

MECHANICAL ENGINEERING

Published by The American Society of Mechanical Engineers

VOLUME 55

NUMBER 10

Contents for October, 1933



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The Control of INDUSTRIAL DUST

The Problem of Local Exhaust and General Ventilation

By J. M. DALLAVALLE¹

IT IS WELL KNOWN that the inhalation of certain industrial dusts is an important factor in causing occupational disabilities. Dust such as granite has been shown to produce a fibrosis of the lungs which is often associated with tuberculosis, while other dusts, such as asbestos, cement, slate, etc., are stated to produce a varying degree of fibrosis. In general, it has been found that dusts whose quartz content is high cause a disabling fibrosis more readily. Hence, in view of the hazards which may prevail by the inhalation of quartz-containing dusts, the problem of control is extremely important. Previous papers² given before this section of the Society have been concerned with the effects of exposure to industrial dusts and the methods used for their quantitation. The following paragraphs are, therefore, designed to supplement those papers and to present fundamental considerations with regard to the control of the dust hazard.

The quantity of dust produced at a given source depends upon the type of operation performed and the method used for its control. In many cases, such factors as speed of production, plant layout, and the application of dry or wet methods in certain operations have a direct bearing upon the quantity of dust generated. The effective removal of dust must consequently take into account the manner in which it is produced. In some instances, where dust is restricted to a small area, local exhaust ventilation is generally used, while in places where dusty operations are conducted on a large scale, as in foundries and batch-mixing rooms, isolation with general exhaust may be preferable. In every case, a careful study and analysis of the problem is necessary so that dust concentrations may be reduced to safe limits. Many attempts to eliminate industrial dust hazards have been unsuccessful, partly because of the lack of attention given to the principles governing the design of control equipment and partly because of failures to utilize proper methods in testing the efficiency of dust removal. The necessity of giving due consideration to these important factors is consequently clear.

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² "Dust in Industry," by A. E. Russell, *MECHANICAL ENGINEERING*, March, 1933, pp. 163-166. "Dust in Industry," by J. J. Bloomfield, *Ibid.*, April, 1933, pp. 229-233.

Contributed by the Process Industries Committee and presented at the Semi-Annual Meeting, Chicago, Ill., June 25 to July 1, 1933, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS.

LOCAL EXHAUST CONTROL

Local exhaust control depends upon the provision of adequate hoods and air velocities. The function of a hood is to direct an air movement of sufficient intensity to prevent the escape of dust particles and to carry them to a collecting system. This fact applies to all hoods, and although not always obvious, should be kept clearly in mind.

The problems involved in the design of hoods are many. There are few types of hoods which are designed to handle sufficient air for the elimination of dust, a condition which arises from two sources: (1) a lack of knowledge of the nature of the air flow into the hood, and (2) insufficient data pertaining to velocities necessary to set dust in motion and to bring it under control. In the following paragraphs, we shall therefore attempt to discuss the velocity characteristics of hoods and their application to the design of exhaust equipment.

HOOD VELOCITY CHARACTERISTICS

A fact little understood is that the effects of drawing in air in the vicinity of an open duct or hood differ vastly from those of blowing out the same air. In the latter case, the condition is not unlike a stream of water issuing from a nozzle; the stream is well defined and intact for a considerable distance from the opening, while in the former, no such effect is noted. This may be demonstrated by merely placing an opening under suction and noting the quickness with which the air movement diminishes as the hand is drawn outward from it. To illustrate the point further, it may be shown by actual measurement that the air velocity at a point one inch outward along the axis of a duct 4 in. in diameter is approximately one-half of what it is within the duct itself. In other words, an air velocity of 4000 fpm in the duct is reduced to 2000 fpm one-quarter of a pipe diameter outward. This rate of decrease is explained by the fact that the air is drawn from all directions. Thus, if at one of the openings we circumscribe a succession of spheres, the areas are as the squares of their radii. The velocities are then inversely proportional to the areas of the spheres; that is, as the areas increase the velocities decrease. Since the same amount of air must pass through each of the circumscribed spheres, it follows that the velocities are inversely proportional to the squares of the radii. This reasoning neglects the effect of the duct itself, but is substantially true when

the distance from the opening is very great in comparison with the duct diameter and when there is no obstruction in the field of influence. It has been found as a matter of experiment^{3,4} that the velocity at any point along the axis of a hood under suction is closely given by the equation

$$\frac{Y}{100 - Y} = \frac{0.1A}{X^2} \dots \dots \dots [1a]$$

or

$$V = \frac{0.1AV_0}{X^2 + 0.1A} \dots \dots \dots [1b]$$

where Y is the percentage of the velocity at the point X along the axis in terms of the velocity at the opening

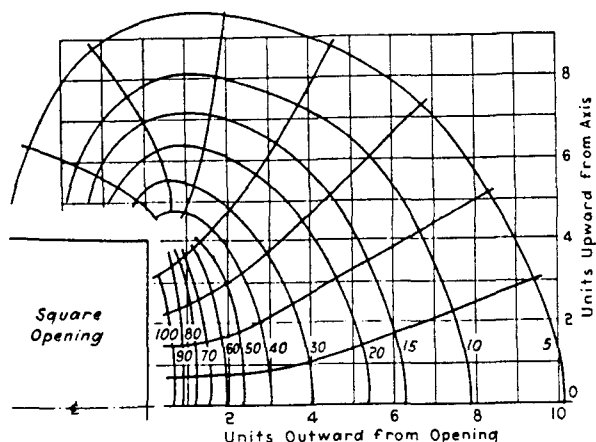


FIG. 1 CONTOUR DISTRIBUTION WITH SQUARE OPENING

V_0 and A is the area of the opening. Now at great distances, Y is small in comparison with 100 in the denominator on the left-hand side and consequently may be called zero. Equation [1a] then reduces to the form as already determined from elementary geometry; that is, Y (or V) is inversely proportional to the square of X . Hence, from the equation, it is at once possible to determine the air velocity at any point along the axis of a free and unobstructed hood, given the air flow.

Table 1 shows the variation of axial velocity with area of hood opening when the volume of air flow is kept constant at 1000 cubic feet per minute. This table illustrates the small change of velocity at great distances from the opening.

VELOCITY CONTOURS

It is possible by the use of a specially constructed pitot tube⁵ to map contours of equal velocity in any axial plane located in the field of influence. It has been found that the positions of these contours for any hood can be expressed as percentages of the velocity at the hood

³ "Studies in the Design of Local Exhaust Hoods," by J. M. Dalla-Valle and Theodore Hatch, Trans. A.S.M.E., vol. 54 (1932), paper no. WDI-54-10.

⁴ "Velocity Characteristics of Hoods Under Suction," by J. M. Dalla-Valle, Heating, Piping and Air Conditioning, vol. 4 (1932), pp. 370-375.

TABLE 1 VELOCITY CHANGE ALONG AXES OF HOODS OF VARIOUS SIZES WITH CONSTANT AIR FLOW OF 1000 CFM

(Determined from formula $\frac{Y}{100 - Y} = \frac{0.1A}{X^2}$)

Area of opening, sq ft	Average velocity at opening, fpm	Distance outward along axis—X—				
		6 in.	12 in.	18 in.	24 in.	30 in.
1	1000	286	91	43	24.4	15.9
2	500	222	83	41	23.8	15.5
4	250	154	71.5	38	22.8	15.0
6	167	107	62.5	35	21.6	14.6
8	125	95	52.5	33.1	20.8	14.2
10	100	80	50	31	20	13.8
20	50	44.5	33	23.7	16.7	12.1

opening and are purely functions of the shape of the hood. Further, the velocity contours are identical for similar hood shapes when the hoods are reduced to the same basis of comparison. These important facts are applicable to all hood problems and from them it is possible to estimate the volume of air necessary to control a given dust source. Figs. 1 and 2 show the contour distribution in half-plane sections of two simple

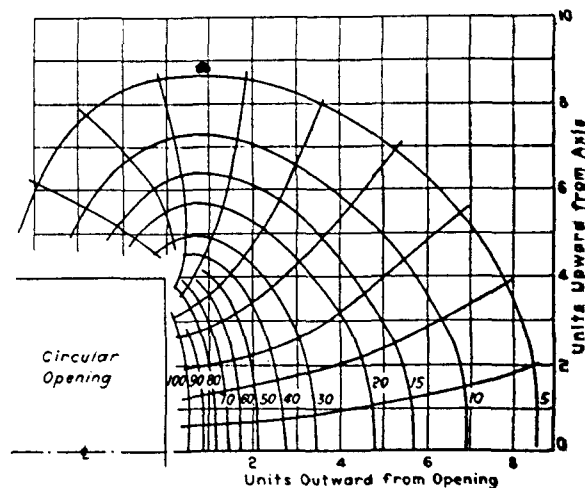


FIG. 2 CONTOUR DISTRIBUTION WITH CIRCULAR OPENING

forms of openings. The contours are typical of all hoods under suction and show the variation of velocity over the region of influence. The curves drawn perpendicular to the contours at their points of intersection with the lines of flow and give the direction of the air stream.

Hatch, Drinker, and Choate⁶ have applied the method of velocity contours to the design of hoods used on granite surfacing machines. They were enabled by development of these contours to find the air velocity necessary to control the dust generated by these surfacing tools and to determine the rates of air flow for each type of hood. The economic advantages of several types were shown to depend upon their shapes which pointed out, directly influenced the contour distribution.

The development of contours for all hood types, with

⁵ "Control of the Silicosis Hazard in the Hard-Rock Industry I—A laboratory study of the design of dust-control systems for pneumatic granite-cutting tools. By T. Hatch, P. Drinker, S. P. Choate. Jour. Ind. Hygiene, vol. 12 (1930), p. 75.

valuable, often involves many difficulties. It is necessary not only to consider the shape of the hood, but also the obstructions within the zone of influence. These obstructions frequently alter the path of the air movement and distort it to such a degree as to render the hood ineffective in removing the dust. Air, like water, moves over paths offering the least resistance.

A typical obstruction often encountered is illustrated by a hood placed over a sand milling machine used in foundries. This case may be investigated by use of contours, but it is capable of a simple analysis which may frequently be applied to other hoods whose area of influence is obstructed.

When the milling machine is placed close to a hood, the air flow is almost entirely from the open sides between them. If, then, we disregard the air flowing from behind the edges of the hood, we may consider all the flow as taking place laterally inward. The open area may then be obtained approximately by multiplying the perimeter of the tank by the distance from the surface of the tank to the plane of the hood opening. We then have to measure the volume of air flow into the hood, which may be ascertained either by an anemometer placed in the throat of the hood or by means of a pitot tube. This volume of air will be the same as passes through the open sides between the hood and the mill. It follows, therefore, that

$$\text{Volume of air } Q = \text{perimeter of mill} \times \text{distance} \times \text{velocity across open sides}$$

Hence by measuring the volume of air flow into the system and by knowing the dimensions of the mill and its distance from the hood, it is possible to deduce the average velocity across the open area. This velocity determines the effectiveness of the hood in controlling the dust arising from the mill. A more exact formula⁶ for determining the velocity close to the edge of the mill is given by the equation

$$Q = 1.4 P d V$$

where Q is the air flow, P the perimeter of the mill, and d the distance between the hood opening and the mill. The factor 1.4 is a correction to take care of the uneven distribution of flow. It is assumed, of course, that the hood is of the same shape as the mill. If the hood is slightly larger, as is generally the case in practise, the formula can be used with greater assurance.

EFFICIENCY OF DUST REMOVAL

While the estimation of velocity characteristics has many inherent advantages, it is, nevertheless, necessary to supplement it with quantitative measurements of dust concentrations. In this way, it is possible to obtain correlations between air volumes and dust counts. In the study of the granite surfacing machines previously cited, Hatch and his coworkers⁷ showed that the particular hoods developed by them required approximately 300 cubic feet of air per minute to reduce the dust con-

centration to the safe limit of 10 million particles per cubic foot. This is the dust concentration which has been found to produce no disabling fibrosis in the granite industry.⁷ The same method of correlating dust counts with air volumes had been previously used by Bloomfield⁸ in field studies conducted among granite plants in Vermont. It is interesting to note in this connection that Bloomfield was able to show that, under the conditions in which granite surfacing hoods were used, an air velocity of 1500 fpm at the opening was necessary to keep the exposure within a safe limit. For the particular hoods used, the air volumes handled were sufficient to maintain air velocities at the cutting tool approximating those obtained by Hatch.

The importance of quantitative measurements is further emphasized by other results obtained in an investigation of the Kelly-Hatch dust trap used in rock drilling. Since this method of dust control is not adapted to any analysis of velocity characteristics, it was necessary to determine the relation existing between the air volumes handled by the trap and the dust concentrations under varying operating conditions. In this way, it was found that a volume of 60 cfm was required to keep the dust formed to less than 3 million particles per cubic foot of air or well under the safe limit of exposure.

SUCTION STANDARDS

An important consideration entering into a discussion of local exhaust control is the present method of evaluating its performance. It is customary in most local exhaust work to express the characteristics of a given hood in terms of the suction maintained at the throat. It is important, however, to observe that suction measurements only determine the air volume through the hood, as may be seen from the equation

$$Q = 4000 a f \sqrt{h} \dots\dots\dots [2]$$

where Q = the volume of air flowing into the system, cfm

a = the area of the throat of the hood, that is, at the connecting duct, sq ft

f = a restriction factor generally equal to 0.7

h = the suction measured by a U-tube, in. of water

In Table 2 the air flows for various-sized connecting ducts are given with varying suction requirements. As is well known, these requirements differ from state to state and vary from 1.5 to 5 in. of water displacement as measured with a U-tube. One of the chief difficulties of a high suction is the losses incurred by the high air velocities in the ducts. A suction of 5 in. in any duct is equivalent to a velocity of about 6000 fpm. It is obvious, therefore, that the losses incurred are great and

⁷ "The Health of Workers in Dusty Trades." II—Exposure to silicosis dust (granite industry). By Albert E. Russell, R. H. Britten, L. R. Thompson, and J. J. Bloomfield. Public Health Bulletin No. 187, July, 1929.

⁸ "A Study of the Efficiency of Dust-Removal Systems in Granite-Cutting Plants," by J. J. Bloomfield. Public Health Reprint No. 1324, October, 1929.

⁶ "The Guide." American Society of Heating & Ventilating Engineers, 1933, Chapter 37.

even excessive in a pipe from 2 to 4 in. in diameter, as may be seen from Table 2 which is based on duct lengths of 10 ft. It would appear, since air volume determines the effectiveness of a hood, that the most efficient way to obtain air volumes corresponding to 5 in. of suction is by using larger ducts and lower suction. Thus, if a duct 3 in. in diameter is replaced by one 5 in. in diameter, the suction requirement would be reduced from 5 to 0.65 in. for the same air flow. The saving in power would be correspondingly great. Likewise, the air velocity would be one-third as large, which would entail a further saving of energy losses. It is important to remember, however, whenever this type of reasoning is employed, that the pipe diameters are not increased so much as to nullify the conveying force of the air in the duct. The velocity should always be sufficient to carry away all the particles collected. There is rarely any need for air velocities approaching 6000 fpm. Therefore, unless it has been predetermined that a stated suction is sufficient for controlling a dust hazard, no measure of hood performance can be obtained by use of the term. If it is desired to express axial velocities in terms of suction, Equation [2] may be substituted in Equation [1b] for this purpose. Suction by itself and with no reference to the type of hood used or its location with respect to the dust source may result in serious errors.

GENERAL VENTILATION

The use of general ventilation for dust control is exceedingly complicated. The adaptability of the method depends upon a multitude of factors ranging from local conditions affecting the distribution of air movements in a building to consideration of heat losses incurred during the winter seasons. General ventilation, nevertheless, is an important factor in control where dusty sources are widely distributed as is the case in foundries, crushing and milling mills, and batch rooms. In these cases, dust exposure is general and involves large numbers of workers in non-dust-producing operations.



Courtesy Norton Company

TABLE 2 AIR FLOW CORRESPONDING TO SUCTION MEASUREMENTS IN HOODS WITH CONNECTING DUCTS OF VARIOUS DIAMETERS

Suction, in. H ₂ O	Duct diameter (inches)					
	2	3	4	5	6	8
1	61	137	244	381	549	748
2	86	194	360	540	770	1060
3	106	239	424	660	950	1300
4	122	274	488	762	1098	1496
5	137	306	550	854	1230	1670
6	150	336	600	935	1350	1840

OCCUPATIONAL SURVEY

Before any attempt is made to utilize general ventilation, it is first necessary to conduct a sanitary and occupational survey. The method of making such a survey has been outlined by Bloomfield⁹ and consists of an analysis of individual dusty operations. For example, in a foundry the dusting of the molds with parting compounds, sand milling, and shakeouts should be independently quantitated in terms of dust-particle-hours. Thus, if parting compounds used intermittently for a total of, say, one-half hour each day per man create 60,000,000 particles of dust, it would be said that the exposure was 30,000,000 particle-hours. The same analysis would apply to each source, and an estimate of the actual extent of dust hazards determined. The average number of particle-hours of all sources has been found by Bloomfield to check closely with the average plant dustiness.

Having conducted a sanitary and occupational survey such as has been described, the next step is to attempt to segregate or control by local exhaust methods where possible the more dangerous dust sources. There can be little benefit, for example, in exposing all the workers in a foundry to the high concentrations produced by two or three men at the shakeout dumps. The same applies to pottery workers during dry batch-mixing operations. Hence, unless some direct means of control can be applied, some effort should be made to segregate the dangerous dust sources.

Frequently, general dusty conditions can be bettered by proper housekeeping supervision. It is a peculiar characteristic of the dusty trades to neglect this matter. The care with which plants are maintained may have an important psychological effect upon workers producing dust, and may result in greater care in the performance of duties.

No specific details of the volumes required to obtain safe concentrations in a room can be given. There is need for a considerable research in this phase of the dust-control problem. At present it is sufficient to point out that quantitative measurements of dust concentrations under varying conditions of control form the most satisfactory approach to individual problems.

⁹ Data to be published in Public Health Reports.