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DUST EMISSIONS FROM GRAIN HANDLING AND PROCESSING OPERATIONS

by

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B.S., Kansas State University, 1971

9589

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agricultural Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1972

Approved by:

J O Hodges

Major Professor

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ACKNOWLEDGEMENTS

Facilities, assistance, and financial support for this study were provided by the United States Department of Agriculture. I am indebted to Mr. George Foster, Mr. Harry Converse, Mr. Dee Hattan, and the rest of the staff of the USDA Grain Marketing Research Center for their assistance in obtaining this support and carrying out this research.

Thanks also goes to Dr. T. O. Hodges, my major professor, for his counseling and advice concerning both coursework and research, and likewise to Dr. Do Sup Chung and Dr. Jason C. Annis, the other two members of my graduate committee, for the help they provided.

And a special thanks goes to my wife, Linda, who has provided endless encouragement as well as financial support throughout this and prior work, and who patiently and painstakingly proofread and typed this thesis.

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INTRODUCTION

The migration of the majority of the United States population from rural areas to the cities has resulted in the gradual relocation of grain handling and processing plants in these population concentrations so as to be near the retail outlets. Many other feed and grain elevators that were originally in sparsely populated areas have found themselves gradually being encircled by the sprawling suburbs of America's growing cities. The result of this transition is a growing concern over the air contaminants released by these elevators. This concern has led to the establishment of Federal regulations limiting emissions, which can only be satisfied through the use of comprehensive dust control programs.

The handling of grain and the manufacture of feed products generate many varieties and concentrations of dusts. With the exception of infrequent odors, this dust is the sole air contaminant from grain handling and processing operations (Danielson, 1967), but it most certainly warrants concern and extensive control efforts.

McLouth and Paulus, (1961) and Cowan, Thompson, Paulus and Mielke (1963) achieved correlations between the incidence of bronchial or allergic responses and the proximity of the grain industry. In doing so, they revealed concrete evidence that uncontrolled grain dust can produce a health hazard.

The control of dust around a mill or elevator could be very beneficial to the plant management as well as to the community surrounding it. The dust that escapes these processes is essentially a part of the material being processed, and any of this dust that is collected represents a reduction of the losses, or shrinkage, associated with that operation. By reducing his losses the operator can also reduce his costs. And the housekeeping, or vacuum cleaning of the interior of the plant, which is a constant and expensive chore, could be eliminated or at least greatly reduced by the careful control of the dust. This would not only lower the cost of obtaining a pleasant and healthy work environment, but would greatly reduce the possibility of fire and dust explosion which are associated with a dusty atmosphere. These factors could possibly contribute a great deal toward offsetting the time and expense involved in a highly effective dust control system.

In times past, it seemed that no practical purpose was served by preventing or controlling grain process emissions, but it is now recognized that these effluents constitute a nuisance to health and well-being and must be controlled. As a result of Federal intervention, basic process equipment for either open or housed plants will be increasingly required to effect dust-tight enclosure by the use of sealants, gasketing, and welded joints. Any air vented from equipment will need to be controlled by air cleaning equipment attached to basic equipment or by systems of duct-work connected to air pollution control equipment (Danielson, 1967).

Although grain dust is varied in make-up, most of it can be collected by inertial devices and fabric filters. Cyclone separators used to be considered adequate in farm or non-sensitive areas, but if air pollution regulations are to be met, highly efficient filtering systems are going to be needed.

The proper design and efficient use of these filtering systems are greatly dependent on the characteristics of the dust generated by the process under consideration. But each process and operation in an elevator or mill could conceivably produce a dust with different physical characteristics and at a different rate than each other process or operation. Before an optimum dust control system can be developed, all of these controlling variables must be established. It is the intent of this research to make some advancement toward understanding the dust generation potentials of typical grain handling and processing operations and controlling these emission sources.

REVIEW OF LITERATURE

General Particle Classifications

As a prerequisite to the design and proper application of industrial air pollution control equipment, an understanding of the fundamental properties and characteristics of gas dispersoids, the classification that grain dust is under, is necessary.

Both Perry (1950) and Leithe (1970) agree that particle size is the primary distinguishing feature of a gas dispersoid. The most widely used unit of particle size is the micro-meter (micron), defined as one one-thousandth of a millimeter, and abbreviated as µm. For air pollution considerations, the size of a particle is the representative dimension that best describes its aerodynamic behavior. For a sphere, the diameter is that dimension and is thus taken as its size. But for an irregularly shaped particle, the size becomes the statistical average of all nonequivalent dimensions and therefore depends on the method used to obtain the average.

For any given irregular particle there is a maximum dimension and a minimum dimension, denoted by d_m and d_s, respectively. Some of the averaging methods used are given in Table 1.

With any particle size measurement method there coexists an inherent diameter average. For example, provided no preferred orientation is encountered, the size obtained from microscopic area measurements is the geometric average of the diameters. Unidirectional microscopic length measurements directly give the arithmetic average of the diameters. When the size is obtained from settling velocities, the opposing force to sedimentation is proportional to the geometric average (Irani and Callis, 1963).

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Table 1. Averaging Methods*

Size Representation		Method of Averaging
Geometric mean of diameters**	M_1	$\left(\prod_{d_i = d_s}^{d_m} d_i \right)^{1/n}$ where n is the number of diameters used.
Arithmetic mean of diameters	M_2	$\frac{1}{n} \sum_{d_i = d_s}^{d_m} d_i$
Harmonic mean of diameters	M_3	$\left(\frac{1}{n} \sum_{d_i = d_s}^{d_m} \frac{1}{d_i} \right)^{-1}$

* Table taken from Irani and Callis (1963).

** Π means the product of all the d_i terms.

Stern (1968a) employs other methods to define the size of a particle. The Stokes diameter is defined as the diameter of a sphere having the same falling velocity as the particle, and a density equal to that of the bulk material from which the particle was formed. This parameter is difficult to use because atmospheric particles have such widely varying densities, so the equivalent aerodynamic size is also used. This is defined as the diameter of a sphere having the same falling velocity as the particle and a density of one gram per cubic centimeter. Another common method is to designate the screen mesh that has an aperature corresponding to the least dimension of the particle.

The size is usually taken to mean the diameter of the particle in the United States, although many European writers, particularly German, specify particle size by the radius.

If all the particles found in a system are the same size, it is termed a monodisperse particle system. The occurance of such a system is rare. More commonly systems composed of different size particles are encountered, and are called polydisperse particle systems (Irani and Callis, 1963).

The particle sizes reported from size measurements on polydisperse particle systems are associated with their frequency of occurance. This may be determined as the number of particles or as a weight greater than or smaller than a stated size or range of sizes. When the frequency of occurance is determined by a number, a number-weighted size distribution is obtained. If size frequencies are measured on a weight of material basis, a mass-weighted size distribution is obtained. Number-weighted size distributions are obtained from microscopic size measurements, while sieving and sedimentation techniques result in mass-weighted size distributions.

The number-weighted and mass-weighted size distribution data for many particulates follow well known laws of probability statistics (Irani and Callis,

1963) as discussed extensively by Herdan (1953). Many particle size distributions follow the logarithmic form of the Gaussian statistical law of errors, commonly known as the log-normal law. Two parameters of the log-normal law adequately describe size distributions of particulate matter. These parameters are the statistical mean and the standard deviation from the mean. When employed by the log-normal law, these parameters are expressed as the geometric mean and the geometric standard deviation. The geometric mean has previously been discussed, while the geometric standard deviation is the deviation of the distributed variable around the geometric mean. Most distributions occuring in nature, including particle size, are log-normal. Thus a thorough understanding of it is invaluable to the air pollution researchers. A detailed treatment of the log-normal distribution is given by Aitchenson and Brown (1957).

Stern (1968a) classifies particles in general as fine if they are less than 100 μm in diameter and coarse if they are greater than 100 μm in diameter. This should not be assumed as a generally accepted classification system, however, as it varies from author to author. The German scientist, Liethe (1970), for example, classifies dust greater than 10 μm in diameter as coarse.

The fine aerosols include particles of metal, dust, and a host of other materials dispersed in a gaseous medium. As particles, they scatter light in conformance with well established physical laws relating wavelength to particle size. As suppliers of large specific areas they afford opportunity for catalysis of normally slow interactions among adsorbed pollutants, and can cause violent explosions. This is because when a solid is broken up into finely divided particles and dispersed in air, two important changes take place. The surface area of the original material is greatly increased, and also, the space occupied by the dispersed solid is expanded many times. The effect of these changes is to intensify the chemical and physical activity of the material. The rates of oxidation, evaporation, and solubility are also increased, and the phenomena of electrostatic activity and adsorption are magnified (Drinker and Hatch, 1954). As plain dust, deposited in accordance with the physical laws governing precipitation and electrostatic attraction, they soil clothing, building, and bodies to constitute a general nuisance. It is this general soiling nuisance that usually arouses the first air pollution complaints, as it is the property most easily perceived by our sensory organs.

The coarser particles, in this case meaning upwards of 100 μm in diameter, present the same type of problems, but to a greatly diminished degree. This is true because their larger mass assures a more prompt removal from the air by gravitational attraction, because physiological defense mechanisms prevent their penetration into the human or animal lungs, and because the same mass of substance in such large units affords substantially less opportunity for interaction with other components in the polluted air supply. On the other hand, their soiling effect may be more evident simply because after leaving a source, they are readily deposited without opportunity for wide dispersal.

There seems to be considerable confusion about the terminology applied in the discussion of gas dispersoids, or aerosols. Perry (1950) places them into two general categories according to their particle size and their method of formation; mechanical dispersoids and condensed dispersoids.

Mechanical dispersoids are formed by pulverization, decrepitation, or disintegration of larger masses of material, or by the grinding of solids, or the spraying of liquids. This class usually has a rather wide size distribution. A mechanical dispersoid can be further classified as a dust or a spray according to its formation from solid or liquid, respectively.

Dusts, which are the object of interest in this study, consist of solid particles dispersed in a gaseous medium as the result of the mechanical disintegration of matter (Green and Lane, 1957). By and large, dusts tend to be very heterogeneous systems of poor stability and contain more large particles than smokes or mists.

The other class, condensed dispersoids, are formed as the result of a vapor phase condensation or reduction, and initially possess a relatively narrow size distribution. Solid and liquid particles formed in either of these manners are termed fumes and mists, respectively.

Each of these terms is generally taken to represent particles of a certain size range. Under the classification of mechanical dispersoid, a dust is usually taken as greater than 1 μm, and a spray as greater than 10 μm. A fume is taken to mean a condensed dispersoid under 1 μm in diameter, while a mist is less than 10 μm.

The representative sizes should, however, be recognized as only interpretations of the most probable cases, as the actual demarcation between sizes is rarely so well defined (Perry, 1950). Some dusts are often as fine as 0.1 μm, and some mists are as large as 20 μm. Also, the condensed dispersoids have a tendency to flocculate or agglomerate and form larger particles, which may actually exceed the size of some mechanical dispersoids, as is the case in the formation of rain from fog.

For purposes of conciseness and simplicity, the terms dust and mist will arbitrarily be used to mean any solid or liquid dispersoid, respectively, unless one of the further distinctions discussed becomes necessary for clarity.

Effects of Air Pollution

Most dusts and mists are either known or suspected causes of several different effects when viewed as air pollutants. Historically the earliest noted, and currently the most easily observed effect of air pollution is the reduction in visibility produced by the scattering of light from the surfaces of the airborne particles. The degree of light obstruction is related to particle size, aerosol density, thickness of the affected air mass, and certain more subtle physical factors (Stern, 1968a) The attenuation of ultraviolet and other radiations reaching the earth through layers of aerosols may be associated with adverse physiological effects in both men and vegetation.

Actual direct damage to structural metals, surface coatings, and fabrics are common examples of the material damage that can result from air pollution. Significant damage can also result from fires and dust explosions in such industries as grain handling and processing. The destructive force of cereal dust explosions has long been recognized, especially the secondary type of explosion that occurs after a primary shock wave has lifted and mixed heavy dust deposits with air, creating a more explosive mixture. An explosion in a mill or elevator is about the worst industrial catastrophe that can occur. Explosions may be set off by open flames, friction sparks, static electricity, faulty wiring, heat, or even spontaneous combustion. As with vapors, upper and lower explosive concentrations exist, with anything below about 5 grains per cubic foot usually considered safe (Dalla Valle, 1948). But there seems to be insufficient data to define any upper explosive limit reliably. Dusts larger than 35 Tyler mesh are usually not considered explosive unless they are chemically unstable.

McLouth and Paulus (1961) investigated the apparently higher than normal incidence of asthma among students at the University of Minnesota. There was speculation that the grain industry in the area was the cause of this health problem, however, no conclusions were drawn associating the asthma with the grain industry. The further work of Cowan, Thompson, Paulus, and Mielke (1963) on the University of Minnesota campus revealed an association between asthma and the grain industry in the area, but failed to establish the degree of the association.

Stern (1968a) indicated that in certain New Orleans districts, the dust from flour mills may have been the cause of increased asthmatic activity. In any event, particulate matter in certain size ranges correlated well with the recorded outbreaks in question. The high incidence of chronic bronchitis in British cities, nasopharyngeal and optic irritation in Los Angeles, and the rapid rise in lung carcenoma among metropolitan populations appear to be closely related to air pollution (Stern, 1968a). More subtle physiological effects of air pollution are suggested by laboratory observations of suppression of ciliary action, alterations in pulmonary physiology, specific enzymic inhibitions, and changes in blood chemistry.

The factors that contribute to the creation of an air pollution problem are both natural and man-made. The natural factors are primarily meteorological phenomena that restrict the normal dilution of emitted contaminants. This includes temperature inversions, which prevent diffusion upwards, and very low wind speeds that do little to move emitted substances away from their source. Sometimes the geographical terrain of the area will cause the flow to follow certain patterns and all emissions are carried to one specific area. Whatever the cause, the natural factors are usually beyond man's control.

The man-made factors involve simply overloading the atmosphere with sufficient quantities of contaminants to produce harmful or deleterious effects. This is the problem Danielson (1967) usually associates with an industrial area, and is certainly within man's sphere of influence.

The significance of dusts, as are generated by the grain handling and processing industry, varies with the type of air pollution problem in which it is involved. In most situations, particulate emissions represent a major portion of the total quantity of air contaminants, and would be important for their soiling and nuisance properties alone, if for no other. In air pollution problems of the type produced by coal burning, which involves only carbon particles, ash, and oxides of sulfur, there are indications that the toxic effects of the sulfur oxides are enhanced by the accompanying particulate matter. This effect has been noted in other cases involving aerosols and toxic gases or liquids, and has given rise to the theory that other contaminants can adsorb on the surface of the particles and thus come into contact with inner surfaces of the lungs and mucous membranes in much greater concentrations than would otherwise be possible (Danielson, 1967).

Small Particle Dynamics

The characteristics of dust dispersion into air, the spread of dust away from its source of generation or release, the control of dusty processes, and the problems of air cleaning are all intimately related to the dynamic behavior of air-borne dust. The dynamic properties of microscopic particles are thus of the greatest importance in a consideration of dust hazards and their control. Physiologically these properties are also of major concern, for they largely determine the depth of penetration and degree of retention of inhaled dust in the respiratory tract and, hence, limit the lung dosage rate in relation to air concentration and with it the dust hazard (Drinker and Hatch, 1954).

Like any other mass, a microscopic particle is attracted toward the earth, but because of its relatively great surface area per unit of mass and the consequent high air resistance, an air-borne particle does not fall with increasing velocity according to ordinary laws of gravity. Almost immediately after it starts to fall, the air resistance imposed on the particle balances the gravitational force, thus preventing further gain in velocity. Due to this fact, there is little interest in considering the acceleration phase in the analysis of behavior of microscopic particles during free fall. The terminal velocity is usually applied to the entire height of fall. The terminal velocity for microscopic particles is low, being measured in centimeters and even millimeters per hour. As a consequence, dust suspensions in air have considerable stability and may persist for long periods. Such factors as normal atmospheric turbulence and natural air movement also tend to keep the smaller particles in suspension. Because of the great air resistance, it is difficult to project microscopic particles through air and equally difficult to remove them from the air. In a sense, the finest particles become a part of the air itself.

The fundamentals of particle motion are generally expressed in a graph of the drag coefficient, C, versus the Reynolds number, Re. Such curves have been determined almost completely for spheres, disks, cylinders, and miscellaneous shapes (Perry, 1950). In defining the drag coefficient and Reynolds number, the velocity term, u, is the relative velocity between the particle and the bulk of the fluid. Except for extraneous effects such as turbulence, it makes no difference whether the fluid moves past the particle or the particle moves through the fluid.

A particle falling under the influence of gravity will reach a terminal velocity as is given by

$$u_t^2 = 2gm/\rho AC, \qquad (1)$$

where $g \equiv$ local acceleration of gravity in cm/second^2,

$m \equiv$ mass of the particle in grams,

$\rho \equiv$ fluid density in grams/cm^3, A ≡ projected area of the particle, perpendicular to direction of motion, expressed in cm^2, and

C ≡ over-all drag coefficient, which is dimensionless.

For spherical particles, this becomes

$$u_t^2 = 4gD(\rho_0 - \rho)/(3\rho C), \qquad (2)$$

where D ≡ diameter of the particle in cm, and

ρ_0 ≡ true density of the particle in $grams/cm^3$.

The various portions of the general drag coefficient curve for spherical particles can be represented by three analytical relationships, as is indicated in Figure 1.

For a Reynolds number less than 2,

$$C = 24/Re. \qquad (3)$$

This corresponds to Stoke's Law, which is usually written as

$$F_d = 3\pi\mu u_t D, \qquad (4)$$

where F_d ≡ drag on the particle in $gram \cdot cm/second^2$,

π = 3.14159, and

μ ≡ viscosity of the fluid in gram/cm·second.

Then, according to Stoke's Law, the terminal velocity when flow past the particle is laminar becomes

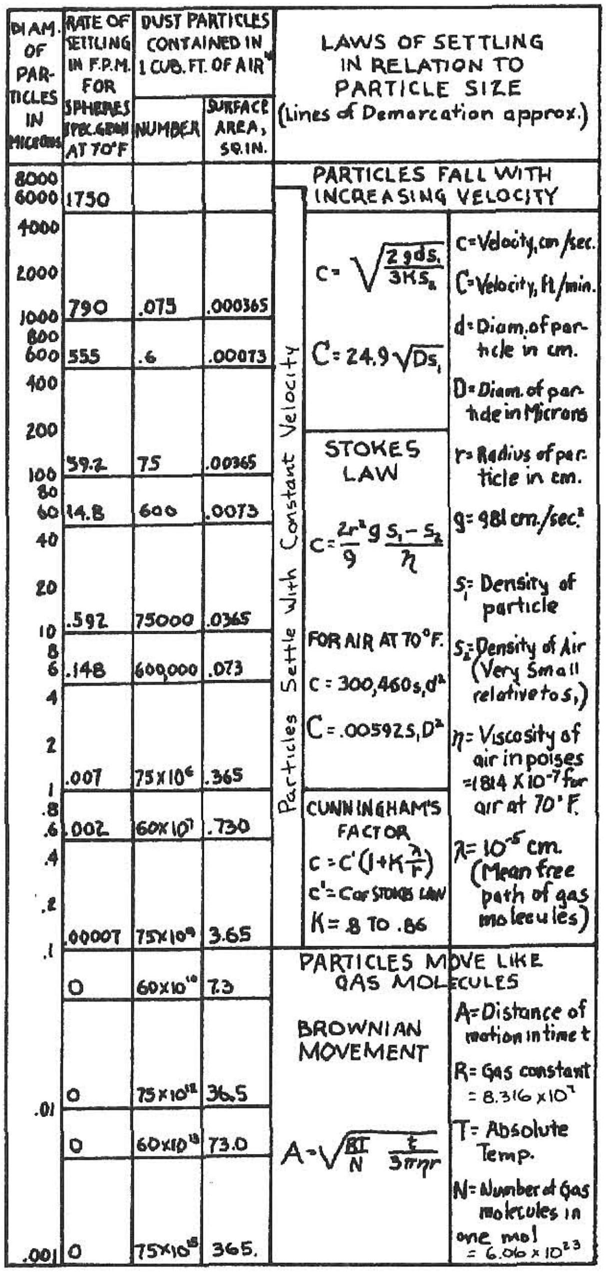

Figure 1. Size and Characteristics of Air-Borne Solids. Taken from Danielson (1967).

$$u_t = gD^2(\rho_0 - \rho)/(18\mu). \tag{5}$$

Since dust control design is primarily concerned with fluid flows where the Reynolds number is less than 10, Stoke's Law is usually directly applicable in defining particle behavior or affords a good approximation.

Stoke'a Law, however, is subject to lower limit. Perry (1950) noted than when the dispersoid particle diameter approaches the mean free path of the gas molecules that comprise the fluid, the resistance to motion will be less than would be calculated from Stoke's Law, while the settling velocity will be greater than calculated. Particles in this size range are also subject to Brownian motion due to the impact of surrounding gas molecules. Brownian motion is the motion incurred when the mass of a particle is so small that it is driven about in the air by the buffeting action of gas molecules (Drinker and Hatch, 1954).

A suitable correction for this range was developed by Cunningham as

$$u_t = u_s(1 + 2A\lambda/D), \tag{6}$$

where u_t = corrected terminal velocity, cm/second,

u_s = Stoke's velocity, cm/second,

$\lambda \equiv$ mean free path of the gas molecules, 10^{-6} cm,

$A \equiv$ a factor dependent on the gas, which is

$\simeq$ 0.43 for air at standard conditions.

However, when increased accuracy is desired, the factor, A, can be calculated from

$$A = A_0 + B \exp(-CD/2\lambda). \tag{7}$$

For air at standard condition, λ corresponds to 6.53×10^{-6} cm (Green and Lane, 1957). With this value of λ, the other variables are

$A_0 = 1.25$,

$B = 0.44$, and

$C = 1.09$.

The resulting equation for the terminal velocity of a sphere in laminar flow is

$$u_t = gD^2(\rho_0 - \rho)\ (1 + 2\lambda A/D)/(18\mu) \tag{8}$$

Although spherical particles are given detailed treatment in the literature, data on irregularly shaped particles is rather scarce. In general, it may be concluded that within the probable precision, the drag coefficient curve for spherical particles holds fairly well for irregular particles of not too extreme shape, for values of the Reynolds number less than 50. For values of Reynolds number greater than 50, the drag coefficient for irregular particles levels off rapidly to a constant value (Perry, 1950).

Sampling Considerations

There are several reasons for obtaining information concerning the types and amounts of materials being emitted from a source. Cooper and Rossano (1971) consider the following six reasons to be the most significant driving forces leading to the acquisition and evaluation of source level information:

1. To determine if the operation is in compliance with current government regulations.

2. To determine the economic impact of material or product loss from a source.
3. To supply data necessary for an engineering design.
4. To allow the evaluation of the efficiency of collection devices.
5. To maintain an optimum process control.
6. To supply information to local or regional enforcement agencies which may require reliable source and emission data as a basis upon which to develop aerometric activity, control regulations, and air resource management programs.

Before the particles that make up an aerosol contaminant can be accurately analyzed and proper conclusions reached concerning such parameters as size distribution, concentration, and chemical composition, it is necessary to obtain a representative sample of the contaminant for study. Accurate and adequate sampling is thus at the very heart of air pollution control and investigation.

Sampling Methods

Sampling methods are extremely important to the success of an air pollution survey. Stern (1968b) considers the principal methods for sampling aerosol contaminants to be filtration, impingement, sedimentation, electrostatic precipitation, thermal precipitation, and centrifugal separation.

Filtration is probably the most commonly used method for collecting aerosols. The filter is composed of varying kinds of fibers woven together to form a mat or porous bed. In most filters, the air is forced to flow along tortuous paths which force it to change direction abruptly and often. These rapid direction changes set up inertial forces that work in conjunction with direct collision to bring particles into contact with the relatively large surface area of the filter. Generally the build up of captured particles on the surface reduces the effective size of the original openings, enabling the filter to capture progressively smaller particles. Collection is also sometimes aided by the existence or development of electrostatic charges that tend to draw particles out of the air stream. The filtering mechanisms employed may be different for various types of filtering materials. A detailed discussion of filtration is given by Strauss (1971).

The main filter classifications are fiber, granular, and controlled pore filters. The fiber filters are made of such materials as wood and other cellulose fibers, mineral wool, plastic, glass and asbestos. The cellulose filters are difficult to stabilize for weighing, and cannot be used at high temperatures or under high moisture conditions.

The granular filters include porous ceramics, fritted glass or metal, and sand. Under special conditions, such soluble materials as sugar crystals have been used. By varying the size of the material grains, the collection efficiency may cover a wide range of sizes down to about 1 μm.

The controlled pore filters are manufactured out of various plastics and metals by maintaining uniform pores of specific sizes. These are more commonly referred to as membrane or molecular filters.

After collection on filters, analysis may be performed by weighing, determining chemical composition, measuring light scatter, microscopic examination, or by particle sizing. Most filter materials are suitable for the first two methods, but the membrane filters are greatly preferred for the last since most of the particles are retained on or near the surface. They can also be made transparent or dissolved in organic solvents for complete recovery of the contaminant.

Impingement collection techniques involve deflecting a moving airstream containing particles of interest around a body. The particles in the airstream tend to resist the change in direction because of their inertia and collect on the body. Impingement efficiency is related to the difference between the mass of the particles and the mass of the gas molecules from which they are to be separated. Therefore it is difficult to get good efficiencies on particles below 2 um in diameter.

Impingers are classified as wet impingers if the deflection surface is submerged in a liquid, or as dry impingers if the surface is exposed to the air. Dry impingers are also referred to often as impactors. A drawback to this technique is that the high velocities usually used often tend to break up large agglomerated particles, resulting in misleadingly high numbers of small particles in the sample.

After collection in an impinger, analysis may be performed on the basis of weight, particle size, or chemical constituents.

Collection by sedimentation techniques depends on the natural settling of particles from an airstream for its effectiveness. Therefore it is suitable for use only in still air and on particles larger than about 5 µm. Sedimentation devices take many forms, with mason jars being frequently used. Some sort of liquid is often placed in the jar to hold collected particles from escaping. This technique is used principally in determining dustfall or sootfall as an indication of the general dirtiness of the community. There are numerous inaccuracies in this method and they are expanded many times in the application of it. They include agglomeration of particles, adherence to the wall of the container, streamline deflection effects of the container and wind eddies which result from nearby objects.

Electrostatic precipitators may be of several designs, but they all operate on the same basic principles (Engineering Equipment Users Association, 1967).

A high voltage difference, on the order of 12,000 to 30,000 volts, is maintained between two spaced electrodes and a current flow is thus established. Many ions are liberated and maintained in the area between the electrodes. As particle laden air passes through this space, suspended particles in the airstream collide with the charged ions and thus assume a charge. The force exerted on the charged particles by the electric field causes them to be transported to the collecting electrode, where the charge is neutralized and the particles collect. This method is, of course, only effective on particles that will accept a charge and will not remove gases. It is obvious that no type of electrostatic precipitator is suitable for collection in an explosive atmosphere. This method is nearly 100 percent effective on particles in the size range of 0.01 to 10 μm. However, the efficiency usually decreases as the particle size increases. The particles collected by this method are not readily examined by microscopic means for particle size determinations because of agglomeration and uneven distribution on the collecting medium (McGill, Holden and Ackley, 1956).

The thermal precipitator works on the principle of thermal force (Stern, 1968). A thermal force is defined as a force greater than that caused by convection, which acts on a mass suspended in a gas not in thermal equilibrium. It is a force of this type that causes the migration of small particles suspended in a gas from a zone of high temperature to one of low temperature. The magnitude of the force is relatively small and can only be observed when it is acting on objects of small mass suspended in a low viscosity medium. In general, the thermal force is negligible if the gradient is less than about 750 degrees Centigrade per centimeter.

Thermal precipitators are claimed to have nearly 100 percent efficiency over a wide range of particle sizes, and high efficiency is noted for particles from 0.001 to 100 µm. Samples collected by thermal precipitation are particularly desirable for direct microscopic examination. The main disadvantage is the low flow rate involved.

Most centrifugal samplers are simply midget cyclone separators, with the primary field of application in the collection of large particles such as fly ash. When properly designed they have good efficiency for removal of particles of more than about 5 µm. Sub-micron particles are usually not captured at all. A high efficiency filter is often used in series with the cyclone in order to capture the particles passing through it. Cyclones are usually used for sampling from ducts, stacks, and similar systems (McGill, Holden and Ackley, 1956).

Allen (1968) discussed several miscellaneous sampling methods. These included the hot wire anemometer which draws particles past a fine, short, hot filament that the particles impinge on, and a diffusion battery in which small particles in a gas are subjected to molecular bombardment, which causes them to move in an erratic manner. Airborne particles passing through a narrow capillary tend to collide with the capillary walls and this property may be used for size determination of sub-micron particles.

Sampling Parameters

The importance of careful sampling cannot be over-stressed as the accuracy of the analytical results can be no better than the accuracy of the sample. There are several parameters that deserve considerable attention before and during the sampling process. These include the size of the sample, the rate of sampling, the duration of sampling, the limitations of the collection device, the limitations of the analytical methods, past-sampling alterations, and the accuracy and precision required (Stern, 1968b). A more detailed discussion of each follows.

The necessary quantity of air to sample obviously must be determined before collection can proceed. This is governed in part by the analytical procedure which is selected, with a more sensitive procedure requiring a smaller sample. It is also affected by the number of individual tests to be performed on the sample as well as the type of collection device used.

However, the type of collection device chosen has more bearing on the permissable rate of sampling. The sampling rate is dependent upon the allowable head loss in the collection device as well as on the experimentally determined optimum flow rate. Sampling rate is extremely important when isokinetic sampling conditions must be maintained.

The length of the sampling period is hardly an arbitrary decision as it first might appear. Factors affecting the minimum possible duration include the expected pollutant concentration to be encountered, the permissible sampling rates for the collection device, and the lower limits of the analytical procedure to be used. Therefore a duration should be selected which will provide the information desired for a specific problem, keeping in mind the basic fact that any sampling period will indicate the average concentration during that period.

For optimum effectiveness, each collection device should be assembled from units that have been shown to be most suitable for the specific pollutant involved. The collection efficiency need not be 100 per cent but it should be known and reproducible.

In the case of collection devices for particulate matter, a variety of limitations may be cited. These were discussed in the previous section when the units themselves were described. When discussing the limitations of collection devices, an important point concerns the definition of the term "collection efficiency." For complete comprehension, the method used to determine the efficiency must be specified. It may be determined on the basis of weight of particles removed, count of particles removed, or reduction in discoloration effects. Judgement on the basis of total particle count is the most severe measure of efficiency.

Precautions must be taken to prevent alteration of the sample after it is collected. This will generally involve selecting a specific sampling technique that minimizes handling, storage, and transportation of the sample. With respect to particulate samples, the most critical change that can occur is probably a loss of the collected particles. Particulates collected on filters should be stored and shipped in clean glass or metal containers which can be policed adequately when necessary.

The objective of the sampling procedure should directly determine the degree of accuracy required. A high degree of accuracy perhaps cannot be justified if the purpose in mind is simply to monitor a phenomenon, but conversely, a laboratory study of this same phenomenon might demand exactitude for success. Also, the accuracy of the least accurate phase of an investigation should be allowed to limit the efforts made to derive maximum accuracy from the remainder of the procedure.

The inexperienced investigator may not be aware that inaccuracy can be introduced into his results through a variation in collection efficiency over a wide range of pollutant concentrations. This cannot be prevented however, as it is impossible to anticipate the existing concentration prior to the performance of the investigation. If previous data is available, it can be extremely valuable in providing an indication of correct rates and durations, especially when dealing with very low concentrations.

Statistical Considerations

Statistical techniques are an extremely powerful tool available to the air pollution investigator. By statistical methods, maximum information can be derived from the data obtained in an experiment. Small amounts of data can thus be used as a basis for interpretation and prediction. Underneath the apparent confusion of observable phenomena, statistics can detect patterns that persist and relationships that dominate the mass of data. Much of the validity of the results from any investigation depends upon a comprehensive statistical analysis of the data. However, it must be kept in mind that probability replaces certainty in the results, and since this is the basis of statistics, the conclusions derived from the observations are, at best, only probably correct. It therefore, becomes a matter of the statistical significance when evaluating conclusions (ASTM, 1968).

Statistics may be utilized to assess the accuracy of a sampling technique. The accuracy in sampling for average concentration and emission rate of materials is dependent upon both systematic errors caused by nonrepresentative sampling methods, and by random errors caused by the limitations in number of sampling points and the finite duration of the sampling period (Cooper and Rossano, 1971).

It is a good procedure to make a detailed introductory study of a source using a number of sampling points for varying conditions, to establish the patterns of emission levels with sample location, time, and operating conditions.

When these patterns are known, the investigator can more adequately design testing procedures. Also, the data collected can be evaluated more objectively when all possible sources of bias have been identified.

Systematic errors are induced by shortcoming in the sampling techniques and methods; these may or may not be easily corrected. These include errors in calibration of sample flow measuring instruments, sampling at a point obstructed by an object, and inaccurate measurement of temperature or static pressure. There is a characteristic variation in both concentration and gas flow rate for particulate materials suspended in a gas stream. Random errors occur due to sampling these variations, and also due to operator error in reading and operating instruments.

Although it is impossible to remove all sources of error from an experiment, statistical techniques enable the investigator to make conclusions concerning collected data and at the same time evaluate the probability that those conclusions are correct.

The Problem Facing the Grain Industry

Almost all phases of the grain industry involve handling, cleaning and storage of grain as a part of their operation; however, there is a wide variation in the extent in which different phases engage in these activities. Certain operations expose grain to physical movement and are therefore significant sources of particulate emissions. McLouth and Paulus (1961) consider the major dust producing operations to be loading, cleaning, sizing, storage, blending, and separation.

Grain usually arrives at the elevators in the uncleaned state and contains a variety of different types and sizes of foreign matter including grain bran, chaff, rust, weed seed, various types of pollens, different mold spores, pieces of broken grain, dirt, and insect parts. Then when it is subjected to the operations listed above the kernels scrape and strike against each other and the conveying media. The motion involved raises the dust and contaminants already in the grain and the abrasive action tends to rub off small particles of chaff and to fragment some kernels resulting in a continual generation of new dust. Hence, although grain is probably dustier the first several times it is handled, it never becomes absolutely clean and controlling the dust remains a constant operation.

There is a great deal of concern within the industry about pollution level requirements that appear to be coming and the trade's ability to meet them. The National Grain and Feed Association recently established an environmental quality committee to investigate the problem. Their preliminary findings indicate particulate emissions to be one of the grain industry's greatest single concerns, both presently and in the next 3 years during which new regulations must be met (NGFA, 1970; Brown, 1971). An insight into the magnitude of the problem facing the trade is given by the fact that the Department of Health, Education and Welfare recognizes the grain industry as the nation's third largest polluter of particulate emissions, behind only coal and oil fired electric plants and the iron and steel industry. It is estimated (Feedstuffs, 1971) that the grain trade is responsible for emitting 1.3 million pounds of particulates per year.

The cost of the average feed and grain elevator meeting the air control regulations in the making will no doubt be considerable. The American Feed Manufacturers Association estimates the cost could run as high as $10,000 to $100,000 per plant (Brown, 1971). This would not be a total loss however. The recovered material is generally recognized as being a part of the grain and contains nutrient value. Therefore, this recovered dust could be worth 2 or 3 cents a pound (Feedstuffs, 1971), and could be pelleted or supplemented with a liquid to be handled.

Specifics of Dust Control in the Grain Industry

As earlier stated, dust is the only pollutant generated directly by the grain industry. The problem facing the industry is then simply to control or contain this dust. Besides improving environmental air quality, the use of efficient dust control systems also benefits the industry through improved working conditions for employees, a reduction in housekeeping costs, a reduction in shrinkage, and an improvement in their relationship with the surrounding community.

Grain is commonly received at an elevator uncleaned. In this state, it contains dust, most of which is carbonaceous material developed by the abrasion or attrition of the individual kernels of grain against each other (Thimsen and Aften, 1971). However, a portion of it is probably pollen and dust from soil and vegetation in the vicinity of where it was grown. Additional dust is generated each time the grain is moved or transferred, whether it is by chute, bucket elevator, transfer belt, or open fall, and becomes a part of the dust load carried by the grain.

Surprisingly little work has been performed concerning the nature of grain dust and the relationship of the surface structure of the grain giving rise to it. One such study by Simmons, St. Clair, and Collins (1970) of the surface structure of wheat revealed three main sources of dust of the type that is actually produced by the grain. The first was surface abrasion during handling due to the fibrous nature of the pericarp. The second significant source was the brush end of the kernel, the bristles of which can readily shear off to provide particles which are not only irritating when inhaled, but can trap and hold other types of dust particles and contaminants. The third source was fragments of the pericarp dislodged by severe impact damage. McCrone, Draftz, and Delly

(1967) made photomicrographs of wheat dust and identified these three types of dust as being present in their samples. Greenaway (1971) also identified 99 per cent of the dust taken from corn samples to be starch cells.

Therefore, in view of the available evidence, it would appear that a very significant portion of the dust produced by grain handling is in reality a protein and carbohydrate material which should have appreciable food value. This low grade "grain" which has previously been discarded as dust, could most likely be developed into a marketable commodity.

The amount of dust generated by any grain operation will depend on the degree of attrition involved in the operation. This would not be a constant factor for the same process in all elevators due to the inherent differences in equipment characteristics in individual elevators. It would also be dependent upon the amount of previous handling, the type, and the source of the grain being handled.

To pinpoint the sources of dust, a simplified diagram of a typical grain elevator is shown in Figure 2.

Unloading is usually considered to be the main contributor to the emission problem. Some estimates (Feedstuffs, 1971) attribute up to 25 per cent of the dust generated to unloading, while others (Vosloh, 1971) range as high as 40 per cent for the combined contribution of trucks and boxcars.

When grain is unloaded from flat bed trucks or boxcars into deep hoppers, it is dropped from 3 to 15 feet in a sudden surge. The particles in the stream of free falling material disperse as they accelerate, and inspirate a downward moving column of air. When the mass hits a hopper bottom, the energy expended causes extreme air turbulence, abrasion, and deagglomeration of the particles. A violent generation of dust occurs. It forms an ascending column that boils out of the opposite end of the elevator (Danielson, 1967).

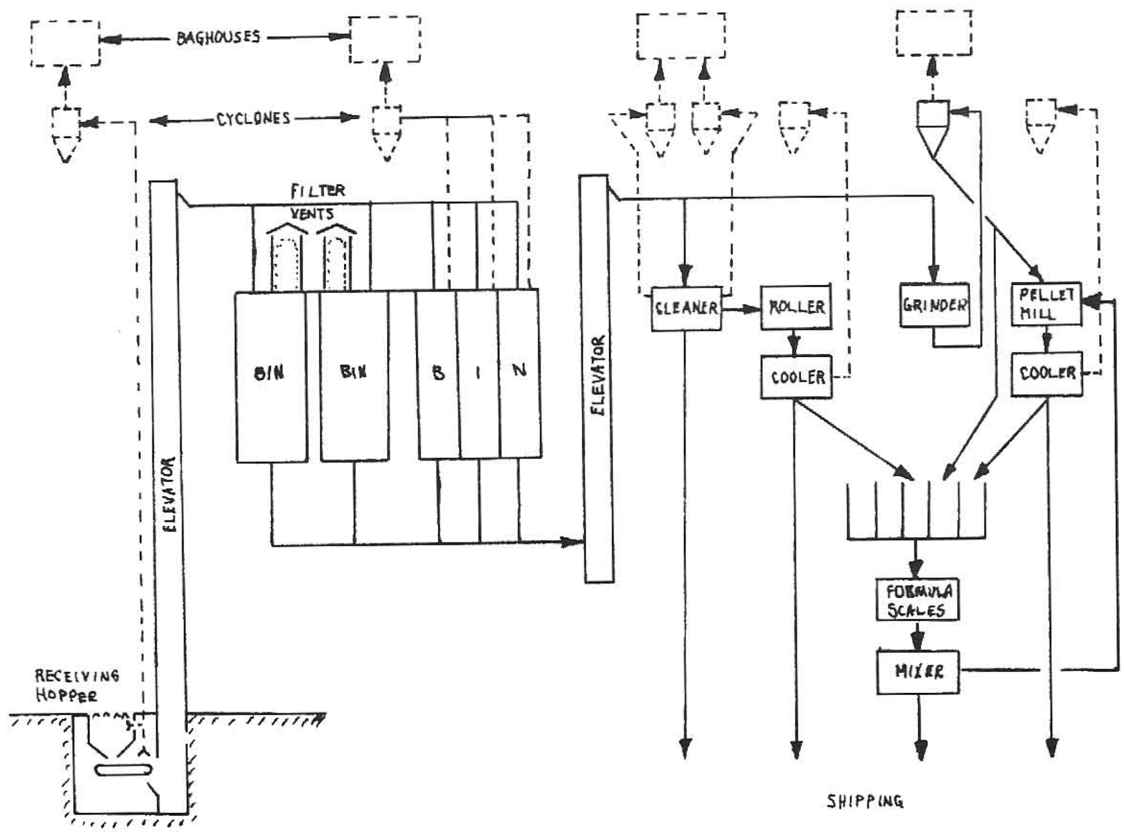

Figure 2. Flow Diagram of a Simplified Feed Mill. Basic equipment shown in solid lines, dust control equipment in dotted lines.

Controlling the dust in the receiving area can be very difficult because most unloading areas are virtual wind tunnels, with air movement through them being several times greater than outside. This usually necessitates complete enclosure of the area during unloading.

Loading out boxcars and trucks is another area to which 10 per cent to 15 per cent of the total dust generation can be traced. Conveying equipment usually does not present difficult dust problems; however, the rubbing friction of screw conveyors, drag conveyors, and bucket elevators on feed and grain abrades these materials, creating fine dust particles. Dust is generated at the transfer points of enclosed conveying equipment, carried through bucket elevators, and emitted at the discharge of the conveyed material.

Belt conveyors are the most efficient type of handling equipment, especially for larger volumes of material or for long conveyances. They cause less mechanical abrasion of the material and separate much less of the dusty fines from the grain than screw conveyors. Dusty air, however, is usually generated at belt transfer points, resulting from aeration of the material as it falls onto or away from a belt. A secondary problem with belt conveyors results from materials adhering to the belt as it turns around the head pulley. These particles, usually coarse, drop from the returning belt along its entire length.

Loadout spouts and direct fall from chutes and overhead bins result in a dust generation from much the same action as occurs during unloading into deep pits.

A particular problem in grain dust emissions is encountered in the drying of high moisture grains. Grain dust is not a difficult dust to handle, unless it contains excessive moisture from a drying operation. Grain is dried by passing a large volume of hot air through a bed of moist grain. The air is still quite warm and contains considerable moisture, as well as dust and chaff, when exhausted into the dust control system. Since the air contains so much moisture, it presents a difficult problem of separation of dust by cyclones because of its high dewpoint and the fact that much of the drying takes place in the fall when the ambient air temperature is low enough to cause excessive condensation in the equipment. The moist dust tends to cake up and clog both cyclones and fabric filters.

Cleaning, by the very nature of its purpose, produces a large amount of dust. Very little dust is generated during the initial screenings, but the aspiration phase yields a significant amount.

Loading grain dust cars is one of the dirtiest operations in the grain industry. It consists of transferring screenings accumulated by collectors from a dust bin to a truck by positive air pressure or by a screw conveyor, forcing dust and dust-laden air out into the atmosphere.

McLouth and Paulus (1961) estimate that cyclone separators will be inoperative on an average of about two times a year due to plugging. From this source, large amounts of nuisance dust have been deposited periodically on the ground, roof tops, automobiles, and neighboring property. Also, as kernels go down spouts, hit baffles, or pass metal surfaces, leaks develop in the system allowing dust to escape. A small hole in a cyclone or pressurized spout can be a major source of dust if it is not quickly repaired.

Storage bins vent dust-laden air originating from two sources. One is air displaced by incoming material that falls freely from a spout at the top of the bin, mixing dust with the air in the bin. The other is air inspirated by the flow of incoming material. This air may contain large quantities of dust.

With approximately 40 per cent of the dust occuring in the receiving areas, 21 per cent from the exhausts of cyclones, and 12 per cent from bulk loadout, almost 75 per cent of the total dust can be attributed to these three areas alone (Vosloh, 1971).

McLouth and Paulus (1961) list six operations as the major sources of particulates from the grain trade. They are unloading, loading, cleaning, loading dust cars, exhausts from dust collectors, and emissions from plugged and faulty equipment.

General Characteristics of Grain Dust

In order to properly apply collection techniques and control methods it is necessary to consider several particle parameters. Among those considered significant by Rose, Stephen, and Stenburg (1958) are particulate characteristics such as particle size range, particle shape, particle density, and physicochemical properties such as agglomeration tendencies, corrosiveness, hygroscopic tendencies, stickiness, inflammability, toxicity, and electrical conductivity. However, Liethe (1970) considers the diameter of the dust particle to be the most important parameter for nonspecific dust effects and the general assessment of injuries due to dust. It is also important to know the size range of particles in order to establish what portion of the dust lies in that region known as the respirable fraction, or the size range that is retained in the lungs. This is usually considered to be from about 0.5 to 5 µm.

It is also important to remember that dust is primarily particles of organic and inorganic materials of various shapes, sizes and densities. These particles are inanimate and heavier than air, and all but the smallest will stay in place if not disturbed. However, the bulk of the dust may be placed in suspension by physical agitation or by currents of air. When these disturbing forces are removed, it will settle due to gravity. Also note that a mass of suspended dust will not move spontaneously from one point to another.

Dust movement requires the application of motion to the dust particles by air currents or other physical disturbances. The movement of air currents from one point to another is the result of a pressure differential. The direction of air movement is from the higher pressure area to the lower pressure area. Then the problem of dust control comes down to the basic problem of controlling the movement of air which contains suspended dust particles. This in turn becomes a matter of controlling air pressures.

The size distribution of dust as is produced in the grain industry will obviously vary to a differing degree for each process in the plant, and probably will demonstrate variation with time from the same machine due to changes in mechanical wear and adjustment.

Perry (1950) stated 15 µm as the mean size of grain dust, while Thimsen and Aften (1971) predicted that it would generally range from approximately 10 to 100 µm, with some expected to be less than 10 µm.

Exactly how much can be expected below 10 µm in diameter is not known. Green and Lane (1957) felt there is a limit to the extent to which a solid can be reduced in size by communition techniques. They established that if a material is ground for an indefinite period, after a certain time further grinding, however prolonged, produces no change in the particle size distribution. The explanation offered was that while particles of all sizes are broken down, some particles, probably the smallest ones, unite with one another or with larger particles as rapidly as they form, so that a dynamical equilibrium is set up. The work of Bowden and his collaborators (1950) suggests one mechanism by which small particles might be united to form larger ones is welding due to frictional energy. Green and Lane (1957) cite the work of B. C. Bradshaw in 1951 which suggests that particles might therefore increase as well as decrease in size upon grinding, and the observed limiting distribution of particle size, which would result from long continued grinding, would hence be a dynamic entity rather than a static one.

The form of the particle size distribution adhered to by grain dust would in most cases be logarithmic-normal, as artifical grinding and natural attrition, the processes by which grain dust is created, both tend to lead to logarithmic-normal distributions (Annis, 1972).

Methods of Dust Control

Dust control from equipment can be accomplished by two methods (T. E. Stivers Organization). One approach is to reduce the air pressure inside a machine or system below outside pressure. In the second method, the pressure outside the machine would be increased to a level greater than inside pressure. The first approach is the more commonly used method today. A fan and duct-work system is used to release the pressure inside the equipment. There are, however, certain situations which make it impractical to prevent the escape of dust from a system by reducing inside pressure. Then it is necessary to control the dust within an area of the plant.

Constrictions and sealing are two important considerations. Too often, care is not taken when equipment is assembled. Spoutings and transitions create more problems of this nature than does equipment. A good preventative maintenance program is also a must if a feed mill dust control system is to be effective and operated at a relatively low cost.

Dust collecting equipment is divided into four major categories: dry mechanical separators, fabric type separators, wet scrubbers, and electrostatic precipitators. The first two groups are the most commonly used in controlling dust emissions from elevators and feed plants. The last two have limited use because of high cost and inherent safety problems.

The first type of dry mechanical separator used in the milling industry was the settling chamber, originally just a totally enclosed room (American Miller and Processor, 1967). By reducing the air speed by expansion, the dust particles will settle according to density and size. In order to be fairly successful, the chamber had to be large enough to reduce air speeds to 50 to 150 feet per minute. This type of equipment has little application today because of its very large proportional size, particularly when the predominant size of dust particle is small.

Slow speed cyclone collection equipment was developed in the United States. It is one of the oldest, cheapest, and simplest types of dust collectors, because of its absence of moving parts. A cyclone separates particulate matter from a carrier gas by transforming the velocity of an inlet stream into a double vortex confined within the cyclone (Danielson, 1967). In the double vortex, the entering gas spirals downward at the outside and spirals upward at the inside of the cyclone outlet. The particulates, because of their inertia, tend to move toward the outside wall, from which they are fed into a receiver. Separation is best when the cyclone diameter is small, the inlet velocity high, the radial thickness of the air stream at a minimum, and the number of convolutions of the vortices relatively great.

Cyclones can be designed to handle a wider range of chemical and physical conditions of operation than most other types of collection equipment can handle. Any conditions for which structural materials are available can be met by a cyclone, if the degree of collection falls within the operating range of the cyclone, and the physical characteristics of the particulates are such that no fouling of the cyclone or excessive wall buildup occurs.

The resistance of the cyclone is often the largest single element in the resistance of the entire system. Tests (American Miller and Processor, 1967) show that the cyclone furnishes as much as 70 per cent of the total resistance against which the fan has to operate.

Although it is highly efficient on larger particles, the collection efficiency falls off rapidly as the particle size goes below 15 µm.

With changes in milling techniques, especially since the introduction of the pneumatic conveying system, comparatively new and better dust separators have been introduced. These are collectors able to collect particles of the low µm size. Cloth filters are gradually replacing the cyclone type dust collectors in milling operations as the latter have a collection efficiency of only up to 95 per cent, and have a very low efficiency on particles less than 5 µm in diameter.

The fabric filters are usually made into bags of tubular or envelope shapes. The entire structure housing the filters is called a baghouse.

Baghouse separators are used to a great extent today. This is an accepted means of reducing dust emissions to meet air quality standards. Fabric separators are indicated to be 98 per cent efficient and will remove particles as small as 0.5 µm (Vosloh, 1971). For many years, dust separation by passing low velocity air through fabric has been recognized as an efficient method. However, the high cost of equipment and maintenance has discouraged its use until the present when air quality standards have demanded its high efficiency.

OBJECTIVES OF STUDY

This work was concerned with the problems created by dusts emitted during large-scale commercial grain handling and processing. The main objectives of the study were:

1. To collect and evaluate the available current literature concerning the present state of development of grain dust control technology. The end result of this would be the determination of the aspects of this subject which have been most neglected.

2. To compare four common grain operations, namely truck unloading, belt conveying, cleaning, and automatic weighing, with regard to the dust generation of each with respect to time.

3. To investigate the possibility that the effectiveness of a negative pressure dust collection system is dependent upon the type of operation producing the dust.

MATERIALS AND EQUIPMENT

The experimental portion of this research consisted of performing four operations on a common cereal grain, wheat, and testing the ambient air with air sampling equipment during each operation. Therefore, the following materials and equipment were employed:

1. Common, uncleaned wheat.
2. The receiving area of the elevator, mainly the deep receiving hopper.
3. Belt conveyors.
4. Automatic shipping scales.
5. Grain cleaner.
6. High-volume air sampler and supplemental equipment.

Description of the Wheat Studied

The reason for choosing wheat for this testing was due mainly to the availability of a large supply of wheat at the experiment site. The decision was enhanced by the fact that wheat is a very common grain in both the Kansas and National economy and any results obtained would have a better probability of being useful. It also worked in well because Simmons, St. Clair, and Collins (1970) had previously performed some preliminary work on the relation of the surface structure of wheat to the type of dust generated by it. It was felt that this previous work might provide some insight to the results obtained from the experiment. The scope of this research and the limited time available made it necessary to limit the kinds of grain studied to one as a means of removing grain type as a source of variation from the experiment. During the course of testing, some of the same grain was no doubt used several times, but the restricted supply and the large amounts needed for testing made it necessary to assume that the dust generation potential of the grain was at all times constant, was independent of the amount of previous handling, and was dependent only upon the operation being performed on it.

The Receiving Area of the Elevator

The receiving area of the particular elevator studied had no truck hoist, therefore all bulk grain received by truck had to be unloaded either manually with scoops and rakes, from trucks with hoppered bottoms and valves, or from trucks with dump beds. In all cases, the act of receiving grain consisted of spilling the grain from the bed of the truck through a grate in the floor of the elevator and into a deep hopper. After entering the hopper, grain could either be stored there temporarily, or immediately elevated to another region of the elevator. This research pertained only to the dust released into the ambient air during the act of unloading, therefore what happened to the wheat after it entered the hopper was of less significance. The method employed by the system under study for controlling dust in this area consisted of air intake louvers located around the perimeter of the hopper, just under the grate in the floor. Air was drawn through the grate and into the louvers by the systems fans in a quantity sufficient to carry a large portion of the dust produced with it. This is illustrated in Figure 3.

The Belt Conveyors

Henderson and Perry (1966) define a belt conveyor as essentially an endless belt operating between two or more pulleys. The belt and its load are usually supported on idlers. They may be used in simple installations or under very heavy conditions, like carrying grain, where it is necessary to

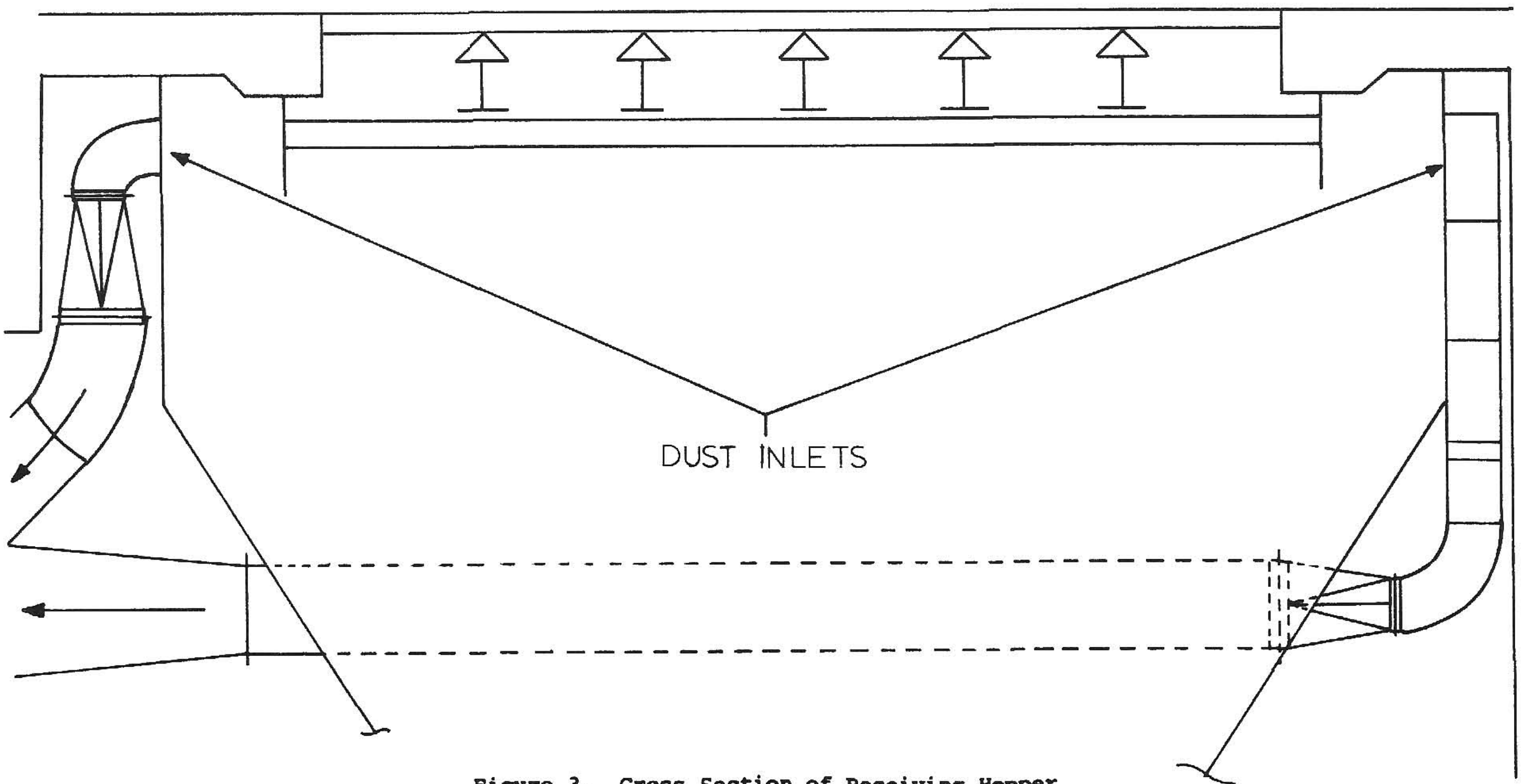

Figure 3. Cross Section of Receiving Hopper Showing Location of Dust Vents.

support the belt by antifriction bearings. Basically, the only difference that can exist between any belt conveyors applicable to the same system is the belt. Belts must be flexible enough to conform to pulleys, yet have strength enough to stand up under the expected load. Belts are usually made of stitched canvas, balata, or vulcanized rubber (Henderson and Perry, 1966). The belts on the conveyors in the elevator under study were constructed of cotton duck with a rubber cover. It was for transferring wheat from a storage bin to the bucket elevator for further handling.

The Automatic Shipping Scale

The scale tested was produced commercially by the Howe Richardson Scale Company. It was designed specifically for handling and weighing all free flowing grains at a reasonable rate of speed and accuracy. It is adaptable for use as an elevator shipping or receiving scale, or as a mill grain scale.

The scale received its grain directly from a supply bin. The grain entered the scale through a chute which is equipped with an automatically operated gate. An equal arm, or 1:1 ratio beam was employed, with the weigh hopper hanging from one end of the beam and the weigh box from the other end. The weigh hopper had a discharge door for emptying the draft of material. The scale also had a compensating device which compensated for weighing the material which was in the act of falling into the weigh hopper when the chute gate closed. A mechanically operated counter was located on the scale to give a record of the number of 15 bushel drafts that passed through the scale.

The Grain Cleaner

A grain cleaner serves two main purposes. It can be used either to separate foreign material from grain or to make some separation between grains, for example, between corn and wheat. The means by which these separations are made is air and screens.

The cleaner studied was a Eureka Continental Mark II Series. On this model there was both head and tail aspiration, three screens, scalper section, top main screen, and bottom main screen. A flow chart of grain through the cleaner is shown in Figure 4. Referring to that figure it is seen that seed from the feed box is distributed by a revolving feed roll (point 1). At that point the grain is subjected to an adjustable front suction which lifts out light impurities and carries them to an air settling chamber (point 3). Heavier air liftings drop into the front air liftings conveyor and are discharged to the side or fed to an optional conveyor unit (point 4) which discharges to the rear waste chute (point 10). Dust and fine impurities are discharged by the centrally-located fan (point 14) to a dust collector. The aspirated seed is fed to the head of the adjustable-pitch auxiliary scalping screen (point 5) where coarse impurities are tailed off and discharged from the front of the grain cleaner.

After passing through the auxiliary scalper screen, the grain flows onto the main screen (point 6) which removes impurities larger than the grain and discharges them through the side discharge trough (point 15). The second main screen (point 7) more closely sizes the seed being processed and eliminates additional impurities through the side discharge trough. The grain then flows down the seed screen (point 8) where dirt, sand, small weed seeds and shrunken or immature kernals pass through to the pan and are discharged into the single point conveyor (point 16). Grain retained on the seed screen (point 8) is discharged into the full width tail aspirating leg (point 11) where powerful air suction again, and more selectively, removes light impurities, carrying them to the rear settling chamber (point 12). Dust and chaff

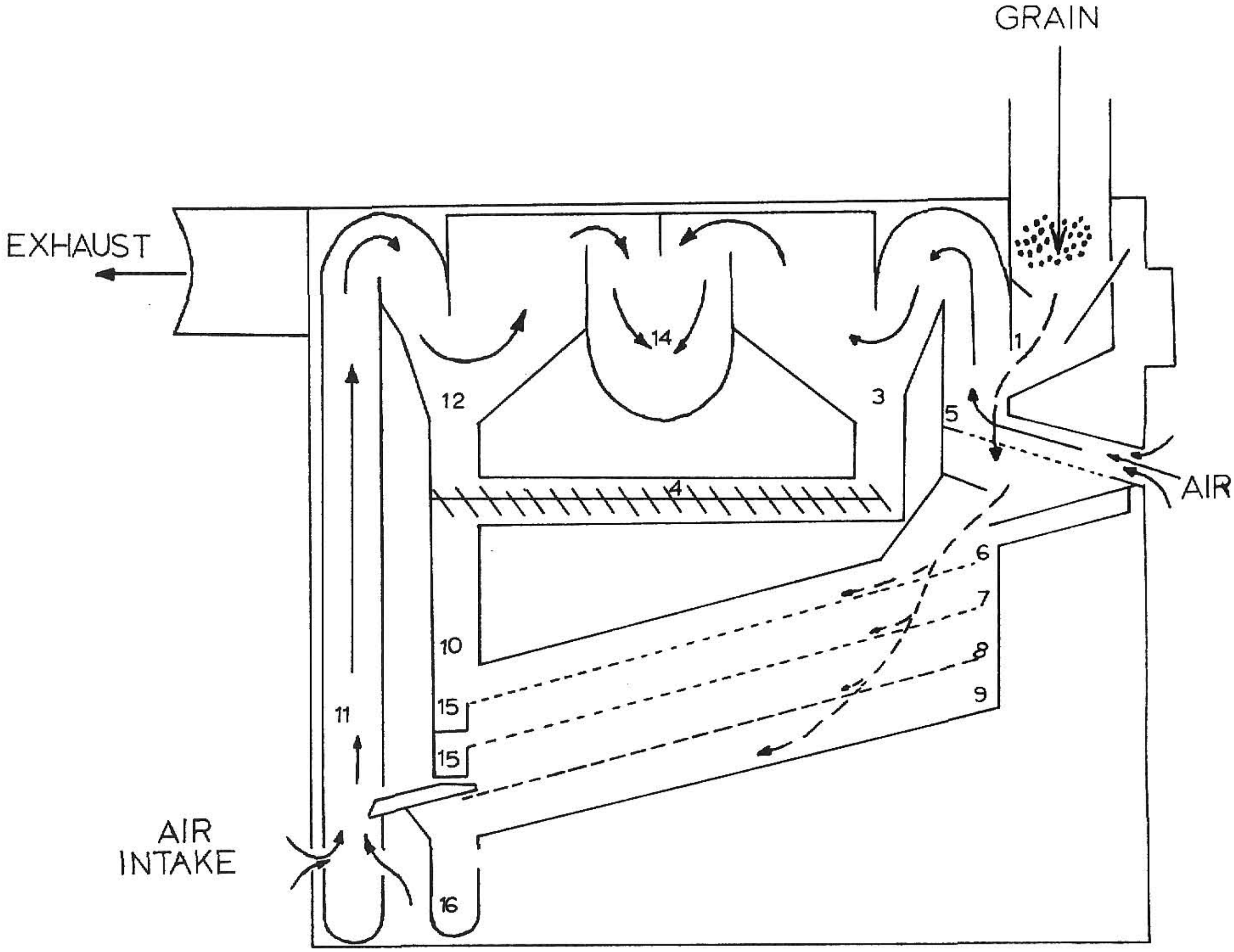

Figure 4. Product Flow Chart for Grain Cleaner.

are drawn to the fan and discharged; heavier impurities are discharged to the rear waste chute (point 10).

The High Volume Air Sampler

The air sampling was done with two Unico 500 high-volume air samplers. These were manufactured commercially by Unico Environmental Instruments, Incorporated, of Fall River, Massachusetts.

The model 500 is a compact, balanced, light-weight, high-volume air-sampler. It is used for collecting a large sample of particulate matter in a short sampling interval. Air was drawn through an eight by ten inch stainless steel filter holder and a Reeve Angel 934AH glass fiber filter at a rate of approximately forty-five to sixty cubic feet per minute. The filter collected the dust particles contained in the air, and knowing the time interval, air flow rate, and net weight gain of the filter, the concentration of dust in the air being sampled could be determined. Figure 5 illustrates the basic components of the air sampler.

Miscellaneous Equipment

In addition to the equipment and instruments previously described, various other laboratory facilities were utilized. These included balances, filter carrying containers, calibration equipment, and electronic calculators.

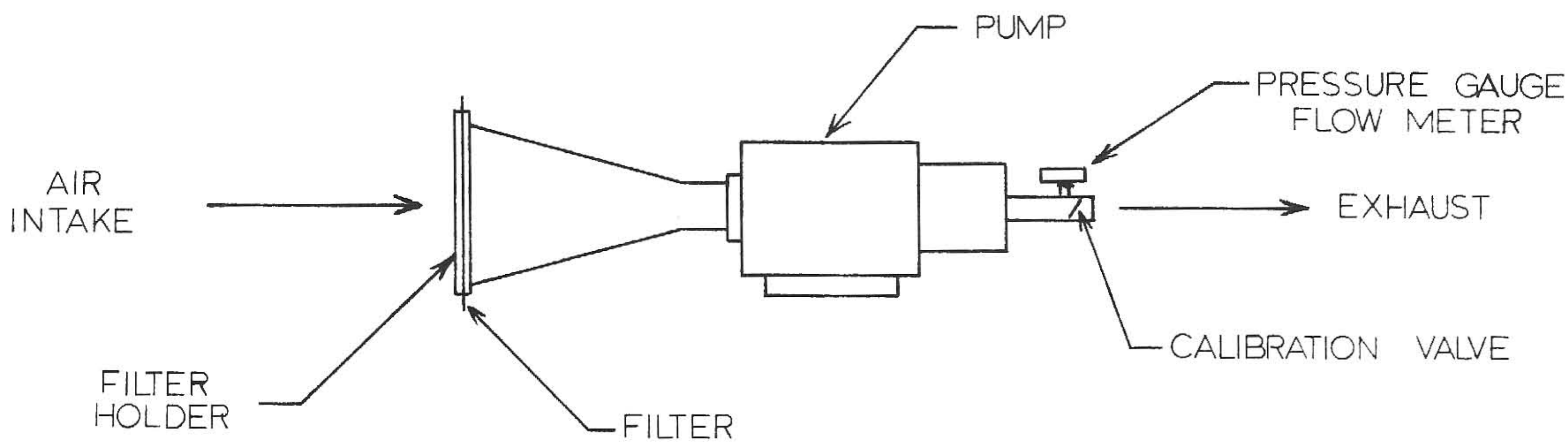

Figure 5. Basic High Volume Air Sampler.

METHODS AND PROCEDURES

Preliminary Testing

Previous to actual experiment, approximately thirty days were devoted to preliminary testing. This served a three-fold purpose. First, it developed a degree of competence, and familiarity with the instrumentation to be used, and therefore reduced the amount of operator error present in the final results of the experiment. It also provided an opportunity to develop techniques of filter preparation and conditioning, and also techniques of data recording and collection which allowed tests to go smoothly and with less chance of a mistake. In short, the preliminary tests provided a practice session during which some degree of sampling ability could be acquired. Thirdly, it afforded an opportunity to vary the location of the sampler with respect to the operation being monitored. This revealed that so long as the sampler was not immediately adjacent to the operation, its exact location had no direct affect on the amount of dust collected. This lack of affect was contributed mainly to the large amount of air sampled by the instrument. As a result of these findings, little emphasis was placed on the location of the sampler, except that it was always at least ten feet from the dust producing operation, and always in the same location for all replications.

Process Simulation

Truck Unloading

Studying the dust generation with respect to time when a truck load of wheat is unloaded into a deep hopper presented a problem as this action is in practice discontinuous in nature. There is a period of time while the grain is being dumped during which dust is being produced, but that is followed by a period of non-productivity as the truck leaves and the next one replaces it. In a large terminal elevator, during a peak busy period, the time between trucks becomes minimal allowing the operation to be assumed continuous without introducing a large error. It was under this assumption that the simulation was developed.

Immediately outside the receiving area of the elevator existed a flexible down-spout for the purpose of loading grain from the elevator into trucks for shipping. That spout was drawn into the receiving area through the main door to the area and secured in such a position that it discharged into the receiving hopper. With this arrangement a continuous flow of grain similar to the discharge from a truck could be maintained indefinitely. This worked well except that the grain acquired a high velocity during its fall down the spout, and the energy associated with this high velocity caused grain to splatter over the entire area as it bounced off the grate. The effect was completely different from the smooth, solid stream of grain that released when a grain truck unloads. To compensate for this, a large metal container was placed directly under the spout discharge and allowed to fill with wheat. It then provided a cushion to absorb the energy of the grain and reduce the bouncing. The overflow from this container was much more similar to the actual process being simulated. Figure 6 shows the final arrangement.

Belt Conveying, Weighing, and Cleaning

The belt conveying, weighing, and cleaning operations did not have to be simulated as it was possible to study them directly due to their continuous nature and accessibility within the elevator. Therefore, studying them required only supplying wheat and sampling for the required time interval.

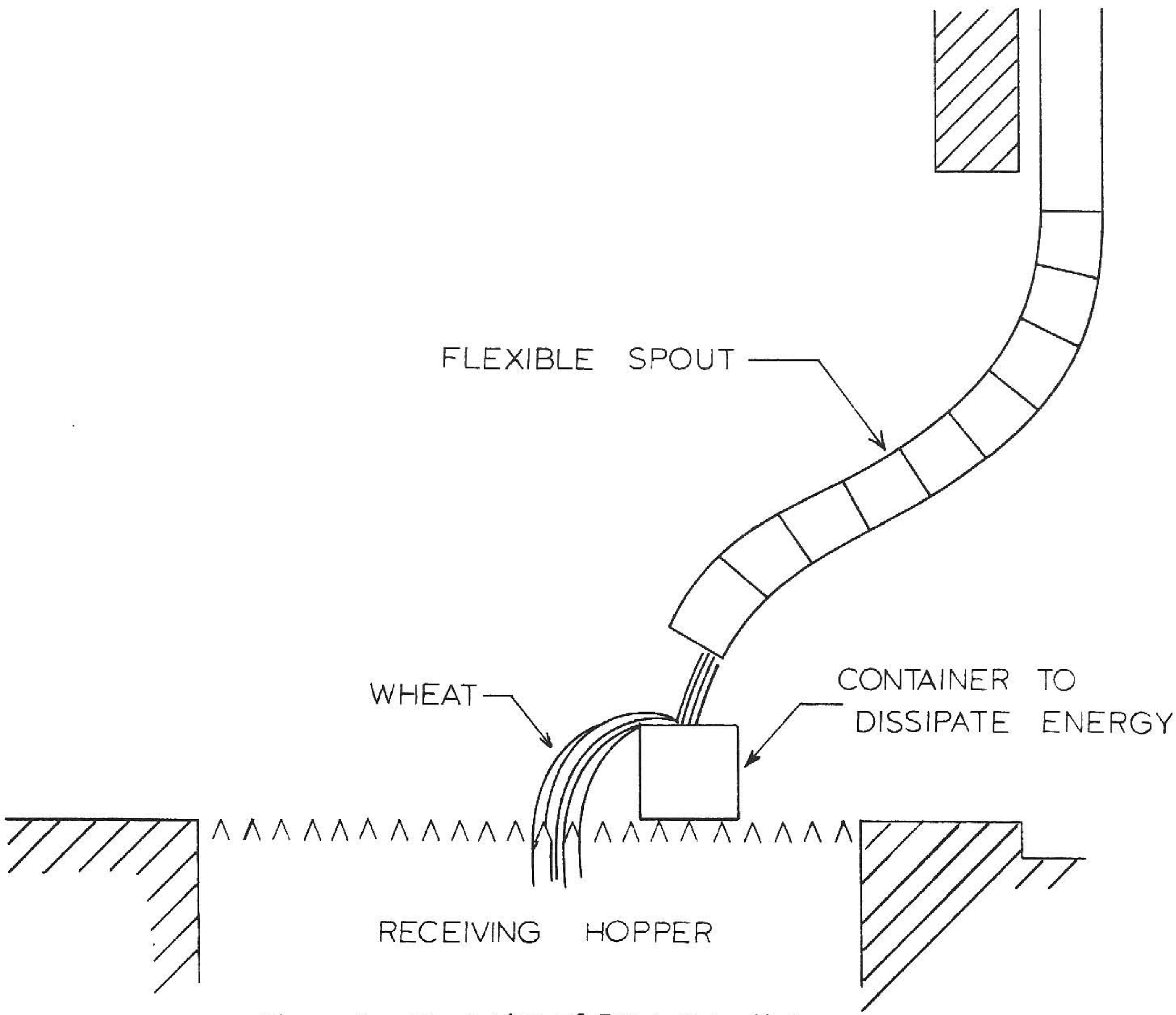

Figure 6. Simulation of Truck Unloading.

Statistical Design

The experiment was originally designed to obtain data for the comparison of the dust generation potential of four operations with the dust control system both operative and inoperative. The resulting statistical design was a two-way classification with four treatments and three observations per treatment-block cell (Fryer, 1968). Analysis of such a classification would have been a routine procedure and would have yielded the desired results, but a complication arose which required a deviation from the initial design.

After testing was well under way, it became apparent that testing the grain cleaner with the dust control system inoperative would not yield data comparable with that obtained from the other operations. This was due to the fact that the dust control system was incorporated into the aspiration phase of the cleaning process, and removal of the dust control air flow altered the entire process. This had the effect of creating an entirely different operation and was not desired. That change left the statistical design as a combination of a two-way classification with three treatments and three observations per cell, and a one-way classification with four treatments and three observations per cell.

Calibration of Sampling Units

Since this was a comparative study and the values obtained for dust concentrations were designed to be an indication of amount of dust produced rather than the actual dust concentration in the area at a given instant, more emphasis was placed on assuring that the two samplers gave identical results than on the absolute accuracy of either of them. This was accomplished by the use of a calibration kit provided by the manufacturer. It consisted of several plates with an increasing number of holes in them. They were designed so as to create a specified pressure drop in accordance to the number of holes. With a manufacturer provided calibration curve, the pressure drop indicated by a manometer could be used to indicate when the adjustment valve in the instrument was set to yield the correct reading on the pressure flow gauge. Since the instruments were pre-set at the factory, the only step taken was to compare the gauge reading for a given plate on the two instruments. This was done and one instrument was adjusted slightly so that the readings indicated on its gauge corresponded as closely as possible to the reference instrument. This step was taken to insure that both instruments would obtain the same results in a test situation, thereby removing some of the instrument variation from the results obtained in the actual experiment. Later tests of the two samplers in the same environment confirmed the fact they gave very nearly identical results. Since the operations being studied were located on different levels of the elevator and they could be ran simultaneously, this synchronization of the instruments reduced the amount of time required to perform the experiment significantly.

Test Procedure

The filters used in the tests were stored in the laboratory on the grounds of the test site. The Federal Register (1971) recommended equilibrating the filters for 24 hours in a filter conditioning environment before weighing. Since the temperature and humidity within the laboratory were assumed reasonably constant, and the glass fiber filters were largely insensitive to moisture, the laboratory was considered a satisfactory filter conditioning environment. Storage of the filters in the area further assured the existance of equilibrium.

An identification number was placed on the filter and it was weighed to the nearest milligram on a balance accurate to 0.1 milligram. This tare weight was recorded on a data sheet along with the identification number of the filter and the date of the test. The filter was then placed in a metal and cardboard container for transporting to the test area.

The sampling unit was placed in a predetermined position and the filter secured into position. The operation and the sampling unit were started simultaneously and the starting time recorded on the data sheet along with the indicated flow rate through the filter. A notation was also made indicating the operation being tested and the status of the dust control system. At regular intervals during the testing, the flow rate was checked for any decrease. If any was noted, it was recorded along with the time it was observed.

The testing was for time intervals of one hour if the dust control system was in operation, and one-half hour, or 30 minutes, if it was not operating. These intervals were chosen based on the reduction in air flow that occured after a sufficient accumulation of dust had developed to increase the resistance of the filter.

After the time expired, the sampling unit was turned off and the filter removed and placed in the container and returned to the laboratory. There it was allowed to equilibrate for 24 hours before it was reweighed to obtain the gross weight. A summary of the conditions of the tests performed is given in Table 2.

The time interval of the test was important because of the use to be made of the results. The principle involved was to start the operation and the sampling unit at the same point in time when the dust concentration in the area was at some datum level defined by factors independent of the testing. Then as the operation proceeded, the amount of dust in the air would increase according to the amount of time elapsed. Therefore the only way to obtain a measure of dust concentration comparable between all of the operations was to

Table 2. Summary of Test Conditions

Test Number	1	2	3	4	5	6	7
Operation Under Study	Unloading	Belt Conveying	Weighing	Cleaning	Unloading	Belt Conveying	Weighing
Dust Control System Status	Operative	Operative	Operative	Operative	Inoperative	Inoperative	Inoperative
Time Period	1 hour	1 hour	1 hour	1 hour	1/2 hour	1/2 hour	1/2 hour
Number of Replications	3	3	3	3	3	3	3

operate them for equal time intervals. The desired result was a concentration level that began at zero and attained some value dependent only upon the amount of dust produced by the operation during the time interval.

Data Evaluation

As soon as the gross weight of the filter was obtained, all of the data necessary for calculation of the dust concentration was available. However, in some instances the flow rate decreased sufficiently and in a non-linear manner. This required the use of a graphical technique to determine the amount of air having passed through the filter.

The technique used was to plot the flow rate versus the elapsed time, being careful to use the same scale. Then a planimeter was used to ascertain the area under the irregular curve resulting, and that area was converted by a proportionality constant into the total volume of air sampled. That value and the net weight were then used to calculate dust concentration.

Data Analysis

It was desired to perform an analysis of variance on the dust concentrations calculated from the data of the tests. First, however, Hartley's maximum F-test (Fryer, 1968) was conducted to check for homogeniety of variance between the groups to be analyzed, as this is one of the necessary prerequisites for an analysis of variance. The test revealed that the variance between the groups could be considered equal with a 95 per cent probability of being correct in this assumption.

An analysis of variance and multiple range test was then conducted on the data through the use of Aardvark (Statistical Laboratory, 1968), a computer program available for use on the 360/50 digital computer.

RESULTS

Preliminary Results of the Experiment

The results of the experiment were values of dust concentrations associated with a particular operation under particular conditions. The concentrations were found in terms of 1 x 10^6 grams of dust per cubic meter of air sampled, or in $\mu gm/m^3$. The value obtained for each test and the conditions associated with that test are given in Table 3.

Figure 7 shows a graphical comparison of the concentrations obtained for each of the three replications of each operation when the dust collection system was in operation. Computation of the coefficient of variation defined by Snedecor and Cochran (1971) as the standard deviation divided by the mean, revealed that all tests performed with the dust system operating failed to lie within their suggested range of 5 to 15 per cent. Figure 8 gives the graphical comparison of the concentrations resulting from each of the three replications of each operation for the case when the dust control system was not in operation. For this situation, only belt conveying was within the suggested limits on the coefficient of variation.

Figure 9 compares the average concentrations for each operation and under each collection system condition. As might be expected, the concentration resulting from any operation was larger with the dust collection system inoperative than for the same operation with the system in operation. Also it appears from the graph that truck unloading was dustier than belt conveying which was dustier than weighing, and weighing produced more dust than cleaning, for the case when the dust control system was operating. With the dust control system inoperative, the order appears from the graph to be again the same, with the exclusion of cleaning for which no values were obtained.

Table 3. Dust Concentrations for Individual Tests

	Operation	Trial 1	Trial 2	Trial 3	Average
Dust Control System in Operation	Unloading	7,430 *	6,626	11,025	8,360
	Belt Conveying	1,077	905	5,090	2,357
	Automatic Weighing	563	770	1,422	918
	Cleaning	697	864	751	771
Dust Control System Off	Unloading	38,929	38,258	48,633	41,940
	Belt Conveying	33,510	29,489	34,948	32,649
	Automatic Weighing	27,074	36,365	9,872	24,437

* Concentration is expressed in micro-grams of dust per cubic meter of air sampled, abbreviated as $\mu gm/m^3$.

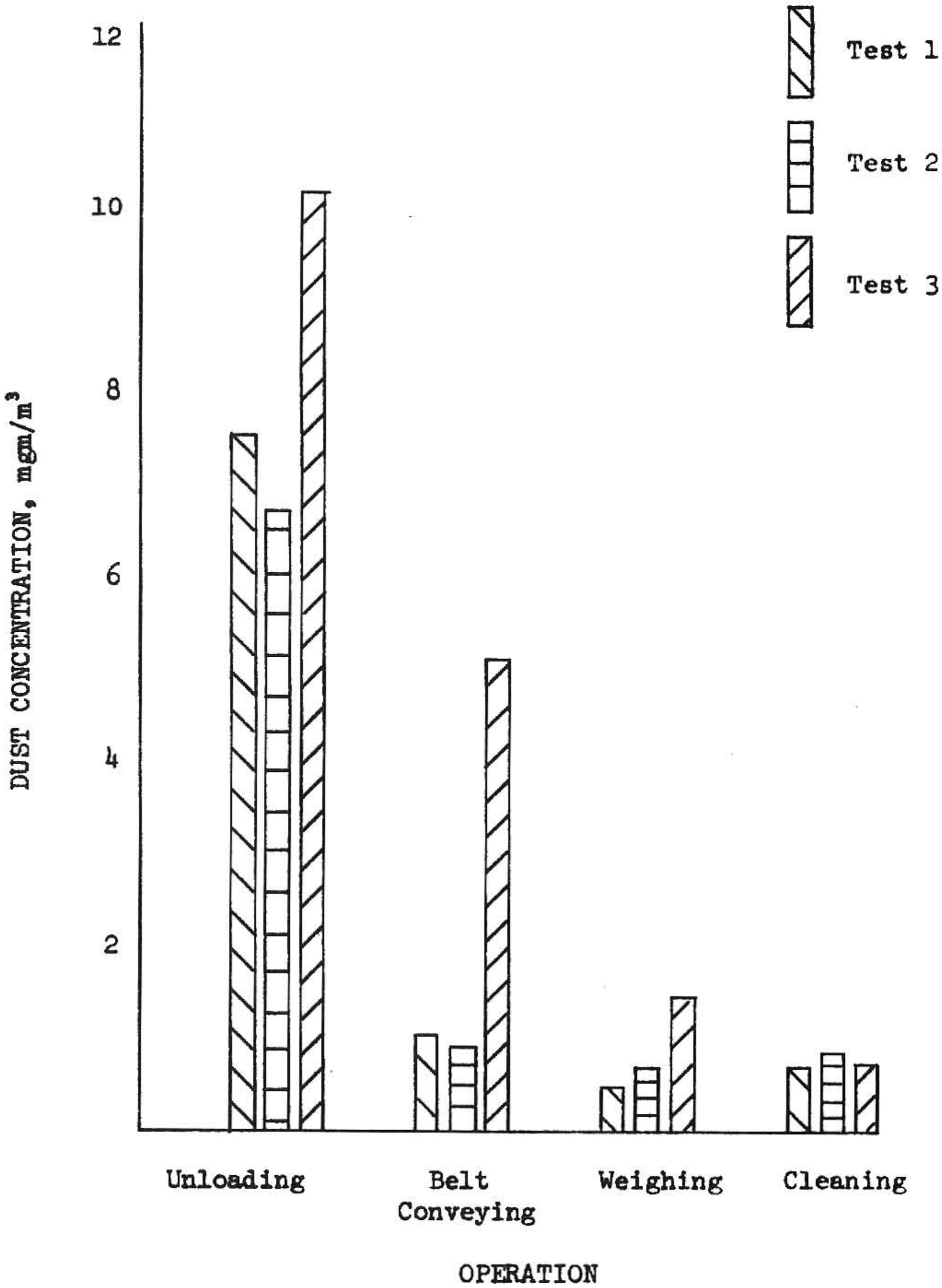

Figure 7. Comparison of Dust Concentrations, in Milligrams Per Cubic Meter (mgm/m^3), Resulting from Replications of the Same Operation with Dust Control System Operating.

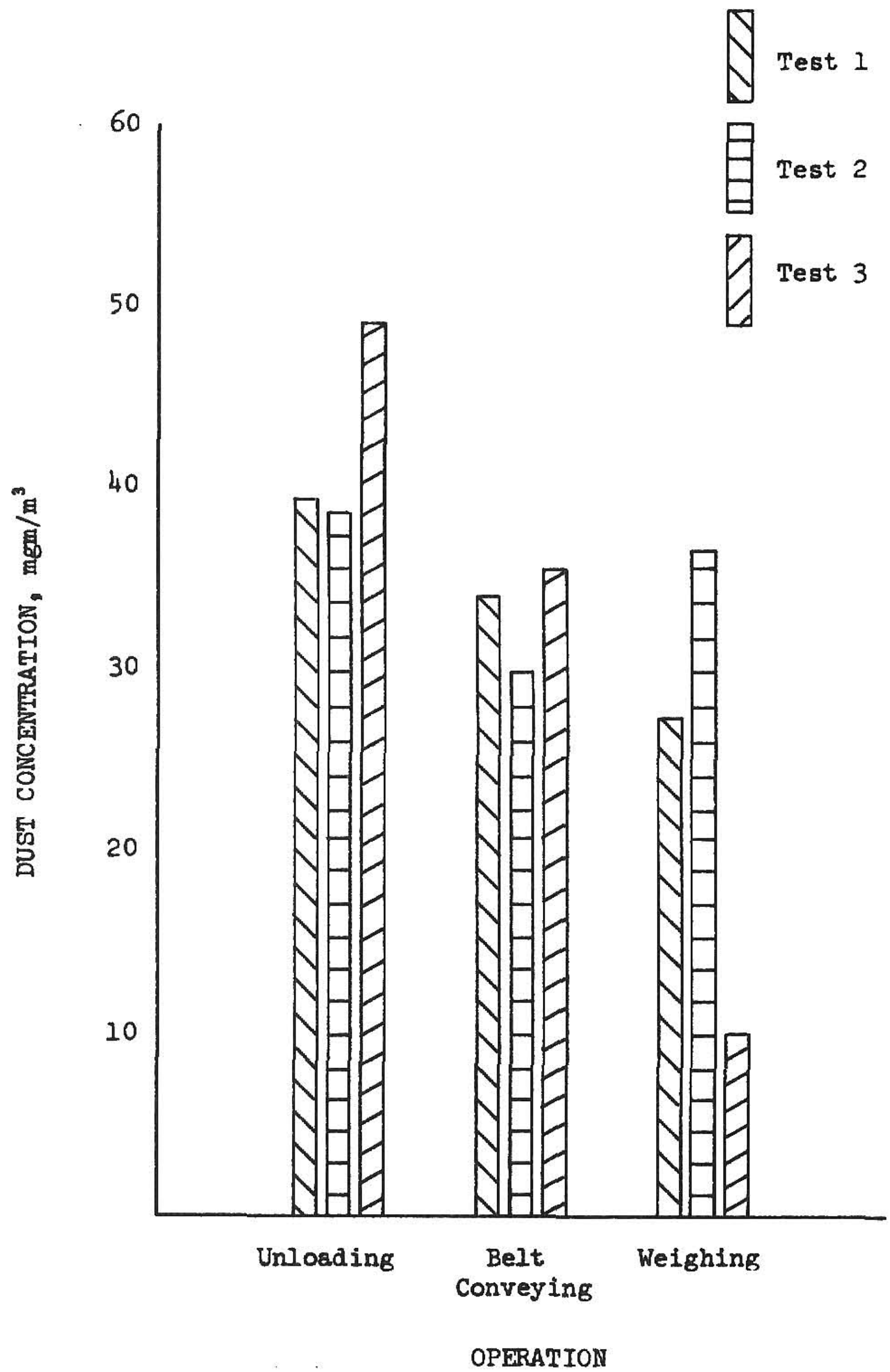

Figure 8. Comparison of Dust Concentration, in Milligrams Per Cubic Meter (mgm/m^3), Resulting from Replications of the Same Operation with Dust Control System Inoperative.

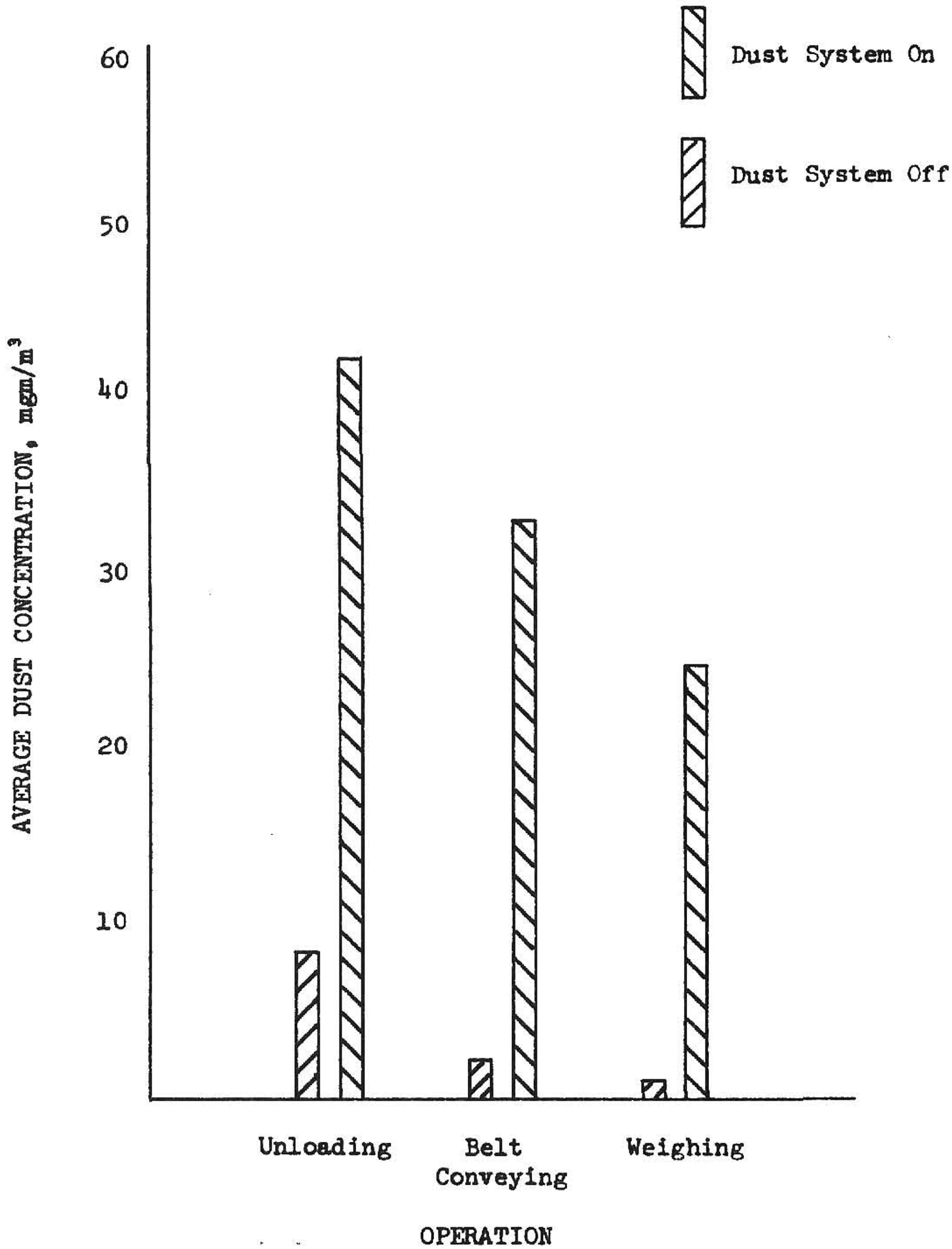

Figure 9. Comparison of Average Dust Concentrations, in Milligrams Per Cubic Meter (mgm/m^3), for Each System with Dust Control System Off and On.

However, the results stated above are only as it appears on the graphical comparisons. To be conclusive about these results, it was necessary to test them for statistical significance.

Results of Statistical Analysis

Before an analysis of variance can be performed on any set of data, it is necessary to either assume or prove that the populations being tested have equal variances. That is because homogeneity of population variance is one of the prerequisites for the analysis of variance procedure.

The procedure chosen to test that assumption was Hartley's maximum F-ratio test (Fryer, 1968). It substantiated the assumption of equal variances and allowed the application of the analysis of variance procedure.

The analysis of variance had to be performed in two parts due to the design of the experiment and the desired results. The first part was a simple one-way analysis of variance to test for equal means among the four operations studied in the case where the dust control system was operating. The results of this analysis of variance are summarized in Table 4. It revealed that there did exist some significant differences in the mean dust concentration produced by the four operations tested, as was indicated by the graphs discussed previously.

However, the analysis of variance did not indicate where the inequality was. To determine which means were unequal, a multiple range test was employed. A summary of the results are presented in Table 5. There was no significant difference between the mean dust concentrations produced by belt conveying, weighing, or cleaning. But the dust concentration resulting from simulated truck unloading was significantly greater than the others.

The second analysis of variance performed was a two-way analysis on the

Table 4. Analysis of Variance for Results of Tests on All Four Operations with Dust Control System On.

Source of Variation	Degrees of Freedom	Mean Square	F	Decision
Between Operations	3	38410976	13.6	Reject
Within Operations	8	2825552		
Total	11			

Hypothesis; $H_0\{\mu_1 = \mu_2 = \mu_3 = \mu_4\}$ versus H_a {some unequal means}

For $\alpha = 0.05$; Reject H_0 if $F > 4.07$

Therefore H_0 is rejected and it is concluded that some significant difference exists between some of the means.

Table 5. Duncan's Multiple Range Test with 0.05 Protection Level.

Number of means spanned =	2	3	4
Significant Range =	3160	3296	3375

Entry	Mean	
Unloading	8360	
Belt Conveying	2357	| *
Weighing	918	|
Cleaning	771	|

* Groups connected by a vertical line indicate a non-significant difference.

three operations that were tested for the two conditions of dust control system both on and off. This test is summarized in Table 6. It tested three hypotheses with a 0.05 level of protection. The first was that the means of all operations were equal. This test was redundant in that it had already been rejected in the previous analysis of variance.

The second hypothesis was that the mean dust concentration for all operations with the dust collection system on was equal to that obtained with the system inoperative. The graphs previously discussed indicated a vast difference between these means, and the analysis of variance confirmed that the difference was statistically significant.

The third hypothesis concerned the interaction between the operation and the status of the dust collection system. The null hypothesis was that no interaction existed, and the analysis of variance led to the acceptance of this hypothesis. That meant the dust control system was no more effective in collecting the dust from one operation than from another.

A multiple range test was also performed along with this analysis of variance. The results of the test are given in Table 7. The only new significant difference revealed was between unloading and weighing with the dust system inoperative for both, with unloading being the dustier.

Table 6. Analysis of Variance for Results of Tests on Unloading, Weighing, and Belt Conveying with Dust Collection System Both On and Off.

Source of Variation	Degrees of Freedom	Mean Square	F	Decision
Operations	2	236877696	6.08	Reject
Dust System	1	3821912064	98.1	Reject
Operation x Dust System Interaction	2	39601888	1.02	Accept
Within Same Operation and System Condition	12	38964944		
Total	17			

Hypothesis: H_{01} $\{\mu_{UL} = \mu_{W} = \mu_{BC}\}$ Reject H_{01} and conclude some means not equal

H_{02} $\{\mu_{ON} = \mu_{OFF}\}$ Reject H_{02} and conclude some means not equal

H_{03} {No interaction between operation and out system} Accept

Decisions made with 0.05 level of protection.

Table 7. Duncan's Multiple Range Test with 0.05 Protection Level.

Number of means spanned =	2	3	4	5	6
Significant Range =	11084	11610	11963	12147	12283

Entry	Means	Grouping*
Unloading, System Off	41940	A
Belt Conveying, System Off	32649	A B
Weighing, System Off	24437	B
Unloading, System On	8360	C
Belt Conveying, System On	2357	C
Weighing, System On	918	C

* Groups connected by a vertical line indicate a non-significant difference.

DISCUSSION OF RESULTS

The results of the experiment confirm estimates in the literature (Feedstuffs, 1971; Vosloh, 1971) that unloading is the major producer of dust among grain trade operations. But the experiment failed to detect any difference between the other three operations studied concerning the amount of dust produced by each. It is possible that in reality no difference existed between these other operations. However, the large variation between replications within operations would have made it impossible for the analysis of variance and the multiple range tests to detect any small differences. In fact, the magnitude of the error variance in the experiment was great enough to conceal even relatively large differences in the mean concentrations.

The experiment also failed to reveal any dependency of dust collection efficiency on operation type. Again this could have been due to the fact that there was none, but the possibility also exists in this case that a small dependency was hidden within the large error variance.

Many factors contribute to the size of the error variance, as it assumes responsibility for any variation not explicitly accounted for elsewhere in the designs of the experiment. Random sampling errors and systematic errors in instrumentation are included in the error variance, but these were controlled well enough that they would only represent a small portion of the total attained. In this particular work, the main cause of the large error variance was in all likelihood the failure to exactly reproduce all variables that were assumed constant in the analysis. The two variables that were particularly difficult to monitor and control were the flow rate of grain to the process, and the amount of dust carried with the grain. Either of these factors could conceivably alter the results of a test by a significant amount if it was to vary either during the test, or between replications of the test.

The size of the error variance, or the variance within an operation, was probably the chief cause of non-significant results. A reduction in this variation would have greatly increased the usefulness of the results. As it is, few conclusive statements can be made with any degree of confidence.

CONCLUSIONS

1. The experiment indicated that four operations considered to be major sources of dust emissions in the grain industry, the unloading of grain into a deep receiving hopper, as simulated in the experiment, had a greater dust generation rate than did belt conveying, automatic weighing, or cleaning, This can be concluded only for the case when wheat was being processed.

2. The results of the experiment revealed that the negative pressure dust collection system in the elevator studied was no more effective in controlling the dust produced by any specific operation than it was the dust from any other operation. This was substantiated only for the case when wheat was the grain from which the dust was produced.

SUMMARY

The grain industry is currently faced with the task of reducing the emission of dust from its processes and operations or be subject to legal action for violation of Federal Air Quality Standards. The cost of reducing these emissions will be great but part of the investment can possibly be recovered through the sale of these collected emissions, which are a part of the grain that produced them.

However, even when an elevator is willing to invest in dust control equipment, it cannot be sure that the equipment it chooses will perform adequately for its particular situation. This insecurity results from the fact that although a great deal of information is available concerning the control of particulates in general, very little is known about the specific problems and peculiarities of controlling the types of dust produced by grain handling and processing operations.

Loading and unloading of grain, along with cleaning of grain, drying of grain, and transferring grain by belt conveyors are usually considered to be the main dust producers among the operations performed at a mill or elevator. Controlling the dust produced by these and the other operations is presently accomplished mainly by the use of cyclone separators, although fabric filters receive limited use in applications.

Current dust control systems are designed by experimental and empirical methods that sometimes result in a system that cannot adequately do the job intended it. More often, however, the result is a system that is overdesigned in that a factor of safety is added through the use of larger equipment just to make sure it will work in that particular location. A more desirable method of designing a system would be through the application of theoretical

relationships and physical characteristics that hold true for the particular situation being considered. The problem with this is the relationships and characteristics have not been developed for grain dust and the grain industry. That is why the purpose of this research was to begin the development of some of these design criteria.

The first step was to evaluate what is currently known about dust control in the grain industry and ascertain what areas needed specific attention. Then experimental work was performed at a research elevator in an attempt to determine the relative dust production capacities of unloading, belt conveying, automatic weighing, and grain cleaning. The possibility that the elevator's dust control system might be more effective on the dust produced by one operation than the others was also investigated. The results of the experiments revealed that unloading was a significantly greater producer of dust than the other three studied. It was also concluded from the results that the system was equally effective on all types of dusts produced.

SUGGESTIONS FOR FURTHER RESEARCH

While the review of literature revealed that very little technical information is available on the subject of controlling the dust created by grain handling and processing operations, it also disclosed areas of the subject that deserve immediate attention. The number of topics that needed researching greatly exceeded the scope of this work, therefore a listing of possible research subjects is offered for the benefit of researchers wishing to carry on this work. They are:

1. Particle size distributions. The development of these for all types of grain dusts should be given top priority. It is felt that particle size is the distinguishing feature of a gas dispersoid (Perry, 1950; Leithe, 1970), therefore that would be the logical starting point for an investigation involving a material about which little is known.
2. Evaluation of other physical and physiochemical properties. Among these might be shape, specific area, density, and agglomeration and hygroscopic tendencies.
3. Further investigation into the exact contribution of each operation in an elevator mill to the emission problem. This could be done in light of revealing which operations require the most strenuous control methods.
4. A study of the variability that might be expected to occur in the dust producing capabilities of an operation due to differences in design, production, and installation.
5. The factors that affect the amount of dust produced by an operation and the degree to which they affect it.

6. Methods of improving cyclone efficiency on grain dusts. If successful, this would allow the use of reliable, inexpensive cyclones for dust control that would still meet Federal standards.
7. Evaluation of filtering materials applicable to grain dust. If improving cyclone efficiency proved impossible, this would be vital information.
8. Evaluation of current, available sampling and testing instruments as to their application to the grain industry.
9. Development of new rapid testing techniques. This might be something portable and easily operated with which a commercial concern could monitor their own operations.

REFERENCES

Aitchenson, J. and J. A. C. Brown. 1957. The lognormal distribution. Cambridge. University Press.

American Society for Testing Materials. 1967. Recommended practice for planning for sampling of the atmosphere. The Society.

Annis, J. C. 1972. Personal communication.

Bowden, F. P. and D. Taylor. 1950. Friction and lubrication of solids. Oxford. Clarendon Press.

Brown, R. H. 1971. AFMA's Karsten predicts rapid, tough pollution control enforcements. Feedstuffs 43(11).

Cooper, H. B. H. and A. T. Rossano. 1971. Source testing for air pollution control. Wilton, Connecticut. Environmental Research and Applications, Inc.

Coway, D. W., H. J. Thompson, H. J. Paulus, and P. W. Mielke. 1963. Bronchial asthma associated with air pollutants from the grain industry. Air Pollution Control Association Journal 13: 546-552.

Dalla Valla, J. M. 1948. Micrometrics. New York. Pitman Corporation.

Danielson, J. A. 1967. Air pollution engineering manual. Cincinnati, Ohio. Public Health Service, National Center of Air Pollution Control.

Drinker, P. and T. Hatch. 1954. Industrial dust. New York. McGraw-Hill.

Engineering Equipment Users Association. 1967. Separation of dust from gases. London. Constable and Company.

Environmental Protection Agency. 1971. National primary and secondary ambient air quality standards. Federal Register 36(84): 8187-8193.

Fact sheet on basic mill and elevator dust collector types and performance. 1967. American Miller and Processor. August.

Fryer, H. C. 1968. Concepts and methods of experimental statistics. Boston. Allyn and Bacon.

Grain handlers told how to cut pollution originating in plants. 1971. Feedstuffs 43(14).

Green, H. L. and W. R. Lane. 1957. Particulate clouds: dusts, smokes, and mists. London, Van Nostrand.

Greenaway, W. 1971. Quick test for corn dust. Agricultural Research 19(10):13.

Henderson, S. M. and R. L. Perry. 1966. Agricultural process engineering. Wiley.

Herdan, G. Small particle statistics. New York. Elsevier Co.

Howe Richardson Scale Company. 1969. Instruction book E-2-2.

Irani, R. R. and C. F. Callis. 1963. Particle size: measurement, interpretation and application. New York. Wiley.

Leithe, W. 1970. The analysis of air pollutants. Ann Arbor. Ann Arbor-Humphrey Science Publishers.

McCrone, W. C., R. G. Draftz, and J. C. Delly. 1967. The particle atlas. Ann Arbor.

McGill, P. L., F. R. Holden, and C. Ackley. 1956. Air pollution handbook. New York.

McLouth, M. E. and H. J. Paulus. 1961. Air pollution from the grain industry. Air Pollution Control Association Journal. 11(7): 313-317.

Meetham, A. R. 1952. Atmospheric pollution: its origin and prevention. London. Pergamon Press.

NGFA unit cites seriousness of air pollution by grain industry. Feedstuffs 42(18).

Perry, J. H. 1950. Chemical engineers' handbook. New York. McGraw-Hill.

Rose, A. H., D. G. Stephan, and R. L. Stenburg. 1958. Prevention and control of air pollution by process changes or equipment. Cincinnati. Technical Report A58-11. Robert A. Taft Sanitary Engineering Center.

Simmons, D. H., M. S. St. Clair, and J. D. Collins. 1970. Surface structure of wheat and its contribution to the dust problem. Cereal Science Today 15(8): 230-239.

Snedecor, G. W., and W. G. Cochran. 1971. Statistical methods. Ames. Iowa State University Press.

Statistical Laboratory. 1968. Numberical analysis - programming series no. 1. Iowa State University. Ames.

Stern, A. C. 1968. Air pollution. Volume 1. New York-London. Academic Press.

__________. 1968. Air pollution. Volume 2. New York-London. Academic Press.

Stivers, T. E. Organization. Date unknown. Environment controls for feed manufacturing and grain handling. Incorporated Consulting Engineers.

Strauss, Werner. 1971. Air pollution control. New York. Wiley-Interscience.

Thimsen, D. J. and P. W. Aften. 1971. A proposed design for grain elevator dust collection. Air Pollution Control Association Journal 18(11): 738-742.

Vosloh, C. J. 1971. Dust control is our primary responsibility. Feed Management 22(12): 18, 21-22.

DUST EMISSIONS FROM GRAIN HANDLING AND PROCESSING OPERATIONS

by

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B.S., Kansas State University, 1971

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

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Manhattan, Kansas

1972

The recent increase in interest on the part of the American public concerning the condition of the environment has brought on a series of Federal regulations regarding air pollution. One of the Nation's largest polluters of particulate emissions, the grain and feed industry, is presently faced with the task of devloping control equipment that can meet these requirements. Development of such equipment is difficult because little technical information about specifically grain dust is available. Previously, equipment has been adapted that was developed for use in other industries. This approach has not resulted in an optimum control system in most cases.

There is a dire need for technical data concerning the characteristics and properties of the dust produced by grain handling and processing operations. It was the objective of this work to begin the evaluation of some of these characteristics. More specifically the purpose of the work was to compare the relative dust generation rates of four operations that are considered to be major contributors to the emission problem. Also included was an investigation of the dependence of a negative pressure dust control system on the type of operation producing the dust. This was accomplished by using the dust concentration developed in the area of the operation in a given time interval as an indication of the dust production rate of that operation. Tests were performed on similated grain unloading into a deep hopper, belt conveying, weighing with automatic shipping scales, and grain cleaning using wheat as the grain processed in all cases.

Values of dust concentrations were obtained and an analysis of variance and multiple range test was performed on the data. The analysis revealed that unloading produced at a significantly greater time rate than did the other three operations. No difference was detected between the other three operations. The analysis also rejected the possibility of an interaction between the effectiveness of the dust control system and the type of operation producing dust. However, the conclusiveness of the analysis was hindered by the presence of a large error variance that decreased the ability of the analysis of variance to detect small differences. This large error variance was contributed to a failure to exactly hold constant variables that were assumed constant in the analysis.