

between the silica that
that are composed of
with other elements in
just cited the 70 percent
silica plus 40 percent of

in certain dusty trades is
silica (as quartz) present
by the silica that is in
to devise a method for
just in a given sample
arising from cutting a
percent of total silica the
70, since only one-third
more, rocks and minerals
although they contain no
a reported in customary
of free silica.

QUANTITATIVE DETERMINATION OF QUARTZ IN ROCKS

determine the percentage of
methods, because it is easy
and other minerals
in thin microscope, as

ways: By examining a thin
of approximately 0.03 mm
slide, or by studying a
by crushing the material
out 0.06 mm in thickness.
tely immersed in oils of
where in no position
between the grains and the
active index of the mineral
it is immersed. In this
axial) or refractive indices
together with other optical
weathered rock and mineral
method."

erals depends upon the

- (2) Pleochroism, in minerals that show selective absorption of light.
- (3) Crystal form.
- (4) Cleavage.
- (5) Refractive indices and relief.
- (6) Birefringence. Numerical value.
- (7) Isotropy or anisotropy. Extinction (complete, parallel, or inclined).
- (8) Optical character of the mineral.
- (9) Optical elongation of principal zones.
- (10) Optical orientation of mineral.
- (11) Value of optic axial angle.
- (12) Twinning.
- (13) Inclusions.
- (14) Alteration products.

No one of the preceding criteria alone is sufficient to determine a mineral, although one criterion may be enough to distinguish it from some other mineral with which it is associated. Some minerals can be identified by determining three or four optical properties, others require more for conclusive determination.

The methods of determining the optical properties require a familiarity with the difficult principles of optics and a special laboratory training in petrography. The reader who desires further information about the detailed technique of the petrographic identification of minerals is referred to the standard works on optical mineralogy, such as Rosenbusch's *Mikroskopische Physiographie der Petrographisch Wichtigen Mineralien*, volume 1, part 1, revised by Wülfing; *Rock Minerals*, by J. P. Iddings; *Manual of Petrographic Methods*, by A. Johannsen; or *Dana's Textbook of Mineralogy*, fourth edition, by W. E. Ford. For a comprehensive description of the immersion method of studying minerals, the reader is referred to *The Microscopic Determination of the Nonopaque Minerals*, by E. S. Larsen.

Quantitative determination

An easy and satisfactory way to determine the percentage of any mineral in a rock section is by the Rosiwal method. This method consists in measuring the linear intercepts of a given mineral along numerous parallel lines. The ratio between the sum of all the intercepts of quartz to the length of the measured traverse gives the percentage of quartz, because, as can be shown mathematically, the linear intercepts are proportional to volumes. The measurement is carried out by the use of a screw micrometer ocular or a mechanical stage. The Rosiwal method can be applied both to rock sections and to rock powders examined by the immersion method.

NOTED BY [illegible] DID
NOT [illegible] FILES

BB 0020024 1

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2518

DETERMINATION OF QUARTZ IN DUSTS

It is comparatively easy for the petrographer to apply the methods described above in making a quantitative determination of quartz in thin sections of rocks or in rock powders, but in dusts where the individual particles are of the order of magnitude of 0.005 mm (5 microns) in diameter petrographic examination of the material must be supplemented by other methods, because the minimum grain size that can be conclusively identified under the petrographic microscope is about 0.010 mm (10 microns) in diameter.

The results of quantitative dust analysis can only be conclusive when several methods are used on the same material, thereby checking one against the other; and the accuracy of the final result depends largely on the skill and experience of the analyst, because each sample to be analyzed presents an individual problem.

The general method that has been found highly satisfactory is a combined chemical and petrographic procedure by which all the constituents other than quartz are eliminated from the material. The accuracy of any method of quantitative estimate is much greater where the estimate is applied to two constituents than where many constituents are present. Therefore, by concentrating the quartz a large factor of error in quantitative determination is eliminated.

If the dust is chiefly composed of quartz, the elimination of foreign constituents is not difficult. If the quartz is in smaller amount than the other constituents, a clean concentration may be more difficult. But a satisfactory quantitative estimate can always be made on a moderately clean quartz concentrate, because the mineral present in marked excess can be much more accurately determined than the other constituents.

For the fine dusts whose individual particles cannot be satisfactorily determined chemical methods are necessary in order to remove the constituents other than quartz. Various methods are used dependent upon the composition of the dust, but the first step in the analysis is to examine a small portion of the material under the petrographic microscope.

Preliminary petrographic examination of the dust

It is a common practice to cite the percentage of silica in the chemical analysis of a dust as a measure of the quartz present. The erroneous nature of this conclusion has been already emphasized. The only value of the chemical analysis to the dust analyst is based upon the fact that the amount of silica locked up in the various silicate minerals in the dust can be calculated from the percentages of bases (K_2O , Na_2O , CaO , etc.) that are shown by the analysis. The percentage of silica that remains after all the bases in the various silicate materials have been satisfied should represent the free silica present.

This is a composite example of granites, siliceous, feldspar, is composite, potassium, muscovite, satisfy the various in rock-form, composite.

As this is to the petrographer, emphasized, suitable procedure, dust sample, quantitative petrographic examination of dust by a method suited to the material, a again examine procedure, free iron may with hydrochloric particles as it works contain heated with residue should. The most difficult mineral dusts or asbestos dust in such material, H_2SiF_6 , not attack quartz.

Chemical examination

After the petrographic the chemical

NOTE: THIS DOCUMENT DID NOT COME FROM PPG FILES

1 BB 0020025 1

THIS DOCUMENT WAS NOT A RECORD OF PPG INDUSTRIES, INC. DID NOT COME FROM IT'S FILES AND CANNOT BE AUTHENTICATED BY PPG INDUSTRIES, INC.

2519

This method of computation is useless, however, unless the mineral composition of the dust has been determined petrographically. For example, in potassium feldspar, which is a common constituent of all granites, every molecule of potash is combined with 6 molecules of silica. If the only minerals in the dust are quartz and potassium feldspar, obviously the silica left over after the potash in the analysis is computed as feldspar will be an accurate measure of the quartz present. But if, as is often true, the dust is made up of several potassium-bearing minerals, such as potassium feldspar, biotite, and muscovite, it is impossible to compute how much silica is required to satisfy the potash, because neither the relative proportions of the various minerals are known nor are their compositions known. Most rock-forming silicate minerals have wide ranges in their chemical composition.

As the chemical analysis of a dust can only serve as a rough guide to the possible amount of quartz present, it cannot be too strongly emphasized that a careful petrographic examination is an indispensable prerequisite to the quantitative determination of quartz in a dust sample. For although it may be impossible to make an accurate quantitative determination of extremely minute individual grains by petrographic methods, it has proved possible in all the samples so far examined to obtain a clear idea of the general composition of the dust by a petrographic examination. The analytical method best suited to the individual sample can then be selected. For example, if the dust shows under the microscope a large admixture of organic material, a preliminary sample should be ignited and the residue again examined under the microscope in order to decide on the further procedure. If the dust shows a large amount of metallic mineral, free iron may be extracted by a magnet or the sample may be heated with hydrochloric acid to remove the iron oxide and such metallic particles as brass shavings from brass-works dust. Dust from marble works containing chiefly particles of carbonate minerals should be heated with hydrochloric acid to dissolve the carbonate, and the residue should then be examined with the petrographic microscope. The most difficult problem is the separation of quartz in rock or mineral dusts that contain silicate minerals, such as granite, slate, or asbestos dust. The procedure employed to separate the quartz in such material depends upon the fact that cold hydrofluosilicic acid, H_2SiF_6 , will in time decompose the silicate minerals but will not attack quartz.

Chemical examination of the dust

After the preliminary petrographic examination the procedure in the chemical separation of quartz is as follows:

NOTE: THIS DOCUMENT DID NOT COME FROM PPG INDUSTRIES, INC. FILES

1 BB 0020026 1

Grinding.—In order to facilitate the action of the hydrofluosilicic acid the material is ground to pass a 150-mesh sieve, thus insuring uniformity of size and a large surface for treatment.

Weighing.—It is then weighed in a platinum crucible. About half a gram makes a convenient amount to work with.

Ignition.—If the preliminary microscopic examination indicates the presence of any organic material, the platinum crucible and its contents are carefully heated to white heat for 30 minutes to burn off the organic matter. It is then cooled. Dusts that are strongly contaminated with oil are digested for 5 minutes with ether, then filtered, and ignited for half an hour to an hour.

Hydrochloric acid treatment

If the preliminary examination shows the presence of carbonate minerals, hydrochloric acid is added to the contents of the platinum crucible and the crucible is gently heated. The contents of the crucible are filtered, washed, and the filter paper and precipitate are ignited in the same platinum crucible, which is then allowed to cool.

Hydrofluosilicic acid treatment

After these operations hydrofluosilicic acid in moderate excess is added to the material in the platinum crucible. If the composition of the dust is such that the ignition and hydrochloric-acid treatment are unnecessary, the hydrofluosilicic acid is added to the substance to be analyzed immediately after the first weighing. The crucible is carefully covered and set away in a place where the temperature is reasonably constant and not above room temperature. Care must be exercised not to raise the temperature during the hydrofluosilicic acid treatment, because hydrofluosilicic acid (H_2SiF_6) decomposes on heating into silicon tetrafluoride (SiF_4) and hydrofluoric acid (HF), which will readily attack the free silica. It is left for a time that ranged in different specimens from 24 to 48 or even 72 hours.

It is then carefully decanted into an ashless filter paper and the crucible is thoroughly washed onto the filter paper. The precipitate is washed until the wash water gives no precipitate in a clear mixture of dilute KCl with 95 percent alcohol. The precipitate is dried, ignited in the platinum crucible, and weighed, and the percentage loss in weight noted.

The hydrofluosilicic acid treatment is repeated until the weight of the residue remains unchanged.

Microscopic examination of residue

A small portion of the residue is then examined under the petrographic microscope. If minerals other than quartz are present, the amount of quartz in the residue can be estimated with a reasonable degree of accuracy. If quartz is the only mineral indicated by the

microscopic
be calcu-

Volatilization

A ether
volatilizing
Free silica
silica in
the treatment
combination
fluorization

RATE OF D

As the
different si
determine
longed treat
analysis of
more to de

The follo
quartz grou

1. _____
2. _____
3. _____
4. _____
5. _____

1. Average = 7.1%

By using t
end of an a
originally pr

It is appare
individual pr
analyzed, the
etc. Therefo
be selected af
dust have be

hydrofluosilicic sieve, thus insuring cent.

ucible. About half h.

nation indicates the crucible and its contents to burn off at are strongly combined, then filtered,

essence of carbonate nts of the platinum he contents of the and precipitate are n allowed to cool.

moderate excess is

If the composition ionic-acid treatment ed the substance in. The crucible ro temperature to. Care must the hydrofluosilicic H_2SiF_6 decomposes on -osilicic acid (HF), left for a time that ven 72 hours.

filter paper and the r. The precipitate e in a clear mixture ipitate is dried, ig- the percentage loss

until the weight of

ed under the petro- rtz are present, the l with a reasonable al indicated by the

microscopic examination, the percentage of quartz in the sample can be calculated directly from the weight of the residue.

Volatilization of residue with hydrofluoric acid

A check on the microscopic determination of quartz is given by volatilizing the residue with hydrofluoric acid in the platinum crucible. Free silica volatilizes completely with hydrofluoric acid. Combined silica in silicate minerals volatilizes with hydrofluoric acid, but after the treatment a residue remains made up of the bases that were in combination in the silicates. If no residue is left after the hydrofluorization, the material was all quartz.

RATE OF DECOMPOSITION OF QUARTZ ON PROLONGED TREATMENT WITH HYDROFLUOSILICIC ACID

As the rate of decomposition was found to differ considerably in different silicates, a control test was run on pure quartz in order to determine the error introduced into quantitative analyses by prolonged treatment of quartz with H_2SiF_6 at room temperature during analyses of dusts that contain refractory silicates requiring a week or more to decompose.

The following table shows the results of a test on 0.509 gm of pure quartz ground to pass a 150-mesh screen:

TABLE 16.—Quartz

(Original weight before treatment with H_2SiF_6 = 0.509 gm)

Time in days	Loss after treatment (grams)	Percent loss in weight	Rate of loss in weight per day in percent of original weight
1	0.015	2.9	1.28
2	.031	6.1	1.67
4	.057	11.2	1.73
12	.094	18.6	1.55
21	.097	19.1	1.38

¹ Average = 0.7 percent per day is rate of loss in original weight.

By using the above factor of error it is possible to compute at the end of an analysis the maximum possible loss in weight of quartz originally present, thus obtaining a maximum figure for quartz.

It is apparent from the preceding discussion that each dust presents individual problems in regard to the purification of the sample to be analyzed, the methods of eliminating the various mineral constituents, etc. Therefore, the best procedure in analyzing a given dust must be selected after the minerals and other constituents making up the dust have been identified; consequently it is impossible to set forth

NOTED BY [illegible] 11/17/48

any one technique that will apply to all dusts regardless of their composition.

In the following table a few results are presented on the determination of quartz in industrial dusts:

TABLE 17.—Percentage of quartz present in various industrial dusts

	Percentage of quartz
Rock drilling dust (bituminous coal mine).....	54.0
Grain elevator dust.....	33.2
Rock drilling dust (anthracite coal mine).....	31.0
Iron-ore dust.....	19.0
Dust from saw mills in cement plant.....	6.5
Flint mill dust (Vermont red shale).....	2.0
Silver-ore dust.....	1.7
Anthracite dust.....	1.5
Bituminous dust.....	1.2
Cement dust.....	Trace
Flint mill dust (Vermont green slate).....	Trace
Talc mill dust.....	None
Marble cutting dust.....	None

V.

Fi

are

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

dis

NOTE: THIS DOCUMENT DID NOT COME FROM PPG INDUSTRIES, INC.

BB 0020029 1

THIS DOCUMENT WAS NOT A RECORD OF PPG INDUSTRIES, INC. DID NOT COME FROM IT'S FILES AND CANNOT BE AUTHENTICATED BY PPG INDUSTRIES, INC.

2523

dusts regardless of their
presented on the determina-

various industrial dusts

	Percentage of quartz
-----	51.0
-----	34.0
-----	31.0
-----	19.0
-----	8.5
-----	7.0
-----	1.7
-----	1.3
-----	1.2
-----	<1.0
-----	Trace
-----	None
-----	None

V. THE APPLICATION OF DUST DETERMINATIONS TO PRACTICAL PROBLEMS

Dust determinations in industry serve a three-fold purpose. First, they enable one to evaluate the extent of the hazard; this is accomplished by obtaining occupational dust exposures, which disclose the dust-creating tasks. Second, if clinical studies are made, dust counts may indicate the permissible amounts of dust which may be breathed with impunity. Third, dust determinations are used in an attempt to control the dust hazard; this is performed by testing the efficiency of any devices which may have been introduced for the suppression of dust in those processes which have been revealed by investigation to be hazardous.

DETERMINATION OF THE EXTENT OF THE DUST HAZARD

Attention has already been called to the three properties of a dust which determine its capacity to produce injury. Having established the composition and size of a dust the only important item remaining for study is the quantity of dust in the air. Prior to evaluating the quantity of dust in the industrial atmosphere, however, certain preliminary steps, such as those outlined in section 1, are essential. For the sake of emphasis these steps are briefly reviewed.

The investigator should first become thoroughly familiar with the industry being studied. This is best accomplished by conducting a sanitary survey and occupational study of each workroom (46). The sanitary survey of workrooms in any plant yields definite information concerning the presence and extent of various health hazards and often serves as a guide in establishing which hazards require further study in the form of actual quantitative analyses. In other words, the sanitary survey may well be regarded as a listing of the facilities afforded the workers while in the industrial environment. The occupational study permits one to learn of the activities involved and the particular hazards associated with each occupation. Such an analysis also shows the number of persons in each occupation, which gives an idea of the importance of each hazard from the viewpoint of the numbers involved. In the case of a dusty industry, the occupational study shows (1) the dusty occupations, (2) the number of persons in each occupation, and (3) the various activities and the time devoted to each activity in any one particular occupation. All this information is essential in the preventive program which

(53)

NOTICE
NOTICE
NOTICE

BB 0020030 1.

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2524

should follow, and experience has proved that only by such a systematic and careful study can dust determinations be of any real value in the control of the industrial dust hazard. Perhaps a typical example of such a study may serve to clarify further the methodology involved.

TABLE 18.—Occupational classification of granite quarriers

Occupation	Number in each occupation	Occupation	Number in each occupation
Drillers:		Other quarry employees—Continued.	
In the hole	17	Herrick men	24
Pick and jack hammer	37	Muckers	23
Other quarry employees:		Blacksmiths	6
Explosives men	1	Tail boys	2
Foremen	1	Water boys	1
Carpenter	1	Machinists	3
Dies and casters	12	Air-line repairmen	1
Lapidary	1	Pipe fitters	2
Lapidary and sand	1		
Pneum shovel men	1		
Crane operator	1	Total	122

Table 18 shows the various occupations in a granite quarry and the number of workers employed in each occupation, and that drillers are the only persons using pneumatic tools, devices known to produce considerable quantities of dust. In other words, 38 percent of the quarry personnel are shown to be exposed to dust of a potentially dangerous size and quality. The occupational analysis at once indicates that the dust investigation should especially concern itself with drillers in an effort to control the dust exposure of these workers.

The next step in this study involves the determination of the occupational dust exposure. Table 19 shows the results of such a study.

TABLE 19.—Occupational dust exposure of granite quarriers

Occupation	Number in each occupation	Dust counts in millions of particles per cubic foot of air		
		Weighted average	Minimum	Maximum
Leyner drillers	17	141.4	4.3	1,055.0
Pick and jack-hammer drillers (quarry hole)	37	112.1	4.1	398.6
Pick drillers (7 men)	7	25.9	4.3	54.0
All other workers	88	4.6	4.1	10.7

It is apparent from the results shown in this table that the drillers are exposed to high dust concentrations, especially the Leyner and jack-hammer drillers working in the quarry hole. From a further analysis of the occupational dust exposure of drillers it is possible to determine which activities are responsible for the dust associated

with the ventilation this research results driller.

TABLE 1

Drillers...
Crane operator...
Water boys...
Machinists...
Pipe fitters...
Total

21

It will dust exp table 20 obtain a occupati is 144.4 found de determin dust haza blowing o hole is att it is an ac is one wh It is evid may be at lastly, suc efforts to activity as a Leyner c So far w rule, do no who have

THIS DOCUMENT WAS NOT A RECORD OF PPG INDUSTRIES, INC. DID NOT COME FROM IT'S FILES AND CANNOT BE AUTHENTICATED BY PPG INDUSTRIES, INC.

BB 0020031

2525

that only by such a systematic analysis be of any real value; hazard. Perhaps a typical clarify further the methodology

Occupation of granite quarriers

Occupation	Number in each occupation
Quarry employees—Continued.	
Drillmen	21
Drillmen	21
Drillmen	6
Drillmen	1
Drillmen	1
Drillmen	1
Drillmen	1
Drillmen	1
Drillmen	1
Drillmen	1
Total	122

tions in a granite quarry and in each occupation, and that systematic tools, devices known to be used to dust of a potential occupational analysis at the dust exposure of these

res the determination of the shows the results of such a

Occupation of granite quarriers

Number in each occupation	Dust count in millions of particles per cubic foot of air		
	Weighted average	Minimum	Maximum
21	144.4	5.3	1,000.0
21	112.1	4.1	300.0
6	35.0	5.3	50.0
1	5.5	4.1	10.7

in this table that the drillers as, especially the Leyner and quarry hole. From a further are of drillers it is possible to able for the dust associated

with this occupation. For example, experience has taught us that the various operations comprising the processes of most dusty occupations are usually associated with dissimilar dust exposures. For this reason it is essential to estimate the amount of time spent in each activity in any one occupation and to determine the dust exposure for each activity in that occupation. Table 20 shows the results of such a differential dust study in the case of a Leyner driller.

TABLE 20.—Summary of dust exposure of Leyner drillers in a granite quarry

Activity	Average dust exposure in millions of particles per cubic foot of air (a)	Number of hours spent in each activity (b)	Particle-hours in millions per cubic foot (aXb)
Drilling	213.4	4	853.6
Blowing drills	5.5	1	5.5
Working drills	5.5	2	11.0
Blowing	5.5	1	5.5
Moving off holes	1,000.0	1	1,000.0
Total		8	1,125.2

1,125.2 particle-hours in millions per cubic foot = 144.4 million particles per cubic foot.
8 hours

It will be seen from table 20 that a Leyner driller has five different dust exposures. A differential analysis, such as the one presented in table 20, yields several valuable findings. First, it enables one to obtain a true average dust exposure for workers engaged in the occupation of Leyner drilling. (In this case the weighted average is 144.4 as contrasted with 213.4 million particles per cubic foot found during drilling operations only.) Second, it enables one to determine which activity, or activities, contribute the most to the dust hazard. In this instance it is quite evident that the practice of blowing off holes by means of inserting a compressed air line into each hole is attended with an exceedingly great amount of dust; and though it is an activity lasting but 15 minutes of the 8-hour working day, it is one which is responsible for 23 percent of the total dust exposure. It is evident that 23 percent of the Leyner driller's dust exposure may be at once eliminated by the prohibition of this practice. And lastly, such an analysis indicates the necessity for devoting all one's efforts to the removal of dust during the drilling process, since this activity accounts for 74 percent of the total dust exposure, although a Leyner driller spends but one-half of the working day at his drill.

So far we have dealt with an industry in which the workers, as a rule, do not change their occupation. Often one encounters workers who have had several occupations, either in the same industry or in

LIBRARY OF THE
COLLEGE OF PHYSICIANS
OF PHILADELPHIA

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

BB 0020032

2526

several different kinds of establishments. If the worker has been employed in various occupations in the industry under investigation, it is a simple matter to determine his total dust exposure during his entire trade life in that industry. This is important from the viewpoint of correlating a worker's dust exposure and his clinical condition. A typical example of such a case will suffice to clarify this point.

TABLE 21.—Total occupational dust exposure of an anthracite coal worker

Occupation	Number of years in each occupation	Dust concentration in millions of particles per cubic foot	Millions of particle-years per cubic foot
Plate picker	3	360	720
Picker	3	71	142
Shut driver	3	71	213
Miner's helper	3	440	1,340
Miner	15	420	7,200
Section foreman	5	7	35
Total	30		9,700

9,700 millions of particle-years per cubic foot — 320 millions of particles per cubic foot.
30 years

In the above table the worker's occupations are arranged in the order of employment, the last one being his present occupation. It is obvious that had one considered this last occupation only the dust exposure for this individual would not have yielded a true state of affairs, nor would it have been possible to correlate this dust exposure with the man's clinical picture. In the above technic correct weight is given to the number of years spent in each occupation and the dust exposure associated with each occupation. Only by such an analysis is it possible to arrive at a fair estimate of a worker's dust exposure and his proper designation. That one is justified in resorting to such an analysis is evidenced by the fact that results obtained with this technic yield excellent correlations with the clinico-roentgenological studies conducted on anthracite coal miners.

APPLICATION OF DUST COUNTS TO CLINICAL STUDIES

Earlier in this chapter it was pointed out that one of the purposes of dust investigations is the determination of the threshold dose for any one particular dust, so that permissible amounts of this dust may be known and efforts to suppress the dust to this limit may be made. Such evaluations are sometimes made possible in studies in which in addition to the occupational dust exposure one also obtains clinical, morbidity, and mortality data on a large group of workers over a period of time. One such study was made in connection with an investigation of the health of granite cutters. Table 3, shown earlier

BB 0020033

If a worker has been under investigation, dust exposure during his important from the view- and his clinical condition. to clarify this point.

an anthracite coal worker

Number of years in each occupation	Dust concentration in millions of particles per cubic foot	Millions of particles per cubic foot
1-5	20	200
6-10	21	112
11-15	21	112
16-20	20	112
21-25	20	112
26-30	20	112
31-35	20	112
36-40	20	112
41-45	20	112
46-50	20	112
51-55	20	112
56-60	20	112
61-65	20	112
66-70	20	112
71-75	20	112
76-80	20	112
81-85	20	112
86-90	20	112
91-95	20	112
96-100	20	112
101-105	20	112
106-110	20	112
111-115	20	112
116-120	20	112
121-125	20	112
126-130	20	112
131-135	20	112
136-140	20	112
141-145	20	112
146-150	20	112
151-155	20	112
156-160	20	112
161-165	20	112
166-170	20	112
171-175	20	112
176-180	20	112
181-185	20	112
186-190	20	112
191-195	20	112
196-200	20	112
201-205	20	112
206-210	20	112
211-215	20	112
216-220	20	112
221-225	20	112
226-230	20	112
231-235	20	112
236-240	20	112
241-245	20	112
246-250	20	112
251-255	20	112
256-260	20	112
261-265	20	112
266-270	20	112
271-275	20	112
276-280	20	112
281-285	20	112
286-290	20	112
291-295	20	112
296-300	20	112
301-305	20	112
306-310	20	112
311-315	20	112
316-320	20	112
321-325	20	112
326-330	20	112
331-335	20	112
336-340	20	112
341-345	20	112
346-350	20	112
351-355	20	112
356-360	20	112
361-365	20	112
366-370	20	112
371-375	20	112
376-380	20	112
381-385	20	112
386-390	20	112
391-395	20	112
396-400	20	112
401-405	20	112
406-410	20	112
411-415	20	112
416-420	20	112
421-425	20	112
426-430	20	112
431-435	20	112
436-440	20	112
441-445	20	112
446-450	20	112
451-455	20	112
456-460	20	112
461-465	20	112
466-470	20	112
471-475	20	112
476-480	20	112
481-485	20	112
486-490	20	112
491-495	20	112
496-500	20	112
501-505	20	112
506-510	20	112
511-515	20	112
516-520	20	112
521-525	20	112
526-530	20	112
531-535	20	112
536-540	20	112
541-545	20	112
546-550	20	112
551-555	20	112
556-560	20	112
561-565	20	112
566-570	20	112
571-575	20	112
576-580	20	112
581-585	20	112
586-590	20	112
591-595	20	112
596-600	20	112
601-605	20	112
606-610	20	112
611-615	20	112
616-620	20	112
621-625	20	112
626-630	20	112
631-635	20	112
636-640	20	112
641-645	20	112
646-650	20	112
651-655	20	112
656-660	20	112
661-665	20	112
666-670	20	112
671-675	20	112
676-680	20	112
681-685	20	112
686-690	20	112
691-695	20	112
696-700	20	112
701-705	20	112
706-710	20	112
711-715	20	112
716-720	20	112
721-725	20	112
726-730	20	112
731-735	20	112
736-740	20	112
741-745	20	112
746-750	20	112
751-755	20	112
756-760	20	112
761-765	20	112
766-770	20	112
771-775	20	112
776-780	20	112
781-785	20	112
786-790	20	112
791-795	20	112
796-800	20	112
801-805	20	112
806-810	20	112
811-815	20	112
816-820	20	112
821-825	20	112
826-830	20	112
831-835	20	112
836-840	20	112
841-845	20	112
846-850	20	112
851-855	20	112
856-860	20	112
861-865	20	112
866-870	20	112
871-875	20	112
876-880	20	112
881-885	20	112
886-890	20	112
891-895	20	112
896-900	20	112
901-905	20	112
906-910	20	112
911-915	20	112
916-920	20	112
921-925	20	112
926-930	20	112
931-935	20	112
936-940	20	112
941-945	20	112
946-950	20	112
951-955	20	112
956-960	20	112
961-965	20	112
966-970	20	112
971-975	20	112
976-980	20	112
981-985	20	112
986-990	20	112
991-995	20	112
996-1000	20	112

of particles per cubic foot.

as are arranged in the present occupation. It is only the dust yield of a true state of the dust exposure to the correct weight of dust and the dust by such an analysis of a worker's dust exposure is resorting to such dust obtained with this linear-radiological

STUDIES

one of the purposes of the threshold dose for dusts of this dust may be limit may be made. in studies in which in also obtains clinical, up of workers over a connection with an Table 3, shown earlier

in section I, is repeated at this time to show the occupational dust exposure of a group of these workers.

TABLE 3.—Ranking the various occupations in the granite-cutting industry according to dust exposure

Occupation	Number of men exposed	Number of observations	Dust count in millions of particles per cubic foot		
			Minimum	Maximum	Average
All pneumatic hand-tool operators.....	363	86	2.4	231.0	88.3
Surface cutters:					
Inside.....	25	31	.6	122.7	44.0
Outside.....	10	10	14.0	102.2	41.0
Carvers and finishers.....	21	20	11.7	99.8	37.0
Tool trimmers.....	20	14	6.3	62.0	27.1
General plant atmosphere.....	121	42	2.4	61.0	20.2
Lathe operators.....	4	4	2.0	21.7	17.0
Polishers.....	43	24	1.3	29.4	9.0
Hand-tool operators.....	4	4	1.0	12.4	6.2
Sawyers.....	10	4	4.0	4.9	4.6
Electricians and others.....	101	4	.9	5.2	2.5
Office employees.....	10	4	1.5	2.4	1.9

It was found possible to divide these granite cutters into four groups, depending upon the average exposure in terms of the amount of dust in the air, when considering the clinical picture associated with these workers. Figure 24 shows the annual frequency of absences from tuberculosis and the annual death rate from this disease among the men in the four groups.

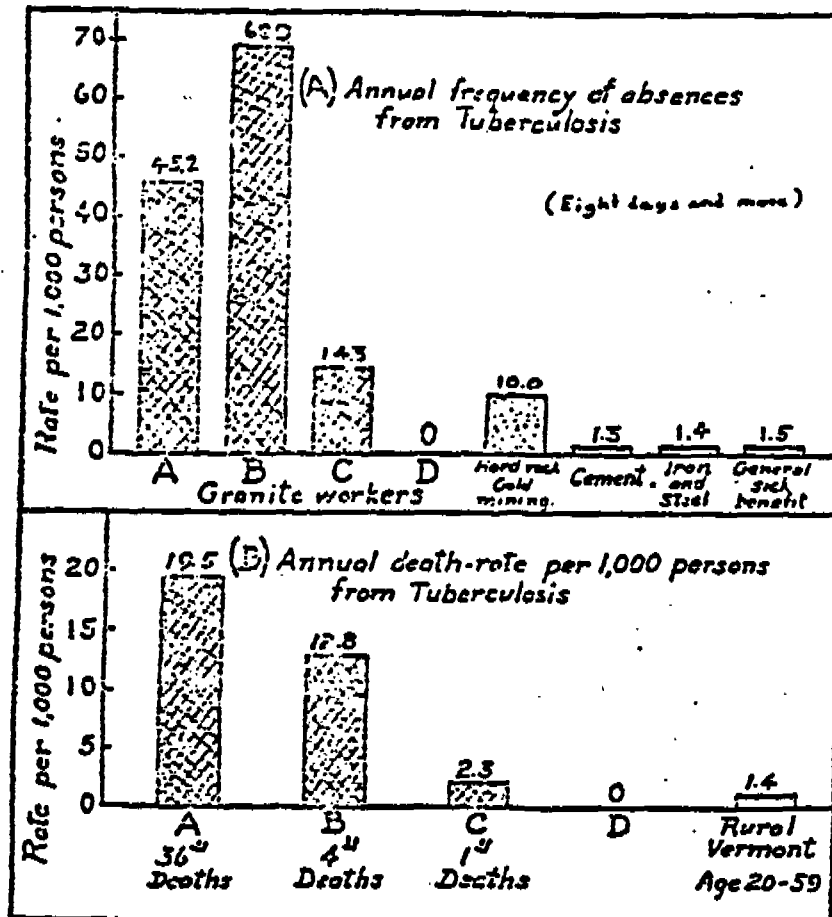
In group A, which included hand-pneumatic tool operators and in which the exposure averaged about 50 million particles per cubic foot of air, it was found that practically 100 percent developed an established silicosis within 10 years from the time of beginning employment. Also, in this group the highest rate was found for cases diagnosed on physical examination as having active tuberculosis. Furthermore, a definite relation was established between length of service in the industry and the prevalence of tuberculosis. All of the statistical data obtained indicated definitely that hand-pneumatic tool operators in these plants suffered from an occupational hazard.

In group B were included those workers other than hand-pneumatic tool operators who were also exposed to more than the average plant dustiness. Taking the group as a whole, the average dust concentration was nearly 45 million particles per cubic foot of air. This group showed the same reflection of a dust hazard as group A.

In group C, consisting of those occupational groups exposed to the average plant dustiness (about 20 million particles per cubic foot of air), silicosis developed much more slowly than in the groups just discussed and there appeared to be very little excess in the rate for tuberculosis, with no tendency for an increase according to length of service. Analysis of occupational mortality over a period of 25 years,

however, indicated that some of the occupations in this group may have been exposed to a real dust hazard.

Group D was made up of those occupations in which the dustiness was less than that of the average plant atmosphere. The average exposure for the group was less than 10 million particles per cubic



From beginning of study to working up of report — about three years — among 972 workers: A, 614; B, 104; C, 146; D, 108.

FIGURE 21—Relationship between tuberculosis morbidity and mortality and dust exposure.

foot of air. Although a certain amount of silicosis was found even in this group, there was no indication of serious results, even when the workers had been employed for many years.

From the results of this study it was found practicable to suggest a tentative standard for the upper limit of allowable dustiness between 10 and 20 million particles per cubic foot of air for workers exposed to dust resulting from granite cutting.

NOTE

NOTE

BB 0020035

DUST COUNTS AS CRITERIA IN THE CONTROL OF THE DUST HAZARD

The sections which will follow discuss in some detail the various principles and methods involved in the control of industrial dust. Descriptions are presented on the correct design, air-flow requirements, and other pertinent data dealing with the control of dust by wet methods, mechanical enclosure, exhaust ventilation, and personal respiratory protection. One of the important factors in the use of such protective equipment is the proper maintenance of these devices and the testing of their efficiency in an effort to determine whether or not the dust is actually being eliminated by the particular equipment in use. Such efficiency tests resolve themselves in making dust determinations in order to determine the dust content at the breathing level of the worker operating a dust-creating machine equipped with a dust-removal device. A few examples of the practical application of efficiency studies may serve to indicate the value of such criteria in the present problem.

Mention has already been made of the study of the health of granite cutters (2) in which it was possible to demonstrate that those persons engaged for many years in tasks associated with a dust exposure of less than 10 million particles per cubic foot of air were not suffering from silicosis or tuberculosis, the diseases most prevalent among these granite cutters. It was also possible to demonstrate that among these granite cutters the incidence of silicosis and tuberculosis, all other factors being equal, was directly proportional to the degree of dust exposure. The solution of the dust problem in the granite-cutting industry therefore, resolved itself in the removal of the dust at its source, to an amount less than 10 million particles per cubic foot, preferably by exhaust ventilation devices (47). Studies of the efficiency of such dust-removal devices have been made, using the dust determination at the worker's breathing zone as a final criterion. In table 22 a comparison of air dustiness is presented between granite-cutting plants using exhaust ventilation devices and those not equipped with such protection.

TABLE 22.—Comparison of atmospheric dust conditions between two groups of granite-cutting plants

Occupation	Average dust count in millions of particles per cubic foot of air—winter observations		
	Plants without efficient local exhaust system	Plants with efficient local exhaust system	
		Plant X	Plant Y
All pneumatic hand-tool operations.....	22.2	21.5	9.5
Foot crushing.....	47.0	15.3	10.0
Foot grinding.....	30.0	3.0	12.1
Stone splitting.....	6.0	1.5	5.5
General plant atmosphere.....	22.6	5.0	5.9

BB 0020036

It is apparent from the results presented in table 22 that in plant X the exhaust devices in use with pneumatic tool operations needed attention, since the dust concentrations associated with these operations were slightly higher than the prescribed standard. On the other hand, the ventilation system in plant Y was apparently functioning satisfactorily at the time these studies were conducted.

In studying the degree of exhaust ventilation necessary to keep the dust at the worker's breathing level to an amount less than 10 million particles per cubic foot, the dust determination method again proved

rela
and
in a

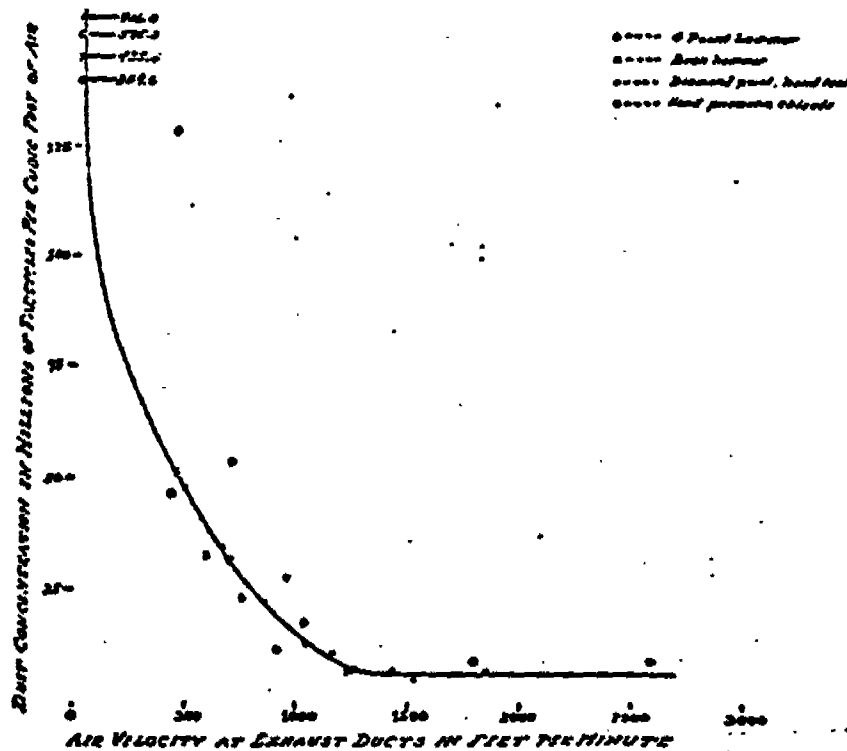


FIGURE 25.—Relationship between the degree of air velocity at exhaust ducts and the amount of dust inhaled by granite cutters using pneumatic tools.

FIGURE 25—

such pro:
inside the
maintaini
the below

very useful. Figure 25 presents the results of a study of the relation between the degree of air velocity at exhaust ducts and the amount of dust inhaled by granite cutters using various pneumatic tools. It is apparent from this figure that by maintaining an exhaust velocity of 1,500 linear feet per minute at the face of the dust-removal head of the type investigated in the present study, the dust concentration at the worker's breathing zone will be less than 10 million particles per cubic foot.

Again, in studying the efficiency of sand-blast helmets used in the protection of men working inside sand-blast rooms, it was found that a

to 22 that in plant operations needed with these operations standard. On the Y was apparently functions were conducted. on necessary to keep the amount less than 10 million on method again proved

..... of Total Pressure
 Dust Volume
 Breasted gun, hand tool
 Dust pressure change

relationship existed between the amount of air supplied to the helmet and the concentration of dust inside the helmet during blasting (48). In an attempt to determine the optimum air volume to be supplied to

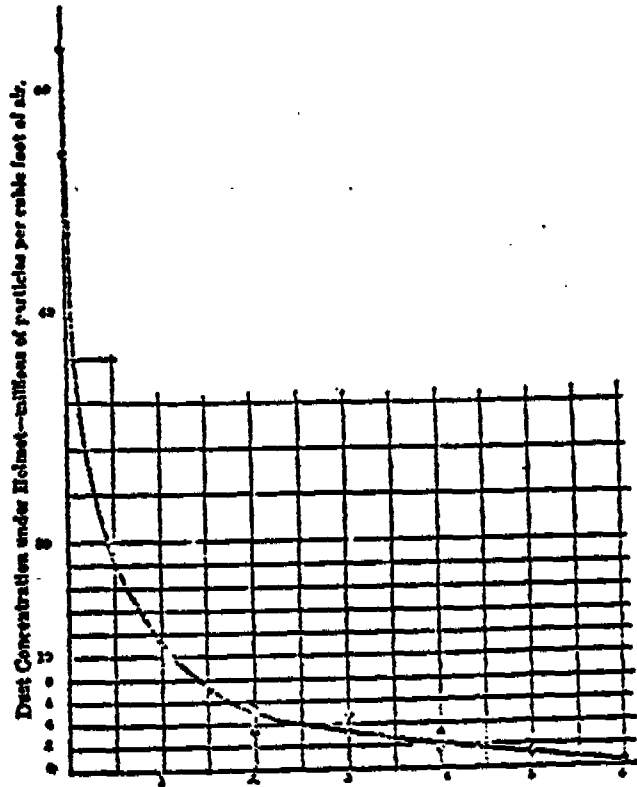


FIGURE 25.—Graph showing relationship between the volume of air supplied to helmets and the number of dust particles in air breathed by workers.

such protective devices, it was necessary to obtain dust samples from inside the helmet while varying the air volume, at the same time maintaining the dust concentration in the sand-blast room (outside the helmet) constant. Figure 26 shows the results of such a study

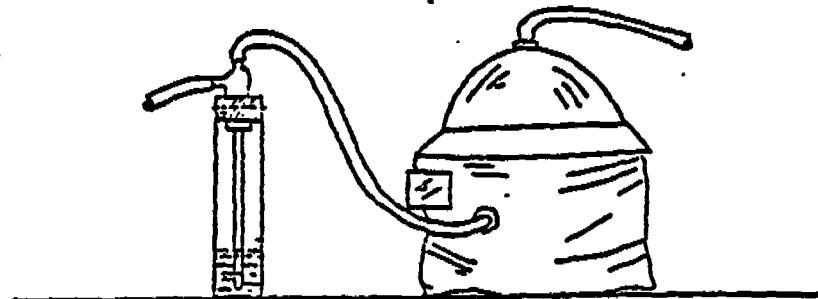


FIGURE 26.—Sketch showing method of testing sand-blast helmets.

1022211-45-6

NOTE: THIS DOCUMENT IS NOT CLASSIFIED

THIS DOCUMENT WAS NOT A RECORD OF PPG INDUSTRIES, INC. DID NOT COME FROM IT'S FILES AND CANNOT BE AUTHENTICATED BY PPG INDUSTRIES, INC.

BB 0020038

2532

and clearly indicates that the positive supply of 6 cubic feet of dust-free air per minute will protect a worker under the operating conditions now in practice in sand-blast rooms. The ultimate criterion of protection, however, is the result of dust determinations of the air within the helmet; that is, the air actually breathed by the worker and not the volume of air supplied. Figures 27 and 28 show the arrangement of the dust sampling devices used in determining the degree of protection afforded a worker by such protective equipment.

It is apparent from the few practical applications shown in this discussion that the dust determination method offers a real criterion for determining the effectiveness of the various dust-control measures which are treated in the sections to follow.

NOTE: THIS DOCUMENT DID
NOT COME FROM
PPG INDUSTRIES, INC. FILES

FIGURE 28 - A5

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

| BB 0020039 |

2533

of cubic feet of dust.
adequate operating con-
Timate criterion
of the air
resisted by the worker
s 27 and 28 show the
ed in determining the
protective equipment.
ications shown in this
l fers a real criterion
dust-control measures

NOTE: THIS DOCUMENT DID
NOT COME FROM PPG FILES

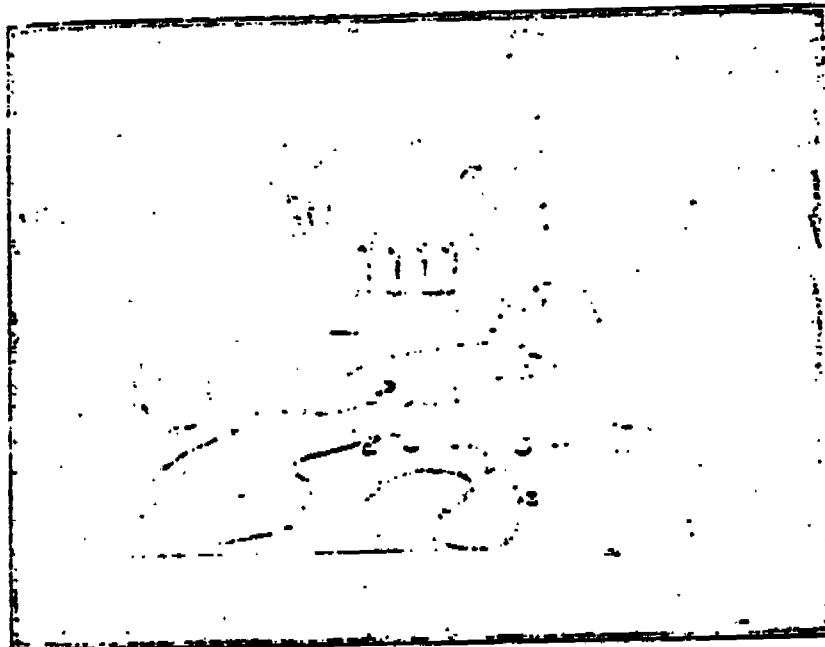


FIGURE 28.—ASSEMBLY OF APPARATUS FOR TESTING THE EFFECTIVENESS OF
SAND-BLAST HELMETS.

BB 0020040

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2534

VI. GENERAL DUST-CONTROL METHODS

The prevention of occupational disease hazards is chiefly an engineering problem. Until recently, very little definite information was available and scarcely any attempt was made to develop control methods. In an age of progress, during which production and mechanization were uppermost considerations in industry, comparatively little thought was given to the health hazards associated with them. The serious consequences of the neglect to provide adequate facilities for prevention have grown, until at the present time, their cost has become a vital concern to industry. There is, moreover, a realization that compensation for the occupational diseases is only a matter of time, and that, as in the case of accidents, a preventive program must be worked out. Just as the cost of insurance under workmen's compensation acts are in a large measure based upon accident experience, so also will the cost of caring for those suffering from the diseases of occupation be determined by their relative frequency. The formation and development of a preventive program at this time is of utmost importance.

It must be realized that the benefits of even the most extensive program of controlling dusts are not always immediately realized. This is particularly true of the fibrosis-producing dusts, whose effects are not evidenced except after a long period of time. Thus, occasional disabilities are likely to occur amongst workers exposed prior to initiating a preventive program. On the other hand, the control of toxic dusts containing lead or cadmium may produce beneficial results in a comparatively short time.

Not all the methods in use for controlling dusts are successful. The choice of any method depends chiefly upon its efficiency in reducing a given hazard and upon its adaptability. A large percentage of reduction in dust concentration achieved by a certain device does not necessarily imply that it is efficient, since the measure of success attained depends upon the ability of the device to reduce concentrations below the threshold or safe limit. A method of control also cannot be said to be completely successful which interferes with the process or which hinders the worker in the performance of his duties.

The chief methods of controlling industrial dust hazards are (1) substitution of nondust-producing or harmless substances, (2) isolation of dusty processes, (3) wetting dust at source, and (4) local

(73)

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

BB 0020041

2535

exhaust ventilation applied at point of dust generation. All these methods have been used and have achieved considerable success in many instances.

With regard to the first method of controlling dust—namely, substitution of nondust-producing or harmless substances—there is only limited application. In certain cases substances have been replaced by others known to be less harmful, such as in the case of parting compounds applied on foundry molds. Pure silica was formerly widely used; but recently this has given way to other compounds which are noninjurious to health. Considering that the chief dust exposure of foundry molders is from the application of parting compounds (49), the substitution of a nonsilica-containing compound has eliminated a serious occupational disease hazard. Again, in the case of abrasive cleaning, sand has to a large measure given way to metal shot. The improvement obtained by such substitution is clearly shown by the dust counts given in the following data, taken from a report on abrasive cleaning (48):

Dust concentration in sand-blast room using sand abrasive, 960 million particles per cubic foot.

Dust concentration in sand-blast room using metal abrasive, 155 million particles per cubic foot.

The improvement as shown by these figures is remarkable, and it is possible that with the cleaning of castings preliminary to blasting with metal shot, the dust concentration might be further reduced.

The second method of controlling an industrial dust hazard consists of isolating the dusty process. This method possesses many possibilities, but unfortunately is not widely used. The theory underlying isolation is to concentrate the dust sources to one locality or to a single closed space. In this way, a minimum number of employees are exposed to dust. At the present time, many foundries, during shake-out, expose workers who normally are engaged in occupations with low dust concentrations. Thus, molders in a particular foundry may be exposed to a dust concentration of 3 million particles per cubic foot under normal occupational conditions, but when shake-out operations are carried on close by their exposure may be increased to more than 50 million. The same condition exists when annealing flasks containing ground slag are emptied in malleable iron foundries, frequently exposing grinders and tumbling barrel attendants at work close by.

Perhaps the best example of isolation of a dusty process is the abrasive cleaning room. This completely encloses a very hazardous process and exposes only the blaster who is generally equipped with a protective helmet. The room is also exhausted which further assists in reducing the dust concentration. Processes which are isolated require good ventilation. Other examples of isolation are

the auto
hatch-m

A pro
limiting
minimum
may be
implicat
with pro

The ti
source—i
about the
getting in
wetting,
The follow
rock-drill

Dust conc
Dust conc

While th
several dri
content, th
sive. In v
drilling, wh
wet method

That wet
by a study
shows an a
brought on

Tuberculos
Tuberculos

Recently
wet method
consists of a
fresh casting
Water under
an operator
washed away
times placed
a suitable ho
fortunately,
ability of thi
castings found
control is far
method at pr
velopment, th

BB 002042

generation. All these
considerable success in

ing dust—namely,
substances—there is
substances have been
such as in the case of
Pure silica was for-
way to other compounds
that the chief dust
lication of parting com-
containing compound has
ard. Again, in the case
sure given way to metal
substitution is clearly
ing data, taken from a

abrasive, 960 million particles
metal abrasive, 155 million

is remarkable, and it is
preliminary to blasting
to be further reduced.

ial dust hazard consists
possesses many possi-
d. The theory under-
es me locality or to
er of employers
foundries, during
engaged in occupations
in a particular foundry
3 million particles per
as, but when shake-out
re may be increased to
exists when annealing
alleable iron foundries,
rel attendants at work

dusty process is the
oses a very hazardous
nerally equipped with
austed which further
Processes which are
uples of isolation are

the automatic turntable for abrasive cleaning, tumbling barrels, and
batch-mixing rooms that are found in some pottery establishments.

A practice which has lately gained wide use in foundries consists in
limiting the shake-out operations to a single night shift when a
minimum number of workers are employed. While such methods
may be described as isolation, they are not exactly so, since isolation
implies that dusty operations shall be carried on in separate quarters
with provision for exhaust ventilation.

The third dust control method—namely, wetting at the dust
source—is generally employed in rock drilling. Water is sprayed
about the hole being drilled, thus preventing the dust generated from
getting into the air. Considerable success has been achieved by
wetting, which is perhaps the oldest dust-control method known.
The following dust counts exhibit the success attained in an actual
rock-drilling operation (50).

Dust concentration with water spray 11.2 million particles per cubic foot.

Dust concentration without water spray 614.5 million particles per cubic foot.

While the reduction has been considerable, it is still possible when
several drills are working simultaneously on rock high in free silica
content, that the concentration of dust produced may become exces-
sive. In view of a more positive method of controlling dust in rock
drilling, which will be described later, it is sufficient to point out that
wet methods actually reduce the concentration of dust.

That wet methods are not positive methods of control is borne out
by a study of wet grinding in a Connecticut ax factory (51), which
shows an abnormally high death rate from tuberculosis presumably
brought on by dust exposure. The data follow:

Tuberculosis death rate (male), State of Connecticut, 1.7 per 100,000.

Tuberculosis death rate (grinders), ax factory employees, 19.0 per 100,000.

Recently there has been developed a combination of isolation and
wet methods for controlling foundry shake-out dusts. This method
consists of a large room similar to a sand-blast room in which the
fresh castings (generally with cope and drag removed) are placed.
Water under high pressure is then directed against these castings by
an operator outside the room until the molding sand and cores are
washed away. In order to facilitate cleaning, the castings are some-
times placed on a slowly revolving table. The sludge is collected in
a suitable hopper and the water drained off and recirculated. Un-
fortunately, there is a lack of published data relative to the appli-
cability of this type of hydraulic cleaning to all the various forms of
castings found in industry, but it is obvious that this method of dust
control is far superior to many other methods now in use. While the
method at present has only limited use and is in the process of de-
velopment, there can be no question that the problem of controlling

the dust formed at foundry shake-outs, which has always been extremely difficult to attain, will gradually be an accomplished fact.

With regard to the fourth method of controlling dusts, it may be said that of the various mechanical methods devised, none has such wide application as exhaust ventilation. Exhaust systems are designed to utilize the directional forces of air currents at the dust source and to convey the dust captured to a suitable collecting place. An exhaust system may briefly be divided into four distinct parts: (1) The hoods used to capture the dust, (2) the duct system to convey the air flow and dust collected by the hood, (3) the dust-collecting equipment, and (4) the fan and motive power.

Hoods assume a wide variety of shapes depending on the manner of dust production. In some cases they completely enclose the dusty process, as in rock drilling, while in others they utilize the directional effects of a dust producing source, being placed so that the issuing dust is thrown into it. Upon hoods which are correctly designed depends a great deal of the success of exhaust methods in controlling dust sources.

The duct system consists of an outlay of duct work so proportioned that its various branches handle the necessary volume of air required by the hoods. The system conveys the dust collected and hence every part of it must maintain velocities which will transport the largest particles which enter it.

Dust-collecting equipment, where used, is designed to capture and to restrain the dust collected by the hoods. Cyclones and cloth filters are frequently used and, in cases where high efficiencies of separation are obtained, recirculation may be practiced.

The fan and motor serve to maintain the air flows through the hoods and duct system. Their size is dependent upon the volume of air handled and the total resistance of the system. The type of material to be conveyed often determines the type of fan blade and housing which must be used.

In the subsequent sections, the chief applications of exhaust ventilation are described, giving the results of researches in granite cutting and rock drilling and the status of exhaust ventilation with respect to grinding, polishing and buffing wheels, foundry shake-outs, and abrasive cleaning. Because methods of exhaust ventilation vary widely even in identical industries, and because pertinent data pertaining to them are meager, the following sections will be devoted to discussing the underlying principles of this method of control.

NOT

ch has always been an accomplished fact. In handling dusts, it may be devised, none has such exhaust systems are directed currents at the dust suitable collecting place. into four distinct parts: a duct system to convey (3) the dust-collecting

depending on the manner to completely enclose the dusty work and utilize the directional flow so that the issuing air is correctly designed methods in controlling

work so proportioned volume of air required to collect and hence which will transport the

to capture and filter and cloth filters efficiencies of separation

air flows through the duct upon the volume of system. The type of fan blade and type of fan blade and

tions of exhaust ventilation in granite cutting ventilation with respect to dry shake-outs, and dust ventilation vary so pertinent data persons will be devoted to method of control.

VII. DESIGN OF HOODS

No field in industry has received so little attention as the design of exhaust hoods. With the exception of two or three instances where some research work has been done, there is a surprising lack of data pertaining to their requirements and design. Hoods have been constructed and installed without any certainty that they will perform as expected.

The design of local exhaust hoods is complicated chiefly by the fact that the conditions vary tremendously, ranging from possible complete enclosure of the point of dust generation to the need for an exhaust hood operated independently of a moving cutting tool, interfering in the least possible way with the manufacturing process. This is well illustrated by comparing the conditions associated with rock drilling where the point of dust generation may be completely enclosed with those involved in the operation of the hand-pneumatic granite carving tool to which no attachment can be made, which is moved about over the stone at will and which is in the hands of a highly skilled and often temperamental individual.

The function of a hood is to create a velocity at the dust source which will direct the particles into the opening and thence through the duct work to a suitable collecting point. Obviously, therefore, if the velocity characteristics of hoods are available, an approximate idea of the performance of the hood could be gained. For it is from such data that the designing engineer can foretell what to expect of a particular hood with a given flow of air. This procedure would be far better than merely stating that so many "inches of suction" are required; the term is perhaps convenient, but it does not express the reaching-out qualities of a hood which are so important. This chapter, therefore, is concerned with the velocity characteristics of hoods and presents many important principles pertaining to them which have practical application.

ESTIMATION OF VELOCITY-DISTANCE RELATIONSHIP

It is well known that the air velocities in the region in front of an opening under suction change rapidly. To obtain an approximate relation between air speed and distance, consider a small opening under suction surrounded by an imaginary sphere of radius r , figure 29. It is clear that all the air entering the opening must pass through the surface of the sphere, except at the region cutting the opening

(77)

NOTE
NOTE

BB 0020045

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2539

which may be considered small in comparison. If the amount of air flowing be represented by Q , then the velocity along the surface of the sphere will be given by the equation $V = Q/A$ where A is the surface of the sphere. The value of A is, however, from elementary geometry equal to $4\pi r^2$. Hence,

$$V = \frac{Q}{4\pi r^2} = 0.80 \frac{Q}{r^2} \quad (1)$$

The relation indicates, therefore, that the velocity at any point on the surface of the sphere is proportional to the volume flowing and inversely proportional to the square of the distance from the opening.

VELOCITY CONTOURS AND STREAM LINES OF HOODS

If the actual distribution of velocities be ascertained and drawn for a circular opening in a diametrical plane they would be of the shape indicated in figure 30.² The curves marked A, B, C , etc., are known as equal velocity curves, that is, every point on the curve represents a constant velocity. The curves 1, 2, 3, etc., drawn so as to be perpendicular at the points of intersection with the velocity contours, are called stream lines, or lines whose tangent at any point indicates the direction of air flow. Obviously, the total flow between two such curves is constant, the convergence of the curves indicating an increased velocity toward the opening.



FIGURE 30.—Flow in duct and considered as passing through an imaginary square of radius r .

From the symmetry of a circular opening it is easily seen that the velocity conditions shown in figure 30 are the same in any other diametrical plane. Consequently, the rotation of the plane about the axis will generate surfaces of equal velocity and tubular sheets of flow. Thus the velocity and stream-line distributions in a single radial plane of a circular opening represent the velocity conditions existing throughout the sphere of influence of the opening.

The determination of velocity conditions in cases of perfect symmetry, as in the case of the circular opening described, is simple. For rectangular openings, however, the procedure would be intricate and practically impossible of representation in two-dimensional figures. A fair approximation of conditions is, however, deducible if the contours be mapped in two radial planes perpendicular to the sides as shown in figure 31. In the case of square openings the contours in each of the planes are identical.

PRINCIPLE OF SIMILARITY OF VELOCITY CONTOURS

It can be shown for a circular opening that whatever its size or volume of flow, the velocity contours and stream lines are always of

² The method of developing the velocity characteristics of a hood is given in section IX.

NOTE

BB 0020046

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2540

ison. If the amount of air
 fitting the surface of the
 2/ are A is the surface
 elementary geometry

(1)

velocity at any point on the
 the volume flowing and
 distance from the opening.

LINES OF HOODS

ascertained and drawn for
 they would be of the shape
 A, B, C , etc., are known
 es, that is, every point on
 a constant velocity. The
 also as to be perpendicular
 section with the velocity
 from lines, or lines whose
 dicates the direction of air
 total flow between two
 t, the convergence of the
 increased velocity toward

of circular opening it is
 low figure 30 are the
 s, the rotation of
 of equal velocity and
 and stream-line distribu-
 tions represent the veloc-
 of influence of the opening.
 in cases of perfect sym-
 metry described, is simple.
 procedure would be intricate
 tion in two-dimensional
 is is, however, deducible
 lines perpendicular to the
 square openings the con-

CITY CONTOURS

that whatever its size or
 stream lines are always of

is given in section 12.

the same general form (52). These facts have been experimentally
 determined and may be extended to all hoods (53); they are covered
 by the following theorem: The positions of the velocity contours for
 any hood when the contours are expressed in terms of the velocity at
 the hood opening are purely functions of the shape of the hood; the
 contours are identical for similar hood shapes when such hoods are

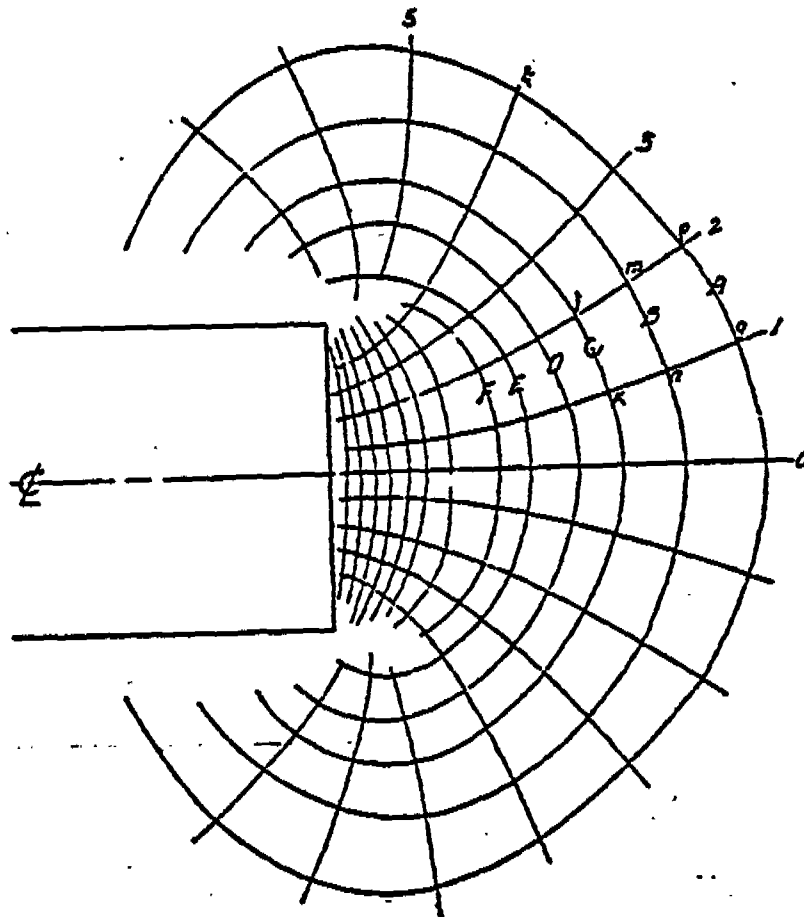


FIGURE 30.—Velocity contours and stream lines for a circular duct end under section

reduced to the same base of comparison. For example, if the velocity
 4 inches outward along the axis of an 8-inch diameter duct end under
 section is 26 percent of the velocity at the plane of the opening, the
 same value must occur for a 12-inch diameter opening at a distance
 of 6 inches.

That the above principle holds for rectangular hoods may appear
 confusing, since the velocity distributions will vary in every axial
 plane through a whole quadrant. However, in corresponding planes
 of two openings the principle does hold (53).

NOTE

NOTE

BB 0020047

THIS DOCUMENT WAS NOT A RECORD OF
 PPG INDUSTRIES, INC. DID NOT COME FROM
 IT'S FILES AND CANNOT BE AUTHENTICATED
 BY PPG INDUSTRIES, INC.

2541

Rectangular hoods are designated as similar if the ratio of their sides is the same. Two rectangular hoods, therefore, will have similar velocity characteristics provided the radial planes are mapped in corresponding units and if the velocities are expressed as percentages of the velocity at the opening.

The principle of similarity offers a powerful tool for research, for large hoods may be tested in model form and their characteristics deduced. It is a basic principle applying to all hoods, reducing them to their simplest terms.

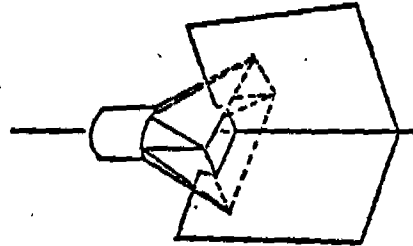


FIGURE 31.—Axial planes in which velocity contours have been determined for rectangular hoods.

The region of influence for all round openings is mapped in the coordinate units corresponding to figure 32 the velocity contours will all be identical and will be expressed in percent of the average velocity in the plane of the opening. The same is true for the various shaped rectangular hoods where the short side of each is divided into eight units, and the long side in the same units in proportion to its length. An opening, therefore, with a ratio of sides of 3 to 4 will have $\frac{8 \times 4}{3} = 10\frac{2}{3}$ units on the long side.

An example will illustrate the application of the contour lines of figures 32-36.

Suppose it is desired to find the speed and direction of the air movement at a point 4 inches outward and 5 inches upward in the radial plane perpendicular to the short side of a 4- by 8-inch hood handling 6-10 cubic feet per minute. The ratio of sides is one-half and expressing the coordinates of the point on the basis that there are 8 units of length on the short side the coordinates of the point in question are 8 units outward of the axis and 4 units upward, as shown by the circle in figure 35. The velocity at this

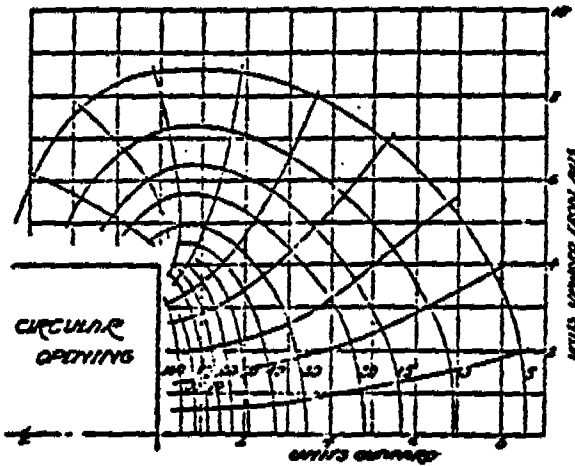


FIGURE 32.—Velocity contours and stream lines in a radial plane of a circular opening. Contours are expressed as percentages of the velocity at the opening.

point
flow
min
min
influe
cont
in ph
sidera
contor

FIGURE 33.

the figure
is remove

Effect of a

It may
flaring of
velocity c
of flow ac
the velocit
of flare in
which are
surface of
contour di
the shape

NOTE: THE DOCUMENT DID NOT COME FROM THE FILES OF PPG INDUSTRIES, INC.

the ratio of the velocity at the point to the velocity at the opening, therefore, will be the same for all points in the same plane. The velocity contours are expressed as percentages of the velocity at the opening.

A tool for determining the velocity contours and their characteristics. It is a basic principle of all fluids, whether in the simplest terms.

CHARACTERISTICS OF VELOCITY CONTOURS FOR A SQUARE OPENING

Velocity contours and streamlines for a square opening are shown in Figure 23, provided the flow is not impeded in the coordinate system. The velocity contours will all be the same for the various shapes.

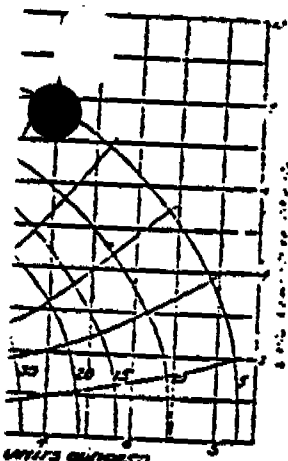


FIGURE 23—Velocity contours for a square opening. Contours are expressed as percentages of the velocity at the opening.

The velocity at the point is approximately 12½ percent of the velocity at the opening. Therefore, the velocity at the opening being $\frac{640 \times 144}{4 \times 8} = 2,880$ feet per minute, the velocity at the point must be $0.125 \times 2,880 = 360$ feet per minute. These calculations assume that the flow in the region of the opening is not grossly impeded by an obstruction. Otherwise the contours are altered and must be redetermined with the obstruction in place. It may be said, however, that if the obstruction is considerably smaller in cross-sectional area than the surface area of the opening, the velocity distributions as shown in

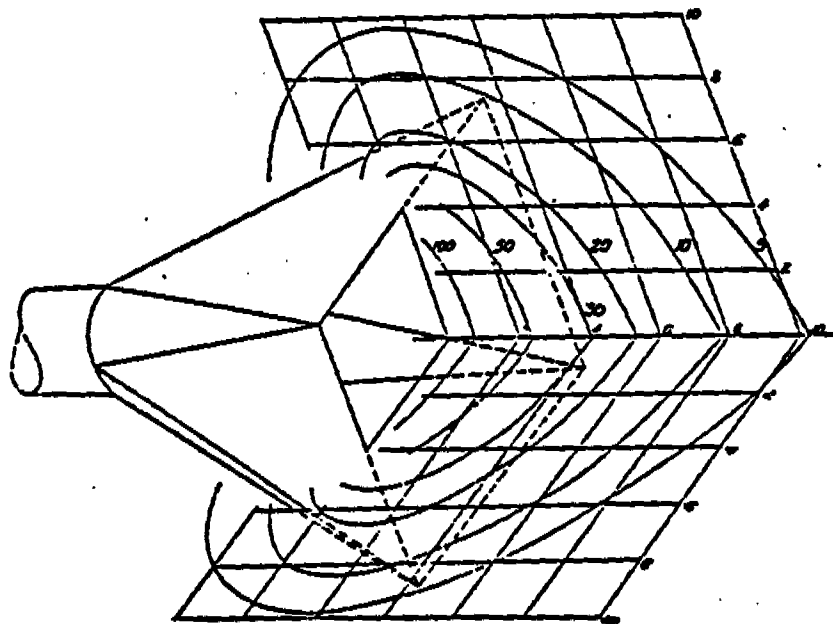


FIGURE 24—Velocity contours for a square opening. Contours are expressed as percentages of the velocity at the opening.

the figures are not substantially altered. The farther the obstruction is removed from an opening the less is the error involved.

Effect of shape on the distribution of velocity contours

It may reasonably be supposed that the amount and the degree of flaring of a hood has considerable effect on the distribution of the velocity contours. If, however, it is assumed that the distribution of flow across two openings of the same size and shape are similar, the velocity contours are substantially the same, although the degree of flare in each differs. The main portions of the sphere of influence which are affected lie behind the edge of the opening, the boundary surface of the flared portion being the chief variable. The velocity contour distribution, therefore, may be said to be dependent upon the shape of the opening only, provided the distribution of flow

THIS DOCUMENT WAS NOT A RECORD OF PPG INDUSTRIES, INC. DID NOT COME FROM ITS FILES AND CANNOT BE AUTHENTICATED BY PPG INDUSTRIES, INC.

BB 0020049

2543

across it does not vary greatly with the degree of flare. As a matter of experiment it has been found that over a very wide range the degree of flare alters the distribution of flow across an opening only slightly (52). Hence a 5- by 10-inch opening with a 12-inch flare to a 3-inch diameter duct gives the same contour distribution forward of an opening as one with an 8-inch flare (say) to a 5-inch diameter duct. In fact, were the opening but the end of a 5- by 10-inch duct, the velocity contour distribution would differ only slightly. Since, as a rule, most hoods are gradually flared in order to reduce entrance losses, it is practical when dealing with contour distributions, to

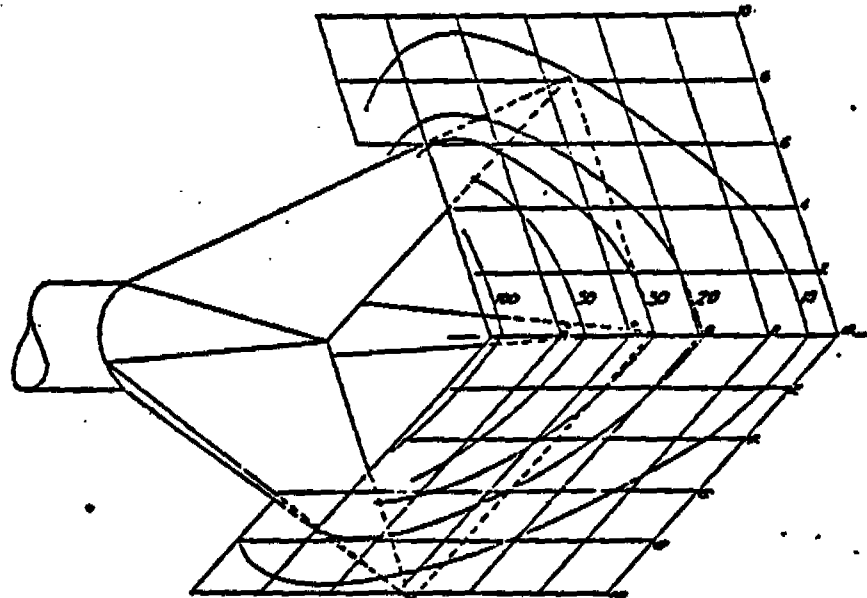


FIGURE 34.—Velocity contours for a rectangular opening whose ratio of sides is 3 to 4. Contours are expressed as percentages of the velocity at the opening.

express the overall shape of the hood in terms of the shape or form of its opening—that is, in terms of the side ratio.

A matter of considerable importance is the velocity distribution over the hood opening. For the purpose of simplifying calculations, it has been assumed in developing the contours in figures 32-36, that the velocity distribution over the opening is uniform. Such an assumption is not correct, as may be judged from an examination of the figures themselves, which show the 100 percent contour to be somewhat displaced from the opening. In other words, the figures show a higher velocity than the average over the central portions of the opening. The situation is somewhat like the phenomenon occurring when a fluid flows through a pipe which, because of viscosity, gives a higher velocity at the axis than toward the edges. The effect in the case of hoods does not, however, arise from similar considera-

FIGURE 35.—Velocity

FIGURE 36.—Velocity

of flare. As a result, a very wide range of velocity distributions is possible. For example, a 12-inch diameter opening with a 5-inch diameter opening would result in a velocity distribution that is only slightly different from the distribution of a 5- by 10-inch opening. In order to reduce entrance velocity distributions, a

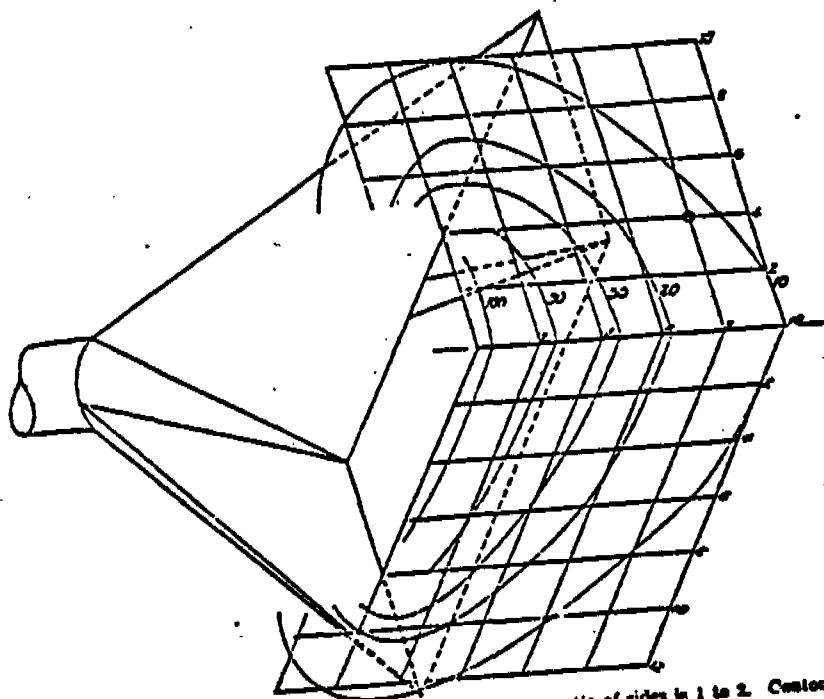


FIGURE 33.—Velocity contours for a rectangular opening whose ratio of sides is 1 to 2. Contours are expressed as percentages of the velocity at the opening.

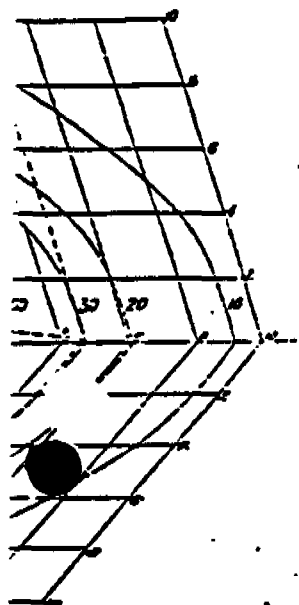


FIGURE 34.—Velocity contours for a rectangular opening whose ratio of sides is 3 to 4. Contours are expressed as percentages of the velocity at the opening.

is of the shape or form ratio.

The velocity distribution simplifying calculations, contours in figures 32-34, is uniform. Such a distribution is obtained from an examination of the 10 percent contour to be other words, the figures show the phenomenon of the velocity at the edges, because of viscosity, and the effect of the edges. The effect of the edges is from similar considera-

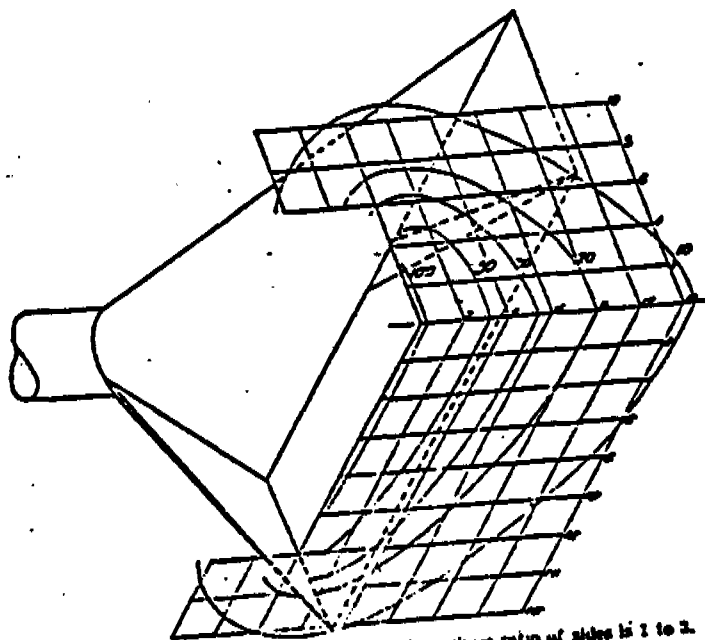


FIGURE 35.—Velocity contours for a rectangular opening whose ratio of sides is 1 to 3. Contours are expressed as percentages of the velocity at the opening.

1 BB 0020051 1

tions. In hood openings it is necessary to contend with an edge effect. Air entering from behind the hood is forced to turn abruptly into it, thus creating a stationary vortex which restricts the effective area to a value less than the actual. At the corner of a rectangular hood, the effect may be considered as intensified. Experimental data tend to show that the effective area is reduced in proportion to the perimeter of the opening.

The edge effect may be considerably reduced by the use of a flange placed around the edge and lying in the plane of the opening. A flange approximately 5 inches in width is sufficient for hoods up to

over, vel.
analysis.

A simple
without
velocities
ordinarily
governing
which may
series of c

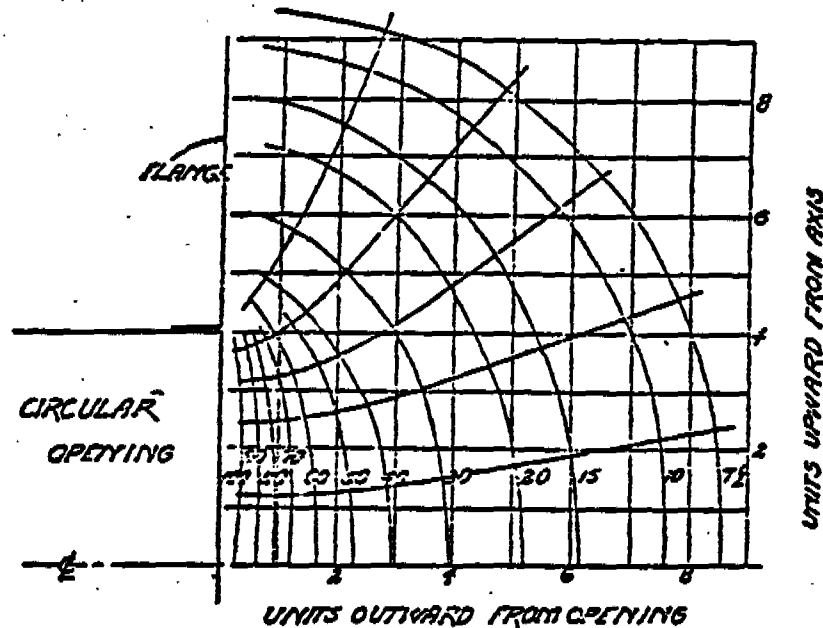


FIGURE 37.—Velocity contours and stream lines in a radial plane of a flanged circular opening. Contours are expressed as percentages of the velocity at the opening.

3 square feet in area. The flange tends to cut off the flow from the region behind the opening which is frequently useless and is advantageous in two respects: First, it increases the effectiveness of the hood in the forward regions, and second, it reduces the energy consumption of the hood. In figure 37 the velocity contours and stream lines of a flanged circular opening are shown and may be contrasted for the sake of clearness with the characteristics for the same opening in figure 32.

AXIAL VELOCITIES

The representation of aerodynamic characteristics of exhaust hoods by means of velocity contours offers a fairly simple means of comparing graphically various types of hoods. The determination of contour lines, however, involves considerable time and labor. More-

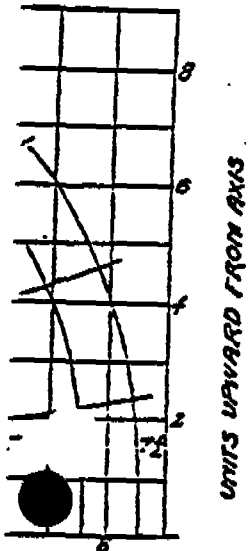
The point
the opening.
in no direct
An analysis
by the equation

where V is the
velocity at the
are constants.

NOTE: DOCUMENT DID
NOT COME FROM PPG INDUSTRIES, INC.

with an edge to turn abruptly restricts the effective area of a rectangular opening. Experimental data is in proportion to the

by the use of a flange of the opening. A vent for hoods up to



OPENING
rectangular opening. Contour
velocity.

off the flow from the useless and is advanced effectiveness of the uses the energy contours and streamlines may be contrasted for the same opening.

ities of exhaust hoods ample means of comparison the determination of time and labor. More-

over, velocity contours do not lend themselves to mathematical analysis.

A simpler and more direct means of comparison of elementary hoods without obstruction to the opening may be had by the analysis of velocities along the projected axis of openings. Since exhaust hoods ordinarily draw dust from the area directly in front, the chief factor governing the efficiencies is the distribution of air flow in this region which may be expressed in terms of the axial-velocity curves. A series of curves for several circular openings are shown in figure 25.

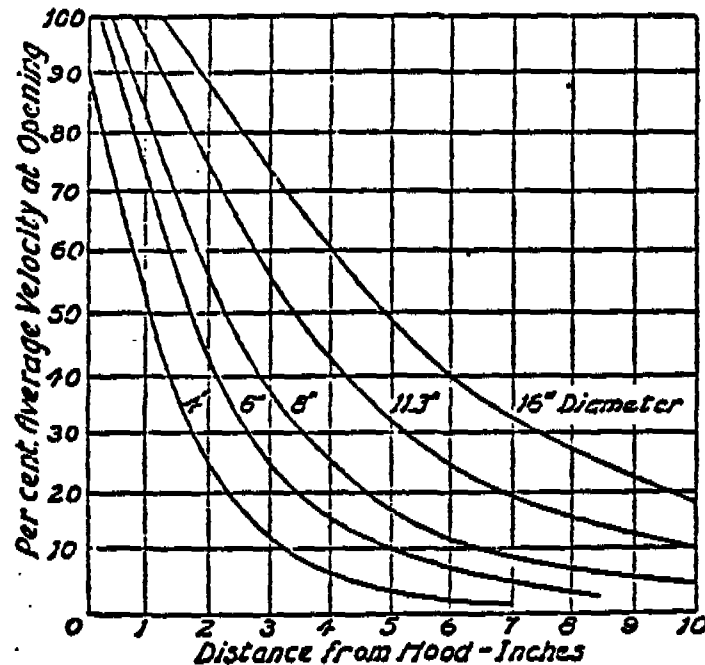


FIGURE 25.—Axial velocity curves for several circular openings

The point velocities are expressed as percentages of the velocity at the opening. As may be seen, the axial-velocity curves are limited in one direction and are almost hyperbolic in shape.

An analysis of the data has shown that the curves may be defined by the equation (52).

$$f(Y) = \frac{m}{x^n} \quad (2)$$

where Y is the point velocity expressed as a percentage of the average velocity at the opening, x the distance from the opening, and m and n are constants. When the function $f(Y)$ has the form

$$f(Y) = \frac{Y}{100 - Y} \quad (2a)$$

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

BB 0020053 1

2547

Substituting the value of b given in this equation in the general equation (3), we obtain finally for square and rectangular openings

$$\frac{Y}{100-Y} = 0.0833 \left[\frac{1}{1 + 0.259 \left(\frac{r}{1-r} \right)^{-1.161}} \right] \cdot 1.181 x^{-1.91} \quad (5)$$

where

x = the distance outward along the axis measured in inches.

A = the area of the opening in square inches.

r = the ratio of sides (less than unity).

Y = the percent velocity at the opening found at the point x .

Thus, the center line velocity curves may be defined completely in terms of the geometric shape and size of the suction openings.

The exponents of A and x in the general equation are close to 1 and 2, respectively. This suggests that the true form of the general equation may be $f(Y) = b'Ax^2$. The following simple formula is suitable for quick and approximate computations for openings usually found in practice:

$$\frac{Y}{100-Y} = \frac{0.1A}{x^2} \quad (6)$$

Equation (6) may also be written so as to give the velocity at a point along the axis directly in terms of the air flow Q , since $Y = V/V_0 \times 100$ where V_0 is the average velocity at the opening and $Q = AV_0$, A being the area of the opening. Thus

$$V = \frac{0.1Q}{x^2 + 0.1A} \quad (7)$$

It is interesting to note that this equation for values of x^2 which are very large in comparison with $0.1A$ gives the relation

$$V = \frac{0.1Q}{x^2} \quad (8)$$

which is identical to equation (1) deduced from elementary considerations, with the exception of a larger constant in the present instance.

The nomograph of figure 41 has been prepared and gives the value of Y when x and A are known. To use this nomograph a ruler is connected between the values of x and A given, and the value of Y read off at the intersection with the middle scale. The line drawn in the figure connects a value of x of 10 units with an area of 150 square units, giving at the intersection with the middle scale a value of Y equal to 15 percent. In other words, the velocity at a distance of 10 units from an opening 150 units square is 15 percent of the velocity at the opening.

TABLE 21.
Flow

1 square foot	1 square foot
2 square feet	2 square feet
4 square feet	4 square feet
6 square feet	6 square feet
8 square feet	8 square feet
10 square feet	10 square feet
20 square feet	20 square feet

Relation betw

In table 2 the hood axis this table su very little ment in effie be gained b ing the ope the hood, the average at the open inversely as and consequ creases as ti the pening However, t two advant large hood: entranceless by reducing ities at the and second, of influence increased in gions forward pening. I contours b: value of app ly 14 feet p for square eq various size: correspondi larger area b the contour i is constant (C

NOTE: THIS DOCUMENT IS

TABLE 24.—Velocity change along axis of hoods of various sizes with constant air flow of 1,000 cubic feet per minute—determined from formula (7)

Area of opening	Average velocity at opening (feet per minute)	Distance outward along axis—r				
		6 inches	12 inches	18 inches	24 inches	30 inches
1 square foot	1,000	12.5	9.1	6.3	4.7	3.9
2 square feet	500	17.7	12.5	8.8	6.6	5.3
3 square feet	333	20.8	14.4	10.2	7.7	6.3
4 square feet	250	23.1	16.0	11.3	8.5	6.9
5 square feet	200	25.0	17.7	12.5	9.4	7.7
6 square feet	167	26.7	18.8	13.3	10.0	8.3
8 square feet	125	31.2	22.4	16.0	12.0	9.8
10 square feet	100	35.4	25.0	18.0	13.7	11.1
12 square feet	83	40.8	28.3	20.3	15.4	12.5

Relation between opening area and velocity gradient

In table 24 are given the velocities of various sized openings along the hood axis when the volume of flow is held constant. The data of this table suggest that very little improvement in efficiency can be gained by increasing the open area of the hood, although the average velocity at the opening varies inversely as the area and consequently decreases as the area of the opening increases. However, there are two advantages of a large hood: First, the entrance loss is lowered by reducing the velocities at the opening, and second, the zone of influence is greatly increased in the regions forward of the opening. Relative contours having a value of approximately 1.4 feet per minute for square openings of various sizes are shown in figure 42. It will be noted that the contour corresponding to the opening 20 square feet in area envelopes a much larger area forward of the opening. The total surface developed by the contour is the same in each case, however, since the total flow, Q , is constant ($Q = VA$).

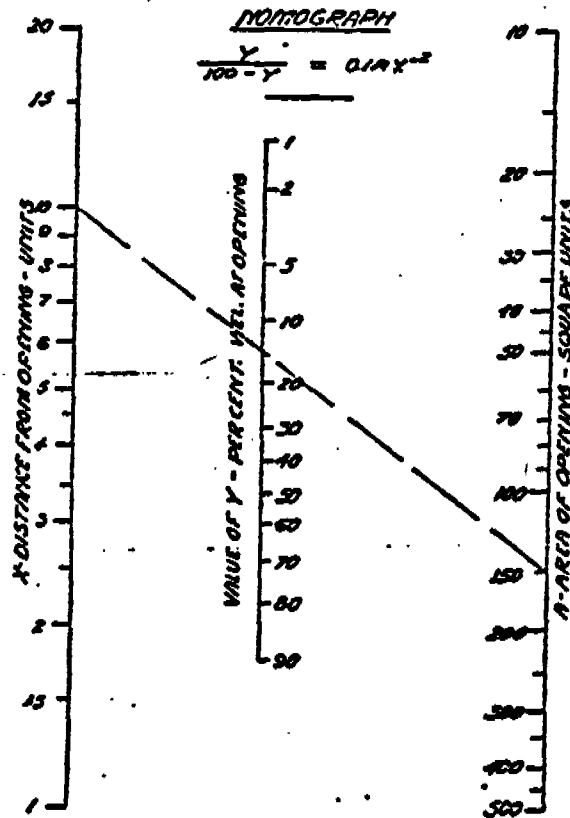


FIGURE 41.—Nomograph for the determination of axial velocities.

It will be noted that the contour corresponding to the opening 20 square feet in area envelopes a much larger area forward of the opening. The total surface developed by the contour is the same in each case, however, since the total flow, Q , is constant ($Q = VA$).

The chief disadvantage of a large opening for dust collection lies in the low rate of change of air speed from the point at which the hood is desired to function to its opening. In the collection of dusts, it is highly desirable to have a high rate of change inasmuch as a dust must not only be arrested at its origin but also conveyed into the hood and to a collecting system. On the other hand, large hoods work success-

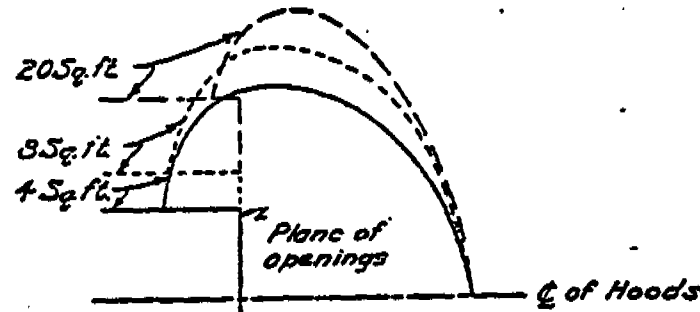


FIGURE 42.—Velocity positions of 11 feet per minute velocity contours for a constant rate of air flow of 1,000 cubic feet per minute through openings 4, 8, and 20 square feet in area.

fully in the collection of fumes which require low velocities for their control and may therefore be handled with a lower consumption of power. It will be shown later that in practice the zones of influence for most hoods are impeded by obstructions, and that it then becomes necessary to alter the treatment of the problem of velocity distribution. However, the factors to hold in mind in any hood installation

are the size of the opening and its location with respect to the region at which it is expected to operate.

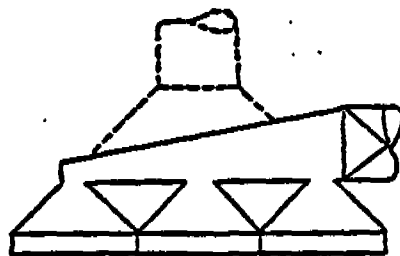


FIGURE 43.—Method of subdividing large hoods.

RELATION BETWEEN SIZE OF HOODS AND CONNECTING DUCTS

The distribution of air flow over the hood opening should be as uniform as possible. This cannot be secured when the ratio of the area

of the hood opening to the connecting duct area is large, unless the length of the transition piece is increased to accommodate the change in air speed from section to section. Otherwise, the movement of the air will all be concentrated at the center of the hood opening, and the hood will fail to function properly. Unless there is an even distribution of air flow across the opening, there is little sense in maintaining the full-size hood.

There are many instances where a high ratio between the size of the opening and the connecting duct is necessary, and yet a long flare cannot be used because of lack of space. In such cases, the hood

may be designed each of which has a ratio of 1 to 2 connected in a considerable saving of the consumption of the hood. It is not possible to establish a relationship between hood opening and practice the ratio of length of flare

FIGURE 44.—Construction of a hood.

DETERMINATION OF AIR FLOW

When hoods are used, the velocity distribution over the single large hood placed in sections as shown in the directions of the contours may be indicated by solid lines indicating a combination of a single opening with a corresponding contour hood into independent original velocity

NOTE: THIS DOCUMENT
NOT COME FROM PPG INDUSTRIES, INC.

collection lies in at which the hood is action of dusts, it is much as a dust must d into the hood and hoods work success-

may be designed so that it is divided into several hoods, edge to edge, each of which is independent of the other. A large hood with a side ratio of 1 to 3, for example, may be divided into three square openings connected in the manner indicated in figure 43, thus effecting a considerable saving in headroom over that occupied by a transition piece of the common type.

It is not possible to formulate a definite rule to govern the relationship between the ratio of the areas of the connecting duct and the hood opening and the degree and length of the flare. In modern practice the ratio is generally taken as 1 to 16 at a maximum, and the length of flare as three times the diameter of the connecting duct.

of Hoods

at a constant rate of air flow of 1000 feet in area.

or velocities for their over consumption of the zones of influence that it then becomes of velocity distribution. by installation the opening and its respect to the region expected to permeate.

SEVEN SIZE OF HOODS SELECTING DUCTS

tion of air flow very ng should be as uni- ble. This cannot be the ratio of the area a is large, unless the modulate the change the movement of the hood opening, and the is an even distribu- sense in maintaining

between the size of the and yet a long flare such cases, the hood

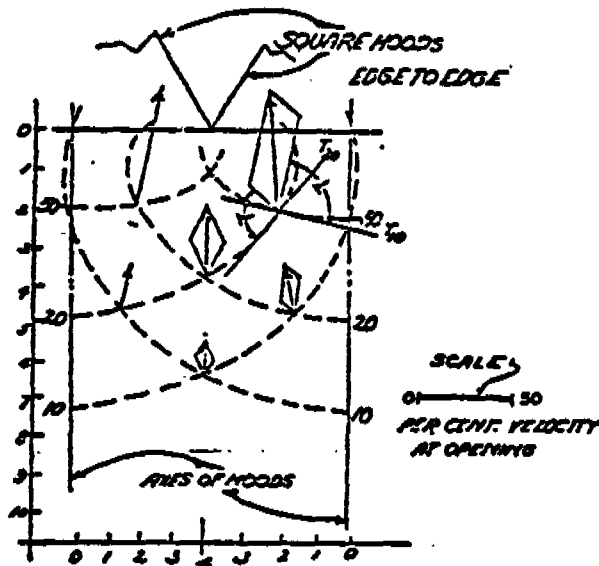


FIGURE 44.—Construction of the velocity contours for a compound hood by vectorial analysis from the contour lines for the separate openings.

DETERMINATION OF VELOCITY CONTOURS FOR COMPOUND HOODS

When hoods are subdivided in the manner indicated above, the velocity distribution is not changed materially from that given by the single large opening. The contour distributions for two square hoods placed edge to edge may be combined vectorially at their intersections as shown in figure 44. From the resultant velocities and directions of the air movement thus obtained, a new set of velocity contours may be drawn. This has been done in figure 45, where the solid lines indicate the contours obtained by the principle of velocity combination and the dotted lines represent the distribution for a single opening whose side ratio is 1 to 2. The proximity of corresponding contour values indicates that the subdivision of a large hood into independent units of smaller dimensions does not alter the original velocity distribution of a hood.

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

BB 0020057 1

2551

92

NOTE

NOT COPIED

This method of combining square hoods, edge to edge, may be employed in establishing the velocity contours for any side ratio although the method is laborious. It may also be applied to the

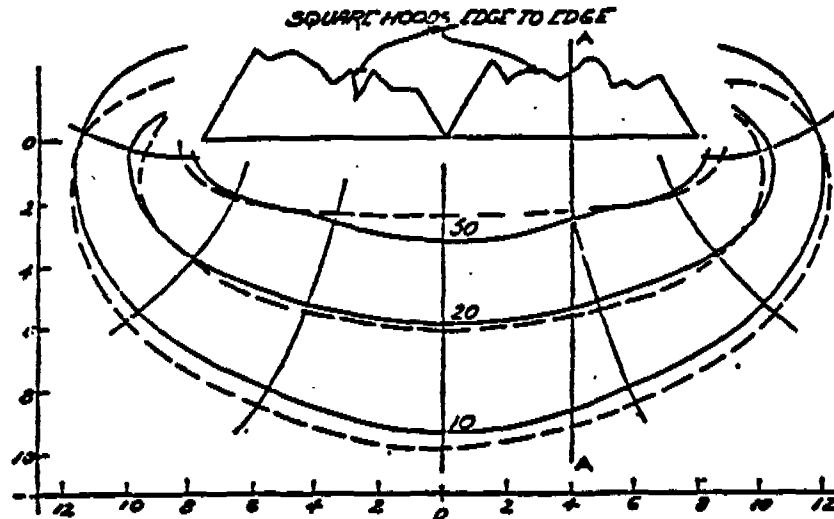


FIGURE 42.—Comparison of velocity distribution for double opening with contours for a single opening of the same shape and size. Contours of double opening calculated as in figure 41.

study of arrangements in which the velocity distribution is not uniform, such as the double hoods recommended for the control of fumes by some State codes. In figure 46 are shown the velocity contours for two square openings, edge to edge, one of which is

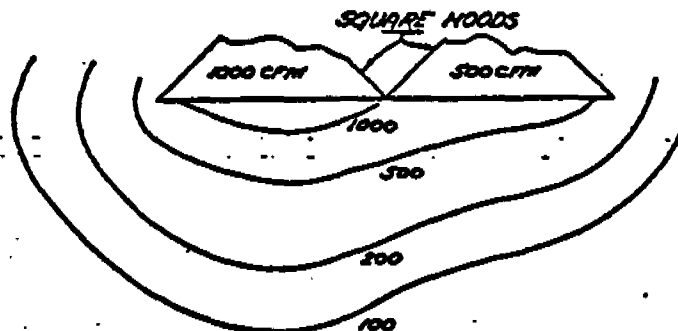


FIGURE 46.—Velocity contours of a double hood having a nonuniform distribution of flow. Contours are expressed in feet per minute (hoods are each 1 square foot in area).

handling twice as much air as the other. As may be seen, there is considerable distortion although it is not difficult to show that there is a slight reinforcement. Studies of this sort suggest that double hoods do not possess marked advantages over the well-designed single hood.

BB 0020058

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2552

edge to edge, may be used for any side ratio. It also can be applied to the

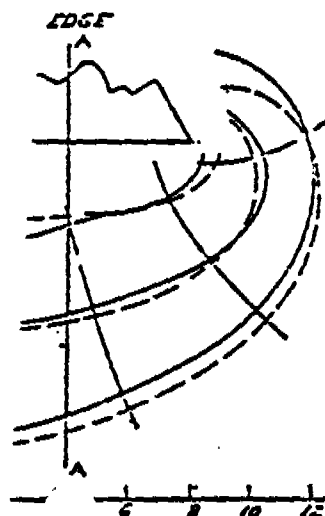


FIG. 46. SIDE RATIO 1 TO 2
The velocity contours for a single opening of side ratio 1 to 2 are shown in figure 46.

velocity distribution is not recommended for the control of flow. In figure 46 are shown the velocity contours to edge, one of which is

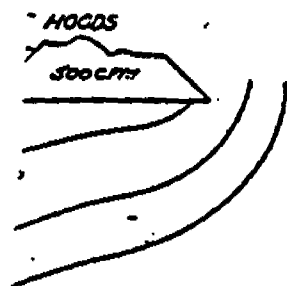


FIG. 47. Velocity distribution of flow. Contours are shown at 1000 cpm (in air).

As may be seen, there is not difficult to show that there is no suggestion that double the well-designed single

VELOCITY CONTOURS OF HOODS WITH SPECIAL BOUNDARY CONDITIONS

The method of compounding velocity contours can be adapted so that the resultant contours hold for openings with special boundaries. Hood are rarely used without some form of obstruction, being bounded either by extended planes or devices placed close to the plane of the opening. Consequently, if contours for special conditions can be developed from those known for simple openings, considerable information may be gained of much practical value. Four special cases are discussed below which indicate the general procedure for developing contours for any shape of hood under similar conditions. The method, while approximate, nevertheless as indicated above, gives results which are surprisingly accurate.

The procedure in determining boundaries under certain conditions is based on the principle that a solid boundary may be substituted for any free stream surface or for any stream plane of symmetry. In this respect, the problem is analogous to the method of images used in capacitance calculations in electrical theory. In fact, the boundary cases discussed below are distinctly "image" problems.

Case I.—Infinite plane perpendicular to axis of hood at a given distance from the opening.

This condition is obtained in the manner shown in figure 47. The velocity characteristics of two square openings lying along the same axis have been combined in the manner described and the velocity distribution traced. Since no flow can take place across the stream plane of symmetry, this plane may be replaced by a solid boundary. Consequently, the hood drawn in dash lines may be removed without altering the flow into the hood. (The hood and contours removed may, as shown above, be regarded as images.)

The velocity contours are the same for all similarly shaped hoods located above an infinite plane so long as their relative distance above the plane remains the same. In the particular case shown in figure 47, the infinite plane is located at a distance equal to one-fourth the length of one of the hood edges. Thus, for an opening 4 feet square, the distance is 1 foot. At other distances, new contours must be found.

Case II.—Infinite plane at a given angle to the plane of the hood opening.

This condition is encountered in practice when a hood is placed at an angle to a large surface. An extreme case is given in figure 48 where the edge of a square hood is shown touching a plane at an angle of 45°. The resultant contours are developed from the distributions of two square openings tilted at 90° to each other with corresponding edges touching. As in the previous case, since no flow takes place across the stream plane of symmetry, a solid boundary may be

NOTE

81

NOT CORRECT

inserted without altering the conditions of flow. The removal of the "image-hood" shown by the broken lines consequently will not change the velocity characteristics of the other. The method may be duplicated for hoods at any angle to a plane (except small angles) and for conditions where the edge of the hood does not touch the plane.

For the case given in figure 4S one may draw conclusions similar to those given for the previous case, namely, that the contours are

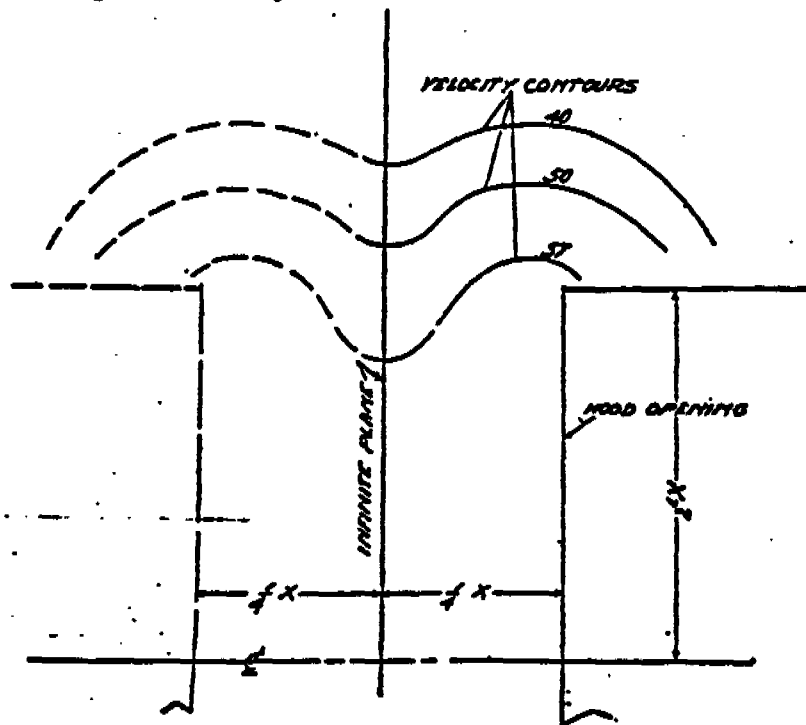


FIGURE 47.—Velocity contours for a square hood located at a distance equal to one-fourth the length of one of the sides above an infinite plane. Contours are expressed as percentages of the velocity at the opening.

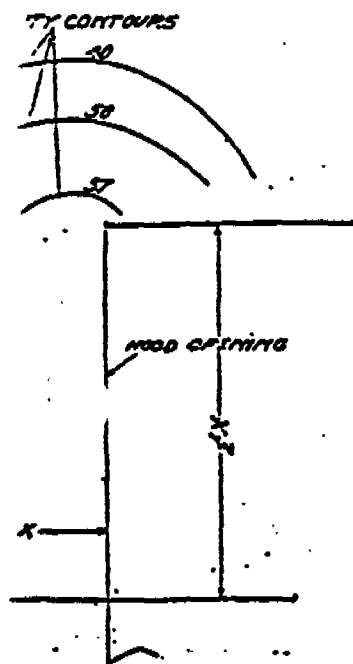
the same for all square hoods at an angle of 45° to an infinite plane, one of whose edges meets the plane. The length of the hood edge may be used to determine the relative locations of the contours.

Case III.—Infinite plane parallel to the axis of a hood and touching one of its edges.

Since the flow in an upper quadrant of a symmetrical hood is the same as that of the lower, it follows that both halves may be separated by a solid boundary without affecting the contour distribution in either. This implies, for example, that the contours for a square opening drawn in a quadrant plane may represent the velocity distribution of an opening with a ratio of sides equal to one-half with an infinite plane attached to the longer side and parallel to the hood axis.

of flow. The removal of the lines consequently will not be other. The method may plane (except small angles) and hood does not touch the

may draw conclusions similar namely, that the contours are



at a distance equal to one-fourth the length of expressed as percentages of the velocity at the

gle of 45° to an infinite plane. The length of the hood edge locations of the contours. the axis of a hood and touching

t f a symmetrical hood is the t both halves may be separated ng the contour distribution in hat the contours for a square may represent the velocity di of sides equal to one-half with r side and parallel to the hood

NOT
NOT COME FROM PPG FILES

Hoods included in case III have a very practical application, especially in exhausting fumes from tanks through lateral openings and dust generated by granite-cutting machines (55). Figure 40 shows the velocity distribution obtained in a quadrant plane perpendicular to the long edges of a rectangular opening with a side

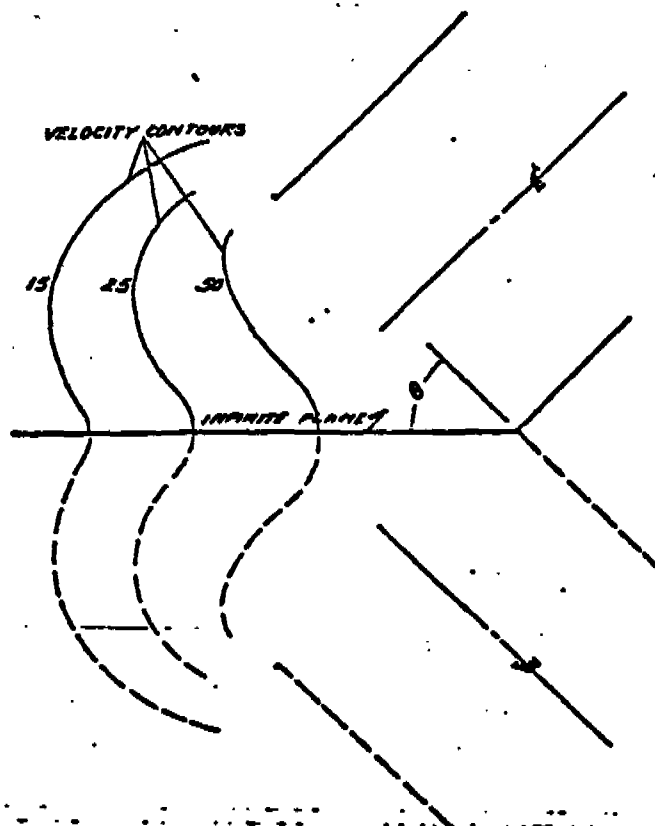


FIGURE 40.—Velocity contours for a square opening at an angle to an infinite plane. Contours are expressed as percentages of the velocity at the opening.

ratio equal to one-half. However, since we are concerned with the distribution of contours above an infinite plane as shown in the figure, the opening must be regarded as having a side ratio equal to one-fourth.

Case IV.—Hood with infinite plane surrounding it and with a plane parallel to its axis.

This case is a combination of the simple-flanged hood and case III and is represented for a circular opening by the region marked "A" in figure 50. This case, however, has only a limited application in industry and need not be discussed in detail.

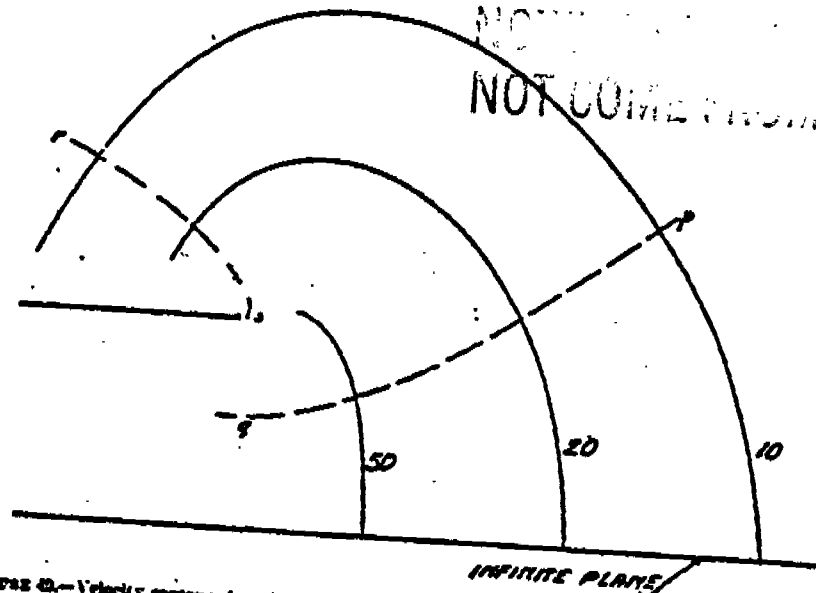


FIGURE 22.—Velocity contours for a broad with a side ratio of 1 to 3 with an infinite plane parallel to the broad axis and touching the longer side. Contours are expressed as percentages of the velocity at the opening.

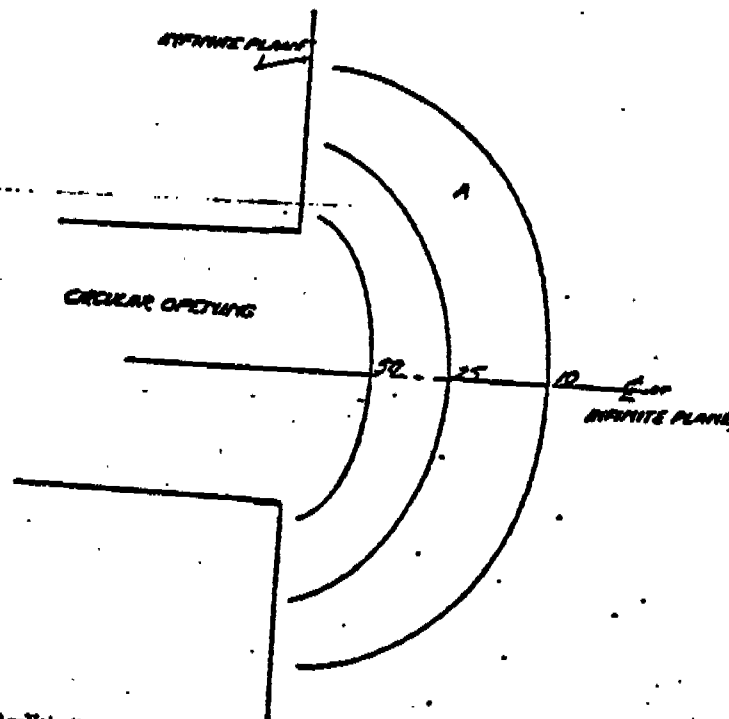


FIGURE 23.—Velocity contours for a circular opening with an infinite plane surrounding it and with an infinite cylindrical probe. Contours are expressed as percentages of the velocity at the opening.

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

BB 0020062

NOT
NOT COME FROM IT'S FILES

VIII. DESIGN OF LOCAL EXHAUST SYSTEMS

General remarks.—A knowledge of the factors governing the design of exhaust systems is important. Installations for controlling dust have failed in the past, because fundamental principles were not considered in their design. In many plants it was customary to regard exhaust systems as necessary evils, prescribed by "blower laws" and because such systems yielded no visible return, but rather added to the cost of operation and maintenance, no attention was paid to them. Winslow and Greenburg (56) have aptly stated the situation in the following words:

The engineering journals carry elaborate accounts of the design of ventilating apparatus; but, once installed, we hear nothing about them if they work well; whereas if they fail, the result is usually a sweeping condemnation of the whole practice of fan ventilation, without any serious attempt to discover the exact source of the difficulty.

The following paragraphs are intended to point out the general considerations which enter into the design of exhaust systems. They attempt to illustrate the few simple principles of design which are within the grasp of most engineers and the methods of their application. For the sake of clearness, it will be necessary to begin with a discussion of simple facts and gradually to show how these are utilized in actual problems.

STATIC AND VELOCITY PRESSURES

It is first necessary to begin with the laws governing the movement of air in ducts. These laws are similar to those pertaining to the flow of other fluids and are, in fact, borrowed directly from hydrodynamics. The primary difference between gaseous and liquid flow is that one is a compressible fluid, markedly affected by temperature, while the other is considered practically incompressible with a fairly constant specific volume over a wide range of temperatures. In actual air-flow computations the factor of compressibility is disregarded, and except for temperature corrections, the laws governing the flow of air are identical to those for water.

In a duct system the flow of air is maintained by virtue of a pressure supplied by the fan. This pressure may be positive or negative depending on whether the duct is connected to the exhaust or suction sides of the fan. The total pressure at any point in a duct has two components which are designated as velocity head and static head. The former is the pressure required to produce the velocity, and the

(25)

1 BB 0020064 1

EXHAUST SYSTEMS

factors governing the design of exhaust systems for controlling dust. Fundamental principles were not known as it was customary to regard exhaust as prescribed by "blower laws." No return, but rather addition, no attention was paid to the exhaust. I have aptly stated the situation.

counts of the design of ventilation systems about them if they were working. Keeping condemnation of the whole, but attempt to discover the exact

led to point out the general design of exhaust systems. They are a series of design which are the methods of their application. It is necessary to begin with a study to show how these are

PRESSURES

laws governing the movement of air and those pertaining to the flow of gas directly from hydraulic flow. Gas and liquid flow is affected by temperature, and is incompressible with a wide range of temperatures. The factor of compressibility is disregarded, the laws governing the flow of water.

maintained by virtue of a pressure may be positive or negative relative to the exhaust or suction at any point in a duct has two velocity head and static head. The velocity head, and the

later, a pressure supplied to overcome the frictional resistance of the moving air in the duct.

Since the velocity pressure depends entirely upon the velocity of flow, any change in velocity either from an enlargement or contraction of the duct, causes a corresponding increase or decrease of static head. Theoretically, the static and velocity heads are interchangeable. In practice, however, a change of velocity is not exactly compensated by an equivalent change of static head, inasmuch as an enlargement or reduction of a duct is accompanied by certain energy losses.

The movement of air in a duct entails a loss of static pressure. This loss is primarily due to the friction of the fluid to resist motion. A change in the motion as a bending of the air through an elbow or a change in duct size also causes a loss of static pressure through eddy effects set up. The pressure difference between any two points in a duct indicates the losses sustained in moving the air over the distance between them.

RELATION BETWEEN VELOCITY AND VELOCITY HEAD

It is obvious that between velocity and pressure some relation must exist. It is shown in textbooks of physics, that if water emerges from an orifice near the bottom of a tank, that the water velocity at the point of issue can be determined from the following relationship

$$h' = \frac{v^2}{2g} \quad (9)$$

where v is the velocity in feet per second, h' , the height of the water level above the orifice, and g is the constant of gravitation, equal to 32.2.

The relation between the velocity of air flow and velocity head is also given by equation (9). In the case of water, the equation merely expresses the fact that a water column of height equal to h' , represents a pressure which is proportional to the square of the velocity. The same interpretation applies to air, where now, however, the pressure created by an air column of height h' , is proportional to the square of the air velocity.

For convenience in air-flow measurements, the term h' of the above equation is generally expressed in inches of water. Thus to convert h' in feet of air to h , in inches of water, we have that

$$h' = \frac{\text{density of water}}{\text{density of air}} \times h$$

If the density of air is taken as 0.0749 pounds per cubic foot and water as 62.4 pounds per cubic foot at 70° F., then

$$h' = \frac{62.4}{0.0749} \times h = 833h$$

1 BB 00 20 065 1

10 NOTE

If h_1 is expressed in inches

$$h_1 = 69.4h_2$$

Thus, the height of an air column at 70° F. equivalent to one inch of water is 69.4 feet.

Substituting in equation (9) we then obtain

$$69.4h_2 = \frac{r^2}{64.4}$$

Therefore, if the velocity is expressed in feet per minute

$$V = 4009\sqrt{h_2} \quad (10)$$

EFFECT OF TEMPERATURE

It was mentioned in a previous paragraph that air is affected by temperature changes, contracting in volume when cooled and expanding when heated. If it is assumed that expansion or contraction is proportional to the absolute temperature, T_1 , then the following proportion is true

$$\frac{h_1}{h_2} = \frac{T_1}{T_2}$$

or if h_2 is desired, T_1 , T_2 , and h_1 being known

$$h_2 = \frac{T_2}{T_1} h_1$$

Thus, given the height of air column h_1 corresponding to an absolute temperature T_1 , the height of air column for any other temperature is at once determined.

Equation (10) may be written

$$V = K\sqrt{h_2}$$

where K is a constant varying with temperature. This constant, following the method outlined in this and the preceding paragraph has been calculated in table 25.

TABLE 25.—Values of air density, height of air column, and K in formula, $V = K\sqrt{h_2}$, for various air temperatures

Temperature	Density of air (pounds per cubic foot)	Column of air equal to 1 inch H ₂ O (feet)	Value of K in $V = K\sqrt{h_2}$	Temperature	Density of air (pounds per cubic foot)	Column of air equal to 1 inch H ₂ O (feet)	Value of K in $V = K\sqrt{h_2}$
32° F.	0.0012	61.40	24.5	70° F.	0.0010	69.40	29.9
40° F.	0.0011	63.44	24.4	80° F.	0.0009	72.80	30.4
50° F.	0.0010	66.71	24.2	90° F.	0.0008	77.40	30.8
60° F.	0.0009	71.40	24.1	100° F.	0.0007	83.20	31.2

* Absolute temperature is the temperature at absolute zero, plus the observed temperature; that is $273 + t$, where t is the observed temperature degrees F.

BB 0020066

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2560

NOTE

NOT COME

Problem: Calculate the height of air column and the air density at 94° F., given the corresponding data at 70°.

Solution:

$$\frac{h}{69.39} = \frac{459.6 + 94}{459.6 + 70}$$

$$h = 72.5$$

To calculate the density, we have, since h is inversely proportional to the density D :

$$\frac{D}{0.0749} = \frac{459.6 + 70}{459.6 + 94}$$

$$D = 0.0717$$

EQUATION OF FLOW

The volume of air flow may be directly obtained in terms of the cross-sectional area of the duct. If Q represents the volume of air flowing in cubic feet per minute at an average velocity equal to V and a is the area of the duct in square feet

$$Q = aV = 4009a\sqrt{h} \quad (11)$$

If the diameter of the duct is expressed in inches, $a = 0.0055d^2$ and

$$Q = 22.9 d^2 \sqrt{h} \quad (12)$$

In the case of a duct of varying sections of areas equal to a, a', a'' , etc., with constant flow,

$$Q = aV = a'V' = a''V'' = \text{etc.} \quad (13)$$

where the V 's correspond to the velocities in the various sections. If the velocity is known in one section, it can then be determined for any section provided that the areas of both sections are known. Thus, if V, a and a' are known, the velocity in the latter section is simply

$$V' = \frac{a}{a'} V \text{ or } V' = \frac{d^2}{d'^2} V$$

where d and d' are corresponding diameters in inches or feet. When d is expressed in inches, the corresponding areas in either square inches or square feet may be obtained from table 26.

π , and K in formula.

Area of circular duct (sq. ft.)	Column of air equal to 1 inch H ₂ O (feet)	Value of $\frac{a}{a'}$
0.0049	0.00	1.00
0.0055	0.01	0.99
0.0061	0.02	0.98
0.0067	0.03	0.97

observed temperature, 100°

BB 0020067

NOT

NOT COME

102

TABLE 26.—Arcs of circles in square feet and square inches, diameters in inches

Dust diameter	Dust area		Dust diameter	Dust area	
	Square inches	Square feet		Square inches	Square feet
1 inch	0.785	0.0054	11 inches	95.03	0.66
2 inches	3.14	0.0218	12 inches	113.1	0.785
2.5 inches	4.91	0.0339	13 inches	132.7	0.92
3 inches	7.07	0.0491	14 inches	153.9	1.06
3.5 inches	9.62	0.0667	15 inches	176.6	1.23
4 inches	12.57	0.0867	16 inches	200.9	1.40
4.5 inches	15.9	0.109	17 inches	226.8	1.58
5 inches	19.63	0.134	18 inches	254.3	1.77
5.5 inches	23.76	0.162	19 inches	283.4	1.97
6 inches	28.27	0.194	20 inches	314.2	2.18
6.5 inches	33.18	0.230	21 inches	346.4	2.40
7 inches	38.48	0.267	22 inches	380.1	2.64
7.5 inches	44.18	0.307	23 inches	415.3	2.88
8 inches	50.27	0.349	24 inches	452.1	3.14
8.5 inches	56.74	0.394	25 inches	490.6	3.40
9 inches	63.62	0.442	26 inches	530.8	3.67
9.5 inches	70.89	0.492	27 inches	572.7	3.95
10 inches	78.54	0.545	28 inches	616.3	4.24
10.5 inches	86.58	0.601	29 inches	661.6	4.54

TRANSPORT VELOCITIES

The design of an exhaust system depends upon the magnitude of the air velocities required for transporting the dust collected by the hood, and upon an estimation of the losses incurred by fluid friction and eddy effects. If the velocities chosen are too low, there is danger of clogging the system with settled dust, while if too high, the friction losses may be so prohibitive as to bring the cost of operation to an unreasonable figure. Great care should therefore be exercised in the choice of velocities to be maintained.

TABLE 27.—Air speeds in ducts necessary to convey various materials

Material	Air velocity (feet per minute)
Grain dust	2,000
Wood chips and shavings	3,000
Raw lint	2,000
Jute dust	2,000
Rubber dust	2,000
Lint	1,500
Metal dust (primaries)	2,000
Lead dust	2,000
Fines (shavings) (fine)	4,000
Fine coal	4,000

Values of transport velocities are meager. Data for some dusts which have been found practical are given in table 27, but whether they are the most economical cannot be stated. No data regarding the size of the particles or their characteristics are available, and in all probability the figures represent the velocities in accord with existing practice. When, however, the maximum size and density

1 BB 0020068 1

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2562

inches in diam.

Duct area

Specific Gravity	Particle Size
1.0	0.001
1.0	0.002
1.0	0.003
1.0	0.004
1.0	0.005
1.0	0.006
1.0	0.007
1.0	0.008
1.0	0.009
1.0	0.010
1.0	0.012
1.0	0.015
1.0	0.020
1.0	0.025
1.0	0.030
1.0	0.040
1.0	0.050
1.0	0.060
1.0	0.075
1.0	0.100
1.0	0.125
1.0	0.150
1.0	0.200
1.0	0.250
1.0	0.300
1.0	0.400
1.0	0.500
1.0	0.600
1.0	0.750
1.0	1.000
1.0	1.250
1.0	1.500
1.0	2.000
1.0	2.500
1.0	3.000
1.0	4.000
1.0	5.000
1.0	6.000
1.0	7.500
1.0	10.000
1.0	12.500
1.0	15.000
1.0	20.000
1.0	25.000
1.0	30.000
1.0	40.000
1.0	50.000
1.0	60.000
1.0	75.000
1.0	100.000

the magnitude of
collected by the
of friction
the danger
the friction
operation to an
exercised in the

as materials

Air velocity feet per minute	Particle Size
0.1	0.001
0.2	0.002
0.3	0.003
0.4	0.004
0.5	0.005
0.6	0.006
0.7	0.007
0.8	0.008
0.9	0.009
1.0	0.010
1.2	0.012
1.5	0.015
2.0	0.020
2.5	0.025
3.0	0.030
4.0	0.040
5.0	0.050
6.0	0.060
7.5	0.075
10.0	0.100
12.5	0.125
15.0	0.150
20.0	0.200
25.0	0.250
30.0	0.300
40.0	0.400
50.0	0.500
60.0	0.600
75.0	0.750
100.0	1.000
125.0	1.250
150.0	1.500
200.0	2.000
250.0	2.500
300.0	3.000
400.0	4.000
500.0	5.000
600.0	6.000
750.0	7.500
1000.0	10.000
1250.0	12.500
1500.0	15.000
2000.0	20.000
2500.0	25.000
3000.0	30.000
4000.0	40.000
5000.0	50.000
6000.0	60.000
7500.0	75.000
10000.0	100.000

for some dusts
27, but whether
data regarding
available, and in
in accord with
size and density

if a particle to be conveyed is known, the following formulas for horizontal and vertical transport are useful (57). For horizontal ducts

$$V = 6,000 \frac{s}{s+1} \delta^{0.388} \quad (14)$$

and for vertical ducts

$$V = 13,300 \frac{s}{s+1} \delta^{0.479} \quad (14a)$$

where V is the air velocity in feet per minute, s is the specific gravity of the particles and δ is the diameter in inches of the largest particle

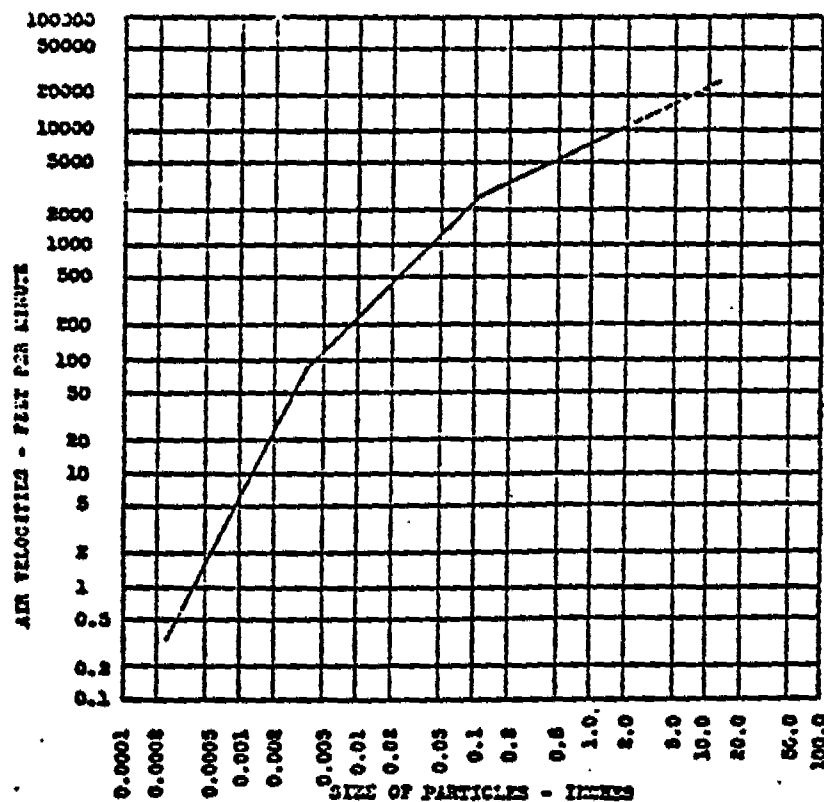


FIGURE 51.—Air velocities required to lift particles of quartz (specific gravity 2.65).

to be conveyed. The velocities determined by the above equations are minimum and should be increased approximately 10 percent to take care of settling which is likely to occur at elbows or enlargements.

For fine particles of dust—that is, those which obey Stokes' law—the data is known of the velocities required to convey them. The curve of figure 51 taken from data given by Martin (58) gives the velocities which must be exceeded in transporting particles of quartz ($s=2.65$)

10-11-55-3

BB 0020069

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2563

NOT
101

from 10 microns (in the range of Stokes' law) to 10 inches in diameter. The values in the extreme ranges are extrapolated.

Determination of duct diameter

When the volume of air required by a hood to control dust at a given source is known, and when the velocity of transport has been fixed, the size of duct required is at once determined from the equation of flow (equation (12))

$$Q = aV = 22.2 d^2 V$$

where d is the diameter of the duct expressed in inches. From this relationship, we obtain

$$d = 0.209 \sqrt{\frac{Q}{V}} \quad (15)$$

the size of duct required to maintain a velocity of V feet per minute when a volume of Q cubic feet per minute of air flows.

ENERGY LOSSES IN A DUCT SYSTEM

The calculations involved in the design of an exhaust system depend upon the energy losses incurred at the hood, and various portions of the system, the latter including the losses due to fluid resistance, elbows, transitions (enlargements or reductions of the duct) and collecting devices. For each duct of the system, the losses must be carefully estimated in order that a fan which will maintain the air flows required may be chosen.

It is well known that when water flows in a pipe, the pressure diminishes in the direction of the opening. This loss of "head" indicates a loss of energy. The same is true for air flowing in a duct. There is a decrease in static head toward the opening (that is, if the flow is toward the opening) and this decrease is due to loss in friction. The nature of these losses are discussed in the following paragraphs.

Hood entrance losses

The entrance losses depend almost entirely upon the structure of the hood. It has been found* that flared hoods without serious obstruction close to the opening have losses equal to about 50 percent of the velocity head in the connecting duct. In the case of plain duct ends, however, without any flaring, the losses are greatly increased due to the excessive spin of the incoming air from region behind the edge of the opening. The losses for duct ends must therefore be taken as equal to the velocity head.

Loss in straight ducts

The movement of a fluid in a duct gives rise to friction effect. These losses are made up by the static head so that in a duct of given

* Unpublished data: J. M. D.

NOTE: THIS DOCUMENT DID
NOT

BB 0020071

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2565

w) to 10 inches in diam
- extrapolated.

hood to control dust at a
city of transport has been
determined from the equa.

used in inches. From thi

(15)

city of V feet per minute
of air flows.

T SYSTEM

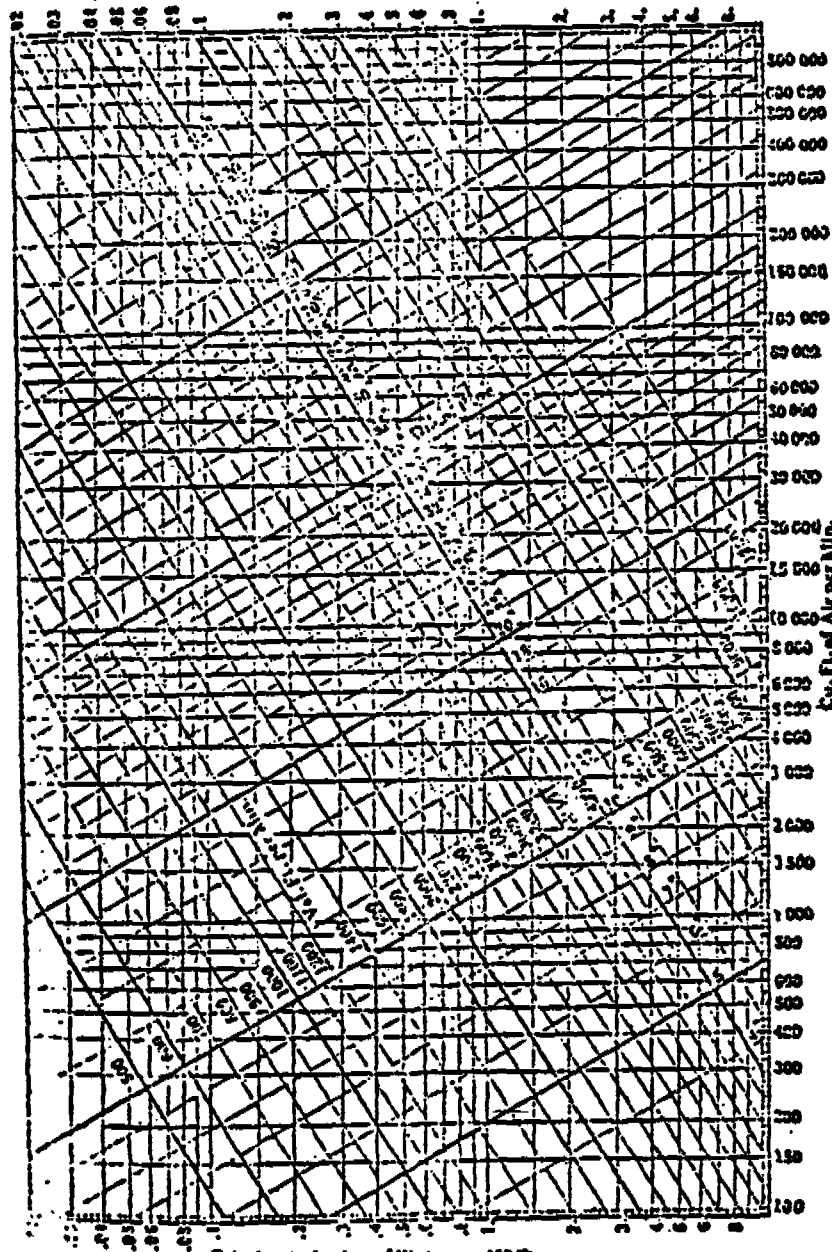
in of an exhaust system
at the hood, and various
ing the losses due to fluid
and reductions of the
the system, the loss
a fan which will maintain

in a pipe, the pressure
ing. This loss of "head"
for air flowing in a duct
the opening (that is, if the
loss is due to loss in friction
the following paragraph:

rely upon the structure of
red hoods without seri-
s equal to about 50 percent
uct. In the case of plan
, the losses are greatly in-
incoming air from re-
losses for duct ends in
- head.

ves rise to friction effe-
d so that in a duct of

length and uniform diameter, the loss is represented by the difference
of static pressure between the ends of the section. In the chart of



Friction in inches of Water per 100 Ft.
FIGURE 32.—Friction loss in air ducts.

32, the friction losses per 100 feet of duct may be obtained
the duct diameter and either the air velocity or volume of
known.

BB 0020072 1

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES, AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2566

NOTE

N 106

The losses given in the above figure are for sleeve-fitted ducts and naturally include the losses at the connections due to eddy effects. An accurate formula for lengths of duct of less than 10 feet is given by Lees' equation (35) based on conditions at 70° F.:

$$k' = 6.0 \frac{V^2}{d} \left(0.0009 + \frac{0.036}{(Vd)^{0.25}} \right) \times 10^{-4} \quad (16)$$

where k' represents the loss per foot of duct.

Example: Air is flowing in a smooth 6-inch diameter duct at a rate of 4,500 feet per minute. Calculate by Lees' formula the loss in a foot of duct and compare with the result obtained from the chart.

Solution:

$$\begin{aligned} (Vd)^{0.25} &= (4,500 \times 6)^{0.25} \\ 0.35 (\log 4,500 + \log 6) &= 0.35 (3.6532 + 0.7782) \\ &= 1.5510 \\ \text{antilog } 1.5510 &= 35.57 \end{aligned}$$

Hence, per foot of length, we have

$$\begin{aligned} k' &= \frac{6.0}{6} \times 4,500 \times 4,500 \times \left(0.0009 + \frac{0.036}{35.57} \right) \times 10^{-4} \\ &= 0.04'' \text{ H}_2\text{O} \end{aligned}$$

For a length of 8 feet, therefore, the loss is

$$8 \times 0.04 = 0.32'' \text{ H}_2\text{O}$$

From the chart the resistance is found to be 6.3'' per 100 feet, or 0.50'' H₂O for a length of 8 feet.

Loss at elbows

The loss of head at elbows may be expressed in terms of the velocity head. The following data, taken from A. S. H. V. E. Guide (59) may be used in determining the loss for elbows of various center line radii.

TABLE 25.—Loss of head due to bends

Radius in percent of duct diameter	Loss in percent of velocity head
20	CR 11
100	
120	
200	

* Formula has been converted from C. G. S. units to feet, pound, second units.

BB 0020073

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2567

for sleeve-fitted ducts and
losses due to eddy effects
less than 10 feet is given
at 70° F.

$$\times 10^{-4} \quad (16)$$

in diameter duct at a rate
of formula the loss in s
obtained from the chart.

$$0.532 + 0.7782)$$

$$\rightarrow \frac{0.036}{57} \times 10^{-4}$$

in

3

to be 6.3" per 100 feet, or

ed in terms of the velocity
H. V. E. Guide (59) may
of various center line radii.

to be

	Loss in per- cent of velocity head
	0.02
	0.04
	0.06
	0.08
	0.10
	0.12
	0.14
	0.16
	0.18
	0.20
	0.22
	0.24
	0.26
	0.28
	0.30
	0.32
	0.34
	0.36
	0.38
	0.40
	0.42
	0.44
	0.46
	0.48
	0.50
	0.52
	0.54
	0.56
	0.58
	0.60
	0.62
	0.64
	0.66
	0.68
	0.70
	0.72
	0.74
	0.76
	0.78
	0.80
	0.82
	0.84
	0.86
	0.88
	0.90
	0.92
	0.94
	0.96
	0.98
	1.00

L, rounded heads.

Loss due to sudden transition

The loss due to sudden enlargement or contraction in a duct may be computed from St. Venant's formula (60)

$$h_s = 0.064 \left(\frac{V_1^2 - V_2^2}{1,000} \right) \quad (17)$$

where V_1 is the velocity in the smaller duct and V_2 that in the larger. Values of the loss h_s in inches of water for various differences $V_1 - V_2$ are given in figure 53.

When the enlargement or contraction is gradual, the losses are greatly reduced and may be taken as approximately 10 percent of the loss obtained by the above equation.

HORSEPOWER REQUIRED

The work done by a fan is equivalent to raising the weight of the air handled per minute to a height equal to the resistance against

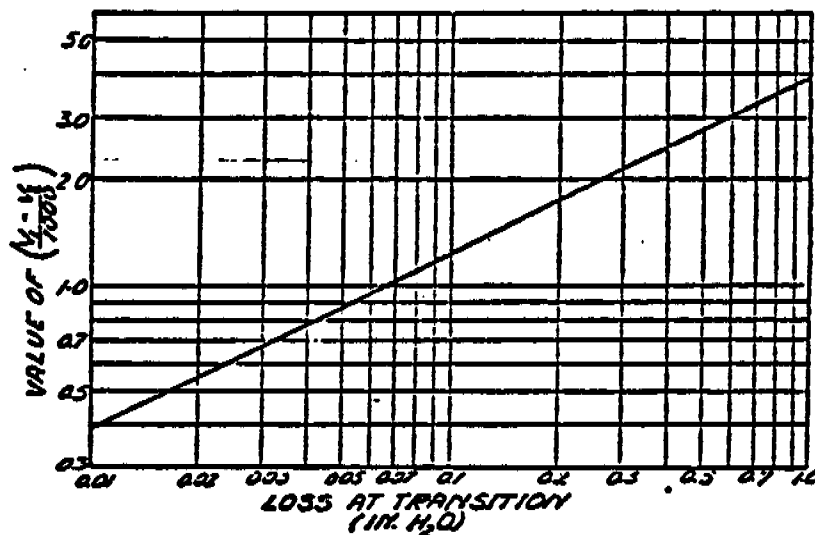


FIGURE 53.—Loss of head at enlargements in ducts.

which it must be delivered, expressed in feet of air. If, therefore, the resistance is expressed in inches of water, it must be multiplied by 0.94 which represents the equivalent of 1 inch of water expressed in feet of air at 70° F. For other temperatures the equivalent may be obtained from table 25. If h represents the total resistance against which the air must flow in inches of water and D represents the density of the air, the work done W is

$$W = QDh$$

BB 0020074

NOTE

103

where z is the height of a column of air equal to 1 inch of water. At 70° , $D=0.075$ and $z=69.4$, hence $W=0.52 Qh$. The horsepower is immediately determined by dividing by 33,000

$$\text{Horsepower} = 0.000158 Qh \quad (18)$$

DUCT COMPUTATIONS

When the volume of air flow and the sizes of the ducts have been determined, and when the general plan of layout has been drawn, it then becomes necessary to calculate the losses or the total resistance against which the fan must work. Without such information, there can be no assurance that a fan will supply an adequate air flow or any method of determining the horsepower that the fan will require.

The total resistance, as has been pointed out in the previous para-

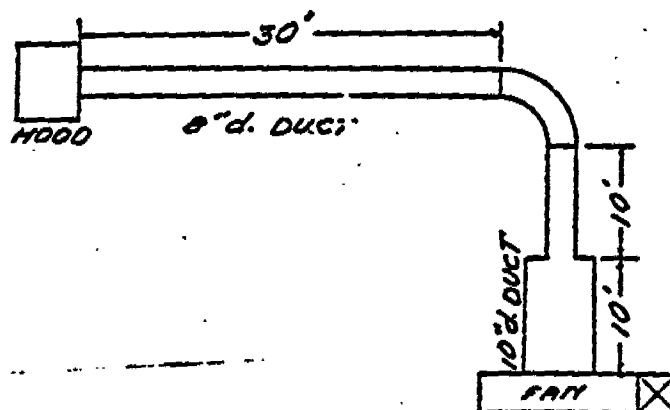


FIGURE 54.—Layout of simple duct system.

graphs, consists of the losses incurred at entrance, elbows and transitions, and those due to fluid friction in straight ducts. The resistance of collectors (see sec. X), if they form part of the system, are also additive. The total losses, therefore, expressed in inches of water (sometimes ounces per square inch) are for the whole system from the point of air entrance furthest removed from the fan to the point of discharge. In rating a fan it is then only necessary to state the volume of air it must handle and the total resistance against which it must deliver. The horsepower required may be calculated by the method outlined above. It is possible, however, to obtain the horsepower and speed required for a given type of fan from the manufacturers' catalogs.

APPLICATION OF LOSS DATA

The following problem demonstrates the application of the above data and formulae:

Given a single duct connected to an exhaust fan as shown in figure 54, determine the resistance which the fan must overcome when 1,000

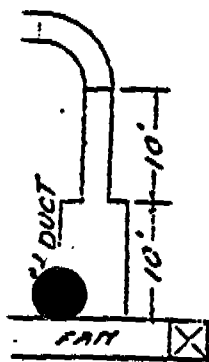
BB 0020075

NOTE
NOTE

1 inch of water. A:
The horsepower

(18)

If the ducts have been
it has been drawn, it
for the total resistance
each information, then
adequate air flow or
at the fan will require
in the previous para.



ance, elbows and transi-
at ducts. The resistance
of the system, are also
essed in inches of water
the whole system from
from the fan to the point
y necessary to state the
istance against which it
ay be calculated by the
ever, to obtain the horse-
of fan from the manufac-

DATA

application of the above

ust fan as shown in figure
must overcome when 1,000

feet per minute of air is handled by the fan. Take the loss at
entrance as 50 percent of the velocity head.

The solution may be arranged as follows:

The cross-sectional area of the 8-inch diameter duct in square feet
from table 26, 0.349, hence the velocity in the duct must be
 $1,000/0.349 = 2,865$ feet per minute (equation (13)). For the
8-inch diameter duct, the cross-sectional area is 0.785 square feet,
hence a velocity of 1,274 feet per minute. The velocity head is,
therefore, substituting for V in equation $h_v = V^2/4000^2 = 2,865^2 \times$
 $1000/4000^2 = 0.51$ inch H_2O . We are now in position to
compute the losses in the duct system as follows:

1. The loss at entrance is $0.50 \times 0.51 = 0.26$ inch H_2O .
2. The loss in an 8-inch diameter duct with an air velocity equal to
2,865 feet per minute obtained from figure 52 is found to be 2.1
inches H_2O per 100 feet of duct, approximately. For a length of 40
feet, therefore, the duct friction loss is $0.4 \times 2.1 = 0.84$ inch H_2O .
3. The loss at the elbow with radius of curvature equal to the
duct diameter is given in table 28 and is 26 percent of the velocity
head $= 0.26 \times 0.51 = 0.13$ inch H_2O .
4. The loss at the enlargement can be obtained from the curve of
figure 53 where $(V_1 - V_2)^2/1,000 = 2,865^2 - 1,274^2/1,000 = 1.59$.

Hence, the loss at enlargement is 0.16 inch H_2O .

5. Finally, we must estimate the loss in 10 feet of 10-inch diameter
duct having a velocity of air flow of 1,274 feet per minute. This is
found to be approximately 0.33 inch H_2O per 100 feet of duct, or
0.033 inch H_2O for a length of 10 feet.

6. The resistance which the fan must overcome is the sum of the
losses in the duct system from the point of entrance to the point
where the duct connects the fan, or 0.26 inch H_2O , loss at entrance;
0.84 inch H_2O , loss in 40 feet of 8-inch diameter duct; 0.13 inch
 H_2O , loss at elbow; 0.16-inch H_2O loss at enlargement; 0.03 inch
 H_2O , loss in 10 feet of 10-inch diameter duct; total, 1.42 inches H_2O
loss in the whole system and resistance which fan must overcome in
handling 1,000 cubic feet of air.

Loss computations in a branch system

In a multiple branch system the ducts must be proportioned to
handle adequately the air flows required for each hood. The problem
is, however, slightly complicated when the velocities are fixed in order
that the materials collected by the hoods may be transported. While
it is possible to have velocities greater than the lower limit required,
it is not good practice to exceed them by a very large amount in view
of the increased losses which are incurred. The following problem
states the procedure involved for a fixed lay-out.

Given a duct lay-out as shown in figure 55 with air flows at each
point indicated. Calculate the sizes of the ducts and the horsepower

BB 0020076

required, assuming that a velocity of not less than 3,600 feet per minute must be maintained in each duct and that the entrance losses are equal to one-half of the velocity head in the respective ducts. Assume a collector loss beyond the fan of 2 inches H_2O .

Following the general procedure given in the previous problem, and beginning with the hood A, we may arrange the computations as follows:

Step 1.—Since the duct velocities are fixed at 3,600 feet per minute, we have that the area of the duct AB is

$$\text{Area } AB = Q_A / V = 300 / 3,600 = 0.081 \text{ square feet}$$

From table 26, the duct which approximates this area has a diameter of 4 inches. The velocity head is from equation (10). $h_v = 3,600 \times$

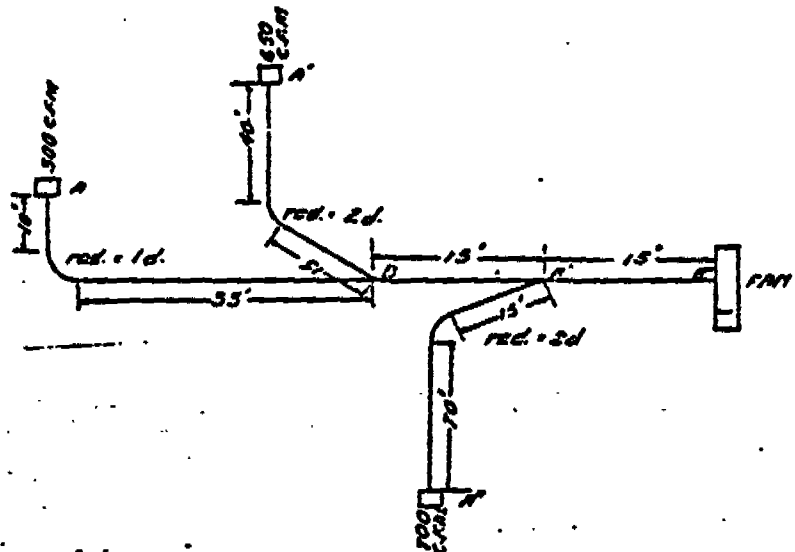


FIGURE 24.—Layout of branch system.

$3,600 / 4,009 \times 4,009 = 0.81$ inch H_2O . This value of the velocity head applies to all parts of the system.

Considering now the losses in the duct AB, we have—

1. Loss at entrance $= 0.50 \times 0.81 = 0.41$ inch H_2O .
2. Loss in 4-inch diameter duct at air velocity of 3,600 feet per minute is 6.8 inches H_2O (figure 52), per 100 feet, or $0.4 \times 0.8 = 3.1$ inches H_2O for 45 feet.
3. The elbow loss is, from table 28, $0.26 h_v = 0.26 \times 0.81 = 0.21$ inch

total resistance in the duct AB for a flow of 300 cubic feet is, therefore, the sum of the losses $0.41 + 3.1 + 0.21 = 3.7$

data h_v
Given
54, determi.

BB 0020077

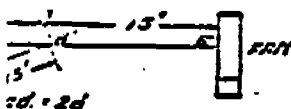
at less than 3,600 feet per minute and that the entrance losses are equal in the respective ducts. 2 inches H_2O .

in the previous problem, and range the computations as

equal at 3,600 feet per minute,

0.084 square feet

Since this area has a diameter equation (10). $h_v = 3,600 \times$



value of the velocity head

At B , we have—
inch H_2O .

velocity of 3,600 feet per minute, or $0.45 \times 6.8 = 3.1$

$h_v = 0.26 \times 0.81 = 0.21$ inch

for a flow of 300 cubic feet per minute $0.41 + 3.1 + 0.21 = 3.7$

This value represents the static at B and hence the resistance of the branch $A'B$ must also be equal to the losses calculated in the branch AB . Otherwise the static head at B will have two values, which is impossible.

Step 2.—The area of the duct $A'B$ is found as in the previous step. Area $A'B = Q_{A'}/3,600 = 650/3,600 = 0.18$ square foot which corresponds to a duct diameter of approximately 5.5 inches. The losses may now be computed as before.

1. The entrance loss at A' is $0.50 \times 0.81 = 0.41$ inch H_2O .
2. The friction loss in a 5.5-inch diameter duct with an air velocity of 3,600 feet per minute is found to be 4.5 inches H_2O per 100 feet of duct, or $0.55 \times 4.5 = 2.5$ inches H_2O for a length of 55 feet.
3. The elbow loss for a bend equal to 200 percent of the duct diameter is 0.14 h_v , or $0.14 \times 0.81 = 0.11$ inch H_2O .
4. The total resistance A' to B is, therefore,

$$0.41 + 2.5 + 0.11 = 2.8 \text{ inches } H_2O.$$

The resistance of the branch $A'B$ is seen to be less than the resistance of the branch AB . Since the fan must maintain the same static at the point B for both branches, it is obvious that if the larger value is to be kept, the air flow in the branch $A'B$ will be increased. The alternative is to cut down the diameter of $A'B$ so that the resistance is equal to the branch AB , or to increase the diameter of AB . The latter, however, is not desirable since it tends to cut down the air velocity which is fixed at a lower limit of 3,600 feet per minute. In the present case, although the resistance is less than in AB , the increase in flow in $A'B$ can be shown to be only slightly greater than the 650 cubic feet required by the hood. The approximation to the actual amount of air handled at A' with a static of 3.7 inches H_2O at B can be made as follows: Assume that the branch $A'B$ handled 700 cubic feet per minute. The air velocity in the 5.5-inch diameter duct will then be $700/0.18 = 3,890$ feet per minute, which corresponds to a velocity head of 0.94 inch H_2O .

Proceeding as above in determining the various losses, we find loss at entrance = 0.47 inch H_2O ; friction loss = 2.92 inches; elbow loss = 0.13 inch; total loss $A'B = 3.52$ inches, which corresponds closely to the loss in the duct AB . Thus a volume of air flow corresponding to a static head at B is approximately 700 cubic feet per minute. More accurately the flow is found to be 710 cubic feet per minute, but for practical calculations 700 cubic feet per minute is sufficiently accurate.

Step 3.—At the point B , there must be a transition to a duct which will accommodate a flow of $300 + 700 = 1,000$ cubic feet per minute at a velocity of 3,600 feet per minute. The area of the new duct will

BB 0020078 1

be, therefore, $1,000/3,600 = 0.278$ square foot, or a duct which is $7\frac{1}{2}$ inches in diameter. The loss in friction in such a duct is 3.5 inches H_2O per 100 feet or $0.15 \times 3.5 = 0.53$ inch H_2O for a length of 15 feet.

The loss at enlargement is, of course, nil by St. Venant's equation. Due to the angle at which the flow from $A'B$ enters, the loss is usually taken as 10 percent of the velocity head, or 0.08 inch H_2O .

The total loss BB' is consequently $0.53 + 0.08 = 0.61$ inch H_2O . This must be added to the value of the static at B and hence gives the static to be maintained at B' ; that is $3.7 + 0.61 = 4.31$ inches H_2O .

Step 4.—As in the case of the branch $A'B$, the losses sustained in the duct $A''B'$ must equal the static calculated at B' , or 4.31 inches H_2O . The procedure is identical to the preceding steps.

The duct area is $700/3,600 = 0.19$ square foot which corresponds to a duct diameter of 6 inches. The loss calculations are then:

1. The entrance loss $= 0.81 \times 0.50 = 0.41$ inch H_2O .
2. The loss due to duct resistance for a 6-inch diameter duct with air velocity of 3,600 feet per minute is found to be 4.5 inches H_2O per 100 feet of duct or $0.85 \times 4.5 = 3.6$ inches for a duct 85 feet in length.
3. The elbow loss $= 0.14 \times 0.81 = 0.11$ inches H_2O .
4. Hence the total loss in $A''B'$ is $0.41 + 3.6 + 0.11 = 4.1$ inches H_2O . Since this is practically equal to the static calculated at the point B' , no corrections need be applied.

Step 5.—There remains now to calculate the loss from B' to B'' and the static at the point B'' which will indicate the total resistance of the system and the suction which the fan must maintain in order that the air flows and velocities in the various parts. Since we must have an enlargement at B' , we may at once calculate the area of the duct $B'B''$ to accommodate an air velocity of 3,600 feet per minute. The total volume of flow in this duct is obviously the sum of the flows of the various branches, or 1,700 cubic feet per minute. Hence area $B'B'' = 1,700/3,600 = 0.47$ square feet, equivalent to a duct diameter of 9.5 inches (approximately). The losses in $B'B''$ are—

1. The duct resistance loss which is found from figure 52 to be 2.7 inches per 100 feet or $0.15 \times 2.7 = 0.41$ inch H_2O for a length of 15 feet.
2. The loss at transition is again taken, because of the branch duct $A'B'$, as 10 percent of the velocity head, or 0.08 inch H_2O .
3. The resistance $B'B''$ is, therefore, $0.41 + 0.08 = 0.49$ inch H_2O . The total resistance to the point B'' is the sum of the resistance to B' plus the loss in $B'B''$ or $4.1 + 0.49 = 4.59$ inches H_2O . This is also the static at B'' and the suction which the fan must maintain to handle the air flows and velocities in the system.

Since the fan must also overcome a collector resistance of 2 inches H_2O , the total resistance of the system including the collector is 4.59 inches + 2.0 inches or 6.59 inches H_2O . The horsepower required by

or a duct which
 a duct is 3.5 inch
 a length of 15 feet.
 Venant's equation
 ers, the loss is usually
 inch H₂O.

$0.05 = 0.61$ inch H₂O.
 B and hence gives the
 $= 4.31$ inches H₂O.
 he losses sustained in
 at D', or 4.31 inch
 ng steps.

which corresponds to a
 s are then:

H₂O.
 h diameter duct with
 be 4.5 inches H₂O per
 et 55 feet in length.

H₂O.
 $0.11 = 4.1$ inches H₂O.
 lat the point B'.

es from B' to B'' and
 the total resistance of
 maintain in order that

Since we must have
 the area of the duct
 feet per minute. The
 the sum of the flows of
 minute. Hence area
 it to a duct diameter
 "B" are—

on figure 52 to be 2.7
 for a length of 15 feet.
 so of the branch duct
 inch H₂O.

$0.05 = 0.49$ inch H₂O.
 of the resistance to B'
 es H₂O. This is also
 an must maintain to

resistance of 2 inch
 the collector is 4.59
 horsepower required by

the fan is, therefore, from equation (18), $0.000158 \times 1700 \times 6.59 = 1.77$
 horsepower.

We may recapitulate in the following table:

TABLE 20.—Summary of results, branch system

Duct	Volume airflow	Equivalent resistance	
	Cubic feet per min- ute	Inches H ₂ O	Inches H ₂ O
1/4"	300	4	2.7
1/2"	750	8.7	3.7
1 1/2"	1,800	77	3.51
1 3/4"	2,100	6	4.1
2 1/4"	3,750	9.5	3.29

NOTE.—Total resistance which fan must deliver against, 6.59 inches H₂O. Horsepower required by fan, 1.77.

Enlargements at branch connections

The above problem illustrates the need of rather extended computations in proportioning a system. It is also quite clear that the sizes of ducts must be carefully determined if proper velocities and air flows are to be maintained in the system. In the calculations given, no allowance was made for future connection or disturbances in air flow which might occur in case one duct or more was cut out of use. Under such circumstances the system should be layed out with all probable connections to be made, and the duct sizes computed on this basis, remembering at all times that velocities in the ducts should with one or more hoods out never get below the limiting transport velocities.

It is necessary to point out that some States require that when a branch duct enters a main, the area of the main duct shall be increased from 10 to 25 percent of the combined areas of both. This rule must be followed, although it is actually not required in a well-designed system. Excess enlargements naturally call for larger air volumes through the hoods in order that adequate velocities may exist.

GENERAL RULES FOR CONSTRUCTING EXHAUST SYSTEMS

The following general rules should be observed in the construction of an exhaust system:

1. The main trunks and branch pipes should be straight, strongly supported, and with the dead ends capped to permit inspection and cleaning when necessary. All branch pipes should join the main at an acute angle, the junction being at the side or top and never at the bottom of the main.

2. Clean-out ports having suitable covers should be placed in the main and branch pipes so that every part of the system can be easily reached in case the system clogs.

1 BB 0020080 1

3. Elbows should be made at least two gages heavier than straight pipe of the same diameter to enable them to withstand the additional wear caused by changing the direction of flow. They should preferably have a throat radius of at least $1\frac{1}{2}$ times the diameter of the pipe.

4. Every pipe should be kept open and unobstructed throughout its entire length, and no fixed screen should be placed in it.

5. The passing of pipes through fire walls should be avoided wherever possible.

6. All permanent circular joints should be lap-jointed, riveted, and soldered, and all longitudinal joints either grooved and locked or riveted and soldered. Every change in pipe size should be made with an eccentric taper flange on the bottom, the taper to be at least 5 inches long for each inch change in diameter.

BB 0020081

is heavier than steel
withstand the rubbing
They should be
in diameter of the
constructed throughout
placed in it.
could be avoided with

lap-jointed, riveted,
grooved and bolted
the size should be
the taper to be at
ter.

IX. EXHAUST VENTILATION IN PRACTICE

The methods of dust prevention vary widely even when identical operations are involved. Each plant in controlling its dust hazards generally applies such methods as it finds best fitted to its particular lay-out. Economic and mechanical factors are also important considerations which result in a diversity of type and construction of preventive equipment. Thus, with few exceptions, information with regard to the performance of various equipment is confusing and renders a comprehensive treatment of preventive methods difficult to accomplish. At the same time, it must be stressed that extensive efficiency data are lacking. This lack may be partially attributed to the reasons stated above, but it especially is due to the fact that methods of testing control equipment as described in section V have not been generally used. The present section, therefore, attempts only to supply information regarding the control of dust in operations which are widely used and for which some data are available.

EXHAUST VENTILATION IN THE GRANITE INDUSTRY

The introduction of pneumatic cutting tools has done much to increase the severity of dust exposure in the industries using them. This has been the case in the granite industry where hand pneumatic tools and pneumatic surfacing machines contribute the maximum dust concentrations.

Reference to table 3 shows that the pneumatic tools create the maximum amount of dust.

Pneumatic hand tools in the granite industry are used for practically all detail work. The tools employed vary in size depending on the type of work done. They are guided by hand over the stone surface and usually demand close attention of the operator whose breathing level ranges from 6 to 15 inches above the tool. Under such conditions it is difficult to control dust without causing some interference in the work performed.

The surfacing machine is used only for bringing the rough stone to plane surface. The tools used in this machine are larger than the hand pneumatic type. They are graded in size so as to bring the surface to any degree of smoothness. The tools are driven by a pneumatic hammer attached to a horizontal beam which swings out a vertical column which may be raised or lowered to accommodate stones of various sizes. The machine is heavily built and

(115)

BB 0020082

In operation the hammer and tool of the surfacing machine are guided over the stone by an operator. The amount of dust generated varies with the type of hammer and tool employed; the concentration being a maximum for a four-point tool, decreasing with the fineness of cut.

It is obvious from the foregoing discussion that the control of dust generated by the hand pneumatic tool and surfacing machines must be flexible. In the former, because the worker must cut on stones in vertical and angular positions, it is extremely difficult to secure adequate control at all times. The general method used consists of connecting a flexible hose to the exhaust system and placing the hood in a position offering the least encumbrance to the worker. As may be judged, however, the success of the method depends upon the care with which the worker places the hood; if it is too far from the work being done, it clearly cannot function properly. With surfacing machines, on the other hand, the hoods were formerly placed on the stone and because of the inconvenience incurred, frequently were not moved although the tool would be operating at a considerable distance from them. The exhaust system consequently failed to function efficiently because it was not properly utilized.

The manner of testing pneumatic cutting tools has been indicated in section V. The results obtained by Bloomfield (47) in comparing the dust concentrations in plants with and without local exhaust systems have shown that, for ordinary operations, effective control of the dust generated can be achieved when the exhaust velocities at the hood were kept above 1,500 feet per minute.

The basic fundamentals of hood design presented in part VII are useful in assisting the engineer to estimate a priori the probable performance of an exhaust system. This has been done to a certain extent in the case of granite cutting. Thus, Hatch, Drinker, and Choate (55) applying the methods given in the above chapter were enabled to deduce the fact that, regardless of hood shape, approximately 200 feet per minute are required about the surfacing tool in order to reduce the dust concentration at the worker's breathing level to an estimated safe limit of 10 million particles per cubic foot. The same investigators analyzed the characteristics of a large variety of hoods connected near the pneumatic surfacing tool until one was devised which adequately controlled the dust generated with a minimum amount of hindrance to the work and with low cost of operation. The hood finally designed by these investigators is shown in figure 56. It comprises a rectangular opening with a semicircular barrier to limit the scattering of particles. With the tool in position within the barrier, a minimum flow of about 320 cubic feet of air per minute is required to keep the dust concentration below 10 million particles per cubic foot under normal conditions of operation. The hood is mounted

of the surfacing machine and the amount of dust generated by the worker must cut on stones in a very difficult to secure method used consists of connecting the hood in close to the worker. As may be seen, the method depends upon the care of the worker if it is too far from the work it will not properly. With surfacing machines were formerly placed on the ground, frequently were not operating at a considerable distance and consequently failed to function properly.

It has been indicated by Bloomfield (47) in comparing the results of local exhaust systems, effective control of dust when the exhaust velocities are 100 feet per minute.

Sign presented in part VII are quite a priori the probable percentage has been done to a certain extent. Thus, Hatch, Drinker, and others in the above chapter were concerned with hood shape, approximated about the surfacing tool in order to maintain the worker's breathing level at 10 million particles per cubic foot. The characteristics of a large variety of surfacing tool until one was developed which generated with a minimum and with low cost of operation.

Investigations is shown in figure 56. It is a semicircular barrier to limit the tool in position within this hood. 10 cubic feet of air per minute is required to maintain below 10 million particles per cubic foot. The hood is mounted

on a carriage holding the cutting tool and connected by means of a flexible duct to an exhaust system. In this way, the hood constantly embraces the cutting tool as it moves over the stone surface.

It is interesting to point out that the study of various hoods used in granite cutting made by Hatch et al., shows that a velocity at the opening which will control the dust generated is approximately 1,500 feet per minute, or the amount specified by Bloomfield in his study above referred to.

CONTROL OF DUST IN ROCK DRILLING

In order to cope with the dust produced in rock drilling, particularly in foundation and tunnel work, special dust traps have been devised.

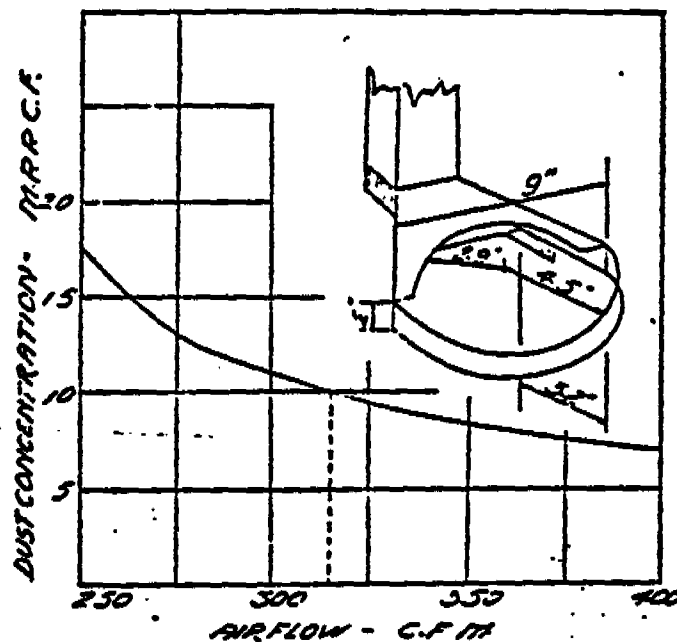


Figure 56.—Characteristics of hood used for granite surfacing machines.

In form these traps are similar to the Hay (61) trap with the exception that, whereas the latter utilizes the suction formed by an ejector connected to the drill exhaust, the new devices are connected to powerful exhaust fans.

The essential requirements of a dust trap have been described by Hatch and his coworkers in a series of articles pertaining to the control of dust in rock drilling (62, 63, and 50). Figure 57 shows the type of trap investigated by the above workers in connection with downward drilling operations in foundation work. The drill is inserted in a hole at the top and the exhaust is applied at the 2-inch connection indicated. About 60 cubic feet of air per minute are required to maintain a low dust concentration, the air passing along the uneven

surface of the rock and through the drill hole, thus making an trap. The dust collected passes through the exhaust ducts to separator and bag filter of high efficiency. In actual operation,

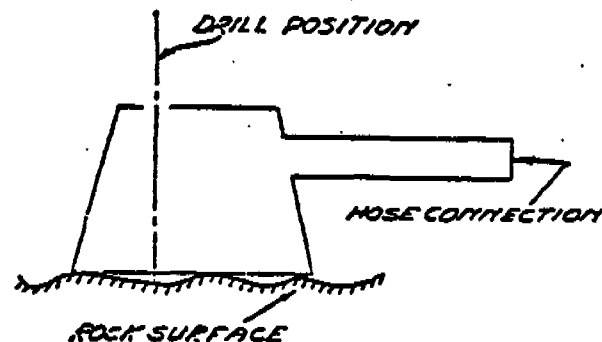


FIGURE 57.—Kelly trap for rock drilling.

convenient pipe exhaust system is installed with a number of manifold trap connections.

The air flow 60 cubic feet per minute necessary represents a static suction at the end of only 0.5 inch of water. However, there is considerable

loss of pressure in the hose connecting the trap with the exhaust manifold. The suction required at the manifolds for hoses of various lengths have been determined and are presented in the table below.

TABLE 30.—Static suction at manifold required for various lengths of 2-inch hose with air flow of 60 cubic feet per minute

Length of hose	Static suction required at manifold (inches H ₂ O)	Length of hose	Static suction required at manifold (inches H ₂ O)
25 feet	3.5	75 feet	7.0
50 feet	7.0	100 feet	7.0

In any design, therefore, it is necessary to provide adequate suction at the manifold to take care of the longest length of hose to be used. It is further important to allocate the manifolds at the most advantageous points to take care of the progress of drilling operations.

For vertical or horizontal drilling, Hatch has described special adapters for placing the trap in any position (50), (fig. 58). Under such circumstances air flows of the order of 200 cubic feet per minute have been recommended to keep the dust concentration below one million particles per cubic foot.

The proper disposal of collected dust is also important. This is particularly true in tunneling and consequently provision must be made to collect the dust efficiently in order to render the tunnel safe to breathe. It is further necessary that any collecting device used should be easily moved and compact.

In collecting the dust conveyed by the exhaust system, a roll was employed which consisted of two stages (63)—a preliminary

BB 0020085

, thus making an air
in the exhaust ducts to a
7. In actual operation, a
convenient pipe-
haust system is in-
stalled with a num-
ber of manifolds for
trap connections.

7
700Y The air flow of
60 cubic feet per
minute necessary
represents a static
suction at the trap
of only 0.8 inch of
water. However,
there is considerable
trap with the exhaust mani-
folds for hoses of various
presented in the table below.

various lengths of 2-inch flexible
at per minute

Length of hose	Static suction required at manifold (inches water)
10	0.5
20	1.0

o provide adequate suction
length of hose to be used.
manifolds at the most advan-
of drilling operations.

ch has described special
on (50), (fig. 58). Under
200 cubic feet per minute
concentration below 10

also important. This is
cently provision must be
to render the tunnel air
that any collecting device

haust system, a collector
ages (63)—A preliminary

sedimentation chamber and cloth screen filters. In the former, the dust was blown into a bell-shaped entrance where part of the dust was thrown out by inertial force. The air then passed through a baffle arrangement at low velocity causing further separation and thence to the cloth screens. The filtering was conducted at a rate of 3 cubic feet per square foot of filter surface. The total filter area was 1,000 square feet and the complete collector unit was capable of handling the dust from a maximum of 60 drills. The amount of dust varied from 1.5 to 4 tons per day, giving an overall collecting efficiency of 99.7 percent.

The use of the trap was shown by Hatch and his associates to increase the speed of drilling from 11 to 21 percent, while the cost of operation was estimated at \$2.21 per day or 1.05 percent of the cost

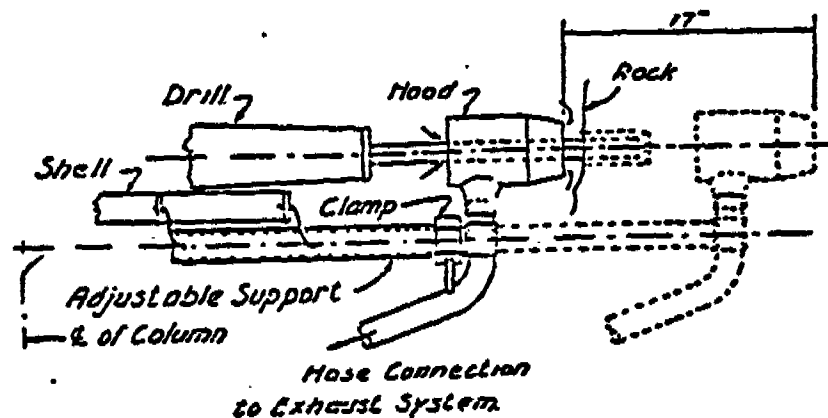


FIGURE 58.—Modified Kelley trap for drilling vertical rock faces.

of removing a cubic yard of stone (63). In view of the increased rate at which drilling can be done with a trap for only a slightly greater cost per cubic yard removed, it may be seen that not only are hygienic conditions improved, but the speed of drilling has been increased at only a slight additional cost.

CONTROL OF DUST FROM GRINDING, POLISHING, AND BUFFING WHEELS

Exhaust systems for grinding, polishing, and buffing wheels vary widely in design. In the case of grinding, the hoods used serve not only to provide a means for capturing the dust, but also act to protect the worker in case the wheel bursts. For the prevention of accidents due to the bursting of high-speed grinding wheels a special code covering the requirements of hood construction has been written (64). With regard to polishing and buffing wheels, which must be adapted to handling intricate parts, the hoods used assume a wide variety of shapes.

107211°—35—0

1 BB 0020086 1

The chief difficulty to be overcome in grinding wheels is the outward sweep of air, a fan action, due to the revolving wheel. This effect is very marked with high speed and rough wheels, and is so strong that in many instances it is sufficient to counteract the normal inward flow of air. The same effect exists with polishing and buffing wheels, but to a less marked degree.

Practically all industrial States have codes regulating the construction and duct connections for grinding, polishing, and buffing wheels. They also regulate the air required for wheels of various sizes in terms of static suction in the connecting duct. These codes, however, possess no uniformity as may be seen from citations taken from the existing codes for Wisconsin and New York, as follows:

The Wisconsin code requires that—

On all grinding, buffing, and polishing wheels, the suction at the connection to the hood must be sufficient to displace a column of water in a U-tube, 5 inches,

The New York code reads:

Sufficient static suction shall be maintained in every branch pipe within 1 foot of the hood to produce a difference of level of at least 2 inches of water between the two sides of a U-shaped tube.

The requirements designated by State codes must be followed. Typical size connections for grinding and buffing wheels required in many States are given in table 31.

TABLE 31.—Size of connections for grinding and buffing wheels

Diameter of wheels	Maximum grinding surface	Minimum diameter of branch pipes
	Square inches	Inches
Grinding:		
6-inch or less, not over 1 inch thick	19	3
7 to 14-inch, inclusive, not over 1½ inches thick	43	3½
15 to 16-inch, inclusive, not over 2 inches thick	101	4
17 to 18-inch, inclusive, not over 3 inches thick	181	4½
19 to 21-inch, inclusive, not over 4 inches thick	312	5
22 to 24-inch, inclusive, not over 5 inches thick	473	6
Buffing:		
6-inch or less, not over 1 inch thick	19	3½
7 to 14-inch, inclusive, not over 1½ inches thick	37	4
15 to 16-inch, inclusive, not over 2 inches thick	101	4½
17 to 18-inch, inclusive, not over 3 inches thick	180	5
19 to 21-inch, inclusive, not over 4 inches thick	328	6
22 to 24-inch, inclusive, not over 5 inches thick	518	7

Table 32 shows the amount of air handled by grinding wheel hoods with connections of various sizes. The effect of suction is clearly indicated. Thus, a duct connection 3 inches in diameter with 2-inch static suction handles only 0.63 the amount of air as when supplied with 5-inch suction. In other words, the volume is proportional to the ratio of the square roots of the static suction ($\sqrt{\frac{2}{5}} = 0.63$). At the same time, the increased static implies a higher velocity and a

7 wheels is the out-
olving wheel. This
ch wheels, and is so
unternact the normal
polishing and buffing

ulating the construc-
and buffing wheels.
various sizes in terms
eso codes, however,
tions taken from the
ollows:

ction at the connection
er in a U-tube, 5 inches,

ranch pipe within 1 foot
inches of water between

must be followed.
g wheels required in

7 wheels

Maximum grinding surface	Minimum diameter of horse's pipe
10	3
12	4
14	4
16	4
18	4
20	4
22	4
24	4
26	4
28	4
30	4
32	4
34	4
36	4
38	4
40	4
42	4
44	4
46	4
48	4
50	4
52	4
54	4
56	4
58	4
60	4
62	4
64	4
66	4
68	4
70	4
72	4
74	4
76	4
78	4
80	4
82	4
84	4
86	4
88	4
90	4
92	4
94	4
96	4
98	4
100	4

grinding wheel hoods
of suction is clearly
diameter with 2-inch
air as when supplied
me is proportional to
 $n \left(\sqrt{\frac{1}{3}} - 0.05 \right)$. At
higher velocity and a

subsequently greater resistance in the duct connection. With 2-inch suction on a 3-inch diameter connection, the air velocity is 4,012 feet per minute while with 5-inch suction it is 6,354 feet per minute; if the resistance is assumed to vary as the square of the velocity, the resistance in the case of the higher velocity is approximately $2\frac{1}{2}$ times that at the lower. Obviously, good design would call for a larger duct connection in the latter instance in order to offset the increased losses. On the other hand, since a 5-inch suction must be maintained in accordance with some State codes, the volume is increased with a larger duct connection and any gain thus obtained is nullified. For example, a suction of 5 inches in a 3-inch diameter duct connection is equivalent to 197 cubic feet per minute; in a 4-inch diameter duct, the volume of flow would be equivalent to a suction of $2\frac{1}{2}$ inches. It is clear, therefore, that the ventilation performance of hoods (at least for the purpose of efficient design) should be based on the air volumes handled and not upon a rigid suction standard. These volumes, of course, should be established by experiment as the most effective for controlling the dust generated. These in turn should take into account the quality, size and speed of the wheel used, the type of hood with which it is fitted and the character of the work done.

TABLE 32.—Cubic feet of air handled per minute through average grinding wheel hoods

[Based on restriction coefficient of 0.75]

Diameter of connecting duct	Suction at throat—inches water gage						
	1	1½	2	2½	3	4	5
3 inches	63	76	85	96	107	124	136
3½ inches	97	119	136	153	174	195	216
4 inches	130	171	197	221	250	273	302
4½ inches	156	201	231	260	295	326	361
5 inches	184	231	261	295	335	377	421
5½ inches	211	261	301	341	385	431	481
6 inches	240	291	331	375	421	471	521
6½ inches	268	321	361	405	451	501	551
7 inches	296	351	391	435	481	531	581
7½ inches	324	381	421	465	511	561	611
8 inches	352	411	451	495	541	591	641
8½ inches	380	431	471	515	561	611	661
9 inches	408	451	491	535	581	631	681
9½ inches	436	481	521	565	611	661	711
10 inches	464	511	551	595	641	691	741
10½ inches	492	531	571	615	661	711	761
11 inches	520	561	601	645	691	741	791
11½ inches	548	581	621	665	711	761	811
12 inches	576	611	651	695	741	791	841
12½ inches	604	631	671	715	761	811	861
13 inches	632	661	701	745	791	841	891
13½ inches	660	691	731	775	821	871	921
14 inches	688	711	751	795	841	891	941
14½ inches	716	741	781	825	871	921	971
15 inches	744	771	811	855	901	951	1,001
15½ inches	772	801	841	885	931	981	1,031
16 inches	800	831	871	915	961	1,011	1,061
16½ inches	828	851	891	935	981	1,031	1,081
17 inches	856	881	921	965	1,011	1,061	1,111
17½ inches	884	911	951	995	1,041	1,091	1,141
18 inches	912	931	971	1,015	1,061	1,111	1,161
18½ inches	940	961	1,001	1,045	1,091	1,141	1,191
19 inches	968	991	1,031	1,075	1,121	1,171	1,221
19½ inches	996	1,011	1,051	1,095	1,141	1,191	1,241
20 inches	1,024	1,041	1,081	1,125	1,171	1,221	1,271
20½ inches	1,052	1,061	1,101	1,145	1,191	1,241	1,291
21 inches	1,080	1,091	1,131	1,175	1,221	1,271	1,321
21½ inches	1,108	1,111	1,151	1,195	1,241	1,291	1,341
22 inches	1,136	1,141	1,181	1,225	1,271	1,321	1,371
22½ inches	1,164	1,161	1,201	1,245	1,291	1,341	1,391
23 inches	1,192	1,191	1,231	1,275	1,321	1,371	1,421
23½ inches	1,220	1,211	1,251	1,295	1,341	1,391	1,441
24 inches	1,248	1,241	1,281	1,325	1,371	1,421	1,471
24½ inches	1,276	1,261	1,301	1,345	1,391	1,441	1,491
25 inches	1,304	1,291	1,331	1,375	1,421	1,471	1,521
25½ inches	1,332	1,311	1,351	1,395	1,441	1,491	1,541
26 inches	1,360	1,341	1,381	1,425	1,471	1,521	1,571
26½ inches	1,388	1,361	1,401	1,445	1,491	1,541	1,591
27 inches	1,416	1,391	1,431	1,475	1,521	1,571	1,621
27½ inches	1,444	1,411	1,451	1,495	1,541	1,591	1,641
28 inches	1,472	1,441	1,481	1,525	1,571	1,621	1,671
28½ inches	1,500	1,461	1,501	1,565	1,611	1,661	1,711
29 inches	1,528	1,481	1,521	1,585	1,631	1,681	1,731
29½ inches	1,556	1,501	1,541	1,615	1,661	1,711	1,761
30 inches	1,584	1,521	1,561	1,645	1,691	1,741	1,791
30½ inches	1,612	1,541	1,581	1,675	1,721	1,771	1,821
31 inches	1,640	1,561	1,601	1,705	1,751	1,801	1,851
31½ inches	1,668	1,581	1,621	1,735	1,781	1,831	1,881
32 inches	1,696	1,601	1,641	1,765	1,811	1,861	1,911
32½ inches	1,724	1,611	1,651	1,795	1,841	1,891	1,941
33 inches	1,752	1,631	1,671	1,825	1,871	1,921	1,971
33½ inches	1,780	1,651	1,691	1,855	1,901	1,951	2,001
34 inches	1,808	1,671	1,711	1,885	1,931	1,981	2,031
34½ inches	1,836	1,691	1,731	1,915	1,961	2,011	2,061
35 inches	1,864	1,711	1,751	1,945	1,991	2,041	2,091
35½ inches	1,892	1,731	1,771	1,975	2,021	2,071	2,121
36 inches	1,920	1,751	1,791	2,005	2,051	2,101	2,151
36½ inches	1,948	1,771	1,811	2,035	2,081	2,131	2,181
37 inches	1,976	1,791	1,831	2,065	2,111	2,161	2,211
37½ inches	2,004	1,811	1,851	2,095	2,141	2,191	2,241
38 inches	2,032	1,831	1,871	2,125	2,171	2,221	2,271
38½ inches	2,060	1,851	1,891	2,155	2,201	2,251	2,301
39 inches	2,088	1,871	1,911	2,185	2,231	2,281	2,331
39½ inches	2,116	1,891	1,931	2,215	2,261	2,311	2,361
40 inches	2,144	1,911	1,951	2,245	2,291	2,341	2,391
40½ inches	2,172	1,931	1,971	2,275	2,321	2,371	2,421
41 inches	2,200	1,951	1,991	2,305	2,351	2,401	2,451
41½ inches	2,228	1,971	2,011	2,335	2,381	2,431	2,481
42 inches	2,256	1,991	2,031	2,365	2,411	2,461	2,511
42½ inches	2,284	2,011	2,051	2,395	2,441	2,491	2,541
43 inches	2,312	2,031	2,071	2,425	2,471	2,521	2,571
43½ inches	2,340	2,051	2,091	2,455	2,501	2,551	2,601
44 inches	2,368	2,071	2,111	2,485	2,531	2,581	2,631
44½ inches	2,396	2,091	2,131	2,515	2,561	2,611	2,661
45 inches	2,424	2,111	2,151	2,545	2,591	2,641	2,691
45½ inches	2,452	2,131	2,171	2,575	2,621	2,671	2,721
46 inches	2,480	2,151	2,191	2,605	2,651	2,701	2,751
46½ inches	2,508	2,171	2,211	2,635	2,681	2,731	2,781
47 inches	2,536	2,191	2,231	2,665	2,711	2,761	2,811
47½ inches	2,564	2,211	2,251	2,695	2,741	2,791	2,841
48 inches	2,592	2,231	2,271	2,725	2,771	2,821	2,871
48½ inches	2,620	2,251	2,291	2,755	2,801	2,851	2,901
49 inches	2,648	2,271	2,311	2,785	2,831	2,881	2,931
49½ inches	2,676	2,291	2,331	2,815	2,861	2,911	2,961
50 inches	2,704	2,311	2,351	2,845	2,891	2,941	2,991
50½ inches	2,732	2,331	2,371	2,875	2,921	2,971	3,021
51 inches	2,760	2,351	2,391	2,905	2,951	3,001	3,051
51½ inches	2,788	2,371	2,411	2,935	2,981	3,031	3,081
52 inches	2,816	2,391	2,431	2,965	3,011	3,061	3,111
52½ inches	2,844	2,411	2,451	2,995	3,041	3,091	3,141
53 inches	2,872	2,431	2,471	3,025	3,071	3,121	3,171
53½ inches	2,900	2,451	2,491	3,055	3,101	3,151	3,201
54 inches	2,928	2,471	2,511	3,085	3,131	3,181	3,231
54½ inches	2,956	2,491	2,531	3,115	3,161	3,211	3,261
55 inches	2,984	2,511	2,551	3,145	3,191	3,241	3,291
55½ inches	3,012	2,531	2,571	3,175	3,221	3,271	3,321
56 inches	3,040	2,551	2,591	3,205	3,251	3,301	3,351
56½ inches	3,068	2,571	2,611	3,235	3,281	3,331	3,381
57 inches	3,096	2,591	2,631	3,265	3,311	3,361	3,411
57½ inches	3,124	2,611	2,651	3,295	3,341	3,391	3,441
58 inches	3,152	2,631	2,671	3,325	3,371	3,421	3,471
58½ inches	3,180	2,651	2,691	3,355	3,401	3,451	3,501
59 inches	3,208	2,671	2,711	3,385	3,431	3,481	3,531
59½ inches	3,236	2,691	2,731	3,415	3,461	3,511	3,561
60 inches	3,264	2,711	2,751	3,445	3,491	3,541	3,591
60½ inches	3,292	2,731	2,771	3,475	3,521	3,571	3,621
61 inches	3,320	2,751	2,791	3,505	3,551	3,601	3,651
61½ inches	3,348	2,771	2,811	3,535	3,581	3,631	3,681
62 inches	3,376	2,791	2,831	3,565	3,611	3,661	3,711
62½ inches	3,404	2,811	2,851	3,595	3,641	3,691	3,741
63 inches	3,432	2,831	2,871	3,625	3,671	3,721	3,771
63½ inches	3,460	2,851	2,891	3,655	3,701	3,751	3,801
64 inches	3,488	2,871	2,911	3,685	3,731	3,781	3,831
64½ inches	3,516	2,891	2,931	3,715	3,761	3,811	3,861
65 inches	3,544	2,911	2,951	3,745	3,791	3,841	3,891
65½ inches	3,572	2,931	2,971	3,775	3,821	3,871	3,921
66 inches	3,600	2,951	2,991	3,805	3,851	3,901	3,951
66½ inches	3,628	2,971	3,011	3,835	3,881	3,931	3,981
67 inches	3,656	2,991	3,031	3,865	3,911	3,961	4,011
67½ inches	3,684	3,011	3,051	3,895	3,941	3,991	4,041
68 inches	3,712	3,031	3,071	3,925	3,971	4,021	4,071
68½ inches	3,740	3,051	3,091	3,955	4,001	4,051	4,101
69 inches	3,768	3,071	3,111	3,985	4,031	4,081	4,131
69½ inches	3,796	3,091	3,131	4,015	4,061	4,111	4,161
70 inches	3,824	3,111	3,151	4,045	4,091	4,141	4,191
70½ inches	3,852	3,131	3,171	4,075	4,121	4,171	4,221
71 inches	3,880	3,151	3,191	4,105	4,151	4,201	4,251
71½ inches	3,908	3,171	3,211	4,135	4,181	4,231	4,281
72 inches	3,936	3,191	3,231	4,165	4,211	4,261	4,311
72½ inches	3,964	3,211	3,251	4,195	4,241	4,291	4,341
73 inches	3,992	3,231	3,271	4,225	4,271	4,321	4,371
73½ inches	4,020	3,251	3,291	4,255	4,301	4,351	4,401
74 inches	4,048	3,271	3,311	4,285	4,331	4,381	4,431
74½ inches	4,076	3,291	3,331	4,315	4,361	4,411	4,461
75 inches	4,104	3,311	3,351	4,345	4,391	4,441	4,491
75½ inches	4,132	3,331	3,371	4,375	4,421	4,471	4,521
76 inches	4,160	3,351	3,391	4,405	4,451	4,501	4,551
76½ inches	4,188	3,371	3,411	4,435	4,481	4,531	4,581
77 inches	4,216	3,391	3,431	4,465	4,511	4,561	4,611
77½ inches	4,244	3,411	3,451	4,495	4,541	4,591	4,641
78 inches	4,272	3,431	3,471	4,525	4,571	4,621	4,671
78½ inches	4,300	3,451	3,491	4,555	4,601	4,651	4,701
79 inches	4,328	3,471	3,511	4,585	4,631	4,681	4,731
79½ inches	4,356	3,491	3,531	4,615	4,661	4,711	4,761
80 inches	4,384	3,51					

TABLE III.—Dust collecting efficiency of grinding and polishing wheels.

Type of wheel	Type of work done	Dust removed	Air flow (cubic feet per minute)	Dust concentration without ventilation (mg/m ³)	Dust concentration with ventilation (mg/m ³)
Emery, 5-inch diameter (grinding)	Surgical tool finishing	Emery and metal	270	21.4	2.25
Do.	Tool finishing	do.	270	2.7	0.8
Do.	do.	do.	230	19.5	2.5
Do.	do.	do.	230	21.5	2.9
Emery, 27-inch diameter (polishing)	Mirror grinding	Emery and glass	670	122.2	4.3

FOUNDRY SHAKE-OUT EXHAUSTS

One of the serious occupational disease hazards encountered in industry is the dust arising from foundry shake-outs. Few

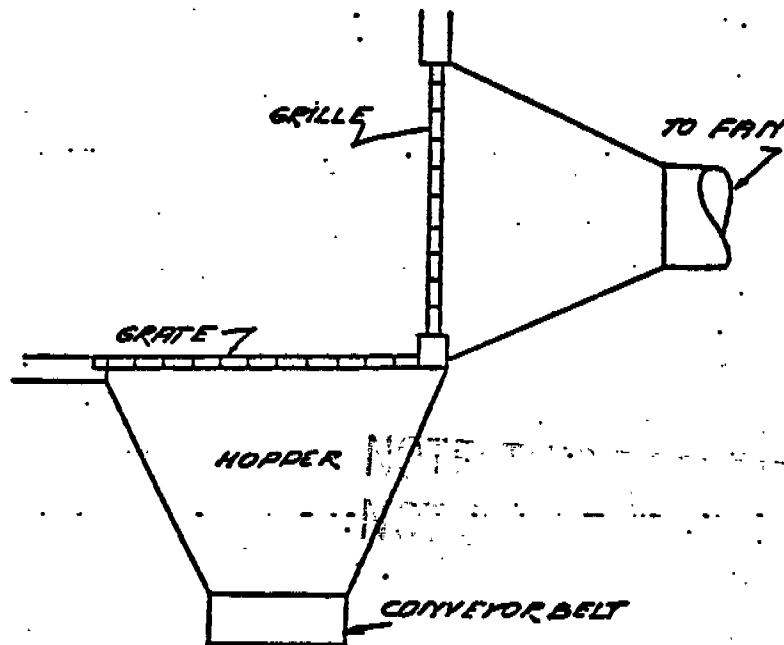


FIGURE 28.—Lateral exhaust at foundry shake-out.

installations have been generally successful. The problem in this case is to have available means for eliminating the dust during shake-out of molds containing fresh castings. The usual process employed is to knock the flasks containing the mold and castings with sledge hammers to pry them loose. In some instances, this is done in places known as shake-out dumps, but more often it is done wherever the casting happens to be. Large castings containing considerable hard

and polishing wheels.

	Air flow (cubic feet per min- ute)	Dust con- centra- tion (lb/1000 cu ft)	Exhaust rate (lb/1000 cu ft)
1	10	21.4	2.2
2	50	4.7	4.4
3	100	2.3	2.2
4	200	1.2	1.1

STB

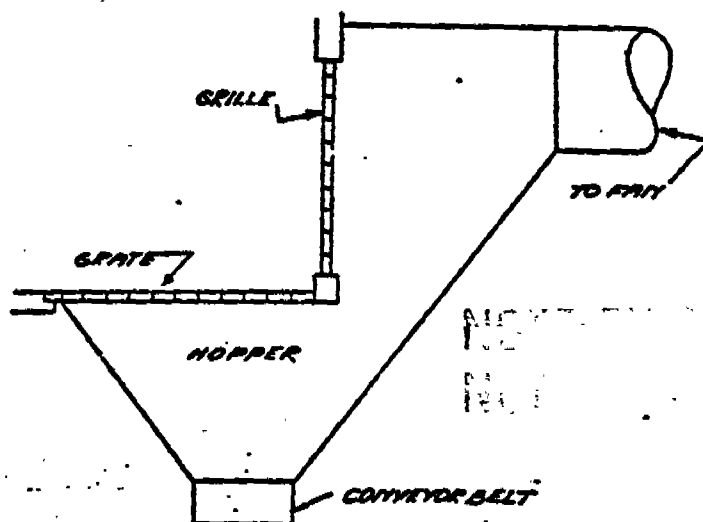
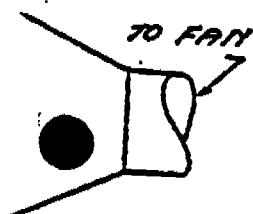
hazards encountered
dry shake-outs. Few

FIGURE 22. Combined lateral and downward exhaust at foundry shakeout.

considerable sand as well as dust enters the ventilating ducts which seriously burdens the collecting devices and cause considerable wear on all parts. The method is, however, desirable where small castings are to be shaken out and when no large accumulation of molding sand is permitted. The second method, shown in figure 60 consists of a similar grating and hopper for placing the casting but utilizes downward as well as lateral exhaust.

There are no set air flows which have been determined for either type of control. A determination made of one type of lateral exhaust 5 by 7 feet in area which came flush with the edge of the grating had a velocity of approximately 350 feet per minute in the plane of its opening. This was in a brass foundry where the castings were small. The control, however, was excellent.

BET

BET

The problem in this the dust during shake-out process employed and castings with sledge, this is done in places is done wherever the using considerable hard

BB 0020090 1

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2584

A fault of all such large exhaust systems, particularly in foundry practice, is the exposure of the workers to detrimental drafts. This is particularly true in winter when the men are first subjected to the heat from their castings which cause sweating and then are subjected to a cold air movement at the shake-out. As a rule, foundries are seldom heated in winter, and this consideration is one of extreme importance. On the other hand, the advantages are beneficial; an exhausted shake-out tends to localize a dangerous operation and at the same time gives protection to all those exposed to the dust which is generated.

Another difficulty which is common to the grate system of shake-outs is the rapid accumulation of molding sand. Hard cores and chunks often fail to pass through the grating or the rate of dumping exceeds the capacity of the hopper and conveyor to remove the sand. This is a strong argument against the use of a downward-draft system in many foundries which is not easily overcome.

It is extremely doubtful that any method of local exhaust ventilation can be used for castings of extremely large size. The core work frequently encountered in such castings is so closely bound with metal that it is necessary to resort to jack hammers to remove them. Moreover, the difficulties of removing the castings and placing them on the grate are prohibitive. In such cases other methods must be used for the protection of the worker.

DUST CONTROL FOR ABRASIVE CLEANING EQUIPMENT*

Abrasive blasting equipment may be roughly divided into four types—namely, rooms, barrels, tables, and cabinets. These four different types of equipment may be classified more simply by stating that rooms are used for the cleaning of large castings, whereas the other three types of apparatus are used to handle material of small size in large quantities.

Blast cleaning rooms

Blast cleaning rooms, are as a rule, constructed of heavy metal plate and the most commonly used size is 10 by 10 by 8 feet. In the more modern type of rooms air is allowed to enter through the ceiling and is exhausted through metal ducts on the sides of the room at the floor level. The material to be cleaned is brought into the room either on a revolving table or by cars or monorail. When the doors of the workroom are closed, the operator in order to protect himself from the impact of the abrasive and also to prevent inhalation of excessive dust, places a respirator or cloth over his nose and mouth and some form of a canvas helmet over his head. In some cases, positive-air pressure helmets are used. These are provided with:

* Unpublished data J. J. R.

BB 0020091 1

particularly in foundry
strimental drafts. This
re first subjected to the
and then are subjected
As a rule, foundries are
tion is one of extreme
tages are beneficial; an
ous operation and at the
ed to the dust which is

grate system of shake-
sand. Hard cores and
or the rate of dumping
or to remove the sand.
of a downward-draft
overcome.

local exhaust ventila-
e size. The core work
loosely bound with rods
ers to remove them.
ings and placing them
ther methods must be

G EQUIPMENT*

ily divided into four
cabinets. These four
ied more simply by
arge castings, whereas
o handle material of

ected of heavy metal
10 by 8 feet. In the
er through the ceiling
es of the room at the
ught into the room,
il. When the doors
er to protect himself
revent inhalation of
his nose and mouth
ad. In some cases,
are provided with a

supply of fresh air obtained outside the blast cleaning room and delivered under pressure to the helmet. It is also necessary for the worker to wear heavy gloves to protect his hands from the impact of the abrasive, and at times he wears canvas leggings and shoes provided with metal toe caps as protection for his legs and feet. With the blast hose in hand, he directs the abrasive stream against the surface of the work, the hose being of sufficient length to allow him freedom of movement so that he may direct the blast against any part of the work.

To provide the abrasive jet a pressure tank, known as the "hose machine", is used. This, or a similar piece of apparatus, is the fundamental unit of all room blast cleaning equipment. In this machine the compressed air and the abrasive are combined and discharged together from a single nozzle or a group of nozzles in the form of the abrasive blast.

After the abrasive has once served its purpose it is returned through a proper separator to the hose machine for re-use. This abrasive handling is accomplished by one of several systems, depending on the type of installation. With the mechanical lift system, the abrasive falls through openings in the floor to a hopper below, where it is picked up by a spiral conveyor and carried to the boot of a belt-and-bucket elevator, which in turn raises it to the separator. The separators are a combination of screens and air exhaust, by means of which the heavier particles are separated and the lighter material is drawn off by suction. The clean, sharp abrasive for re-use is delivered to a storage bin, from which the hose machine is automatically refilled. The rejected material and refuse is accumulated in a separate bin provided with a spout for unloadings.

In some installations it is necessary to have a solid room floor, in which case the operator at intervals, shovels the used abrasive into a hopper from which it is raised by a belt-and-bucket elevator to an overhead separator. This system is known as the "semimanual" type.

Where it is practicable and desirable to locate the hose machine in a bin beneath the room no abrasive handling system is necessary since the spent abrasive is allowed to fall by gravity through a hopper to the hose machine below it. This type is known as the "gravity system."

In the pneumatic lift system, the abrasive, after passing through the floor perforations, falls into the air current of a pneumatic lift, which raises it by suction to the separator.

Practically all blast cleaning rooms now in use have provisions for ventilation. In some of the more modern installations, the exhaust air, after passing through dust arrestors where it is cleaned, is

BB 0020092

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2586

NOTE

NOTE

126

delivered back into the workroom in order to save its heat content and to provide ventilation.

The correct amount of ventilation required in abrasive cleaning rooms has not been determined. Older types utilize from 2 to 5 air changes per minute, while the more recent types use from 8 to 12 and sometimes as high as 20 air changes per minute. From a number of observations made in recent types of abrasive cleaning rooms it appears that air movements at the breathing level bear no relationship to the dust concentrations found. For example, a high dust count of 251 million particles per cubic foot was obtained with a velocity of 74 feet per minute at the breathing level, whereas a velocity of 75 feet per minute was associated with 171 million particles per cubic foot, and a velocity of 77 feet per minute with a dust count of 48.8 million particles. In all these cases metallic grit was used as the abrasive. The variation in counts with practically the same air movements in the abrasive cleaning rooms may be ascribed to differences in nozzle pressure, to the cleanliness of the castings, and to the rate at which the work is being done.

The above results may be contrasted with a velocity of 68 feet per minute in an abrasive cleaning room using sand, and yielding a high dust count of 620 million particles per cubic foot. From such data, it would naturally appear that when more than eight air changes per minute are provided, the abrasive used plays an important part in the dust concentration to be expected, and is apparently much more important than the amount of ventilation provided.

The low value of 48.8 million particles per cubic foot cited in a previous paragraph, was found for an abrasive room of modern construction with 12 air changes per minute. It is clear, therefore, that in spite of the best equipment available, it is essential that other methods (personal respiratory protection devices) be used to prevent exposure of the blaster to rather high dust concentrations.

The conduct of work in abrasive cleaning rooms may contribute a considerable quota of dust to the general atmosphere of the plant in which the room is situated. Naturally the dust introduced by this means may have an important bearing on the health of workers not specifically engaged in abrasive blasting occupations. The need for maintaining abrasive rooms in good condition is evinced from an analysis of data which show that with average equipment, workers in the general air of a plant in which abrasive cleaning is done may be exposed to concentrations which may run as high as 20 million particles per cubic foot during blasting, while when no blasting is done, the average concentration is normally below 4 million particles. The modern type of abrasive cleaning room is, on the other hand, so constructed that unless it is poorly maintained no dust can possibly escape. Obviously, dust-tight and well-maintained abrasive cleaning

BB 002093

127
NOTE

rooms are methods of eliminating a considerable portion of the dust which is found in many plants.

Blast cleaning barrels

Blast cleaning barrels are often confused with the "tumbling mill" or barrel as a method of cleaning. The principles on which these methods depend are entirely different. In the "tumbling barrel" cleaning is accomplished by the abrasion of the objects to be cleaned against each other or against a given abrasive which is dumped into the barrel, whereas in the blast cleaning barrel the cleaning is accomplished by the abrasive blast, the rotation of the barrel serving merely to bring the metal objects under the abrasive blast streams. Various types of blast cleaning barrels are in use. In general, a blast cleaning barrel consists of a drum made of heavy sheet plate, mounted as a rule on trunnions and capable of rotating. A rather common type now in use consists of a properly fashioned, movable series of plates driven by a chain drive, and so arranged that the work is constantly carried on this endless belt.

There are various types of blast cleaning barrels, all of them differing in the method of abrasive handling and reclamation. The three most common abrasive handling methods in blast cleaning barrel installations are the suction, pressure, and gravity types.

Some blast cleaning barrels are provided with a complete outer housing which encloses the barrel while in operation. During loading the door of such a housing is opened, the barrel door is then opened and the material to be cleaned is placed in the barrel. Both doors are then closed and the air jets set into operation. Such a housing may be, and often is, provided with exhaust ventilation. In many cases the barrel is not provided with a complete outer housing.

As a rule the use of abrasive blast cleaning barrels constitutes a small portion of the chain of processes in the course of the manufacture of certain articles. For this reason barrels are usually located in one portion of the plant or foundry where the material to be blasted is made. In other words, barrels are not generally segregated from other dusty processes. Thus, it is necessary to bear in mind that adjoining processes may possibly contribute a certain amount of dust to the atmosphere in which the attendant works.

The advantage of housing is clearly demonstrated in the following data obtained from a series of dust counts made on various equipment in use:

	Million particles per cubic foot
Barrel using metal abrasive and housed.....	6.2
Barrel using sand abrasive and housed.....	2.2
Barrel using metal abrasive and not housed.....	24.6
Barrel using sand abrasive and not housed.....	33.0

1 BB 0020094 1

a heat content and

abrasive cleaning use from 2 to 5 air use from 8 to 12. From a number cleaning rooms it bear no relation- mple, a high dust s obtained with a level, whereas a 71 million particles with a dust count allic grit was used ctically the same ay be ascribed to f the castings, and

ority of 68 feet per wing a high an such data, ght air changes per important part in arently much more ed. able f ot cited in a om of m dem con- lear, therefore, that essential that other) be used to prevent ntrations.

ns may contribute a hero of the plant in t introduced by this culty of workers not tions. The need for is evinced from an equipment, workers oning is done may ie as 20 million particles blasting is done, the lion particles. The o other hand, so con- no dust can possibly usive cleaning

The discrepancy in counts for metal and sand abrasives in barrel, which are housed is due to design factors in the equipment studied. However, it is evident from the data presented that unhoused barrels are productive of rather high concentrations of dust.

In the handling of fresh castings, especially while loading the barrels, considerable dust is evolved. The dust, thus formed may be reduced somewhat by the use of chain-hoist loading skips and a certain degree of care on the part of the barrel attendant. During the unloading operation, similar care should be exercised so as to prevent the dissemination of dust from the abrasive admixed with the castings. The most important source of atmospheric pollution however, in connection with blast cleaning barrels is that dust which emerges from the openings in the barrel structure. Such openings are provided to a small extent by poor design and to a greater extent by poor maintenance of equipment.

Blast cleaning rotary tables

For certain types of work, it has been found efficacious to use the rotating blast cleaning table method. These tables are of a heavy metal, substantial type of construction; are circular in shape and of an average diameter of 6 or 7 feet, mounted usually about 3 feet above the floor level and rotating at a speed of 1.5 revolutions per minute. The table is divided into two halves by means of a series of flexible, split rubber curtains. One side of the table is completely enclosed, and is provided with three or more traveling nozzles for directing the abrasive onto the work lying on the surface of the table below. At the other half of the table is stationed a worker, whose function is to remove the finished objects, to replenish the supply of work to be done, and to turn over the objects on the table so that the under surface may be blasted. The abrasive is, as a rule, delivered against the objects at an air pressure of 60 or more pounds to the square inch. With such tables the abrasive reclamation is accomplished by either suction, gravity, or pressure methods.

With reference to abrasive cleaning tables, the remarks made in connection with abrasive cleaning rooms apply to a large extent. Well constructed and maintained tables permit little dust to escape. For example, a poorly maintained table, using metal abrasive, gave dust counts of approximately 42 million particles per cubic foot of air in the general air close by, whereas another table of good construction, using sand, gave dust concentrations below 3 million particles. These results so clearly emphasize the importance of proper care and construction of abrasive cleaning equipment that they should be carefully noted.

NOT
NOT

1 BB 0020095 1

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2589

abrasives in barrels in the equipment studied. It is noted that unholed barrels are a source of dust.

By while loading the barrels, dust formation may be reduced by skips and a certain degree of ventilation. During the unloading of the barrels so as to prevent the dust from being mixed with the castings. The dust, however, in connection with the openings are provided to a certain extent by poor maintenance.

found efficacious to use the these tables are of a heavy circular in shape and of diameter usually about 3 feet. The speed of 1.5 revolutions per minute is provided by means of a series of gears. The top of the table is completely covered by means of a series of rotating nozzles for the purpose of cleaning the surface of the table. A worker, whose duty is to replenish the supply of castings on the table so that the abrasive is, as a rule, delivered at a pressure of 60 or more pounds to the abrasive reclamation is pressure methods.

As the remarks made in this report apply to a large extent, it is noted that little dust to escape. The dust, being metal abrasive, gave an average of 100 particles per cubic foot of air. The table of good construction is below 3 million particles. The importance of proper care and maintenance is that they should be

Blast cleaning cabinets

For special kinds of work, where it is necessary to clean small objects using air pressures of 60 pounds or more, the blast cleaning cabinet finds much use. Blast cleaning cabinets are of steel plate construction usually approximately 5 by 3 and 7 feet in height. They are, as a rule, provided with a single nozzle through which the abrasive material is forced by means of air pressure. In the front of the cabinet, there is usually provided a window of heavy plate glass, through which the operator may view the work in progress. Also in front of the cabinet there are hand holes through which the worker places his hands and arms in order to manipulate the work. The material to be cleaned is placed inside the cabinet through a hinged door, located at the front or side of the cabinet. The operator then turns on the abrasive jet by means of a foot treadle. The worker exposes all surfaces of the object to be cleaned to the action of the jet and removes the piece on completion of this task. As a rule, most cabinets of this type are provided with an exhaust system for the removal of the fine dust created in the blasting process. The abrasive reclamation employed with cabinets is either of the suction or pressure type.

It is possible to conduct abrasive cleaning in properly designed and well-maintained cabinets with a low dust exposure. It is necessary, however, to point out the important part played in dust control by proper operation of equipment. In many cabinet installations, the hand holes are provided with gauntlets and a separate opening is furnished by which work may be introduced and removed. Such an installation would be considered excellent from the point of view of preventing the pollution of the atmosphere by dust. On the other hand, where gauntlets or curtains are not provided for the restriction of the hand hole openings, it becomes possible for dust to be deflected from the inside of the cabinet through these holes, and contaminate the workroom air. Hand holes, therefore, should be as small in size as compatible with the tasks to be performed, and suitable exhaust ventilation (5-10 air changes per minute) should be provided, in order to minimize the possibility of dust being forced outward through the hand holes.

Automatic blast cleaning equipment

In the blast cleaning of certain large objects ordinarily conducted in rooms, it has been found convenient and desirable to conduct the cleaning operations without the intervention of a worker for the manipulation of the object to be cleaned. Usually this is accomplished by what is known as automatic blast cleaning equipment. The work is placed on a belt conveyor by a "loader", the work passing through the blasting chamber or room where it is cleaned by the

NOT RECORDED IN FILES

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

BB 0020096

2590

abrasive stream. The material emerges in the cleaned state on the endless belt at the exit side of the room where it is removed by a worker.

Automatic abrasive cleaning equipment obviously provides an excellent means for cleaning certain articles too large to be handled by table or barrel equipment. Here again, however, the importance of proper design and upkeep of this type of equipment must be stressed in order to prevent excessive dust exposure of the operators. Housings should be of sufficient length and baffled so as to prevent the egress of dust. Thus, it has been found that old automatic equipment without proper care may expose the operator to concentrations of approximately 90 million particles per cubic foot of air, while newer types of equipment reduce the dust concentration to about 5 million particles.

Tumbling barrels

Tumbling barrels are frequently the source of high dust concentrations. As a general rule, State codes provide that such apparatus shall be exhausted and that a stated suction shall be maintained at the duct connection. Most of the modern equipment is now so constructed that there is little opportunity for the dust to escape. Thus in comparing the new with the old type barrels, the former gave rise to a dust concentration in the general plant air of 2.7 million particles per cubic foot, while the latter averaged 34 million particles. As may be expected, however, the care given the equipment is an important factor in its performance.

HOUSEKEEPING

Good housekeeping is an important aid in reducing dust concentrations. The dust collected on floors, benches, rafters, etc., should be removed at frequent intervals. Either wet sweeping or vacuum cleaning should be used. Good housekeeping not only serves to remove sources which contribute to the general dustiness of a plant, but also adds an important psychological factor. A clean workplace not only tends to keep clean, but frequently compels some method of control to be applied to those sources which are dustiest.

AIR VELOCITY REQUIREMENTS FOR HOODS

The required air velocity at a dust source is determined by the characteristics of dust production and operation of the process. The friction on the surfaces of the particles created by the moving air must be sufficient to overcome the force with which the particles are thrown off. This force is a function of the size, shape, and weight of the particles and their speed of travel. Heavy par-

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

BB 0020097

2591

the cleaned state on the
where it is removed by a

obviously provides an
too large to be handled
however, the importance
of equipment must be
posure of the operators.
baffled so as to prevent
and that old automatic
o the operator to con-
ticles per cubic foot of
the dust concentration

co of high dust concen-
side that such apparatus
shall be maintained at
equipment is now so
for the dust to escape.
type barrels, the former
at air of 2.7 mil-
aged 34 million
are given the equip-
co.

reducing dust concen-
hes, rafters, etc., should
et sweeping or vacuum-
ng not only serves to
al dustiness of a plant,
tor. A clean workplace
compels some method
ich are dustiest.

ON HOODS

o is determined by the
eration of the process.
created by the moving
a with which the per-
tion of the size, shape,
of travel. Heavy par-

ticles require a higher air velocity than light ones, and the air speed increases with the velocity of the dust particles.

In many instances, the machine throws off the dust in a well-defined direction. This fact should be utilized in shaping and locating the hood, since it has an important bearing on the strength of the air stream required. It is well illustrated in the application of exhaust hoods to high-speed grinding wheels.

The use of partial or complete enclosure of the point of dust generation offers an effective means of reducing the air velocity requirement. The speed of travel of the dust particles may be reduced and their direction changed by the proper location of baffles or housing. This phase of hood design is limited chiefly to processes that do not require close attention of the operator or delicate manipulation. The trap for use with rock-drills is an example of complete enclosure and the application of partial enclosure is illustrated by the hood used on granite surfacing machines. Many examples of partial and complete enclosure are found in the wood-working industry.

The characteristics of operation of the dusty process must be carefully studied and every possible step taken to reduce the air velocity required to capture the dust. In general no other phase of hood design will give as great a saving in operating cost as reduction in the required air speed.

RATE OF AIRFLOW REQUIRED

The air velocity at a given point in the zone of influence of a suction opening is a function of the rate of airflow through the opening, but also of the direction and distance from the opening, and the shape and size of the exhaust hood. Hence, the rate of airflow through the hood, necessary to produce the required air velocity at the point of dust generation, depends upon the size, shape, and location of the hood, as well as the characteristics of dust production. It follows, therefore, that some knowledge of the aerodynamic characteristics of suction openings is necessary to the proper choice of hoods if economic design is to be obtained. The airflow characteristics discussed in section VII are important in this connection.

The rapidly decreasing center-line velocity curves presented in figure 38 show clearly the need for locating the hood as closely as possible to the point of dust generation. This is a general rule, and is applicable to all conditions. It is important to note, however, that the rate of decrease of velocity with distance from the hood decreases with an increase in area of the opening. Moreover, the contour lines become more flattened as indicated in figure 42. These facts point to the desirability of using as large an opening as possible which

LIBRARY
COLLEGE OF PHYSICIANS
OF PHILADELPHIA

BB 0020098

the further advantage of reducing the power consumption by lowering the entrance pressure loss.

The area of dust production must also be considered in choosing the size of the hood opening. For a concentrated point of dust generation, a flat velocity contour is not as necessary as for more extensive areas of dust generation. In all cases, the object is to obtain a uniform air velocity over the region of dust production, and the lowest possible flow from areas of no dustiness, the so-called ineffective areas. In other words, the ratio of effective to ineffective flow should be made as high as possible. Since the distribution of flow in the zone of influence of suction openings is intimately associated with the size and shape of the opening, great care must be exercised in choosing a hood to give a high ratio of distribution in effective to ineffective areas. In this connection, the use of flanged openings is often advantageous. The use of flanged exhaust hoods on hand pneumatic granite carving tools (55), in place of unflanged openings, demonstrates the saving in power consumption possible. For this process an air velocity of 200 feet per minute at the tool is required. Operating conditions demand that the hood be at least 5 inches from the tool. At this distance, the required air velocity is obtained by a flow of 300 cubic feet per minute through a rectangular opening 3 by 6 inches in dimension. The addition of a 3-inch flange around the opening reduces the rate of air flow to 200 cubic feet per minute, a saving of 33½ percent. Since the pressure loss at entrance is also reduced, the power consumption is lowered by more than a third. Wherever conditions permit their use, the installation of flanges is recommended.

THIS DOCUMENT DID NOT
COME FROM PPG FILES.

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

BB 0020099

2593

ruption by low.

considered in char-
acterized point of
necessary as for
the object is to
most production,
ness, the suc-
jective to ineffe-
the distribution
is intimately a
great care must
of distribution
the use of flame
nged exhaust loc-
place of unflam-
consumption per
minute at the hood
no hood be at le-
pur- air velocity
ough a
The addition of
of air flow to

Since the pres-
ription is lowered
mit their use, the

X. DUST COLLECTION AND DISPOSAL

INTRODUCTION

As a general rule, the material collected and transported by an exhaust system yields no economic return. Nevertheless, its proper disposal is an item of considerable importance for three reasons: (1) To prevent reentrance of dust-laden air into a building thus contaminating working places, (2) to avoid public nuisances, and (3) to conserve, especially in winter, warm indoor air for recirculation.

The methods in use for the collection and disposal of dusts are by direct discharge to the atmosphere through suitable ports or stacks, by separators or cyclones, by cloth filters or screens, and by electrical precipitation. Of these methods the first three are most commonly used. Electrical precipitation is usually employed where the material to be collected has some value, such as the recovery of potash dust in a cement plant. It is also used in the abatement of nuisances caused by large power plants burning powdered coal, the ash of which must be discharged through the stack. Because of their limited use as collectors of dusts found in most industries, no further description of them will here be given.

Direct elimination of dust to atmosphere

Unless the dust-laden air collected by the exhaust system can be eliminated through a stack of considerable height, it is undesirable to exhaust directly to the atmosphere. In some States, codes prevent direct discharge. Such methods, if practiced, may with strong contrary winds cause the dust to be swept back into the plant or to adjoining buildings and cause a general nuisance.

Disposal through stacks, if sufficiently tall, has been found adequate and is resorted to in many establishments. The success achieved by this method is due to the dilution attained by the scattering of particles over a wide area.

Cyclone separators

A cyclone consists of two concentric cylinders, the outer fitted to a conical hopper and connected tangentially to the exhaust duct of the fan (fig. 61). The inner cylinder fits partially into the hopper and discharges upward to the atmosphere. The air forced tangentially between the cylinder is caused to rotate at a high speed and forces the dust particles toward the outer shell by centrifugal action. The

(123)

BB 0020100

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2594

NOT
NOT
134

dust reaching the outer cylinder continues to spin and to drop gradually into the hopper, the clean air passing through the opening provided by the inner cylinder.

Because of their simplicity and freedom from care, cyclones are very widely used. Unfortunately, however, many cyclones have been installed without due attention to their capacities. As a result they frequently do not function effectively and are discarded.

The efficiency of a cyclone depends upon its size and the volume of air handled. Whiton (65) has obtained a number of interesting

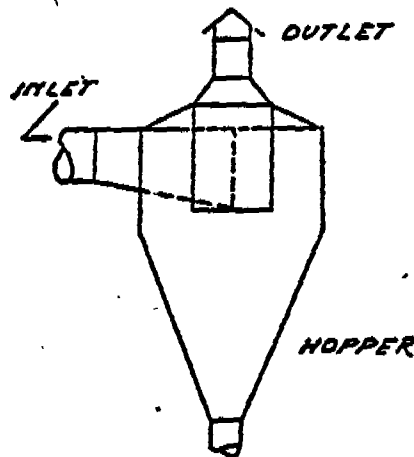


FIGURE 61.—Sketch of cyclone.

curves relative to the collection efficiencies and resistances of various cyclones using precipitated fly ash as a dust. These curves are shown in figure 62 and as will be noticed, low resistance indicates a comparatively low collection efficiency. Whiton has also shown that dust concentration does not materially affect percentage recovery.

It will be noticed in figure 62 that the smaller the cyclone the more efficient a separator it becomes. In recent years, this fact has been used in the design of small

cyclones connected in parallel. These multicyclones have the advantage of being flexible. They can be operated at their maximum efficiencies regardless of varying air flows since units are easily added or shut off as required.

Various manufacturers have designed special cyclones which have relatively high efficiencies. In choosing a cyclone, for a particular operation, therefore, efficiency and cost of operation should receive careful consideration.

When the air velocity in the fan discharge duct is known, the following equation is useful in computing the resistance loss through the cyclone:

$$h_s = 0.013 \left(\frac{V}{1,000} \right)^2 \quad (19)$$

where V is the velocity in feet per minute in the fan discharge duct and h_s is the pressure drop through the cyclone in inches of water. The above formula is an average which applies to the common cyclones in use. Whenever possible, it is best to secure the manufacturers' figures for various flows.

Frequently the air exhausted from a cyclone is recirculated without further cleaning. This is possible under certain conditions, but for

1
2
3

4
5
6
7
8
9
10

PERCENT COLLECTION

held
temp
point
A
serve
them
side
be lo
flag
oxide
neeti
bag n
pende
from
Re
of the

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

BB 0020101

and to drop gradually the pening pressure.

care, cyclones and any cyclones have efficiencies. As a result are discarded.

and the volume of number of interesting to the collection resistances of varying precipitated fly

These curves are 62 and as will be distance indicates a low collection efficiency has also shown concentration does not affect percentage re-

noticed in figure 62. In a cyclone the manufacturer it has been years, this fact in the design (small ones have the advantages at their maximum units are easily added

cyclones which have one, for a particular situation should receive

is known, the following loss through the

(19)

in discharge duct and ches of water. The common cyclones the manufacturers'

recirculated without conditions, but for

toxic dusts or such dusts with small particle-size, for which the efficiency of a cyclone is low, the air leaving it should be carefully analyzed by methods described in chapters 2 and 3 before recirculation.

CLOTH FILTERS

Cloth filters are used where the product collected is valuable, or where clean air is desired for recirculation. The materials used for filtering mediums vary considerably. High efficiencies are claimed for both muslin and wool. Each manufacturer of filter equipment recommends that which is best adapted for the collection of a particular product. It is, however, important to remember that cloth filters do not withstand temperatures over 200° F. and are easily acted upon by caustic and acid substances. Wet materials also are not easily collected without overloading the system and it should be

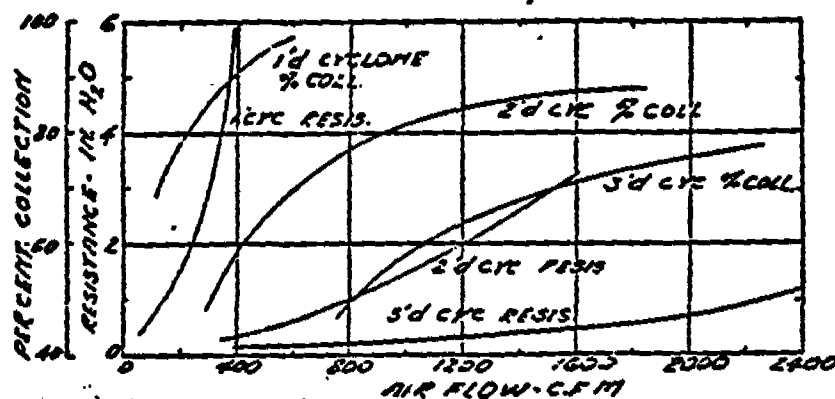


FIGURE 62.—Cyclone characteristics.

held in mind that if filter units are subjected to places where the air temperature is low, the warm air collected may be chilled to the dew-point and cause the filter to become wetted.

A filter unit consists of a closed compartment with either cloth screens or bags so placed that the dust-laden air must pass through them. Filters may be operated either on the positive or negative side of a fan. Cloth screens whether under suction or pressure must be housed while bags need only be housed when placed under suction. Bag filters operated under positive pressure, such as are used for zinc oxide and flour dust collection must be well collared at the duct connection in order to reduce leakages and to support the weight of the bag and the dust collected upon it. Bag filters of this type are suspended vertically, ranging in size from 4 to 40 inches in diameter and from 5 to 20 feet in length.

Because the process of filtration gradually increases the resistance of the system due to the accumulation of material on the filter surface,

10-2111-55-10

THIS DOCUMENT WAS NOT A RECORD OF PPG INDUSTRIES, INC. DID NOT COME FROM IT'S FILES AND CANNOT BE AUTHENTICATED BY PPG INDUSTRIES, INC.

1 BB 0020102 1

2596

it is necessary to shake or tap the units at definite intervals. This is accomplished mechanically by clock arrangement, or by hand. Terry (60) has recommended the use of a manometer device whereby filters may automatically be shaken when the limiting resistance set by the manufacturer is reached. Large filter bags of the type described above are mounted in batteries in special buildings and are shaken down manually by tapping with long sticks.

In order to prevent overloading, a cyclone or separator is used to eliminate the coarser and heavier dusts. Some filters operating under negative pressure are so constructed as to produce a cycloning effect before the dust laden air enters the filter. Preliminary separators reduce the load on the filter surface.

The dust collected by filter units is removed from the hoppers periodically or continuously by means of screw conveyors.

The amount of filtering surface necessary varies with the type of material collected and the type of filter surface used. Wool has a very low resistance while some muslins, depending on their weave, may offer considerable obstruction to the flow. Table 34 gives the resistance of some cloths in common use.

TABLE 34.—Resistance of various filter materials to the flow of air

Material	Resistance to flow of 1 cubic foot of air per minute per square foot of filter surface (British water gauge)	Material	Resistance to flow of 1 cubic foot of air per minute per square foot of filter surface (British water gauge)
Cotton muslin.....	0.004-0.011	Various cleaner cloth.....	0.005-0.070
Wool cloth.....	.005-.007	Wool pattern filter.....	.010
Cotton cloth, heavy.....	.012-.020	Felt cloth.....	.004-.008

A high concentration of dust naturally requires more filter surface in order to keep the resistance of the system low and to avoid frequent shaking of the units. Similarly, materials which pack easily require large surfaces. The usual filter rates employed in practice range from one half to 10 cubic feet per square foot per minute. Higher rates can be used where filters are shaken at frequent intervals and where the dust is not cohesive in character.

Typical time-resistance curves for flyash are shown in figure 63 for filter operated under suction. The filtration rate for each filter at 10 cubic feet per minute per square foot of filter effect of various dust concentrations is clearly indicated. Under conditions found in practice, fans operate at constant speed; hence an increase in filter resistance is compensated by an increase in the volume of air flow. The curves shown in figure

64 if
typical
then

RESISTANCE - IN. H. O.

FIGURE 64

velocity
longer
The
resistance
produces

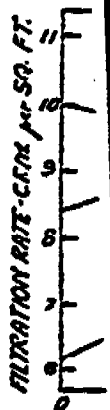


FIGURE 65

under w
than fly
give diff
ary in
The rate
large nu
the syste

FIGURE 66

BB 0020103

definite intervals. This arrangement, or by hand, nometer device whereby the limiting resistance set for bags of the type or special buildings and are sticks.

a or separator is used to no filters operating under reduce a cycloning effect Preliminary separators

moved from the hoppers on conveyors.

varies with the type of face used. Wool has a depending on their weave, ow. Table 34 gives the

ials to the flow of air

	12-1/2 inches to flow of 1 cubic foot of air per minute (for purpose of filtering equipment (See how to use page))
1/2 inch 1/4 inch 1/8 inch	0.015-0.020 0.020-0.025 0.025-0.030

quires more filter surface w and to avoid frequent which pack easily require d in practic range from minute. Higher rates ent intervals and where

are shown in figure 63 : filtration rate for each er square foot f filter ions is clearly indicated. e, fans operate at con- istance is compensated curves shown in figure

64 illustrate the relation between resistance and filtration rate in a typical installation due to a dropping fan characteristic. It is obvious, therefore, that filter cloths should be rapped or shaken before the

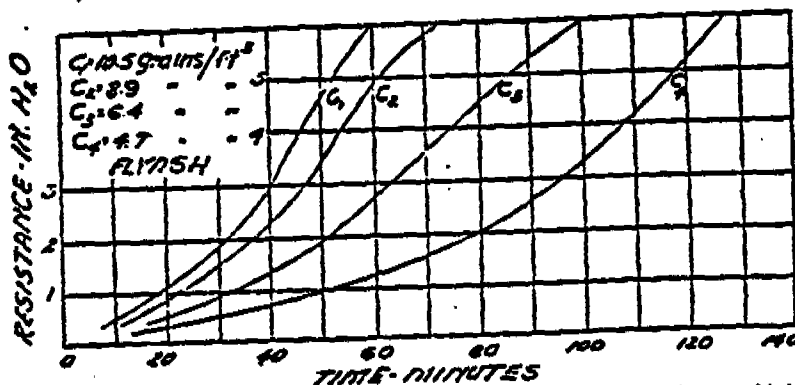


FIGURE 64.—Resistance of woolen filter to various concentrations of flyash (rate of air flow 10 cubic feet per square foot per minute).

velocities in the various ducts are reduced to a point where they no longer can convey the dust particles. (See sec. VIII.)

The curves of figure 65 serve to illustrate the relation between resistance and filtration rates at various times. The curves are produced from data obtained from an experimental unit using a

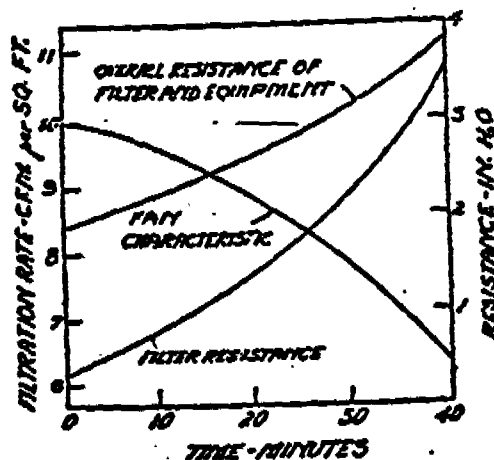


FIGURE 65.—Effect of fan characteristic on filtration rate.

under which the curves were determined. Obviously, dusts other than flyash of the type used in obtaining the above figures would give different results. Much preliminary experimentation is necessary in handling materials whose filtering properties are unknown. The rate of resistance build-up, as has been stated, determines in a large measure the type of fan necessary to meet the requirements of the system.

* Unpublished data J. M. D.

BB 0020104

Filters, when not overloaded, are very efficient, and it is possible to recirculate the filtered air. In this way, the winter heat losses in a building normally due to exhausting air outdoors may be lowered, frequently to a point where the operation costs may balance those due to heat losses. Here again, however, it is necessary to check upon the efficiency of filtration by means of dust counts.

MAINTENANCE OF DUST COLLECTING SYSTEMS

Dust collecting systems should be inspected at definite intervals. Abrasive materials cause considerable wear in elbows and ducts connected to the collector and these should be repaired as soon as detected.

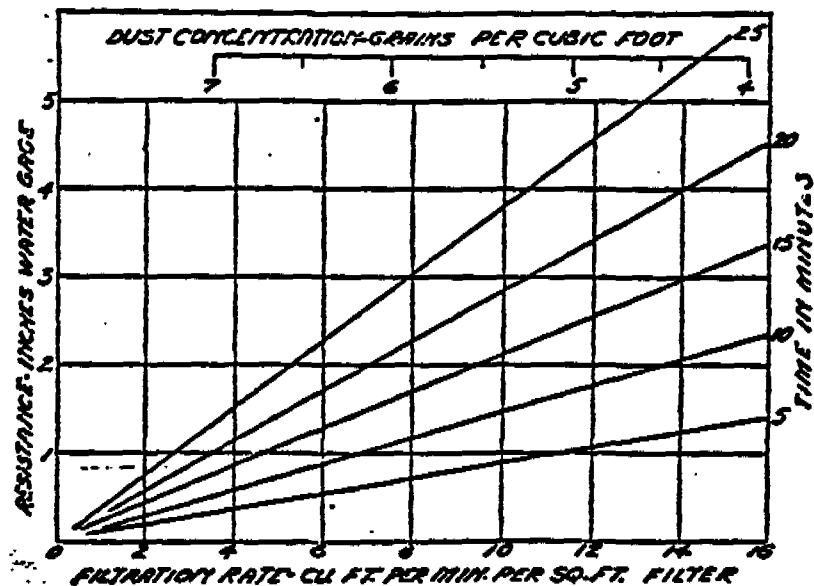


FIGURE 51.—Linear relationship between filter resistance and filtration rate at various time intervals.

Cloth filters often become wetted and mold with non-use, or else break with continued shaking. Tears in the filter medium should be repaired as soon as possible in order to prevent the air from bypassing other units connected to it, or as in the case of some systems, overloading the unimpaired filters. Compartments containing filters should also be inspected for leaks.

Due to the vortex formed in cyclones the cone-shaped hoppers are continually under negative pressure. Consequently, if they are opened, the dust collected in them will be drawn upward and either pass through the exhaust or else circulate continuously, thus reducing the efficiency of the system. It is therefore important to avoid leakages. The usual method of collection for some types of single units is to connect the cyclone hopper with a duct leading to an air-tight

NOTE: THIS DOCUMENT DID
NOT COME FROM PPG FILES

139

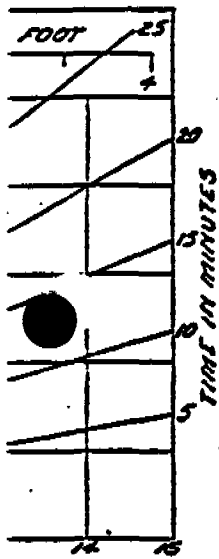
compartment. In such a device the suction will be low and will not interfere with the removal of the dust collected while the cyclone is in operation.

When hot substances are conveyed to a filter collector there is danger of setting it on fire. As a method of avoiding such an occurrence, a preliminary coarse screen should be used. Otherwise, it is necessary to remember in case of fire to first shut off the fan or blast gate. The use of a sprinkler system in the filter compartment in plants where potential fire hazards caused by hot substances exist, is good practice.

and it is possible to
ter heat losses in a
s may be lowered,
y balance those due
y to check upon the

SYSTEMS

2 definite intervals,
ows and ducts con-
as soon as detected.



FT. FILTER
at various time intervals.

on-use, r else break
dium should be re-
air from bypassing
ome systems, over-
containing filters

-shaped hoppers are
ently, if they are
upward and either
usly, thus reducing
rtaut to avoid leak-
ypas of single units
ding to an air-tight

BB 0020106

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2600

NOTE: THIS DOCUMENT DID
NOT COME FROM PPG FILES

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

NOTE: THIS DOCUMENT DID
NOT COME FROM PPG INDUSTRIES, INC.

XI. MEASUREMENT OF AIR FLOW

In Part V it was pointed out that the efficiency of dust control is best measured with dust counts. The methods of air-flow measurement, on the other hand, assist the engineer in checking upon the exhaust system from the aerodynamic viewpoint. It assists him in gauging the velocities which may be required for the transport of certain substances and it gives him a powerful method in estimating the mechanical efficiency of a system. In the present section, it will be shown how the air velocities and volumes necessary to effect control may be measured. Not all the methods for measuring air flow are

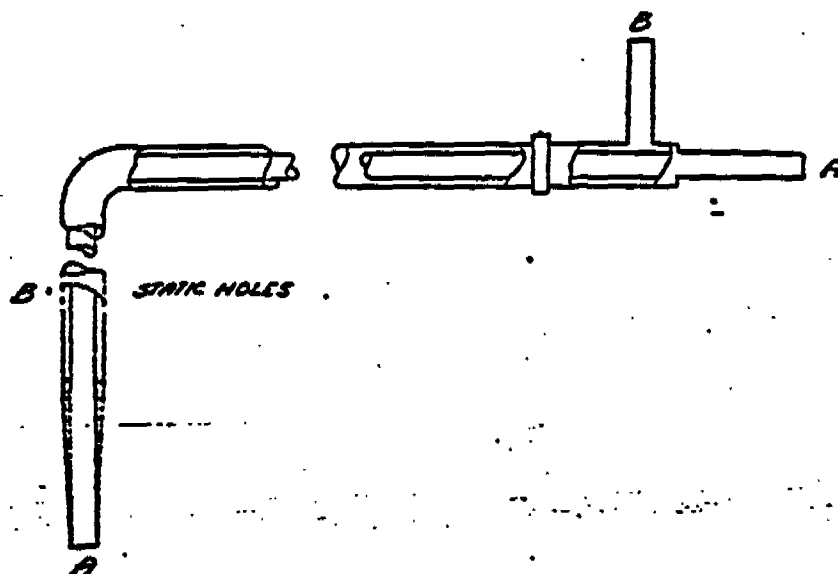


FIGURE 66.—Pitot tube.

included but only those which are most widely used and are therefore most practical.

THE STANDARD PITOT TUBE

Air velocity is measured by means of a pitot tube shown schematically in figure 66. This instrument consists of two independent concentric tubes bent into an L. In use, the tube is inserted into a duct and directed along the axis so that it points upstream. The two terminals A' and B' are connected to a suitable gage and the deflection observed is a measure of the speed with which the air is moving.

(140)

BB 0020107

The theory of measurement of this simple device is briefly as follows: The point *A* measures the total pressure within the duct which consists of a dynamic or impulsive pressure and a static pressure (see VIII). The former is accurately measured only when the tube is pointed upstream, but the latter is a pressure which at a given point is the same regardless of direction. If therefore, the total pressure be denoted by *H*, the velocity pressure by *h*, and the static pressure by *h_s*, then the pressure measured at *A* is $H = h_s \pm h$, depending on whether the duct is under positive or negative pressure.

Obviously, since the velocity pressure can only be measured in a direction upstream, it cannot possibly exert any effect at *B* where the holes are perpendicular to the flow. Hence, at *B* only the static pressure *h_s* can have any influence. Since also, the two concentric tubes are independent and are connected by means of a U-tube containing fluid, it follows that the deflection observed is equal to $h_s \pm h$, or simply *h*, the velocity pressure. By using equation (10), *h*, may be directly converted in terms of velocity.

$$V = 4009 \sqrt{h} \quad (10)$$

Information regarding the design of pitot tubes has been given by Ower, (67), who has shown that the static holes should be at least 10 diameters removed from the dynamic opening. Ower has also shown the effect of yawing and turning of the tube in making measurements.

When the volume of air flow is desired from the pitot reading, a correction factor must be applied to obtain the average velocity of flow. The movement of air in a duct is not uniform, but is highest at the axis. The average velocity is generally taken as 0.8 the axial velocity measured by the pitot. Consequently, multiplying through the right hand side of equation (12) by this factor, we obtain

$$Q = 18.3d^2 \sqrt{h} \quad (20)$$

where *d*, of course, is expressed in inches.

For simplifying calculations, the nomograph given in figure 67 has been prepared. To find *Q*, it is merely necessary to lay the ruler on the value of *d* and connect it to the observed pitot reading *h*. The point where the line drawn between the values of *d* and *h*, taken and the intersection of the *Q*-line indicates the volume of air flowing. The line drawn in the figure connects the point representing a diameter of 5 inches with the observed pitot reading of 1.4 inches. The intersection with *Q* shows that a volume of 540 cubic feet per minute flows

of dust control is
air-flow measure-
ment upon the ex-
isting. It assists him in
transport of cer-
tain estimating the
section, it will be
to effect control
during air flow are

and are therefore

shown schemati-
cally independent con-
verted into a duct
team. The two
and the deflec-
tion of air is moving.

in the duct. Actual computation by equation (20) above gives a value of 539.8 cubic feet per minute.

Simple pitot

In event a pitot tube cannot be secured, the velocity head may be measured by drilling a small hole in the duct, say three-sixteenths inch in diameter, and inserting into it an L-shaped one-eighth inch

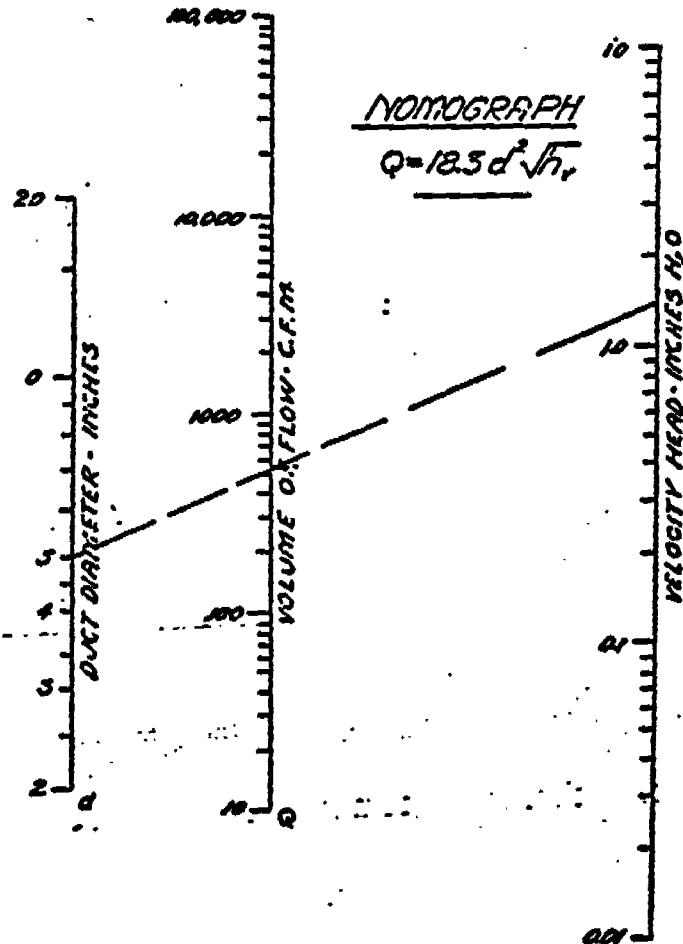


FIGURE 47.—Nomograph for computing volume of air flow in terms of duct diameter and pitot reading.

copper tubing, figure 6S, the outer end of which may be connected to a manometer. This gives the total pressure. The tube may then be bent and a nipple with a rubber bushing almost flush with one end in the hole as shown in B of the figure. If no leaks occur during the pressure recorded by the manometer will be the velocity head. The absolute difference observed between the readings of the velocity head.

(b)
total
Coul-
at an
pitot
a tub-
be us-
cylind-
diam-
ments
0.02 in
section
open e-
measur-
through
ings so

Per Cent of Velocity in Zero Position (V/P₀)

larger than
1.6 to 1.75
For nom-
mounting.
desired un-
calibration

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

BB 0020109

2603

SPECIAL PITOT FOR MEASURING POINT VELOCITIES

One of the difficulties of the ordinary pitot is the fact that the total and static pressures are not measured at identical points. Consequently in regions where the air movement changes rapidly as at an opening under suction, the ordinary pitot cannot be used. For such conditions, a tube of the type shown in figure 69 may be used. This tube consists of a thin brass cylinder approximately one-eighth inch in diameter with two independent compartments closed at one end. Two small holes 0.02 inch in diameter are drilled at its mid-section and a pointer is fastened near the open end in the direction of the hole. For measurement of duct velocities the tube is inserted diametrically through the duct with the pointer directed along the axis. The readings so taken are a measure of the velocity head. They are much

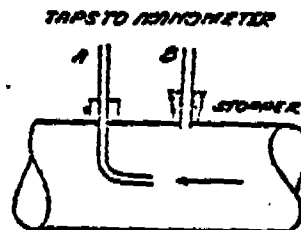


FIGURE 68.—Simple pitot for approximate measurement of air flow.

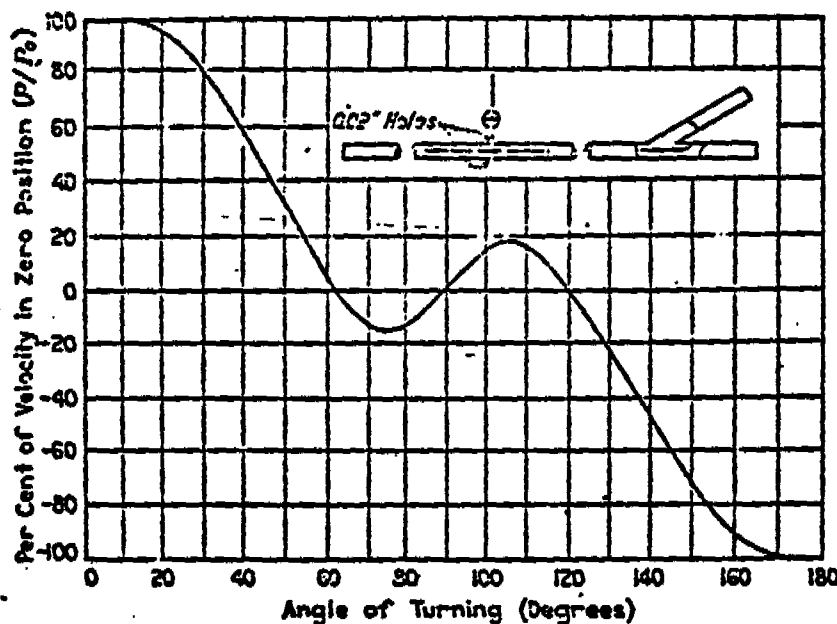


FIGURE 69.—Special pitot for measuring point velocities.

larger than those obtained for an ordinary pitot, ranging from about 1.6 to 1.75 times as great depending upon the velocity measured.

For measuring velocities near a hood, the tube requires a special mounting. The tube is turned at the point where the velocity is desired until a maximum reading is obtained on a manometer. If a calibration with an ordinary pitot has been made, this reading may be

converted directly and the velocity determined by equation (1). The tube is very sensitive to the direction of flow and can be used as an indicator within $\pm 15^\circ$ of arc as may be seen from the characteristics shown in the figure 69. Because of the comparative smallness of the device and the fact that it does not obstruct the flow of air, the instrument is capable of giving accurate readings at a point.

Determination of velocity contours

The special tube described in the above paragraph may be used in determining velocity contours (52). The tube requires a special mounting which may be moved vertically and horizontally and fixed at definite points with respect to the axis of the hood. The coordinates at which readings are made is indicated in figure 70 (A).

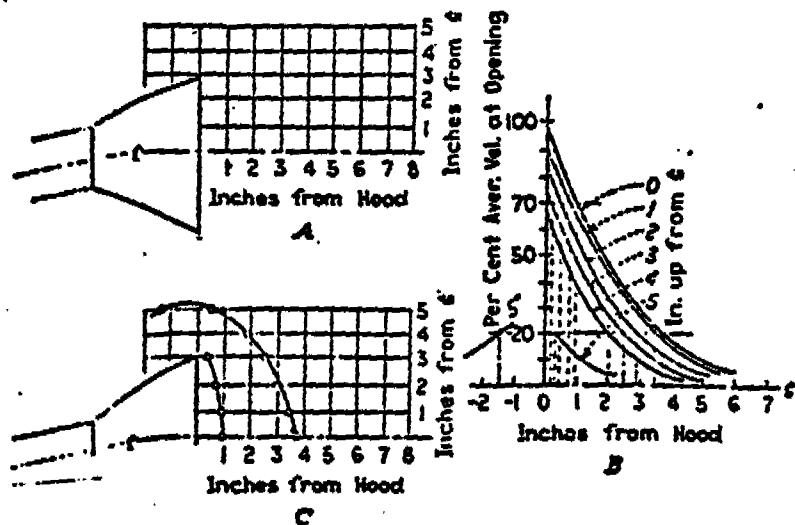


FIGURE 70.—Method of developing velocity contours.

Readings are taken with the tube horizontally outward from the opening at each level above the centerline. The data so obtained are then plotted as shown in B of the figure, the ordinates representing the percentage of velocity at the opening and the abscissae the distance from the opening. From these curves the velocity contours may be determined. For example, to determine the contours of velocities equivalent to 20 and 70 percent of the average velocity at the face of the opening, the values of the abscissae corresponding to the intercepts are obtained for the various velocity curves, as in B and plotted as in C of Figure 70.

THE ANEMOMETER

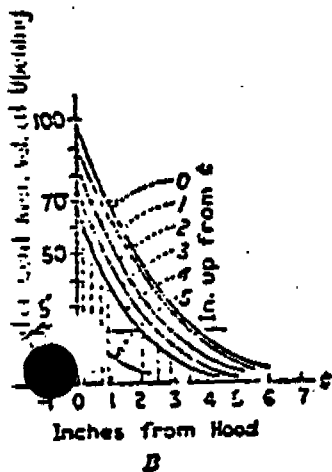
The vane anemometer is a direct reading instrument. When it is set in an air current, the vanes turn and actuate a calibrated tachometer.

BB 0020111

NOTE
185

etermined by equation (16).
of flow and can be used as
seen from the characteristic
comparative smallness of the
et the flow of air, the instrum-
as at a point.

e paragraph may be used in
o tube requires a special
ally and horizontally and
the axis of the hood. The
indicated in figure 70 (A).



Velocity contours.

ntally outward from the
The data so obtained are
e ordinates representing the
the abscissae the distance
e velocity contours may be
the contours of velocities
age velocity at the face of
corresponding to the inter-
curves, as in B and plotted

in

g instrument. When it is
tuate a calibrated tachom-

eter. A stop watch must be used in connection with this instrument, since the reading of the tachometer dial merely indicates the linear feet of air travel.

Anemometers require calibration at frequent intervals. They are not reliable at low air velocities, although special forms (67) have been developed which are very sensitive. Vane anemometers cannot be used in duct work, but are useful in making quick velocity traverses over large hood openings.

AIR VELOCITY MEASUREMENTS BY MEANS OF THE KATA THERMOMETER

The kata thermometer was originally devised for the measurement of body comfort (68). It is, however, highly sensitive to air movements and can be used for velocity determinations. The instrument is essentially a thermometer with a large bulb filled with red-colored alcohol and two graduation lines on the stem marked 95 and 100, figure 71. When used to measure velocities in air below 95° F., the thermometer is inserted in warm water (about 150° F.) and the fluid allowed to rise half way up the safety bulb at the top. The large bulb is then quickly dried and held at the point where the air velocity is to be measured. The time, in seconds, taken for the alcohol to drop between the markings is observed; the average of 2 or 3 such readings is considered sufficient to insure accuracy.

The time θ is then divided into the factor F marked near the top of the kata by the manufacturer, that is, $H = F/\theta$, where H is called the cooling or warming power. For temperatures below 95°, H is positive.

When the temperature is above 100° F., the kata thermometer is immersed in cold water and the time for the liquid to rise from 95 to 100 is noted, first taking care of course that the bulb is carefully dried. H is then obtained in the same manner as previously, with the exception that it is now regarded as negative.

Yaglou and Dokoff (69) were unable to develop reliable formulae for determining velocities with the kata thermometer which would hold over a wide range of air conditions. The kata is inaccurate when used between 85° and 110° F., because these temperatures are near its cooling range and air movements have little effect. The above investigators therefore have prepared a chart (fig. 72) from which the air velocities can be determined. In order to determine velocity, follow the curve corresponding to the given dry bulb tem-

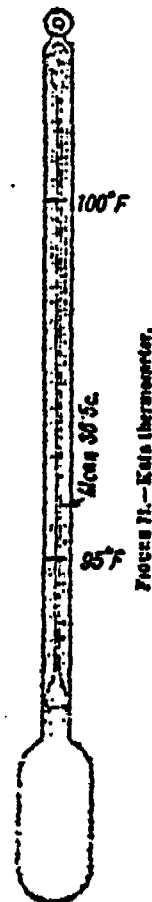


Figure 71.—Kata thermometer.

perature to the value of H (equal to F/θ), and read off the velocity vertically on the horizontal scale. The following problem illustrates the use of the chart:

Problem.—The time taken by the liquid in a rod kata thermometer to fall from the 100 to the 95 markings on the stem is 53 seconds. The air temperature while taking the reading is 66°F. , and the factor engraved on the stem is 477. Calculate the air velocity.

Solution.—The cooling power H is, following the procedure outlined above, $477/53=9$. If now the temperature curve corresponding to 66° is followed until

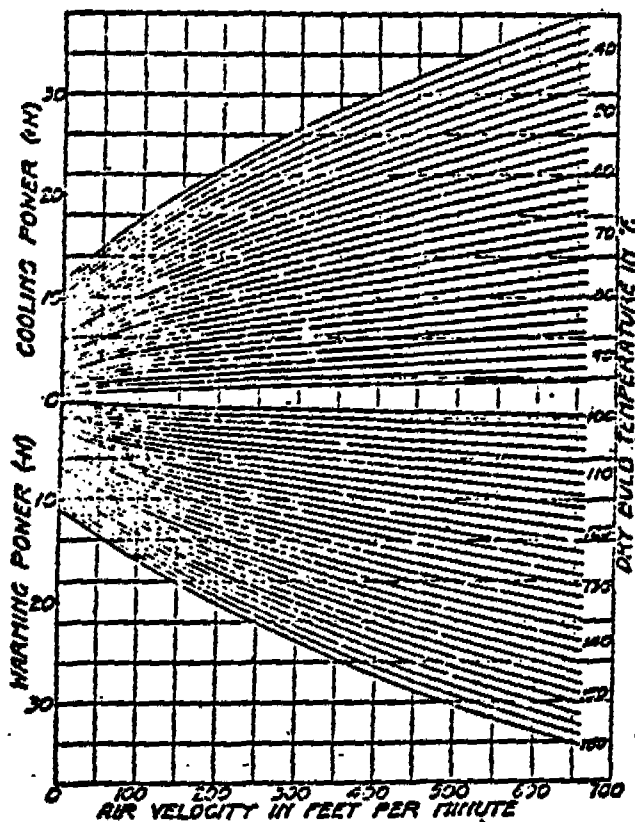


FIGURE 72.—Dry Kata chart for computing air velocity.

It intersects the H -line corresponding to 9, we find that the velocity read off on the abscissa is approximately 340 feet per minute.

The principle of the instrument is based on temperature difference and air motion. Except in the temperature range above noted, the kata is very accurate; for obtaining readings from 55° to 110°F. , a special high temperature kata (blue kata) has been developed.

Kata thermometers are very sensitive to radiant energy sources. To avoid personal errors the observer should hold the kata at some distance from himself while making observations.

BB 20 20 113

DETERMINATION OF AIR FLOW BY MEASUREMENT OF STATIC AT HOD

For simple and approximate computation of air flow, the static pressure at the throat of a hood or opening obtained as described for duct above can be used. The formula for determining the air volume is then

$$Q = 4009af\sqrt{h_s} \quad (21)$$

where f is a factor called a restriction coefficient and h_s the static at the throat. This factor varies considerably (59) from 0.63 for obstructed or small openings to as high as 0.94 for shaped openings. A good value for most hoods encountered in practice is 0.71 although values of 0.55 are not too high.

If it is assumed that the static h_s at the throat is proportional to the velocity head h_v , an assumption which is closely in accord with experiment, then f can be obtained from the formula (59)

$$f = \sqrt{\frac{h_s}{h_v}} \quad (22)$$

VENTURI AND ORIFICE MEASUREMENTS

The venturi meter

For continuous measurement of large volumes of air flow, the venturi meter shown in figure 73 is useful. The meter consists of a

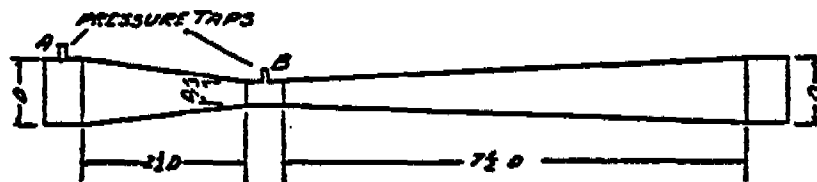


FIGURE 73—Venturi meter.

converging and diverging duct connected by a narrow collar. The usual dimensions followed are given in the figure. The converging tube is coned to one-third of a pipe diameter in a total distance of $2\frac{1}{2}$ pipe diameters. The diverging tube has a length of $7\frac{1}{2}$ duct diameters in order to minimize the losses due to a reduction in air velocity and at the same time to prevent eddying.

The principle of the device is based on the fact that, neglecting losses, the velocity head and the static heads at A and B are mutually convertible. In other words, the total head H is preserved. Thus, we have

$$H = h_{s,A} + h_{v,A} = h_{s,B} + h_{v,B}$$

A manometer connected to A and B will, therefore, register the difference $h_{s,A} - h_{s,B}$. Hence

$$h_{s,A} - h_{s,B} = h_{v,B} - h_{v,A} \quad (23)$$

But $h_A = \left(\frac{V_A}{4009}\right)^2$ and $h_B = \left(\frac{V_B}{4009}\right)^2$ by equation (10). Also by the equation of flow, $V_A A_A = V_B A_B$ where A_A and A_B are the duct areas at A and B, respectively, so that $V_B = \frac{A_A}{A_B} V_A$. Substituting in equation (22) and calling $h_A - h_B = h$

$$h = \left(\frac{V_A A_A}{4009 A_B}\right)^2 - \left(\frac{V_A}{4009}\right)^2 = \left(\frac{V_A}{4009}\right)^2 \left(\frac{A_A^2}{A_B^2} - 1\right) = \left(\frac{V_A}{4009}\right)^2 \left(\frac{d_A^4}{d_B^4} - 1\right)$$

where d_A is the duct diameter at A and d_B the diameter at B. Hence

$$V_A = \frac{4009 \sqrt{h}}{\left[\frac{d_A^4}{d_B^4} - 1\right]^{1/2}} \quad (24)$$

The volume of air handled is, therefore

$$Q = V_A A_A = \frac{4009 A_A \sqrt{h}}{\left[\frac{d_A^4}{d_B^4} - 1\right]^{1/2}}$$

Thus Q is determined in terms of the manometer difference observed and known constants of the instrument. Some loss, however, does take place between A and B; a more accurate relationship is

$$Q = \frac{3889 A_A \sqrt{h}}{\left[d_A^4/d_B^4 - 1\right]^{1/2}} \quad (25)$$

where a factor 0.97 has been multiplied into the right side of the equation to compensate for the loss of head due to velocity change.

Orifices

Sharp-edged and bell-shaped orifices are often used for measuring air flows. Orifice measurements depend on a principle similar to the venturi (5S). The pressure difference between the upstream and downstream sides of the orifice are observed and a formula identical to equation (24) above is used. Because, however, energy losses are large when an orifice is used, the multiplying factor is approximately 0.60, which is much smaller than the value used for the venturi.

Orifice measurements are not generally used in dust-collecting systems because they act as obstructions and as a result frequently give inaccurate readings.

MANOMETERS

Water manometers

Water manometers are used in connection with pitot tubes and static readings. The simplest form consists of a vertical U-tube partially filled with water, figure 74. When the tube is connected to a

Also by the
are the duct areas
substituting in equa-

$$\frac{1}{2} \frac{A^2}{a^4} - 1)$$

$$\frac{1}{2} \frac{A^2}{a^4} - 1)$$

meter at B. Hence

(24)

difference observed
loss, however, does
relationship is

(25)

right side of the
velocity change.

used for measuring
principle similar to the
the upstream and
a formula identical
or, energy losses are
or is approximately
or the venturi.
dust-collecting sys-
result frequently give

with pitot tubes and
vertical U-tube par-
is connected to a

pressure source, the water column will be displaced to an amount sufficient to balance the force acting upon it. Thus, the distance between the water levels indicates the amount of pressure exerted by the fluid. When one end of the U-tube is connected to a nipple flush with the inner surface of a duct, the pressure indicated by the difference in water levels is the static head. When both ends are con-

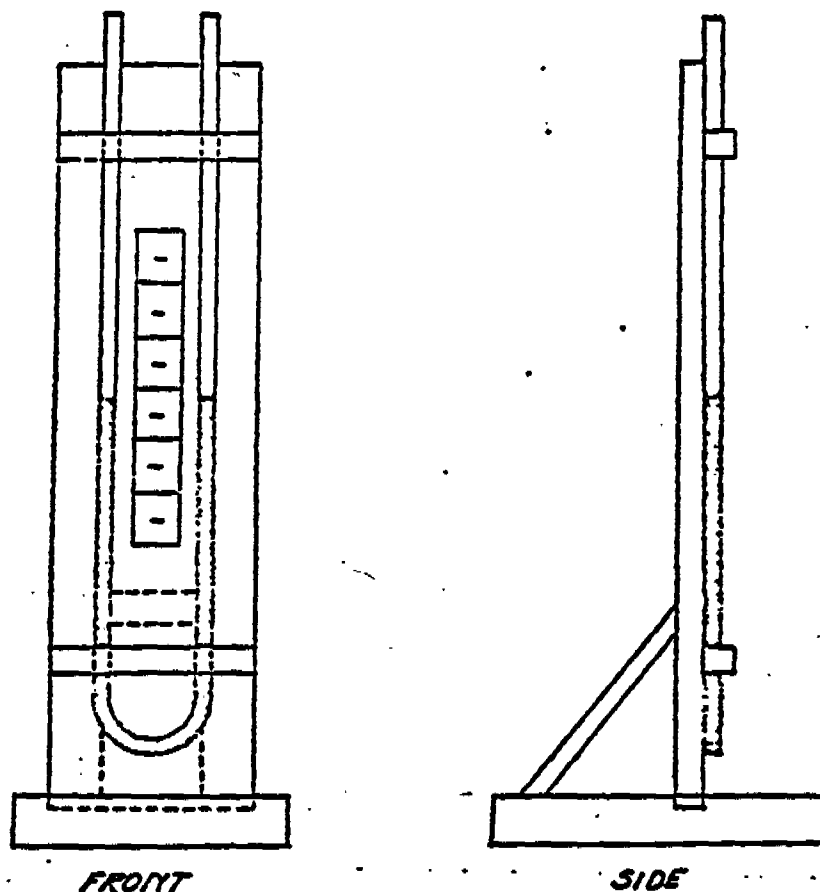


FIGURE 74.—Vertical manometer.

connected to a pitot, the displacement indicates the velocity head. A displacement of 1 inch of water corresponds to a column of air equal to 69.4 feet, or to 0.58 ounces (0.036 pounds) per square inch.

To increase the sensitivity, the U-tube may be inclined. A manometer which is mounted on a right-angled wedge-shaped block with a rise of 1 inch for every 10 inches of tube length (figure 75) has a sensitivity ten times as great as a vertical manometer. In other words, a displacement of 10 inches in a sloping U-tube corresponds to a displacement of 1 inch in a vertical manometer. U-tubes may

BB 0020116

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

also be sloped to give sensitivities twenty times as great as vertical tubes, but such sensitivities do not guarantee accurate readings.

In case, a sloping manometer should always be carefully leveled. A three-point mounting should be provided with at least one point adjustable for leveling purposes.

The Walden gage

This instrument is extremely sensitive and is used for the measurement of velocities ranging from 100 to 4,000 feet per minute (70). The gage is shown schematically in figure 76 and consists of two large bulbs filled with colored alcohol connected by an inverted U-tube containing kerosene. The bulb *B* is so connected to the U-tube that it can be moved in a vertical direction by means of a vernier caliper mounted to a framework. A stopcock is provided near the bottom of

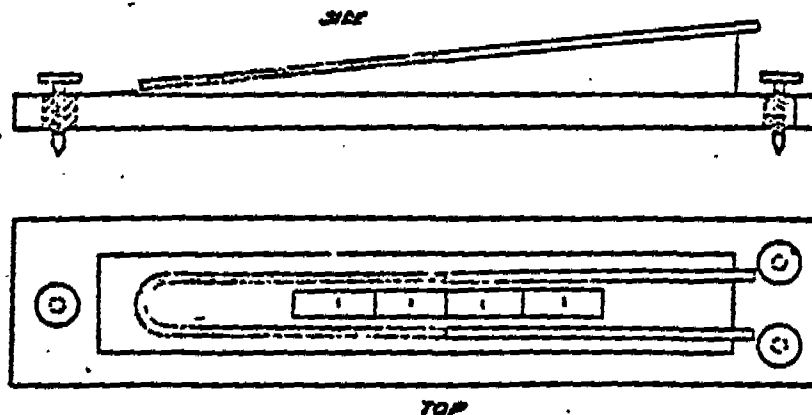


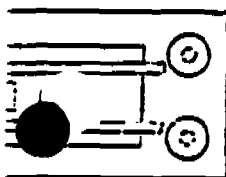
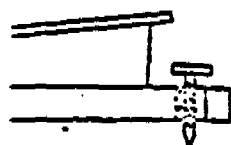
FIGURE 76.—Sloping manometer.

the stem connection the of bulb *B* so that when pressures are applied to the bulbs the liquids will not be violently disturbed. When ready to use an initial reading is taken with both bulbs open to the atmosphere by bringing the meniscus at *D* to the hairline. Connections are then made and the stopcock opened slightly to ascertain the direction in which the liquids move, and the calipers turned until the meniscus at *D* is again on the hairline. The difference between this reading and initial reading of the vernier is the actual displacement in terms of the heavier liquid. The reading may be converted to inches of water by multiplying the difference by the specific gravity of the alcohol. Being a null method, the Walden gage has a distinct advantage over other forms of manometers. Accurate readings, however, depend upon a knowledge of the specific gravities of the alcohol over the range of temperatures the instrument is to be used and upon maintaining the instrument level at all times. Zero readings should be taken frequently during experiments since the meniscus at *D* tends to vary somewhat.

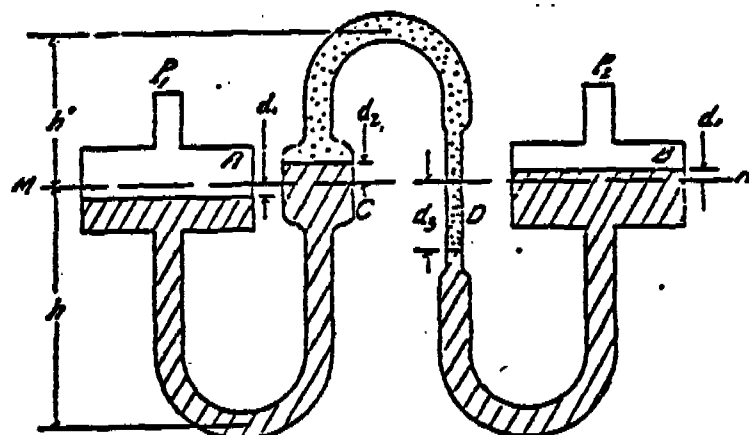
BB 0020117

as great as vertical
urate readings.
are fully leveled. A
at least one point

ed for the measure-
et per minute (70).
consists of two large
an inverted U-tube
to the U-tube that
of a vernier caliper
near the bottom of



The factors contributing to the sensitivity of the instrument are easily derived by observing the deflections of the liquids when the pressure applied at A is greater than that at B. Obviously, the liquid columns to the left of the axis of symmetry must balance those on the right. If p_A and p_B represent the pressures at A and B, respectively, and if s_1 denotes the specific gravity of the alcohol and s_2 that of the kerosene, then the deflection in the D-tube, d_3 , is deter-



Alcohol
 Kerosene

"At Liquid levels when $p_A = p_B$
Area A = Area B = A_1
Area C = A_2
Area D = A_3

FIGURE 7A—Wablen gage.

pressures are applied
rbed. When ready
open to the atmos-
irline. Connections
ly to ascertain the
ers turned until the
ference between this
actual displacement
ay be converted to
the specific gravity
a gage has a distinct
Accurate readings,
ific gravities of the
ument is to be used
at all times. Zero
periments since the

mined by equating the net pressures to the left with those on the right, thusly

$$p_1 + (h-d_1)s_1 - (h+d_2)s_1 - (h'-d_2)s_2 + (h'+d_2)s_2 = p_2 + (h+d_1)s_1 - (h-d_2)s_1$$

If we write $b = s_1 - s_2$ and $p = (p_1 - p_2)$ for convenience and collect terms

$$d_3 = \frac{p - 2d_1 s_1 - d_2 b}{b}$$

But $A_1 d_1 = A_2 d_2 = A_3 d_3 = a$ constant, so that substituting for d_1 and d_2

$$d_3 = \frac{p}{b \left\{ 1 + \frac{A_2}{A_1} \right\} - 2s_1 \frac{A_2}{A_1}} \quad (26)$$

From this relationship, we note that the sensitivity of the gage depends chiefly on a low specific gravity difference between the liquids,

10-2371-35-11

1 BB 0020118 1

b, and on the ratio of the areas of the large bulbs to the area of the D-tube. The enlargement at *C*, which acts as a reservoir for the kerosene, does not materially affect the sensitivity.

The liquids used in the Walden gage should be allowed to stand in the presence of each other in a stoppered bottle for some time. This permits the liquids to reach a stable condition and reduce the variation of the meniscus at *D* due to the solubility of kerosene in alcohol.

COMPARISON OF DEVICES FOR MEASURING AIR FLOW

In table 35 are given the principle characteristics of the devices used for the measurement of air flow. It will be seen from the arrangement presented that both the standard pitot and special pitot have accuracies dependent on the sensitivity of the manometer used. The pitot is the most practical device which has been developed for measuring air velocities in ducts and requires only moderate skill in use. The anemometer, while being the simplest device to use, has limited application to air-flow measurements and frequently gives erroneous readings.

BB 0020119

the to the area of the
a reservoir for the
ity.
o allowed to stand in
for some time. This
and reduce the varia-
f ketone in alcohol.

ING AIR FLOW

istics of the devices
ll be seen from the
d pilot and special
ty of the manometer
It has been developed
s only moderate skill
plest device to use,
and frequently gives

TABLE 35.—Comparison of devices used in the measurement of air flow

Device	Method of use	Range of air velocities or volumes which can be measured	Calculations based on—	Accuracy obtainable	Skill required
Pitot tube.....	Used for measuring velocity head in ducts. Is pointed against direction of air flow.	200 feet per minute. 1'p-per limit not determined.	Formula $V = 800 \sqrt{h}$ (feet per minute).	Depends on sensitivity of the manometer used.	Same. Location of tube is important.
Special pitot.....	Used for measuring point velocities and velocity of air in ducts. Requires special mounting.	100 feet per minute. 1'p-per limit not determined.	Formula or curve. Device requires calibration against a standard pitot.	do.....	Considerable. The device is sensitive to direction of flow and requires careful mounting.
Anemometer.....	A vane instrument actuating a tachometer arrangement.	200 to 2,000.....	Requires stop watch timing. Device is direct reading, giving linear feet of air travel. Requires a chart.....	Requires a correction curve for high and low air velocities. With careful use, the device is very accurate.	No skill required.
Katz thermometer.....	Bulb must be dried, and time of bulb call or rise between 2 markings and air temperature are correlated with velocity.	15 to 500.....	Can be built to handle any volume of air flow.	Device is very accurate for volume determinations (0.5 — 5 percent error).	Its limit energy sources must be avoided.
Venturi.....	Fixed convergent and divergent tubes forming part of the duct system.	Can be built to handle any volume of air flow.	Formula. $Q = \frac{31.3 d_2 \sqrt{h}}{\left[\frac{d_1^4}{d_2^4} - 1 \right]^{1/4}}$ d_1 —diameter of main (inches). d_2 —diameter of throat (inches).	Device is very accurate when carefully calibrated.	No skill required. Manometer scale can be made to read volumes directly.
Orifice.....	Orifice plate is fixed between two flanges in duct system.	Can be made to handle any volume of air flow.	Formula. $Q = \frac{33.4 d_2 \sqrt{h}}{\left[\frac{d_1^4}{d_2^4} - 1 \right]^{1/4}}$ d_1 —diameter of main (inches). d_2 —diameter of orifice (inches).	Do.	Do.

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
ITS FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

1 BB 0020120 1

The hot wire thermometer is perhaps one of the most sensitive instruments developed for measuring low air velocities. It gives average readings depending on the period of time required by the liquid to pass between the markings on its stem. The device, however, cannot be conveniently used for duct work and must be kept free from radiation effects.

The venturi and orifice are widely used for measurement of air volumes. Since they form a part of the duct system, they give continuous readings. Their characteristics have been determined and are well known, so that when they have been carefully constructed, no extensive calibration is required.

NOTE:
NOT

BB 0020121

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2615

sensitive instru-
It gives average
by the liquid in
however, cannot
kept free from

asurement of air
n, they give con-
determined and
ully constructed,

NOTE: THIS DOCUMENT DID
NOT

XII. PERSONAL RESPIRATORY PROTECTION

In some dusty occupations the methods of controlling dust have not been developed. In fact, industrial operations, such as removing the cores from very large foundry castings, sand-blasting, handling of used storage battery plates, paint clipping, and cadmium oxide manufacture appear to offer no practical means of adequately controlling the dust generated. In such cases, it is therefore necessary to furnish the worker with personal respiratory protection devices in order to prevent his exposure to the harmful effects of the dusts present. These devices consist of various types of respirators, masks, and helmets.

It is important first of all to hold in mind the limited use of personal protection devices. Because a worker cannot with comfort wear a mask or helmet continuously, such devices must be employed intermittently. As a consequence, their use is generally extended to those operations where all other methods have failed or supplementary to them, as in storage battery repair where the exposure to small amounts of lead breathed is known to be detrimental to health. Respirators and helmets are in a sense the last resort in dust protection.

TYPES OF RESPIRATORY PROTECTION APPARATUS FOR INDUSTRIAL DUST

Respiratory protection devices may be divided into two general groups: (1) Respirators or facepieces using filters, and (2) masks or helmets using positive pressure.

The first group consists of many types, the simplest being perhaps a cheesecloth packing covering the nose and mouth and tied to the back of the neck. Other forms vary from what is generally called a pig-snout type to those consisting of facepieces connected to large filter surfaces strapped about the waist. The pig-snout respirator consists of a metal body, usually aluminum, with a rubber-lined edge, shaped to fit the contour of the face. It covers the nose and mouth and is strapped tightly to the back of the neck. A small cylindrical disk-like filter and a flutter valve form the essential parts of the device. The valve is so arranged that it closes on inspiration forcing the air to pass through the filter piece. On expiration, the flutter valve opens, thus affording the expired air an easy exit. The so-called Folger or Burrell filter is essentially a mask covering the whole face. It is made of a pliable composition with goggles and is comfortably but tightly strapped to the face to prevent leakage. The

(155)

BB 0020122

mask is connected with a corrugated flexible tube to a felt filter strapped to the waist. In this way, a large surface is provided for reducing the breathing resistance.

The filter mediums used in respirators of the first group consist of paper, paper filter, sponge, wool cloth, and felt. Manufacturers of various respirators provide the type of material believed best suited to their designs. Respirators are so constructed that the filter medium may be easily replaced. In use, because of the small surface given for filtration, the medium must be changed frequently; otherwise the resistance builds up, and breathing becomes difficult. The flat Folger or Burrell type, which has been described, has a longer period of usefulness than the ordinary pig-snout respirator and is capable of being cleaned. It is one of the most efficient of the types so far employed in industry for retaining very fine suspensoids (71)

EFFICIENCIES OF FILTER MEDIUMS USED IN RESPIRATORS

Respirators may be tested by several different methods, of which two are most commonly used. The first consists of testing the filtering medium independently of the respirator while the second consists of tests made with the facepiece imbedded in clay or some similar pliable substance.

APPARATUS FOR DETERMINING EFFICIENCIES OF FILTER MEDIUMS

The usual methods of determining efficiencies are based upon methods described in section V, that is, by use of the impinger or electrical precipitator. A considerable number of published tests, however, are based upon the now obsolete Palmer apparatus (11) whose efficiency in terms of the present impinger is approximately 20 percent (8).

A method which is frequently used with tobacco smoke and dust suspensions is the so-called "tyndall" meter. This consists of an arrangement (72), whereby the suspension to be estimated is passed through a beam of light. The absorption and reflection of the beam on the particles of dust weakens it almost in direct proportion to the concentration of particles present. The readings may be observed with a photometer or photo-electric cell arrangement. In actual tests, the suspension from a dust chamber which is to be used in testing the respirator is passed through the beam chamber and a reading obtained. A second reading is obtained with the filtered air in the same manner and the efficiency determined by the usual relation 100 minus tyndall reading of filtered air divided by the tyndall reading of the original suspension. As a laboratory procedure the method is simple and convenient.

to
th
la
re
hi
Re

ly
Sel
le
in
elic
fite
The
resp
smal
cent
ter is
Agar
cies a
case
tests
from 9
exper
ker, F
rangin
The hi
lattere
due to
partic
mist th
table 3S
those for
This inc
size and
demonstr
below ten
appear to
larger.
With n
not increa
hand, inc
clogging p
and closely

NOT A RECORD OF
NOT A RECORD OF FILES

BB 0020123 1

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2617

tube to a felt filter
surface is provided for

first group consist of
Manufacturers of
believed best suited
ected that the filter
o of the small surface
ed frequently; other
comes difficult. The
scribed, has a longer
ut respirator and is
efficient of the types
fine suspensoids (71)

IN RESPIRATORS

at methods, of which
of testing the filtering
he second consists of
r some similar pliable

OF FILTER MEDIA

are based upon
o of the impinger or
r f published tests,
dmer apparatus (11)
r is approximately 20

acco smoke and dust

This consists of an
o estimated is passed
lection of the beam on
proportion to the con-
may be observed with
. In actual tests, the
o used in testing the
ad a reading obtained.
r in the same manner
ion 100 minus tyndall
eading of the original
method is simple and

The procedure in testing respirators consists in setting up a dust or tobacco smoke cloud in a dust chamber and passing it at a fixed rate through a definite area of filter medium. The arrangement used for holding the filter is also provided with a means of determining the resistance which is important in estimating the life of the respirator filter.

Results of filter tests

Results of tests of various filter media have been published chiefly by the United States Bureau of Mines (71) and by the Harvard School of Public Health (73). The data obtained from these research laboratories are given in tables 36, 37, and 38. It will be seen that in practically every case the efficiencies are low for sponge filters and high for wool cloths. The efficiencies of industrial respirators against tobacco smoke range from 3 to 33 percent. The Folger flat type filter is most efficient, 97 percent. Against silica dust, the efficiencies are slightly higher. In the case of the Bureau of Mines tests the efficiencies ranged from 9 to 70 percent and in the experiments of Barreto, Drinker, Finn, and Thomson (73) ranging from 49 to 97 percent. The higher efficiencies in the latter experiments are probably due to the larger size of dust particles used. In filtering lead mist the efficiencies given in table 38 are much higher than those for silica, the sponge respirator giving an efficiency of 84 percent. This increase is undoubtedly due to the fact that lead mist is large in size and tends to settle rapidly. Barreto and his associates have also demonstrated that respirators do not favor any particular size range below ten microns, as may be seen in figure 77. The finer particles appear to be filtered with practically the same efficiencies as the larger.

With regard to resistance, it is to be noted that tobacco smoke does not increase the resistance of the filters. Silica dust, on the other hand, increases the resistance to air flow, but some materials have clogging properties more marked than others. Dense paper filters and closely woven muslin clog rapidly, while loose textures clog slowly.

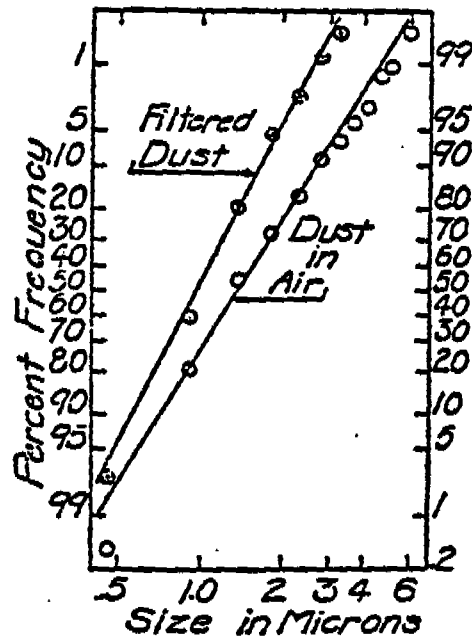


FIGURE 77.—Size frequencies of dust particles in respirator tests (efficiencies on probability scale, abscissa on logarithmic scale).

TABLE 36.—Filtering efficiencies and resistances of masks and respirators when new¹

Type of mask	I. Effective filtering area	II. Air flow	III. Resistance	Tyndall efficiency against	
				IV. Tobacco smoke	V. Silica
	Sq. cm	Liters per minute	Min H ₂ O	Percent	Percent
Burrell.....	540	25	2.6	82	>97
		75	1.8	85	>97
		80	2.8	86	>97
Experimental cotton.....	1,530	25	2.7	22	86
		75	1.9	25	71
		80	1.1	31	
Pig snout no. 1: Sponges:					
Wet.....	(3)	25	37	41	97
		75	15	15	97
Dry.....	(3)	25	23	31	97
		80	13	15	72
Pig snout no. 2: Sponges:					
Wet.....	(3)	25	2.5	10	78
		75	2.0	7	64
Dry.....	(3)	25	2.3	3	67
		80	2.5	3	66
Pig snout no. 3: Felt:					
Wet.....	30	25	26	44	>97
		75	12	39	97
Dry.....	30	25	15	38	97
		80	15	38	97
Pig snout no. 4: 2 papers.....	45	25	6.9	5	86
		75	2.0	5	82
4 papers.....	45	25	10.2	7	97
		75	4.7	13	65
6 papers.....	45	25	9.7	5	64
		75	4.8	14	86

¹ Taken from data of Barreto, Drinker, Finn, and Thomson (73). Silica tests on pig snouts are approximate since it was impossible to prevent plugging and rapid increase in efficiency.

TABLE 37.—Efficiencies of industrial dust respirators filtering silica dust, determined with Tyndall apparatus
(Rate of air flow, 33 liters per minute)

Respirator	Resistance to flow of air at 33 liters per minute		Number of tests	Initial efficiency		Highest efficiency after plugging	Time to reach highest efficiency	
	Before test	After test (maximum)		Maximum	Minimum		Minutes	Seconds
	Inches of water	Inches of water		Percent	Percent	Percent		
Sponges:								
1 inch.....	0.7	1.1	1	33		30	2	0
1 1/2 inch.....	0.8	1.6	3	25		25	4	0
2 inch.....	0.8	0.9	3	17	8	25	2	15
2 1/2 inch.....	0.8	0.9	3	21	9	30	2	30
3 inch.....	0.8	10.7	4	23	30	100	0	20
Papers:								
Do.....	0.25	2.5	1	45		100	1	30
Felts:								
Do.....	1.2	2.8	3	70	70	100	1	30
Do.....	1.5	2.3	1	37		100	2	0
Do.....	1.1		1	27		100	2	15
Silk gauze and cheesecloth.....	0.4	6.1	3	30	10	100	2	30
Cotton linters.....	0.6	5.0	3	61	34	100	2	0
Absorbent cotton.....	0.3	0.8	1	25		100	2	0
Cheesecloth.....	0.3	0.8	1	22		33		

¹ Specimen dry.

² Specimen wet.

³ Filtering efficiency is taken from tests of cheesecloth held in clamp extending 100 square centimeters and tested at rate of 10 liters per minute. There was no increase in filtering efficiency during two minutes.

TABLE
Res.
mch.

Tyndall

Fig. 1000

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

Do.....

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

1 BB 0020125 1

2619

NOTE: Efficiency of respirators filtering dust in print test from spray gun. Rate of air flow, 55 liters a minute. Time of testing, 3 1/2 minutes giving 1 cubic meter of filtered air. Area of filter medium, 100 cm².

Typhoid efficiency against

IV. Typhoid grade	V. Filter
100	100
95	95
90	90
85	85
80	80
75	75
70	70
65	65
60	60
55	55
50	50
45	45
40	40
35	35
30	30
25	25
20	20
15	15
10	10
5	5
0	0

100% efficiency

100% efficiency

Time to reach highest efficiency	Efficiency	Resistance
10	100	100
20	95	95
30	90	90
40	85	85
50	80	80
60	75	75
70	70	70
80	65	65
90	60	60
100	55	55
110	50	50
120	45	45
130	40	40
140	35	35
150	30	30
160	25	25
170	20	20
180	15	15
190	10	10
200	5	5
210	0	0

100% efficiency

100% efficiency

100% efficiency

100% efficiency

100% efficiency

100% efficiency

100% efficiency

100% efficiency

100% efficiency

Filter material	Resistance to air flow at 55 liters per minute, in-hr of water		Average amount of dust in air multi-grains per cubic meter	Filtering efficiency of respirator, percent	Remarks
	Start	End			
Sponge	0.3	0.3	385	84	Sponge was wet before test.
Cotton paper	1.0	2.5	356	94.7	1-ply paper in filter.
do	1.0	1.6	357	97.3	Do.
do	1.1	2.0	417	94.3	Do.
do	1.5	2.0	220	96	Do.
do	2	2	374	94	Do.
do	2	2	253	94.3	2-ply paper in filter.
Gauzy tissue paper	2.5	2.8	465	92	4-ply paper in filter.
Cotton flannel	2	2	485	95	2-ply cotton flannel in filter.
Silk gauze and cheesecloth	2.05	2.05	480	74	1-ply silk, 3-ply cheesecloth.
Cotton wool	2	2	251	94	Cotton between cheesecloth, 100 square centimeters of filter was exposed.
Gauzy tissue paper	2.5	4.4	424	90.7	Cartridge with charcoal and 2 filters each of 10-ply.
Cotton wool	2.5	2.9	76.1	92.7	The Army type gas mask canister contains 2 cotton filters, 1 of low-resistance, and 600 cubic centimeters charcoal.
do	2.5	2.9	71.3	91.3	Do.
do	2.4	2.6	73.3	91.6	Do.
do	2.4	2.5	80.6	94.3	Do.
do	2.6	2.8	62.7	92.7	Do.

With regard to the resistance of filters the following quotation taken from a Bureau of Mines publication (71) gives several important conclusions based on a large number of tests:

The resistance of the filters to the flow of air through them is a highly important factor in the design of dust respirators, because respirators having a resistance greater than 4 inches of water when the rate of air flow is 55 liters per minute are unsatisfactory. They will not be worn, even for short periods, because they necessitate too much exertion in breathing. Respirators with resistances of 2 to 4 inches may be worn, but after about half an hour the wearer must rest or exert himself less. The resistance of filters in dust respirators intended for continuous working use should not exceed 2 inches of water, and preferably should be less than 1 inch. These limitations on the resistance of filters restrict filtering efficiencies, so in a practicable respirator it is necessary to strike a balance between the filter resistance and the filtering efficiency that may be obtained.

The area of respirator filters should be made as large as is practicable, because the increased area reduces the rate of air flow per unit of area and thereby tends to increase the filtering efficiency and decreases the resistance.

POSITIVE PRESSURE MASKS OR HELMETS

The second group of respiratory protection apparatus consists of masks or helmets with fresh air supply. In these types, compressed air from a dust-free source is supplied to the worker. Positive pressure masks as a rule are constructed of light metal, shaped to the contour of the face by special cushions, and supplied with a small valve to prevent the vitiated air to escape. The air is bled into the mask near

1 BB 0020126 1

the top and diverted across the goggles to prevent fogging and sensations produced by air jets. It is necessary in using positive pressure masks to fasten the air supply hose to the worker so as not to induce a drag on the mask.

Various types of positive pressure masks are available. Some have been designed with light pumps and motors with cloth filters which may be strapped about the waist. In this way the worker need only carry about with him an electric extension cord. Such devices are especially adapted for operations requiring freedom of movement, which cannot be attained with a stiff heavy compressed air hose.

Positive pressure helmets are made of rubber, leather, or canvas. They fit over the head and rest on the shoulders of the worker. They are provided with large protected windows which may be replaced. Sufficient air is supplied to these helmets to keep a constant flow of air leaking outward at the shoulder contacts, thus preventing any dust from entering.

Positive pressure helmets are used almost entirely in abrasive cleaning rooms and serve a twofold purpose: (1) To furnish the worker with a clean supply of fresh air, and (2) to protect his head and neck from the force of rebounding sand or metal particles.

EFFICIENCIES OF POSITIVE PRESSURE DEVICES

Bloomfield and Greenburg have investigated the air requirements of helmets used in sand-blasting under normal working conditions (48). Their studies were planned with the purpose of obtaining samples of air from inside a helmet, when: (1) The quantity of air supplied to the helmet was varied while the dust concentration in the room was maintained at as constant a level as possible, and (2) the dust concentration in the room was varied while the quantity of air supplied to the helmet was kept constant, this quantity being the optimum as determined in (1) above.

The studies were conducted in an abrasive blasting room in which fairly clean castings were blasted with sand at a pressure of ranging from 55 to 60 pounds. A modern room, equipped with down-draft ventilation, was used. An ordinary cloth-covered, fiber helmet was employed connected in the manner shown in figure 27, section V. This helmet was provided with a rectangular double screen about 4 by 2 inches in size, located at a point directly in front of the worker's eyes. The outer screen was a coarse mesh while the inner one was of a 32-mesh size. The dust concentrations were determined with the impinger apparatus.

The general air of the blast cleaning room (the air in the room, but outside the helmet), was sampled at a time corresponding with the midpoint of a pair of helmet samples by means of a second impinger

flu:
det
uni
mer
In
acce
Tab
Tabl

With the
Glass eye

Blow
first se
casting
the ser
ditions
are sup
taining
under s
the helm

In re
under al
keeping
helmet w
ing the n

With 4
were 3.1
within the
concentra
low when
ticles per c
in the room
ticles per c
contain as
ditions in
because of

It may ti
fect of dust-
ting conditi

NOTE

at fogging and sensing positive pressure or so as not to induce

available. Some have cloth filters which the worker need only clean. Such devices are freedom of movement, compressed air hose.

leather, or canvas, of the worker. They which may be replaced, to a constant flow of air thus preventing any

ely in abrasive cleaning furnish the worker protection for his head and neck.

DEVICES

the requirements conditions (4S). obtaining samples of air supplied to the room was and (2) the dust concentration (air supplied being the optimum

blasting room in which pressure of ranging with down-draft hood, fiber helmet was 27, section V. This screen about 4 by 2 of the worker's eyes. inner ne was of a determined with the

air in the room, but responding with the of a second impinger

flask suspended in the blasting zone. (See fig. 2S for assembly details.) The operator was instructed to conduct blasting in a uniform manner so that operating conditions throughout the experiments would be as constant as possible.

In the first series of samples, the helmet was tested with the double screens in place, while in a second series, a glass eyeshield was used. Table 39 shows the results of the two series of tests.

TABLE 39.—Dust concentration ¹ beneath helmet with air supply of different volumes
(Millions of particles per cubic foot)

	Dust in room air	Volume of air supply (c. f. m.) ²					
		0	2	3	4	5	6
With double eye screen.....	523	—	9.7	8.4	2.1	1.8	4.9
Glass eye shield.....	563	26	4.4	4.0	2.2	1.15	.35

¹ Each average based on 2 samples.

² Dust in air supply 0.3 million.

Bloomfield and Greenburg have assumed the inconsistencies of the first series as being due to the fact that the dust deflected from the casting at a considerable velocity gained access to the helmet through the screens. It is clear from the table, however, under the test conditions of the second series, that when 6 cubic feet of air per minute are supplied to the helmet, the worker breathes an atmosphere containing but 0.3 million particles per cubic foot of air. In other words under such conditions, practically no blasting-room dust filters into the helmet. This represents ideal protection for the worker.

In order to determine whether 6 cubic feet of air was sufficient under all conditions of work, another series of samples were taken keeping a constant flow of air of 6 cubic feet per minute through the helmet while the dust concentration in the room was varied by changing the amount of room ventilation.

With 4,000 million particles per cubic foot in the general air, there were 3.1 million particles within the helmet; with 3,000 there was 1.0 within the helmet; with 1,000 there was 0.5. In other words, the dust concentration of the air beneath the helmet during blasting remains low when the air in the room contains as much as 1,000 million particles per cubic foot and more. It is only when the dust concentration in the room reaches the enormously high figure of 4,000 million particles per cubic foot, that the air beneath the helmet was found to contain as much as 3.1 million particles per cubic foot. Such conditions in practice are rare and in fact impossible to work under because of obscured visibility.

It may therefore be concluded that a positive air supply of 6 cubic feet of dust-free air per minute will protect a worker under the operating conditions now in practice in abrasive cleaning rooms if the worker

is supplied with a helmet similar to that described above. The final criterion, however, is the result of dust determinations of the air within the helmet, that is, the air actually breathed by the worker, and not the volume of air supplied.

EFFICIENCY STANDARDS IN TESTING PERSONAL PROTECTION APPARATUS

It is necessary to point out that tests of personal protection apparatus should always be carried out against the dust to which these devices are to be used in practice under the most severe conditions which are likely to be encountered.¹⁰ Furthermore, in connection with ratings given in percent, great care should be exercised that correct interpretations be made. For example, a device which is 90 percent efficient, does not necessarily mean that it is sufficient protection against dusts with high quartz content when the concentration is of the order of between 50 and 100 million particles per cubic foot. Under such circumstances, with continued exposure, the worker is likely to breathe dangerous amounts of dust. Ratings, should therefore, be obtained with regard to the quantity of dust which actually passes the respirator or helmet under the conditions employed.

MAINTENANCE OF RESPIRATORY PROTECTIVE DEVICES

Devices used to protect the worker should always be maintained in good order. Frequently, in many industries they are not properly cared for or maintained in good condition, with a result that they no longer function efficiently. It is important that periodic checks be made of all respiratory protective devices, observing any physical defects which they may have, and to retest them whenever any doubt arises as to their effectiveness.

A necessary precaution in connection with positive pressure masks and helmets is to make certain that the air supply is always from a clean or filtered source.

CHOOSING RESPIRATORY PROTECTIVE DEVICES

The choice of respiratory protective devices depends upon a number of factors. As has been pointed out, their efficiencies must be rated in terms of the dust actually passing the respirator or helmet under the conditions against which they will be used; there are, however, other considerations, equally important, which in a large measure are determined by the type of operation under which they must be employed. These factors are—

1. *Lightness.*—Respiratory protection apparatus should be light and durable. Heavy devices are cumbersome and the worker is prone to avoid using them.

¹⁰ In connection with standard routine tests of respirators, see schedule 21, U. S. Bureau of Mines.

NOTE: THIS

NOT

BB 0020129 1

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2623

bed above. The final
minations of the air
sathed by the worker.

PROTECTION APPARATUS

nal protection appa-
rust to which these de-
vere conditions which
, in connection with
exercised that cor-
ce which is 90 per-
s sufficient protection
he concentration is of
rticles per cubic foot.
posure, the worker is
Ratings, should there-
of dust which actually
ions employed.

POSITIVE DEVICES

maintained in
they are not properly
a result that they m-
at periodic checks b-
observing any physical
them whenever any

positive pressure masks
ply is always from a

POSITIVE DEVICES

depends upon a num-
ir efficiencies must be
e respirator or helmet
used; there are, how-
high in a large measure
r which they must be

tus should be light and
the worker is prone to

U. S. Bureau of Mines

2. *Fit.*—The fit of a respirator or mask is important. They should in every case be fitted to the wearer. Otherwise leaks will interfere with the effective use of the device.

3. *Visibility.*—Masks or helmets should attempt to give clear and easy visibility to the worker. The air supply should attempt to keep the glass from fogging. Glasses should be easily replaced in case of breakage or pitting and should fit well.

BB 00 20130

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

XIII. BIBLIOGRAPHY

1. Winslow, C.-E. A., and Greenburg, Leonard: A useful factory inspection form. Public Health Reports, vol. 37, no. 1, January 6, 1922.
2. Russell, A. E., Britten, R. H., Thompson, L. R., and Bloomfield, J. J.: The health of workers in dusty trades. II. Exposure to siliceous dust (granite industry). Public Health Bulletin No. 187, July 1929.
3. Brundage, D. K., and Bloomfield, J. J.: The pneumonia problem in the steel industry. Jour. Ind. Hyg., vol. 14, no. 10, December 1932.
4. Bloomfield, J. J., and Knowles, Fred L.: Health aspects of radium dial painting. II. Occupational environment. Jour. Ind. Hyg., vol. 15, no. 5, September 1933.
5. Russell, A. E., Jones, R. R., Bloomfield, J. J., Britten, R. H., and Thompson, L. R.: Lead poisoning in a storage battery plant. Public Health Bulletin No. 205, June 1933.
6. Drinker, P., and Thomson, R. M.: Determination of suspensoids by alternating-current precipitators. Jour. Ind. Hyg., vol. 7, no. 6, June 1925.
7. Knowles, E. R.: Dust determinations in air and gases. Trans. Amer. Soc. Heat and Vent. Eng., vol. 23, 1919.
8. Greenburg, Leonard: Studies on the industrial dust problem. II. A review of the methods used for sampling aerial dust. Public Health Reports, vol. 40, no. 16, April 17, 1925.
9. General report of the Miners' Phthisis Prevention Committee of South Africa, Pretoria, 1916, p. 20, appendix O. 66.
10. Higgins, E., Lanza, A. J., Lancy, F. B., and Rice, G. S.: Siliceous dust in relation to pulmonary disease among miners in the Joplin district, Missouri. U. S. Bureau of Mines Bull. 132, 1917.
11. Palmer, G. T.: A new sampling apparatus for the determination of aerial dust. Amer. Jour. Pub. Health, vol. 6, no. 1, January 1916.
12. Final report of the Miners' Phthisis Prevention Committee: Union of South Africa, March 10, 1919.
13. Trostel, L. J., and Frevert, H. W.: Collection and examination of explosive dust in air. Ind. and Eng. Chem., vol. 15, no. 3, March 1923.
14. Anderson, F. P., and Armspach, O. W.: A new method of making air dust determinations. Jour. Amer. Soc. Heat and Vent. Eng., vol. 25, July 1922.
15. Owens, J. S.: Jet dust counting apparatus. Jour. Ind. Hyg., vol. 4, no. 12, April 1923.
16. Drinker, P.: Alternating current precipitators for sanitary air analysis. I. An inexpensive precipitator unit. Jour. Ind. Hyg., vol. 14, p. 364, 1932.
17. Greenburg, Leonard, and Bloomfield, J. J.: The impinger dust sampling apparatus as used by the United States Public Health Service. Public Health Reports, vol. 47, no. 12, March 18, 1932.
18. Hatch, T., Warren, H., and Drinker, P.: Modified form of the Greenburg-Smith impinger for field use, with a study of its operating characteristics. Jour. Ind. Hyg., vol. 14, no. 8, October 1932.
19. Badham, Charles, Rayner, H. E. G., and Brouse, H. D.: Dust sampling in Sydney sandstone industries. Report of the Director-General of Public Health, New South Wales, for the year 1927. Serial no. 12.

(164)

NOTE

128

BB 0020131

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

2625

A useful factory inspection
January 6, 1922.

and Bloomfield, J. J.: The
ure to siliceous dust (granu-
ally 1929.

umonia problem in the steel
December 1932.

pects of radium dial paint.
Ind. Hyg., vol. 13, no. 3,

itten, R. H., and Thompson,
ant. Public Health Bulletin

ion of suspensoids by alter-
vol. 7, no. 6, June 1923.

l gases. Trans. Amer. Soc.

ust problem. II. A review
Public Health Reports,

Committee of South Africa,

: Siliceous dust in
the Poplar district, Missouri.

the determination of aerial
January 1916.

Committee: Union of South

and examination of explosive
3, March 1923.

method of ranking air dust
nt. Eng., vol. 28, July 1922.

. Ind. Hyg., vol. 4, no. 12.

for sanitary air analysis.
Hyg., vol. 14, p. 264, 1922.

o Impinger dust sampling
ic Health Service. Public
32.

ed form of the Greenbaum
s operating characteristic.

. H. D.: Dust sampling in
Director-General of Public
Serial no. 12.

1. Myers, W. M.: Solubility of finely divided rock dusts in water, kerosene, and alcohol. Bureau of Mines Reps. of Invest., serial no. 2548, November 1923.
2. Simon, Stahl u. Eisen, vol. 25, p. 1069, 1905.
3. Mariner and Hoskins, Report to Chicago Association of Commerce Committee on Smoke Abatement and Electrification of Railway Terminals. Laboratory Report on Air Analysis, 1915.
4. Katz, S. H., Smith, G. W., Myers, W. M., Trowel, L. J., Lugeb, M., and Greenburg, L.: Comparative tests of instruments for determining atmospheric dusts. Pub. Health Bulletin 144, January 1923.
5. Greenburg, Leonard: Studies on the industrial dust problem. Public Health Reports, vol. 40, no. 40, 1923.
6. Smith, R. B., and Friis, H. S. T.: Portable motor-driven impinger unit for determination of sulphur dioxide. Jour. Ind. Hyg., vol. 13, no. 10, December 1931.
7. Bloomfield, J. J., and Blum, W.: Health hazards in chromium plating. Public Health Reports, vol. 43, no. 36, September 7, 1928.
8. Moir, J.: Report on a Specimen of Dust from Silicotic Lungs. General Report of the Miners' Phthisis Prevention Committee, Pretoria, 1916, appendix 9.
9. Watkins-Pitchford, W.: The Situation, Outline, and Dimensions of Mineral Particles Visible by Polarized Light in Sections of Silicotic Lungs, Mounted in Canada Balsam. General Report of the Miners' Phthisis Prevention Committee, 1916, appendix 8.
10. Marzoggiorato, A.: The Value of the Konimeter. Publications of the South African Institute of Medical Research, no. 17.
11. Scheid, C. F.: The Presentation and Determination of the Dust Deposited in Pneumonoconiotic Tissues. Beitr. Path. Anat. u. z. Allg. Path., vol. 89, 1932.
12. Drinker, Philip: The Size-Frequency and Identification of Certain Phagocytosed Dusts. Jour. Ind. Hyg., vol. 7, no. 7, July 1925.
13. King, Earl J., and Dolan, Margery: Silicosis and the Metabolism of Silica. The Canadian Medical Association Jour., vol. 31, July 1934, pp. 21-26.
14. Drinker, P., Thomson, R. M., and Finn, J. L.: Quantitative Measurements of the Inhalation, Retention, and Exhalation of Dusts and Fumes by Man. I. Concentrations of 50 to 450 milligrams per cubic meter. Jour. Ind. Hyg., vol. 10, no. 1, January 1928.
15. Brown, C. E.: Quantitative Measurements of the Inhalation, Retention, and Exhalation of Dusts and Fumes by Man. II. Concentrations below 50 milligrams per cubic meter. Jour. Ind. Hyg., vol. 13, no. 8, October 1931.
16. Brown, C. E.: Studies in Dust Retention. III. Factors Involved in the Retention of Inhaled Dusts and Fumes by Man. Jour. Ind. Hyg., vol. 13, no. 9, November 1931.
17. Experimental studies on the effect of ethyl gasoline and its combustion products. United States Bureau of Mines Monograph, no. 2.
18. Shaw, N., and Owens, J. S.: The smoke problem of great cities. Constable & Co., Ltd., London, England, 1925.
19. Bloomfield, J. J.: The Size-Frequency of Industrial Dusts. Public Health Reports, vol. 48, no. 32, August 11, 1933.
20. Kagan, M., and Brounstein, W.: Rational method for calculating records obtained by means of Owens' Jet Dust Counting Apparatus. Jour. Ind. Hyg., vol. 13, no. 1, January 1931.

NOTE: THIS DOCUMENT DID NOT COME FROM ITS FILES AND CANNOT BE AUTHENTICATED BY PPG INDUSTRIES, INC.

BB 0020132

THIS DOCUMENT WAS NOT A RECORD OF PPG INDUSTRIES, INC. DID NOT COME FROM ITS FILES AND CANNOT BE AUTHENTICATED BY PPG INDUSTRIES, INC.

2626

39. Bloomfield, J. J., and Isbell, H. S.: The presence of lead dust and fumes in the air of streets, automobile repair shops, and industrial establishments of large cities. *Jour. Ind. Hyg.*, vol. 15, no. 3, May 1933.
40. Charnot, E. M., and Mason, C. W.: *Handbook of Chemical Microscopy*. John Wiley and Sons, Inc., New York, 1930, p. 402.
41. Thompson, J. R., Brundage, D. K., Russell, A. E., and Bloomfield, J. J.: The Health of Workers in Dusty Trades. I. Health of Workers in a Portland Cement Plant. *Public Health Bulletin* no. 176, 1928.
42. Dræsen, Waldemar C.: Effect of inhaled marble dust as observed in Vermont marble subbers. *Public Health Reports*, vol. 49, no. 25, June 22, 1934.
43. Hillebrand, W. F.: The analysis of silicate and carbonate rocks. *United States Geological Survey Bulletin* No. 700, 1919.
44. Dale, Nelson T.: The commercial granites of New England. *United States Geological Survey Bulletin* No. 738, 1923.
45. Knopf, A.: The quantitative determination of quartz (free silica) in dusts. *Public Health Reports*, vol. 48, 1933.
46. Bloomfield, J. J.: Preliminary surveys of the industrial environment. *Public Health Reports*, vol. 48, no. 44, November 3, 1933.
47. Bloomfield, J. J.: A study of the efficiency of dust-removal systems in granite-cutting plants. *Public Health Reports*, vol. 44, no. 42, October 18, 1929.
48. Bloomfield, J. J., and Greenburg, Leonard: Sand and metallic abrasive blasting as an industrial health hazard. *Jour. Ind. Hyg.*, vol. 15, no. 4, July 1933.
49. Bloomfield, J. J.: The determination and control of industrial dust. Paper given before Dust in Industry Session of the 12th Annual Midwest Safety Conference, May 10, 1934.
50. Hatch, Theodore. Control of the silicosis hazard in the hard-rock industries. IV. Application of the Kelley trap to underground drilling operations. *The Jour. of Ind. Hyg.*, vol. 15, no. 1, January 1933.
51. Drury, W. Herbert: The incidence of tuberculosis among polishers and graders in an ax factory. *Public Health Reports*, February 4, 1921, or reprint no. 640.
52. DallaValle, J. M. and Hatch, Theodore. Studies in the design of local exhaust hoods. *Trans. Am. Soc. Mech. Engrs.*, 1932, 54.
53. DallaValle, J. M.: Velocity characteristics of hoods under suction. *Am. Soc. Heat and Vent. Engrs., Jour. Section, Heating, Piping and Air Conditioning*, 1932, 4.
54. DallaValle, J. M.: The importance of velocity characteristics in the design of local exhaust hoods. *Jour. Ind. Hyg.*, vol. 15, no. 1, January 1933.
55. Hatch, Theodore, Drinker, Philip, and Choate, Sarah P.: Control of the silicosis hazard in the hard-rock industries. I. A laboratory study of the design of dust control systems for use with pneumatic granite cutting tools. *Jour. Ind. Hyg.*, vol. 12, no. 3, March 1930.
56. Winslow, C.-E. A., and Greenburg, Leonard: Notes on the efficiency of various systems of air-conditioning in a munition factory. *Public Health Reports*, February 10, 1922, or reprint no. 729.
57. DallaValle, J. M.: Determining minimum air velocities for exhaust systems. *Jour. Am. Soc. Heat and Vent. Engrs., Jour. Section, Heating, Piping and Conditioning*, September 1932.
McGraw-Hill: Chemical Engineering. London, Crosby Lockwood and Co.
Am. Soc. Heat and Vent. Engrs., 1934 (12th ed.).

60. H.
61. H.
62. H.
63. H.
64. Safet
65. Whit
66. Terry
67. Over
68. H.M.
69. Yaglor
70. Bulletin
71. Katz, S
72. Drinker
73. Harret
and re
vol. 9,

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

BB 0020133

2627

ce of lead dust and fumes in
nd / industrial establishments:
- 1933.

Chemical Microscopy,
p. 402.

L. E., and Blumfeldt, J. J.:

1. Health of Workers in a
letin no. 176, 1925.

his dust as observed in Ver-
ets, vol. 49, no. 25, June 22.

d carbonate rocks. United
12.

ew England. United States

quartz (free silica) in dusts.

ustrial environment. Public
1933.

of dust-removal systems in
la, vol. 44, no. 42, October

and and metallic abrasive
Ind. Hyg., vol. 15, no. 4,

d of industrial dust. Paper
2th Annual Midwest Safety

in the hard-rock industries
ground drilling operations.
- 1933.

losis among polishers and
part February 4, 1921, or

in the design of local
- 1932, 54.

oods under suction. Am-
ating, Piping and Air Con-

haracteristics in the design
13, no. 1, January 1933.

Sarah P.: Control of the
A laboratory study of the
pneumatic granite cutting
930.

V tes on the efficiency of
on factory. Public Health

cities for exhaust systems-
ection, Heating, Piping and

on, Crosby Lockwood and

th ed.).

60. Hughes, Hector J., and Safford, Arthur T.: A treatise on hydraulics. New York. The Macmillan Co., 1925.
61. Hay, P. S.: A method of trapping the dust produced by pneumatic drills. Paper no. 23. Safety in Mines Research Board. Cited by Moss, K. Neville. Gases, Dust and Heat in Mines, London, Charles Griffin & Co., Ltd. (Philadelphia. J. B. Lippincott Co.) 1927, p. 83.
62. Hatch, Theodore, Kelley, George S., and Fehnel, J. William: Control of the silicosis hazard in the hard-rock industries. II. An investigation of the Kelley dust trap for use with pneumatic rock drills of the "Jack-hammer" type. Jour. Ind. Hyg., vol. 14, no. 2, February 1932.
63. Hatch, Theodore, Warren, Henry, and Kelley, George S.: Control of the silicosis hazard in the hard-rock industries. III. Design and operation of a dust-control system for use with pneumatic rock drills in open excavation. Jour. Ind. Hyg., vol. 14, no. 7, September 1932.
64. Safety code for the use, care, and protection of abrasive wheels. Bulletin of the United States Bureau of Labor-Statistics, no. 436, 1927.
65. Whiton, Louis C., Jr.: Research on cyclone dust collectors. Presented at the technical meeting of the Metropolitan section, New York, N. Y., February 18, 1932, of the American Society of Mechanical Engineers.
66. Terry, W. F.: Operation, maintenance of cloth-screen dust collectors. Heating, Piping, and Air Conditioning, May and June 1933.
67. Ower, E.: The Measurement of Air Flow. London, Chapman & Hall, Ltd. 1927.
68. Hill, Leonard: The science of ventilation and open-air treatment, part 1. Medical Research Council; Special Report Series, no. 32, London.
69. Yaglou, C. P., and Doloff, Kroum: Calibration of the kato-thermometer over a wide range of air conditions. Jour. Ind. Hyg., vol. 11, no. 8, October 1929.
70. Bulletin No. 120. University of Illinois Engineering Experiment Station, Urbana, Ill.
71. Katz, S. H., Smith, G. W., and Meiter, E. G.: Dust respirators, their construction and filtering efficiency. Technical paper 394, United States Bureau of Mines, 1926.
72. Drinker, P., Thomson, R. M., and Finn, Jane L.: Photometric methods for studying and estimating suspensions of dusts, fumes, and smoke. Jour. Ind. Hyg., vol. 7, no. 12, December 1925.
73. Barreto J. B., Drinker, Philip, Finn, Jane L., and Thomson, R. M.: Masks and respirators for protection against dusts and fumes. Jour. Ind. Hyg., vol. 9, no. 1, January 1927.

102211-12

THIS DOCUMENT WAS NOT A RECORD OF
PPG INDUSTRIES, INC. DID NOT COME FROM
IT'S FILES AND CANNOT BE AUTHENTICATED
BY PPG INDUSTRIES, INC.

1 BB 0020134 1

2628