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CORRELATION OF DUST-COUNT RESULTS BY ZEISS KONIMETER AND MIDGET IMPINGER

BY

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A

THESIS

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Approved by

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ABSTRACT

In this modern age, the scientific and technological developments have advanced mechanized mining to the status wherein the attendant dust problems have reached very serious hazard proportions. The significant roles, which have been perfected for the Zeiss konimeter and the midget impinger, in evaluating dust concentrations and thereby revealing possible improvements in making the atmospheric conditions safer, cannot be over emphasized.

While introducing the subject of this paper in the first chapter, the author has presented a historical resume, wherein he pointed out that performaces of these instruments have not been correlated in the past. However, the work reported on each individual mechanism has been reviewed in chapter two.

The above instruments and their standard techniques for measuring dust concentrations are described in chapter three and the experimental procedures based on these techniques and the data collected during the investigation, are presented in chapter four.

The data are analysed and discussed in chapter five whereby it is revealed that, due to the inherent nature of the dust particles in creating rapid fluctuations and due to great divergence in sampling characteristics of the instruments, no constant ratio or conversion factor from dust concentration measurements of one instrument to equal values for another, has been possible. The relative performance of these instruments is presented graphically.

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CHAPTER I

INTRODUCTION

General

At the turn of the century, when a new scientific, political, and economic development began in the entire industrial world, a greater demand for minerals resulted in a widespread increase in the mining operations that had been practiced during the latter part of the nineteenth century. New reciprocating and rotating drills were introduced by which most orebodies could be broken more easily and readily than had been previously possible. Many heavy machines were installed for transporting and handling mass production of minerals. With this progress, however, came diseases which were caused by unhealthful working conditions that grew worse as the mines reached greater depths and production reached higher levels. The air-borne dust in the mines thus became by far the largest problem to the well-being of the mine workers and of great economic significance to the mining industry. The toll in sickness and death due to harmful dusts continued to mount. According to Peele (38), mortality from siliceous dusts was far greater than that from accidents of all kinds, and it probably caused more suffering than the spectacular calamities in coal mining.

The injuries to human life and health in the first ruthless years of industrialization were so evident that it proved necessary to investigate working conditions and their effect on human health. This was done by private individuals, scientists, governmental councils and industrialists. Many research laboratories were set up for finding out ways and means of alleviating such unhealthful conditions. Many health surveys were undertaken to learn the effects of air-borne dust on the miners working under various contaminated conditions. Large sums of money have been and are being spent on this problem. Many effective steps to measure the dust in the mine atmosphere and to exercise control on its production have been and are being undertaken. As a result of these investigations, and through enforcement of effective controls in mines, the high levels of pollution of the earlier days have been largely reduced. But the potential hazards still remain and the control of industrial dust continues as a never ending battle. Beginning with emperical but commonsense measures, the dust control program has now the benefit of considerable insight into the nature of dust hazards and is aided by quantitative methods for the measurement and evaluation of dust exposures. An understanding of the physical behavior of dust provides an increasingly sound engineering basis for the design of dust-control measures.

Historical Resume

Though the fact that dust is injurious to the miner's health has only been properly appreciated since the beginning of this century, it has been known for many centuries. Collis (34, p. 54), says "Hippocrates, the father of medicines (370 B.C.), speaks of the metal digger, who we may presume was exposed to dust, as having a costive belly, breathing with difficulty and liable to swellings of the knee and of a pale wan complexion." Among these appeared some of the symptoms of miners disease, which is therefore at least 2300 years old. Pliny the Elder (39, p. 125), in the first century of our era speak of miners using a form of respirator to avoid the inhalation of dust; and Agricola (1, p. 6), in his famous "De Re Metallica" (1557) speaks of the dust of some dry mines ulcerating the lungs and causing consumptions and early death to many miners. He also describes how on one field the men bind bladders to their lungs and eyes. Other references follow in later centuries, but chiefly on the life shortening effect of dust to stone masons working in sandstones.

It was not until 1862 that "miners disease" was established by a royal commission in England which inquired into the health of miners in metalliferous mines. There was evidently some prejudiced person on this committee, for, despite the evidence of men themselves that dust was their chief trouble, the cause of the disease was put down to the defective hygienic condition below ground (17).

The awakening to the seriousness of the dust hazards came in 1901, when the government mining engineer in South Africa reported an annual death rate of 73 per 1000 employed miners. Only since then, as a result of an immense amount of research work on dust and systematic study of dust disease among miners, in South Africa and later on in such other industrial countries as the United States of America, Great Britain, Germany, Canada, and Australia, has the danger of dust been fully understood. These extensive investigations have lead to the universal conclusion that inhalation of dust is the main cause of pulmonary diseases among miners, and that every mine atmosphere must be measured for dust and its concentration must be kept as low as possible.

Sources of Mine Dust

Many mining operations involve the rubbing of rock with the rock itself or with machinery. Drilling, loading and the passage of ore in chutes and cars all produce dust in the process, and this happens when the men are actually at work. Blasting is another major source of dangerous dust in mining operations. Besides developing fine dust that tends to remain suspended in the mine air because of the large amount of water vapor produced after blasting, noxious gases also result. The noxious gases, particularly the oxides of nitrogen and sulphur, tend to accelerate the harmful effects of silicosis.

In Metal Mines

The main sources of dust in metal-mine air in the order of importance are:

a) Dry-drilling holes for blasting;
b) Blasting;
c) Shovelling or mucking very fine dry material at the working face which is usually poorly ventilated;
d) Loading cars from chutes and dumping loaded cars into chutes; and
e) Timbering.

Dry crushing in metal-mine mills is also likely to be dangerously dusty.

In Coal Mines

The main sources of dust in coal mines in the order of importance are:

a) Cutting or loading dry coal by machines;
b) Blasting;
c) Shovelling;
d) Drilling; and
e) Rock dusting by machinery.

In addition to the miners and their helpers, rockworkers, timbermen and drivers who must enter the miners' working places when the air is particularly dusty are exposed to relatively large amounts of dust.

Physiological Considerations

Types of Dust Injurious to Health

As a result of earlier investigations, so much attention was focussed on one particular dust - silica - as the most harmful encountered in the industry, that most investigators had accepted other dusts as harmless or of negligible importance. It is, however, not true as other dusts, such as the silicates (asbestos, for example), have been found almost as harmful as silica dust but the effects on lungs are somewhat different from that of silica, and the hazards are not so widespread. Forbis, Devenport, and Morgis (17, p. -) in their "Review of Literature on Dust" quote Harrington's conclusion which states;

> "Any dust insoluble in the fluids of the respiratory passages and in sufficiently finely divided form to float in the air and be breathed by underground workers will ultimately be harmful to health if the dust is in the air in large quantity and is breathed by workers for considerable periods of time. This applies to insoluble non-mineral as well as mineral dusts or mixtures of them and includes coal dust or mixtures of coal and other dusts. There are also some definitely harmful mine dusts which are soluble, and some dust experts appear to believe that the so-called insoluble dusts under certain conditions become soluble and are harmful only when soluble."

In spite of the above fact, free silica or quartz has been considered the outstanding dust factor in industries with excessive mortality from dust diseases. Silica is one of the most common mineral constituents and is said to constitute approximately 60 per cent of the earth's crust; a large part of this is free silica (quartz chert, flint, etc.).

Particle Size

The most dangerous dust is said to be that ranging from 5 microns to 0.5 microns or smaller; in other words, the smaller the particles the greater the danger, and particles of these sizes are too small to be seen by naked eye. One micron is 1/1000mm or approximately 1/25000 inch in diameter.

Quantity of Dust

Although extensive research work has been done on dust and its harmfulness, no precise method has so far been developed whereby the exact quantity of dust in the atmosphere may be determined. The more accurately are the instruments designed, the greater is the number of dust particles recorded in the same atmosphere. This is mostly due to the ability of the more accurate instrument to collect a greater number of smaller size particles which remain undetected by the less accurate equipment. To do away with this anamoly, some standards of harmfulness of the dust concentration in the atmosphere have been fixed. These standards vary in different countries; depending upon the quality of the dust and the type of equipment used for determining the dustiness of the mine atmosphere.

Research in the field of dust inhalation appears to have demonstrated that, in general, the degree of health hazard associated with the inhalation of dust, largely depends on its percent silica content. It is evidenced by the fact that almost all countries fix the maximum allowable dust concentration on the basis of silica composition in the rock.

Length of Exposure

The length of exposure to silica dust required to produce silicosis depends primarily on the individual concerned and the amount and size of the dust particles in the air breathed; however, numerous other factors may exert a definite influence. According to Forbes, et al, the shortest period worked underground was two years for first stage silicotics and the longest was forty years for third stage silicotics. They mention; (17, p.)

> "In the granite industry some workers exposed to the heaviest dust concentration develop silicosis after two years whereas others do not develop the disease before fifty years of exposure. Among sand blasters, silicosis may develop after three years of exposure; in Ontario gold mines it is said to develop in some individuals in 9 or 10 years; in a sand pulverizing plant the longest period of occupation before lung infection became apparent is said to have been 2.5 years during which the dust was breathed at intervals; and shortest, 35 days during a period of little over a year. Data collected by the Federal Bureau of Mines in one study show that first stage silicotics had worked underground an average of 12.99 years for all men, irrespective of occupation; those in the second stage had worked an average of 15.8 years for all men, irrespective of occupation; and third stage silicotics had worked an average of 18 years for all men in all occupations."

Dust Diseases

The most common dust diseases are:

a) Pneumoconiosis.---A general term covering all dust diseases of the lungs, fibrous or non-fibrous (from Greek Pneumon, lung; and konis, dust)

b) Silicosis.---A fibrosis caused by free silica (or quartz) and the best shown scientifically of the dust diseases of the lungs.

c) Silicatosis.---A type of fibrosis found after exposure to certain mineral dusts and assumed to be caused by various silicates. It is distinct from the sharply defined, coarse, nodular fibrosis caused by silica dust.

d) Anthracosis.---A dust disease of the lungs found in coal miners; it is ill-defined and is presumed to depend on inorganic dust in coal. The lungs are black.

e) Siderosis.---A term applied to fibrosis of the lungs found in metal workers. The condition is ill-defined. The lungs are yellow or red from metallic oxides, generally of iron.

f) Asbestosis.---A fibrosis of the lungs with characteristic microscopical sigmata due to breathing asbestos dust, a silicate of magnesium.

In spite of the medical research on silicosis and other dust diseases, no cure has so far been discovered for these diseases. Prevention, therefore, appears to be the only effective remedy; at least until science comes to the front with some cure not now available. Prevention of dust disease in mining industry involves the engineering problem of controlling dust production and conditioning the air breathed by workers by removal of dust and other contaminants polluting the atmospheric air.

Economic and Legal Considerations

Besides causing irremediable damage to the health of the mine workers, dust creates significant economic problems to the mining industry. Money paid as compensation for silicosis has been costing the mining industry large amounts and has involved frequent court disputes with additional expenditures to fight racketeers. The compensation laws for silicosis, in many countries, are very stringent, and small companies are affected more seriously than larger ones.

The magnitude of this problem can be judged by the statement that follows. The committee on the economic, legal and insurance phase of the silicosis problem set up by the United States Government in 1938 reported (49):

> "That approximately one million industrial workers may be exposed to a silica hazard, reference is made to potential rather than actual exposure."

Harrington and Davenport (23, p. -) mention that in 1935 about $100,000,000 in silicosis claims were pending in courts in the United States.

They also state that "The total amount paid for silicosis compensation since the enactment of the miners phthisis laws of South Africa to 1934 exceeded 14,000,000 pounds (about $70,000,000). The cost of compensation per ton of ore milled has been about 6d. (about 12 cents) and per ounce of gold recovered is 1s.7d. (about 38 cents); the cost per underground European shift was about 4s. (one dollar)." In Canada it is said that cost of silicosis compensation is 1¼ percent of the total mine payroll although only 2¼ percent of the men employed by the mining companies are actually exposed. The estimated cost of each case to the company is $11,000 to $12,000. It has been said that for every five dollars spent in mining and concentrating a ton of gold ore, one dollar is required for "silicosis".

Air Dustiness In Mines

Purpose

The increasing recognition of the fact that the inhalation of air containing certain dusts is harmful is stimulating much interest in equipment and methods for determining the composition, concentration and particle size distribution of the dust in the air of mines. The information on these properties of the dust is needed for the following reasons:

a) To determine the maximum concentration of the particular dust that can be inhaled over a normal working lifetime without apparent harm. Clinical findings on the exposed workers are also needed to obtain this information.

b) To estimate the effect of a dusty atmosphere on exposed workers.

c) To determine the effect of control measures.

Mine officials are usually interested in obtaining information on the properties of dust in the air of their mine to estimate the effect of the particular dusty atmosphere on the workers or to determine the effect of control measures. The effect of the dusty atmosphere is estimated by comparing the results obtained in the mines with the maximum or threshold concentration of similar dusts found to be safe to breathe by organizations such as the U. S. Bureau of Mines and the U. S. Public Health Service in this country and corresponding governmental organizations in other countries.

Composition

The determination of the composition of air-suspended dust is not necessary when the dust is generated from a single compound or when the assumption is made that all the air suspended dust is silica or other harmful material. This assumption is rather commonly used in formulating dust control programs. The air-suspended dust generated from complex substances or materials consisting of two or more compounds is not necessarily the same as that of the material from which the dust is generated because of possible differential disintegration of the different constituents and the selective settling of these materials from the air. There is some evidence that the dust generated from the substances consisting of silica and softer materials contains less silica than the material from which the dust is generated. Hatch (24) has found that the percentage of silica in foundry dust decreases with a decrease in the particle size range of the dust.

Thus, until more pertinent information is obtained, it seems safer to assume that the percentage of silica in the air suspended dust is the same as that of the material from which the dust is generated. Any error will probably be in over-estimating the percentage of silica in the air-suspended dust.

Concentration

Determination of concentration of dust in the air of a mine in which quartz or some other harmful dust is generated is important for determining whether a dust condition harmful to the health of the workers exists, and is essential in routine dust control work.

Particle Size Distribution

At present, information on particle-size distribution of air-suspended dust, for the purposes mentioned above, is of relatively minor importance because it has been fairly well established that most of the particles are small enough to reach the depths of the lung.

Concentration as an Index of Hazard

The first purpose, namely, to determine whether a harmful dust condition exists, is usually accomplished by comparing concentration results found in the mine with the best available information on the "permissible" or maximum concentration of the particular dust which may be inhaled over a normal working lifetime without apparent harm. Since dust concentration results obtained by different methods and types of equipment are, in general, not comparable, information for this purpose should be obtained by the same type of equipment and method used in determining the permissible dust concentrations.

Sampling Apparatus

A number of methods have been developed for the determination of the dust concentration in air. Some of them have been reported as very efficient and may be more satisfactory for research than the most common methods employed for regular routine sampling purposes.

The thermal precipitator, which is considered to be the most accurate instrument, was originally devised by Whitelaw-Gray and Lomax (36) in England. Its accuracy has been established by comparing counts on thermal precipitator samples with absolute measurements made on the same atmosphere with a special ultra microscope and with a sedimentation cell. It is, however, somewhat delicate and requires an accumulator as a source of current. It may, therefore, be found somewhat cumbersome for taking large numbers of routine samples (25).

In practical mine use, the accurate research equipment is unwieldy and requires a high degree of technical skill to manipulate it. Also it gives less general practical information to the operator in the same length of time than the routine types of sampling methods which are in most common use in the mines. Moreover, it is doubtful whether, at the present stage of affairs, the results obtained from the precise methods have any more practical significance than those obtained with the simpler and more portable apparatus, which can rapidly give a sufficiently reliable indication of the relative dust hazard.

Of the several types of dust sampling apparatus which are available for routine observations, the Zeiss Konimeter has proved very popular in South Africa, Canada, and various countries in Europe including Great Britain and Germany; whereas, in the United States of America, the Midget Impinger is the most common instrument employed for the same purpose.

Zeiss Konimeter

The Konimeter was devised in 1916 by Sir Robert Kotze the then Chairman of the Miners' Phthisis Prevention Committee and Government Mining Engineer, in South Africa where dust investigations have proceeded on a considerable scale because of incidence of silicosis on the gold and other metalliferous mines. This invention of a practical little instrument for trapping suspended matter in the air for examination under microscope brought a big innovation in solving the dust problems on which the entire industrial world, at that time, was seriously busy.

Several improvements were later made on this instrument and it was ultimately developed into the Circular Konimeter which became popular for a considerable time in South Africa and other countries using it. In 1928 the Carl Zeiss firm in Jena constructed the instrument which was named "Zeiss Konimeter" after its firm. This instrument had several improvements over the circular one and almost replaced it. In the Modified Zeiss Konimeter, which is a further improvement on the original, all particles above a certain size which are not considered harmful, are removed from a sample of air by filteration. The finest particles remaining in suspension are deposited on a slide in the original way.

Standard of Permissible Dustiness

In a survey conducted on the health of South African miners for standardizing maximum dust limit in a mine, the circular konimeter was used. In south Africa, where dust is said to contain more than 85 percent free silica as quartz, a tentative standard of 300 particles per cubic centimeters of air (8.5 million particles per cubic foot) has been set as the upper permissible limit of dustiness.

Comparative tests made with the Zeiss and Kotze instruments under identical conditions revealed that the Zeiss has an efficiency 50 percent higher than the Kotze; therefore, in making determinations with Zeiss konimeter the permissible limit of dust concentration is increased from 300 to 450 particles per cubic centimeter (17).

Midget Impinger

The impinger was developed in the United States of America by the Bureau of Mines in cooperation with the Public Health Service in 1922. The instrument has been used widely, but it has always been criticised for its bulk, weight, and power requirements. It was thought that these criticisms could be overcome to some extent by developing a more readily portable and easily operated instrument. It was also believed that a smaller instrument identical in principal and using the same counting technique should give the same results within experimental limits.

With these ideas in mind, the midget impinger dust-sampling apparatus was developed by the United States Bureau of Mines in 1937, and since then has been the most popular one being employed by the mining as well as other dusty industries for all routine sampling purposes.

Standard of Permissible Dustiness

The Bureau of Mines has made the following tentative recommendations on the permissible limits of air dustiness (49):

> "In bituminous-coal and lignite mines, the average full shift concentration of atmospheric dust to which a workman may be exposed should not exceed 20 million particles per cubic foot of air, and a maximum concentration for any single operation should not exceed 40 million particles of dust per cubic foot of air. When the dust contains silica, not more than 5 million particles of silica dust per cubic foot of air should be present in the above limiting concentrations. The dust count may be multiplied by the percentage of silica concentration, and if the result is less than 5 millions the dust concentration will be considered safe."

As shown in Figure 1, to maintain these standards, the maximum dust concentration limit is 18.9 million particles per cubic foot of air when average shale roof is drilled and 9.1 million particles when the average sandstone roof is drilled.

For metal mines following limitations have been made:

Dust (nuisance, no free silica).....50 m.p.p.c.
Silica:
    High (above 50% free silica)... 5 m.p.p.c.
    Medium (5 to 50% free silica)..20 m.p.p.c.
    Low (below 5% free silica).....50 m.p.p.c.
Slate:
    Below 5% free silica...........50 m.p.p.c.
Total dust:
    Below 5% free silica...........50 m.p.p.c.

The above limiting concentrations for permissible air dustiness in coal, lignite, or metal mines, as the case may be, are based on midget impinger samples in which light field counts are made under microscope.

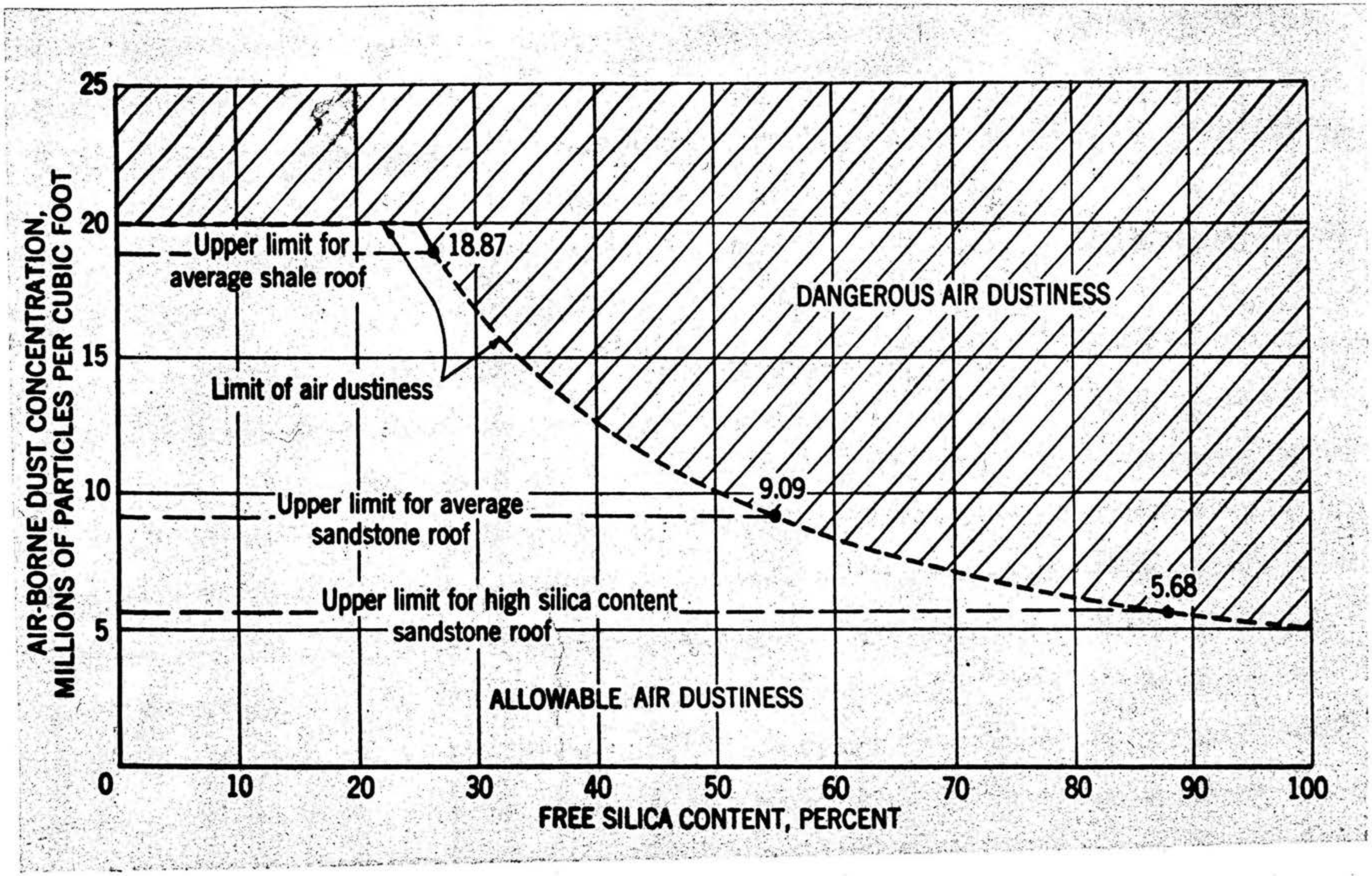

Figure 1. - Allowable atmospheric-dust concentrations relative to free silica content
From - United States Bureau of Mines, I. C. 7615

Correlation of Standards of Dustiness

Ever since the severity of the miner's disease was recognized by the industrial world, investigations have been continuing on devising an ideal instrument capable of efficiently sampling the dusty atmosphere in the manner quite similar to the inhaling of dust by the miners. It should be portable, light in weight, simple in procedure and its samples should be analysed with minimum errors. It should also eliminate, as far as possible, variations or errors due to the "human equation". No such perfect equipment has, however, been made which could incorporate all the qualities of an ideal equipment. The instruments described here have still been serving the industry for the last several decades and have proved to be the boon to the mining industry.

According to Barcza (3) the incidence rate of silicosis, as recorded in 1952, was less than one tenth of the mortality rate fifty years before. This appreciable reduction has been attributed to these sampling instruments, as, before any effective steps could ever be taken it was necessary to know the quantity of dust in the atmosphere. These instruments have done remarkable work towards the safety of the mine workers and improving the economy of the industry.

For the last several decades silicosis has been the subject of discussion on an international level. It is surprising that the instruments gauging the harmfulness of silica dust have been different in different countries, with different safety limits of permissible dustiness. The instruments are both very popular but altogether different in character. The Konimeter is a snap shot instrument whereas the Impinger records average dustiness. The conditions causing silicosis have universally been accepted, i.e., the percentage of silica dust particles in the atmosphere has been considered an important factor in spreading the severity of the disease, the difference in safe limits of dustiness makes a ridiculous picture. In order to explain this difference, no available literature anywhere describes the characteristics of one instrument in an atmosphere of air-borne dust for which the characteristics of the other instrument are known.

The standards of permissible dustiness, whether they are on an arbitrary basis or bear any kind of relationship with the merits of the equipment concerned, can be explained if the relative performance of one equipment with respect to the other can be determined over a long range of varied conditions. This can be determined by taking simultaneous samples of air-borne dust with the sampling location of each instrument as close to one another as possible, by using a standard procedure of the dust evaluation and then by correlating the resulting sampling data obtained from each. In order, therefore, to fulfill these objectives and to bridge the gap between different standards of dustiness for the purpose of correlating data resulting from their respective applications, this investigation was undertaken.

CHAPTER II

REVIEW OF LITERATURE

General

In 1934, Green (22) found that, in the literature dealing with hazards due to mineral dusts, there was a general lack of information concerning the intrinsic nature of the dusts as they exist in the air. Later, in 1937, Harrington and Davenport (23) made a review of the literature on the incidence, effects, determination and control of dusts. This review was revised, in 1950, by Forbes, Davenport and Morgis (17), and they added data that had accumulated during the interval and some that had appeared previous thereto but were not available to the authors at that time. On page 12, they concluded this review of the enormous literature with the following statement:

> "Close analysis of the status of dust in industry (and in general life outside of industry also) indicates that numerous--one might almost say innumerable--uncertainties still exist as to specific features connected with dust harmfulness. So numerous and far-reaching are these uncertainties... that almost the only definite fact is that dust is a menace and that all kinds of it likely to come in contact with human beings should be reduced to a minimum or at least be held under positive control until much well-planned, well-correlated research and investigation (field and laboratory) have been conducted on almost every phase of the subject."

According to Drinker and Hatch (15), in the case of active dust-producing processes, dustiness is subject to rapid fluctuations from moment to moment and from day to day. These fluctuations are therefore likely to be normal and not exceptional events. If these are not shown by the survey, then the samples and the survey are both misleading and incomplete. The probelm is further complicated by the fact that the universe to be sampled is not stable; either in space or in time. A proper measure of dust exposure requires a picture of the variations in dustiness and dust floods, as well as a measure of the average concentration.

On Konimeter

According to Nelson (35), the Zeiss konimeter is probably the best of the portable types of mine dust sampling instruments presently available. By means of a microscope, which is incorporated in the instrument, the dust samples can be examined on the site, and, if shown to be necessary, immediate steps can be taken to improve the condition.

According to the Coal Research Committee of the Monmouthshire and South Wales Coal Owners' Association (11), the Zeiss konimeter is more efficient than the Kotze. They also state (11, p. 486):

> "The konimeter only takes snap samples, and unless several samples are taken over a period, very misleading results may be obtained. Snap samples are, however, very useful when comparative figures are required for a rapid change in dust concentration, e.g., during the loading of a tram. The konimeter is the only instrument available for recording such quick changes."

Davies (13) has tested several instruments of the impingement type and has found that, when used in coal dust, a proportion of the larger aggregates of size range 3 microns to 10 microns become disaggregated when passing through the jet of the instrument. In his opinion, the konimeter is suitable for making routine mine tests, but, if used for investigations into the effects of particle size, a distorted picture might result.

Burdekin (10) has compared the mean of a number of konimeter samples with thermal precipitator samples taken at the same time. He found that the error involved in counting konimeter spots is less than $\nleq$ 10 per cent of the mean of several counts. He also stated, that with the tests made in a moving dust cloud, the konimeter returned a mean result approximating that given by the thermal precipitator for the particle size range 0.9 to 5.0 microns.

Patterson (36) has published figures which indicate a very low efficiency for the konimeter; particularly for the smaller particles. Rabson (40), on the other hand, claims a collecting efficiency of 90 per cent for the konimeter.

Beadle (4) found that when three konimeter samples are spaced over a 2 minute interval, they can give an average count which is close to the true mean concentration for that period. In a comparative study of the konimeter and the thermal precipitator, he has found that the efficiency of the konimeter decreases with the increase in dust concentration but shows high apparent efficiency in sampling the coarse dust due to the disaggregation of the particles impinging on the glass plate. Hardy (4, p.285), also reports that the konimeter samples deviate from the average count according to the dust concentration of the air at the time of sampling; this is when the thermal precipitator is used to measure the average count over the period of sampling.

According to Flugge-De-Smidt (4, p. 284)

> "The filteration processes of the human body are capable of filtering dust out of the air when that dust is only present up to a certain concentration, say for the sake of argument, 300 particles per c.c. Should a person encounter a dust cloud of, say 1,000 particles per c.c. as registered by a konimeter, than the human body can only cope with, say, 300 particles and the remaining 700 particles enter the lungs. The rate of breathing is another factor affecting the filtering process of the human body. Believing this to be fundamentally correct,... an average of, say, 200 particles per c.c. over half an hour can be more dangerous than an average of 300 particles per c.c. if in the first case a number of peaks ocurred, and in the second case a smoother curve was obtained."

This statement is, however, not supported by any pathological experiment (4).

Gibson (20) states that the konimeter counts of the order of 100 to 300 particles per cubic centimeter are good; those of the order of 500 to 700 or 800 are only fair; while those in excess of 1,000 p.p.c.c. are poor.

According to Andrew (2), the konimeter is a simple, portable and rugged instrument that can be used in almost any situation encountered in a mine or plant. It has a fair efficiency in the countable range. If maintained in good mechanical condition and conscientiously used, its results are consistent and it will enable the operator to adequately assess dust conditions.

On Impinger

Watson (47) states that the impinger, as used according to the standard practice in the United States, has an over all efficiency of less than 40 per cent, and that particles smaller than 0.8 micron are not revealed. This is true of the Greenburg-Smith impinger of which midget impinger is a modification.

Tilson (45), however, reports 94 to 96 per cent efficiency for the same instrument.

Barnes (17) has pointed out various objections to the use of the impinger. According to him, the impinger is not suitable for particles of less than 0.7 to 0.8 micron, and that all aggregates of particles, which may exist in air, are broken up or shattered when they strike the impinger plate. These objections are, however, not supported by any experimental proof (17).

According to Brown (6), the collecting efficiency of the midget impinger is about 95 per cent for large particles (about 1 micron in diameter) but decreases for smaller ones.

Drinker and Hatch state (15, p. 151), "the impinger is superior to the dry-impingement instruments." On the same page, they also state, "owing to the lower impinging velocity and the use of liquid instead of a dry or adhesive-coated plate, there is less danger from actual shattering of particles."

From the foregoing and from what has been stated in the previous chapter, it is evident that no correlation of these instruments seems to have been attempted in the past. Furthermore, even in the case of a single instrument, its efficiency and its limitations have been the subjects of great controversy. There have been as many opinions as the number of investigators who worked on them. Nevertheless, this investigation has been undertaken by the author not only as a possible contribution to science, in partial fulfilment of the requirement of an advance academic degree, but also to satisfy his own curiosity.

CHAPTER III

DUST SAMPLING TECHNIQUES

Zeiss Konimeter

Principle

When a stream of dust-laden air impinges at high velocity, normal to a flat, adhesive coated surface, the sudden change in direction of air flow combined with the inertia of the particles, results in a separation of the dust from the air with the latter passing on and leaving the particles adhering to the impinging surface. This principle was first applied to dust sampling by Sir Robert Kotze in a konimeter by which a known quantity of air was made to impinge on the surface of a glass slide which was coated with a thin layer of vaseline. Various other techniques have since been developed for using the konimeter and many materials, such a petroleum, mineral oil and glycerine jelly, have been used in preparing the adhesive film which traps and retains the dust in the form of a spot. Thirty or more samples may be collected on each glass slide of the modern instrument and the slides are so mounted as to be removable for counting the dust particles under a microscope of known magnification. Some konimeter models are made with an attached microscope for the purpose of making rapid observations and rough estimates of dust pollution on the site.

Description

The Zeiss konimeter representing the present day stage of konimeter evolution consists of a small valveless cylindrical suction pump with a spring operated piston of the leather-cup type as shown in Figures 2 through 12. The piston is kept in a depressed position against the compression of the spring by means of a catch which, when released, allows the piston to rapidly push back to a stop and thereby drawing in a sample of dust laden air. This is done by first setting the plunger to either a 5 c.c. or 2.5 c.c. (full or one half volume) position which controls the size of sample collected and then pushing the button shown in Figure 6, which releases the catch.

The cylinder of the pump opens into a space between the metal body of the instrument and a glass sample disk (slide). A seal is maintained around the periphery of this space by a small rubber gasket which forms a flat circular space connecting the intake orifice with a small central hole leading to the piston chamber. The gasket also serves to space the glass disk from the intake orifice at the required distance of 0.5 to 0.6 millimeters.

The graduated glass disk is cemented into a metal rim and has 30 numbered sample spots or positions which are spaced equally on a circle just inside the rubber gasket. A small notch in the rim defines the position of the disk with regard to the rotating ring shown in the Figure 8.

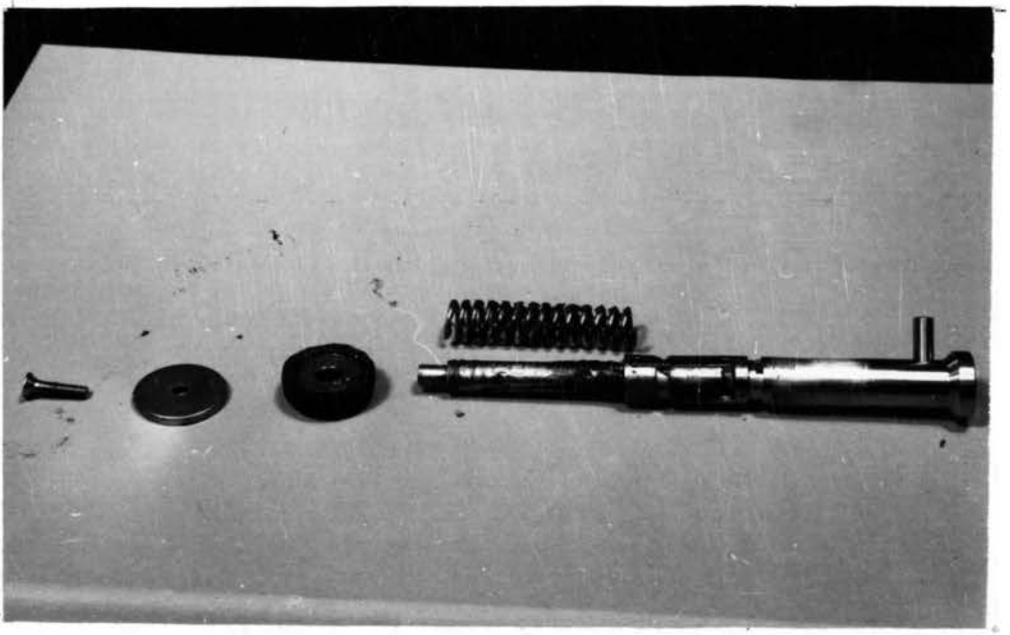

Figure 2. - Piston, spring and leather washer

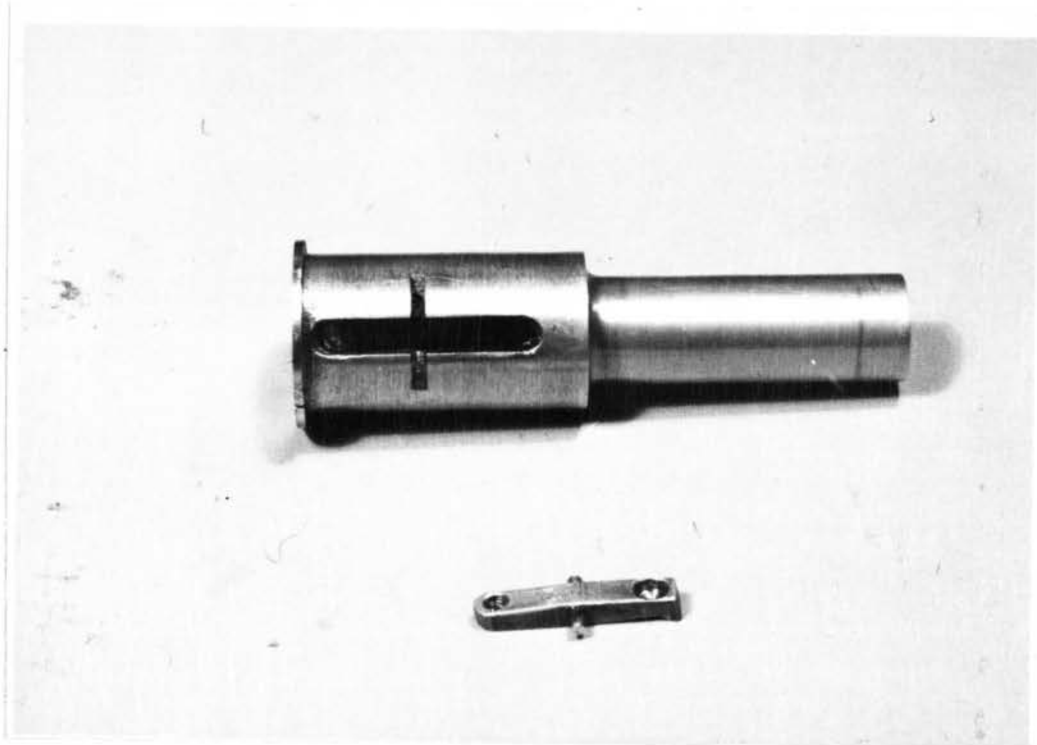

Figure 3. - Piston cylinder and spring catch

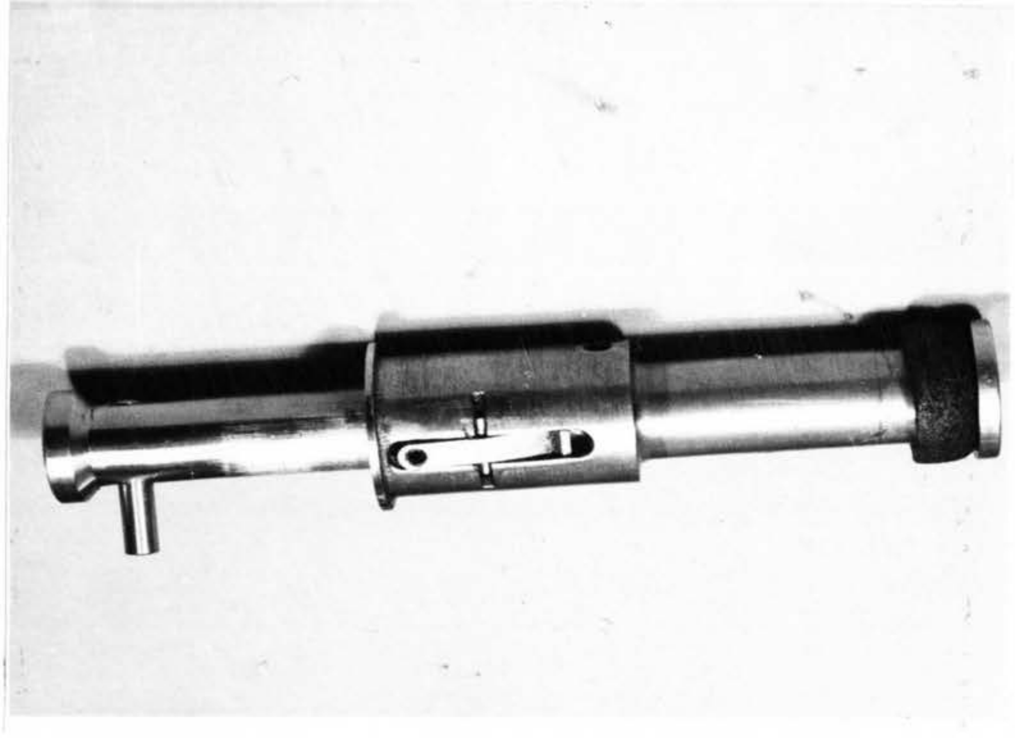

Figure 4. - Piston inside the cylinder with the spring catch in position

Figure 5. - Pump barrel

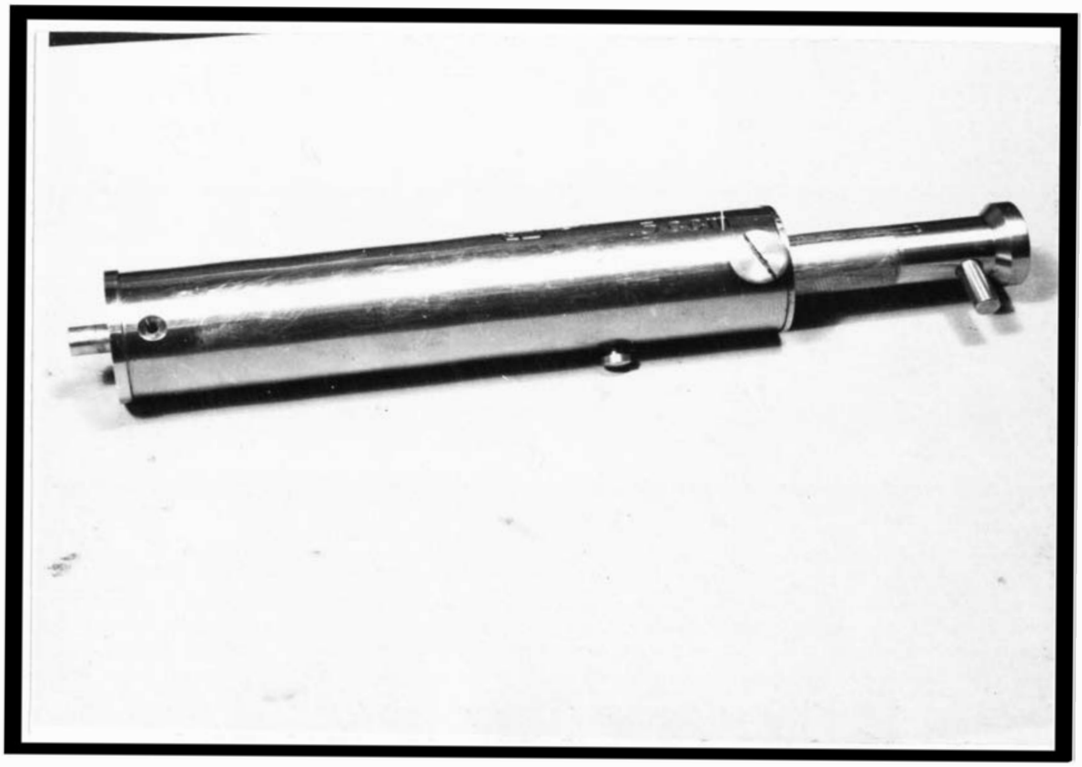

Figure 6. - Pump barrel with push button in position

Figure 7. - Base plate showing rubber gasket and disk holder

Figure 8. - Graduated glass disk and rotating ring with base plate

In order to bring any sample spot under the intake orifice, it is necessary only to rotate the ring until the desired number is in position. A ball catch gives a ratchet like movement to this rotating ring so that each number in turn clicks into position. This ratchet movement is easily felt by the hand.

An orifice or nozzle, in the body of the instrument, as shown in Figure 9, faces the inside of the glass sample disk. The nozzle is round and 0.5 to 0.6 mm. in diameter. It opens to the outside through a cone and is protected from being clogged by large particles by a 250-mesh screen. The nozzle cap is removed only when dust-laden air is to be drawn in. As soon as the sample has been taken the nozzle is again covered with the cap.

Checking Specifications

In order to obtain consistently accurate dust samples it is imperative that standard specifications be adhered to and that the instrument be regularly checked and maintained in the best possible condition.

The following construction specifications need routine checking as they are important in affecting sampling consistency and efficiency:

Orifice diamter - inner end	0.5 to 0.6 m.m.
Orifice to slide distance	0.5 to 0.6 m.m.
Volume of sample	2.5 c.c. and 5 c.c.

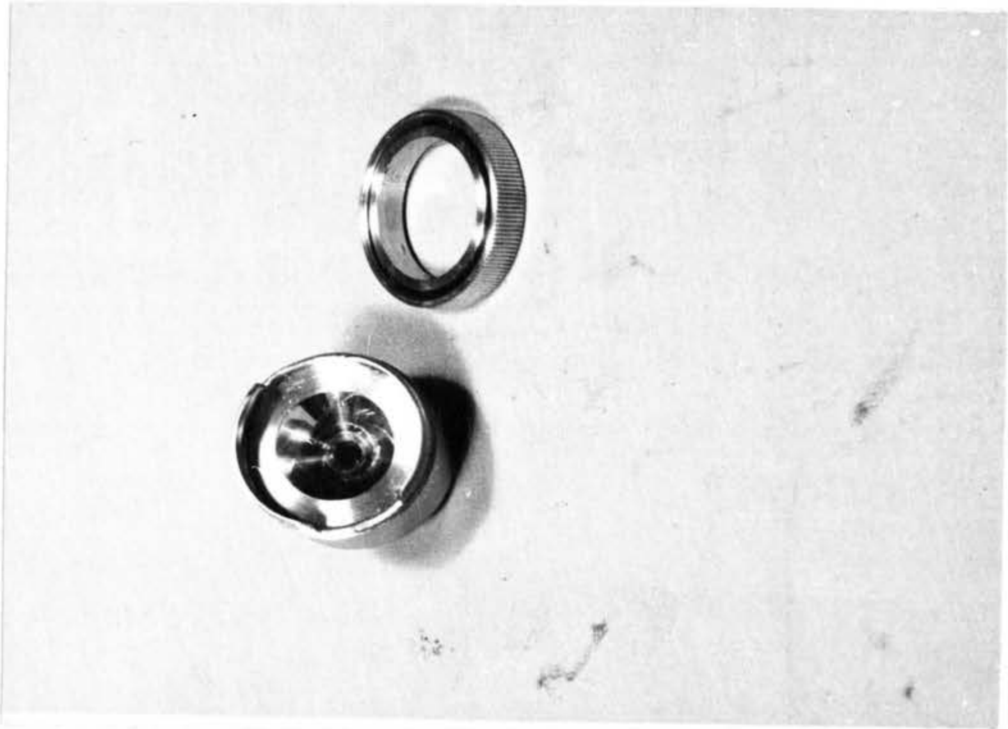

Figure 9. - Orifice with cover ring

Orifice diameter: - This may be checked by placing the konimeter on the stage of a dust counting microscope and directing the light used so as to illuminate the orifice. When the objective is focussed centrally on the orifice, the diameter of the latter may be read directly on the eye-piece grid as each square in the grid is equal to 0.1 m.m.

The orifice can be checked for obstruction by sighting through it to a window or other source of illumination. Underground it may be inspected by placing it against a caplamp and sighting as before. If dirt is found in the orifice it may be cleaned by carefully passing a clean bristle or piece of nonfraying material through the opening. Particular care should be taken not to erode the inner surface so as to alter its critical diameter. A steel wire should never be used.

Orifice to slide distance: - The distance from the impinging disk to the orifice should be checked in order to ensure that the gasket is not flattening or that the orifice has not advanced through the konimeter case. This may be done by using a 1 in. to 2 in. micrometer with a one inch extension bar and measuring; first, the total length of the orifice; next, the thickness of the disk, and then, after placing the disk in the konimeter, the distance from outside the orifice to the outside of the disk. This total distance minus the sum of the disk and orifice distances will be the space between the orifice and the disk.

Volume of sample: - The leakage of air in the konimeter may occur at any or all of the following four places:

1) Around the orifice threads.
2) Between the disk and the gasket.
3) At the joint between the disk chamber and the pump.
4) By air-leakage past the piston washer.

Leakage can be checked by ascertaining the correct volume of water displaced by the pump when depressed to 5 c.c. position. The equipment required for this purpose consists of a small beaker, some water, a 5 cubic centimeter pipette and a piece of rubber tubing. The pipette should be cut off about 3/4 inch about the 5 c.c. mark in order to reduce extra volume.

The outer end of the orifice is connected to the pipette whose tip is inserted in the water contained in a beaker. If, upon depressing the piston, the water in the pipette rises to the 5 c.c. mark, it is ascertained that there is no leakage. Should there be leakage on the other hand, all the possible four sources mentioned should be carefully checked and resealed. The rubber gasket should be kept pliable and lubricated with a mixture of glycerine and water. The leather washer on the piston may be lubricated with neetsfoot oil.

Velocity of orifice discharge: - The pump should be lubricated with grease (graphite may be used) that limits the motion of the piston to a speed that gives an air velocity of 100 to 150 meters per second through the nozzle. In other words, the piston should make the full 5 c.c. stroke in about .3 seconds or the half stroke in .15 seconds. An experienced observer can tell from the spread of the particles on the disk whether the sampling rate is right. If it is too slow, the particles will extend beyond the field of view in the microscope; if too rapid, even low concentrations will be grouped so closely that counting will be difficult.

Preparation for Use

Cleaning the disk: - Pure filtered alcohol or chloroform gives the best results in cleaning the glass sampling disk, though both substances leave residue which must be removed by polishing. Polishing is best accomplished with a clean cheese cloth. Silk or lens paper produces a greater static charge of electricity which causes particles of dust from the air or polishing medium to be attracted and to adhere to the glass surface. For this reason, cleaning is more difficult in cold dry weather. It may be facilitated somewhat by increasing the humidity of the room in which cleaning is done. Washing the disk with distilled water is not so effective as a residue is invariably left after evaporation and is difficult to remove by polishing.

Preparation of adhesive: - Adhesive is prepared by mixing 1 ounce of microscopic glycerine jelly and 1 ounce

Figure 10. - Glycerine, glycerine jelly, and adhesive in bottles

of pure glycerine with 10 to 20 drops of distilled water. A lesser quantity of water should be added in hot weather. The above mixture is then heated in a clean bottle held in hot (not boiling) water until the jelly melts and mixes completely with the other ingredients. It is then allowed to cool a few hours to become a soft jelly. It is then ready for application to the sample side of the glass disk.

Application of adhesive: - Before the adhesive is applied on the sample disk, the hands are thoroughly washed in warm water and then dipped in cold water to close the pores of the thumb and the index finger. They are then dried on a linen cloth and brushed to remove lint. A piece of jelly, about the size of a pin head (about 1/16th inch in diameter), is picked up between the index finger and the thumb. It should not be rubbed as a small bubble that forms in the jelly cannot be removed and may be confused with the dust particles.

When the jelly softens on the index finger, it is spread on the sampling disk by the same finger, by turning the disk to attain a sweeping circular motion. Upon spreading the jelly in this manner, streaks are left by the finger ridges. These may be removed by breathing gently upon the disk until the hygroscopic jelly has taken up enough moisture to spread. Care should be exercised in preparing the sampling disk and to see that the atmosphere is as free from dust as possible. While the adhesive is being applied, the sampling side of the disk is always held down so that there is less chance for the atmospheric dust to deposit on the sampling side.

Examining the disk for dust: - After cleaning the disk and applying the adhesive, the results should be completely examined under the microscope. This is done to make sure that not more than 8 to 10 dust particles per field remain on the disk. Less particles than this will not materially affect the count and can be left because it is practically impossible to get it perfectly clean. If there are more particles on the disk, it should be thoroughly cleaned and, after the applicaion of adhesive, be again examined under microscope as before.

Care should be taken not to touch the face of the disk with the fingers as they will leave a deposit that will spread and be difficult to remove. Each glass disk should be marked for identification so that it will always be kept in its correct relative position. If the disk is to be used for sampling, then it is placed on the konimeter with the adhesive side towards the orifice. The threaded rim is then put on over the disk and turned until the rubber gasket makes good contact leaving the annular space at 0.5 to 0.6 millimeters.

Before placing a disk on the konimeter, however, the nozzle cap, the outside of the nozzle and the interior of the konimeter and its gasket should be thoroughly

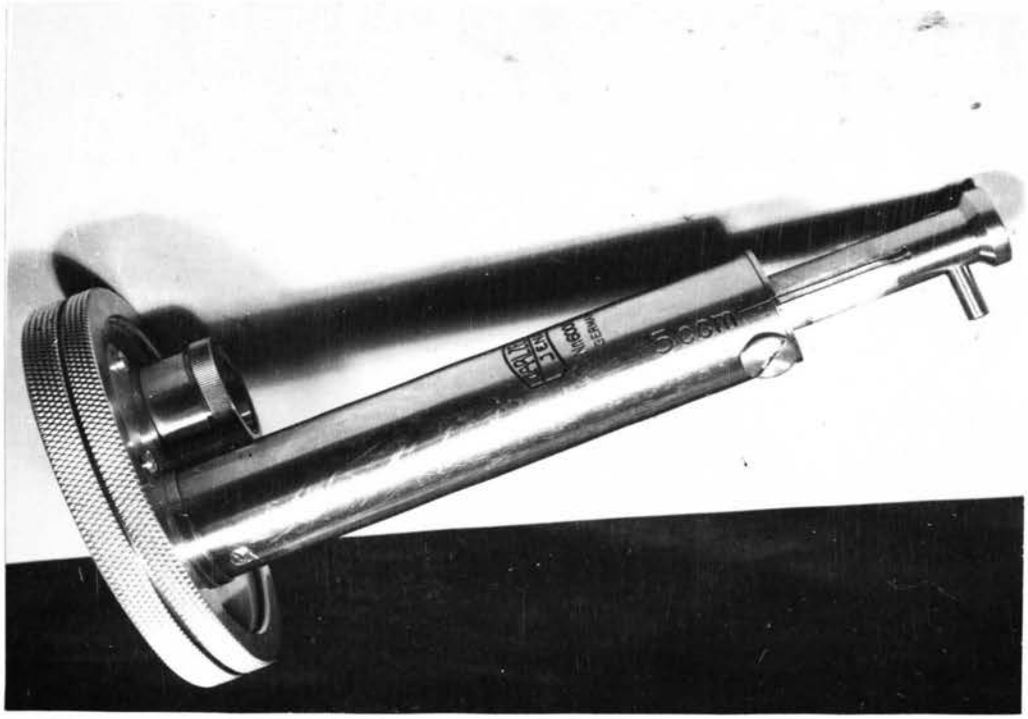

Figure 11. - Zeiss konimeter ready for taking samples

Figure 12. - Metal carrying case for extra slide

wiped using a piece of cheese cloth dampened with alcohol. It is especially important to keep the inside of the screwed nozzle cap clean. The nozzle inlet should always be covered by the cap when not taking samples and special care should be taken not to let the dirt deposit inside or on the nozzle inlet while handling.

If the disk is carried as a spare for later use, it should be kept in a special metal carrying case with the adhesive side down. After preparation, the disk should always be handled with the adhesive side down.

The konimeter is now ready for collecting 30 dust samples on the disk already placed on it. Generally, numbers 10, 20 and 30 of the sample spots are left as blanks to serve as references.

Collection of Samples

When ready to take samples, the operator should not move around too fast and thereby create dust eddies. The cap over the nozzle inlet should be removed and the piston depressed and set at the 5 or 2.5 c.c. position. To take a sample, finger pressure is applied to the push button which releases the piston and thus causes the required volume of dust-laden air to be drawn in through the nozzle, to impinge the dust upon the adhesive coated surface of the glass disk and to make the dust free air continue on its way to the pump through the air hole provided. After the sample has been taken, the cover on the nozzle must be closed immediately and the disk turned at once to the next position and the piston again cocked.

The sample is taken by holding the konimeter with the nozzle inlet at the desired point with the glass disk in the upward position, at arm's length and with the operator facing the incoming air current. The first sample on each disk may, however, be disregarded, as there may be a little dust in the nozzle. If, at any time, a mistake is made and the piston is released with the cap still on the nozzle, one or more samples will be spoiled by heavy dust drawn in from around the threads which will spread more on the disk than a sample drawn in freely.

Three samples are usually taken together in immediate succession for any time or location. A record is kept of the date, konimeter number, slide number, time, sample numbers, location and any other special or pertinent features.

When one disk is full and more samples are to be taken, the disk is replaced by the spare. The exchange may be made in any relatively clean location, using care not to get loose dust in the konimeter or on the disks and not to touch the face of any of the disks. After all desired samples have been taken, they can be set aside for later treatment and examination or they can be examined immediately.

Counting of Samples

Konimeter samples can be evaluated only in terms of numbers of particles. At the outset, light-field microscopy was used with a 2/3 inch objective and 10x or 12x ocular giving a total magnification of 150 diameters. Microscopic examination now made is at a magnification of 200 diameters with the dark field illumination provided by an ordinary central stop in the standard condenser. The ocular micrometer or grid in the eyepiece has either two opposite 18° sectors divided into two equal parts of 9° or two single 9° sectors. A line drawn parallel to one of the diameters and at a distance of 5 microns from it is useful for estimating the sizes of dust particles when viewed with the dust sample.

Two types of stages are used for holding the sample disk. One of the holders has a rotary ring similar to that found on the konimeter and is provided with a pawl that stops the disk at each sample position. This ring is adjustable in two horizontal directions and in this way, the dust spot can be centered in the microscope field so that approximately the same number of dust particles appear on all sides of the heavy square in the center. When any one dust spot is located in this manner, each of the others may then be rotated into the field with equal adjustment.

The other type is a standard mechanical stage which has been modified to hold the konimeter disk. With this, somewhat more difficulty is encountered in finding and centering the samples.

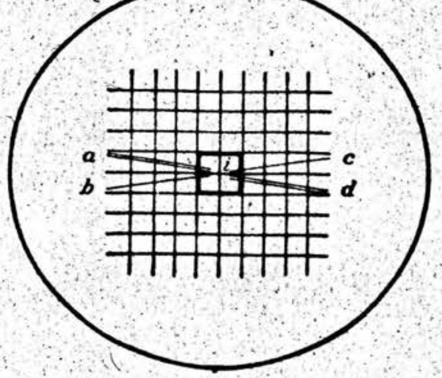

Fig. 43. Ruled eyepiece disk for konimeter microscope. (*Courtesy Carl Zeiss Company.*)

Figure 13. - Ruled Eyepiece Disk for Konimeter Microscope
From - Industrial Dust, McGraw-Hill Book Company, 1954

In counting the particles in the dust spots, the light is set at 9 inches from the microscope plane mirror and thereby is directed to center a light spot on a disk below the objective lens. The microscope is set to give 200 diameter magnification and is racked up and down to locate the lower surface of the glass with the stop in place for dark field illumination. There is usually enough dust on the outside of the disk so that, with a little practice, the surface can be found easily. The condenser and the mirror are then set to give maximum illumination. The disk is rotated to bring the first dust spot under the microscope. The spot is centered, as described, and all visible particles in the two opposite 9° segments are then counted. The eyepiece is then revolved 90° and two more 9° segments, at right angles to the first, are counted; care being taken that the intersection is still at the center of population.

The four counts are added and multiplied by 2, to give the dust particles per cubic centimeter when the dust has been taken from a 5 c.c. sample of air. If the dust has been taken from a 2.5 c.c. sample of air the four counts are added and multiplied by 4. If the results are desired in millions of particles per cubic foot they may be calculated by multiplying the number of particles per cubic centimeter by 28,320 (number of cubic centimeters per cubic foot) and dividing it by one million.

For a 2.5 c.c. sample the actual count for four 9° sectors may be multiplied by the factor 0.113. If a 5 c.c. sample has been taken, the count for four 9° sectors is multiplied by 0.057.

All results are tabulated and any special observations or any samples spoiled in taking or handling, or because of disk defects or improper cleaning are also noted at the time of counting. The counts are then grouped as the samples were taken, the usable counts averaged for the group and the average recorded for that time and location. These average counts may or may not be plotted on curves of dust count against time or distance depending upon what studies are being made. After counting, the glass disk either may be kept in a dust proof case for reference or it may be cleaned and used again.

MIDGET IMPINGER

Principle

The impinger was developed in 1922 by the United States Bureau of Mines in cooperation with the United States Public Health Service. Later, 1937, it was simplified into a more readily portable and easily operated instrument and named "Midget Impinger". The underlying principle of this instrument is based on impingement and wetting of the dust particles by drawing contaminated air through a nozzle, at high velocity, onto a smooth surface where it disperses beneath a bubbling column of liquid. The dust particles are retained in the liquid. The liquid sample, representing a known volume of dusty air, is then placed under a microscope or microprojector for counting the contained dust particles and computing the number of particles (in millions) per cubic foot of air samples.

Description

Figure 15 shows the complete midget impinger sampling apparatus with the 9 sample flasks, pump and surge tanks. The gage is in the top and is protected by a celluloid cover. The carrying strap is shown hooked to a ring at the side with the strap across the shoulder.

Figure 16 shows the midget impinger flask which is about 11 cm. long and 2.5 cm. in diameter. It has a side arm about 1 cm. in diameter and tilted upward at an angle of 45° to facilitate dilution and cleaning. The flask is graduated at 5 ml. intervals for a total of 30 ml. A mark at a point 5 mm. from the bottom serves as a guide for setting the nozzle of the impinger tube at the proper distance from the bottom. Four projections from the impinger tube near the lower end aid in holding it centrally in the flask. The tube, through which the air is drawn, has an orifice 1 mm. in diameter.

One-hole Neoprene stoppers, as shown in Figure 17, are used in the tops of the flasks. Ordinary rubber stoppers are not used because of the possibility of contamination of the impinger liquid with the particulate matter.

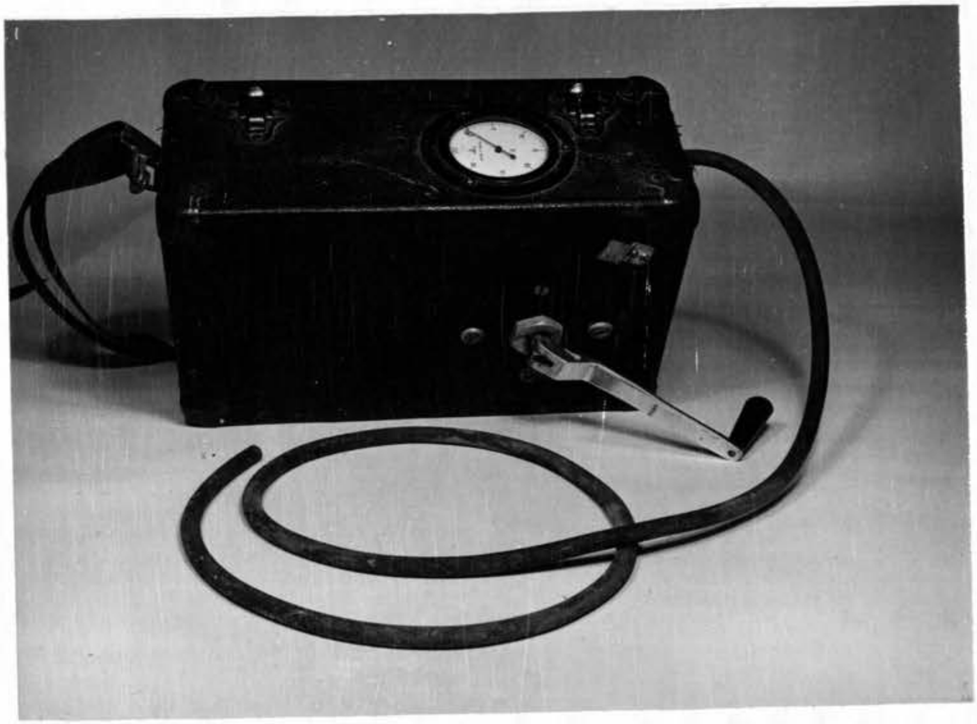

Figure 14. - Impinger box showing gage and carrying strap

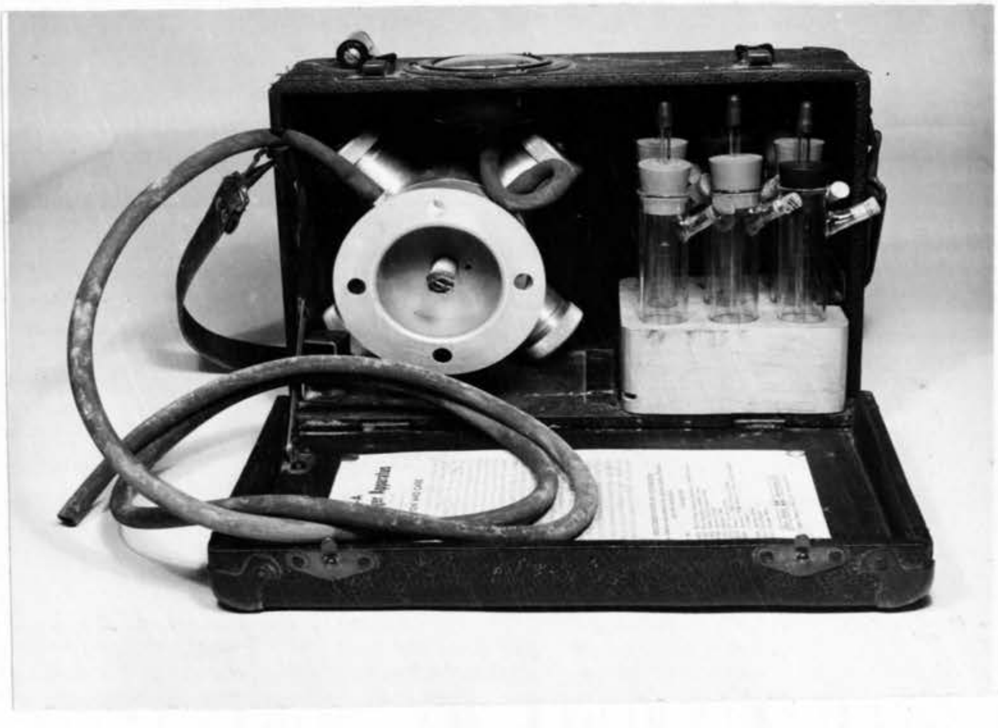

Figure 15. - Midget impinger sampling apparatus

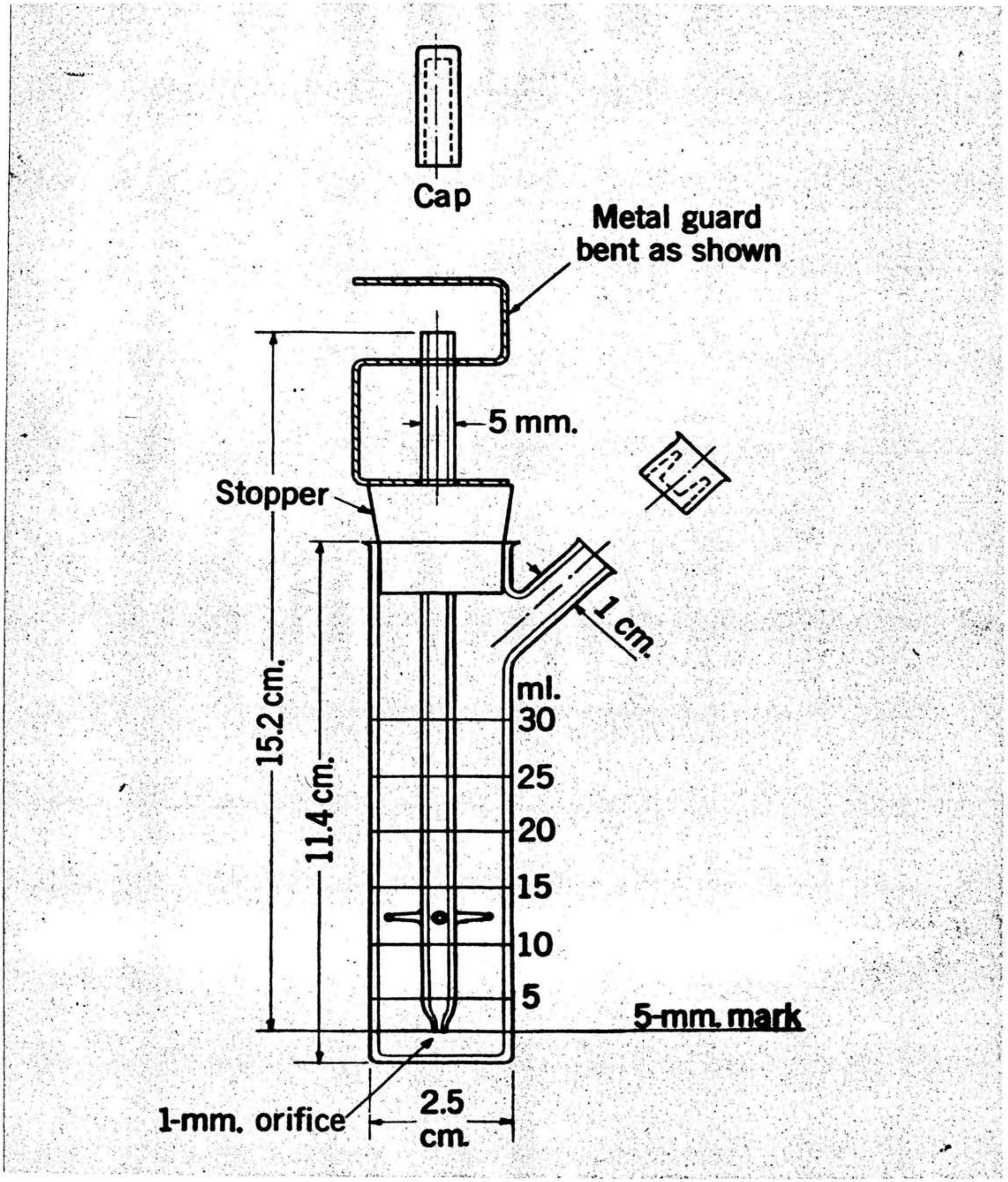

Figure 16. - Midget Impinger Flask
From - United States Bureau of Mines, I. C. 7076

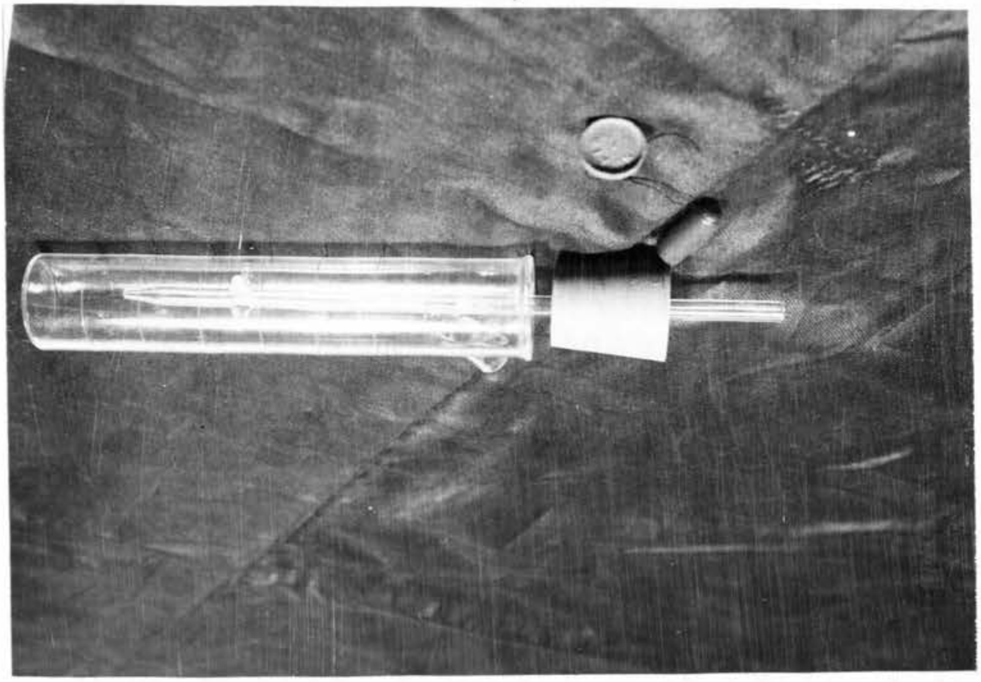

Figure 17. - Impinger flask with neoprene stopper, impinging tube and the rubber cap

Figure 18. - Impinger flask corked and covered with rubber caps after dust collection

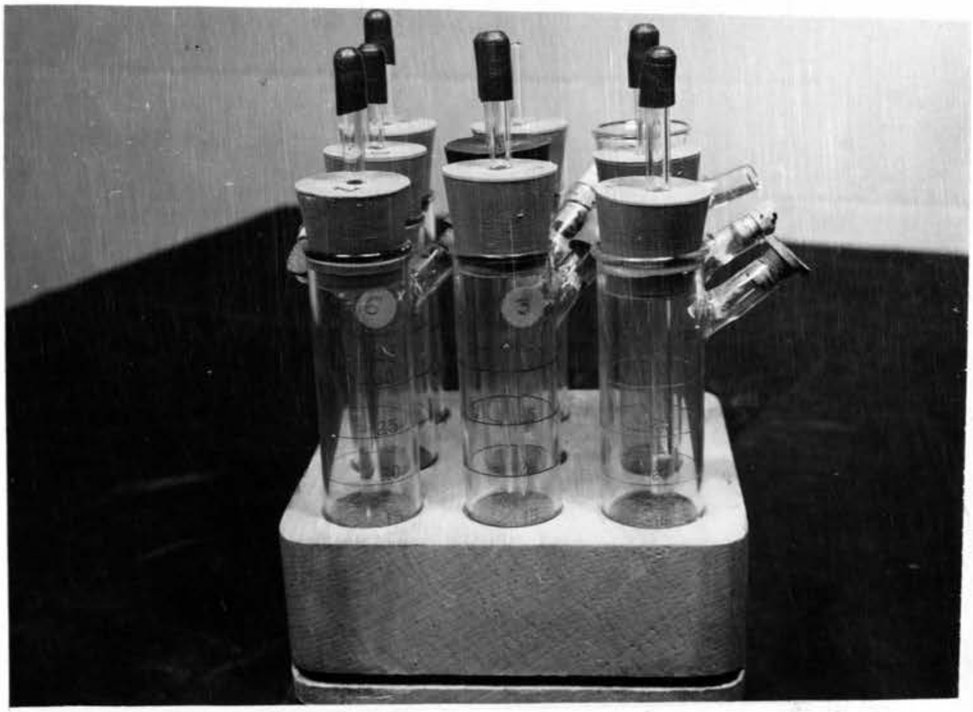

Figure 19. - Carrying case for 9 impinger flasks

which they are known to shed. No air rubber stoppers are satisfactory for closing the side arm, and rubber caps or "policemen" can be used for closing the inlet to the impinger. A metal S-shaped guard is used on top of the stopper to prevent material from dropping into the intake.

Figure 20 is a diagrammatic sketch of the impinger assembly showing the specially designed pump. The pump consists of four cylinders disposed of radially at 90° about a single throw crank. The intake-valves connect to a collector ring which, in turn connects through a check valve to the first surge tank and this, in turn, connects to a second tank through a needle valve. A vacuum gage is used to indicate the suction necessary to pull through 0.1 cubic foot of air per minute. The pump is so designed that minor variations in the crank speed do not affect the flow of air significantly.

Preparation for use

Before actual use, the impingers are washed, the stoppers treated, the liquid added to the impingers and the impinger suction device calibrated.

Cleaning apparatus:- The impingers are scrubbed in water with brushes and soap or some other cleaning compounds. They are then thoroughly rinsed with tap water, followed by distilled water and finally with the clean liquid which is to be used as the dust collecting medium. All rubber stoppers, especially when alcohol

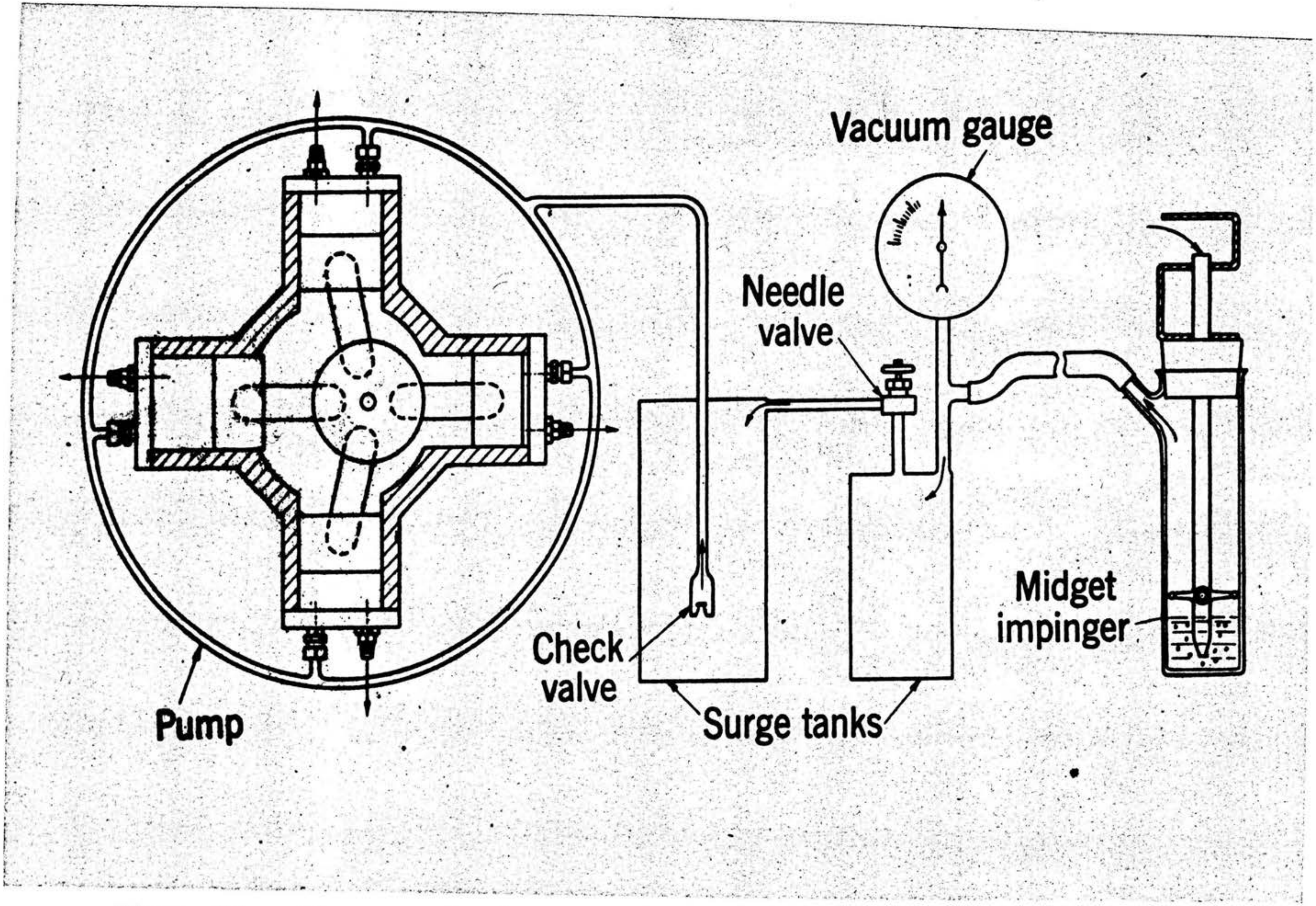

Figure 20. - Diagrammatic sketch of the impinger assembly
From - United States Bureau of Mines, R. I. 3387

is used, are treated and washed to remove any particulate matter adhering to their surface. They are boiled in a strong sodium hydroxide solution for about an hour, rinsed with water, immersed in acid solution (one part hydrochloric acid to two parts water) for a few minutes, then scrubbed with cleaning agent and water and again rinsed with water and, finally, with the impinger liquid. New stoppers and those that have not been used for several months are given the same treatment.

Approximately 10 ml. of liquid is usually added to the midget impingers. The large stopper, containing the impinger tube, is inserted tightly into the flask after the orifice has been adjusted to a 5-mm distance above the bottom of the flask. A covering is used over the groove at the junction of the flask and stopper to prevent contamination of the sample when the stopper is removed. All other openings into the impinger are closed with appropriate rubber stoppers. Each impinger is numbered by scratching on the flask or by marking on the stopper.

Calibration of suction device: - The impinger suction device is calibrated to determine the rate at which it draws air through the impinger as used in actual sampling. This calibration is done at frequent enough intervals to eliminate any question of the sampling rate.

For calibration, the impinger outfit is assembled as for sampling, i.e., with the same kind and amount of liquid and the same connection hose used between the impinger and suction device. In addition, the inlet of the impinger is connected, by a short length of rubber tubing, to the outlet of a suitable gas-measuring device; either dry or wet gas meter will serve. Determination of the time required for several complete revolutions of the meter dial is made until the results of the two consecutive tests are identical or agree within about one percent.

Impinger liquid: - In the initial stage of development of the impinger apparatus, distilled water was used as the dust collection medium. It was later on found that when the samples are retained for more than twenty four hours after their collection, some of the particles go into solution and the results are erratic. Ethyl alcohol was therefore selected as the collecting liquid after experiments showed no evidence of solubility; even if the samples were examined after 28 days. The collecting efficiency of impingers using alcohol was found to be the same as for those using distilled water. At present, where the samples are to be counted within 24 hours of their collection, distilled water is preferred because of its economy, but where the samples are collected in the field and are to be examined sometime later than 24 hours, only ethyl alcohol or the propyl alcohols are used.

Collection of Samples

In order to determine the dust concentration to which workers are exposed throughout the working day, it is necessary to take samples during representative operations. For this purpose, the nature and number of dust generating and disseminating processes, location and number of exposed persons, kind of work done by the workers, and characteristics of working places, should be considered. In addition, it is important to note the atmospheric conditions (particularly the ventilation or air movement) to which the workers are exposed at the time of dust sampling.

The duration of the sampling period is determined by the length of the operation, but usually it does not exceed 20 minutes; owing to the evaporation of alcohol. Higher dust concentration will logically require a shorter sampling time, but ordinarily it is not less than 5 minutes.

Samples are generally collected at the breathing zone of the exposed persons. To take a sample, one end of the sampling case is hung from the operator's belt by a hook and the other is supported by a strap passing in back of the operator's neck. The impinger flask is connected to the suction apparatus by a piece of 1/4-inch rubber tubing. The impinger is then placed in the small holster and held at the sampling point. By means of a safety pin it is generally attached to the pocket or any portion of clothing near the breathing zone of the person exposed to dust. The operator moves the crank at such a speed that the vacuum gage always shows a reading of 12 inches water-gage. He uses a stop watch for recording the correct time to the nearest second. After the sample has been taken, the impinger flask is again corked and the impinger tube covered with the rubber cap. The flask is then kept in its marked position, in the case, inside the box.

Preparation of Sample for Examination

Before removing a sample of dust-containing liquid for counting purposes, the liquid, in the flask, is diluted to a known volume by adding to it the dust free impinger liquid. From its appearance, or by experience, it can be roughly estimated whether the concentration of dust, in the sample, is high or low. The number of dust particles in the counting field should not normally exceed 50. Before bringing the dust containing liquid to a known volume, care must be taken to protect it from contamination. The outside of the impinger is cleaned carefully before any of the stoppers are removed. First, the small stopper at the side of the impinger flask is removed; and then, the stopper holding the impinger tube is loosened. The impinger tube is then raised so that it is just out of the liquid, and the inside of the tube and the stoppers, originally inside of of the flask, are rinsed with a clean liquid which is allowed to drain into the flask. Sufficient clean liquid is then added to the impinger to bring its liquid level to the next graduation or to any other suitable mark if the liquid is to be diluted further. The flask is then closed by solid stoppers.

Cells of any convenient shape may be used for counting so long as their depth is known. The Sedgwick-Rafter cells, 1 mm. deep and of about 1 cm^3 volume, are generally used. The cells are thoroughly washed with soap and water and then rinsed with distilled water and clean alcohol. The cells are then wiped with a clean, soft, lintless cloth and brushed with a dry camel-hair brush. After they have been used they are emptied, rinsed with a stream of clean alcohol, and immersed in a beaker of clean alcohol until they are used again.

Before removing the dust-containing liquid from the impinger flask for filling into the cell, the flask is thoroughly shaken for about half a minute. A representative sample is removed with the help of a pipette by slowly drawing its tip from near the base of the flask up through the liquid. The cover slip is kept on the cell keeping two openings, one for the sample to be drained in the cell and the other for the air bubbles to move out when the cell is being filled with the pipette. The cover slip is moved into place after the cell is completely filled with the sample liquid.

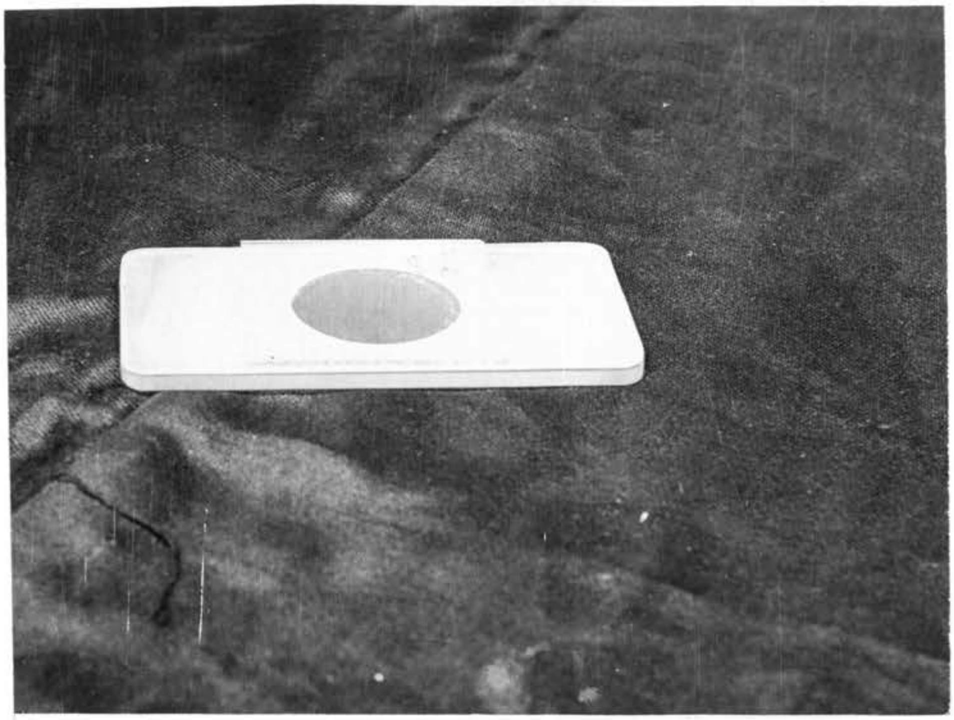

Figure 21. - Sedgwick-Rafter cell

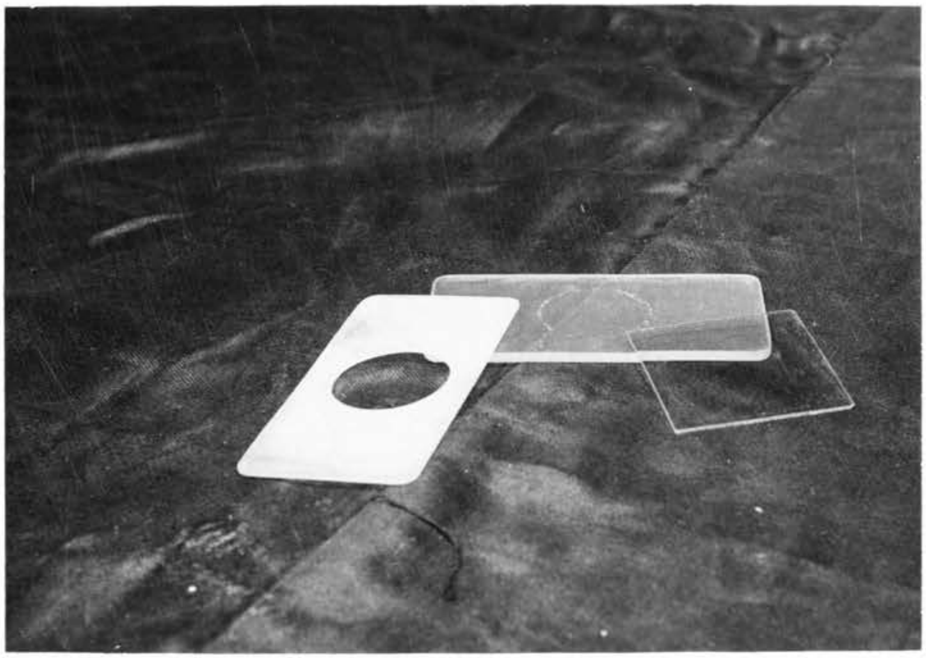

Figure 22. - Sedgwick-Rafter cell assembly

If water is used as the dust collecting medium, the Sedgwick-Rafter cell is allowed to stand for about 20 minutes to allow the dust particles to settle to the bottom of the cell. In the case of alcohol, the settling time should be about 30 minutes. During this time, however, the alcohol starts evaporating thus allowing the air bubbles to come into the cell chamber. The air bubbles are sometimes so big that they make the counting of dust particles, at the floor of the cell, almost impossible. To prevent this, the edges of the Sedgwick-Rafter cell are wrapped with Scotch tape; a material which has been found quite effective in stopping such evaporation.

Counting of Samples

The counting cell, after it has been allowed to remain undisturbed for the proper settling time, is transferred to the stage of the microscope. The microscope is focussed on the dust particles on and near the bottom of the cell by first locating the contamination in a corner or near an edge of the cell. Five fields are counted in each cell, with one located centrally and the others distributed toward the four corners of the chamber. The microscope is moved continuously in an up-and-down motion during counting to make the particles go in and out of focus, making them easier to see and to assist in distinguishing between the particles in the cell and those on the eyepiece micrometer.

Two cells are usually prepared from each sample and five fields are counted in each. A control count is made in the same way, using liquid from the control flask, and the control average is subtracted from the median of the sample. This serves to eliminate the error due to the residual particles in the sampling liquid and on the cell. The result is converted to the number of particles per cubic foot of air by the following formula:

$$C = \frac{(N_s - N_c)V_w}{V_a AD}$$

where, C = dust concentration of numbers per cubic foot of air

N_s = median dust count in the sample

N_c = median control count

A = area of field

D = depth of cell

V_w = water volume, cc., allowing for dilution

V_a = air volume, cubic feet.

The number of particles obtained, as above, is divided by one million to get the result in millions of particles per cubic foot.

If the average counts per field for the two cells from each impinger sample differ by more than the following limit, additional cells are filled and counted:

For average counts up to 20 particles per field........up to 3%

For average counts from 20 to 40 particles per field...up to 4%

For average counts from 40 to 75 particles per field...up to 5%
For average counts from 75 particles per field and up..up to 10%

Suitable file cards for recording particle counts and other information on dust samples have been suggested by the U. S. Bureau of Mines (42).

Microprojector: - To avoid eyestrain and discomfort associated with the direct microscopic counting of impinger samples, Brown and Yant have developed a convenient projection arrangement in a device known as the microprojector. It gives an over-all magnification of 1000 diameters and reveals the particles on a ruled screen for direct viewing and counting. A one micron particle can thus be seen as a 1-mm image on the screen. The microprojector. has been described in detail by Brown, Baum, Yant, and Shrenk. Its essential components are as follows:

a) An automatic-feed carbon-arc lamp complete with condenser and suitable rheostat for the available current.
b) A heat filter for removing heat from the light before it enters the microscope.
c) A microscope with a standard 16-mm objective lens and a 20X eyepiece.
d) A right-angle projection prism to fit above the eyepiece and to transmit the light horizontally onto a grid-ruled translucent screen.

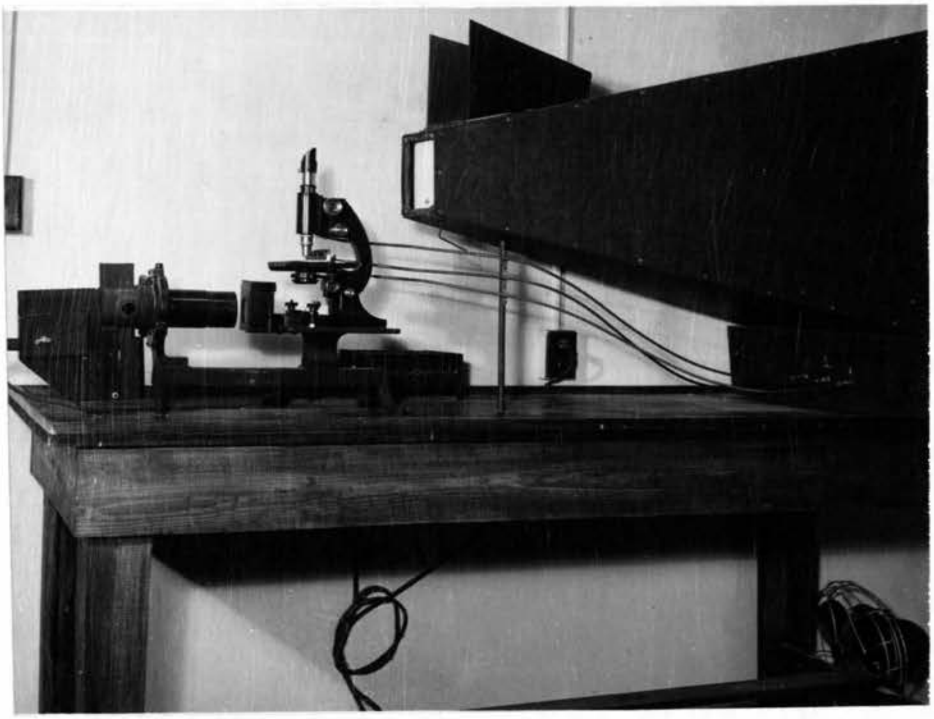

Figure 23. - Microprojector

Figure 24. - Adjusting microprojector

e) A ruled translucent screen with a grid area which is 50-cm square and divided into smaller 10-cm squares; the central square being further sub-divided into 1-mm squares.

f) Remote controls to permit the observer at the screen to focus the microscope and operate the mechanical stage.

<u>Setting up of microprojector for counting</u>: - A stage micrometer is used to adjust the microprojector for correct magnification of 1000 diameters. The micrometer is placed on the mechanical stage and the screen is moved back and forth until the images of the 0.1-mm rulings of the micrometer are 1000 times larger, i.e., they coincide with the 10-cm rulings on the screen. This adjustment is further assisted by raising or lowering the tube of the microscope. After having obtained the correct magnification, the Sedgewick-Rafter cells are placed on the mechanical stage and the floor of the cell focussed as mentioned before. The microprojector is now ready for having the dust particles counted on its screen.

CHAPTER IV

EXPERIMENTAL PROCEDURE AND THE COLLECTION OF DATA

Testing Equipment

During the course of this investigation, the midget impinger and the Zeiss konimeter were used for sampling dust laden air and the microprojector was used for counting. Before starting the experiments however, these instruments were thoroughly cleaned, checked and tested for accuracy in the manner described in the preceding chapter.

The impingers were cleaned with soap and water and rinsed thoroughly with tap water, distilled water and clean alcohol. The rubber stoppers were treated in sodium hydroxide and hydrochloric acid solutions and then cleaned and rinsed thoroughly with the tap water, distilled water and the clean alcohol.

Each impinger was calibrated, by using a Sargeant Wet Test Meter, and then numbered on the flask as well as on the large stopper. The results and data pertinent to the calibration are given in Table 1.

The parts of the konimeter were all separated for cleaning, lubricating and testing for correct adjustments. The pump was lubricated with graphite grease; the leather washer, with standard leather lubricating oil; and the rubber gasket, with the prescribed mixture of glycerine and water. The konimeter was then reassembled and tested for leakage of air by using the water displacement method already mentioned.

TABLE I

DATA ON CALIBRATION OF MIDGET IMPINGER FLASKS

1 Flask No.	2 Run No.	3 Number of Revolutions	4 Time in Seconds	5 Average Flow Rate C.Ft./ Min.
1	1	1	59.8	.101
1	2	1	59.8	
2	3	1	59.7	.101
2	4	1	59.9	
3	5	1	60.3	.0998
3	6	1	60.1	
4	7	1	59.2	.101
4	8	1	63.7	
4	9	1	59.8	
4	10	1	59.8	
5	11	1	59.6	.102
5	12	1	59.8	
6	13	1	60.3	.0998
6	14	1	60.2	
7	15	1	60.4	.0998
7	16	1	60.1	
8	17	1	59.6	.102
8	18	1	59.8	
9	19	1	59.9	.100
9	20	1	60.0	
10	21	1	61.4	.0998
10	22	1	59.9	
10	23	1	60.3	.0998
10	24	1	60.2	
11	25	1	60.4	.0998
11	26	1	60.1	
12	27	1	60.0	.0999
12	28	1	60.1	
13	29	1	60.7	.0991
13	30	1	60.4	
14	31	1	59.7	.1003
14	32	1	60.1	
15	33	1	60.3	.0998
15	34	1	60.1	

Taking Samples

Dust samples were collected at the following mines: -

1) St. Joseph Lead Company, Bonne Terre mine, Bonne Terre, Mo.
2) St. Joseph Lead Company, Flat River mine, Flat River, Mo.
3) Pittsburg Glass Company, Sand mine, Crystal City, Mo.
4) The Experimental mine, Department of Mining Engineering School of Mining and Metallurgy, Rolla, Mo.

The above mines provided a variety of atmospheric conditions which proved quite favorable for obtaining samples from a wide range of dust concentrations. In all, 5 visits were made to these mines. Before each visit, the impingers were cleaned, rinsed thoroughly, filled to the 10 ml. mark, stoppered and stored in the wooden case provided for carrying. Similarly, the glass disk of the konimeter was cleaned thoroughly and after application of the adhesive, placed on the konimeter with the threaded rim, and turned until its gasket made good contact with the disk and leaving the annular space at 0.5 to 0.6 mm. An extra disk, having been prepared in the same manner, was kept in the dust free metal carrying case for immediate replacement in the konimeter when all samples on the original disk were completed.

Choice of Sampling Position

The principal operations underground which give rise to dust are drilling, blasting, shovelling, tipping, and loading into trucks. The greatest dust hazard will occur nearest these activities but as fine particles settle out very slowly, they may be carried great distances in the ventilating air currents. It is important to note, that a newly-formed dust cloud contains a few large particles which are greater then 5 microns in diameter and up to 100 microns or more, as well as the usual range below 5 microns. It has been stated in the introduction to this paper, that it is generally agreed, that particles larger than 5 microns do not normally reach the lung alveoli, and, therefore, can play no part in the onset of pulmonary disease. If we seek a sample of dust which is likely to reach the lung alveoli we must therefore concern ourselves only with the small particles; these large particles must be eliminated somehow. As it is not possible to use any of the standard laboratory methods of elutriation in mines, the most convenient method of approach is to take advantage of the natural settling out by gravity, e.i., particles falling at a rate which varies as the square of their diameters. The following table gives the rates at which particles of quartz, of specific gravity 2.65, will fall in free air:

Table II

Diameter of particle microns	Rate of fall cm. per sec	Time to fall 1 ft.
1.0	0.008	56 min.
5.0	0.196	2 min. 36 sec.
10.0	0.784	39 sec.

In several unventilated ends, Watson found the distance at which the larger particles are settled out, to be about 20 feet from the face when drilling and between 40 and 50 feet when shovelling. A sample taken beyond these distances will contain only that dust which is likely to be of pathogenic importance.

In accordance with the above, practically all samples were taken at a distance of 20 feet or more from the drilling face and 30 feet or more from the shovelling and the loading places. In deciding these distances, consideration was also given to the range of dust concentration as well as to its uniformity.

Frequency of Samples

For the purpose of taking dust samples, 14 working places in the aforesaid four mines were used. At each place, 3 or more impinger samples were taken; each over a period of 5 or 10 minutes. Three or six konimeter samples were taken within a few centimeters of the impinger inlet at two-minute intervals during the period of each impinger sample. Beadle (4) found that three konimeter samples spaced over two minutes gave an average count which is close to the true mean concentration for this period of time. The total number of samples collected by the midget impinger was 61 and that collected by the konimeter was 248.

Sampling Data

The data cards, which were used for recording all of the pertinent sampling information, were prepared according to the form suggested by the U.S. Bureau of Mines. The information pertaining to each set of samples has been recorded on a separate card. Besides recording time and the mine location, other environmental conditions, under which the dust was sampled, were also recorded. This information is shown in Appendix A.

COUNTING OF DUST PARTICLES

The microprojector, as described in Chapter 2, was used for counting the dust particles in the impinger samples. Before use, it was cleaned and adjusted as described earlier.

The impinger sample was diluted to 10, 20, or 25 mls., depending upon its dust concentration and, after agitating it well, the Sedgwick-Rafter cell was filled and allowed to settle for 30 minutes. The edges of the cell were wrapped with Scotch tape to prevent air bubbles from entering the cell. It was then transferred to the mechanical stage of the microprojector and the dust particles counted on the screen. Two or more cells were prepared for each impinger sample and five fields in each cell were counted as previously mentioned.

The microscope and the lighting arrangement, provided in the microprojector, also were used in counting dust particles in the konimeter samples. The particles were not projected as were the impinger samples, but they were counted at a magnification of 200 diameters, directly through the microscope, with dark field illumination provided by an ordinary central stop in the standard condenser. The glass disk, with its sampling side downward, was placed on the mechanical stage and the microscope was racked up and down to locate the dusty spot on the glass disk.

A semi-circular protractor reticule was placed in the eyepiece of the microscope, and the sampling disk was moved concurrently as the eyepiece was rotated until the center of No. 1 dust spot was directly aligned and focussed at the center of the reticule. All visible particles in the 20° sector (between 80° and 100°) were counted and recorded. This process was repeated until all particles in the 20° sector of all dust samples were counted. The eyepiece was then rotated about 100° and the center of No. 1 spot refocussed as before. All dust particles visible in this 20° sector were again counted and recorded. This process was repeated until all the samples of the glass disk were evaluated. The sum of the two 20° sector counts was multiplied by 0.051 to give the dust concentration in millions of particles per cubic foot of air sampled.

The results and data on counting of the impinger as well as the konimeter samples are given in Appendix B.

CHAPTER V

RESULTS AND THEIR ANALYSES

Results

The konimeter and impinger dust counts and the ratios of one with respect to the other, for like atmospheric dust conditions, are presented in Table III. The mean konimeter counts, the corresponding impinger counts, and the ratios of their means are given in Table IV. These data are arranged in the ascending order of the impinger counts and shown in Table V. They are then divided into groups, according to arbitary concentration ranges and presented in Tables VI through X. The mean ratios, with their standard deviations, are calculated for each such group as well as for those figures in each group which are in close agreement (within 20 per cent) with the mean of that group. The means, and their standard deviations, are summed up in Table XI. The general trend of the konimeter and impinger count ratios, in relation to the dust concentration shown by the midget impinger, is represented by a curve in Figure 25.

Analysis of the Results

It is obvious from the results in Table III, that the dust clouds, which were sampled underground, fluctuate greatly in their dust content. These fluctuations, though primarily dependent upon the source of dustiness and its distance from the sampling location, are detected

TABLE III

RESULTS OF THE IMPINGER AND KONIMETER SAMPLES

1 Experimental Set. No.	2 Konimeter Sample No.	3 Konimeter Count MPPCF	4 Mean Konimeter Count MPPCF	5 Impinger Sample No.	6 Impinger Count MPPCF	7 Ratio 4/6	8 Sample Location
A.	1.	4.4					Taken in 20 ft. from large stope; wet drilling
	2.	3.7	5.0	1.	3.3	1.52	
	3.	6.8					
	4.	5.7					
	5.	4.7	4.2	2.	2.8	1.50	
	6.	2.1					
	7.	3.4					
	8.	4.5	4.4	3.	3.0	1.48	
	9.	5.3					
B.	10.	6.7					Taken in a large stope; shovelling at 50 ft. to right and wet drilling 20 ft. to left.
	11.	6.0	7.6	4.	5.5	1.38	
	12.	10.1					
	13.	6.1					
	14.	5.6	5.5	5.	5.3	1.02	
	15.	4.9					
	16.	4.3					
	17.	7.5	7.7	6.	8.7	0.89	
	18.	11.3					
C.	19.	10.3					Taken in a large stope 30 ft. east of loading and 20 ft. west of wet drilling
	20.	7.5	9.0	7.	8.3	1.08	
	21.	9.1					
	22.	10.8					
	23.	12.4	13.5	8.	8.6	1.57	
	24.	16.9					

1	2	3	4	5	6	7	8
	25.	12.1	9.8	9.	8.4	1.17	
	26.	8.3					
	27.	9.0					
D.	28.	Too high		10.	66.7		Taken 6 ft. from drilling. Four holes drilled and sampling continuously
	29.						
	30.						
	31.	Too high		11.	207.8		
	32.						
	33.						
	34.	Too high		12.	178.7		
	35.						
	36.						
E.	37.	41.9	33.2	13.	34.6	0.96	Taken 30 ft. from the drilling face in a drive; dust was raised by drilling four dry holes before sampling was commenced.
	38.	38.1					
	39.	19.6					
	40.	29.6	22.9	14.	31.4	0.73	
	41.	17.4					
	42.	21.6					
	43.	11.5	14.5	15.	23.4	0.62	
	44.	8.7					
	45.	23.2					
F.	46.	12.2	11.8	16.	43.7	0.27	Taken 30 ft. from the drilling face in a drive; holes drilled dry; drilling and sampling simultaneous
	47.	10.9					
	48.	12.6					
	49.	49.3	33.0	17.	49.4	0.67	
	50.	33.4					
	51.	16.5					

1	2	3	4	5	6	7	8
	52.	13.8	12.9	18.	61.4	0.21	
	53.	12.4					
	54.	12.5					
G.	55.	23.2	24.6	19.	12.7	1.94	Taken 60 ft. from the drilling face; dust raised by drilling four dry holes; sampling commenced 10 minutes after the drilling was stopped.
	56.	24.2					
	57.	26.4					
	58.	11.4	9.2	20.	10.9	0.84	
	59.	7.1					
	60.	9.2					
	61.	8.9	13.2	21.	10.4	1.27	
	62.	12.2					
	63.	18.6					
	64.	11.8	10.5	22.	10.6	0.99	
	65.	9.5					
	66.	10.3					
	67.	11.1	12.8	23.	5.8	2.20	
	68.	11.6					
	69.	15.5					
	70.	14.0	10.4	24.	9.2	1.13	
	71.	12.4					
	72.	5.00					
H.	73.	11.1	8.4	25.	8.7	0.97	Taken 10 ft. from Jumbo drill; two wet holes being drilled simultaneously
	74.	8.8					
	75.	5.4					
	76.	13.6	13.4	26.	8.3	1.62	
	77.	10.0					
	78.	16.6					

Table III Continued

1	2	3	4	5	6	7	8
	79.	10.9	8.7	27.	8.6	1.01	
	80.	7.8					
	81.	7.3					
I.	82.	6.5	10.4	28.	12.3	0.85	Taken 6 ft. from loading point. Loading continuous
	83.	9.5					
	84.	15.3					
	85.	14.3	11.0	29.	10.3	1.07	
	86.	12.4					
	87.	5.8					
	88.	7.3	8.4	30.	13.1	0.64	
	89.	8.5					
	90.	9.4					
J.	91.	4.4	4.9	31.	5.4	0.91	Taken between two drills; 20 ft. from the one and 7 ft. from the other; holes drilled wet; in a cross-drift
	92.	4.7					
	93.	4.5					
	94.	8.2	6.9	32.	5.3	1.30	
	95.	4.9					
	96.	7.6					
	97.	20.5	11.7	33.	5.5	2.13	
	98.	9.1					
	99.	5.7					
K	100.	46.5	44.6	34.	48.0	0.93	Taken 20 ft. from drilling face; dry holes; drilling continuous
	101.	45.7					
	102.	41.6					
	103.	Too high	Too High	35.	75.3		
	104	" "					
	105	" "					

Table III Continued

1.	2	3	4	6	6	7	8
	106.	Too High	Too High	36.	103.5		
	107.	" "					
	108.	" "					
L.	109.	43.1	40.1	37.	55.7	0.72	Taken 20 ft. from drilling face. Dust raised by drilling 3 dry holes; sampling commenced after drilling was stopped
	110.	38.5					
	111.	38.8					
	112.	37.5	32.4	38.	39.0	0.83	
	113.	31.9					
	114.	27.7					
	115.	12.3	10.9	39.	34.0	0.32	
	116.	11.1					
	117	9.2					
M.	118.	30.4	32.8	40.	24.8	1.32	Taken 45 ft. from the drilling face in a drive; three dry holes drilled to set up dusty atmosphere
	119.	41.3					
	120.	26.6					
	121.	23.2	20.3	41.	25.7	0.79	
	122.	20.8					
	123	17.0					
	124.	13.1	16.7	42.	19.7	0.85	
	125.	15.1					
	126.	22.0					
N.	127.	25.4	24.6	43.	16.3	1.51	Taken 45 ft. from the drilling face in a drive; dust raised by drilling 3 dry holes. Sampling was commenced two minutes after drilling was stopped
	128.	25.2					
	129.	22.2					
	130.	16.2	13.6	44.	13.1	1.04	
	131.	9.4					
	132.	15.1					

Table III Continued

1	2	3	4	5	6	7	8
	133.	12.9	11.6	45.	13.3	0.87	
	134.	11.2					
	135.	10.7					
O.	136.	7.6	9.5	46.	7.5	1.27	Taken 60 ft. from the drilling face in a drive; dust raised by three dry holes; sampling commenced half-hour after the drilling stopped.
	137.	11.6					
	138.	9.3					
	139.	8.3	11.3	47.	7.9	1.43	
	140.	10.1					
	141.	15.4					
P.	142.	1.8	1.4	48.	0.8	1.75	Taken 20 ft. from the Jumbo drill in a sand mine; 10 minutes sampling by impinger with 6 konimeter samples for each; wet drilling
	143.	1.4					
	144.	1.2					
	145.	1.4					
	146.	1.5					
	147.	0.92					
	148.	.71	1.5	49.	0.9	1.67	
	149.	1.3					
	150.	2.3					
	151.	1.1					
	152.	1.6					
	153.	1.8					
	154.	0.92	0.70	50.	0.8	0.87	
	155.	0.56					
	156.	1.4					
	157.	0.31					
	158.	0.26					
	159.	0.81					
Q.	160.	5.5	4.3	51.	2.5	1.76	Taken 30 ft. from shovelling; two shovels working simultaneously
	161.	4.8					
	162.	2.7					

Table III Continued

1	2	3	4	5	6	7	8
	163. 164. 165.	2.2 5.2 6.8	4.7	52.	2.3	2.04	
	166. 167. 168.	6.2 3.5 2.9	4.2	53.	2.3	1.83	
R.	169. 170. 171.	9.0 8.4 5.9	7.8	54.	2.9	2.71	Taken 15 ft. from shovelling; two shovels working; one at a time
	172. 173. 174.	6.5 7.3 6.5	6.8	55.	2.8	2.43	
	175. 176. 177.	3.5 7.1 6.3	5.6	56.	4.5	1.25	
S.	178. 179. 180.	9.6 6.7 7.4	7.9	57.	3.7	2.16	Taken 20 ft. from dumping
	181. 182. 183.	4.4 5.8 6.6	5.6	58.	3.8	1.49	
	184. 185. 186.	6.5 6.8 4.7	6.0	59.	4.3	1.41	

in nearly all areas of the mines. They appear in the form of small eddy currents of high dust concentrations which are followed, within a few inches, by pockets of air which are relatively free from dust.

The rates of coagulation and settling of dust particles, according to the Brownian Movement and Stokes Law, are important in bringing about variations in the particle concentration. It is also possible that it may merely appear so, as large size particles may make their way through the nozzle of the sampling instrument and the smaller ones will not be collected in their true proportion. This is due to the fact that the motion of the particles is determined by the net force acting to cause the motion. The net force, in turn, depends upon the weight and dimensions of the individual particle. Hence, two dusts, with the same particle size distribution, but with different densities, may be expected to yield different results. Similarly, dust formations, of the same substance, having different size distributions, will also yield different results. In summation, the greater the density of the solid, and the larger the particle size, the lower will be the percentage of dust particles in the air actually drawn in the sample, and consequently, the lower will be the reported dust concentrations.

Another characteristic property of the aerosol particles is their ability to take on an electric charge by collision with free ions. Once having become charged, the particles are attracted to others of opposite charge and thus bring about a change in the original arrangement and apparent concentration of dust particles in the aerosol; both in space and time.

Added to the above, is the complication created by the breathing of the sampling personnel and the intake of dust-laden air by the sampling instruments. It is not really known where, in the fluctuating clouds, this air comes from and what effect it may have upon the original concentration. It is certain, however, that they do affect momentary variations in the dust concentration in their immediate vicinity.

The major fluctuations in dust concentrations caused by the mining operations, or other dust sources, have been detected by both the instruments considered in this investigation, but momentary changes have been recorded only by the konimeter. It is evident, from the counting results obtained, that where the impinger has recorded only a certain average condition, the konimeter has shown the average condition as well as its various high and low components spread over this period. The data in Table III have shown that these components sometimes vary as much as ± 100 per cent, or even more, from the average figure. In the case of the konimeter, a relatively small amount of air is collected in each sample, and a single sample therefore gives a measure of dustiness which has less statistical value than the average concentration results given by the impinger which operates at a constant sampling rate over a longer period of time. On the other hand, a series of instantaneous samples, as collected at intervals by the konimeter, show how dustiness actually fluctuates in the sampled area, and thus provides information not given by the continuous samples of the impinger.

The importance of the sampling time interval and volume of sample collected depends upon the pattern of dust production and release. Compared with mine atmospheres, the air movement and other disturbing factors are much greater in rock crushing plants, foundries, or granite cutting establishments, and fluctuations in dustiness are correspondingly higher. Under these circumstances, the konimeter may have even less value. The large number of instantaneous samples, required to give a reliable average, involves too much work in subsequent analyses to warrant their collection. The impinger has similar limited statistical value where there are major fluctuations in the rate of dust production and release.

Average dust concentrations are probably of greater importance in the appraisal of chronic pneumoconiosis hazards than they are in the evaluation of exposures to acutely toxic dusts. For exposures to the toxic dusts, the peak concentrations, revealed by a series of snap samples, are of greatest importance.

In the case of human respiration, it is evident that a man does not inhale an average dust concentration each time. The peaks or troughs, as recorded by the konimeter, and not shown by the impinger, therefore, represent a better picture of the dusts inhaled by the persons exposed to it. It is still more important to record these peaks if the filteration process of the human respiratory system is capable of filtering only a certain maximum dust per breath and if the concentration is more than such a maximum which is deposited in the lungs and contracts infection.

From the results shown in Tables IV and V, it is evident that there is no constant ratio between the mean konimeter count and its corresponding impinger count. As a matter of fact, there does not appear to be any constant relationship between their counts even for a given mining condition. The results indicate a wide range in ratios for specific operations such as drilling, loading, or dumping. It is also evident, that in these results, the impinger counts show much more consistency than that shown by the konimeter counts.

In order to investigate possible reasons for this wide range of ratios, the results in Table V have been analysed in the following two ways.

a) The various results have been divided into groups according to the dust concentration shown by the impinger count and the mean ratio with its percentage deviation for each group calculated. The results are shown in Tables VIa through Xa.

TABLE IV

MEAN OF THE RATIO OF THE MEAN KONIMETER COUNT AND THE CORRESPONDING MEAN IMPINGER COUNT

1 Experimental Set No.	2 Impinger Sample No.	3 Impinger Count MPPCF	4 Mean Impinger Count MPPCF	5 Mean Konimeter Count MPPCF	6 Mean of Mean Konimeter Count MPPCF	7 Ratio of 6/4
A.	1.	3.3	3.03	5.0	4.53	1.50
	2.	2.8		4.2		
	3.	3.0		4.4		
B.	4.	5.5	6.5	7.6	6.93	1.096
	5.	5.3		5.5		
	6.	8.7		7.7		
C.	7.	8.3	8.43	9.0	10.76	1.273
	8.	8.6		13.5		
	9.	8.4		9.8		
D.	10.	66.7	151.1	Too high	-	-
	11.	207.8		" "		
	12.	178.7		" "		
E.	13.	34.6	29.8	33.2	23.53	0.77
	14.	31.4		22.9		
	15.	23.4		14.5		
F.	16.	43.7	51.5	11.8	19.23	0.383
	17.	49.4		33.0		
	18.	61.4		12.9		
G.	19.	12.7	9.93	24.60	13.45	1.39
	20.	10.9		9.2		
	21.	10.4		13.2		
	22.	10.6		10.5		
	23.	5.8		12.8		
	24.	9.2		10.4		

Table IV Continued

1	2	3	4	5	6	7
H.	25.	8.7	8.53	8.4	10.16	1.20
	26.	8.3		13.4		
	27.	8.6		8.7		
I.	28.	12.3	11.9	10.4	9.93	0.85
	29.	10.3		11.0		
	30.	13.1		8.4		
J.	31.	5.4	5.4	4.9	7.83	1.45
	32.	5.3		6.9		
	33.	5.5		11.7		
K.	34.	48.0	75.6	44.6	-	-
	35.	75.3		Too high		
	36.	103.5		" "		
L.	37.	55.7	42.9	40.1	27.8	0.623
	38.	39.0		32.6		
	39.	34.0		10.9		
M.	40.	24.8	23.4	32.8	23.26	0.99
	41.	25.7		20.3		
	42.	19.7		16.7		
N.	43.	16.3	14.23	24.6	16.60	1.14
	44.	13.1		13.6		
	45.	13.3		11.6		
O.	46.	7.5	7.7	9.5	10.4	1.35
	47.	7.9		11.3		
P.	48.	0.8	0.83	1.4	1.2	1.43
	49.	0.9		1.5		
	50.	0.8		0.7		

Table IV Continued

1	2	3	4	5	6	7
Q.	51.	2.5	2.36	4.3	4.4	1.88
	52.	2.3		4.7		
	53.	2.3		4.2		
R.	54.	2.9	3.3	7.8	6.73	2.13
	55.	2.8		6.8		
	56.	4.5		5.6		
S.	57.	3.7	3.9	7.9	6.5	1.69
	58.	3.8		5.6		
	59.	4.3		6.0		

TABLE V

RATIOS OF TABLE IV IN ASCENDING ORDER OF IMPINGER COUNTS

1 Serial No.	2 Experimental Set No.	3 Impinger Sample No.	4 Impinger Count MPPCF	5 Mean Konimeter Count MPPCF	6 Ratio 5/4
1.	P.	50.	0.8	0.7	0.87
2.	P.	48.	0.8	1.4	1.75
3.	P.	49.	0.9	1.5	1.67
4.	Q.	53.	2.3	4.2	1.83
5.	Q.	52.	2.3	4.7	2.04
6.	Q.	51.	2.5	4.3	1.76
7.	A.	2.	2.8	4.2	1.50
8.	R.	55.	2.8	6.8	2.43
9.	R.	43.	2.9	7.8	2.71
10.	A.	3.	3.0	4.4	1.48
11.	A.	1.	3.3	5.0	1.52
12.	S.	57.	3.7	7.9	2.16
13.	S.	58.	3.8	5.6	1.49
14.	S.	59.	4.3	6.0	1.41
15.	R.	56.	4.5	5.6	1.25
16.	B.	5	5.3	5.5	1.02
17.	J.	32.	5.3	6.9	1.30
18.	J.	31.	5.4	4.9	0.91
19.	J.	33.	5.5	11.7	2.13
20.	B.	4.	5.5	7.6	1.38
21.	G.	23.	5.8	12.8	2.20
22.	O.	46.	7.5	9.5	1.27
23.	O.	47.	7.9	11.3	1.43
24.	H.	26.	8.3	13.4	1.62
25.	C.	7.	8.3	9.0	1.08
26.	C.	9.	8.4	9.8	1.17
27.	C.	8.	8.6	13.5	1.57
28.	H.	27.	8.6	8.7	1.01
29.	H.	25.	8.7	8.4	0.97
30.	B.	6.	8.7	7.7	0.89
31.	G.	24.	9.2	10.4	1.13
32.	I.	29.	10.3	11.0	1.07
33.	G.	21.	10.4	13.2	1.27
34.	G.	22.	10.6	10.5	0.99
35	G.	20.	10.9	9.2	0.84
36.	I.	28.	12.3	10.4	0.85
37.	G.	19.	12.7	24.6	1.94
38.	I.	30.	13.1	8.4	0.64
39.	N.	44.	13.1	13.6	1.06
40.	N.	45.	13.3	11.6	0.87
41.	N.	43.	16.3	24.6	1.51
42.	M.	42.	19.7	17.7	0.85
43.	E.	15.	23.4	14.5	0.62
44.	M.	40.	24.8	32.8	1.32
45.	M.	41.	25.7	20.3	0.79

Table V Continued

1	2	3	4	5	6
46.	E.	14.	31.4	22.9	0.73
47.	L.	39.	34.0	10.9	0.32
48.	E.	13.	34.6	33.2	0.96
49.	L.	38.	39.0	32.4	0.83
50.	F.	16.	43.7	11.8	0.27
51.	K.	34.	48.	44.6	0.93
52.	F.	17.	49.4	33.0	0.67
53.	L.	37.	55.7	40.1	0.72
54.	F.	18.	61.4	12.9	0.21

b) Those results which appear consistent in their ratio are grouped according to the dust concentration shown by the impinger count and the mean ratio with its percentage deviation for each of these groups is also calculated. The results of these analyses are shown in Tables VIb through IXb.

The summary of the results is shown in Table XI and represented graphically in Figure 25. The curve in Figure 25 suggests that, in spite of the wide variation in their corresponding ratios, there is a tendency for the konimeter to show higher dust counts for the low concentrations indicated by the impinger, whereas, for at higher higher concentrations, the konimeter has shown constantly diminishing values. In other words, considering that the impinger counts are more consistent, konimeter counts decrease with the increase in dust concentration. It can also be stated, that for low dust concentrations, the konimeter is more efficient than the impinger, but with the increase in dusty conditions, the efficiency of the konimeter decreases so rapidly that, for concentrations beyond 35 million particles per cubic foot, it is almost impossible to get any indication of the aerosol. These results, if interpreted in the foregoing manner, also confirm the tendency of the impinger to show relatively lower values for the low dust concentrations.

Looking to the extreme figures in which konimeter counts have deviated from their own mean and, also, from

TABLE VIA

RATIOS OF TABLE IV FOR IMPINGER COUNT RANGE 0.0-4.9 MPPCF

Serial No.	Experimental Set No.	Impinger Sample No.	Impinger Count MPPCF	Mean Konimeter Count MPPCF	Ratio 5/4	Remarks
1.	P.	50.	0.8	0.7	0.87	Too Low
2.	P.	48.	0.8	1.4	1.75	
3.	P.	49.	0.9	1.5	1.67	
4.	Q.	53.	2.3	4.2	1.83	
5.	Q.	52.	2.3	4.7	2.04	
6.	Q.	51.	2.5	4.3	1.76	
7.	A.	2.	2.8	4.2	1.50	
8.	R.	55.	2.8	6.8	2.43	Too High
9.	R.	54.	2.9	7.8	2.71	Too High
10.	A.	3.	3.0	4.4	1.48	
11.	A.	1.	3.3	5.0	1.52	
12.	S.	57.	3.7	7.9	2.16	Too High
13.	S.	58.	3.8	5.6	1.49	
14.	S.	59.	4.3	6.0	1.41	
15.	R.	56.	6.5	5.6	1.25	Too Low

Mean - 1.72

Standard Deviation - ±.44

Percentage Standard Deviation - 25%

TABLE VIB

RATIOS OF TABLE IV FOR IMPINGER COUNT RANGE 0.0-4.9 MPPCF, ADJUSTED*

Serial No.	Experimental Set No.	Impinger Sample No.	Impinger Count MPPCF	Mean Konimeter Count MPPCF	Ratio 5/4
1.	P.	48.	0.8	1.4	1.75
2.	P.	49.	0.9	1.5	1.67
3.	Q.	53.	2.3	4.2	1.83
4.	Q.	52.	2.3	4.7	2.04
5.	Q.	51.	2.5	4.3	1.76
6.	A.	2.	2.8	4.2	1.50
7.	A.	3.	3.0	4.4	1.48
8.	A.	1.	3.3	5.0	1.52
9.	S.	58.	3.8	5.6	1.49
10.	S.	59.	4.3	6.0	1.41

Mean - 1.65

Standard Deviation - ± .19

Percentage Standard Deviation - 11.5%

***All those counts which are too high or too low have been eliminated in this table.**

TABLE VIIA

RATIOS OF TABLE IV FOR IMPINGER COUNT RANGE 5-9.9 MPPCF

Serial No.	Experimental Set No.	Impinger Sample No.	Impinger Count MPPCF	Mean Konimeter Count MPPCF	Ratio 5/4	Remarks
1.	B.	5.	5.3	5.5	1.02	Too Low
2.	J.	32.	5.3	6.9	1.30	
3.	J.	31.	5.4	4.9	0.91	Too Low
4.	J.	33.	5.5	11.7	2.13	Too High
5.	B.	4.	5.5	7.6	1.38	
6.	G.	23.	5.8	12.8	2.20	Too High
7	O.	46.	7.5	9.5	1.27	
8.	O.	47.	7.9	11.3	1.43	
9.	H.	26.	8.3	13.4	1.62	Too High
10.	C.	7.	8.3	9.0	1.08	
11.	C.	9.	8.4	9.8	1.17	
12.	C.	8.	8.6	13.5	1.57	
13.	H.	27.	8.6	8.7	1.01	Too Low
14.	H.	25.	8.7	8.4	0.97	Too Low
15.	B.	6.	8.7	7.7	0.89	Too Low
16.	G.	24.	9.2	10.4	1.13	

Mean -- 1.32

Standard Deviation - ±0.38

Percentage Standard Deviation - 28.8%

TABLE VIIB

RATIO OF TABLE IV FOR IMPINGER COUNT RANGE 5.0-9.9 MPPCF, ADJUSTED*

Serial No.	Experimental Set No.	Impinger Sample No.	Impinger Count MPPCF	Mean Konimeter Count MPPCF	Ratio 5/4
1.	J.	32.	5.3	6.9	1.30
2.	B.	4.	5.5	7.6	1.38
3.	O.	46.	7.5	9.5	1.27
4.	O.	47.	7.9	11.3	1.43
5.	C.	7.	8.3	9.0	1.08
6.	C.	9.	8.4	9.8	1.17
7.	C.	8.	8.6	13.5	1.57
8.	G.	24.	9.2	10.4	1.13

Mean - 1.29

Standard Deviation - $\underline{\neq}$ .15

Percentage Standard Deviation - 11.95%

*All those counts which are too high or too low have been eliminated in this table.

TABLE VIIIA

RATIOS OF TABLE IV FOR IMPINGER COUNT RANGE 10-15 MPPCF

Serial No.	Experimental Set No.	Impinger Sample No.	Impinger Count MPPCF	Mean Konimeter Count MPPCF	Ratio 5/4	Remarks
1.	I.	29.	10.3	11.0	1.07	
2.	G.	21.	10.4	13.2	1.27	
3.	G.	22.	10.6	10.5	0.99	
4.	G.	20.	10.9	9.2	0.84	
5.	I.	28.	12.3	10.4	0.85	
6.	G.	19.	12.7	24.6	1.94	Too High
7.	I.	30.	13.1	8.4	0.64	Too Low
8.	N.	44.	13.1	13.6	1.04	
9.	N.	45.	13.3	11.6	0.87	

Mean - 1.06

Standard Deviation - ± .38

Percentage Standard Deviation - 35.4%

TABLE VIIIB

RATIOS OF TABLE IV FOR IMPINGER COUNT RANGE 10-15 MPPCF, ADJUSTED *

Serial No.	Experimental Set No.	Impinger Sample No.	Impinger Count MPPCF	Mean Konimeter Count MPPCF	Ratio 5/4
1.	I.	29.	10.3	11.0	1.07
2.	G.	21.	10.4	13.2	1.27
3.	G.	22.	10.6	10.5	0.99
4.	G.	20.	10.9	9.2	0.84
5.	I.	28.	12.3	10.4	0.85
6.	N.	44.	13.1	13.6	1.04
7.	N.	45.	13.3	11.6	0.87

Mean - 0.99

Standard Deviation - ± .143

Percentage Standard Deviation - 14.5%

*All those counts which are too high or too low have been eliminated in this table.

TABLE IXA

RATIOS OF TABLE IV FOR IMPINGER COUNT RANGE 15-35 MPPCF

Serial No.	Experimental Set No.	Impinger Sample No.	Impinger Count MPPCF	Mean Konimeter Count MPPCF	Ratio 5/4	Remarks
1.	N.	63.	16.3	24.6	1.51	Too High
2.	M.	62.	19.7	16.7	0.85	
3.	E.	15.	23.4	14.5	0.62	Too Low
4.	M.	40.	24.8	32.8	1.32	Too High
5.	M.	41.	25.7	20.3	0.79	
6.	E.	14.	31.4	22.9	0.73	
7.	L.	39.	34.0	10.9	0.32	Too Low
8.	E.	13.	34.6	33.2	0.96	

Mean - 0.89

Standard Deviation - ± .36

Percentage Standard Deviation - 40%

TABLE IXB

RATIOS OF TABLE IV FOR IMPINGER COUNT RANGE 16-35 MPPCF, ADJUSTED *

Serial No.	Experimental Set No.	Impinger Sample No.	Impinger Count MPPCF	Mean Konimeter Count MPPCF	Ratio 5/4
1.	M.	42.	19.7	16.7	0.85
2.	M.	41.	25.7	20.3	0.79
3.	E.	14.	31.4	22.9	0.73
4.	E.	13.	34.6	33.2	0.96

Mean - 0.83

Standard Deviation - ± .079

Percentage Standard Deviation - 9.5%

*All those counts which are too high or too low have been eliminated in this table.

TABLE XA

RATIOS OF TABLE IV FOR IMPINGER COUNT RANGE 39.0 MPPCF AND ABOVE

Serial No.	Experimental Set No.	Impinger Sample No.	Impinger Count MPPCF	Mean Konimeter Count MPPCF	Ratio 5/4	Remarks
1.	L.	38.	39.0	32.4	0.83	Too High
2.	F.	16.	43.7	11.8	0.27	Too Low
3.	K.	34.	48.0	44.6	0.93	Too High
4.	F.	17.	49.4	33.0	0.67	
5.	L.	37.	55.7	40.1	0.72	
6.	F.	18.	61.4	12.9	0.21	Too Low

Mean	- 0.61
Standard Deviation	- ± .27
Percentage Standard Deviation	- 44.5%

TABLE XI

SUMMARY OF DATA PRESENTED IN TABLES VIA THROUGH X

Range in concentration shown by the impinger	0.0 to 4.9	5.0 to 9.9	10.0 to 15.0	16.0 to 35.0
A. Considering the entire group				
1. Average concentration in the range	2.71	7.2	11.8	26.2
2. Total number of samples	15	16	9	8
3. Mean ratio $\frac{\text{konimeter}}{\text{impinger}}$	1.72	1.32	1.06	0.89
4. Standard deviation	.44	.38	.38	.36
5. Per cent standard deviation	25%	28.8%	35.4%	40.0%
B. Considering those counts in the group which are within ±20 per cent of the mean in category A above				
1. Average concentration in the range	2.6	7.6	11.5	27.8
2. Total number of samples	10	8	7	4
3. Percentage of samples in the whole group	66.6%	50%	77%	50%
4. Mean ratio $\frac{\text{konimeter}}{\text{impinger}}$	1.65	1.29	.99	.83
5. Standard deviation	.19	.15	.143	.079
6. Per cent standard deviation	11.5%	11.95%	14.5%	9.5%

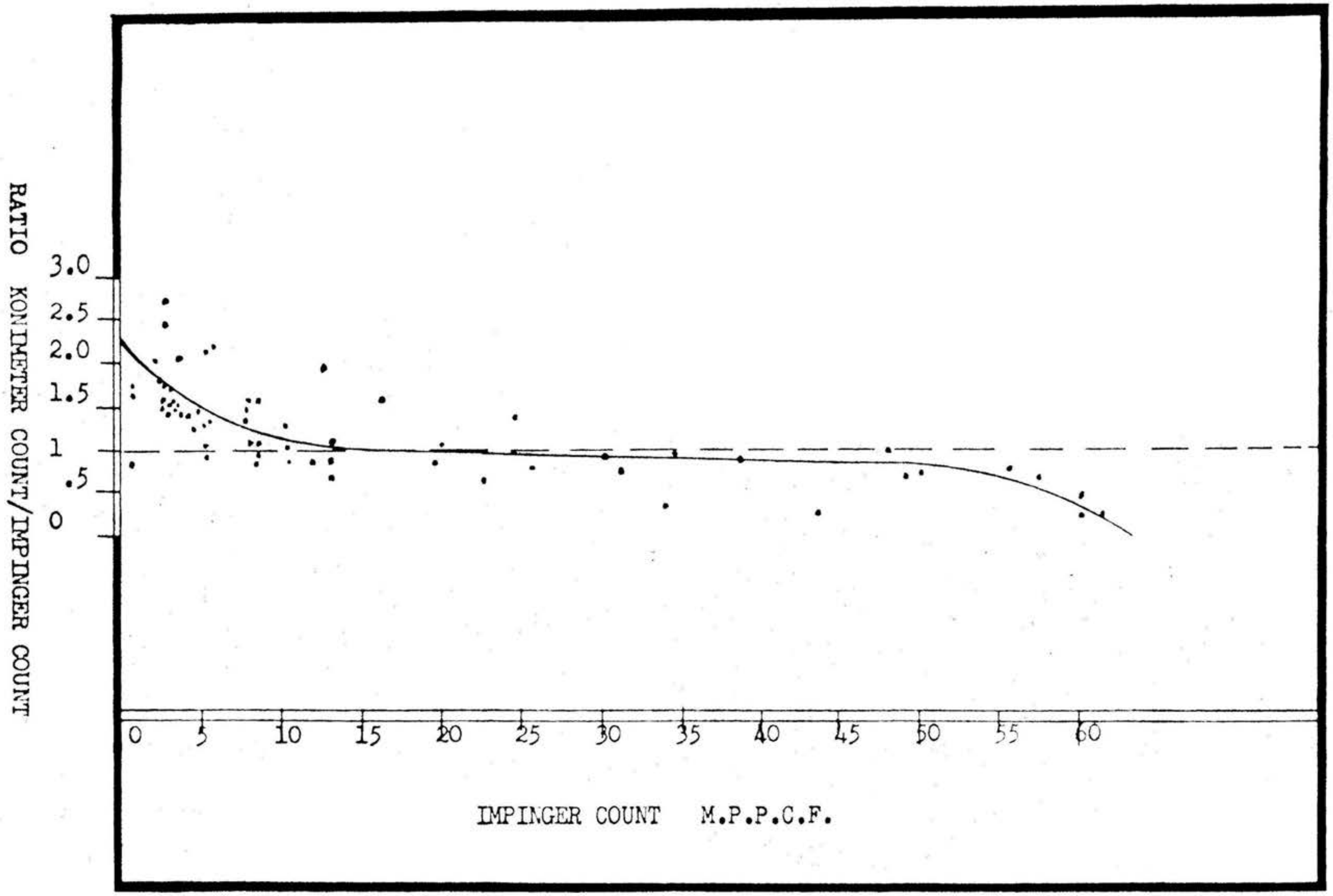

Figure 25 - Correlation of the Instruments at Various Dust Concentrations

those of the corresponding impinger values, it becomes quite apparent that the snap-sampling instruments are difficult to correlate with instruments which record the average conditions. In case of the very high values, it may be possible that the coarse particles, shattering against the glass slide of the konimeter, result in a large number of dis-aggregated finer particles. This possibility is further supported by the fact that most of the high figures represented by the konimeter counts correspond to the loading or dumping samples which normally produce coarser particles than those taken near drilling face. This also suggests that the impingement of the coarser particles in a liquid media, as it does in the case of impinger, does not result in particle disaggregation. If it does so, it is insignificant in comparison to what appears to have been indicated by the konimeter.

The air velocities in the human respiratory system are generally of the order of about 2 meters per second. Furthermore, the respiratory tissues provide a very effective cushion. Aggregates are not, therefore, likely to be broken up by impingement in the respiratory system as they may be in the konimeter in which the particles impinge upon glass at a velocity of about 100 meters per second. They may be broken up to some extent by chemical action once they have settled on the surfaces of the respiratory passages, but the larger aggregates, at any rate, will settle in the nasal passages, traches, and upper parts of the respiratory system. Particles settling in these passages do not play any part in the production of the pulmonary diseases (4). The behaviour of the konimeter, with regards to the particle dis-aggregation, does not, therefore, correspond to the action within the human respiratory system, and cannot, for this reason, represent the true condition.

Another observation made during this study is in connection with the permissible limits of dustiness which have been fixed for each instrument. As already stated, there is no constant relationship between the counts of one instrument with respect to those of the other. Because their ratios show wide variations, there can be no standard relation between their maximum limits of permissible dust concentration. The higher permissible figure of 450 particles per cubic centimeter (12.5 million particles per cubic foot), applicable to the Zeiss konimeter, suggests that this value incorporates all peak recordings of this instrument, whereas the 5 million particles per cubic foot, in the case of the maximum limit set for the midget impinger, reflects on its continuous performance including all peaks and troughs, within the sampled atmosphere, to produce an over-all average. It also suggests that, in evaluating dustiness by means of the konimeter, a greater number of counts would be necessary in order to obtain a correct representation of the peaks and troughs which abound in the dust concentrations. It is conceivably possible to record the troughs and miss the peaks completely if a sufficient number of samples are not collected, and, in which case, it would be hazardous to rely upon those results. This danger is limited in the case of midget impinger.

The accuracy of the results discussed above is the product of the collecting and counting efficiencies associated with the sampling instruments used. In both the cases, it is usual to count only a known fraction of the whole sample. Any errors, shown in Tables VI through IX, are, therefore, the result of correlations between the instruments involving their collecting as well as counting efficiencies.

It has been observed, that there is nothing offered in the results of the investigators quoted, which can not be explained by the results presented and discussed above. At the same time, these results offer food for future thinking and stimulus for extensive research which appears to be so very badly needed in this field.

CHAPTER VI

SUMMARY AND CONCLUSIONS

This study was undertaken to determine the relation between dust concentration measurements obtained by the Zeiss konimeter and those of the midget impinger in order to provide a basis for comparison of their respective results, and for the purpose of conversion of concentration measurements by one instrument to equivalent values for the other. During this study, nineteen working places, in four different mines, were selected for simultaneous sampling by the aforesaid two instruments. At each place, 3 or more impinger samples were collected, each over a period of about 5 or 10 minutes. During this period of each impinger sample, 3 or more konimeter samples were taken, at two minute intervals, within a few inches from the impinger intake. A total number of 59 samples was collected by the impinger, and 186 by the konimeter. The atmospheres were sampled within a wide range of varied dust concentrations in order to provide sufficient data for analysis of the instrument performances.

The ratios obtained from the corresponding sample counts have shown wide variations from one dusty condition to another, and even for the same condition. It was found that no single conversion factor or factors could be obtained. The reasons for such differences, as stated in the previous chapter, are further borne out by the results of this investigation as they were by many previous individual investigators who were concerned with only single instruments. The possible explanations for these differences have been summarised as below:

1) The dust clouds underground fluctuate widely in their dust content, both in space as well as in time.

2) The sampling characteristics of the two instruments differ greatly. The konimeter is a snap-sampling instrument in which a relatively small amount of air is collected in a moment, and a single sample gives a measure of dustiness which has less statistical value than the average concentration given by the midget impinger which operates continuously, at constant sampling rate, over a comparatively much longer period of time. On the other hand, a series of instantaneous samples collected by the konimeter show how dustiness fluctuates and thus provide information not given by the continuous samples collected by the impinger.

3) The relative collecting and the counting efficiency of these two instruments, in relation to the magnitude of dust concentration, vary significantly.

4) Lastly, but probably of greater influence in determining ratios, is the varying extent of disaggregation and shattering of particles brought about in the course of collecting samples.

A comparative study of the dust count ratios, in relation to the dust concentrations shown by the midget impinger has, however, shown that, in spite of wide variations in their corresponding ratios, there is a general tendency of the konimeter to record higher counts in low dust concentrations, whereas, in higher concentrations, its values decrease rapidly. Beyond 35 million particles per cubic foot, it is almost impossible to get any indication of the dusty atmosphere by means of this instrument, whereas the impinger can successfully operate in even higher concentrations. This again leads to the other important conclusion; that there is no definite correlation between their standards of permissible dustiness, and their maximum permissible dustiness bases seem to be entirely arbitrary. The higher figure assigned, in the case of konimeter, seems to have incorporated all the peak recording characteristics of that instrument. On the other hand, the low figure, in the case of impinger, reflects on its continuous performance; including peaks and troughs to give an over all average.

The author feels that the konimeter and the impinger methods of collecting, analysing and evaluating dust are purely empirical and not absolute. They may be of value in comparing results of each individual instrument, but of little or no significance if comparison is attempted between the results of one instrument with those of the other. It is recommended, however, that further investigations be made to understand more fully the effects of coarse dust particles disaggregating on impingement;

essentially in the case of konimeter, but also with the impinger. Further, better knowledge of the physical, chemical and numerical significance of the dusts evoked ailments be obtained by expert pathologists to cast more light on the respiratory behavior of contaminated air so that an engineer may become armed with better tools for combating the dust problems.

APPENDICES

Appendix A

Information on Samples of Dust-laden Air Collected from the Mines

Information on Samples of Particulate Matter

Experiment Set A

Sample of Dust from Air Date Sampled January 20, 1961
Co. St. Joseph Lead Company Mine or Plant Bonne Terre Mine
State Missouri County St. Francis Town Bonne Terre
Location in Mine or Plant Stope Elevation 800

20 ft. from
the drill

Sampling Location Plan

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
1	8.55	5	0.1 cfm	0.5 c.ft	3	5 cc.
					4	5 cc.
					5	5 cc.
2	9.00'30"	5	0.1 cfm	0.5 c.ft	6	5 cc.
					7	5 cc.
					8	5 cc.
3	9.05	5	0.1 cfm	0.5 c.ft	9	5 cc.
					11	5 cc.
					12	5 cc.

Conditions during sampling - Wet drilling, one drill; one man drilling. Two holes were drilled.

Air: Temp; D.B. 60°F R.H. 85% Flow; F.P.M. 15
Place; W 110 Ft. Ht. 20 Ft. Area Large

Remarks - Konimeter Sample 2 was spoiled; No. 10 left blank for reference. Dust from Dolomite.

Information on Samples of Particulate Matter

Experiment Set B

Sample of Dust from Air Date Sampled January 20, 1961
Co. St. Joseph Lead Company Mine or Plant Bonne Terre Mine
State Missouri County St. Francis Town Bonne Terre
Location in Mine or Plant Stope Elevation 800

50 ft. from shovel on the
western side
Sampling Location

Plan

MIDGET IMPINGER			ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Sample No.	Sample V Volume
4	9.38'00"	5	13	5 cc.
			14	5 cc.
			15	5 cc.
5	9.43'30"	5	16	5 cc.
			17	5 cc.
			18	5 cc.
6	9.49'00"	5	19	5 cc.
			21	5 cc.
			22	5 cc.

Conditions during sampling - Shovelling and loading into truck. 1/2 ton shovel. Sampling done in the direction of ventilative current flowing from east to west. The operation was continuous.

Air: Temp; D.B. 60°F R.H. 85% Flow; F.P.M. 15
Place: W Large Ht. 30 Ft. Area Large

Remarks - Konimeter sample No. 20 left blank for reference.
Dust from dolonictic limestone.

Information on Samples of Particulate Matter

Experiment Set C

Sample of Dolomite Dust from Air Date Sampled January 20, 1961
Co. St. Joseph Lead Company Mine or Plant Bonne Terre Mine
State Missouri County St. Francis Town Bonne Terre
Location in Mine or Plant A Large Stope Elevation 800

30 ft. east of loading and 20 ft. west of drilling.

Sampling Location

Plan

MIDGET IMPINGER					ZEISS KONIMETER		
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Time	Sample Volume
7	10.08'00"	5	0.1 c.ft/m	0.5 c.ft	23	23	5 cc.
					24	24	5 cc.
					25	25	5 cc.
8	10.13'30"	5	0.1 c.ft/m	0.5 c.ft	26	26	5 cc.
					27	27	5 cc.
					28	28	5 cc.
9	10.18'55"	5	0.1 c.ft/m	0.5 c.ft	29	29	5 cc.
					30	30	5 cc.
					1	1	5 cc.

Conditions during sampling - Loading into truck by 1/2 ton shovel on western side and one wet drilling on the eastern side. Operation continuous.

Air: Temp; D.B. 60°F R.H. 85% Flow; F.P.M. 15
Place; W Large Ht. 25 to 30 Ft. Area Large

Information on Samples of Particulate Matter

Experiment Set D

Sample of Limestone Dust from Air Date Sampled January 27, 1961
Co. M.S.M. Mine or Plant Experimental Mine
State Missouri County Phelps Town Rolla

6 ft. from the
drilling face.

Section **Sampling Location** **Plan**

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
1	2.38'00"	5	0.1 cfm	0.5 c.ft	1	2.5 cc.
					2	2.5 cc.
					3	2.5 cc.
2	2.43'20"	5	0.1 cfm	0.5 c.ft	4	2.5 cc.
					5	2.5 cc.
					6	2.5 cc.
3	2.48'40"	5	0.1 cfm	0.5 c.ft	7	2.5 cc.
					8	2.5 cc.
					9	2.5 cc.

Conditions during sampling - One drill operating; drilling. Four holes were drilled each for 2 1/2 to 3 minutes period.

Air: Temp; °F WB 57° D.B. 61° Flow; F.P.M. Almost Still
Place; W 7 Ft. Ht. 9 Ft. Area 63 Sq. Ft.

Remarks - Drilling was dry as such. There was heavy dust concentration.

Information on Samples of Particulate Matter

Experiment Set E

Sample of Limestone Dust from Air Date Sampled January 27, 1961
Co. M.S.M. Mine or Plant Experimental Mine
State Missouri County Phelps Town Rolla

30 ft. from the
drilling face.

Sampling Location Plan

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
4	2.56'00"	5	0.1 cfm	0.5 c.ft	11	2.5 cc.
					12	2.5 cc.
					13	2.5 cc.
5	3.01'40"	5	0.1 cfm	0.5 c.ft	14	2.5 cc.
					15	2.5 cc.
					16	2.5 cc.
6	3.07'00"	5	0.1 cfm	0.5 c.ft	17	2.5 cc.
					18	2.5 cc.
					19	2.5 cc.

Conditions during sampling - Four drill holes were drilled dry to set up the dust in the atmosphere. Last hole was finished at 2.51 before sampling at abeut 30 ft. away from drilling face started.

Air: Temp; °F WB 57°F D.B. 61°F Flow; F.P.M. 15
Place; W 10 Ft. Ht. 9 Ft. Area 90 Sq. Ft.

Information on Samples of Particulate Matter

Experiment Set F

Sample of Limestone Dust from Air Date Sampled January 27, 1961
Co. M.S.M. Mine or Plant Experimental Mine
State Missouri County Phelps Town Rolla

30 ft. from the
drilling face

Sampling Location Plan

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
7	3.17'00"	5	0.1 cfm	0.5 c.ft	21	2.5 cc.
					22	2.5 cc.
					24	2.5 cc.
8	3.22'30"	5	0.1 cfm	0.5 c.ft	25	2.5 cc.
					26	2.5 cc.
					27	2.5 cc.
9	3.27'55"	5	0.1 cfm	0.5 c.ft	28	2.5 cc.
					29	2.5 cc.
					1B	2.5 cc.

Conditions during sampling - Dry drilling; one drill operating. Sampling started when the dusty air passed through the sampling location. Drilling started 3.14'00" and sampling commenced at 3.17'00". Four holes were drilled. Drilling was over at about 3.30'00".

Air: Temp; °F WB 57°F D.B. 61°F Flow; F.P.M. 15
Place; W 10 Ht. 9 Area 90 Sq. Ft.

Remarks - Sample No. 23 of the konimeter spoiled; Samples No. 30 and 20 left blank for reference. Spare disk (b) was transfered to the konimeter and already completed one placed in the metal box.

Information on Samples of Particulate Matter

Experiment Set G

Sample of Limestone Dust from Air Date Sampled January 27, 1961
Co. M.S.M. Mine or Plant Experimental Mine
State Missouri County Phelps Town Rolla

60 ft. from the
drilling face

Sampling Location   Plan

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
10	3.40'00"	5	0.1 cfm	0.5 c.ft	2B	2.5 cc.
					3B	2.5 cc.
					4B	2.5 cc.
11	3.45'30"	5	0.1 cfm	0.5 c.ft	5B	2.5 cc.
					6B	2.5 cc.
					8B	2.5 cc.
12	3.50'55"	5	0.1 cfm	0.5 c.ft	9B	2.5 cc.
					11B	2.5 cc.
					12B	2.5 cc.
13	3.56'20"	5	0.1 cfm	0.5 c.ft	13B	2.5 cc.
					14B	2.5 cc.
					15B	2.5 cc.
14	4.01'45"	5	0.1 cfm	0.5 c.ft	16B	2.5 cc.
					17B	2.5 cc.
					18B	2.5 cc.
15	4.07'15"	5	0.1 cfm	0.5 c.ft	19B	2.5 cc.
					21B	2.5 cc.
					22B	2.5 cc.

Conditions during sampling - Four holes were drilled. Sampling started 10 minutes after the drilling was over. Drilling was dry.

Air: Temp; °F WB 56°F D.B. 61°F Flow; F.P.M. 15
Place; W 11 Ft. Ht. 9 Ft. Area 99 Sq. Ft.

Information on Samples of Particulate Matter

Experiment Set H

Sample of Limestone Dust from Air Date Sampled January 31, 1961
Co. St. Joseph Lead Company Mine or Plant Federal No. 11
State Missouri County St. Francis Town Flat River
Location in Mine or Plant Stope Elevation 700

10 ft. from Joy
Jumbo drill.

Sampling Location Plan

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
					1	5 cc.
1	9.37'	5	0.1 cfm	0.5 c.ft	2	5 cc.
					3	5 cc.
					4	5 cc.
2	9.42'20"	5	0.1 cfm	0.5 c.ft	5	5 cc.
					6	5 cc.
					8	5 cc.
3	9.47'45"	5	0.1 cfm	0.5 c.ft	9	5 cc.
					11	5 cc.

Conditions during sampling - Joy Jumbo drill operated by one driller, two drill holes simultaneously working. Wet drilling. Two holes by each were drilled simultaneously.

Air: Temp; D.B. 60°F R.H. 80% Flow; F.P.M. 15
Place; W Large Ht. 18 Ft. Area Large

Remarks - Sample 7 of konimeter spoiled and No. 10 left blank for reference.

Information on Samples of Particulate Matter

Experiment Set I

Sample of Limestone Dust from Air Date Sampled January 31, 1961
Co. St. Joseph Lead Company Mine or Plant Fedral No. 11
State Missouri County St. Francis Town Flat River
Location in Mine or Plant Stope Elevation 700

6 ft. from loading point.

Sampling Location Plan

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
					12	5 cc.
4	10.07'00"	5	0.1 cfm	0.5 c.ft	13	5 cc.
					14	5 cc.
					15	5 cc.
5	10.12'25"	5	0.1 cfm	0.5 c.ft	16	5 cc.
					17	5 cc.
					18	5 cc.
6	10.17'50"	5	0.1 cfm	0.5 c.ft	19	5 cc.
					21	5 cc.

Conditions during sampling - First seven minutes loading continued, then the car left. Loading continued after four minutes interval. Sampling continued.

Air: Temp; D. B. 60°F R.H. 85% Flow; F.P.M. 15
Place; Ht. 20 Ft. Area Large

Remarks - Konimeter Sample 20 was left blank for reference.

Information on Samples of Particulate Matter

Experiment Set J

Sample of Limestone Dust from Air Date Sampled January 31, 1961
Co. St. Joseph Lead Company Mine or Plant Fedral No. 11
State Missouri County St. Francis Town Flat River
Location in Mine or Plant Drift Elevation 700

25 ft. from Drill A
& 7 ft. from Drill B

Sampling Location   Plan

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
7	10.37'00"	5	0.1 cfm	0.5 c.ft	22	5 cc.
					23	5 cc.
					24	5 cc.
8	10.42'30"	5	0.1 cfm	0.5 c.ft	25	5 cc.
					26	5 cc.
					27	5 cc.
9	10.47'50"	5	0.1 cfm	0.5 c.ft	28	5 cc.
					29	5 cc.
					30	5 cc.

Conditions during sampling - Two drilling machines continuously drilling. Both drilling wet. Direction of air flow from A to B drift was being widened.

Air: Temp; D.B. 60 R.H. 85% Flow; F.P.M. 15
Place; W 12 Ft. Ht. 15 Ft.

Information on Samples of Particulate Matter

Experiment Set K

Sample of Limestone Dust from Air Date Sampled February 7, 1961
Co. M.S.M. Mine or Plant Experimental Mine
State Missouri County Phelps Town Rolla

20 ft. from the drilling face

Sampling Location

Plan

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
1	2.17'00"	5	0.1 cfm	0.5 c.ft	1	2.5 cc.
					2	2.5 cc.
					3	2.5 cc.
2	2.22'30"	5	0.1 cfm	0.5 c.ft	4	2.5 cc.
					5	2.5 cc.
					6	2.5 cc.
3	2.28'00"	5	0.1 cfm	0.5 c.ft	7	2.5 cc.
					8	2.5 cc.
					9	2.5 cc.

Conditions during sampling - Three holes drilled; dry drilling. Drilling and sampling simultaneous. Drilling started at 2.16' PM and lasted at 2.32'00".

Air: WB 50 D.B. 56° Flow; F.P.M. Still
Place; W 11 Ht. 9 Ft. Area 99 Sq. Ft.

Information on Samples of Particulate Matter

Experiment Set L

Sample of Limestone Dust from Air Date Sampled February 7, 1961
Co. M.S.M. Mine or Plant Experimental Mine
State Missouri County Phelps Town Rolla

20 ft. from the
drilling face

Sampling Location

Plan

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
4	2.37	5	0.1 cfm	0.5 c.ft	11 12 13	2.5 cc. 2.5 cc. 2.5 cc.
5	2.42'30"	5	0.1 cfm	0.5 c.ft	14 15 16	2.5 cc. 2.5 cc. 2.5 cc.
6	2.48'00"	5	0.1 cfm	0.5 c.ft	17 18 19	2.5 cc. 2.5 cc. 2.5 cc.

Conditions during sampling - Three holes drilled, drilling was dry. Drilling commenced at 2.16' PM and lasted 2.32'00" PM. Sampling started 2.38'00".

Air: Temp; °F WB 50°F D.B. 56° Flow; F.P.M. 15
Place; W 11 Ft. Ht. 9 Ft. Area 99 Sq. Ft.

Information on Samples of Particulate Matter

Experiment Set M

Sample of Limestone Dust from Air Date Sampled February 7, 1961
Co. M.S.M. Mine or Plant Experimental Mine
State Missouri County Phelps Town Rolla

45 ft. from the drilling face

Sampling Location Plan

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
					21	2.5 cc.
7	3.15'00"	5	0.1 cfm	0.5 c.ft	22	2.5 cc.
					23	2.5 cc.
					24	2.5 cc.
9	3.20'30"	5	0.1 cfm	0.5 c.ft	25	2.5 cc.
					26	2.5 cc.
					27	2.5 cc.
10	3.26'00"	5	0.1 cfm	0.5 c.ft	28	2.5 cc.
					29	2.5 cc.

Conditions during sampling - Three holes drilled; drilling was dry. Drilling commenced at 3.12'00" PM and lasted at 3.26'00". Sampling started at 3.15'00" PM.

Air: Temp; °F WB 50°F D.B. 56°F Flow; F.P.M. 15
Place; W 10'6" Ht. 9' Area 94.5 Sq. Ft.

Remarks - Sample No. 8 of Midget Impinger was spoiled. Its stopper was found loose.

Information on Samples of Particulate Matter

Experiment Set N

Sample of Limestone Dust from Air Date Sampled February 7, 1961
Co. M.S.M. Mine or Plant Experimental Mine
State Missouri County Phelps Town Rolla

45 ft. from the
drilling face

Sampling Location

Plan

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
11	3.36'00"	5	0.1 cfm	0.5 c.ft	1B	5 cc.
					2B	5 cc.
					3B	5 cc.
12	3.41'30"	5	0.1 cfm	0.5 c.ft	4B	5 cc.
					5B	5 cc.
					6B	5 cc.
13	3.47'00"	5	0.1 cfm	0.5 c.ft	7B	5 cc.
					9B	5 cc.
					11B	5 cc.

Conditions during sampling - Three holes drilled; all dry. Sampling started 10 minutes after the drilling was over.

Air: Temp; °F WB 50 D.B. 56 Flow; F.P.M. 15
Place; W 11 Ht. 9 Ft. Area 99 Sq. Ft.

Remarks - Sample No. 8B of Konimeter got spoiled.

Information on Samples of Particulate Matter

Experiment Set O

Sample of Limestone Dust from Air Date Sampled February 7, 1961
Co. M.S.M. Mine or Plant Experimental Mine
State Missouri County Phelps Town Rolla

60 ft. from
drilled face

Sampling Location Plan

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
					12B	5 cc.
14	3.55'00"	5	0.1 cfm	0.5 c.ft.	13B	5 cc.
					14B	5 cc.
					15B	5 cc.
15	4.00'30"	5	0.1 cfm	0.5 c.ft	16B	5 cc.
					17B	5 cc.

Conditions during sampling - Three holes drilled; all dry. Sampling started at 3.55 PM. Drilling was over 3.26 PM.

Air: Temp; °F WB 50 D.B. 56°F Flow; F.P.M. 15
Place; W 10 Ht. 9 Ft. Area 90 Sq. Ft.

Information on Samples of Particulate Matter

Experiment Set P

Sample of Silica Dust from Air Date Sampled February 16, 1961
Co. Pittsburg Glass Company Mine or Plant Sand Mine
State Missouri Town Crystal City

20 ft. from
drilling face

Section **Sampling Location** **Plan**

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
1	9.03'00"	10	0.1 cfm	1 c.ft	1	5 cc.
					2	5 cc.
					3	5 cc.
					4	5 cc.
					5	5 cc.
					6	5 cc.
2	9.13'30"	10	0.1 cfm	1 c.ft	7	5 cc.
					8	5 cc.
					9	5 cc.
					11	5 cc.
					12	5 cc.
					13	5 cc.
3	9.24'00"	10	0.1 cfm	1 c.ft	14	5 cc.
					15	5 cc.
					16	5 cc.
					17	5 cc.
					18	5 cc.
					19	5 cc.

Conditions during sampling - Wet drilling by Jumbo Drill. 15 feet hole; three holes drilled. Machine stopped in the middle due to some trouble. Sampling continuous. Driller operating from about 15 to 20 ft. from the face.

Air: Temp; D.B. 58°F R.H. 98% Flow; F.P.M. 15
Place; W 30 Ft. Ht. 30 Ft. Area 900 Sq. Ft.

Remarks - Impinger sample 10 minutes each; for each impinger sample konimeter samples were six. No. 10 konimeter sample left blank for reference.

Information on Samples of Particulate Matter

Experiment Set Q

Sample of Silica Dust from Air Date Sampled February 14, 1961
Co. Pittsburg Glass Company Mine or Plant Sand Mine
State Missouri Town Crystal City

30 ft. from
shovelling

Sampling Location   Plan

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
4	9.40'00"	5	0.1 cfm	0.5 c.ft	21 22 23	5 cc. 5 cc. 5 cc.
5	9.45'30"	5	0.1 cfm	0.5 c.ft	24 25 26	5 cc. 5 cc. 5 cc.
6	9.51'00"	5	0.1 cfm	0.5 c.ft	27 28 29	5 cc. 5 cc. 5 cc.

Conditions during sampling - Two 8 tons shovels working from both the sides A & B.

Air: Temp; D.B. 58 R.H. 98% Flow; F.P.M. 15
Place; W 40 Ft. Ht. 30 Ft. Area 1,200 Sq. Ft.

Information on Samples of Particulate Matter

Experiment Set R

Sample of Silica Dust from Air Date Sampled February 14, 1961
Co. Pittsburg Glass Company Mine or Plant Sand Mine
State Missouri Town Crystal City

15 ft. from
shovelling

Sampling Location Plan

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
7	9.54'00"	5	0.1 cfm	0.5 c.ft	1B 2B 3B	5 cc. 5 cc. 5 cc.
8	9.59'30"	5	0.1 cfm	0.5 c.ft	4B 5B 6B	5 cc. 5 cc. 5 cc.
9	10.05'00"	5	0.1 cfm	0.5 c.ft	7B 8B 9B	5 cc. 5 cc. 5 cc.

Conditions during sampling - Two 8 ton shovels working alternatingly from the same side. Shovelling almost continuous.

Air: Temp; D.B. 58 R.H. 98% Flow; F.P.M. 15
Place; W 40 Ft. Ht. 30 Ft. Area 1,200 Sq. Ft.

Remarks - Konimeter disk replaced with the extra disk B.
Sample No. 10B left blank for reference.

Information on Samples of Particulate Matter

Experiment Set S

Sample of Silica Dust from Air Date Sampled February 14, 1961
Co. Pittsburg Glass Company Mine or Plant Sand Mine
State Missouri Town Crystal City

20 ft. from dumping into chute

Sampling Location Plan

MIDGET IMPINGER					ZEISS KONIMETER	
Sample No.	Time Started	Minutes	Rate	Sample Volume	Sample No.	Sample Volume
10	10.18'00"	10	0.1 cfm	1 c.ft	11	5 cc.
					12	5 cc.
					13	5 cc.
					14	5 cc.
					15	5 cc.
					16	5 cc.
11	10.28'30"	10	0.1 cfm	1 c.ft	17	5 cc.
					18	5 cc.
					19	5 cc.
					21	5 cc.
					22	5 cc.
					23	5 cc.
12	10.39'00"	10	0.1 cfm	1 c.ft	24	5 cc.
					25	5 cc.
					26	5 cc.
					27	5 cc.
					28	5 cc.
					29	5 cc.

Conditions during sampling - 8 ton shovel cum trucks cum dumpers dumping into chute. Two such machines operating.

Air: Temp; D.B. 58 R.H. 98% Flow; F.P.M. 15
Place; W 40 Ft. Ht. 25 Ft. Area Large

APPENDIX B

INFORMATION ON DUST CONCENTRATIONS RECORDED FROM THE KONIMETER SAMPLES

1 Experimental Set No.	2 Sample No.	3 Air Sampled	4 Number of Particles per 40° Sector	5 Number of Particles MPPCF
A.	1.	5 cc.	87	4.4
	2.	5 cc.	73	3.7
	3.	5 cc.	134	6.8
	4.	5 cc.	113	5.8
	5.	5 cc.	92	4.7
	6.	5 cc.	41	2.1
	7.	5 cc.	67	3.4
	8.	5 cc.	89	4.5
	9.	5 cc.	103	5.3
B.	10.	5 cc.	132	6.7
	11.	5 cc.	117	6.0
	12.	5 cc.	198	10.1
	13.	5 cc.	119	6.1
	14.	5 cc.	109	5.6
	15.	5 cc.	97	5.0
	16.	5 cc.	84	4.3
	17.	5 cc.	147	7.5
	18.	5 cc.	223	11.4
C.	19.	5 cc.	203	10.4
	20.	5 cc.	146	7.5
	21.	5 cc.	178	9.1
	22.	5 cc.	211	10.8
	23.	5 cc.	243	12.4
	24.	5 cc.	332	16.9
	25.	5 cc.	238	12.1
	26.	5 cc.	163	8.3
	27.	5 cc.	174	9.0
D.	28.	5 cc.	Too High	
	29.	5 cc.	" "	
	30.	5 cc.		
	31.	5 cc.	Too High	
	32.	5 cc.	" "	
	33.	5 cc.	" "	
	34.	5 cc.	" "	
	35.	5 cc.	" "	
	36.	5 cc.	" "	
E.	37.	2.5 cc.	410	41.9
	38.	2.5 cc.	373	38.1
	39	2.5 cc.	192	19.6

1	2	3	4	5
	40.	2.5 cc.	290	29.6
	41.	2.5 cc.	170	17.4
	42.	2.5 cc.	211	21.6
	43.	2.5 cc.	113	11.5
	44.	2.5 cc.	85	8.7
	45.	2.5 cc.	227	23.2
F.	46.	2.5 cc.	119	12.15
	47.	2.5 cc.	107	10.9
	48.	2.5 cc.	123	12.6
	49.	2.5 cc.	483	49.3
	50.	2.5 cc.	327	33.4
	51.	2.5 cc.	161	16.5
	52.	2.5 cc.	135	13.8
	53.	2.5 cc.	121	12.4
	54.	2.5 cc.	122	12.5
G.	55.	2.5 cc.	227	23.2
	56.	2.5 cc.	238	24.3
	57.	2.5 cc.	258	26.4
	58.	2.5 cc.	112	11.4
	59.	2.5 cc.	69	7.1
	60.	2.5 cc.	90	9.2
	61.	2.5 cc.	87	8.9
	62.	2.5 cc.	119	12.2
	63.	2.5 cc.	182	18.6
	64.	2.5 cc.	116	11.8
	65.	2.5 cc.	93	9.5
	66.	2.5 cc.	101	10.3
	67.	2.5 cc.	109	11.1
	68.	2.5 cc.	114	11.6
	69.	2.5 cc.	152	15.5
	70.	2.5 cc.	137	14.0
	71.	2.5 cc.	121	12.4
	72.	2.5 cc.	49	5.00
H.	73.	5 cc.	217	11.1
	74.	5 cc.	172	8.8
	75.	5 cc.	105	5.4
	76.	5 cc.	267	13.6
	77.	5 cc.	195	10.0
	78.	5 cc.	325	16.6
	79.	5 cc.	213	10.9
	80.	5 cc.	153	7.8
	81.	5 cc.	144	7.3
I.	82.	5 cc.	127	6.5
	83.	5 cc.	185	9.5
	84.	5 cc.	300	15.3
	85.	5 cc.	281	14.3
	86.	5 cc.	243	12.4
	87.	5 cc.	114	5.8

1	2	3	4	5
	88.	5 cc.	143	7.3
	89.	5 cc.	167	8.5
	90.	5 cc.	184	9.4
J.	91.	5 cc.	87	4.4
	92.	5 cc.	93	4.7
	93.	5 cc.	89	4.5
	94.	5 cc.	160	8.2
	95.	5 cc.	97	4.9
	96.	5 cc.	147	7.6
	97.	5 cc.	403	20.5
	98.	5 cc.	179	9.1
	99.	5 cc.	112	5.7
K.	100.	2.5 cc.	457	46.6
	101.	2.5 cc.	449	45.7
	102.	2.5 cc.	408	41.6
	103.		Too High	
	104.		Too High	
	105.		Too High	
	106.		Too High	
	107.		Too High	
	108.		Too High	
L.	109.	2.5 cc.	423	43.1
	110.	2.5 cc.	379	38.5
	111.	2.5 cc.	381	38.8
	112.	2.5 cc.	367	37.5
	113.	2.5 cc.	313	31.9
	114.	2.5 cc.	271	27.7
	115.	2.5 cc.	121	12.3
	116.	2.5 cc.	109	11.1
	117.	2.5 cc.	90	9.2
M.	118.	2.5 cc.	297	30.1
	119.	2.5 cc.	405	41.3
	120.	2.5 cc.	280	26.5
	121.	2.5 cc.	227	23.2
	122.	2.5 cc.	204	20.8
	123.	2.5 cc.	167	17.0
	124.	2.5 cc.	129	13.1
	125.	2.5 cc.	148	15.1
	126.	2.5 cc.	215	22.0
N.	127.	5 cc.	519	26.4
	128.	5 cc.	493	25.2
	129.	5 cc.	435	22.2
	130.	5 cc.	317	16.2
	131.	5 cc.	184	9.4
	132.	5 cc.	297	15.1

1	2	3	4	5
	133.	5 cc.	253	12.9
	134.	5 cc.	219	11.2
	135.	5 cc.	210	10.7
O.	136.	5 cc.	149	7.6
	137.	5 cc.	227	11.6
	138.	5 cc.	182	9.3
	139.	5 cc.	163	8.3
	140.	5 cc.	198	10.1
	141.	5 cc.	302	15.4
P.	142.	5 cc.	35	1.8
	143.	5 cc.	28	1.4
	144.	5 cc.	26	1.2
	145.	5 cc.	27	1.4
	146.	5 cc.	30	1.5
	147.	5 cc.	18	.92
	148.	5 cc.	14	.71
	149.	5 cc.	26	1.3
	150.	5 cc.	45	2.3
	151.	5 cc.	22	1.1
	152.	5 cc.	32	1.6
	153.	5 cc.	36	1.8
	154.	5 cc.	18	.92
	155.	5 cc.	11	.56
	156.	5 cc.	27	1.4
	157.	5 cc.	6	.31
	158.	5 cc.	5	.26
	159.	5 cc.	16	.81
Q.	160.	5 cc.	108	5.5
	161.	5 cc.	93.	4.8
	162.	5 cc.	52	2.7
	163.	5 cc.	43	2.2
	164.	5 cc.	101	5.2
	165.	5 cc.	133	6.8
	166.	5 cc.	122	6.2
	167.	5 cc.	68	3.5
	168.	5 cc.	56	2.9
R.	169.	5 cc.	177	9.0
	170.	5 cc.	165	8.4
	171.	5 cc.	116	5.9
	172.	5 cc.	128	6.5
	173.	5 cc.	143	7.3
	174.	5 cc.	128	6.5
S.	175.	5 cc.	69	3.5
	176.	5 cc.	139	7.1
	177.	5 cc.	123	6.3

1	2	3	4	5
	178.	5 cc.	189	9.6
	179.	5 cc.	131	6.7
	180.	5 cc.	146	7.4
	181.	5 cc.	87	4.4
	182.	5 cc.	113	5.8
	183.	5 cc.	130	6.6
	184.	5 cc.	127	6.5
	185.	5 cc.	134	6.8
	186.	5 cc.	93	4.7

INFORMATION ON DUST CONCENTRATIONS RECORDED FROM THE IMPINGER SAMPLES

1 Experimental Set No.	2 Sample No.	3 Liquid, ml.	4 Air Sampled cft	5 Average net count per field	6 Number of Particles MPPCF
A.	1.	10	0.5	8.25	3.3
	2.	10	0.5	7.0	2.8
	3.	10	0.5	7.5	3.0
B.	4.	10	0.5	13.75	5.5
	5.	10	0.5	13.25	5.3
	6.	10	0.5	21.75	8.7
C.	7.	10	0.5	20.75	8.3
	8.	10	0.5	21.50	8.6
	9.	10	0.5	21.00	8.4
D.	10.	25	0.5	66.7	66.7
	11.	25	0.5	207.8	207.8
	12.	25	0.5	178.7	178.7
E.	13.	25	0.5	34.6	34.6
	14.	25	0.5	31.4	31.4
	15.	25	0.5	23.4	23.4
F.	16.	25	0.5	43.7	43.7
	17.	25	0.5	49.4	49.4
	18.	25	0.5	61.4	61.4
G.	19.	20	.5	15.85	12.7
	20.	20	.5	13.60	10.9
	21.	20	.5	13.0	10.4
	22.	20	.5	13.20	10.6
	23.	20	.5	7.25	5.8
	24.	20	.5	11.5	9.2
H.	25.	10	0.5	21.75	8.7
	26.	10	0.5	20.75	8.3
	27.	10	0.5	21.50	8.6
I.	28.	10	0.5	30.75	12.3
	29.	10	0.5	25.75	10.3
	30.	10	0.5	32.75	13.1
J.	31.	10	0.5	13.50	5.4
	32.	10	0.5	13.25	5.3
	33.	10	0.5	13.75	5.5
K.	34.	25	.5	48.0	48.0
	35.	25	.5	75.3	75.3
	36.	25	.5	103.5	103.5

1	2	3	4	5	6
L.	37.	25	.5	55.7	55.7
	38.	25	.5	39.0	39.0
	39.	25	.5	34.0	34.0
M.	40.	25	.5	24.8	24.8
	41.	25	.5	25.7	25.7
	42.	25	.5	19.7	19.7
N.	43.	25	.5	16.3	16.3
	44.	25	.5	13.1	13.1
	45.	25	.5	13.3	13.3
O.	46.	20	.5	9.35	7.5
	47.	20	.5	9.85	7.9
P.	48.	10	1	2.0	.8
	49.	10	1	2.25	.9
	50.	10	1	2.0	..8
Q.	51.	10	.5	6.25	2.5
	52.	10	.5	5.75	2.3
	53.	10	.5	5.75	2.3
R.	54.	10	.5	7.25	2.9
	55.	10	.5	7.00	2.8
	56.	10	.5	11.25	4.5
S.	57.	10	1	9.25	3.7
	58.	10	1	9.50	3.8
	59.	10	1	10.75	4.3

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VITA

Chandmal Jain, the eldest son of Buddhalal Jain, was born on November 16, 1926, at Lalsot, Rajasthan, India. He began his elementary education in 1931, passed high school in 1942, and graduated in science and mathematics from the Agra University, India, in 1946. On the merits of his educational accomplishments, he was awarded a Government of Rajasthan scholarship for a full four years degree course in mining engineering at the Banaras Hindu University, India, from where he obtained a B.Sc. (mining) degree in 1950.

He started his service career in September, 1950, as a mining probationer in the Department of Mines & Geology, Government of Rajasthan. In February, 1951, he was awarded a Government of India's scholarship for advance training in mines which he completed in 1952. In July, 1952, he again joined the Mines Department as assistant mine manager of The Palana Coal Mines, a first class colliery owned and operated by the State of Rajasthan; and in the same year he was appointed as officer on special duty for dispute settlements in Bhilwara, the second largest mica bearing district in India. In 1953, he became assistant mining engineer in charge of that district. In 1957, he was promoted to the post of mining engineer and, in 1959, became Head of the Mining Engineering Department, in the Poly-technic Institute in Rajasthan.

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