System: Dust Collection
Type of Sampling: Total Dust
Testing Condition: Exhaust Volume - 6000 cfm.
Crusher Throughput: 675 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m^3		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
6/21/83	E S	3805.9 170.9	1.5 28.7	99.9 83.2	69	100	6/21/83	System 'off' and 'on' data are average of two sets.
6/22/83	E S	5153.2 805.0	75.0 128.7	98.6 84.0	79	54	6/21/83	System 'off' and 'on' data are average of two sets.

TABLE 21. - TOTAL DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT CONVEYOR #4 - 6000 cfm, 675 ton/h (Con'd)

	SAMPLING LOCATION(1)	
	E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)(2):	5093.6	789.2
Standard Deviation:	1722.1	737.4
Standard Error:	519.2	222.3
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)(2):	48.6	102.9
Standard Deviation:	64.8	87.9
Standard Error:	20.5	27.8
DUST CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	99.0	87.0
Standard Error:	0.4	5.1
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	$3950.8 < X < 6236.4$	$299.9 < X < 1278.5$
Control System On Concentration (Y) (mg/m^3):	$3.0 < Y < 94.2$	$41.0 < Y < 164.8$
Control System Performance (E) (mg/m^3):	$98.2 < E < 99.9$	$76.4 < E < 97.5$

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

TABLE 22. - TOTAL DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT CONVEYOR #4 -

3000 cfm, 675 ton/h

Control System: Dust Collection
Type of Sampling: Total Dust
Testing Condition: Exhaust Volume - 3000 cfm.
Crusher Throughput: 675 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m^3		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
6/21/83	E	3805.9	5.5	99.9	69	100	6/21/83	System 'off' and 'on' data are average of two sets.
	S	170.9	66.6	61.0				
6/22/83	E	5153.2	135.7	97.4	79	54	6/21/83	System 'off' and 'on' data are average of two sets.
	S	805.0	227.1	71.8				

TABLE 22. - TOTAL DUST RESULTS FOR SECONDARY CRUSHER-TO-BELT CONVEYOR #4 - 3000 cfm, 675 ton/h (Con'd)

	SAMPLING LOCATION[1]	
	E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	5093.6	789.2
Standard Deviation:	1722.1	737.4
Standard Error:	519.2	222.3
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)[2]:	105.9	181.5
Standard Deviation:	129.2	131.4
Standard Error:	40.9	39.6
DUST CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	97.9	77.0
Standard Error:	0.8	8.2
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	$3950.8 < X < 6236.4$	$299.9 < X < 1278.5$
Control System On Concentration (Y) (mg/m^3):	$14.9 < Y < 197.0$	$94.3 < Y < 268.7$
Control System Performance (E) (mg/m^3):	$96.2 < E < 99.6$	$60.0 < E < 94.0$

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

5) The efficiency of the control system may depend not only on the exhaust volume but also on dust emissions with the dust collection system "off."

Figures 62 and 63 show an "E" location, with and without the control system, for the secondary crusher-to-belt conveyor #4 transfer point. Figure 64 shows an "S" location with the exhaust system operating.

5.1.3. Conveyor Belt #7-to-Conveyor Belt #8

The following three approaches were used to establish the upper and lower limits for the exhaust volume in the design of the dust collection system.[4]

1)	Anderson	1400 cfm
2)	Morrison	2950 cfm
3)	Industrial Ventilation Manual (IVM)	
	- Non-dusty material	2000 cfm
	- Dusty material	4700 cfm.

Based on our past experience, we believed that some of these exhaust volumes were overestimates; therefore, the dust collection system was arbitrarily designed to operate at a maximum exhaust volume of 2400 cfm.

Table 23 summarizes the test data under various conditions. Tables 24 through 26 present summaries of test data for individual test conditions. The following discussions are based on Table 23 unless otherwise noted:

1) The mean respirable dust concentrations at all locations with the dust collection system "off" ranged from only 4.4 to 16.5 mg/m^3. Concentrations were low at this transfer point because

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[4] Detailed calculations are shown in Appendix B.

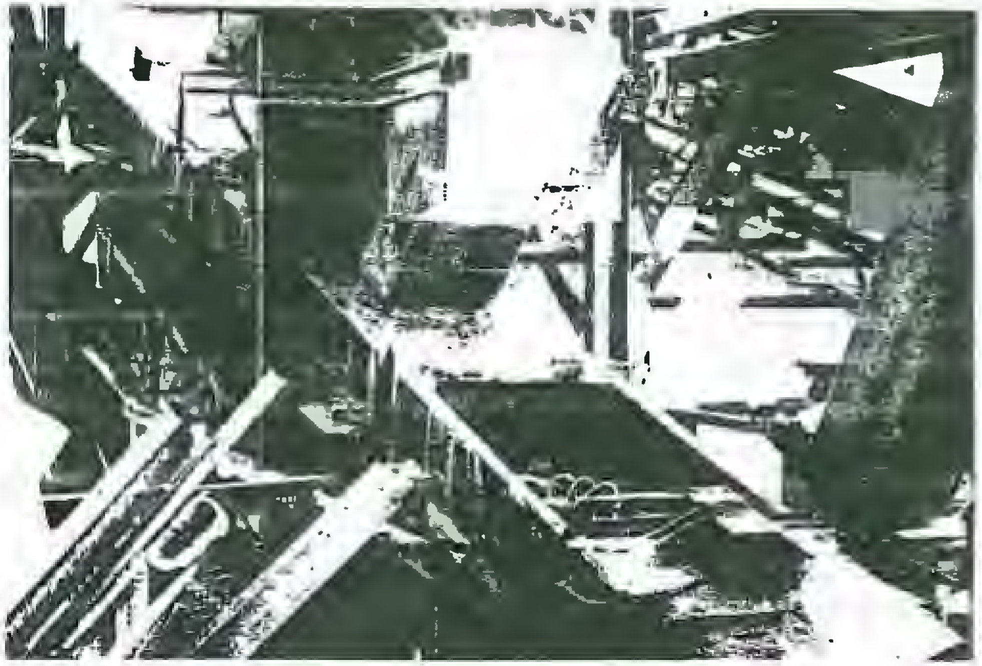

FIGURE 62.- "E" location at the secondary crusher-to-belt conveyor #4 transfer point. Dust collection system "on."

FIGURE 63.- "E" location at the secondary crusher-to-belt conveyor #4 transfer point. Dust collection system "off."

FIGURE 64.- "S" location at the secondary crusher-to-belt conveyor #4 transfer point. Dust collection system "on."

TABLE 23. - SUMMARY OF TEST RESULTS AT BELT CONVEYOR #7-TO-BELT CONVEYOR #8

CONTROL SYSTEM: Dust Collection

TEST CONDITION	TIME PERIOD	SAMPLING LOCATIONS[1]									REFERENCE TABLES
		E			T			S			
		ARITH. MEAN DUST CONC.[2] SYS. OFF	EFFICIENCY		ARITH. MEAN DUST CONC.[2] SYS. OFF	EFFICIENCY		ARITH. MEAN DUST CONC.[2] SYS. OFF	EFFICIENCY		
			MEAN	STANDARD ERRORS		MEAN	STANDARD ERRORS		MEAN	STANDARD ERRORS	
		mg/m^3	%	%	mg/m^3	%	%	mg/m^3	%	%	
					RESPIRABLE DUST						
2400 cfm	7-8/82	13.4	94.1	1.1	20.8	97.2	0.5	16.5	92.5	2.1	24
2400 cfm	06/83	12.8	86.0	5.5	—	—	—	4.4	60.1	21.5	25
1750 cfm	06/83	12.8	74.5[3]	—	—	—	—	4.4	5.3[3]	—	25
900 cfm	06/83	12.8	67.3[3]	—	—	—	—	4.4	47.4[3]	—	25
					TOTAL DUST						
2400 cfm	08/82	162.7	88.0	1.9	198.4	94.4	1.8	140.6	87.7	7.0	26

(1) E - End of the settling box.
T - Tail end of the conveyor.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

(3) Data based on one test set.

no new surfaces were created, and the transfer of bulk material from belt conveyor #7-to-belt conveyor #8 was very gradual and smooth (due to multiple rockboxes).

2) At 2400 cfm, the respirable dust control efficiencies at all locations were over 90%, and the mean dust concentrations at the three locations with the dust collection system "on" were less than 1.5 mg/m^3.

3) Dust control efficiencies for total dust ranged from 87.7% to 94.4%; mean total dust concentrations with the control system "on" ranged from 11.1 to 19.5 mg/m^3 at all locations.

Plans to conduct additional tests for other exhaust volumes were cancelled when, due to process modifications at the plant, conveyor belt #8 was taken out of the circuit and conveyor belt #7 discharge was diverted to conveyor belt #4. Consequently, only one set of data could be obtained at different exhaust volumes. These very limited data indicated that:

1) Only a marginal improvement in dust control efficiency was obtained at "E" locations when exhaust volume was increased from 900 cfm to 2400 cfm.

2) The dust emission data at "S" locations were too erratic to provide a basis for any conclusions.

5.1.3.1. Results

1) The dust sealing system and multiple rockbox design used at this transfer point were mainly responsible for the reduction in dust generation.

2) Exhaust volumes recommended by the Industrial Ventilation Manual for dusty material (4700 cfm) and those calculated using Morrison's approach (2950 cfm) seem to be overestimates. The data show that 2400 cfm is adequate to control both respirable and total dust emissions. Although the IVM calls for an exhaust hood at the head box of conveyor belt #7, we believe that a hood at this location is unnecessary. The large chute allows the induced air to travel down with the material, and a hood at this point would unnecessarily exhaust ambient air.

3) Due to process modifications, we could not rigorously test the performance of the dust collection system at the exhaust volumes recommended by Anderson, or the IVM for "non-dusty" material. However, our limited visual observations and test data showed good promise for those two approaches.

TABLE 24. - RESPIRABLE DUST RESULTS FOR BELT CONVEYOR #7-TO-BELT CONVEYOR #8 - 2400 cfm

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Exhaust Volume - 2400 cfm.

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m^3		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
7/15/82	E	7.6	0.6	92.1	89	83	7/14/82	
	T	14.4	0.4	97.2				
	S	7.5	0.9	88.0				
7/21/82	E	----	0.4	----	76	65	7/20/83	
	T	----	0.6	----				
	S	----	0.6	----				
7/22/82	E	21.2	----	----	74	74	7/20/82	Primary dust collector off
	T	21.2	----	----				
	S	8.5	----	----				
7/26/82	E	17.4	1.4	92.0	93	63	7/23/82	Primary dust collector off
	T	14.8	0.5	96.6				
	S	21.5	1.5	93.4				
7/27/82	E	3.8	0.4	89.5	94	62	7/23/82	
	T	11.2	0.4	96.4				
	S	9.2	0.5	94.6				
8/4/82	E	19.9	1.3	93.3	91	60	8/2/82	Wet suppression system off
	T	16.4	1.0	93.9				
	S	23.5	4.2	82.1				
8/5/82	E	11.5	0.6	94.3	88	62	8/4/82	Wet suppression system off
	T	35.0	0.4	98.9				
	S	27.3	1.1	96.0				

TABLE 24. - RESPIRABLE DUST RESULTS FOR BELT CONVEYOR #7-TO-BELT CONVEYOR #8 - 2400 cfm (Con'd)

	SAMPLING LOCATION[1]		
	E	T	S
DUST CONTROL SYSTEM "OFF"			
Arith. Mean Dust Concentration (mg/m^3)[2]:	13.4	20.8	16.5
Standard Deviation:	7.2	11.6	8.2
Standard Error:	1.8	3.0	2.5
DUST CONTROL SYSTEM "ON"			
Arith. Mean Dust Concentration (mg/m^3)[2]:	0.8	0.6	1
Standard Deviation:	0.4	0.3	1.0
Standard Error:	0.1	0.1	0.3
DUST CONTROL SYSTEM PERFORMANCE			
Mean Control System Efficiency (%):	94.1	97.2	92.5
Standard Error:	1.1	0.5	2.1
95% CONFIDENCE LEVELS (APPROXIMATE)			
Control System Off Concentration (X) (mg/m^3):	9.6< X < 17.2	14.4< X < 27.2	11.0< X < 2
Control System On Concentration (Y) (mg/m^3):	0.6< Y < 1.0	0.4< Y < 0.7	0.6< X < 1
Control System Performance (E) (mg/m^3):	91.9< E < 96.4	96.1< E < 98.3	88.1< X < 9

(1) E - End of the settling box.
T - Tail end of the conveyor.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

TABLE 25. - RESPIRABLE DUST RESULTS FOR BELT CONVEYOR #7-TO-BELT CONVEYOR #8 - 900, 1750, 2400 cfm

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Set 1: Q1 = 900 cfm. (3)
Set 2: Q1 = 1750 cfm.
Set 3: Q1 = 2400 cfm.

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³ System off	System on Set 1	System on Set 2	System on Set 3	SYSTEM EFFICIENCY % Set 1	Set 2	Set 3	TEMP. °F	RELATIVE HUMIDITY %	DATE OF LAST PRECIPITATION	COMMENTS
6/24/83	E	17.8	---	---	2.0	---	---	88.8	85	57		
	S	6.8	---	---	0.8	---	---	88.2				
6/27/83	E	5.5	1.8	1.4	1.3	67.3	74.5	76.4	97	45		
	S	1.9	1.0	1.8	1.6	47.4	5.3	15.8				

TABLE 25. - RESPIRABLE DUST RESULTS FOR BELT CONVEYOR #7-TO-BELT CONVEYOR #8 (Con'd)

	SAMPLING LOCATION(1)	
	E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)(2):	12.8	4.4
Standard Deviation:	9.6	2.5
Standard Error:	4.3	1.5
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)(2):	1.8	1.8
Standard Deviation:	0.8	1.3
Standard Error:	0.4	0.7
DUST CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	86.0	60.1
Standard Error:	5.5	21.5
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	$1.8 < X < 23.8$	$0.1 < X < 9.1$
Control System On Concentration (Y) (mg/m^3):	$0.7 < Y < 2.8$	$0.1 < Y < 4.1$
Control System Performance (E) (mg/m^3):	$73.5 < E < 98.5$	$7.6 < E < 99.9$

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

(3) Q_e = Exhaust Volume Rate

TABLE 26. - TOTAL DUST RESULTS FOR BELT CONVEYOR #7-TO-BELT CONVEYOR #8 - 2400 cfm

Control System: Dust Collection
Type of Sampling: Total Dust
Testing Condition: Exhaust Volume - 2400 cfm.

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
8/19/82	E	125.5	19.6	84.4	77	48	8/17/82	Wet suppression system was down
	S	6.2	5.2	16.1				
	T	124.0	5.0	96.0				
8/25/82	E	181.1	19.4	89.3	82	78	8/25/82	Very windy, wet suppression system was down.
	S	201.2	23.1	88.5				
	T	261.3	15.5	94.1				

TABLE 26. - TOTAL DUST RESULTS FOR BELT CONVEYOR #7-TO-BELT CONVEYOR #8 - 2400 cfm (Con'd)

	SAMPLING LOCATION(1)		
	E	T	S
DUST CONTROL SYSTEM "OFF"			
Arith. Mean Dust Concentration (mg/m³)(2):	162.7	198.4 mg/m³	140.6
Standard Deviation:	55.5	84.0 mg/m³	133.1
Standard Error:	24.8	37.6 mg/m³	66.6
DUST CONTROL SYSTEM "ON"			
Arith. Mean Dust Concentration (mg/m³)(2):	19.5	11.1 mg/m³	17.3
Standard Deviation:	0.7	6.2 mg/m³	10.9
Standard Error:	0.4	2.8 mg/m³	5.5
DUST CONTROL SYSTEM PERFORMANCE			
Mean Control System Efficiency (%):	88.0	94.4%	87.7
Standard Error:	1.9	1.8%	7.0
95% CONFIDENCE LEVELS (APPROXIMATE)			
Control System Off Concentration (X) (mg/m³):	98.9< X < 226.5	101.8< X < 295.2	0.1< X < 325.4
Control System On Concentration (Y) (mg/m³):	18.2< Y < 20.9	3.9< Y < 18.3	2.1< X < 32.5
Control System Performance (E) (mg/m³):	83.7< E < 92.3	90.5< E < 98.3	71.6< X < 99.9

(1) E - End of the settling box.
T - Tail end of the conveyor.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

5.1.4. Vibrating Screen #2 Circuit

The vibrating screen circuit consists of the following transfer points (fig. 65):

1) Belt conveyor #4-to-vibrating screen #2
2) Vibrating screen #2-to-belt conveyor #5
3) Vibrating screen #2-to-storage bin #1
4) Vibrating screen #2-to-storage bin #5.

To evaluate the performance of the dust control system, data were first obtained with dust control system "off" and then with the system "on" for different exhaust volumes. The following two approaches were used to establish the upper and lower limits of the exhaust volume in the design of the dust collection system.[5]

Industrial Ventilation Manual

- At vibrating screen #2	4200 cfm
- Vibrating screen #2-to-belt conveyor #5	
Non-dusty material	1250 cfm
Dusty material	3200 cfm
- Vibrating screen #2-to-storage bin #1	850 cfm
- Vibrating screen #2-to-storage bin #5	850 cfm
- Conveyor belt #4 head box	
Non-dusty material	1250 cfm
Dusty material	2500 cfm

[5] Detailed calculations are shown in Appendix B.

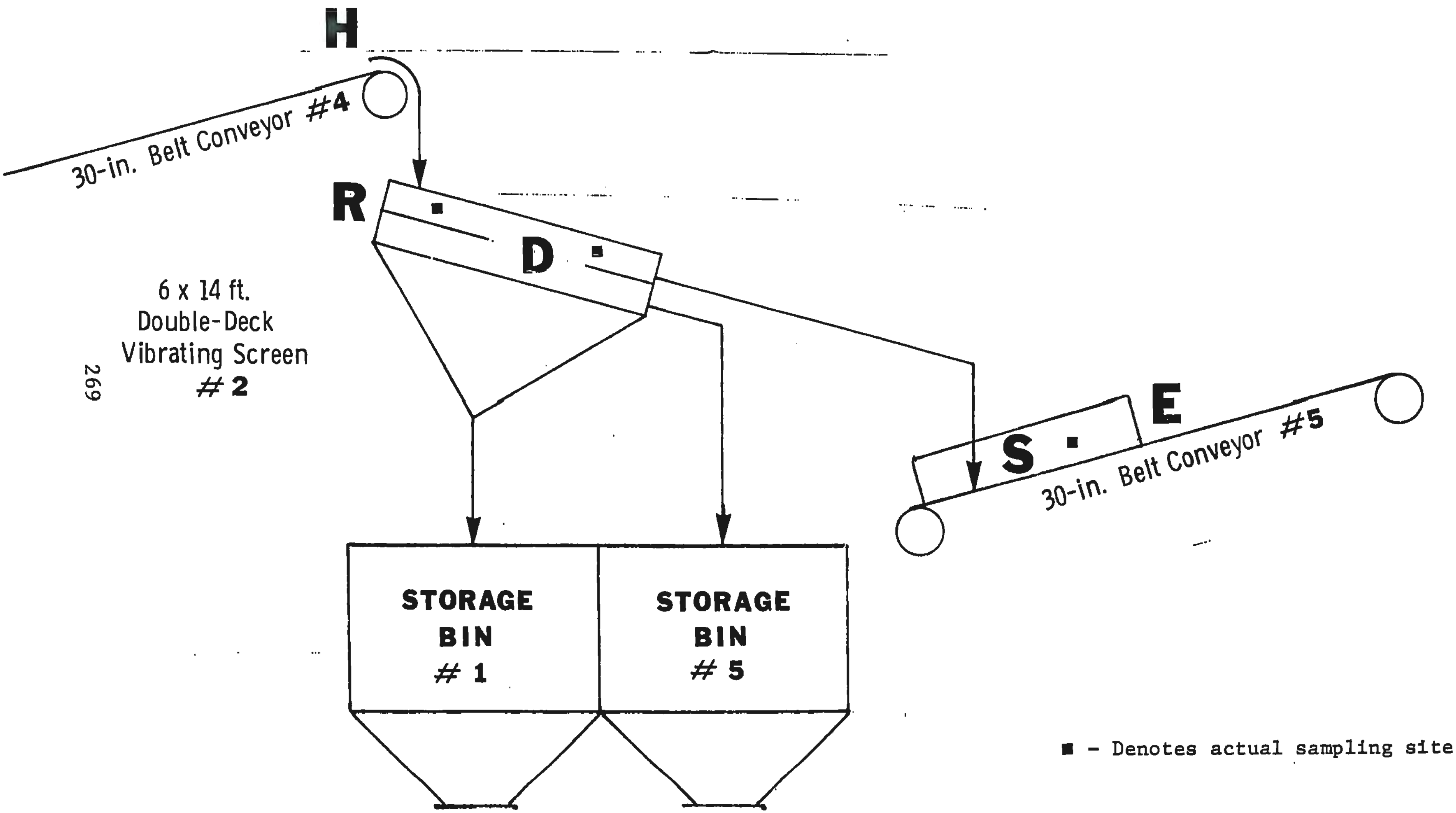

FIGURE 65. - Sampling locations for vibrating screen #2 circuit.

Anderson:

- At vibrating screen #2 — 750 cfm
- Vibrating screen #2-to-belt conveyor #5 — 3150 cfm
- Vibrating screen #2-to-storage bin #1 — 1850 cfm
- Vibrating screen #2-to-storage bin #5 — 1850 cfm

Thus, the total exhaust volume calculated according to the Industrial Ventilation Manual ranged from 8400 cfm to 11,600 cfm, while the total exhaust volume calculated by the Anderson approach was 7600 cfm.

The installation of the bulk material handling systems, including the Trellex dust sealing system at the vibrating screen, covers at the storage bins, and new settling box skirting at conveyor belt #5, reduced the visible dust emissions. Moreover, based on our experience, we believed that some of the recommended exhaust volumes were overestimates. Therefore, the dust control system was arbitrarily designed to exhaust the following volumes at various points, although, in some cases exhaust volumes estimated by the IVM or Anderson approach exceeded these design volumes.

1) Vibrating screen — 2500 cfm
2) Conveyor belt #5 — 2500 cfm
3) Storage bin #1 — 1700 cfm
4) Storage bin #5 — 1700 cfm

The dust collection system was designed so that exhaust volumes at any one or more points could be partially reduced or totally shut off.

Respirable dust sampling was conducted in two groups consisting of four sets each, at the exhaust volumes (Q) shown.

Group I

Set 1

Q screen	=	2500 cfm
Q conveyor #5	=	2500 cfm
Q bin #1	=	1700 cfm
Q bin #5	=	1700 cfm
Total exhaust volume	=	8400 cfm

Set 2

Q screen	=	0
Q conveyor #5	=	1250 cfm
Q bin #1	=	850 cfm
Q bin #5	=	850 cfm
Total exhaust volume	=	2950 cfm

Set 3

Q screen	=	0
Q conveyor #5	=	1250 cfm
Q bin #1	=	1700 cfm
Q bin #5	=	1700 cfm
Total exhaust volume	=	4650 cfm

Set 4

Exhaust system off
Total exhaust volume = 0 cfm

Group II

Set 1

Q screen	=	2500 cfm
Q conveyor #5	=	2500 cfm
Q bin #1	=	1700 cfm
Q bin #5	=	1700 cfm
Total exhaust volume	=	8400 cfm

Set 2

Q screen	=	2500 cfm
Q conveyor #5	=	1250 cfm
Q bin #1	=	0
Q bin #5	=	0
Total exhaust volume	=	3750 cfm

Set 3

Q screen	=	0
Q conveyor #5	=	1250 cfm
Q bin #1	=	0
Q bin #5	=	0
Total exhaust volume	=	1250 cfm

Set 4

Exhaust system off

Total exhaust volume = 0 cfm

Table 27 summarizes test data for groups I and II. The detailed data are presented in Table 28 for group I and in Table 29 for group II.

The following discussions are based on Table 27 unless otherwise noted

1) The mean dust concentrations with the dust collection system "off" ranged from 5.7 mg/m^3 to 25.6 mg/m^3 at various locations, and the data within groups showed good agreement.

2) The mean dust control efficiencies, presented in Table 27, are plotted in figure 66. It can be seen that throughout the testing period, the collection efficiency essentially remained between 60% and 90%. Further, there seems to be no consistant trend in dust control efficiency with increasing total exhaust volume.

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TABLE 27. - SUMMARY OF TEST RESULTS AT VIBRATING SCREEN AND RELATED TRANSFER POINTS

Control System: Dust Collection
Type Of Sampling: Respirable Dust

SAMPLING LOCATION[1]	TOTAL EXHAUST VOLUME cfm		GROUP I			GROUP II		
			8400	2950	4650	8400	3750	1250
			SET 1	SET 2	SET 3	SET 1	SET 2	SET 3
H	ARITH. MEAN DUST CONCENTRATION(2) SYSTEM OFF	$\frac{mg}{m^3}$	8.1	8.1	8.1	9.5	9.5	9.5
	EFFICIENCY ARITH. MEAN	%	66.7	74.7	76.3	83.3	74.6	87.2
	EFFICIENCY STANDARD ERROR	%	11.0	5.5	5.6	3.0	4.7	2.0
D	ARITH. MEAN DUST CONCENTRATION(2) SYSTEM OFF	$\frac{mg}{m^3}$	7.0	7.0	7.0	5.7	5.7	5.7
	EFFICIENCY ARITH. MEAN	%	52.3	79.6	87.5	73.5	65.1	72.5
	EFFICIENCY STANDARD ERROR	%	19.0	10.9	2.6	5.4	6.8	4.6
R	ARITH. MEAN DUST CONCENTRATION(2) SYSTEM OFF	$\frac{mg}{m^3}$	17.5	17.5	17.5	17.0	17.0	17.0
	EFFICIENCY ARITH. MEAN	%	69.6	72.1	62.6	83.6	73.1	78.4
	EFFICIENCY STANDARD ERROR	%	5.0	7.4	5.8	3.9	6.5	4.4
E	ARITH. MEAN DUST CONCENTRATION(2) SYSTEM OFF	$\frac{mg}{m^3}$	14.0	14.0	14.0	16.0	16.0	16.0
	EFFICIENCY ARITH. MEAN	%	84.6	84.6	-	80.6	82.6	90.7
	EFFICIENCY STANDARD ERROR	%	5.7	6.9	-	6.0	4.0	1.7
S	ARITH. MEAN DUST CONCENTRATION(2) SYSTEM OFF	$\frac{mg}{m^3}$	25.6	25.6	25.6	17.7	17.7	17.7
	EFFICIENCY ARITH. MEAN	%	85.5	84.3	74.1	79.1	67.0	68.8
	EFFICIENCY STANDARD ERROR	%	10.2	12.0	21.2	3.8	7.8	10.2

TABLE 27. - SUMMARY OF TEST RESULTS AT VIBRATING SCREEN AND RELATED TRANSFER POINTS (Con'd)

	Group I	Group II
Individual Exhaust Volumes cfm(3):	Set 1 - Q_1 = 2500 Q_2 = 2500 Q_3 = Q_4 = 1700 Set 2 - Q_1 = 0 Q_2 = 1250 Q_3 = Q_4 = 850 Set 3 - Q_1 = 0 Q_2 = 1250 Q_3 = Q_4 = 1700	Q_1 = 2500 Q_2 = 2500, Q_3 = Q_4 = 1700 Q_1 = 2500 Q_2 = 1250 Q_3 = Q_4 = 0 Q_1 = 0 Q_2 = 1250 Q_3 = Q_4 = 0
Time Period:	June, 1983	July, 1983
Reference Tables:	28	29

(1) H = Head box for feed conveyor #4
D = Side of the screen #2
R = Rear of the screen #2
E = End of the settling box, conveyor #5
S = Side of the conveyor #5

(2) Refer to section 4.2.5. for explanation.

(3) Q_1 = Screen exhaust volume
Q_2 = Belt conveyor #5 exhaust volume
Q_3 = Bin #1 exhaust volume
Q_4 = Bin #5 exhaust volume

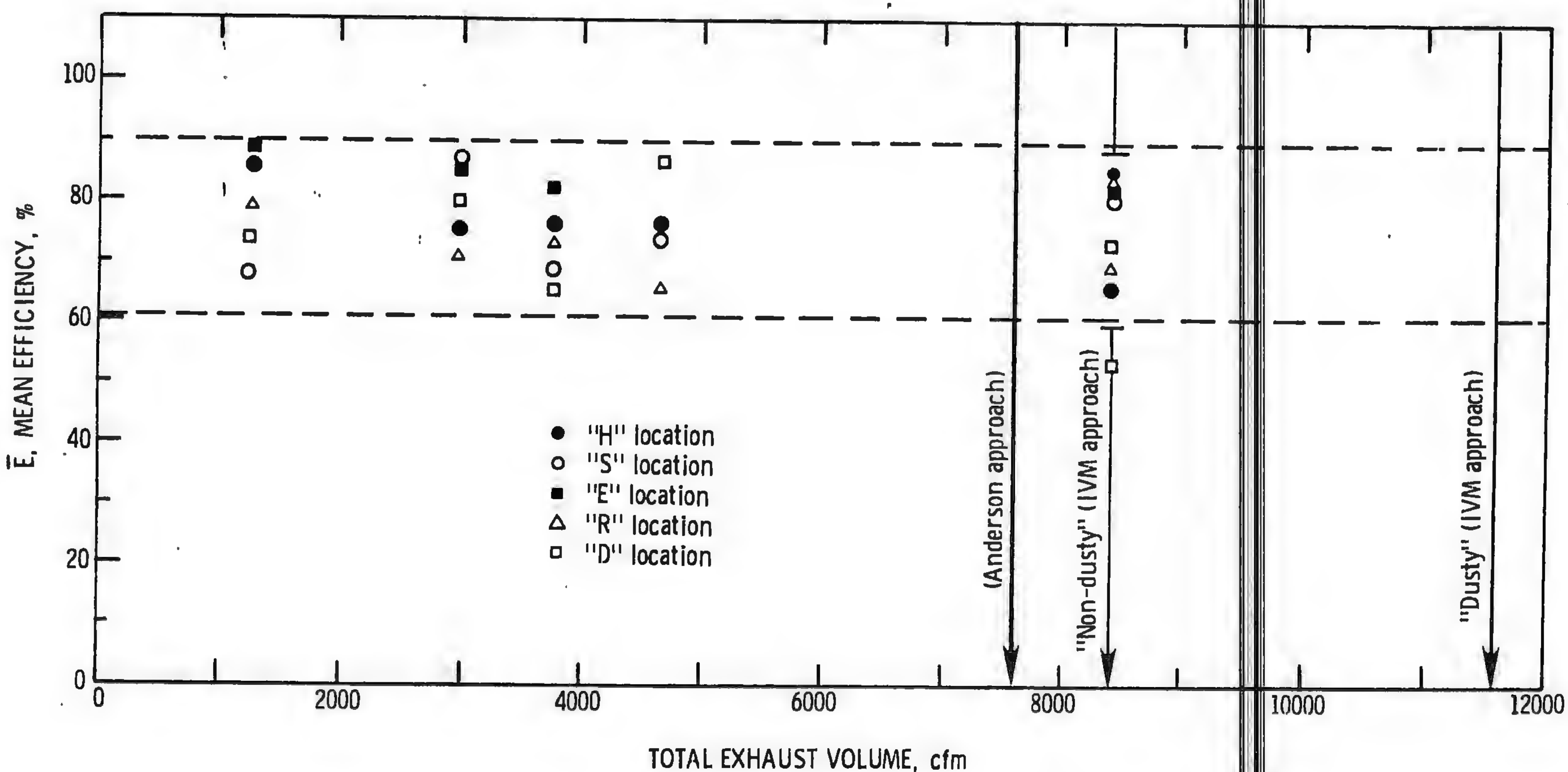

FIGURE 66.- Effect of exhaust volume on dust control efficiency at the vibrating screen #2 circuit. Type of sampling - respirable dust.

3) No trends are apparent when mean dust control efficiency along with 95% confidence levels are plotted for individual locations separately (fig. 67 through 71). The effectiveness of the exhaust system was essentially constant between the total exhaust volumes of 1250 cfm and 8400 cfm.

4) The day-to-day efficiency of the dust collection system at a total exhaust volume of 1250 cfm at all the sampling locations is plotted in figure 72.

5.1.4.1. Results

Based on the detailed discussion so far, the following conclusions can be drawn concerning dust control for the vibrating screen #2 circuit:

1) The bulk material handling components, including the Trellex dust seals, can achieve sizable reductions in dust generation and emissions.

2) An exhaust volume of only 1250 cfm at belt conveyor #5 alone was enough to produce more than a 65% dust control efficiency at all the sampling locations. Increasing total exhaust volume from 1250 cfm to 8400 cfm produced only marginal improvements, if any, at all the sampling locations (figs. 67 to 71).

3) The exhaust volumes calculated using the Industrial Ventilation Manual (8,400 cfm to 11,600 cfm) and Anderson approaches (7,600 cfm) are gross overestimates for a well-sealed system (fig. 71).

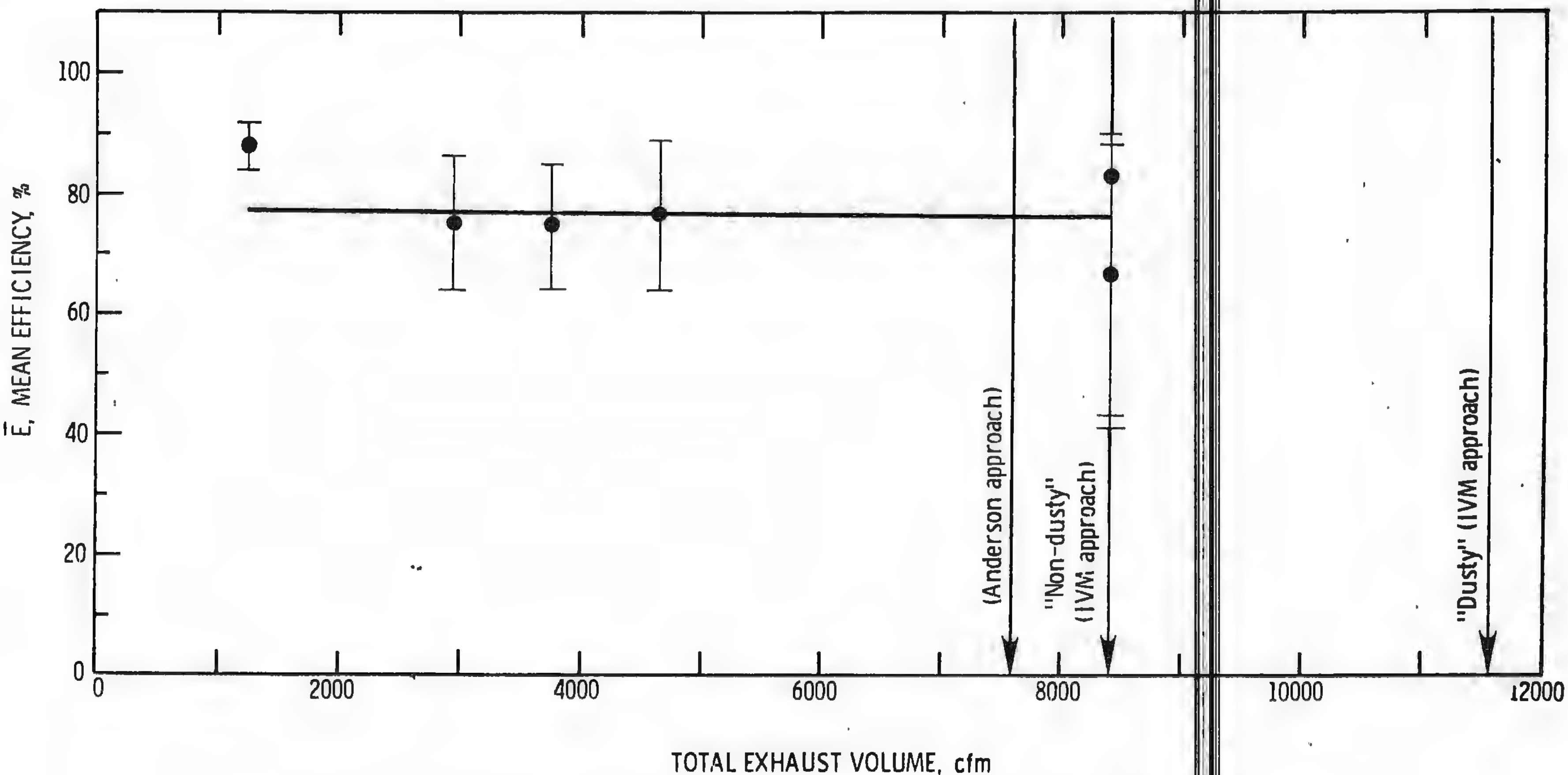

FIGURE 67.- Effect of exhaust volume on dust control efficiency (and probable trends) at "H" locations for the vibrating screen #2 circuit. Type of sampling - respirable dust.

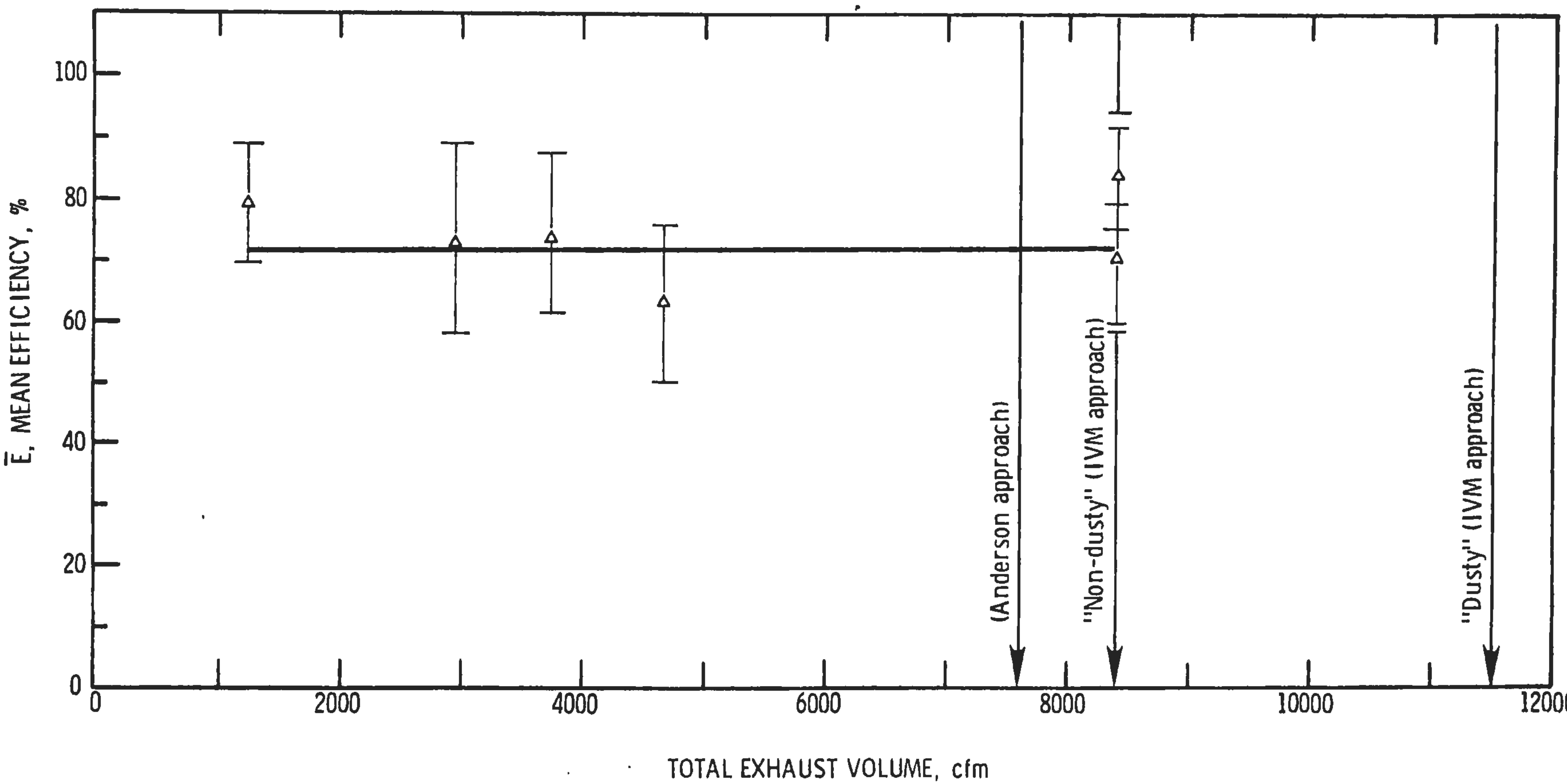

FIGURE 68.- Effect of exhaust volume on dust control efficiency (and probable trends) at "R" locations for the vibrating screen #2 circuit. Type of sampling - respirable dust.

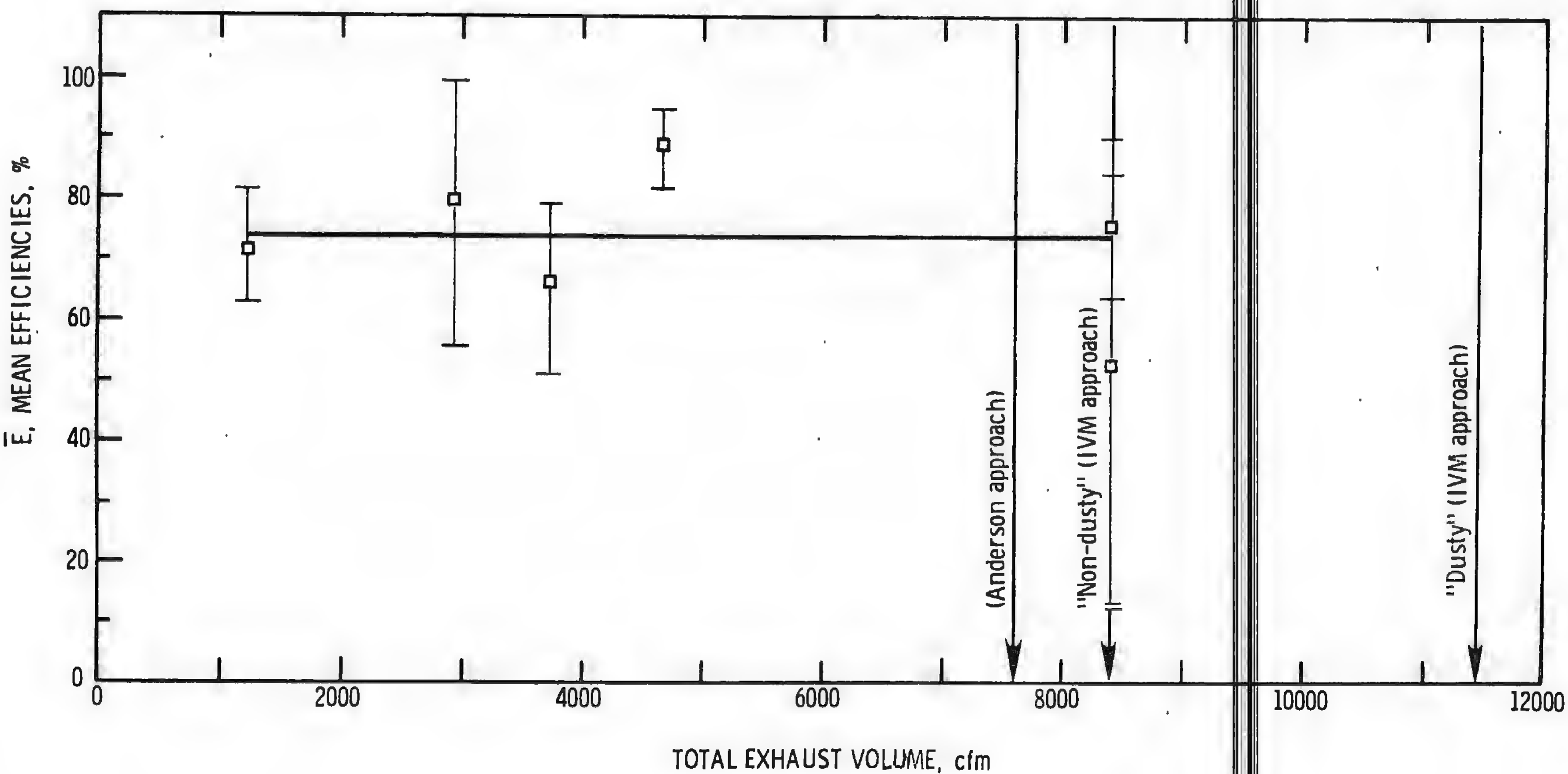

FIGURE 69. - Effect of exhaust volume on dust control efficiency (and probable trends) at "D" locations for the vibrating screen #2 circuit. Type of sampling - respirable dust.

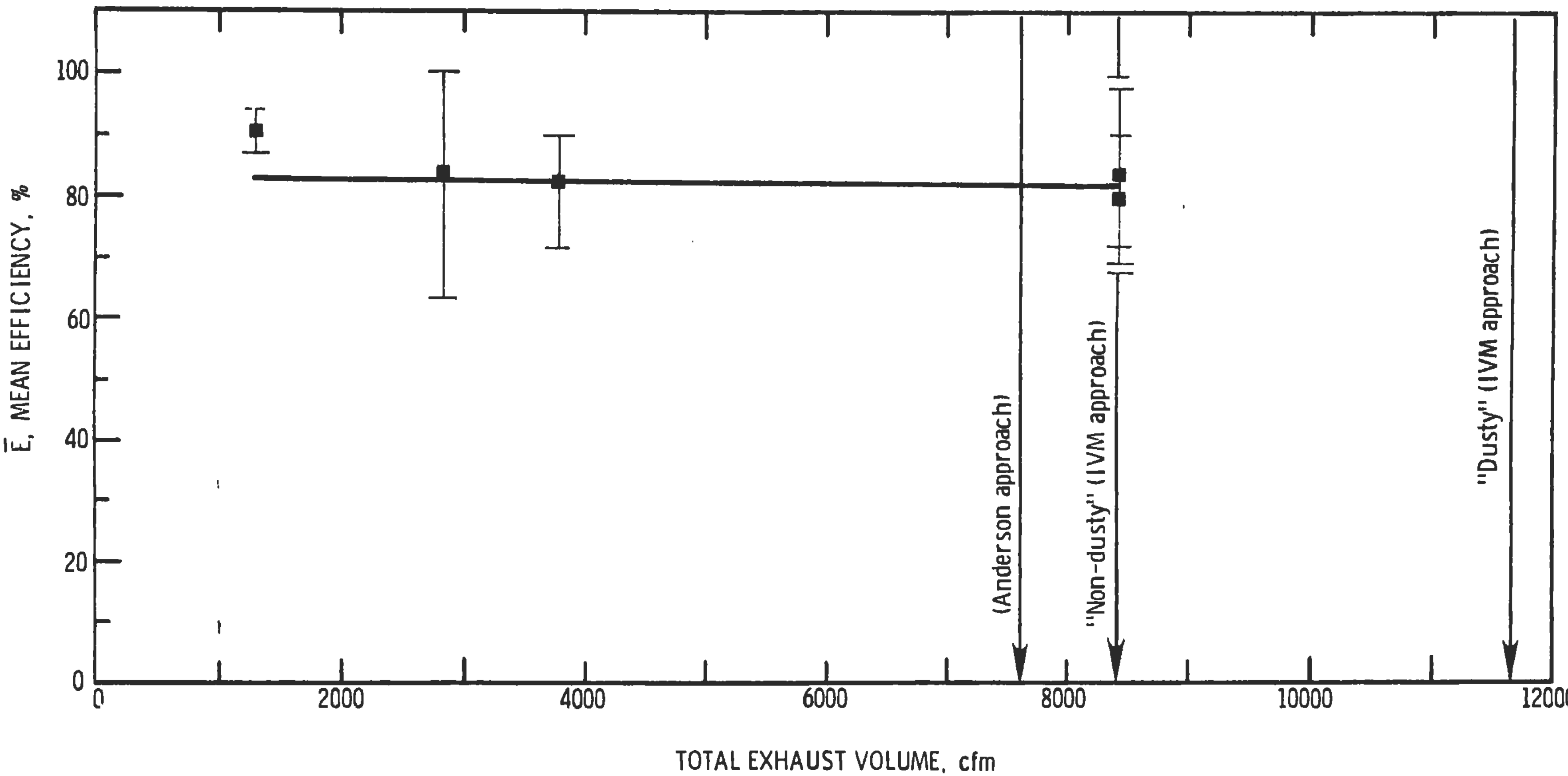

FIGURE 70. - Effect of exhaust volume on dust control efficiency (and probable trends) at "E" locations for the vibrating screen #2 circuit. Type of sampling - respirable dust.

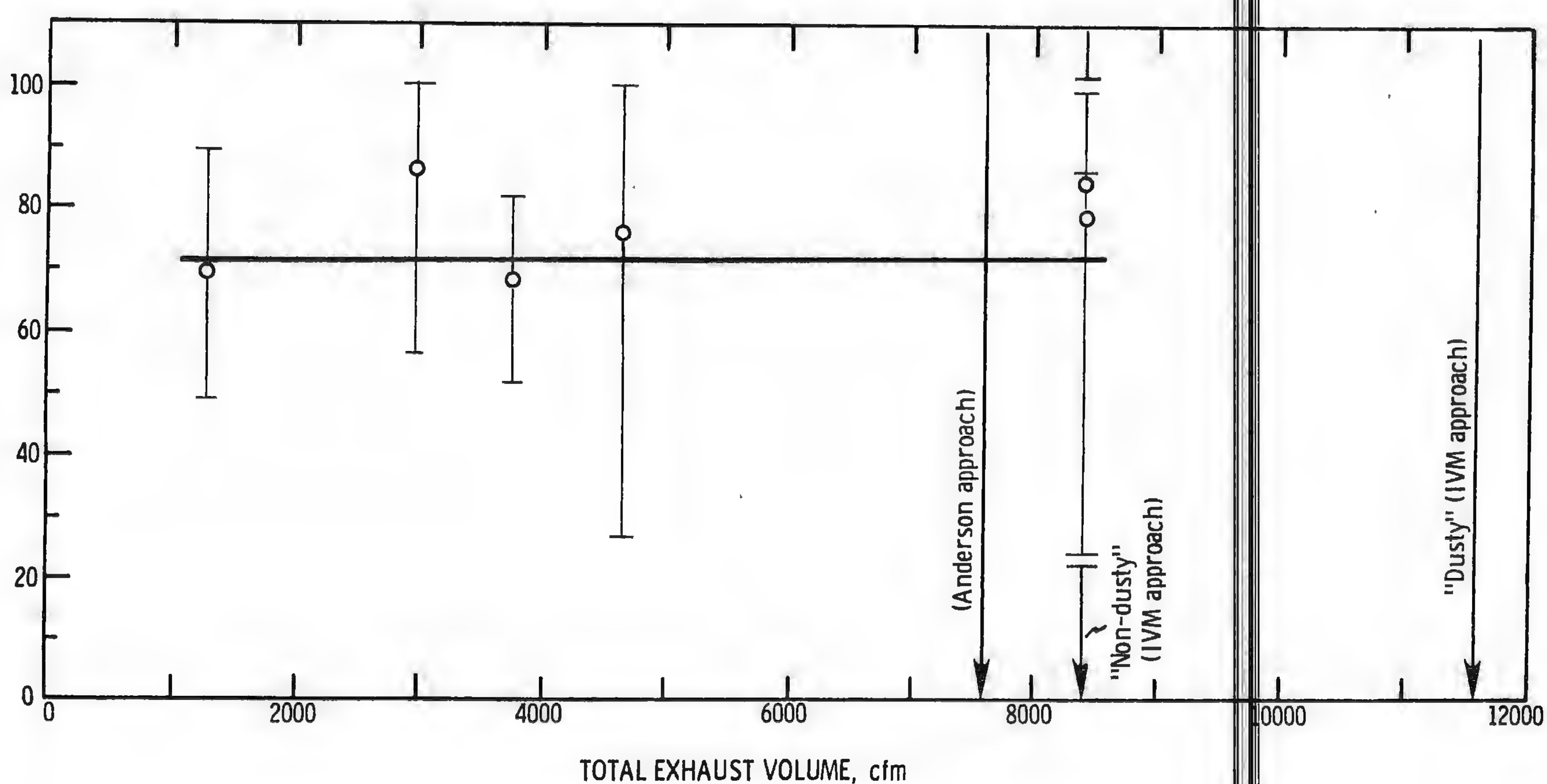

FIGURE 71. - Effect of exhaust volume on dust control efficiency (and probable trends) at "S" locations for the vibrating screen #2 circuit. Type of sampling - respirable

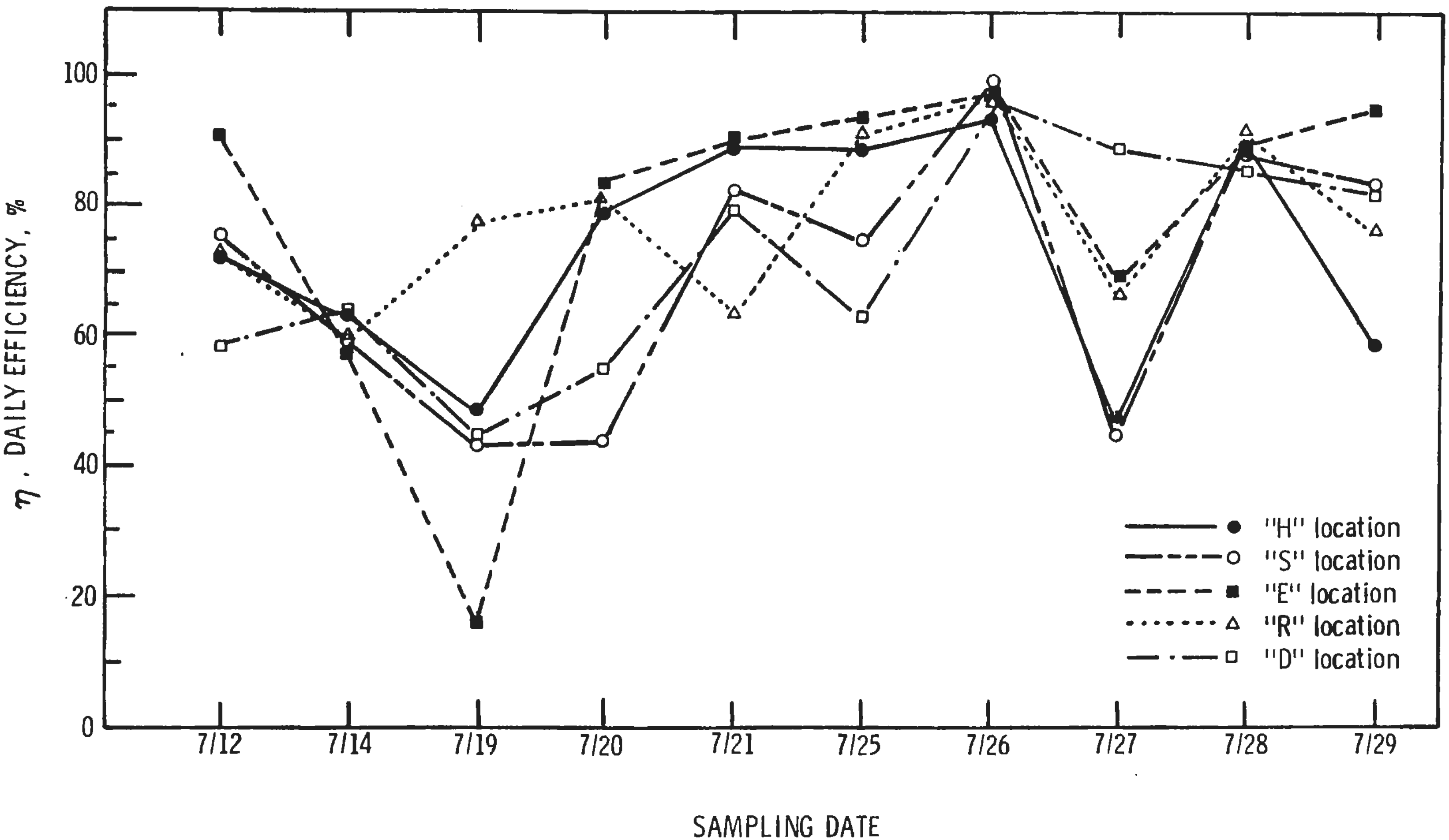

FIGURE 72. - Day-to-day variation in efficiency of dust control system at the vibrating screen #2 circuit. Type of sampling - respirable dust; total exhaust volume = 1250 cfm (Group II).

TABLE 28. - RESPIRABLE DUST RESULTS FOR VIBRATING SCREEN #2 CIRCUIT -

GROUP I

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Conditions: Group I

Set 1: Q_1 = 2500 cfm. Q_2 = 2500 cfm. $Q_3 = Q_4$ = 1700 cfm.[4]
Set 2: Q_1 = 0 cfm. Q_2 = 1250 cfm. $Q_3 = Q_4$ = 850 cfm.
Set 3: Q_1 = 0 cfm. Q_2 = 1250 cfm. $Q_3 = Q_4$ = 1700 cfm.

DATE	SAMPLING LOCATION[1]	GEOMETRIC MEAN CONCENTRATIONS[2] mg/m³				SYSTEM EFFICIENCY			TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on			%			°F	%		
			Set 1	Set 2	Set 3	Set 1	Set 2	Set 3				
6/24/83	H	7.4	4.8	3.1	-	36.0	58.1	-	85	57	over one week	Plant was
	D	3.8	7.4	-	-	?[3]	-	-				running at
	R	18.5	5.4	-	-	71.0	-	-				partial capa-
	E	13.7	3.0	1.9	-	78.0	86.1	-				city. New
	S	5.9	4.6	-	-	21.4	-	-				plant was operating.
6/27/83	H	8.6	1.5	1.1	1.1	82.9	86.8	87.6	97	45	over one week	Plant was
	D	7.8	2.0	1.9	0.8	73.6	75.6	89.1				running at
	R	18.3	5.9	5.5	5.5	68.1	69.9	69.9				full capacity
	E	-	1.0	-	-	-	-	-				New plant off
	S	35.1	1.4	4.9	6.4	96.0	86.2	81.7				
6/28/83	H	7.8	0.9	1.5	2.7	87.8	80.7	65.9	85	69	over one week	
	D	6.3	0.9	0.4	0.8	85.7	93.7	86.6				
	R	14.2	4.0	3.0	7.0	72.0	79.1	54.6				
	E	-	-	-	-	-	-	-				
	S	9.7	3.1	2.0	3.6	68.1	79.3	63.2				

TABLE 28. - RESPIRABLE DUST RESULTS FOR VIBRATING SCREEN #2 CIRCUIT - GROUP I (Con'd)

	SAMPLING LOCATION[1]				
	H	D	R	E	S
DUST CONTROL SYSTEM "OFF"					
Arith. Mean Dust Concentration (mg/m^3)[2]:	8.1	7.0	17.5	14.0	25.6
Standard Deviation:	1.5	3.2	4.3	3.1	38.3
Standard Error:	0.5	1.2	1.5	3.1	17.1
DUST CONTROL SYSTEM "ON"					
SET 1					
Arith. Mean Dust Concentration (mg/m^3)[2]:	2.7	3.3	5.3	2.2	3
Standard Deviation:	2.5	2.9	2.1	1.4	1.9
Standard Error:	0.9	1.2	0.7	0.6	0.9
SET 2					
Arith. Mean Dust Concentration (mg/m^3)[2]:	2.0	1.4	4.9	2.2	4
Standard Deviation:	1.2	1.6	2.7	1.2	2.6
Standard Error:	0.4	0.7	1.2	0.8	1.5
SET 3					
Arith. Mean Dust Concentration (mg/m^3)[2]:	1.9	0.9	6.5	-	6
Standard Deviation:	1.0	0.2	1.9	-	5.4
Standard Error:	0.4	0.1	0.8	-	3.1
CONTROL SYSTEM PERFORMANCE					
SET 1					
Mean Control System Efficiency (%):	66.7	52.3	69.6	84.6	85.5
Standard Error:	11.0	19.0	5.0	5.7	10.2
SET 2					
Mean Control System Efficiency (%):	74.7	79.6	72.1	84.6	84.3
Standard Error:	5.5	10.9	7.4	6.9	12.0
SET 3					
Mean Control System Efficiency (%):	76.3	86.5	62.6	-	74.1
Standard Error:	5.6	2.6	2.8	-	21.2

TABLE 28. - RESPIRABLE DUST RESULTS FOR VIBRATING SCREEN #2 CIRCUIT -

GROUP I (Con'd)

95% CONFIDENCE LIMITS (APPROXIMATE)

SET 1

		H	D	R	E	S
Control System Off Concentration	(X)(mg/m^3)[2]:	6.9< X < 9.3	4.1< X < 9.8	14.0< X <21.0	0.1< X <[illegible].1	0.1< X <69.7
Control System On Concentration	(Y)(mg/m^3)[2]:	0.7< Y < 4.7	0.4< Y < 6.2	3.6< Y < 7.0	0.5< Y <[illegible].8	0.1< Y <16.6
Control System Performance	(E)(mg/m^3)[2]:	43.5< E <89.9	11.3< E <93.3	59.2< E <80.1	70.6< E <[illegible].6	24.3< E <99.9

SET 2

		H	D	R	E	S
Control System Off Concentration	(X)(mg/m^3)[2]:	6.9< X < 9.3	4.1< X < 9.8	14.0< X <21.0	0.1< X <[illegible].1	0.1< X <69.7
Control System On Concentration	(Y)(mg/m^3)[2]:	1.1< Y < 3.0	0.1< Y < 3.3	1.7< Y < 8.0	0.1< Y <[illegible].8	0.1< Y < 8.8
Control System Performance	(E)(mg/m^3)[2]:	63.1< E <86.4	55.7< E <99.9	56.2< E <88.0	62.8< E <[illegible].9	56.7< E <99.9

SET 3

		H	D	R	E	S
Control System Off Concentration	(X)(mg/m^3)[2]:	6.9< X < 9.3	4.1< X < 9.8	14.0< X <21.0	0.1< X <[illegible].1	0.1< X <69.7
Control System On Concentration	(Y)(mg/m^3)[2]:	0.8< Y < 3.0	0.6< Y < 1.1	4.4< Y < 8.7	---< Y <---	0.1< Y <16.6
Control System Performance	(E)(mg/m^3)[2]:	64.1< E <88.4	81.9< E <93.1	50.0< E <75.1	---< E <---	25.3< E <99.9

(1) H = Head box for feed conveyor #4.
D = Side of the screen.
R = Rear of the screen.
E = End of the settling box, conveyor #5.
S = Side of the conveyor #5.

(2) Refer to section 4.2.5. for explanation.

(3) Control system efficiency is not computed because mean concentration with control system 'off' was lower than the mean concentration with control system 'on'.

(4) Q_1 = Screen exhaust volume.
Q_2 = Belt conveyor #5 exhaust volume.
Q_3 = Bin #1 exhaust volume.
Q_4 = Bin #9 exhaust volume.

TABLE 29. - RESPIRABLE DUST RESULTS FOR VIBRATING SCREEN #2 CIRCUIT - GROUP II

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Conditions: Group II
Set 1: Q_1 = 2500 cfm. Q_2 = 2500 cfm. $Q_3 = Q_4$ = 1700 cfm.(3)
Set 2: Q_1 = 2500 cfm. Q_2 = 1250 cfm. $Q_3 = Q_4$ = 0 cfm.
Set 3: Q_1 = 0 cfm. Q_2 = 1250 cfm. $Q_3 = Q_4$ = 0 cfm.

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m^3				SYSTEM EFFICIENCY			TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on			%			°F	%		
			Set 1	Set 2	Set 3	Set 1	Set 2	Set 3				
7/12/83	H	15.5	4.6	4.3	-	70.3	72.3	-	91	64	over one week	New plant was not running, heavy flow.
	D	6.5	2.1	2.7	-	67.7	58.5	-				
	R	46.7	9.7	12.5	-	79.2	73.2	-				
	E	15.7	0.9	1.3	-	94.3	91.7	-				
	S	17.2	4.3	4.2	-	75.0	75.6	-				
7/14/83	H	10.9	1.7	4.0	-	84.4	63.3	-	91	30	over one week	New circuit was running, normal rock flow.
	D	9.6	4.2	3.4	-	56.3	64.6	-				
	R	18.4	3.1	7.3	-	83.2	60.1	-				
	E	19.3	10.3	8.3	-	47.2	57.3	-				
	S	-	4.7	14.6	-	-	-	-				
7/19/83	H	5.8	1.4	3.0	1.1	75.9	48.3	81.0	89	54	over one week	
	D	2.7	0.5	1.5	2.0	81.5	44.4	25.9				
	R	7.9	1.9	1.7	5.1	75.9	78.5	35.4				
	E	4.9	1.7	4.1	1.3	65.3	16.3	73.5				
	S	11.2	5.4	6.2	2.8	51.8	44.6	75.0				
7/20/83	H	11.6	1.9	2.5	1.9	83.6	78.4	83.6	94	38	over one week	
	D	8.7	1.3	3.9	2.2	85.1	55.2	74.7				
	R	15.7	2.3	2.9	5.9	85.4	81.5	62.4				
	E	13.6	2.3	2.3	1.5	83.1	83.1	89.0				
	S	13.6	3.0	7.4	3.1	77.9	45.6	77.2				
7/21/83	H	11.1	1.5	1.2	-	86.5	89.2	-	93	37	7/21/83	
	D	7.3	2.0	1.5	-	72.6	79.5	-				
	R	9.6	2.7	3.6	-	71.9	62.5	-				
	E	15.8	1.3	1.7	-	91.8	89.2	-				
	S	20.5	3.6	3.6	-	82.4	82.4	-				

TABLE 29. - RESPIRABLE DUST RESULTS FOR VIBRATING SCREEN #2 CIRCUIT - GROUP II (Con'd)

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³				SYSTEM EFFICIENCY			TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on			%			°F	%		
			Set 1	Set 2	Set 3	Set 1	Set 2	Set 3				
7/25/83	H	9.3	0.5	1.3	0.8	94.6	88.2	91.4	80	34	7/21/83	
	D	6.1	0.8	2.3	-	86.9	62.3	-				
	R	26.9	0.9	2.3	-	96.7	91.8	-				
	E	26.2	1.7	1.7	-	93.5	93.5	-				
	S	15.9	2.6	3.9	2.9	83.6	75.5	81.8				
7/26/83	H	7.1	0.8	0.4	0.8	88.6	94.3	88.6	95	15	7/21/83	
	D	5.1	0.9	0.2	1.6	82.0	96.0	68.0				
	R	20.4	2.4	0.8	2.4	88.2	96.1	88.2				
	E	24.8	1.7	0.7	1.2	93.1	97.2	95.1				
	S	33.7	2.8	0.7	1.3	91.7	97.9	96.1				
7/27/83	H	4.4	1.1	2.3	1.1	75.0	47.7	75.0	94	25	7/21/83	
	D	2.3	0.3	0.2	0.8	87.0	91.3	65.2				
	R	9.7	1.3	3.3	3.8	86.6	66.0	60.8				
	E	11.5	1.8	3.6	1.3	84.2	68.4	88.6				
	S	12.0	2.6	6.7	7.5	78.3	43.7	37.0				
7/28/83	H	8.5	0.3	0.7	1.0	96.4	91.7	88.1	94	27	7/21/83	
	D	3.0	0.4	0.4	1.4	86.2	86.2	48.3				
	R	8.1	0.7	0.8	2.3	90.1	90.1	71.6				
	E	7.7	0.8	0.7	2.3	89.5	89.5	69.7				
	S	22.9	2.7	2.3	9.9	88.2	90.0	56.8				
7/29/83	H	4.8	0.6	2.0	1.0	85.4	58.3	79.2	92	28	7/21/83	
	D	3.3	0.4	0.6	0.4	87.9	81.8	87.9				
	R	4.3	1.0	1.0	1.2	76.7	76.7	72.1				
	E	8.1	0.9	0.4	1.1	87.5	95.0	86.3				
	S	6.7	2.2	1.2	2.4	67.2	82.1	64.1				

TABLE 29. - RESPIRABLE DUST RESULTS FOR VIBRATING SCREEN #2 CIRCUIT - GROUP II (Con'd)

	SAMPLING LOCATION[1]				
	H	D	R	E	S
DUST CONTROL SYSTEM "OFF"					
Arith. Mean Dust Concentration (mg/m^3)[2]:	9.5	5.7	17.0	16.0	17.7
Standard Deviation:	4.9	3.4	12.3	10.7	10.0
Standard Error:	0.9	0.6	2.4	2.0	2.4
DUST CONTROL SYSTEM "ON"					
SET 1					
Arith. Mean Dust Concentration (mg/m^3)[2]:	1.6	1.5	2.8	3.1	3.7
Standard Deviation:	1.3	1.2	2.8	3.9	1.9
Standard Error:	0.2	0.3	-	0.9	0.4
SET 2					
Arith. Mean Dust Concentration (mg/m^3)[2]:	2.4	2.0	4.6	2.8	5.9
Standard Deviation:	2.0	1.6	4.6	2.6	4.8
Standard Error:	0.4	0.3	0.9	0.5	1.1
SET 3					
Arith. Mean Dust Concentration (mg/m^3)[2]:	1.3	1.6	3.7	1.5	5.5
Standard Deviation:	0.6	0.7	2.1	0.7	5.7
Standard Error:	0.1	0.2	0.5	0.2	1.6
CONTROL SYSTEM PERFORMANCE					
SET 1					
Mean Control System Efficiency (%):	83.3	73.5	83.6	80.6	79.1
Standard Error:	3.0	5.4	3.9	6.0	3.8
SET 2					
Mean Control Efficiency (%):	74.6	65.1	73.1	82.6	67.0
Standard Error:	4.7	6.8	6.5	4.0	7.8
SET 3					
Mean Control System Efficiency (%):	87.2	72.5	78.4	90.7	68.8
Standard Error:	2.0	4.6	4.4	1.7	10.2

TABLE 29. - RESPIRABLE DUST RESULTS FOR VIBRATING SCREEN #2 CIRCUIT - GROUP II (Con'd)

95% CONFIDENCE LEVELS (APPROXIMATE)

	H	D	R	E	S
SET 1					
Control Sys. Off Concen. (X)(mg/m^3)(3):	7.6 < X < 11.3	4.4< X < 7.0	12.1< X < 22.0	11.9< X < 20.2	12.6< X < 22.9
Control Sys. On Concen. (Y)(mg/m^3)(3):	1.1 < Y < 2.1	1.0< Y < 2.0	1.7< Y < 3.9	1.3< Y < 4.9	2.8< Y < 4.6
Control Sys. Performance (E)(%)(3):	77.3 < E < 89.4	62.5< E <84.4	75.7< E < 91.4	68.5< E < 92.6	71.5< E < 86.8
SET 2					
Control Sys. Off Concen. (X)(mg/m^3)(3):	7.6 < X < 11.3	4.4< X < 7.0	12.1< X < 22.0	11.9< X < 20.2	12.6< X < 22.9
Control Sys. On Concen. (Y)(mg/m^3)(3):	1.6 < Y < 3.2	1.3< Y < 2.6	2.8< Y < 6.4	1.7< Y < 3.9	3.5< Y < 8.2
Control Sys. Performance (E)(%)(3):	65.2 < E < 84.0	51.5< E <78.7	60.2< E < 86.1	74.5< E < 90.7	51.2< E < 82.8
SET 3					
Control Sys. Off Concen. (X)(mg/m^3)(3):	7.6 < X < 11.3	4.4< X < 7.0	12.1< X < 22.0	11.9< X < 20.2	12.6< X < 22.9
Control Sys. On Concen. (Y)(mg/m^3)(3):	0.9 < Y < 1.5	1.1< Y < 2.0	2.5< Y < 4.8	1.1< Y < 1.9	2.0< Y < 9.1
Control Sys. Performance (E)(%)(3):	83.2 < E < 91.3	63.2< E <81.8	69.6< E < 87.3	87.3< E < 94.1	47.9< E < 89.7

(1) Q_1 = Screen exhaust volume
Q_2 = Belt conveyor #5
Q_3 = Bin #1 exhaust volume
Q_4 = Bin #5 exhaust volume

(2) H = Head box for feed conveyor #4
D = Side of the screen
R = Rear of the screen
E = End of the settling box, conveyor #5
S = Side of conveyor #5

(3) Refer to section 4.2.5. for explanation.

5.2. TRANSFER POINTS EQUIPPED WITH WET DUST SUPPRESSION SYSTEMS

5.2.1. Hammermills-to-Belt Conveyor #7

This transfer point consisted of two hammermills installed back to back, both feeding belt conveyor #7 located underneath. Wet dust suppression at this transfer point consisted of two independent wet dust suppression systems:

1) A Sonic wet dust suppression system to control airborne respirable dust -- a control technique
2) A GH system consisting of two garden hose nozzles to "condition" the material to generate less dust -- a preventive technique.

To evaluate the performance of these systems separately and combined, respirable dust emission samples were obtained under the following four conditions:

1) Both systems "off"
2) Only the Sonic system operating
3) Only the GH system operating
4) Both systems operating at the same time.

Throughout the sampling period, test conditions, such as water and compressed air flow rates and pressures and material throughput, were maintained at the same level.[6] The samples at "E" locations were taken with the cyclones facing "out" (180° from the "in" position) of the air-

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6 Compressed air pressure - 55-60 psig
Compressed air flow rate - 9.5 scfm/nozzle
Water pressure - 10-14 psig
Water flow rate - 5-6 gph/nozzle
GH system water flow rate - 1 gpm

stream, as described earlier in Chapter 4. The samples at "S" and "T" locations were obtained using the same sampling strategy as established for the rest of the transfer points.

Table 30 describes the test data collected for 15 sampling days. The following discussions are based on Table 30.

1) The dust emissions data with the control system "off" showed significant day-to-day scatter at all locations (e.g., at "E" locations, they varied from 15.6 mg/m^3 to 521.2 mg/m^3).
2) The efficiency of the Sonic system alone was significantly lower at all three locations than that of the GH system.
3) The combined GH and Sonic system efficiency was only marginally better than that of the GH system alone.

The Sonic system was also evaluated with the GH system operating all the time at 1 gpm and the Sonic system "on" and "off." The data in Table 31 show that with this approach, mean Sonic system efficiency at "E" locations was 34.7%, vs 43.9% with the GH system "on" and "off" (Table 31). The efficiency with the GH system "on" was lower because, as discussed earlier, the dust control efficiency is a non-linear function of the dust concentrations with the control system "off," i.e., lower initial dust concentrations produce lower system efficiencies.

5.2.1.1. Problems Encountered - Negative Efficiencies

The question marks in the efficiency columns in Table 31 indicate occasions when the dust concentrations with the Sonic system "on" were higher than those with the system "off." This occurred for 7 days out

TABLE 30. – RESPIRABLE DUST RESULTS FOR HAMMERMILLS-TO-BELT CONVEYOR #7 –

SONIC & GH

Control System: Dust Suppression
Type of Sampling: Respirable Dust
Testing Conditions: Sonic System: Water Flow Rate = 6-6.5 gph/nozzle, Water Pressure = 10-14 psig, Compressed Air Flow Rate = 9.5 scfm/nozzle, Compressed Air Pressure = 55-60 psig, Number of Nozzles/Spray Bar = 2, Number of Spray Bars = 2, G.H. Nozzle System: Water Flow Rate = 1 gpm
Crusher Throughput: 400 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³				SYSTEM EFFICIENCY			TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		Sonic and GH Nozzle off	System on			%			°F	%		
			Sonic Only	GH Nozzle Only	Sonic & GH	Sonic Only	GH Nozzle Only	Sonic & GH				
2/08/83	E	322.1	524.5	30.4	30.4	?(3)	89.6	90.5	33	47	2/02/83	
	T	60.1	39.8	4.1	5.6	34.3	93.2	90.8				
	S	43.4	10.7	4.2	—	75.3	90.3	--				
2/09/83	E	421.9	54.3	27.1	--	87.1	93.6	--	28	49	2/02/83	
	T	83.8	8.9	2.3	--	89.4	97.3	--				
	S	54.6	9.2	5.4	--	83.2	90.1	--				
3/15/83	E	—	36.5	13.0	22.0	--	--	--	58	37	3/13/83	
	T	—	23.5	7.0	8.2	--	--	--				
	S	—	14.2	15.0	8.9	--	--	--				
3/16/83	E	84.1	23.8	21.0	16.3	71.7	75.0	80.6	52	46	3/13/83	
	T	55.6	6.0	4.1	8.8	89.2	92.6	84.2				
	S	28.1	2.2	1.8	3.3	92.2	93.6	88.3				
3/22/83	E	196.8	63.0	25.9	24.3	68.0	86.8	87.6	36	34	3/21/83	
	T	177.4	77.1	12.1	8.2	56.5	93.2	95.4				
	S	49.1	27.5	2.0	2.0	44.0	95.9	95.9				
3/23/83	E	308.5	142.7	17.8	9.6	53.7	94.2	96.9	36	36	3/21/83	
	T	183.9	115.2	17.2	4.2	37.4	90.6	97.7				
	S	—	22.5	8.7	8.6	--	--	--				
3/24/83	E	99.4	110.2	23.9	5.9	?	75.9	94.1	34	40	3/21/83	
	T	67.9	55.3	--	16.0	18.6	--	76.4				
	S	—	—	6.3	6.2	--	--	--				
4/04/83	E	41.8	62.0	25.5	17.0	?	39.0	59.3	42	45	4/02/83	
	T	33.7	109.1	13.0	7.4	?	61.4	78.0				
	S	19.8	35.2	9.3	5.0	?	53.0	74.7				

TABLE 30. - RESPIRABLE DUST RESULTS FOR HAMMERMILLS-TO-BELT CONVEYOR #7 -

SONIC & GH (Con'd)

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³				SYSTEM EFFICIENCY			TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		Sonic and GH Nozzle off	System on			%			°F	%		
			Sonic Only	GH Nozzle Only	Sonic & GH	Sonic Only	GH Nozzle Only	Sonic & GH				
4/05/83	E	32.8	14.7	12.3	17.3	55.2	62.5	47.2	49	49	4/02/83	
	T	41.0	2.5	13.4	--	93.9	67.3	--				
	S	--	1.0	2.2	--	--	--	--				
4/12/83	E	15.6	18.2	27.3	14.8	?(3)	?	5.1	54	45	4/11/83	
	T	2.4	2.8	1.0	1.4	?	58.3	41.7				
	S	7.0	8.5	1.8	2.0	?	74.3	71.4				
4/13/83	E	485.3	99.9	43.4	13.2	79.4	91.0	97.3	55	47	4/11/83	
	T	25.3	12.7	5.0	2.1	49.8	80.2	91.7				
	S	--	6.0	2.1	1.2	--	--	--				
4/22/83	E	52.6	82.4	33.7	28.8	?	35.9	45.2	62	26	4/20/83	
	T	8.5	17.7	3.3	1.6	?	61.2	81.2				
	S	20.2	17.0	9.4	40.3	15.8	53.5	?				
4/26/83	E	234.6	256.1	83.5	34.7	?	64.4	85.1	70	22	4/24/83	
	T	18.5	42.1	16.7	2.4	?	9.7	87.0				
	S	18.8	48.7	--	5.8	?	--	69.1				
7/11/83	E	243.9	288.7	94.2	36.7	?	61.4	84.9	79	41	7/04/83	
	T	118.5	355.0	20.2	14.5	?	83.0	87.8				
	S	150.2	68.2	6.9	6.9	54.6	95.4	95.4				
7/12/83	E	521.2	61.0	52.9	43.7	88.3	89.9	91.6	70	37	7/04/83	
	S	5.4	59.2	?	6.1	?	?	?				

TABLE 30. - RESPIRABLE DUST RESULTS FOR HAMMERMILLS-TO-BELT CONVEYOR #7 -

SONIC & GH (Con'd)

	SAMPLING LOCATION[1]		
	E	T	S
DUST CONTROL SYSTEM "OFF"			
Arith. Mean Dust Concentration (mg/m^3)[2]:	236.7	72.0	43.5
Standard Deviation:	193.8	63.6	40.6
Standard Error:	30.6	13.6	14.3
DUST CONTROL SYSTEM "ON"			
SONIC ONLY			
Arith. Mean Dust Concentration (mg/m^3)[2]:	132.8	63.1	27.3
Standard Deviation:	150.0	91.7	25.1
Standard Error:	23.4	17.6	6.3
GH NOZZLE ONLY			
Arith. Mean Dust Concentration (mg/m^3)[2]:	40.5	9.4	10.6
Standard Deviation:	35.6	7.7	14.0
Standard Error:	5.4	1.6	3.7
SONIC AND GH			
Arith. Mean Dust Concentration (mg/m^3)[2]:	26.5	9.6	7.8
Standard Deviation:	19.2	14.0	9.3
Standard Error:	3.1	3.1	2.6
CONTROL SYSTEM PERFORMANCE			
SONIC ONLY			
Mean Control System Efficiency (%):	43.9	12.3	37.3
Standard Error:	12.3	29.5	25.3
GH NOZZLE ONLY			
Mean Control System Efficiency (%):	82.9	87.0	75.5
Standard Error:	3.2	3.3	11.8
SONIC AND GH			
Mean Control System Efficiency (%):	88.8	86.6	82.0
Standard Error:	2.0	4.9	8.4

TABLE 30. - RESPIRABLE DUST RESULTS FOR HAMMERMILLS-TO-BELT CONVEYOR #7 -

SONIC & GH (Con'd)

		SAMPLING LOCATION[1]	
	E	T	S
95% CONFIDENCE LEVELS (APPROXIMATE)			
SONIC ONLY			
Control System Off Concentration (X) (mg/m^3)[2]:	174.7 < X < 298.6	43.9 < X < 100.1	10.4 < X < 76.5
Control System On Concentration (Y) (mg/m^3)[2]:	85.5 < Y < 180.1	27.0 < Y < 99.2	13.9 < X < 40.6
Control System Performance (E) (mg/m^3)[2]:	19.4 < E < 68.4	0.1 < E < 71.6	0.1 < X < 89.4
GH NOZZLE ONLY			
Control System Off Concentration (X) (mg/m^3)[2]:	174.7 < X < 298.6	43.9 < X < 100.1	10.4 < X < 76.5
Control System On Concentration (Y) (mg/m^3)[2]:	29.6 < Y < 51.5	6.0 < Y < 12.8	2.6 < X < 18.6
Control System Performance (E) (mg/m^3)[2]:	76.5 < E < 89.2	80.2 < E < 93.7	51.0 < X < 99.9
SONIC AND GH			
Control System Off Concentration (X) (mg/m^3)[2]:	174.7 < X < 298.6	43.9 < X < 100.1	10.4 < X < 76.5
Control System On Concentration (Y) (mg/m^3)[2]:	20.2 < Y < 32.8	3.3 < Y < 16.0	2.2 < X < 13.4
Control System Performance (E) (mg/m^3)[2]:	84.9 < E < 92.7	76.7 < E < 96.6	64.4 < X < 99.5

(1) E - End of the settling box.
T - Tail end of the conveyor.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

(3) Control System efficiency is not computed because mean concentration with Control System 'off' was lower than mean concentration with Control System 'on'.

TABLE 31. - RESPIRABLE DUST RESULTS FOR HAMMERMILLS-TO-BELT CONVEYOR #7 -

GH & SONIC

Control System: Dust Suppression
Type of Sampling: Respirable Dust
Testing Conditions: Sonic System: Water Flow Rate = 6-6.5 gph/nozzle, Water Pressure = 10-14 psig,
Compressed Air Flow Rate = 9.5 scfm/nozzle, Compressed Air Pressure = 55-60 psig
Number of Nozzles/Spray Bar = 2, Number of Spray Bars = 2,
G.H. Nozzle System: Water Flow Rate = 1 gpm
Crusher Throughput: 400 tph

DATE	GEOMETRIC MEAN CONCENTRATIONS(2)		SONIC SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
	SONIC SYSTEM OFF mg/m^3	SONIC SYSTEM ON mg/m^3	%	°F	%		
2/08/83	33.5	30.4	9.3	33	47	2/2/83	
2/09/83	27.1	-	-	28	49	2/2/83	
3/15/83	13.0	22.0	?(3)	58	37	3/13/83	
3/16/83	21.0	16.3	22.4	52	46	3/13/83	
3/22/83	25.9	24.3	6.2	36	34	3/21/83	
3/23/83	17.8	9.6	46.0	36	36	3/21/83	
3/24/83	23.9	5.9	75.3	34	40	3/21/83	
4/04/83	25.5	17.0	33.3	42	45	4/2/83	

TABLE 31. - RESPIRABLE DUST RESULTS FOR HAMMERMILLS-TO-BELT CONVEYOR #7 -

GH & SONIC (Con'd)

DATE	GEOMETRIC MEAN CONCENTRATIONS(2)		SONIC SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
	SONIC SYSTEM OFF mg/m^3	SONIC SYSTEM ON mg/m^3	%	°F	%		
4/05/83	12.3	17.3	?	49	49	4/2/83	
4/12/83	27.3	14.8	45.8	54	45	4/11/83	
4/13/83	43.4	13.2	69.6	55	47	4/11/83	
4/22/83	33.7	28.8	14.5	62	26	4/24/83	
4/26/83	83.5	34.7	58.4	70	22	4/20/83	
7/11/83	94.2	36.7	61.0	79	41	7/4/83	
7/12/83	52.9	43.7	17.4	70	37	7/4/83	

TABLE 31. - RESPIRABLE DUST RESULTS FOR HAMMERMILLS-TO-BELT CONVEYOR #7 - GH & SONIC (Con'd)

	SAMPLING LOCATION[1]
	E
SONIC SYSTEM "OFF"	
Mean Dust Concentration (mg/m^3)[2]	40.5
Standard Deviation:	35.6
Standard Error:	5.4
SONIC SYSTEM "ON"	
Mean Dust Concentration (mg/m^3)[2]	26.5
Standard Deviation:	19.2
Standard Error:	3.1
SONIC SYSTEM PERFORMANCE	
Mean Control System Efficiency %:	34.7
Standard Error:	11.6

(1) E - End of the settling box.

(2) Refer to section 4.2.5. for explanation.

(3) Sonic system efficiency was not computed because mean concentration with the Sonic system "off" was lower that mean concentration with the Sonic system "on."

of 15 at "E" locations. We believe that these results were due to variations in parameters beyond our control. For example, the dust concentration with the control system "off" varied significantly from day to day (coefficient of variation[7] = 81.8% at "E" locations) even though the size range and material throughput of the hammermills were the same throughout the sampling period. Therefore, other variables, such as type of rock and moisture content must have contributed to the day-to-day variation. Indeed, the GH system data showed that the addition of 1 gpm of water prior to the hammermills -- only 0.07% of the total throughput by weight -- produced a dust control efficiency on the order of 80%, proving that a minor variation in moisture content significantly affects the dust emission rate. With such a small change in a parameter making such a large difference in measured dust emissions, it is likely that the one set of system "off" data obtained on each sampling day was not representative of dust emissions throughout the day. Thus, if the time variation in dust emissions (with the system "off") were on the order of the change produced by the control system, the performance calculated on any given day would not only be unreliable but meaningless.

To test this hypothesis, we collected several sets of dust emission data with the control system "off" for 3 days (Table 32). The data showed a coefficient of variation as high as 75.7%, supporting the hypothesis that the negative efficiencies for the Sonic system were due to the large daily variations in dust emissions.

For the same reason, some of the positive efficiencies on other days may have been higher (or lower) than the actual efficiencies.

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7 Coefficient of variation = standard deviation/arithmetic mean dust concentration.

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TABLE 32. - RESPIRABLE DUST RESULTS FOR HAMMERMILLS-TO-BELT CONVEYOR #7 -

CONTROL SYSTEM OFF

Control System: Dust Suppression
Type of Sampling: Respirable Dust
Testing Conditions: Control System Off
Crusher Throughput: 400 tph

DATE	SAMPLING(1) LOCATION	TIME	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m^3	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
			Control system off	°F	%		
9/28/83	E	8:58 a.m.	451.0	70	45	9/21/83	
		10:54 a.m.	320.5				
		1:33 p.m.	839.5				
10/11/83	E	11:15 a.m.	189.0	62	88	10/10/83	Slight misty rain at 2:45
		11:50 a.m.	814.7				
		1:57 p.m.	884.2				
		2:45 p.m.	968.5				
		3:40 p.m.	608.1				
11/17/83	E	9:23 a.m.	244.5	43	80	11/16/83	
		9:58 a.m.	251.2				
		1:28 p.m.	278.6				
		2:29 p.m.	374.0				
		3:05 p.m.	178.4				

TABLE 32. - RESPIRABLE DUST RESULTS FOR HAMMERMILLS-TO-BELT CONVEYOR #7 - CONTROL SYSTEM OFF (Con'd)

	9/28/83	10/11/83	11/17/83
CONTROL SYSTEM "OFF"			
Arith. Mean Dust Concentration (mg/m^3)(2):	609.1	713.2	285.6
Standard Deviation:	460.9	321.2	113.0
Standard Error:	163.0	85.8	30.2
Coefficient of Variation (%)(3):	75.7	45.0	39.6

(1) E - End of the settling box.

(2) Refer to section 4.2.5. for explanation.

(3) Coefficient of Variation = Standard Deviation/Mean Dust Concentration.

5.2.1.2. Results

1) Although the GH system used more water than the Sonic system, it was far superior to the Sonic system in controlling respirable dust emissions at this transfer point. However, the results for the Sonic system cannot be generalized to different transfer points or to different environments. The lower efficiencies for the Sonic wet dust suppression system at this transfer point are attributed to:
   - The high turbulence in the impact zone of the belt conveyor
   - The high average velocity of the dust-laden air (400 ft/min; 2 m/s) in the settling box
   - The high dust concentrations.
2) The GH system performance was good because the nozzles were strategically located and the hammermill acted as a good mixing chamber for water and material.

Figures 73 through 76 show photographs of "E" and "S" locations with and without the dust suppression systems "on."

5.2.2. Conveyor Belt #11-to-Conveyor Belt #4

The dust control system at the conveyor belt #11-to-conveyor belt #4 transfer point consisted of the Sonic wet dust suppression system. Sampling was not conducted at "T" locations because the dust collection system installed at the secondary crusher-to-belt conveyor #4 transfer point could have affected the dust concentrations at this tranfer point.

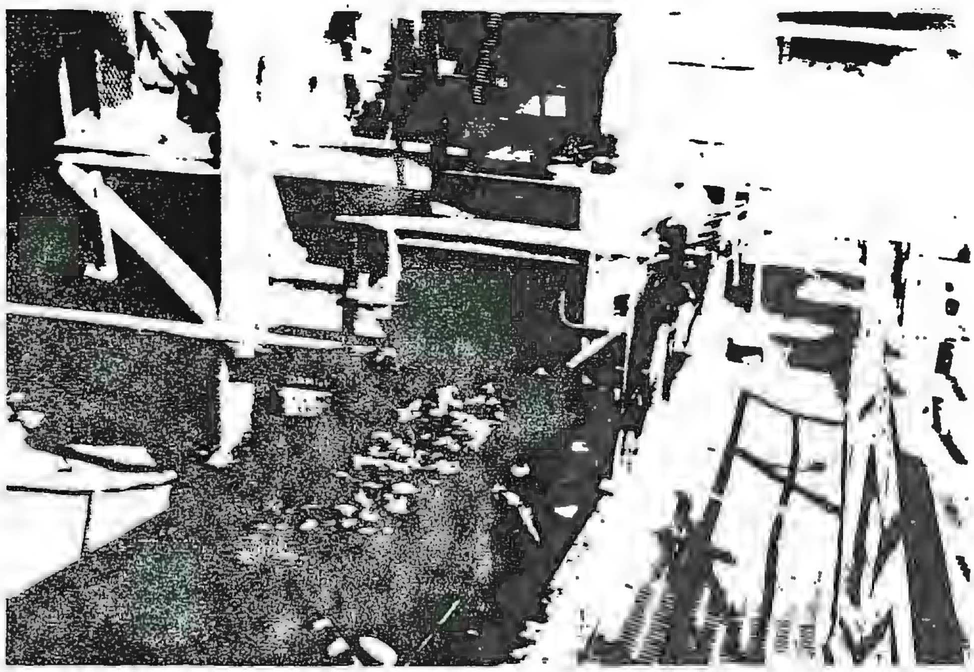


FIGURE 73. - "E" location at the hammermills-to-belt conveyor #7 transfer point. GH and Sonic system "on."

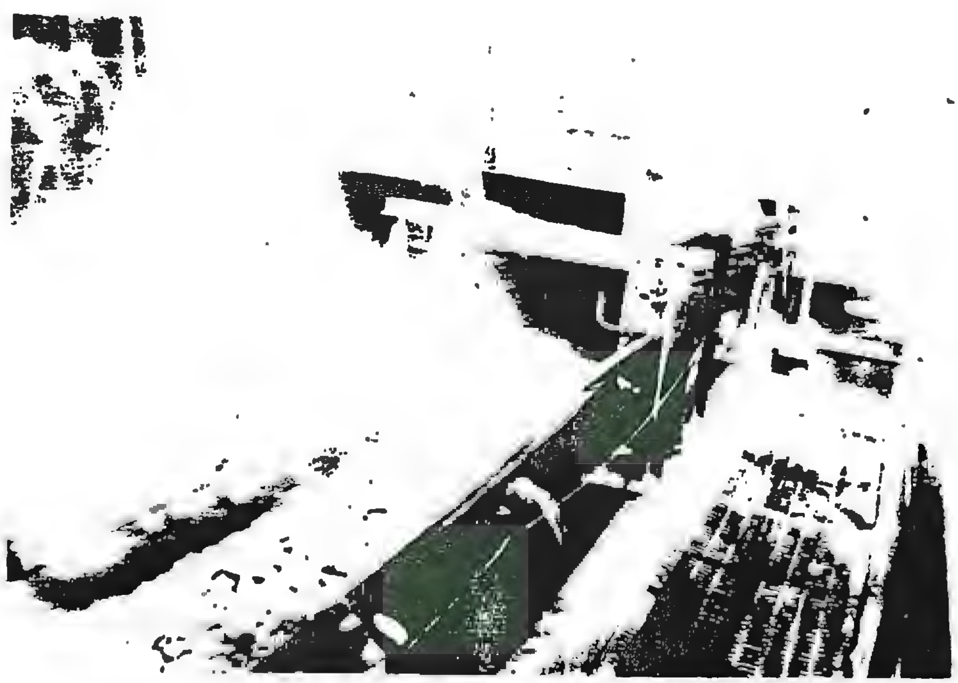


FIGURE 74. - "E" location at the hammermills-to-belt conveyor #7 transfer point. GH and Sonic system "off."

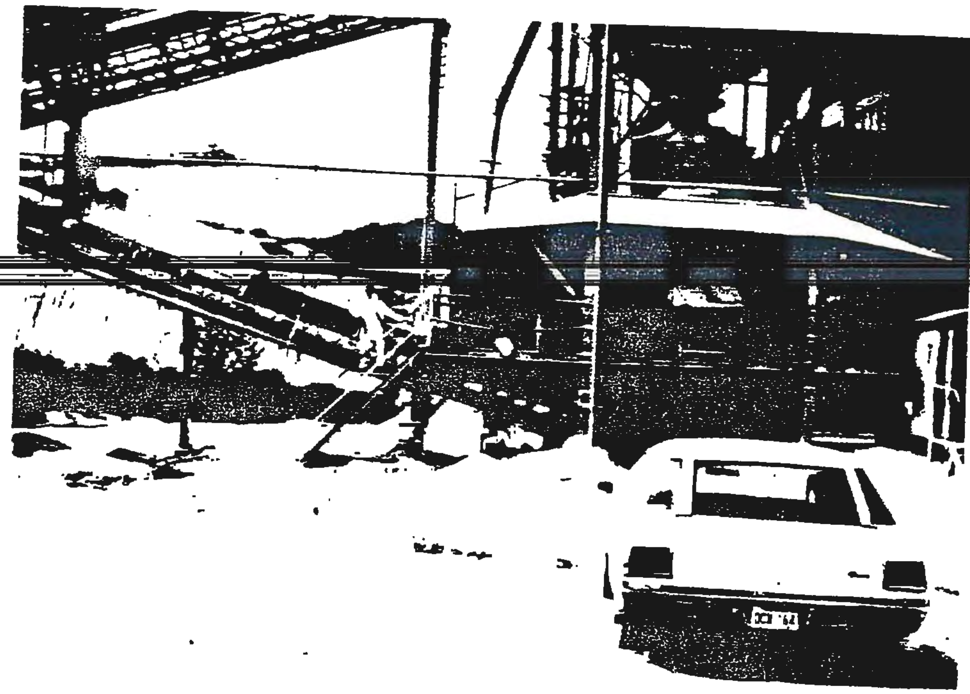


FIGURE 75.- "S" location at the hammermills-to-belt conveyor #7 transfer point. GH and Sonic systems "on."

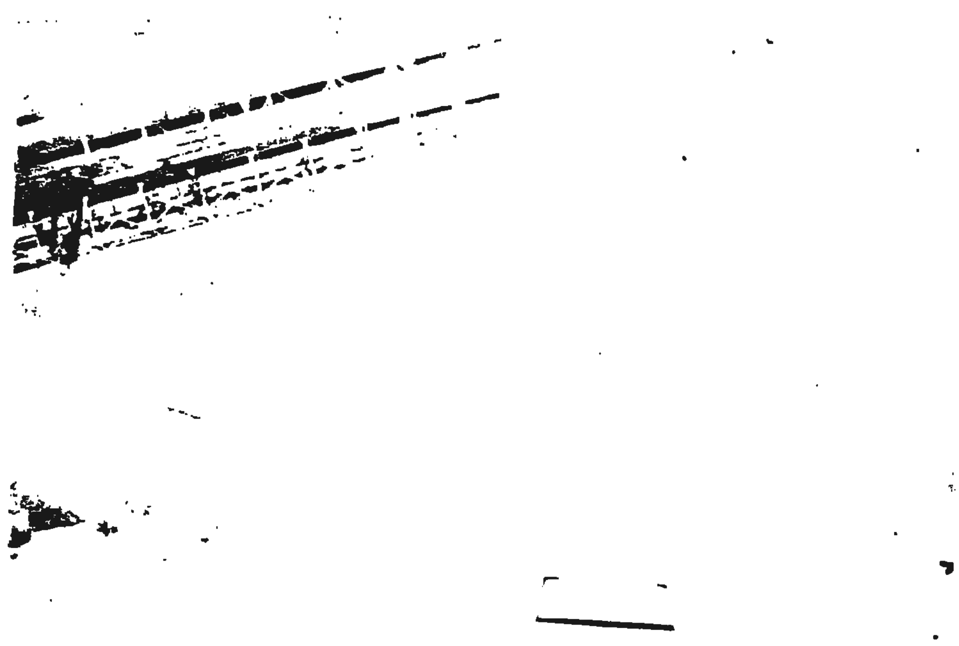


FIGURE 76.- "S" location at the hammermills-to-belt conveyor #7 transfer point. GH and Sonic systems "off."

Table 33 presents the respirable dust emission and performance data for the Sonic wet dust suppression system. These data indicate that:

1) The Sonic wet dust suppression system achieved a 72.7% mean control efficiency at "E" locations; however, the mean dust concentrations with the control system "on" were still high — 54.8 mg/m^3.

2) The bulk material handling system was operating satisfactorily, since the dust concentrations with the dust control system "off" were only 1.6 mg/m^3 at "S" locations.

The Sonic system seemed to work better at this transfer point than at the hammermills-to-belt conveyor #7 transfer point (discussed earlier). The reasons are believed to be lower turbulence and lower average air velocity.

TABLE 33. - RESPIRABLE DUST RESULTS FOR BELT CONVEYOR #11-TO-BELT CONVEYOR #4

Control System: Dust Suppression
Type of Sampling: Respirable Dust
Testing Conditions: Sonic System: Water Pressure = 10-14 psig, Water Flow Rate = 6-6.5 gph/nozzle, Number of Nozzles/Spray Bar = 2, Compressed Air Pressure = 55-60 psig, Compressed Air Flow Rate = 9.5 Scfm/nozzle, Number of Spray Bars = 1

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m^3		SYSTEM EFFICIENCY	TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off	System on	%	°F	%		
7/11/83	E	322.2	114.3	64.7	90	50	over one week	
	S	2.8	1.1	60.7				
8/16/83	E	201.8	---	---	80	42	---	System off data are average of four sets.
	S	1.9	---	---				
8/17/83	E	76.4	---	---	80	49	---	System off data are average of four sets.
	S	0.9	---	---				
8/18/83	E	---	21.7	---	85	54	8/17/83	System on data are average of two sets.
	S	---	1.8	---				
8/19/83	E	---	31.7	---	89	35	8/18/83	System on data are average of four sets.
	S	---	1.0	---				
8/26/83	E	272.8	69.1	74.7	79	52	8/18/83	At 'E' location System off and on data are average of two sets.
	S	0.4	0.6	?(3)				

TABLE 33. - RESPIRABLE DUST RESULTS FOR BELT CONVEYOR #11-TO-BELT CONVEYOR #4 (Con'd)

	SAMPLING LOCATION(1)	
	E	S
DUST CONTROL SYSTEM "OFF"		
Arith. Mean Dust Concentration (mg/m^3)(2):	200.8	1.6
Standard Deviation:	146.7	1.2
Standard Error:	26.4	0.3
DUST CONTROL SYSTEM "ON"		
Arith. Mean Dust Concentration (mg/m^3)(2):	54.8	1.3
Standard Deviation:	53.8	0.8
Standard Error:	11.2	0.3
CONTROL SYSTEM PERFORMANCE		
Mean Control System Efficiency (%):	72.7	16.1
Standard Error:	6.6	23.5
95% CONFIDENCE LEVELS (APPROXIMATE)		
Control System Off Concentration (X) (mg/m^3):	$147.1 < X < 254.6$	$0.9 < X < 2.3$
Control System On Concentration (Y) (mg/m^3):	$31.6 < Y < 78.0$	$0.8 < Y < 1.9$
Control System Performance (E) (mg/m^3):	$59.4 < E < 86.0$	$0.1 < E < 64.6$

(1) E - End of the settling box.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

(3) Control System efficiency is not computed because mean concentration with Control System 'off' was lower than mean concentration with Control System 'on'.

*** 6. DESIGN GUIDELINES

6.1. INTRODUCTION

This chapter contains guidelines for designing an effective dust control system for some commonly encountered transfer points involving belt conveyors, crushers, screens etc., in mineral processing operations. Although the nature of dust emissions varies significantly from facility to facility and depends on the type of equipment and processes used, how well the equipment is maintained, the type of material being processed, weather conditions, etc., these guidelines can be a useful tool for designing dust control systems for specific conditions.

Most of this information is discussed in greater detail in previous chapters; the purpose of including this simplified version here is to provide an overall view of dust control concepts to a novice reader.

In general, adequate dust control at any transfer point can be achieved by a combination of properly designed bulk material handling components and dust suppression or collection systems. Although the dust collection and suppression systems treat the dust emission problem directly, the importance of well-designed bulk material handling components for reducing dust generation and emissions should not be underestimated.

The guidelines presented here for designing dust collection or wet dust suppression systems are based on the assumption that the recommended bulk material handling system has been implemented. The following transfer points are discussed:

1) Belt-to-belt conveyor

2) Crusher-to-belt conveyor

3) Vibrating screen-to-belt conveyor

4) Belt conveyor-to-vibrating screen

5) Vibrating screen-to-bin.

Sections 6.2 through 6.4 illustrates the design criteria common to all the transfer points, while Section 6.5 describes the application of dust control systems to specific transfer points.

6.2. BULK MATERIAL HANDLING SYSTEMS FOR DUST CONTROL

Proper design of bulk material handling components should be the first step in designing a dust control system for a transfer point. Since most transfer points covered under this program included a belt conveyor and a transfer chute, the following discussion primarily deals with the bulk material handling considerations for these two elements. However, basic design guidelines for bulk material handling components for other equipment, such as vibrating screens, crushers and storage bins, are also provided.

6.2.1. Belt Conveyors

Belt conveyors emit dust exclusively from four points:

1) The tail pulley where material is received

2) The head pulley where material is discharged

3) The return idlers (due to the "carryback" of fine dust on the return belt)

4) The sides of the conveyor.

The following factors must be considered in designing belt conveyors.

6.2.1.1. Belt Loading

The amount of dust generated at a belt conveyor transfer point depends partially on how the material is initially loaded on the belt. Belt loading should meet the following criteria:

1) ~~The material should be loaded centrally on the belt.~~
2) The material should enter the belt travelling in the same direction and at the same speed as the belt whenever possible.

These measures will reduce turbulence in the material and thus decrease dust generation.

6.2.1.2. Impact at Loading Point

Adequately spaced (1-ft centers) impact idlers should be located at the transfer point (fig. 77) to absorb the impact of the incoming material and prevent deflection of the belt between the idlers. These measures will reduce dust leakage under the skirting rubber seals.

6.2.1.3. Conveyor Skirting

Figure 78 shows the conventional skirting ("knife-edge") design. This design is not recommended because the vertical rubber seals tend to wear out quickly, requiring frequent adjustment of the rubber to prevent dust leakage. This maintenance is time consuming and, hence, often neglected.

Figure 79 shows the recommended skirting design. This design has the following important features:

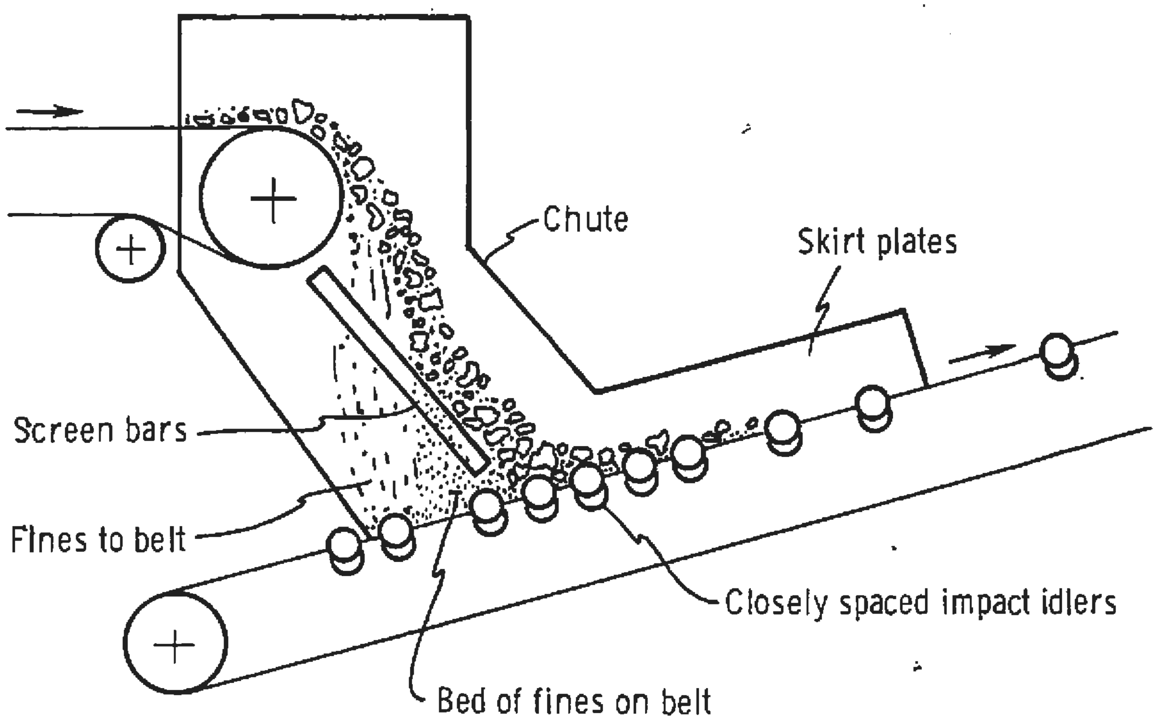


FIGURE 77. - Impact idler location.

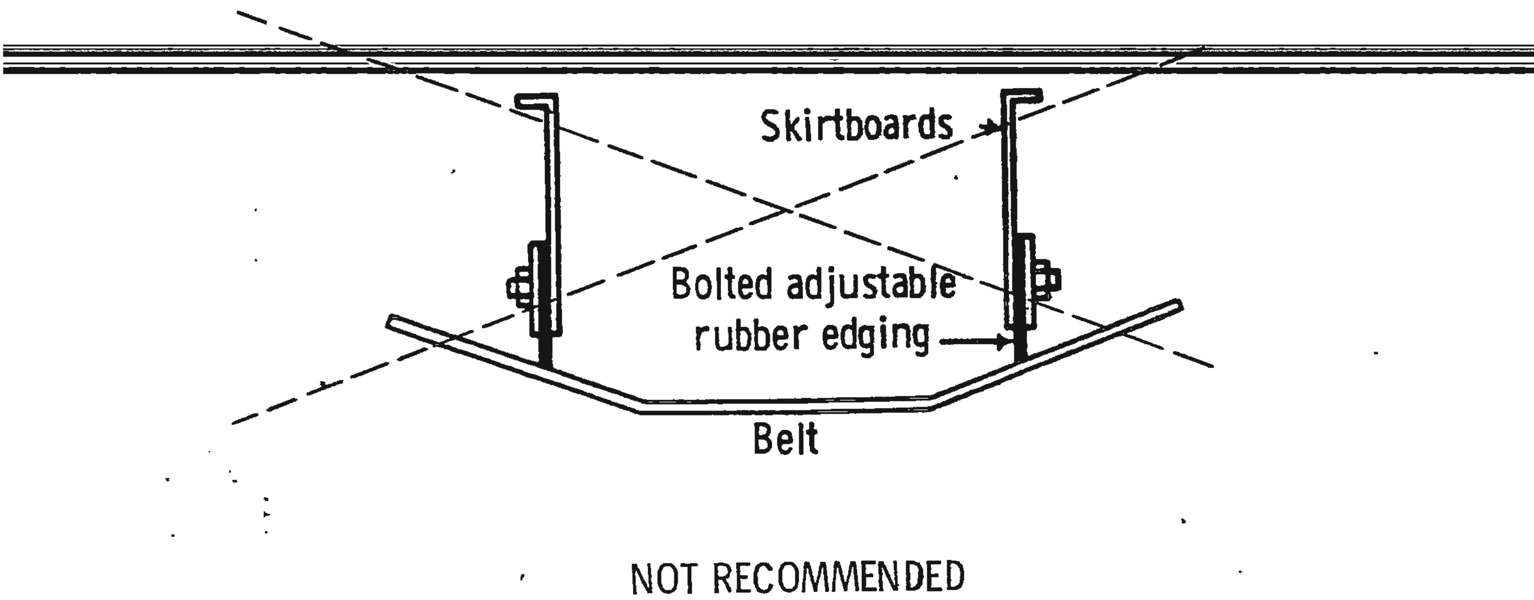
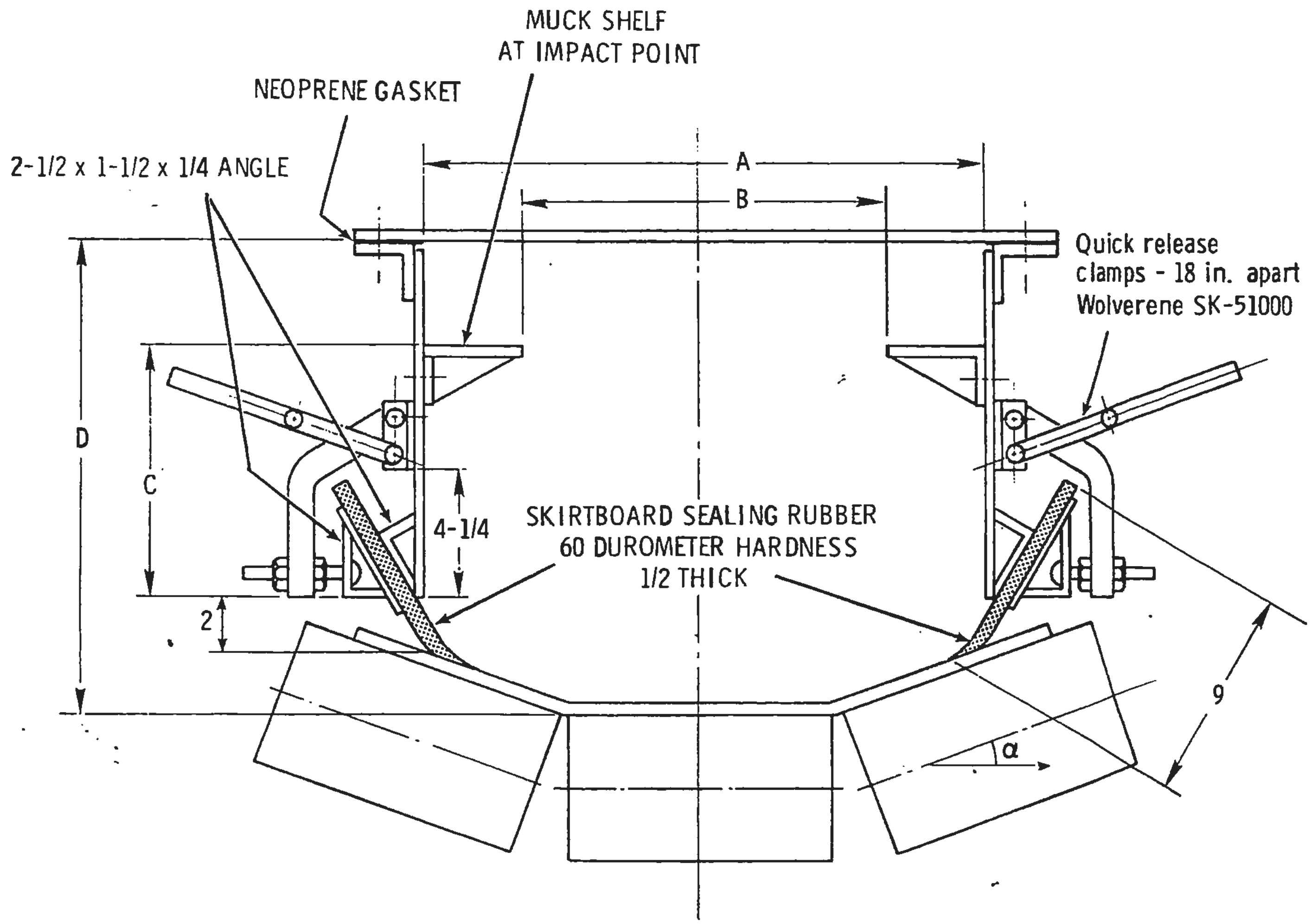


FIGURE 78. - Conventional skirting design.



Belt Width	A	B	C*	D
24	24	15	6	18
30	30	20	8	21
36	36	24	9	27
42	42	30	10	32
48	48	36	12	36

All dimensions in inches.

* This dimension may vary depending on rock size.

FIGURE 79. - Recommended skirting design.

1) The skirtboard is high and wide enough to accommodate both the material volume and the pressure surges caused by the inflowing material and induced air.

2) The inclined skirting rubber provides greater wear area.

3) The flexibility of the inclined skirting rubber allows it to rest on the moving belt at all times.

4) The skirting rubber is 1/2 in. thick and 60 to 65 durometer hardness.

5) Quick-disconnect clamps are used instead of conventional bolts to allow quick and easy adjustment.

6) The top edges of the skirtboard are covered and sealed with self-adhesive neoprene rubber gaskets.

6.2.1.4. Conveyor Capacity

The belt conveyor should be operated at 75% of its theoretical capacity. (The theoretical capacity of the belt conveyors can be calculated by the approach recommended by CEMA; Ref. 1.) This measure will reduce spillage, dust emissions, and wear on skirting rubber seals.

To bring the loading of existing installations into conformance with this specification, the following measures are recommended:

1) Increase belt speed.

2) Change idlers (e.g., from 20° to 35°).

3) Change the conveyor width (e.g., from 24 to 30 inches).

6.2.1.5. Belt Scrapers

A belt scraper should be installed at the head pulley of the belt conveyor to reduce carryback of fine materials on the return belt and to provide a cleaner belt surface. A scrapings chute should be installed to redirect the material removed by the belt scraper into the process stream or into a covered container.

6.2.1.6. V-Plows

A V-plow should be installed, as shown in figure 80, to clean the non-carrying side of the belt, thus preventing material and dust buildup on the tail pulley. This measure will also keep the belt properly aligned.

6.2.2. Transfer Chute Design

The function of a transfer chute is to transport material from one piece of equipment to another, primarily by gravity. The following general guidelines should be considered in designing a transfer chute:

1) To reduce air entrainment and wear, the chute should be sized adequately and its design should take into consideration the path or trajectory that material will tend to follow when it is discharged over a pulley. This path/trajectory is affected by a combination of gravity, belt speed, and pulley diameter. To avoid jamming, the chute should be at least three times the maximum lump size when lumps and fines are mixed in the product stream.

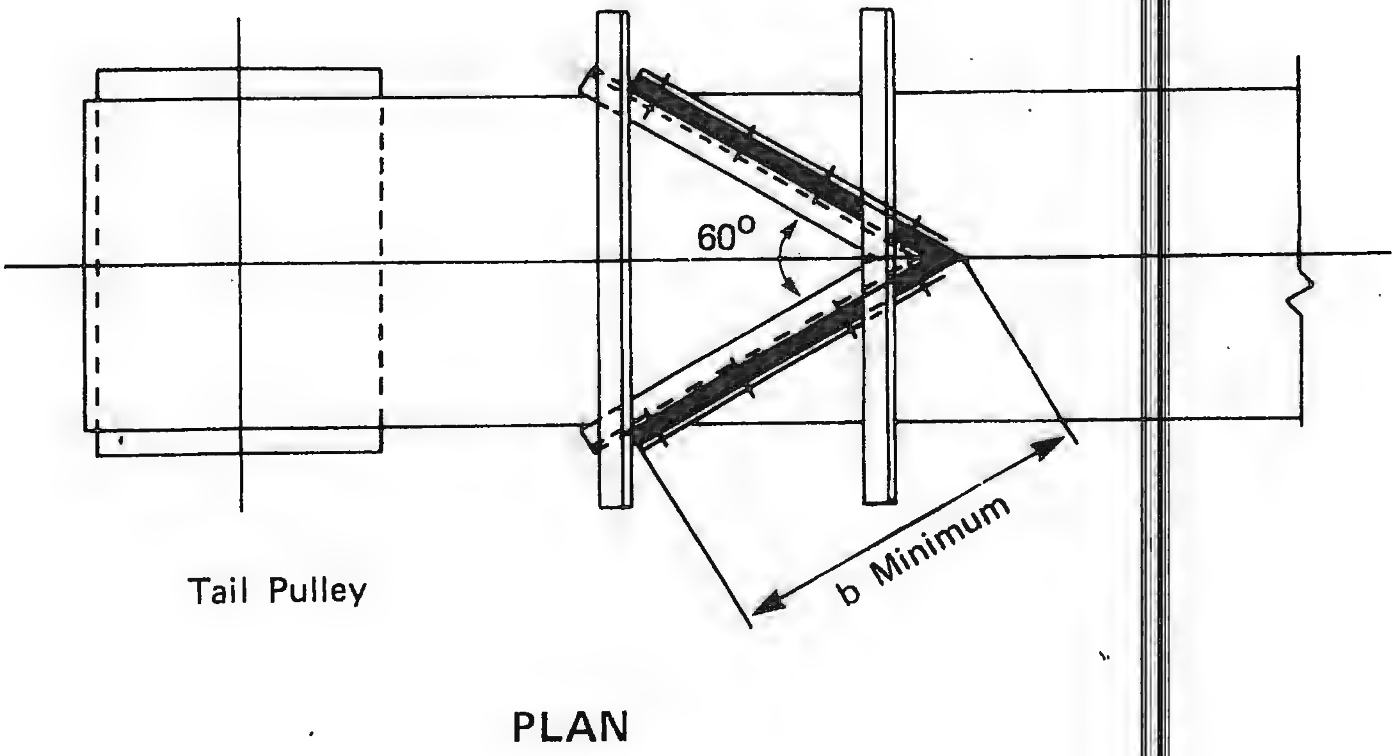


FIGURE 80. - V-Plow location.

2) Curved chute bottoms, perforated chute bottoms, or grizzly chutes should be used to place a layer of fines on the belt ahead of the lumps to avoid heavy impact from loading (fig. 81).

Whenever possible, the following components should be incorporated into a transfer chute.

6.2.2.1. Rockboxes

Rockboxes or stoneboxes should be used to absorb the impact of incoming material. Reducing impact reduces the wear and abrasion on the chute bottom, reduces the height of material fall, and also reduces dust emissions from the backspill rubber seal at the tail end of the conveyor (fig. 82).

6.2.2.2. Muckshelves

Muckshelves should be installed at the impact point for the following reasons:

1) They help load the material centrally on the belt and keep the belt properly aligned.
2) There is room for air to expand under the muckshelves, which reduces pressure surges.
3) They protect the inclined skirting rubber from the direct impact of the incoming material.

Refer to figure 79 for a typical muckshelf location.

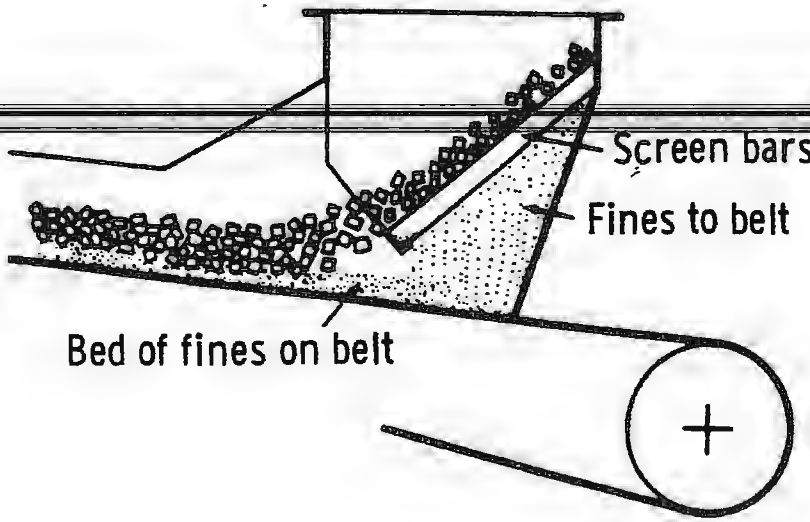


FIGURE 81. - Loading chute equipped with grizzly or screen bars to provide a layer of fine material ahead of impacting lumps.

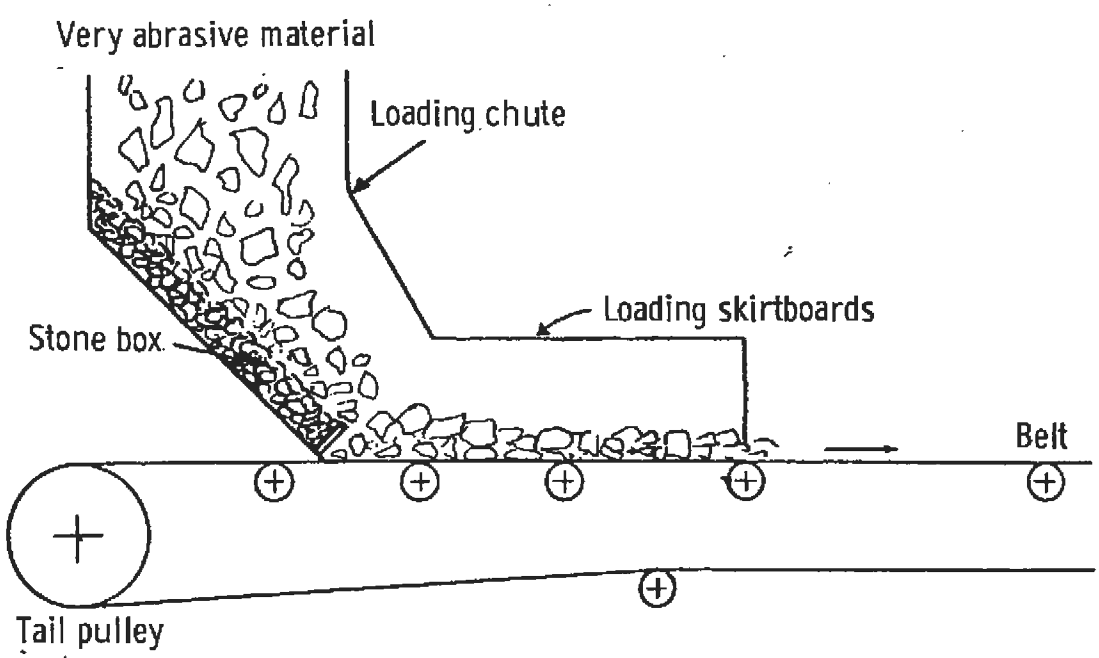


FIGURE 82. - Rockbox location.

6.2.3. Crushers

Dust generation at the crushers is due to a combination of new surfaces being created and violent rock motion. The dust is emitted primarily from the following two points:

1) Crusher discharge

2) Crusher feed.

Following the transfer chute design guidelines mentioned earlier will minimize dust emissions when the crusher discharges material through a transfer chute onto other equipment.

To reduce emissions at the crusher feed, the opening should be large enough to avoid jamming, but small enough to keep induced air volumes low. Choke feeding of the crusher is also recommended, whenever possible, to reduce induced air volume.

6.2.4. Vibrating Screens

A large amount of dust may become airborne due to the vibrations of screens that are not properly enclosed. The Trellex dust sealing system shown in figure 83 was found to be satisfactory in containing the dust emissions and reducing air entrainment.

6.2.5. Storage Bins

The storage bins should be completely covered to reduce dust emissions. An inspection door should be provided to check the level of material in the bin, if necessary. A level indicator with an alarm may also be installed to facilitate monitoring of the material level in the bin.

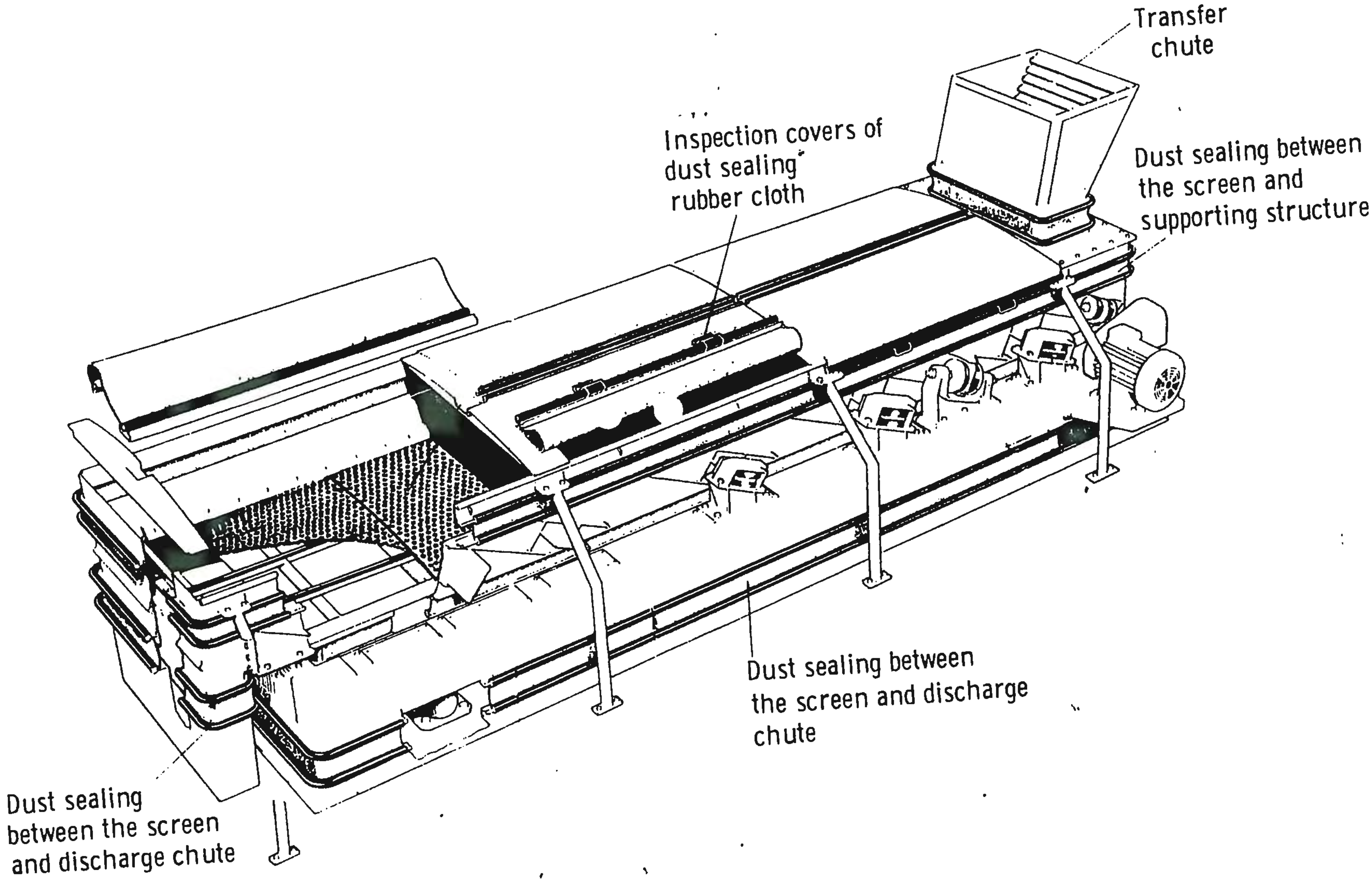


FIGURE 83. - Trellex dust sealing system.

6.3. DUST COLLECTION SYSTEM

A dust collection system is one of the most effective ways available to reduce respirable dust emissions. It is the only known "dry" method of capturing dust from the process stream.

A dust collection system has four major components (fig. 84):

1) An exhaust hood to capture dust emissions at the source
2) Ductwork to transport the captured dust to a dust collector
3) A dust collector to clean the dust-laden gases
4) A fan and motor to provide the necessary exhaust volumes.

Of the four major components, the design of the exhaust hood is most critical for efficient capture of dust emissions at a transfer point, and will be specifically addressed here. The principles of ductwork design, dust collector and fan selection, etc., are available in most standard reference manuals, such as the Industrial Ventilation Manual (3), and are not included here. Chapter 2 describes some of the important design and/or selection criteria for these components.

6.3.1. Exhaust Hood

The exhaust hood must be carefully designed because it is the capture efficiency of the exhaust hood and not the collection efficiency of a dust collector that is important from the occupational health standpoint. The degree of dust control at a transfer point depends upon the location of the exhaust hood and the rate of air flow through it, i.e., the exhaust volume.

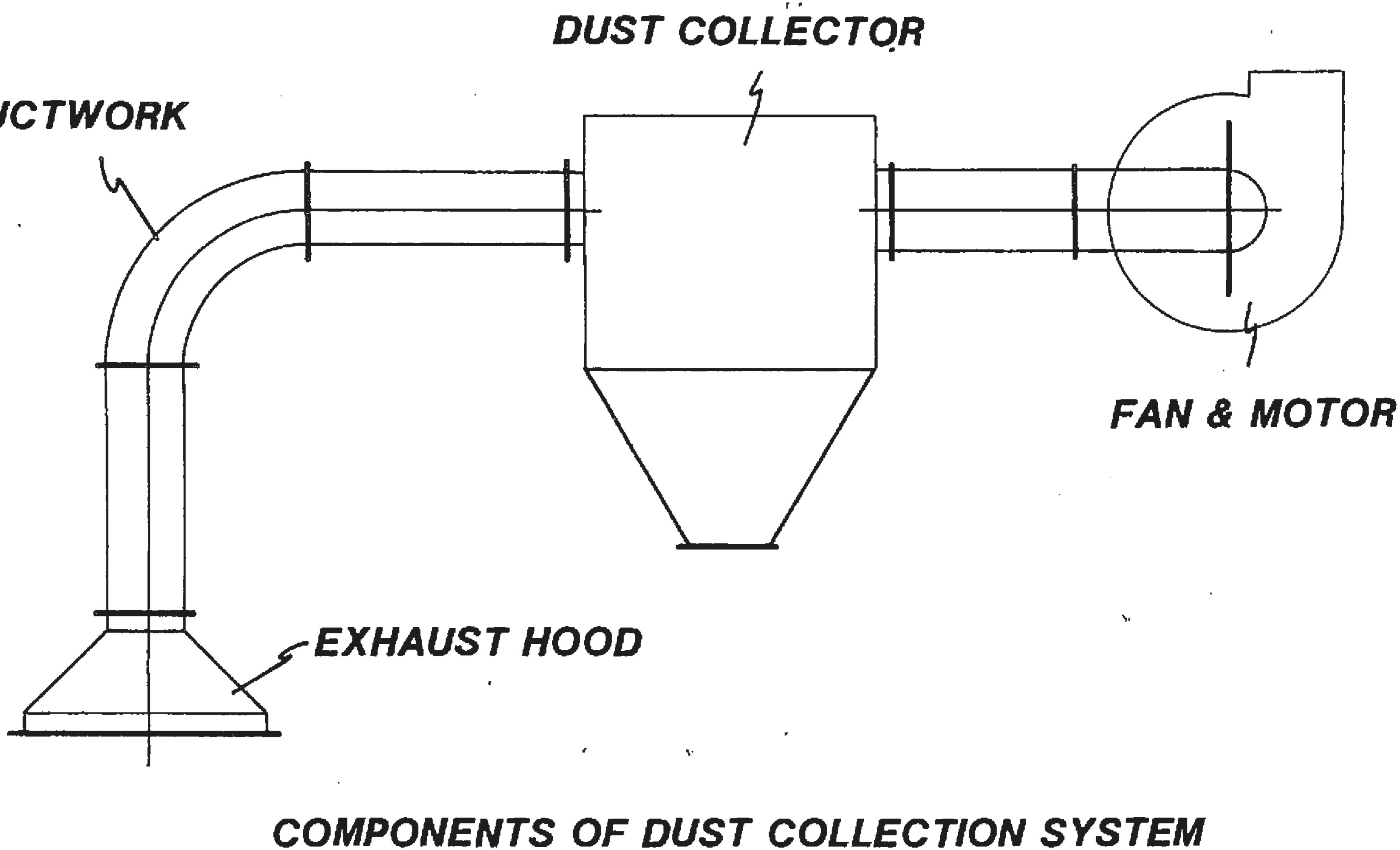


FIGURE 84. - Major components of a dust collection system.

6.3.1.1. Location

The exhaust hood should be located so that it captures predominantly respirable-sized dust. The coarser dust should be allowed to settle down in long and spacious enclosures. This arrangement will reduce dust concentrations in the exhaust stream, prevent unnecessary transportation of coarse and valuable product material, and also reduce the possibility of dust settling in the horizontal ducts.

6.3.1.2. Exhaust Volume

Determination of adequate but not excessive exhaust volume is the most important step in the design of a dust collection system. Two basic concepts commonly used in the industry are:

1) Air induction

2) Control velocity.

The air induction approach is the most generally applicable to calculating exhaust volumes because the calculations take into account the characteristics of a transfer point, such as the material feed rate, height of free fall, aggregate size, bulk density, etc.

The control velocity approach, on the other hand, has very limited use because it does not take into account these important variables. We, therefore, do not recommend this approach. It is discussed in greater detail in Chapter 2 for the readers who want additional information.

The Anderson approach, widely used in the industry to determine exhaust volume, is based on the air induction principle. It was found to be satisfactory for computing adequate exhaust volumes for some of the transfer points included in this program. Based on our past experience, we recommend its application in calculating exhaust volumes for many other transfer points.

6.3.1.2.1. Anderson Approach

Following is a brief outline of Anderson's approach. The relationship for induced air volume suggested is:

$$Q_{ind} = 10.0 \times A_u \times \sqrt[3]{RS^2/D}$$

where Q_{ind} = induced air flow, cfm,

A_u = enclosure open area at the upstream end (point where air is induced into the system by the action of the falling material), ft^2,

R = rate of material fall, ton/h,

S = height of fall, ft,

and D = average material particle diameter, ft .

In the above equation, the most important parameter is A_u, the open area at the upstream end through which air is induced. Its values for different equipment/transfer points are presented in Section 6.5 for specific transfer points.

Anderson suggests that for some transfer points, exhaust volume, Q_E, may not be the same as induced volume, Q_{ind}. He therefore arbitrarily defines the following relationships between Q_E and Q_{ind} for various transfer points:

Belt-to-belt transfer point	$Q_E = Q_{ind}$
Crusher-to-belt transfer point	$Q_E = 1/3\ Q_{ind}$
Belt-to-bin and chute-to-bin transfer point	$Q_E = 1/2\ Q_{ind}$

6.4. WET DUST SUPPRESSION SYSTEMS

By definition, wet dust suppression systems use liquids (mainly water) to control dust emissions. The dust control can be achieved primarily by one or a combination of the following approaches:

1) Preventive approach: The product is wetted so that it generates less dust.
2) Control approach: Through interaction with water droplets, the dust becomes too heavy to remain airborne, thus settling out.

The constraints on allowable water and the desired performance of the control system dictate the wet dust suppression approach to be used (i.e., preventive, control, or a combination of both). The degree of control achieved under the preventive approach depends on the extent of mixing between the material and water sprays. Thus, the use of surfactants may help water sprays to spread further onto the material and wet a greater surface area. On the other hand, small water droplet size (10–100 μm), high droplet velocity, high residence time, and low air turbulence are essential for the control type of dust suppression. The volume of water needed for the preventive approach may be significantly larger than for the control approach.

We recommend the use of the preventive type of wet dust suppression first, wherever possible, because it helps reduce the load on the dust control system. A control type of wet dust suppression system can then be installed, if necessary, to reduce the dust emissions further.

6.4.1. Selection of a Wet Dust Suppression Approach

Selection of the appropriate approach should be based on an engineering analysis of the facility. The plant should be surveyed in detail by a qualified engineer to determine operating conditions and the nature of the dust problem. Some of the factors to be determined are:

1) Type of material being handled
2) Material flow through the plant
3) Plant layout, including overall dimensions
4) Size, capacity, and type of crushers, conveyors, screens, bins, feeders, etc.
5) Retention time of material in bins or stock piles
6) Material temperatures at various transfer points
7) Water availability
8) Electrical service availability
9) Areas requiring protection against freezing
10) Major dust points and conditions that occur at these points during normal operation
11) Desired performance of the system.

6.4.2. Wet Dust Suppression Techniques

The various commercial wet dust suppression systems, both the preventive and control type, can be classified into three broad categories employing the following wet dust suppression techniques:

1) Water sprays
2) Water sprays with additives (i.e., surfactants, polymers, etc.)
3) Electrostatically charged fogs.

A detailed discussion of the mechanisms of wet dust suppression and the parameters affecting performance of wet dust suppression systems is included in Chapter 2. However, the salient features of some commercially available wet dust suppression systems are summarized in Table 34 to aid in system selection.

6.4.3. Designing a Wet Dust Suppression System

Wet dust suppression systems are quite popular in the mining industry; however, designing an effective wet dust suppression system requires a careful evaluation of the operations, materials, and processes involved.

The engineering analysis outlined in Section 6.4.1 should be conducted before any system is considered. The analysis will help identify the transfer points suitable for the application of specific wet dust suppression systems based on the product specifications, water availability, equipment, process, etc. The following steps in designing wet dust suppression systems are recommended.

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TABLE 34. - COMPARISON OF VARIOUS WET SUPPRESSION SYSTEMS

CONCEPT/SYSTEM	WATER REQUIREMENTS gph/nozzle pressure	AIR REQUIREMENTS: QUANTITY (cfm) PRESSURE (psi)	POWER REQUIREMENTS	DROPLET SIZE µm	ENCLOSURE REQUIREMENTS
I. WATER SPRAYS Sonic Development Corp. - Sonic Dry Fog	5-15 gph @ city water pressure	7 scfm/nozzle @ 65 psi	15 kW	1-10 µm to 200-600 µm; can be varied	As tight as possible to avoid excess turbulence - very critical
II. ELECTROSTATICALLY CHARGED FOG - INDUCTION RING METHOD - Ritten Corp. - Electrostatic fogger	Fogger I, 5-15 gph @ 60 psi Fogger II, 5-30 gph @ 60 psi Fogger III, 5-20 gph @ 60 psi	6 scfm/nozzle @ 100 psi	115 V, 60 Hz, 30W	60 µm (number median)	As tight as possible
III. ELECTROSTATICALLY CHARGED FOG - DIRECT CONTACT METHOD Aero Vironment Corp. - Electrostatically charged fog generator (Commercially unavailable at this time)	2-18 gph @ 2 gph no pump required - gravity feed above 2 gph water pump is necessary	Required but unspecified	115 V, 60 Hz, 1000W	90-100 µm (average number median) 200 µm (mass average)	Good enclosure essential
IV. WATER WITH SURFACTANT (foam) Deter Company, Inc. - Deter Microfoam System	2 @ 10 to 150 psi 5 @ 10 to 150 psi 10 @ 10 to 150 psi 10 @ 10 to 150 psi	10 cfm @ 100 psi 40 cfm @ 100 psi 80 cfm @ 100 psi 100 cfm @ 100 psi		100 to 200 microns	None, but aids the overall efficiency
V. WATER WITH SURFACTANTS PREVENTIVE TECHNOLOGY: Johnson-March Chem-Jet System	Depends on application but approximately = 0.5% of material to be treated	None	12 kW	Not specified	None, but aids the overall efficiency

NOTES: 1. Based on information supplied by manufacturer.
2. Annual operating costs are based on
- power cost = $0.05/kWh
- depreciation is based on a 5-year amortization period
- annual maintenance cost = 7% of capital cost.
- annual operating hours = 4,800

REQUIREMENTS FOR MAINTENANCE	ANNUAL OPERATING ($ x 10^3) COST	CHIEF ADVANTAGES	CHIEF DISADVANTAGES	COMMENTS
Nozzles, compressor	7.7 K (0.32 ¢/ton)	1. Low maintenance cost 2. Purely mechanical system with no moving parts 3. Low water contamination & no chemical contamination 4. Easy winterizing 5. 1:30 turndown ratio	1. Tight enclosure requirements, so cannot be used in open space nor in excessively turbulent zone 2. In very dry conditions, evaporative losses could be significant, and it would be necessary to increase droplet size 3. Resonator cap is a fragile component and may need frequent replacement or adjustments.	It is difficult to differentiate between the fog and the dust to visually evaluate the effectiveness of the system.
Fan, pump, electric insulation, compressor, nozzles	Not available	1. No chemical contamination; low water contamination 2. Flexibility to change to to +, −, or neutral fog	1. High capital cost 2. Good insulation essential	All the droplets may not be charged by the induction ring method, especially at high flow rates.
Fog thrower, fan, pump, electric insulation	Not available	1. Flexibility to change to +, −, or neutral fog 2. Very attractive for lower fraction of respirable dust if it carries predominantly one type of charge	1. High capital cost 2. Electrical insulation very critical 3. Highly charged droplets - explosion hazard in underground operation	Not yet commercially available
Metering device, pumps, nozzles, compressor	79.5 K (3.32 ¢/ton)	1. Carryover effect 2. Enclosure tightness not critical	1. High operating costs 2. Not suitable when use of surfactant is objectionable 3. Not attractive, if crusher or screen follows the transfer point	
Metering device, pumps, nozzles	9.4 K (0.4 ¢/ton)	1. Carryover effect 2. Enclosure tightness not critical	1. High working cost 2. Not suitable when surfactant is objectionable 3. Not attractive if crusher or screen follows the transfer point because of packing or clogging.	

6.4.3.1. Select Nozzle

The nozzle is the heart of the wet dust suppression system. The physical characteristics of the spray must be appropriate for its intended application. The flow rate, operating pressure, angle of spray, spray pattern, droplet size distribution, and droplet velocity are all characteristics of the nozzle. Following is a general discussion about types of nozzles and some of their parameters affecting dust control performance.

6.4.3.1.1. Nozzle Selection Criteria

The nozzle should be selected based on the following criteria:

1) Droplet size: The droplet size distribution is the most important characteristic of a nozzle for dust suppression. For a given nozzle, droplet size decreases as operating pressure increases. Most manufacturers can provide droplet size data at various operating pressures. For the preventive-type wet dust suppression system, we recommend coarser droplets (200-500 µm). For controlling airborne dust, very fine droplets on the order of 10-50 µm are required. The fine droplets are usually generated by fogging nozzles, which normally use compressed air to atomize water in the desired droplet range. For very turbulent conditions in the vicinity of the dust source, the fine droplets may be ineffective for dust suppression.

2. Spray pattern: Nozzles fall into three basic categories depending on the spray patterns produced: solid cone, hollow cone, and flat sprays (fig. 85).

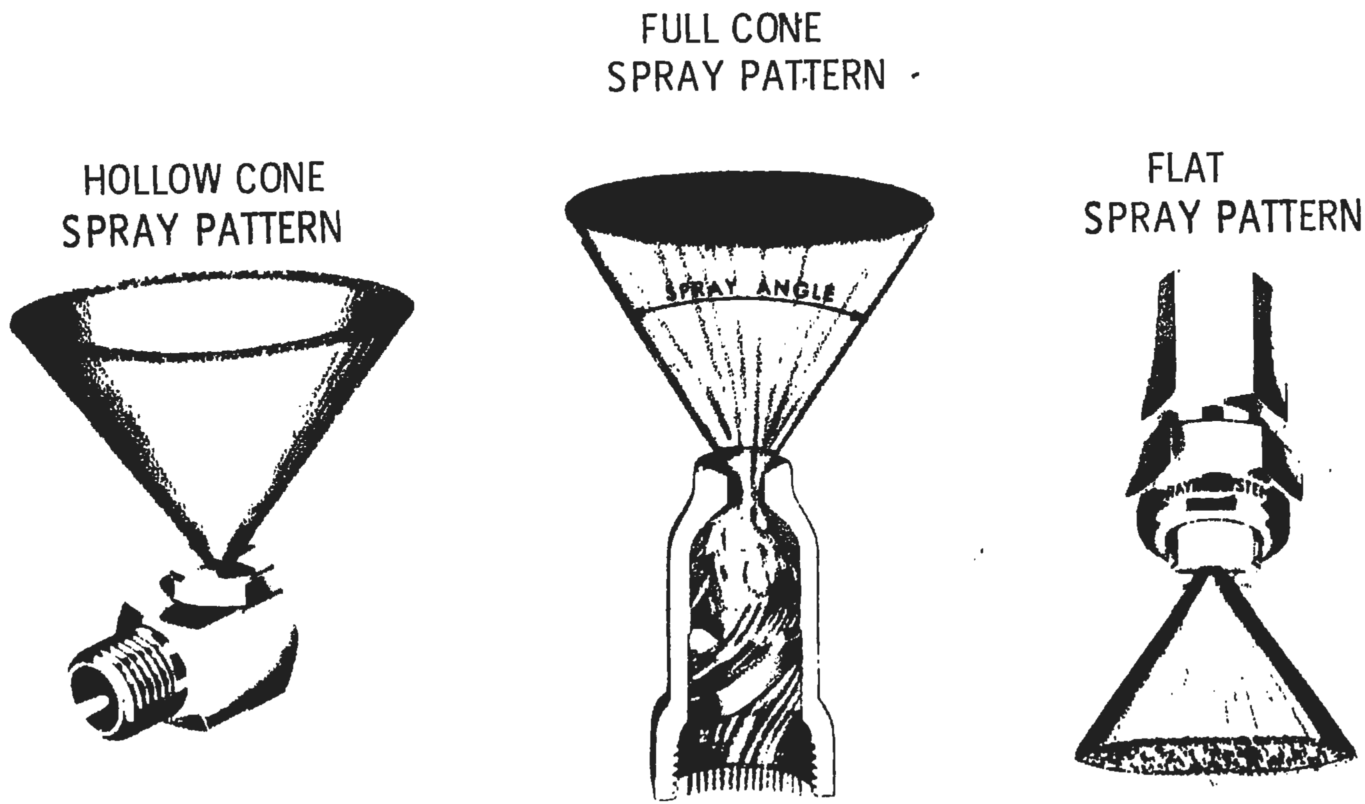


FIGURE 85. - Basic categories of nozzles based on spray patterns.

- Solid cone: Solid cone nozzles produce droplets that maintain a high velocity over a distance. They are therefore recommended for preventive-type wet dust suppression systems where the spray has to reach over longer distances.
- Hollow cone: These nozzles generally produce smaller droplets. They are usually not used for dust suppression applications.
- Flat spray: The droplets produced are relatively large and are delivered at high pressure. These nozzles are useful in preventive dust control applications.

3) Spray angle: Each nozzle has a characteristic spray angle, available from the manufacturer. A knowledge of spray angle and spray pattern is essential to determine the area of coverage of a nozzle, and, therefore, the total number of nozzles needed to control dust for a required area.

4) Flow rate: The flow rate through any nozzle depends on the operating pressure according to the following relationship:

$$\text{Flow rate} = K \times \sqrt{\text{operating pressure}}$$

where K = nozzle constant.

Flow rate determines how much material can be treated per unit time.

5) Droplet velocity: Higher droplet velocities are desirable for dust suppression applications.

6.4.3.2. Select Nozzle Location

The nozzle should be located so that:

1) It is readily accessible for maintenance.
2) It is not in the path of flying material.
3) For preventive applications, it should be located prior to the point where new surfaces are being created and where maximum mixing between material and water can be achieved. For control applications, it is located where maximum residence time for the water droplets can be obtained.

6.4.3.3. Determine Water (and Air) Flow Rate and Pressure Requirements

Once the nozzle is chosen, its spray pattern and area of coverage allow the designer to derive flow rates (water and air) and pressure requirements from the literature published by the nozzle manufacturers. These must be carefully coordinated with the maximum allowable water usage.

6.4.3.4. Design the Piping, Insulation, and Heat Tracing

The piping should be designed so that each nozzle receives water and/or air at specified flow rates and pressures. Drains must be provided at the lowest point in each subcircuit to flush the air and water lines in winter months. Heat tracing and insulation must be provided at facilities where the ambient temperature may drop below 30°F. The heat tracing tape should be able to provide approximately 4 watts per linear foot for water pipes up to 2 in. in diameter. The pump and other hardware, such as valves, gauges, etc., should also be heat traced and insulated.

6.4.3.5. Select the Instrumentation

A few inexpensive instruments, such as pressure and flow gauges, are recommended to ensure consistency in system performance. The instruments should be located as close to the point of application as possible. Liquid-filled pressure gauges and rotameter-type flow meters were found to be very satisfactory during the present program.

6.4.3.6. Select the Pump, Compressor, Etc.

An appropriate pump (and compressor) should be selected once the water (and air) delivery rates and pressure are determined.

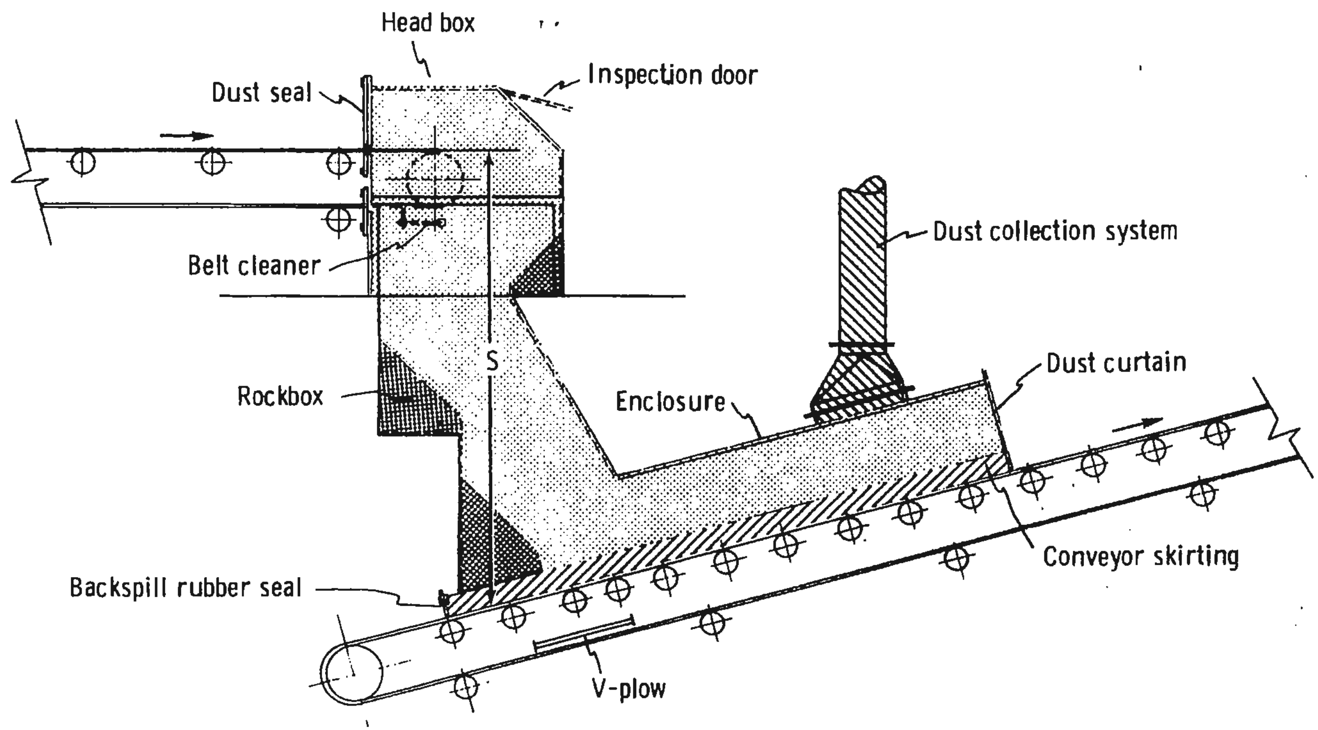
6.5. ILLUSTRATIONS OF DUST CONTROL SYSTEMS

6.5.1. Dust Collection System

1) Belt-to-belt transfer point (fig. 86)
2) Impactor crusher-to-belt transfer point (fig. 87)
3) Belt-to-vibrating screen transfer point (fig. 88)
4) Vibrating screen-to-belt transfer point (fig. 89)
5) Vibrating screen-to-bin transfer point (fig. 90)

6.5.2. Wet Dust Suppression System

1) Hammermill crusher-to-belt transfer point (fig. 91)
2) Belt-to-belt-transfer point (fig. 92)



$$Q_E = 10 \times A_u \times \sqrt[3]{\frac{RS^2}{D}}$$

Where,

Q_E = Exhaust volume, cfm

A_u = 0.5 x feed conveyor belt width, ft^2

R = Material feed rate, ton/h

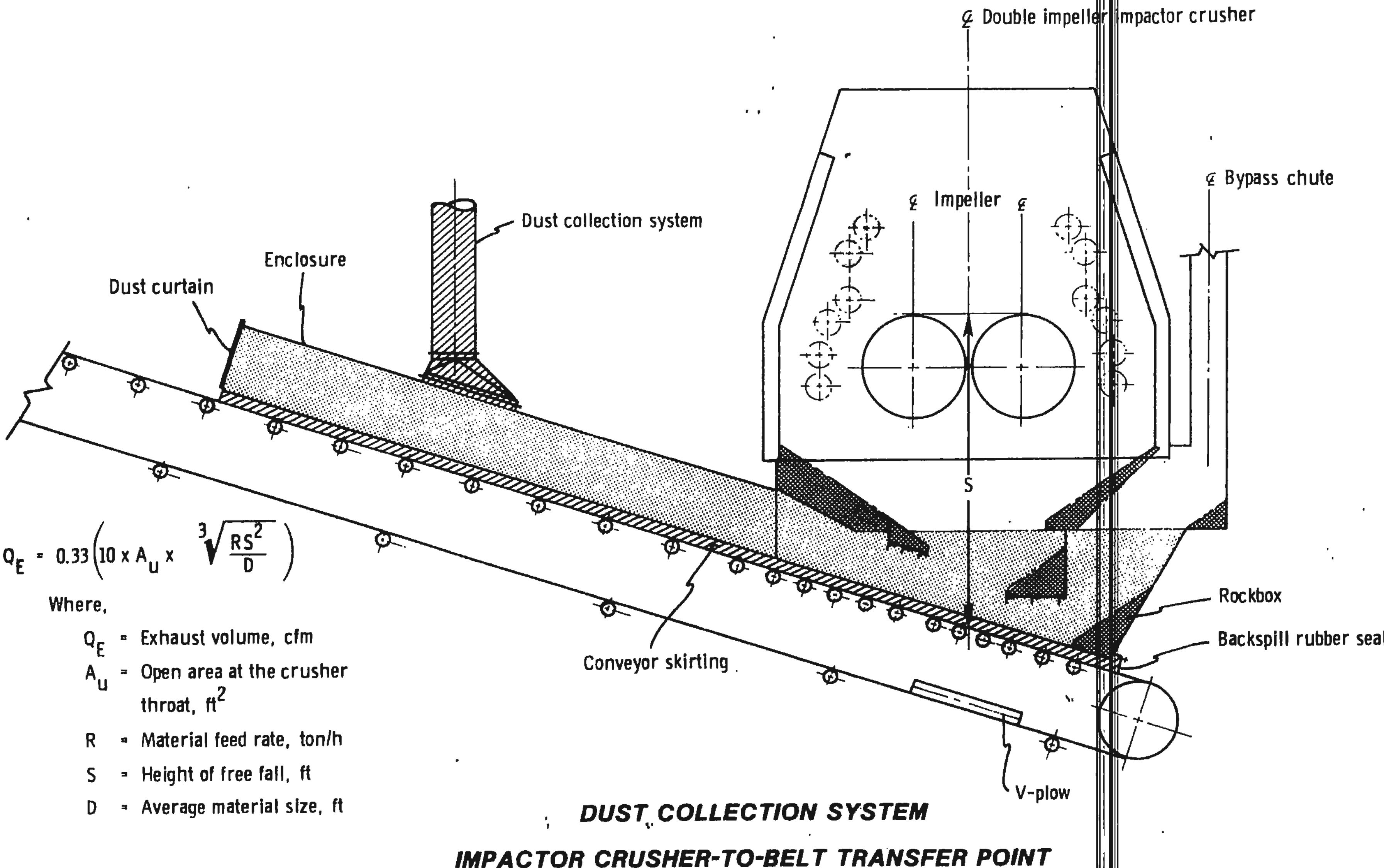
S = Height of free fall, ft

D = Average material size, ft

DUST COLLECTION SYSTEM

BELT-TO-BELT TRANSFER POINT

FIGURE 86. - Dust collection system: Belt-to-belt transfer point.



$$Q_E = 0.33\left(10 \times A_u \times \sqrt[3]{\frac{RS^2}{D}}\right)$$

Where,

Q_E = Exhaust volume, cfm

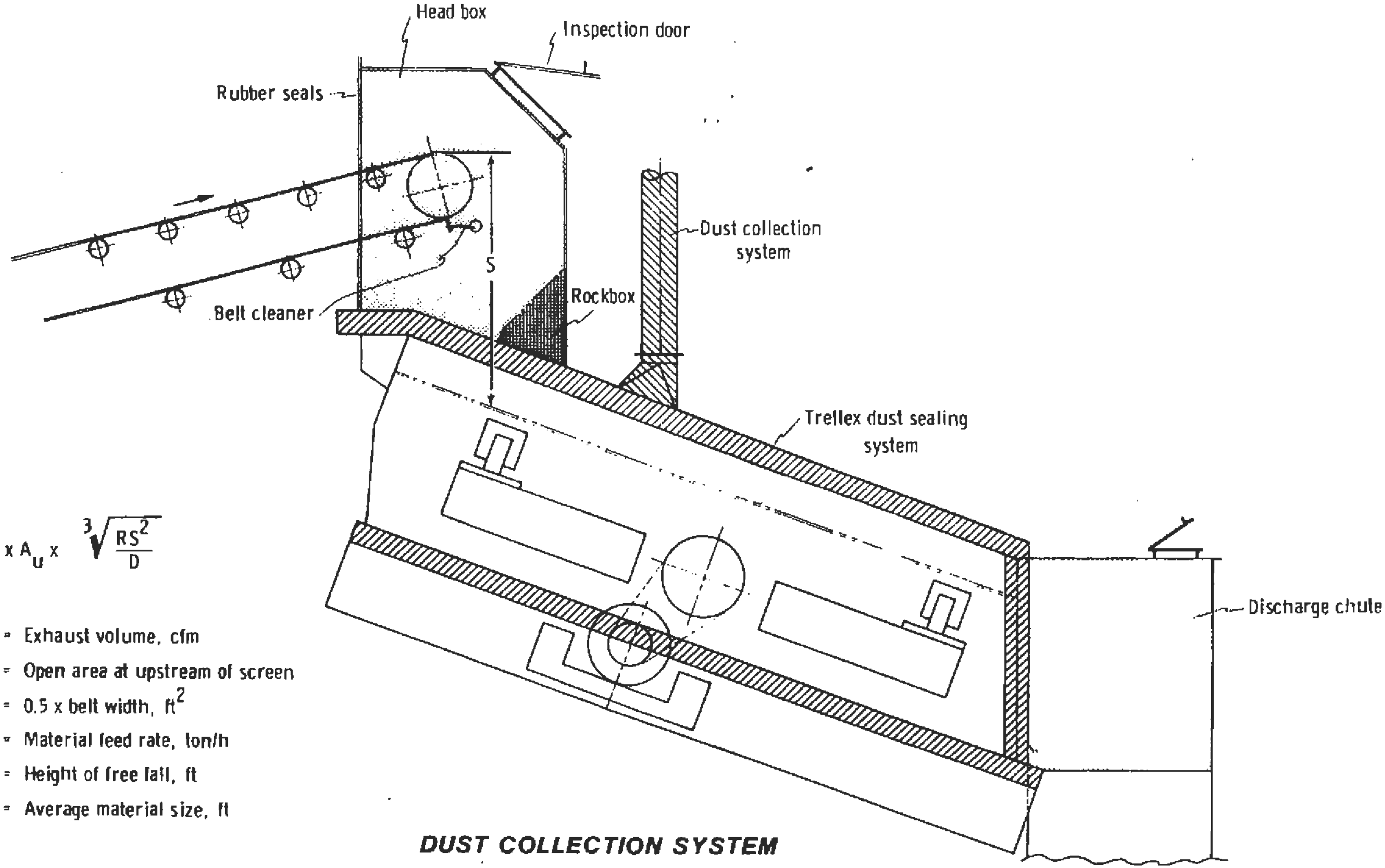
A_u = Open area at the crusher throat, ft^2

R = Material feed rate, ton/h

S = Height of free fall, ft

D = Average material size, ft

FIGURE 87. - Dust collection system: Impactor crusher-to-belt transfer point.



$$Q_E = 10 \times A_u \times \sqrt[3]{\frac{RS^2}{D}}$$

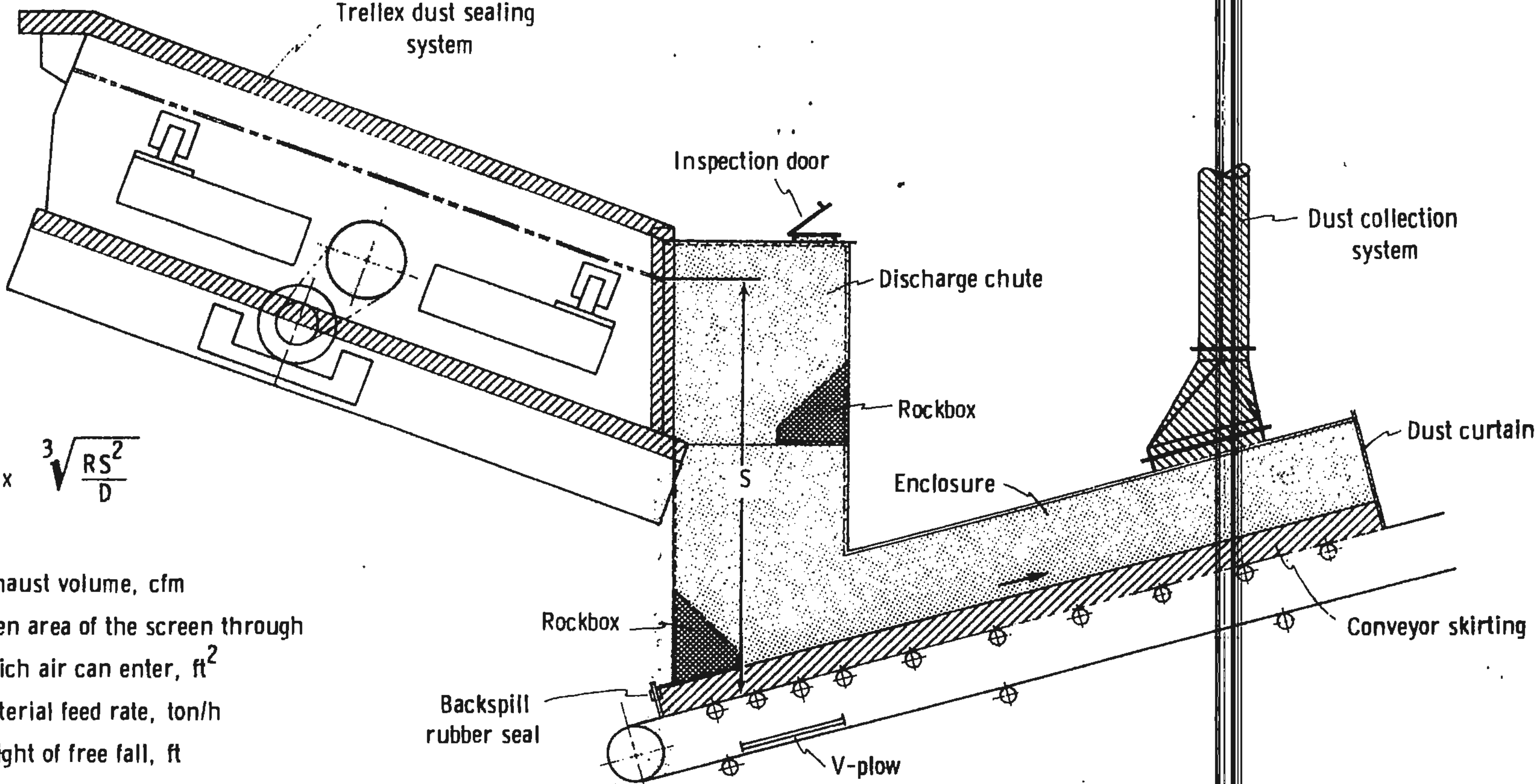
Where,

- Q_E = Exhaust volume, cfm
- A_u = Open area at upstream of screen = 0.5 x belt width, ft^2
- R = Material feed rate, ton/h
- S = Height of free fall, ft
- D = Average material size, ft

DUST COLLECTION SYSTEM

BELT-TO-VIBRATING SCREEN TRANSFER POINT

FIGURE 88. - Dust collection system: Belt-to-vibrating screen transfer point.



$$Q_E = 10 \times A_u \times \sqrt[3]{\frac{RS^2}{D}}$$

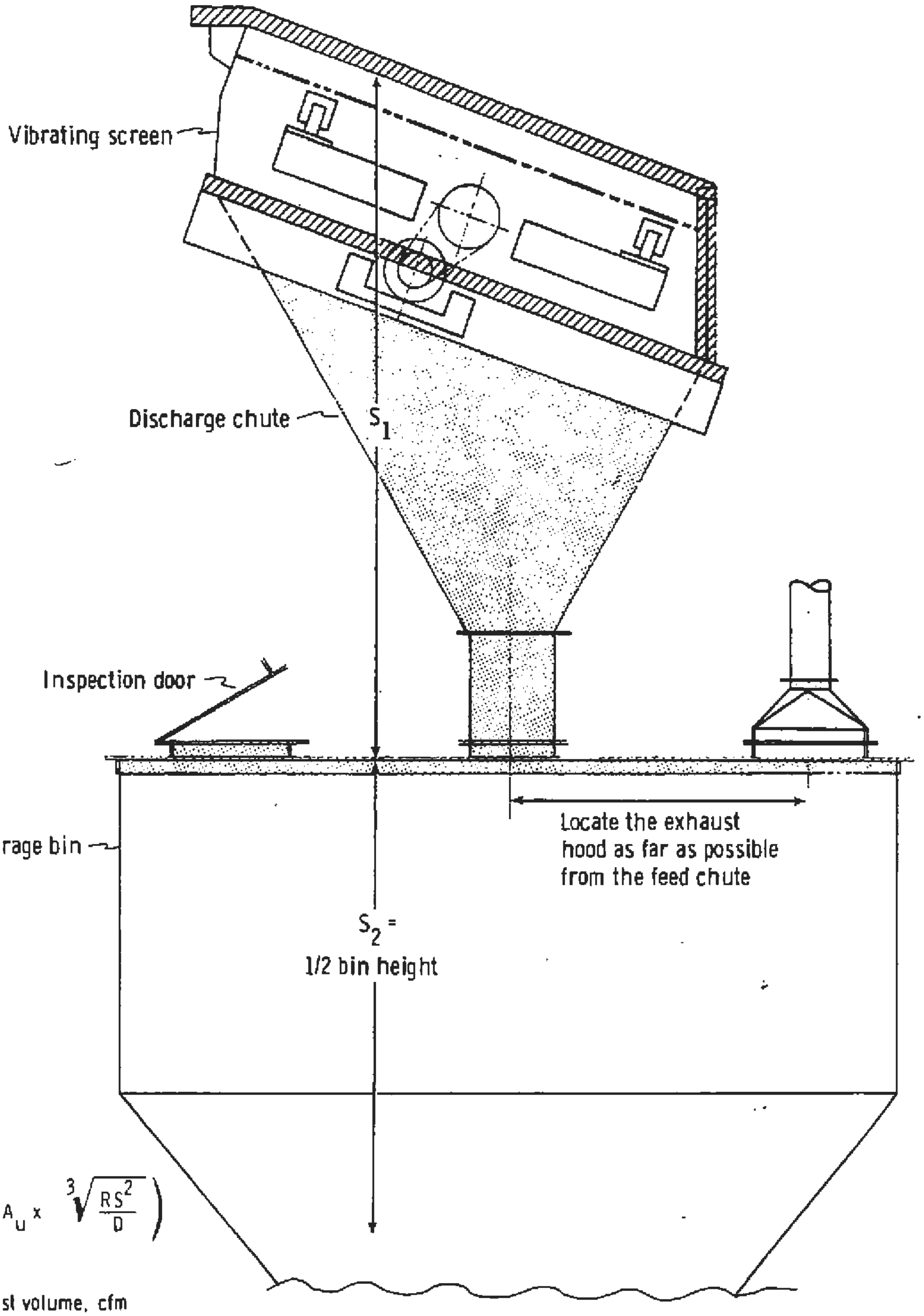
Where,

- Q_E = Exhaust volume, cfm
- A_u = Open area of the screen through which air can enter, ft^2
- R = Material feed rate, ton/h
- S = Height of free fall, ft
- D = Average material size, ft

DUST COLLECTION SYSTEM

VIBRATING SCREEN-TO-BELT TRANSFER POINT

FIGURE 89. - Dust collection system: Vibrating screen-to-belt transfer point.



$$Q_E = 0.5 \left(10 \times A_u \times \sqrt[3]{\frac{RS^2}{D}}\right)$$

Where,

Q_E = Exhaust volume, cfm

A_u = Open area of the screen through which air can enter, ft^2

R = Material feed rate, ton/h

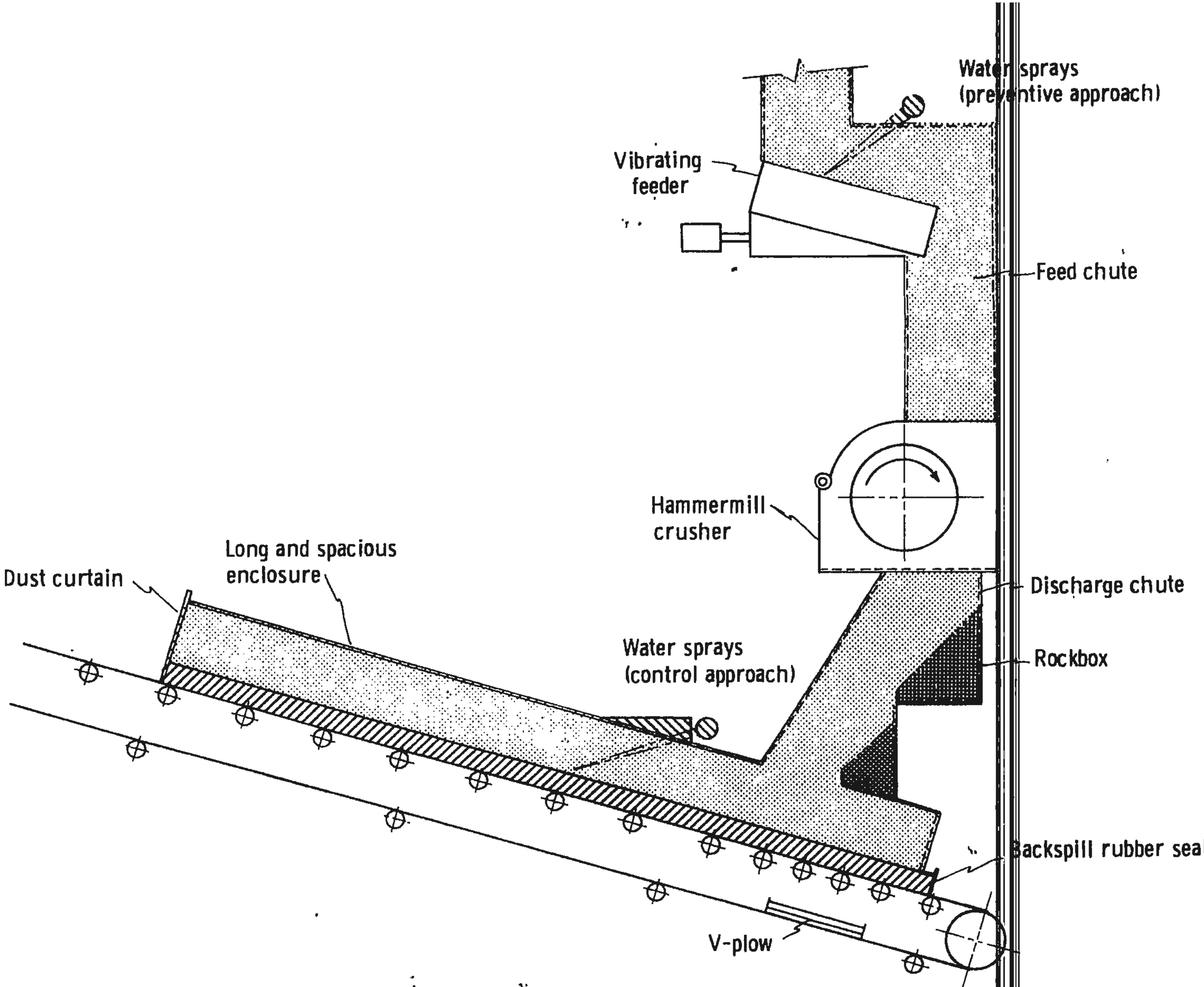
S = $S_1 + S_2$ = height of free fall, ft

D = Average material size, ft

DUST COLLECTION SYSTEM

VIBRATING SCREEN-TO-BIN TRANSFER POINT

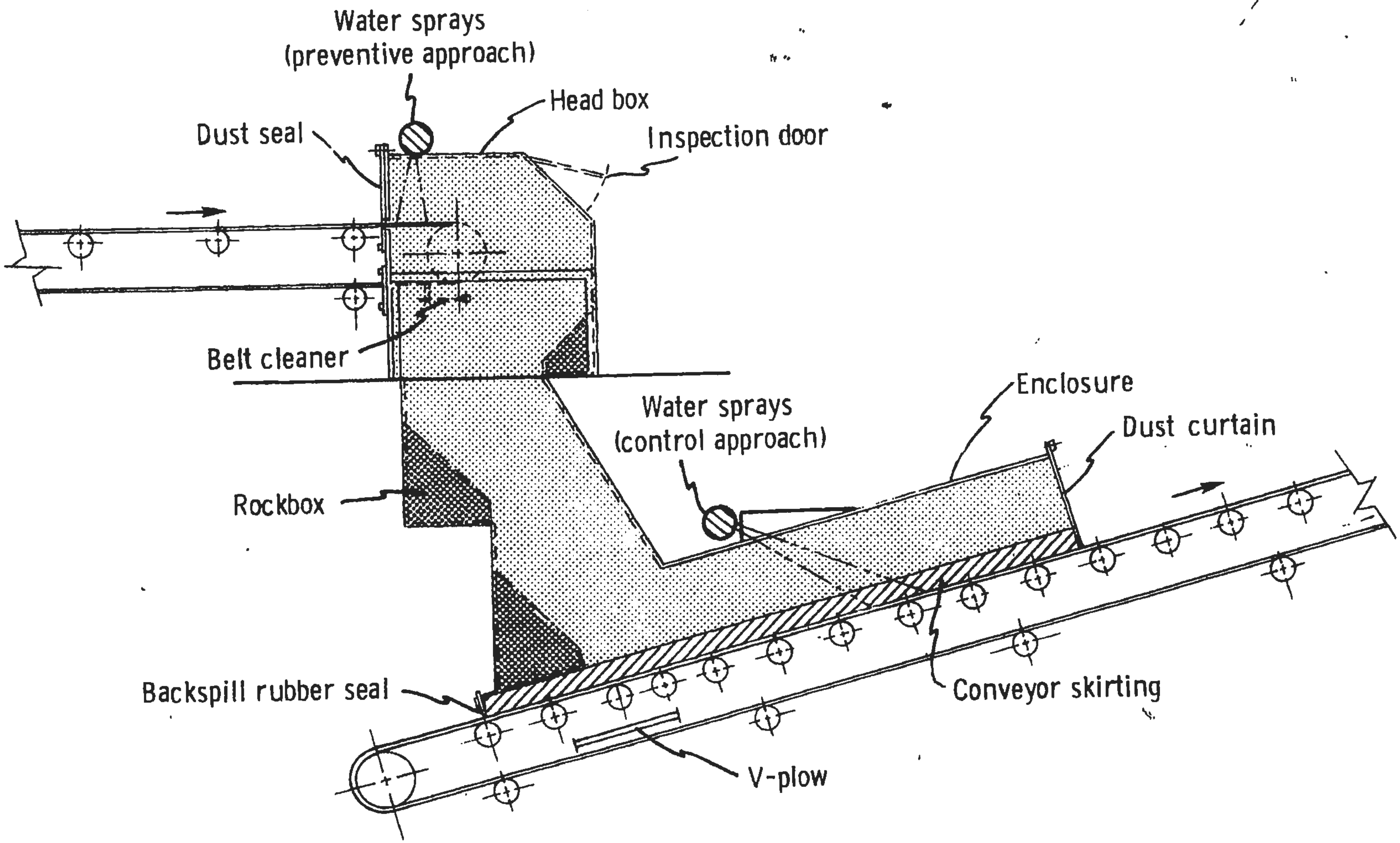
FIGURE 90. - Dust collection system: Vibrating screen-to-bin transfer point.



WET DUST SUPPRESSION SYSTEM

HAMMERMILL CRUSHER-TO-BELT CONVEYOR TRANSFER POINT

FIGURE 91. - Wet dust suppression system: Hammermill crusher-to-belt transfer point.



WET DUST SUPPRESSION SYSTEM

BELT-TO-BELT TRANSFER POINT

FIGURE 92. - Wet dust suppression system: Belt-to-belt transfer point.

*** 7. SUMMARY AND CONCLUSIONS

The primary objective of the program was to apply existing technologies to reduce respirable dust emissions from a wide variety of belt conveyor transfer points in use in mining operations. Accordingly, dust control systems based on state-of-the-art technologies were installed at 10 of the most commonly encountered belt conveyor transfer points. These transfer points were selected from the primary, secondary, and tertiary crushing circuits so that control system performance could be evaluated under variable operating and processing conditions.

In Phase I of the program, we critically reviewed the state of the art of dust control technologies, and selected those to be used in field testing. In Phase II, we designed and installed systems based on these technologies, and in Phase III, we field tested the installed systems during an 18-month period at a test site provided by Genstar Corporation.

The dust control systems installed consisted of:

1) Bulk material handling components to reduce dust generation and emissions and to contain dust at the source

2) A dust collection system to capture airborne respirable dust or a wet dust suppression technique to control airborne dust or to prevent dust from becoming airborne.

Our work during Phase I indicated that use of suitable bulk handling components, such as rockboxes, enclosures and dust seals, improved conveyor skirting, etc., could play a significant role in reducing respirable dust emissions from transfer points. The rockboxes were installed to decrease the height of free fall, and to provide smooth transfer of material, thus reducing turbulence and dust generation. They

After appropriate bulk material handling components were installed to reduce the generation and dispersion of the dust, dust control systems -- dust collection or wet dust suppression -- were then installed to control the remaining dust.

The Phase I work established that dust collection is the only known dry method for controlling dust emissions at a transfer point. Of the four main components of a dust collection system, we found that the exhaust hood is the most important element for occupational health considerations because it is the capture efficiency of the exhaust hood that is important for respirable dust control and not the collection efficiency of the dust collector. Designing an effective exhaust hood critically depends on accurately determining adequate exhaust volume; however, the Phase I work showed that many of the existing rules-of-thumb and empirical formulas used in calculating exhaust volumes lead to an unacceptably broad range of exhaust volumes.

We further found that no comprehensive approach exists that is suitable for calculating proper exhaust volumes for a wide variety of transfer points in mining operations. Therefore, the major emphasis in the design of a dust collection system for capturing airborne respirable dust emissions at the transfer points was on determination of adequate, but not excessive, exhaust volumes.

The review of state-of-the-art wet dust suppression techniques during Phase I indicated that these systems can be classified into two broad categories: preventive (prevent dust from becoming airborne) or control (remove airborne dust). Both approaches have advantages and disadvantages. The degree of dust control achieved under the preventive approach depends on the extent of mixing between the material and water. In the control approach, on the other hand, the critical parameters for effective operation are small water droplet size (comparable to airborne dust particles), high droplet velocity, high residence time, and low air turbulence. We also collected information on various commercially available systems and evaluated them against a uniform set of criteria, such as predicted effectiveness, capital and operating costs, reliability during freezing weather conditions, and applicability to a wide range of belt conveyor transfer points. On the basis of this assessment, the Sonic Dry Fog Development Corporation system was selected and recommended to the Bureau for field testing and evaluation in the subsequent phases of the program.

Phase II of the program included the detailed design and installation of the prototype dust control systems at the following transfer points:

<u>Dust Collection System</u>

Primary crusher-to-belt conveyor #1

Secondary crusher-to-belt conveyor #4

Belt conveyor #7-to-belt conveyor #8

Belt conveyor #4-to-vibrating screen

Vibrating screen-to-belt conveyor #5

Vibrating screen-to-storage bins #1 and #5

<u>Wet Dust Suppression System</u>

Hammermill crushers-to-belt conveyor #7

Belt conveyor #11-to-belt conveyor #4

In Phase III, we evaluated the installed dust control systems to establish their effectiveness and reliability. During the field tests, several problems were found and remedied.

1) Some of the belt conveyors were skewed with respect to adjoining equipment, i.e., their centerlines did not coincide. This resulted in uneven loading of the conveyor and excessive wear on one side of the inclined skirting rubber due to rock impact. The situation was partially corrected by extending the muckshelf on the affected side.
2) The skirting design at the secondary crusher caused plugging of the secondary crusher, primarily because the peak throughput of the secondary crusher exceeded the theoretical capacity of the belt conveyor. To rectify the situation, the skirting design was expanded to account for such variations in production.
3) When the skirting rubber at the hammermill crushers-to-belt conveyor transfer point continued to wear out due to the direct impact of the incoming material from the hammermills, we installed double skirting attached to the existing muckshelves.
4) The Trellex rubber seals installed at the vibrating screen lasted initially for only about 2 months. The primary cause for this failure was inadequate slack in the rubber. The problem was resolved by installing new rubber cloth with adequate slack.
5) The belt scrapers installed initially were equipped with stainless steel blades that wore out quickly, probably due to excessive moisture in the material and its abrasiveness. This problem was rectified by installing tungsten carbide-tipped blades.

6) The resonators on the nozzles of the Sonic Dry Fog system repeatedly wore out or were damaged due to the rocks flying in all directions near the impact point at the hammermill crusher #1-to-belt conveyor #7 transfer point. Replacing the existing nozzles with shielded nozzles improved the length of the wear cycle, but results were still not considered satisfactory.

7) At the same transfer point, the higher air velocities within the enclosure (created by two hammermills acting as fans) not only carried the fine droplets but also the agglomerated dust particles out of the enclosure. Measures such as rubber curtains to increase the residence time and the interaction between droplets and dust particles improved the system's efficiency.

For the dust collection system, no major difficulties were encountered, and the system has been performing satisfactorily.

Our detailed conclusions for the overall program are presented below. They are based on actual field data and our observations from the systems designed and installed under the Bureau sponsorship. These conclusions are generally consistent with the initial indications derived from our Phase I study. It should be noted that our comments and conclusions are based on the systems at specific transfer points. Therefore, a careful evaluation should be made before these conclusions are generalized or extrapolated.

7.1. BULK MATERIAL HANDLING SYSTEM

1) The design of a bulk material handling system should be the first step in developing a dust control system. For new plants,

the bulk material handling systems should be incorporated at the design stage. For the older plants, they must be retrofitted along with the appropriate dust control system.

2) For a belt conveyor, dust is emitted from the side, the tail pulley, and the end of the settling box. The dust emissions from the side of the conveyor and the tail pulley are primarily due to spillage and puffing through the conveyor skirting and the rubber seals, and are more sensitive to changes in production rate. The exhaust hood, which is located some distance away (at the end of the settling box), is not as efficient in controlling dust at these points as it is for the end of the settling box. Very high exhaust volumes are needed to control dust puffing. Therefore, good sealing between the conveyor and the backspill rubber and the conveyor and the skirting is essential to obtain good results.

3) Even a well-designed dust control system can become ineffective if it is not maintained properly. Our inclined skirting design needed less maintenance and adjustments than the conventional straight edge skirting, but periodic checking and adjusting were still required. We found that at least monthly inspection and adjustment were necessary to keep it functioning properly.

4) A Trellex dust sealing system installed at the vibrating screen contained the dust emissions at the vibrating screen and also helped minimize the amount of induced entrained air in the entire screening circuit.

7.2. DUST COLLECTION SYSTEM

1) For a well sealed system at the vibrating screen and associated transfer points, the calculated exhaust volumes of 8,400 cfm to 11,600 cfm (based on the Industrial Ventilation Manual approach) and 7,600 cfm (based on Anderson's approach) were clearly overestimates. We found no difference in dust control system efficiency between 1,250 cfm and 8,400 cfm. At an exhaust volume of 1,250 cfm, the dust control system efficiency at all the sampling locations was over 65%, and the respirable dust concentrations were less than 5.5 mg/m^3 at all sampling locations.
2) The data and all visual observations showed that below a certain exhaust volume, the efficiency of dust collection decreased drastically at "E" locations (end of the settling box) for the primary crusher-to-belt conveyor and the secondary crusher-to-belt conveyor transfer points. Above this exhaust volume, however, efficiency remained almost constant. We, therefore, call this exhaust volume the "critical exhaust volume." This breakpoint is significant because the design exhaust volume must exceed the "critical exhaust volume" to achieve adequate and reliable dust control, but volumes greatly in excess (obtained at additional cost) will not lead to improvements in efficiency.
3) The data and our visual observations at "S" locations (side of the conveyor) for the primary crusher-to-belt conveyor and secondary crusher-to-belt conveyor transfer points indicated that the efficiency of dust control increased continuously

with increase in exhaust volume. We believe that in the range of practical exhaust volumes, the critical exhaust volume phenomenon does not exist at these locations.

4) The exhaust volumes calculated based on Anderson's approach were adequate in controlling both respirable and total dust emissions at "E" locations for the primary crusher-to-belt conveyor and the secondary crusher-to-belt conveyor transfer points. We believe that these results are applicable to any similar crusher-to-belt conveyor transfer points, provided that the bulk material handling system is designed and maintained as per the guidelines suggested in Chapter 6.

5) The exhaust volumes calculated based on the approach recommended in the Industrial Ventilation Manual for non-dusty material were inadequate for controlling dust at both the primary and secondary crusher transfer points. Therefore, we do not recommend this method for computing exhaust volumes for crusher-to-belt conveyor transfer points.

6) The efficiency of the dust control system is a nonlinear function of initial concentration, i.e., the efficiency depends not only on the exhaust volume of the collection system, but also on the initial dust concentration.

7.3. WET DUST SUPPRESSION SYSTEM

1) Dust generation at the hammermills (tertiary crushers) was substantially reduced by the addition of simple water sprays at strategic locations. A dust suppression efficiency of over

75% was obtained at all locations, primarily because of the good material-water mixing provided by the hammermills. The results obtained are unique for hammermill installations and may not be extrapolated to other types of crushers without further studies. However, these results demonstrate that even a small amount of water (0.07% of product weight), if properly mixed, can produce dramatic results. We recommend usage of such water sprays (weather and process permitting) to reduce dust generation, and also to reduce the load on any other dust control systems.

2) Based on test data in this program, it seems that the Sonic system alone may not be able to control respirable dust emissions effectively. However, it may be useful in supplementing other dust control techniques.

3) For "E," "S," and "T" (tail end of the conveyor) locations at the hammermills-to-belt conveyor transfer point, the Sonic wet dust suppression system efficiencies were only 43.9%, 37.3%, and 12.3%, respectively. The probable causes for the low efficiencies at these transfer points were:

   - High dust concentrations
   - High turbulence in the impact zone
   - High air velocities (approximately 2 m/s).

4) For "E" locations at the belt conveyor #11-to-belt conveyor #4 transfer point, the Sonic system proved to be 72.7% efficient; but, the dust concentration with the system operating was still high: 54.8 mg/m^3.

***8. FURTHER RESEARCH RECOMMENDATIONS

Phase I of the program established that adequate control of respirable dust emissions is possible through an integrated approach of first designing a bulk material handling system and then applying appropriate dust collection or wet dust suppression systems. This concept was demonstrated at some commonly encountered transfer points in a minerals processing plant in subsequent program phases. The conclusions from the program are based on specific equipment and processes used at the Genstar test facility, but the program has also led to definition of general critical design parameters for dust control systems at typical transfer points. The potential thus exists for using these design parameters to develop dust control systems at other commonly encountered transfer points.

Through numerous site visits and personal communications during the course of the program, we also discovered a general lack of awareness of state-of-the-art dust control technologies within the mining industry. We therefore suggest that a better method of technology transfer is needed, perhaps through audiovisual aids or more direct channels such as informal seminars. A comprehensive dust control handbook, which could be used by all personnel in the field, is also warranted. Other specific areas of recommended research are discussed below.

8.1. BULK MATERIAL HANDLING SYSTEM

The program demonstrated that exhaust volume requirements could be substantially reduced by use of a well-designed bulk material handling system. We therefore recommend that existing bulk material handling designs be optimized and new ones developed.

8.2. DUST COLLECTION SYSTEM

Our data indicated that none of the empirical formulas or rules-of-thumb widely used in the industry is universally applicable to all processes and equipment. Hence, we recommend fundamental research to determine the various parameters affecting exhaust volumes. In the meantime, a number of field research programs, similar to the present program, should be carried out to determine the applicability of various dust control approaches for other processes and equipment, such as:

1) Bulk loading and unloading operations
2) Truck unloading operations at the primary crusher
3) Crushing operations.

8.3. WET DUST SUPPRESSION SYSTEM

We have shown that at the hammermill-to-belt conveyor transfer point, effective control of dust emissions can be achieved through use of simple water sprays. We believe that a similar potential exists for controlling dust at other processes and equipment and recommend further work in the following areas:

1) Fundamental research in the areas of water and material mixing, fluid penetration, dust agglomeration and settling, and airborne dust capture by liquid droplets
2) Applied research in the design and testing of wet dust suppression systems at various transfer points.

8.4. SAMPLING HARDWARE

We encountered considerable difficulties in testing the Sonic wet dust suppression system because it produces very fine water droplets. These fine droplets, along with the heavy dust concentrations and high air velocities at the hammermills, invalidated the conventional sampling strategy of using a 10-mm nylon cycle to pre-separate the respirable dust. Since wet dust suppression systems are widely used and fine droplets are becoming more common in commercially available systems, better sampling hardware for testing wet dust suppression systems is needed.

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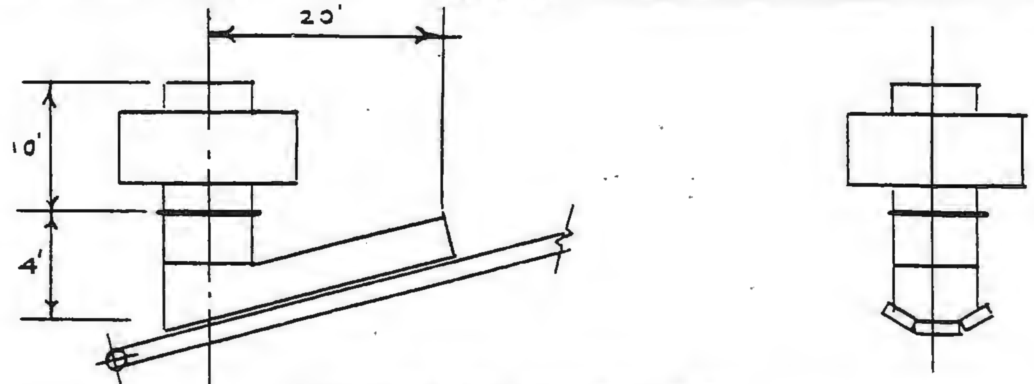
APPENDIX A

*** HYPOTHETICAL CRUSHER-TO-BELT AND BELT-TO-BELT TRANSFER POINTS



CRUSHER TO BELT TRANSFER POINT

BELT CONVEYOR

INCLINED

35^{o} TROUGHED IDLERS

BELT SPEED - 300 FPM

BELT WIDTH - 36"

AGGREGATE SIZE - -1"

FEED RATE - 500 T.P.H.

MOISTURE CONTENT - 1-6%

MATERIAL CARRIED: CASE 1) COAL - 50-60 #/FT^3

CASE 2) LIMESTONE - 90-100 #/FT^3

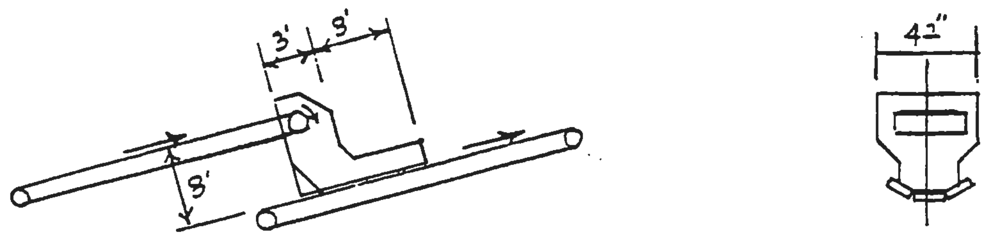
CASE 3) METAL ORE - 125-150 #/FT^3

EXPECTED DUST CONCENTRATION AT THE CONVEYOR

	RESPIRABLE	TOTAL
BEFORE THE IMPACT POINT	5 mg/m^3	60 mg/m^3
AFTER THE IMPACT POINT	7 mg/m^3	75 mg/m^3

COHE CENTER FOR OCCUPATIONAL HEALTH ENGINEERING MARTIN MARIETTA LABORATORIES MARTIN MARIETTA	TITLE TYPICAL CRUSHER TO BELT TRANSFER POINT	U.U.M. NO. PROJECT NO. / DIVISION NO. DRAWING NUMBER / REV

FIGURE A-1. - Typical crusher-to-belt transfer point.



BELT TO BELT TRANSFER POINT

(IN THE DIRECTION OF BELT TRAVEL)

FEED & RECEIVING BELT CONVEYORS

INCLINED
35^{o} TROUGHED IDLERS
BELT SPEED - 300 FPM
BELT WIDTH - 36"
AGGREGATE SIZE - -1"
FEED RATE - 500 T.P.H.
MOISTURE CONTENT - 1-6%
MATERIAL CARRIED: CASE 1) COAL - 50-60 $\#/FT^3$
CASE 2) LIMESTONE - 90-100 $\#/FT^3$
CASE 3) METAL ORE - 125-150 $\#/FT^3$

EXPECTED DUST CONCENTRATIONS AT THE RECEIVING CONVEYOR

	RESPIRABLE	TOTAL
BEFORE THE IMPACT POINT	5 mg/m^3	60 mg/m^3
AFTER THE IMPACT POINT	7 mg/m^3	75 mg/m^3

COHE CENTER FOR OCCUPATIONAL HEALTH ENGINEERING MARTIN MARIETTA LABORATORIES	TITLE TYPICAL BELT TO BELT TRANSFER POINT	B.O.M. NO. PROJECT NO. / DIVISION NO. DRAWING NUMBER REV

FIGURE A-2. - Typical belt-to-belt transfer point.

APPENDIX B

*** DESIGN OF DUST COLLECTION SYSTEM

APPENDIX B

*** DESIGN OF DUST COLLECTION SYSTEM

The exhaust volume calculations based on various approaches reported in the literature are presented below and summarized in Table B-1.

PRIMARY CRUSHER-TO-BELT CONVEYOR #1 TRANSFER POINT

Specifications

B = Belt width = 48 in.

S = Belt speed = 430 ft/min

T_{avg} = Average throughput = 800 ton/h

T_{max} = Maximum throughput = 1000 ton/h

Z = Bulk material density = 90 lb/ft^3

D_{max} = Maximum size = 14 in. (1.17 ft)

D_{avg} = Average size = 7 in. (0.58 ft)

H = Height of fall = 10 ft

A_u = Crusher throat area = 36 ft^2

Exhaust Volume Calculations

Industrial Ventilation Manual (IVM)(3)

Non-Dusty Material

Q = 500 cfm/ft of belt width
Q_E = 2000 cfm

Dusty Material

Q = 1000 cfm/ft of belt width

Q_1[1] = 1000 cfm at the tail pulley

Q_E = 5000 cfm

1 This volume is added when the exhaust volume at the main hood (QE) is calculated.

TABLE B-1. EXHAUST VOLUMES COMPUTED USING VARIOUS APPROACHES

TRANSFER POINT	INDUSTRIAL VENTILATION MANUAL	ANDERSON	MORRISON
Primary Crusher to Belt Conveyor #1	Non-Dusty-2000 cfm Dusty-5000 cfm	6700 cfm	-
Secondary Crusher to Belt Conveyor #4	Non-Dusty-1250 cfm Dusty-3200 cfm	3000 cfm	-
Belt Conveyor #7 to Belt Conveyor #8	Non-Dusty-2000 cfm Dusty-4700 cfm	1400 cfm	2950 cfm
Vibrating Screen #2	4200 cfm	750 cfm	-
Vibrating Screen #2 to Belt Conveyor #5	Non-Dusty-1200 cfm Dusty-3200 cfm	1350 cfm	-
Vibrating Screen #2 to Storage Bins #5&1	850 cfm/each	1850 cfm/each	-
Belt Conveyor #4 Head Box	Non-Dusty-1250 cfm Dusty-2500 cfm	-	-

where

Q_E = Exhaust volume

Q = Exhaust volume per foot of belt width

Thus, according to IVM, the required exhaust volume is 2000 cfm to 5000 cfm, depending on the dustiness of the material.

Anderson Approach (9)

$$Q_I = 10 \times Au \sqrt[3]{\frac{TH^2}{D_{avg}}}$$

and

$$Q_E = 1/3\ Q_I$$

where

Q_I = Induced air volume.

Therefore,

Q_E = 6700 cfm.

SECONDARY CRUSHER-TO-BELT CONVEYOR #4 TRANSFER POINT

Specifications

B = Belt width = 30 in.

S = Belt speed = 535 ft/min

T_{avg} = Average throughput = 775 ton/h

T_{max} = Maximum throughput = 968 ton/h

Z = Bulk material density = 90 lb/ft^3

D_{max} = Maximum size = 3-1/2 in. (0.29 ft)

D_{avg} = Average size = 1-3/4 in. (0.146 ft)

H = Height of fall = 6 ft

A_u = Crusher throat area = 14.25 ft^2

Exhaust Volume Calculations

Industrial Ventilation Manual(IVM)(3)

Non-Dusty Material

Q_E = 1250 cfm

Dusty Material

Q_E = 3200 cfm

Thus, according to the IVM approach, the required exhaust volume varied from 1250 cfm to 3200 cfm, depending on the dustiness of the material.

Anderson Approach (9)

Q_E = 3000 cfm

CONVEYOR BELT #7-TO-CONVEYOR BELT #8 TRANSFER POINT

Specifications

		Conveyor Belt #7	Conveyor Belt #8
B	= Belt width	24 in.	24 in.
S	= Belt speed	410 ft/min	420 ft/min
T_{avg}	= Average throughput	375 ton/h	375 ton/h
T_{max}	= Maximum throughput	530 ton/h	530 ton/h
D_{max}	= Maximum size	2 in. (0.17 ft)	2 in. (0.17 ft)
D_{avg}	= Average size	0.42 in. (0.035 ft)	0.42 in. (0.035 ft)
H	= Height of fall	-	13 1/2 ft
A_u	= Area of opening		1 ft^2

Exhaust Volume Calculations

Industrial Ventilation Manual(IVM)(3)

Non-Dusty Material

Q_E = 1000 cfm at the head box of conveyor #7

Q_E = 1000 cfm at the settling box of conveyor #8

Total Q_E = 2000 cfm

Dusty Material

Q_E = 2000 cfm at the head box of conveyor #7

Q_E = 2700 cfm at the settling box of conveyor #8

Total Q_E = 4700 cfm

Thus, according to the IVM, the required exhaust volumes are 2000 cfm to 4700 cfm, depending on the dustiness of the material.

Anderson Approach (9)

Q_E = 1400 cfm

Morrison Approach (11)

Q_E = 2950 cfm

See figure B-1 for detailed calculations.

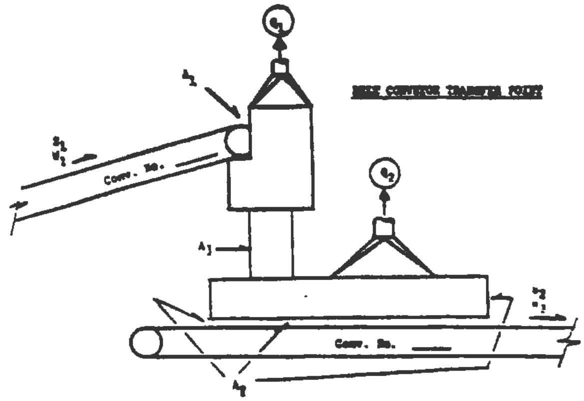
VIBRATING SCREEN AND ASSOCIATED TRANSFER POINTS

Specifications

Vibrating Screen #2

Screen size = 14 ft x 6 ft

T_{max} = Maximum throughput = 968 ton/h



DESIGN DATA

Belt Widths

W_1 = 24 inches

W_2 = 24 inches

Belt Speeds

S_1 = 410 fpm (150 fpm minimum)

S_2 = 420 fpm (150 fpm minimum)

Head Pulley Enclosure Openings

A_1 = 2.89 sq. ft. (See TABLE 1

Tail Pulley Enclosure Openings

A_2 = 3.14 sq. ft. (See TABLE 1

Cross-Sectional Area of Material Stream

A_3 = 1.88 sq. ft. (See TABLE 1

Material Flow Rate

T = 375 tons per hour (1 ton = 2000 lbs.)

Material Bulk Density

G = 90 lbs. per cu. ft.

Average Material Lump Size

D = .42 inches (1/8 in. min.)

Height of Material Fall

H = 8.25 feet (See TABLE 2

Material Temperature

t = 77 °F

Ambient Air Temperature

t' = 77 °F

HEAD PULLEY EXHAUST RATE, Q_1

1. Induced air through head pulley enclosure openings caused by stream of falling material.

$$q_1 = 110 \sqrt[3]{\frac{TH^2A_3^2}{GD}}$$

$$= 110 \sqrt[3]{\frac{(375)\,(8.25)^2\,(1.88)^2}{(90)\,(.42)}} = \underline{1470} \text{ scfm}$$

2. Control velocity at head pulley enclosure openings due to induced air in 1.

$$v_1 = \frac{q_1}{A_1} = \frac{(1470)}{(2.89)} = \underline{510} \text{ fpm}$$

3. If v_1 is greater than belt speed S_1 required head pulley exhaust rate.

$Q_1 = 0$

4. If v_1 is less than belt speed S_1 required head pulley exhaust rate,

$Q_1 = A_1S_1 - q_1 = (\quad)(\quad) - (\quad) = \underline{0}$ scfm

5. The appropriate Q_1 value from 3 and 4 is equal to the Minimum Required Head Pulley Exhaust Volume, (Q_1 = 0 scfm)

TAIL PULLEY EXHAUST RATE, Q_2

6. Induced air from falling material into tail pulley enclosure.

$q_1 - Q_1 = (1470) - (0) = \underline{1470}$ scfm

7. Air displaced by material stream

$33.3 \frac{T}{G} = 33.3 \frac{(375)}{(90)} = \underline{140}$ scfm

8. Required control volume through tail pulley enclosure openings

$A_2S_2 = (3.14) \times (420) = \underline{1320}$ scfm

9. The addition of air volumes in 6, 7 and 8 is equal to the Minimum Required Tail Pulley Exhaust Volume. (Q_2 = 2950 scfm)

10. Estimating the actual temperature of the exhaust air volumes

$t'' = 0.7t' + 0.3t = 0.7(\quad) + 0.3(\quad) = \underline{\qquad}$ °F

CONVERSION OF EXHAUST VOLUMES TO ACFM*

11. Head Pulley Exhaust Volume conversion to acfm.

Q_1 (in acfm) = Q_1 (in scfm from line 5) $\times \frac{t'' + 460}{530}$

$= (\quad) \times \frac{(\quad) + 460}{530}$ (Q_1 = ______ acfm)

12. Tail Pulley Exhaust Volume conversion to acfm.

Q_2 (in acfm) = Q_2 (in scfm from line 9) $\times \frac{t'' + 460}{530}$

$= (\quad) \times \frac{(\quad) + 460}{530}$ (Q_2 = ______ acfm)

*Standard conditions based on 29.92" Hg and 70° F.

TABLE 1**

W_1 (inches)	A_1 (sq. ft.)	A_2 (sq. ft.)	A_3 (sq. ft.)
18	2.66	2.98	1.04
24	2.89	3.14	1.58
30	3.12	3.40	2.93
36	3.93	3.70	4.16
42	5.19	4.04	5.63
48	6.90	4.42	7.08
54	9.06	4.84	8.72
60	11.67	5.30	10.50

**Values in Table 1 are based on belt conveyor transfer point design according to Dravo mechanical design standards MS-15, MS-22, and MS-23.

TABLE 2

Height of material fall requires special consideration for transfer point arrangements which impose obstructions to the free fall of material. Obstructions commonly encountered are stoneboxes and sloped transfer chutes. Illustrated below are typical cases. Shown with each case is an empirical formula which estimates an "effective" height of material fall. A height (H) calculated by one of these formulas should be used in performing the calculations on Page 2.

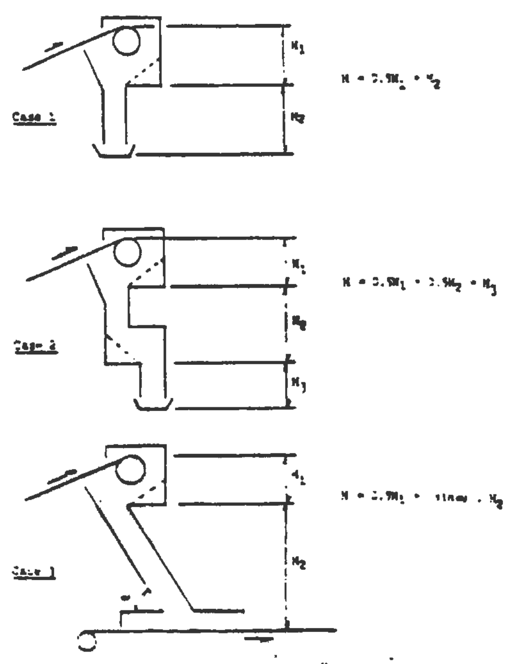


FIGURE B-1. - Exhaust volume calculation at belt conveyor #7-to-belt conveyor #8 transfer point using Morrison approach.

T_{avg} = Average throughput = 775 ton/h

D_{max} = 3-1/2 in. (0.29 ft)

D_{avg} = 1 in. (0.83 ft)

Belt Conveyor #4

Specifications given earlier

Storage Bins #1 and 5

H_{max} = Maximum height of fall = 30 ft

H_{avg} = Average height of fall = 15 ft

D_{avg} = Average size = 1 in. (0.08 ft)

A_u = Chute opening = 3.34 ft^2

T_{max} = 500 ton/h

T_{avg} = 250 ton/h

Belt Conveyor #5

B = belt width = 30 in.

S = belt speed = 400 ft/min

Exhaust Volume Calculations

Industrial Ventilation Manual(IVM)(3)

Belt Conveyor #4 Head Box

Non-Dusty Material

Q_E = 1250 cfm

Dusty Material

Q_E = 2500 cfm

Vibrating Screen #2

Q_E = 50 cfm/ft^2

Q_E = 4200 cfm

Storage Bins #1 and 5

Bins are fully enclosed.

Q_E = 250 cfm/ft^2

Q_E = 850 cfm

Belt Conveyor #5

Non-Dusty Material

Q_E = 1250 cfm

Dusty Material

Q_E = 3200 cfm

Thus, the total exhaust volume required by the IVM at the vibrating screen #2 circuit ranges from 8,400 cfm to 11,600 cfm.

Anderson Approach (9)

Conveyor Belt #4

Q_E = 0

Vibrating Screen

$$Q_E = 10 \times A_u \times \sqrt[3]{\frac{TH^2}{D_{avg}}}$$

A_u = open area at the head pulley and conveyor #4 = 1.25 ft^2

T = 968 ton/h

H = Height of fall = 4 ft

Q_E = 750 cfm

Conveyor Belt #5

T_{max} = 500 ton/h

H = 8 ft

D_{avg} = 2 in. (0.17 ft)

A_u = 3.34 ft^2

$$Q = 10 \times A_u \sqrt[3]{\frac{TH^2}{D_{avg}}}$$

Q_E = 3150 cfm

<u>Bins #1 and 5</u>

A_u = 3.34 ft^2

T_{max} = 500 ton/h

T_{avg} = 250 ton/h

H_{avg} = 15 ft

D_{avg} = 1 in. (0.083 ft)

Q_I = Induced volume = $10 \times A_u \sqrt[3]{\frac{TH^2}{D_{avg}}}$ = 3675 cfm

Q_E = 1/2 Q_I

Q_E = 1850 cfm

Thus, the total exhaust volume required by the Anderson approach is 7,600 cfm.

APPENDIX C

*** COMPARISON OF OLD AND NEW DUST CONTROL SYSTEMS

APPENDIX C

*** COMPARISON OF OLD AND NEW DUST CONTROL SYSTEMS

Limited total dust emissions data were obtained with the old dust control system operating under normal plant condition ("as is") prior to installation of the modifications. These data are shown in Tables C-1, C-2, and C-3 for the primary crusher-to-belt conveyor #1 transfer point, the secondary crusher-to-belt conveyor #4 transfer point, and the belt conveyor #7-to-belt conveyor #8 transfer point, respectively. A summary of these data and sampling results from the new dust control system are given in Table C-4. Data analysis shows that at all transfer points, the new dust control systems were significantly more effective in controlling dust than the old dust control system, with mean dust concentration from 78.6% to 99.8% lower. The improvements are particularly impressive at the primary crusher and secondary crusher "E" locations -- the most severe problem points.

TABLE C.1. - RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1 TRANSFER POINT WITH THE OLD PLANT DUST CONTROL SYSTEM.

Control System: Old Dust Control System
Type of Sampling: Total
Testing Condition: "As Is"

DATE	SAMPLING LOCATION(1)	MEAN GEOMETRIC CONCENTRATION mg/m^3	COMMENTS
11/13/81	E	658.9	
11/16/81	S	4878.8	
11/17/81	E S	2693.5 636.9	These data are average of two sets

	SAMPLING LOCATION(1) E	S
Arithmetic Mean Dust Concentration (mg/m^3)(2):	2082.2	3019.1
Standard Deviation:	2392.5	2398.1
Standard Error:	1069.9	1673.2

(1) E - End of the settling box
S - Side of the conveyor

(2) Refer to section 4.2.5. for explanation.

TABLE C-2. - RESULTS FOR SECONDARY CRUSHER-TO-BELT CONVEYOR #4 TRANSFER POINT WITH THE OLD PLANT DUST CONTROL SYSTEM.

Control System: Old Dust Control System
Type of Sampling: Total
Testing Condition: "As Is"
Crusher Throughput: 675 ton/h

DATE	SAMPLING LOCATION(1)	MEAN GEOMETRIC CONCENTRATION mg/m³	COMMENTS
11/02/81	E S	7664.7 1130.9	
11/10/81	E S	3620.4 946.0	The data are average of two sets.
11/11/81	E S	3161.6 907.8	"S" location data are average of two sets.
11/16/81	E S	3635.3 1396.2	The data are average of two sets.
11/17/81	E S	3806.5 582.8	"E" location data are average of three sets. "S" location data are average of two sets.

DUST CONTROL SYSTEM "AS IS"	SAMPLING LOCATION(1) E	S
Arithmetic Mean Dust Concentration (mg/m^3)(2)	4393.6	1119.1
Standard Deviation:	2213.3	838.2
Standard Error:	411.0	153.0

(1) E - End of the settling box
S - Side of the conveyor

(2) Refer to section 4.2.5. for explanation.

TABLE C-3. - RESULTS FOR BELT CONVEYOR #7-TO-BELT CONVEYOR #8 TRANSFER POINT WITH THE OLD PLANT DUST CONTROL SYSTEM.

Control System: Old Dust Control System
Type of Sampling: Total
Testing Condition: "As Is"

DATE	SAMPLING LOCATION(1)	MEAN GEOMETRIC CONCENTRATION mg/m^3	COMMENTS
11/02/81	E	24.9	
11/10/81	E	33.8	
11/11/81	E	90.8	
11/16/81	E	124.2	The data are average of two sets.
11/17/81	E	67.4	The data are average of three sets

DUST CONTROL SYSTEM "AS IS"	SAMPLING LOCATION(1) E
Arithmetic Mean Dust Concentration (mg/m^3)(2):	91.3
Standard Deviation:	81.7
Standard Error:	17.4

(1) E - End of the settling box
S - Side of the conveyor

(2) Refer to section 4.2.5. for explanation.

TABLE C-4. - ARITHMETIC MEAN DUST CONCENTRATION AT THREE TRANSFER POINTS FOR OLD AND NEW DUST CONTROL SYSTEMS

Type of Sampling: Total
Exhaust Volumes: Primary crusher-to-belt conveyor #1 6700 cfm
Secondary crusher-to-belt conveyor #4 3000 cfm
Belt conveyor #7-to-belt conveyor #8 2400 cfm

Transfer Point	Sampling(1) Location	Dust Emissions Old Dust Control System		Dust Emissions, New Dust Control System		Improvement %
		Arithmetic Mean Dust Concentration mg/m³	Standard Deviation mg/m³	Mean Dust Concentration mg/m³	Standard Deviation mg/m³	
Primary Crusher	E	2082.2	2392.5	3.9	1.0	99.8
to	T	-	-	56.8	35.8	-
Belt Conveyor #1	S	3019.1	2898.1	332.0	102.6	89.0
Secondary Crusher	E	4393.6	2213.3	105.9	129.2	97.6
to	T	-	-	-	-	-
Belt Conveyor #4	S	1119.1	838.2	181.5	131.4	83.8
Belt Conveyor #7	E	91.3	81.7	19.5	0.7	78.6
to	T	-	-	11.1	6.2	-
Belt Conveyor #8	S	-	-	17.3	10.9	-

(1) E - End of the settling box
T - Tail of the conveyor
S - Side of the conveyor

(2) Refer to section 4.2.5. for explanation.

APPENDIX D

*** TYPICAL FIELD DATA SHEET AND LABORATORY ANALYSIS SHEET

SAMPLE DOCUMENTATION FORM

DATE 7-26-82			WEATHER CONDITIONS:	10am	2pm	PLANT CONDITIONS: Early [illegible] town
SURVEYOR K. Holderied			TEMP DRY BULB°F	83	102	NO OF OPERATING HOURS — HRS
CONTROL SYSTEM	On	Off	WET BULB°F			TOTAL PRODUCTION TONS
TYPE OF SAMPLE	☒ Respirable	Total	WIND VELOCITY		0-5	AVERAGE PRODUCTION TPH
PUMP CALIBRATION DATE 7-23-82			DIRECTION		—	COMMENTS: Air Compressor at
PUMP FLOW RATE 1.7 Liters/Min			% RELATIVE HUMIDITY	56	71	Primary not running. [illegible]
DATE SUBMITTED 7-27	ANALYZED 7-29		DATE OF LAST PRECIPITATION	7-23-82		system shut down.

LOCATION	PUMP NO.	CASSETTE NO.	TEST PERIOD START	STOP	TOTAL MINUTES	LAB ANALYSIS NO.	NET RESP. WT. mg	NET NON RESP. WT. mg	AIR VOLUME m^3	RESPIRABLE CONC. mg/m^3	GEO. MEAN mg/m^3
		Control System OFF									
SE1	BM20	361	2:20	2:45	25		91.254		0.0425	2147.15	
SE2	BM15	152					4.651			*109.44	2021.2
SE3	BM19	358					80.858			1902.54	
ST1	BM14	386					3.419			80.45	
ST2	BM16	382					6.149			144.68	202.9
ST3	BM11	714					30.519			718.09	
SS1	BM10	428					1.587			37.34	65.7
SS2	BM1	621					4.913			115.60	
		Control System ON — 8800 C.F.M.									
SE1	BM20	157	12:15	1:55	100		6.287		0.1700	36.98	
SE2	BM15	359					0.013			*0.08	29.7
SE3	BM19	152					4.651			27.36	
ST1	BM14	550	12:12	1:40	88		1.515		0.1496	10.13	
ST2	BM16	160					0.844			5.64	9.1
ST3	BM11	666					1.980			13.24	
SS1	BM10	607					0.423			2.83	4.8
SS2	BM1	605					1.229			8.22	
Blank		122				+	0.012				
Blank		207				−	0.022				
Blank		332				−	0.021				
Blank		419				−	0.022				
						Avg. loss =	0.013				

*This data omitted from geometric mean calculation.

SECONDARY CRUSHER TO BELT CONVEYOR #4 TRANSFER POINT.

MARTIN MARIETTA LABORATORIES
CENTER FOR OCCUPATIONAL HEALTH ENGINEERING
SAMPLE WORKSHEET
(GRAVIMETRIC)

DATE SUBMITTED: 7-29-82

~~SUBMITTED BY: K. HOLDERIED~~

PLANT: BUREAU OF MINES

ANALYSIS: GRAVIMETRIC

CHAIN OF CUSTODY

	INITIALS	DATE
REC'D BY LAB:	KRH	7-29
REC'D BY ANALYST:	KRH	7-29
~~ANALYSIS COMPLETED:~~	~~KRH~~	~~7-29~~
DATA CHECKED:		
REPORT COMPLETED:		

BALANCE CALIBRATION PERFORMED
CALIBRATION WEIGHT USED

FIELD ID	LAB ANALYSIS NUMBER	GRAVIMETRIC ANALYSIS PRE WEIGHT mg	POST WEIGHT mg	FINAL WT. mg	ADJUSTED WT. mg
VM-157		13.598	19.872	6.274	6.287
359		12.825	12.825	0.0	0.013
152		10.907	15.545	4.638	4.651
550		11.241	12.743	1.502	1.515
160		10.872	11.703	0.831	0.844
666		12.720	14.687	1.967	1.980
607		14.042	14.452	0.410	0.423
605		13.572	14.788	1.216	1.229
332	BLANK	13.637	13.616	-0.021	
419	BLANK	14.196	14.174	-0.022	

MARTIN MARIETTA LABORATORIES
CENTER FOR OCCUPATIONAL HEALTH ENGINEERING
SAMPLE WORKSHEET
(GRAVIMETRIC)

DATE SUBMITTED: 7-29-85

SUBMITTED BY: K.R. Holderied

PLANT: Bureau of Mines

ANALYSIS: Gravimetric

CHAIN OF CUSTODY

	INITIALS	DATE
REC'D BY LAB:	KRH.	7-29
REC'D BY ANALYST:	KRH.	7-29
ANALYSIS COMPLETED:	KRH.	7-29
DATA CHECKED:		
REPORT COMPLETED:		

BALANCE CALIBRATION PERFORMED
CALIBRATION WEIGHT USED

FIELD ID	LAB ANALYSIS NUMBER	GRAVIMETRIC ANALYSIS			
		PRE WEIGHT mg	POST WEIGHT mg	FINAL WT. mg	ADJUSTED WT. mg
VM-361		13.209	104.45	91.241	91.254
152		10.907	15.545	4.638	4.651
358		13.734	94.759	80.845	80.858
386		13.897	17.303	3.406	3.419
382		13.227	19.363	6.136	6.149
714		13.941	44.447	30.506	30.519
428		13.248	14.822	1.574	1.587
621		13.009	17.909	4.900	4.913
122	BLANK	14.361	14.373	+0.012	
207	BLANK	14.930	14.908	-0.022	

APPENDIX E

*** SAMPLE AMBIENT DATA

APPENDIX E

*** SAMPLE AMBIENT DATA

Due to physical constraints, the individual transfer points could not be isolated from the other dust sources. Therefore, the original sampling strategy provided for ambient sampling to determine and correct for the contribution of background dust levels to the true source concentrations.

Tables E-1 and E-2 show the source and ambient sampling data for the primary crusher-to-belt conveyor #1 transfer point and the secondary crusher-to-belt conveyor #4 transfer point, respectively. Data analysis shows that:

1) Ambient concentrations were not constant for the control systems "off" or "on."
2) Ambient concentrations followed the trends of the source concentrations at all three sampling locations for the control systems "off" and "on."

We therefore concluded that these ambient samples were not representative of true background dust levels. After consultation with the Bureau of Mines Technical Project Officer, we discontinued ambient sampling during the subsequent testing.

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TABLE E-1. - AMBIENT SAMPLING RESULTS FOR PRIMARY CRUSHER-TO-BELT CONVEYOR #1

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Exhaust Volume 6700 cfm
Crusher Throughput: 700 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³				TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System Off		System On		°F	%		
		Source	Ambient	Source	Ambient				
7/13/82	E	63.0	23.2	0.6	0.3	89	92	7/13/82	
	T	27.4	26.7	0.5	0.2				
	S	30.0	32.4	10.8	16.5				
7/16/82	E	53.6	17.9	3.4	1.6	84	88	7/15/82	
	T	30.2	15.2	1.6	0.2				
	S	24.1	19.1	7.5	5.0				
7/27/82	E	66.6	27.2	1.7	0.5	94	62	7/23/82	
	T	32.3	22.5	2.1	1.4				
	S	23.5	17.5	5.5	5.4				
8/2/82	E	84.3	6.2	0.7	0.6	90	72	7/31/82	Water spray system upstream of primary crusher was off.
	T	8.5	5.3	6.5	8.3				
	S	15.4	17.1	7.3	6.5				
8/4/82	E	259.9	42.4	0.4	0.3	91	60	8/2/82	Same as above
	T	46.3	32.1	22.1	16.2				
	S	104.0	59.7	24.7	23.3				
8/5/82	E	117.0	-	0.3	-	88	62	8/4/82	Same as above
	T	19.4	75.5	7.6	8.0				
	S	63.1	33.5	8.4	5.8				

(1) E - End of the settling box.
T - Tail end of the conveyor.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

TABLE E-2. - AMBIENT SAMPLING RESULTS FOR SECONDARY CRUSHER-TO-BELT CONVEYOR #4

Control System: Dust Collection
Type of Sampling: Respirable Dust
Testing Condition: Exhaust Volume 8800 cfm
Crusher Throughput: 675 tph

DATE	SAMPLING LOCATION(1)	GEOMETRIC MEAN CONCENTRATIONS(2) mg/m³				TEMP.	RELATIVE HUMIDITY	DATE OF LAST PRECIPITATION	COMMENTS
		System off		System on		°F	%		
		Source	Ambient	Source	Ambient				
7/12/82	E	313.2	0.4	2.4	0.3				
	T	6.5	2.9	0.9	1.0	82	89	7/9/82	
	S	1.9	6.7	1.4	1.9				
7/15/82	E	380.7	1.1	1.4	0.4				
	T	21.7	12.2	1.9	0.6	89	83	7/14/82	
	S	13.7	14.7	3.0	2.3				
7/22/82	E	601.7	1.1	3.8	0.4				
	T	48.0	36.3	2.2	1.4	74	74	7/18/82	
	S	27.6	23.4	6.7	4.9				
7/26/82	E	2021.2	6.1	31.8	0.4	92	63	7/23/82	Primary dust collector
	T	202.9	80.3	9.1	5.8				as well as wet suppres-
	S	65.7	59.1	4.8	5.4				sion system was down.
7/27/82	E	288.9	–	4.7	0.2				
	T	43.0	14.1	4.1	1.7	94	62	7/23/82	
	S	25.6	33.1	5.7	5.8				
8/2/82	E	59.3	4.5	1.8	0.5				
	T	12.0	5.2	2.3	1.2	90	72	7/31/82	Same as above
	S	---	-	---	-				
8/4/82	E	123.9	31.3	8.9	0.6				
	T	33.8	17.2	13.7	10.4	91	60	8/2/82	Same as above
	S	42.5	35.5	5.4	5.4				
8/5/82	E	983.3	2.1	1.1	0.3				
	T	132.6	83.7	1.9	2.3	88	62	8/4/82	Same as above
	S	77.3	36.6	4.1	2.8				
8/26/82	E	677.6	8.8	16.5	1.6				
	T	53.2	23.6	19.4	7.6	75	68	8/25/82	Primary dust collector
	S	124.1	105.5	16.0	13.3				as well as suppression system was down.

(1) E - End of the settling box.
T - Tail end of the conveyor.
S - Side of the conveyor.

(2) Refer to section 4.2.5. for explanation.

APPENDIX F

*** ADDITIONAL TEST DATA AT THE HAMMERMILLS-TO-BELT CONVEYOR #7 TRANSFER POINT

APPENDIX F

*** ADDITIONAL TEST DATA AT THE HAMMERMILLS TO BELT CONVEYOR #7 TRANSFER POINT

As mentioned previously, we encountered severe clogging problems with the cyclone in evaluating the performance of the Sonic wet dust suppression system at the hammermills transfer point. Table F-1 presents some of the data taken while we were establishing a sampling technique with the cyclones facing "out" (i.e., at 180° from the "in" position). These tests were conducted with some cyclones facing "in" to the airstream and some facing "out" of the airstream. Our trial data indicated that clogging was less severe for cyclones facing "out," but, even so, the cyclones started clogging after about 15 minutes. Our final sampling strategy for this transfer point called for a 10-minute sampling with the system "on" and the cyclones facing "out." The data in Table F-1 indicate that dust concentrations for cyclones facing "out" were lower than actual concentrations. Therefore, the dust concentrations reported with the modified sampling strategy were lower than the true dust concentrations.

TABLE F-1. - RESPIRABLE DUST CONCENTRATIONS - CYCLONE FACING IN vs. FACING OUT

Test #	Date	Water @ Top on	Water @ Top off	Sonic System on	Sonic System off	Cyclone Facing in	Cyclone Facing out	Respirable Concentrations - at Sampling Location "E" mg/m³ 1	2	3	4	5	Geom. Mean Conc. (mg/m³)	Comments
1	9/13	X			X	X		211.67		489.41		269.87	303.45	
	9/13	X			X		X		228.57		261.42		244.41	
2	9/14		X		X		X	651.67		749.91		297.16	526.28	
	9/14		X		X	X			1587.12		991.40		1254.38	
3	9/14	X			X		X	26.220		47.62		36.93	35.88	
	9/14	X			X	X			97.59		77.64		87.04	
4	9/13		X		X	X		434.99		1053.58		737.38	696.54	
	9/13		X		X		X		707.17		732.99		719.96	
5	9/13	X			X	X		14.48		49.92		32.63	28.68	
	9/13	X			X		X		36.4		40.92		38.59	
6	10/7	X		X			X	21.14*		43.46*		21.00*	26.82*	
	10/7	X		X		X			21.42*		21.82*		21.62*	
7	10/8	X			X		X	26.16		41.13		14.117	24.76	
8	10/8	X		X			X	10.85*		16.18*		8.14*	11.26*	
9	10/8	X			X	X			50.10		44.70		47.32	
10	10/8	X		X		X			14.64*		12.31*		13.42*	
11	10/18	X			X		X	126.65	137.65	123.98	103.16	77.92	111.68	
12	10/18	X		X			X	23.44*	19.47*	75.32*	18.67*	16.98*	25.55*	
13	10/19		X		X		X	567.94	525.53	472.07	395.93	321.19	447.36	
14	10/19		X	X			X	(8232)*	187.76*	209.78*	187.56*	83.44*	157.56*	
15	10/19		X		X		X	(4)	453.9	543.7	454.8	396.7	459.4	
16	10/19	X		X			X	19.2*	27.4*	24.1*	17.3*	14.6*	20.2*	
		X			X		X	28.12	-	21.94	-	15.098	21.04	
17	10/11	X			X	X		-	38.04	-	32.04	-	34.93	
		X		X			X	18.34*	-	-	-	10.32*	13.75*	
18	10/11	X		X		X		-	(.901)*	-	16.65*	-	16.65*	
			X	X			X	245.2*	-	257.3*	-	171.3*	221.1*	
19	10/11					X		-	324.1*	-	230.1*	-	273.1*	

NOTE: Data with asterisks are not reliable for the reasons mentioned in the text. Data in parentheses are neglected in the calculation of geometric mean.