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Industrial Dust: Its Estimation and Mitigation

By J. J. BLOOMFIELD
**Assistant Sanitary Engineer, United States Public Health Service,
New Haven, Conn.**

The subject of the health of workers in dusty trades has received considerable attention from students of industrial hygiene, and although much work has been done in the study of the dust hazard we find that many phases of this problem are still being investigated with great interest. The importance of the dust problem cannot be overestimated, since it is well known that the workmen employed in the dusty trades comprise the largest group exposed to any one industrial hazard. Furthermore it has also been well established that exposure to certain kinds of dust has increased the mortality rate from respiratory diseases.

Since it has been recognized that there is a marked difference in the action of certain dusts on the human system, attempts have been made to classify dusts in accordance with the harmful effects exercised by them. The most recent classification is that suggested by Pancoast and Pendergrass, who state that, (1), while all dusts if inhaled in excessive quantities may be harmful, only a few may be classed as dangerous. The dangerous dusts were divided by them into (a) poisonous dusts such as lead, etc.; (b) those causing irritation in the respiratory tract, resulting in certain diseases such as asthma and bronchitis; and (c) those which tend to produce pulmonary fibrosis and thereby may predispose to tuberculosis and pneumonia. As will be discussed more fully later, the Public Health Service, in its investigations of the dust problem, has attempted a classification based upon the chemical and mineralogical composition of dusts, which allows one to associate more accurately the pathological results with the exact nature of the dust under consideration.

Effects of Industrial Dusts on Health

Prior to discussing the present day methods employed in the estimation and suppression of industrial dusts, it seems well to present briefly the most recent evidence concerning the effects of the inhalation of industrial dusts upon the health of workers. This evidence is the result of six intensive investigations conducted by the United States Public Health Service, each dealing with a different type of dust. The first two of these studies have already been completely analyzed and reported in two bulletins issued by the Public Health Service (2) (3). Much of the material which follows has been drawn from these two publications. A list of these dusts follows:

1. Calcium Dust (Portland Cement Plant).
2. Silica Dust (Granite Industry).
3. Metallic and Other Dusts (Silverware polishing).
4. Carbon Dusts (Anthracite and bituminous coal mining).
5. Vegetable Dust (Cotton cloth manufacturing).
6. Municipal Dust (Street sweeping).

In the past our knowledge of the effect of industrial hazards on the health of workers has been gained either from the study of occupational mortality statistics or from the physical examination of sample groups of employees in an industry. In the investigations conducted by the Public Health Service an attempt has been made to utilize both of the above procedures and in addition large groups of workers were observed for a considerable period of time, in order to learn something of the character and severity of the sickness they experienced and to correlate such illness with the occupational environment.

In order to permit as detailed a comparison as possible between the different dust studies, the same methods of conducting these investigations were utilized. Briefly these methods of study may be divided into six parts, as follows: (1), examination to determine the general physical condition of the workers under observation; (2) special physical examination to determine the prevalence of specific diseases of the respiratory system and the lung pathology resulting from exposure to the particular dust hazard; (3) record of the nature and severity of the disabling illnesses; (4) analysis and detailed study of the occupational environment; (5) occupational mortality statistics relating to the specific dust; and lastly (6) autopsies. In brief, the chief value of each of these studies lies in the fact that it represents careful and detailed observations on a fairly large group of persons whose working environment was accurately determined, especially with reference to the nature and quantity of the dust exposure.

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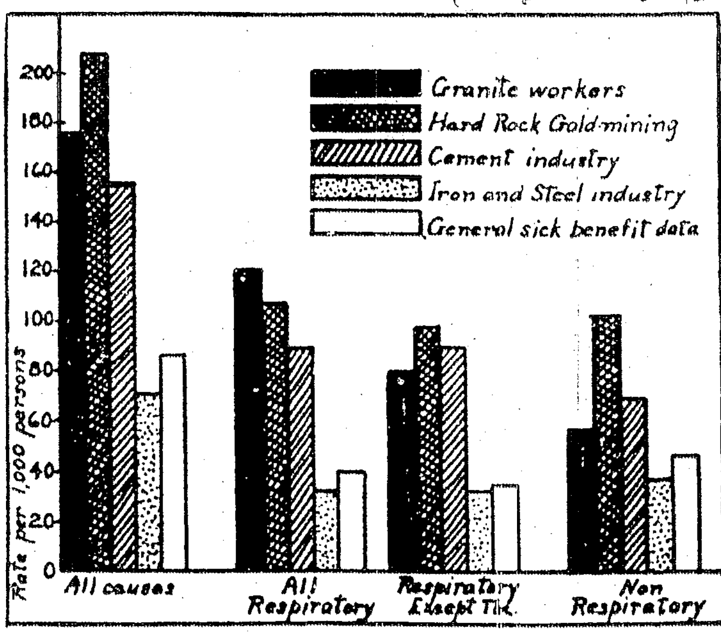

Figure 6

As previously mentioned two of these studies, cement and granite, have already been reported upon in full, and although the complete data for the other four studies are as yet not available, sufficient analysis of the morbidity records of all the studies is at hand and is presented in Table 1 which follows.

This table presents a comparison of sickness for two working days or longer from respiratory conditions in six dusty trades, the annual rates being based on 100 years of observation. An examination of this table shows that in the anthracite industry and in the cement plant there is a high rate of illness from grip and certain other minor respiratory affections. In the bituminous coal industry, bronchial diseases and pneumonia are excessive; in the cotton industry grip and diseases of the nasal fossae are predominant; whereas in the granite industry, tuberculosis and pleurisy are excessive. The dusty occupations in silver polishing show no excess from any cause.

In order to show the significance of some of these rates another comparison is presented in the accompanying illustration (Figure 6). This figure shows a com-

TABLE I

Sickness[1] from Respiratory Conditions in Six Dusty Trades

Diagnosis	Annual Rate per 100 Years of Observation.						Number of cases					
	Granite	Cement	Hard Coal	Soft Coal	Cotton	Silver Polishing[2]	Granite	Cement	Hard Coal	Soft Coal	Cotton	Silver Polishing
Asthma	0.2	....	0.4	....	0.9	0.4	3	....	4	....	7	3
Bronchitis	0.3	5.0	9.0	14.4	2.0	2.1	4	38	100	71	16	15
Pneumonia	0.5	0.4	0.2	1.0	0.2	0.1	7	3	2	5	2	1
Tuberculosis	3.7	0.1	0.7	....	....)	0.1	50	1	6	....	....	..)
Suspected Tuberculosis	0.8	....	....	....	....)		11	....	....	....	....	..)
Diseases of the nasal fossae	4.9	8.7	8.4	....	26.0	7.4	66	66	94	....	208	53
Influenza and grip	4.3	20.6	18.1	1.2	18.6	6.6	58	157	202	6	149	47
Pharyngitis & tonsilitis	0.7	7.5	5.7	4.7	2.9	0.7	9	57	64	23	23	5
Pleurisy	1.1	0.3	0.9	0.2	0.2	0.4	15	2	10	1	2	3
Other respiratory diseases	....	0.1	1.7	1.4	0.4	....	....	1	19	7	3	....
Total respiratory diseases.	16.5	42.7	45.1	22.9	51.2	17.9	223	325	503	113	410	126
Years of Observation	....	....	....	....	....	....	1346	763	1116	494	801	715

[1] Lasting two consecutive working days or longer.
[2] Males only, to agree with the other studies.

parison of the frequency of absence due to sickness among granite workers with that in certain other industrial groups. It is to be seen that the rate for all causes (eight days and longer in the dusty trades is much higher than in the general experience represented by the sick benefit data, but it is not unique. (This general sick benefit data is based on information reported by many industrial concerns to the Public Health Service). For respiratory conditions, however, the rate for the granite industry is higher than any of the other groups compared. When allowance is made for the incidence of sickness due to tuberculosis, the gold mining experience (where dust of a similar nature is involved) and the cement experience are somewhat higher, all three dusty trades being marked above the usual experience. For non-respiratory sickness, except ill-defined, the granite industry shows nothing significant. Later it will be shown that some of these variations in the severity and nature of the respiratory diseases may be attributed to the nature and quantity of dust exposure. Suffice it to say for the present, these results established a real difference in the nature of respiratory diseases occurring among workers exposed to different kinds of dust.

Estimation of Dust

From the evidence just presented concerning the injurious effects produced by the inhalation of certain dusts it is quite evident that a knowledge of the dust content of the atmosphere is a matter of considerable importance. Such evidence is needed not only for the sake of determining the extent of the hazard involved in various industrial processes but is also useful in measuring the efficiency of certain protective devices which may be used for the suppression of the dust hazard.

The numerous investigations of the dust problem in industry have conclusively shown that in studies of this sort a knowledge of the nature, particle-size and concentration of the dust under consideration is of the utmost importance. Concerning the nature of dusts there is ample evidence at hand that those dusts containing free silica in the form of quartz are dangerous, since they produce silicosis which usually terminates in tuberculosis. For this reason in all our dust studies chemical and petrographic analyses were conducted on the various dusts encountered. Table 2 presents the results obtained on analyzing dusts in five industries. Examination of this table shows the wide variation in the amount of quartz found and also shows that this amount of quartz bears no relationship to the total amount of silica in the dust as disclosed by chemical analysis.

TABLE 2

Chemical and Petrographic Analysis of the Dust in each Study

	Total Silica Per cent		Quartz (free silica) Per cent
Granite: Average	70.0		35.2
Silver polishing:			
Hollow-handle-making room	2[illegible].2		1.7
Wet pumice (2 averaged)	70.5	less than	0.5
Brass foundry	73.3		19.0
Cement:			
Pack house	21.2	less than	1.0
Crusher house, raw mill, stone house	16.8		6.5
Soft Coal:			
Coal dust	(?)		1.2
Rock dust	high		54.0
Hard Coal:			
Coal Dust	(?)		1.5
Rock dust	high		31.0

It is evident that from the standpoint of the amount of quartz our analyses indicate that the rock drilling occupations in the coal mining industry and certain occupations in the granite cutting industry may be considered as dangerous. In fact, reference to Table 1, previously discussed, shows that in the granite cutting industry there was a high rate of illness from tuberculosis. Since only a few rock drillers were studied we were not able to establish a definite dust hazard among them.

Since the South African (4) and other investigators have conclusively demonstrated that only particles under 10 microns in longest diameter are found in the lungs on autopsy, particular attention has been given to express the magnitude of exposure in terms of size of particles. Concerning the lower size limit of the potentially dangerous particles Mavrogordato (5) and other investigators believe that the smaller ultra-microscopical particles are not dangerous and that the minimum size of particles which are likely to be retained by the lungs is about 0.5 microns. For this reason we have used methods which revealed the number of dust particles of a diameter between ½ and 10 microns.

With reference to the quantity of dust exposure it has been agreed by students of this problem that the particle count is the best index of the extent of the atmospheric pollution. For this reason our dust determinations are always expressed in numbers of particles per unit quantity of air, usually in millions per cubic foot of air.

Many methods have been devised and employed for the sampling and estimation of atmospheric dust. These methods have been discussed in an excellent review of this subject by Dr. Greenburg (6) and for this reason need not be considered at this time. Prior to undertaking the series of exhaustive dust studies the Public Health Service, in cooperation with other interested agencies in this country, carried out comparative tests at the U. S. Bureau of Mines laboratories in Pittsburgh, Pennsylvania, of various instruments for determining atmospheric dusts (7). As a result of these studies the Impinger apparatus was developed and found to contain all the requirements of the ideal instrument for dust studies of this sort, namely, simplicity of operation and accuracy in both high and low dust concentrations. This instrument was utilized in all our dust studies, being supplemented at times by the Konimeter of the South Africans (5) and the Jet Dust Counter of Owens (8). At the present time these three instruments are the ones finding greatest use in dust studies of a public health nature. It is of interest to note at this point that each of these instruments depends on the principle of impingement at a high velocity for its dust sampling efficiency.

The Kotzé konimeter is a small instrument capable of sampling the dust in 9 or 10 cubic centimeters of air. Essentially it consists of a circular brass chamber into which fits a glass plate cemented into a toothed frame of brass. Firmly attached to the brass chamber is a cylinder in which moves a spring-actuated piston, so arranged that on release of the piston spring, air is drawn out of the chamber. The only means of ingress of air to the chamber is through the impinging orifice, and the air enters here, striking the previously vaselined glass plate and leaving its dust thereon. After taking one spot the glass plate is revolved by means of a pinion gear and the instrument is ready for the next sample. The technique involved in analyzing konimeter samples has been described in detail by the inventor of this instrument (9) and needs no further discussion at this time. This instrument is small, portable and very convenient for use. With it twenty-nine samples may be taken on one slide, and once taken, may be very rapidly analyzed. It is highly efficient for sampling dust in ordinary work places where the atmosphere is not too highly polluted. The objections to its use are that it takes an instantaneous sample of only 9 or 10 cubic centimeters of air, that a weight analysis is not available and that it yields low results when used in very dusty atmospheres. The konimeter may be used for studies of atmospheres of low or medium dust content where the desideratum is to quickly establish the conditions of the atmosphere. For plant engineers it is to be highly recommended.

The Owens Jet Dust Counter depends for its action on the following principle: When air which contains dust passes through a narrow orifice towards a glass surface which faces the jet a short distance away, the dust will adhere to the glass and can be examined microscopically. In the instrument this result is brought about by causing a very fine ribbon-shaped jet of air to strike a microscope cover glass placed about 1mm. from a slot-shaped opening forming the jet. The air before entering the slot passes through a dampening chamber, and the velocity in the jet is such that a fall of pressure results, thus bringing about a condensation of moisture. The air is then deflected and the dust, being unable to turn the corner, strikes the cover glass, the velocity of the air falls off, the pressure and temperature rise, causing the water to be evaporated and the dust is left behind.

The dust sample is examined microscopically in a manner very similar to the technique employed for the konimeter samples. This instrument is also not adapted for studying dusts of a high concentration, such as are encountered in many of our industries today. It has been found to be very useful in studying the pollution of the atmospheres of our large cities and is especially valuable in obtaining samples for the determination of particle size of dusts.

The Impinger apparatus, which has already been described in numerous publications of the Public Health Service (2), (6), (7), also operates on the principle of impingement, but in this instrument air is impinged at a high velocity on a wetted surface and then bubbled through distilled water of a known dust content. After sampling, the dust-laden water is examined at the laboratory in a manner described in the papers just mentioned. We have found this instrument to be highly efficient, capable of sampling large volumes of air (one cubic foot per minute), and one having low control errors. It is recommended for use in all intensive dust studies, no matter how high or low the dust concentrations may be. We have also found it useful in other investigations, such as the lead hazard in storage battery plants and in studying the amount of chromic acid present in chromium plating establishments.

In Table 3 which follows, there is presented a summary of the average dust content of the air in certain dusty trades. This table shows that with the exception of soft and hard coal the highest dust exposure was in the granite cutting industry. Owing to the higher percentage of free silica as quartz, however, granite cutting is certainly first on the list so far as the magnitude of exposure and dangerousness to health are concerned.

TABLE 3
Average Dust Counts in Certain Dusty Trades

Industry	Dust Count Million particles per cu. ft. of air.
Cement	26.0
Granite Cutting:	
Cutters	
Hand pneumatic tool operatives[1]	59.2
Others[2]	35.9
Attendant labor	17.0
Anthracite Coal Mining:	
Miners and miners' helpers	231.5
Attendant labor	31.1
Bituminous Coal Mining:	
Coal cutters and coal loaders	112.3
Attendant labor	3.9
Silverware Manufacturing:	
Rooms where dust is created	
Dusty processes	5.2
Non-dusty processes	1.7
Other rooms	0.8
Municipal Dust (Street Cleaners):	
Congested district	4.1
Residential district	1.8
Cotton Industry:	
Carding room	8.6
Weaving and spinning room	4.5

(1) Including 58 per cent of all workers.
(2) Carvers and letterers included with other cutters (surface machine operatives, lathe operatives and sand blast operatives).

As a result of all these dust studies in this country, as well as studies of a somewhat similar nature in South Africa and Australia, it has been possible to suggest tentative standards for the upper limit of dustiness to be regarded as allowable in certain industries.

The South African investigators (9), using the Kotzé konimeter for dust sampling and dealing with a dust found to contain free silica as quartz in excess of 85 per cent, set a tentative standard of 300 particles per cubic centimeter of air (i. e., 8.5 million particles per cubic foot) as the upper limit of dustiness to be regarded as allowable. On the other hand, the Australian investigators dealing with a sandstone dust in the Sydney mines, found that the quartz content of this dust was from 86 to 95 per cent, and advocated a standard of dustiness not to exceed 200 particles per cubic centimeter as determined by the Owens jet dust sampler. These investigators also found that the Owens dust counts correlated very well with the weight of the dust determined by the Impinger apparatus, the instrument used in all our studies.

Our investigation in certain plants of the granite cutting industry discussed above has shown the dust to contain from 31 to 38 per cent of free silica in the form of quartz. At the outset, then, we might expect to arrive at a less severe dust standard than advocated by the South Africans and Australians. Of particular importance in our study was the fact that it was possible to divide the workers into four groups, depending upon the average exposure in terms of the amount of dust in the air.

In Group A, which included hand-pneumatic tool operators and in which the exposure averaged about 59 million particles per cubic foot of air, it was found that

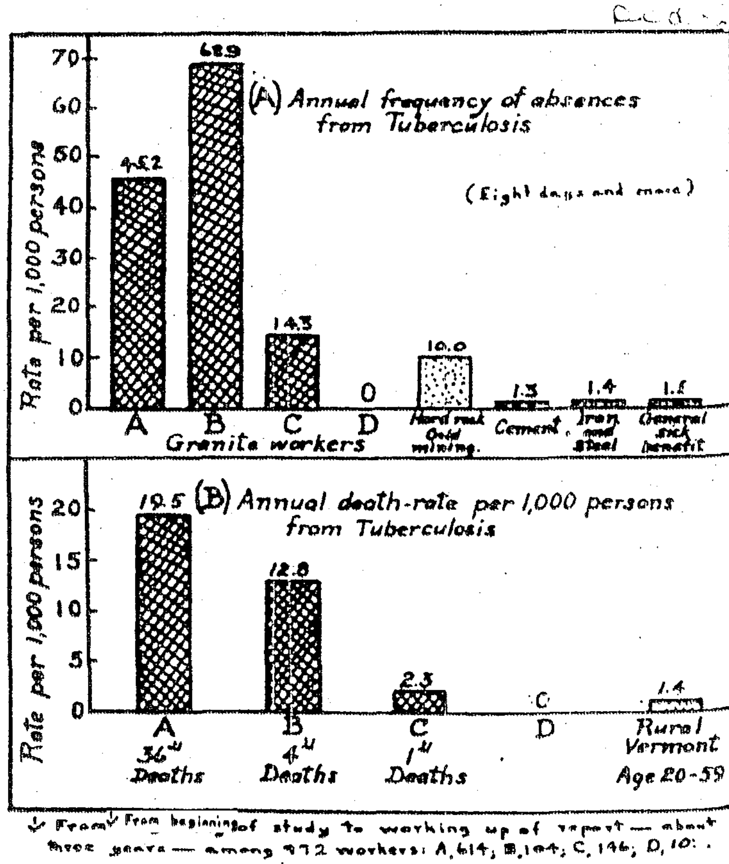

Figure 22

practically 100 per cent 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. (See Figure 22). 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 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. The same limit would presumably be applicable in the case of other dusts with the same physical characteristics, particularly with a quartz content of about 35 per cent.

Dust Supervision

In the foregoing pages of this paper sufficient evidence has been presented to indicate the close relation existing between the morbidity and mortality rates from various respiratory diseases and the exposure to certain dusts in industry. In the study of the dust hazard in the granite cutting industry we have been able to definitely prove that there is a direct relation between the magnitude of the dust exposure and sickness and death resulting from tuberculosis. It is quite evident, as a result of all our studies, that the remedy of the dust evil lies in the effective removal or suppression of the dust to a concentration considered safe. There are several methods at present in use in combatting the dust hazard, the application of any one particular method depending largely on the industrial process creating dust.

The protection of workers against certain dusts may be at times accomplished by the mechanical enclosure of the dust creating processes. An excellent illustration of this type of protection is afforded by the modern sandblast barrel used in the cleaning of small objects. Sometimes it is possible to protect workers by the substitution of wet for dry processes. In one instance in our granite study an operator using a diamond point pneumatic tool worked the stone wet; the resulting dust amounted to 21.8 million particles per cubic foot. The same operator was then requested to work the stone dry; as a result, the amount of dust reached the high figure of 45.2 million particles per cubic foot. In the weaving of asbestos cloth it has been possible to reduce the amount of dust in the air by wet weaving to one-fourth of the amount present when the process is conducted by dry methods. However, wet methods are not always to be relied upon for the complete suppression of dust. For example, in a study of the dust hazard in the wet and dry grinding shops of an ax factory, Winslow and Greenburg (11) have shown that protection afforded by wet grinding, as compared with dry grinding using an exhaust system, is, in most instances, illusory. The same result was found in our granite study in determining the exposure of tool grinders in that industry.

In certain extreme cases such as in the sandblasting of large castings in sandblast rooms, the only practical safeguard to the worker is to provide him with a helmet of the positive air pressure type. In most dusty processes, however, the most effective means of dust elimination, are by the use of properly designed local exhaust ventilation systems. In certain rock drilling operations in mines a dust trap is now in use which effectively removes dust created by pneumatic rock drills. Such a trap has been designed by Captain Hay of London (12), and the practical tests conducted with his device have demonstrated its ability to remove fine dust created by pneumatic drills. Quite recently workers at the Harvard School of Public Health (13) have reported the results of their laboratory study of the design of dust control systems for use with pneumatic granite cutting tools. These workers, using our tentative standard of allowable dustiness in the granite cutting industry, namely, 10 million particles of dust per cubic foot of air, have designed hoods and determined air flows to be used in keeping the dust created by pneumatic tools below this proposed standard. A similar investigation, but somewhat briefer in scope, was made by the writer in studying the efficiency of dust removal devices now actually in use in modern granite cutting plants. The results of this study were reported in the

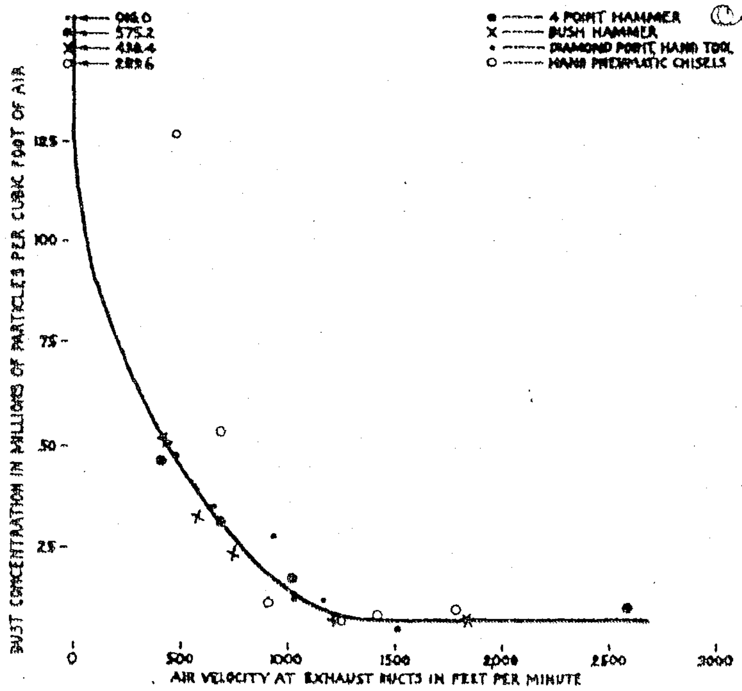

Figure 5

Public Health Reports (14) and Figure 5, summarizes the results of this study. This figure shows the relation between the dust concentration in the air at the worker's breathing level when using various pneumatic tools and the air velocity at the local exhaust ducts. From this figure it is apparent that a velocity of 1,500 linear feet per minute is necessary to keep the dust concentration at the worker's breathing level below 10 million particles per cubic foot of air, the amount found in our study as not associated with any disabling illness.

The Massachusetts State Board of Health some years ago laid down the principle that in fixing standards of industrial hygiene it was reasonable to require that conditions should be maintained in any industry approximately equal to those already found in the best plants of that industry in actual operation. With such a rule in mind, Winslow, Greenburg and Angermyer (15), in studying the efficiency of exhaust systems in polishing shops, also found that an air flow of 1,500 linear feet per minute was the minimum exhaust velocity to be maintained at exhaust ducts used with polishing and grinding processes. In the absence of clinical and morbidity data, this is a pretty good rule to follow.

At the present time many states have industrial codes which specify the amount of suction and type of exhaust hoods to be maintained in connection with dust removal systems. All of these codes are general in nature and are not based on definite knowledge of the harmfulness of the particular dust under consideration. It is necessary to maintain certain suction heads and air velocities in dust removal systems, but what one really wants to ascertain is whether the dust has actually been removed. For this reason the only standard that can be satisfactory and one which should be incorporated in our State Industrial Codes, is the one based on the number of particles of dust which has been found by careful investigation to be an amount which can be inhaled with impunity. The Public Health Service, in undertaking its series of dust studies, has had such an object in mind, and as a result of these investigations we are in a position to present data in connection with threshold doses of dusts, as illustrated by the results just given for the granite cutting industry. It is only through such studies, which take into consideration all the factors of occupational environment and their relationship to the physical condition and sickness of workers, that we may hope to make progress in coping with the industrial dust problem.

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CHAIRMAN WHITTEMORE: I think this is a very interesting subject and we would like to hear any comments you may have at this time.

JOHN S. SHAW (Hercules Powder Co., Wilmington, Del.): I would like to ask, in arriving at the tolerance of ten million particles of dust per cubic foot how do you determine that this is the safe limit to which the worker may endure dust? Also how is dust eliminated from the bronchi and lung tissue. Is it thrown off through the expectorant as a result of the raising of the mucus from the bronchi?

MR. BLOOMFIELD: These people in group "D" exposed to ten million particles per cubic foot of air were not disabled, even after working thirty or forty years in the industry.

I wonder if we couldn't hear from Dr. Greenburg on this particular matter.

DR. LEONARD GREENBURG (U. S. Public Health Service): I think Mr. Bloomfield's contribution is an interesting one and it causes me to go back ten or twelve years ago. Really the first study we did before I came with the Service was in cooperation with the Bureau of Mines in regard to work being carried on in hard rock mines. We got some interesting results, and we compared them with the South African findings.

Even today it constitutes the best literature on the subject, outside of what we have received from the Public Health Service, and the accomplishments of a half dozen who have given the matter study have been a real contribution to the medical aspect and public health aspect of this whole problem.

To you, as chemists, perhaps some of these things may be uninteresting but nevertheless in the chemical industry for grinding sand for the making of scouring soap and carborundum and allied fields of that type, the problem is an exceedingly important one.

One very interesting thing to me about this whole afternoon's discussion is the new aspect of our handling these problems. Some years ago we were happy if we could get a few fundamental facts to talk about, and today you see a new status quo, and the studies are being put on a careful quantitative basis. I think perhaps that leads us to believe that we will have a very warm outlook for the future.

We know more about the handling of dust problems, and we know more about the handling of ventilating problems, than we ever knew before. If we keep up this quantitative type of work, and instead of generalizing so much, perhaps, keeping up this type of work as described by Mr. Gumaer this afternoon, and also the type of work as described by Mr. Bloomfield, we will be able to handle these subjects in a more satisfactory manner than ever before.

ADJOURNMENT