JobHealth Highlights

3M

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Particulate Filtration Theory

This article is the first of a series intended to familiarize the reader with examples of inhalable particles and how respiratory filtration works to remove them from the air. This first part will deal with the typical mechanically-generated dust particles. Subsequent articles will cover fumes and fibrous particles.

Dust particles vary widely in size. For example, ragweed pollen is about 16 microns in diameter. Cigarette smoke is approximately .15 microns average size. The rough range of .2 to 15 microns is called inhalable, depending upon the prevailing definitions. It is this range of sizes against which respiratory protection particulate filters are expected to perform.

Because of this wide range of sizes, it is only logical that different outside forces will affect the particles to different degrees depending upon the size range in which they lie. For example, in a moving airstream there are several factors which affect particle behavior.

These factors are discussed on page 5.

Product Profile

3M 3520 Organic Vapor Monitor

Organic vapor sampling under conditions of high relative humidity, el vated temperatures and potentially high concentrations has posed a dilemma for the industrial hygienist.

Additionally, problems have arisen when sampling for vapors which have a high vapor pressure, or a low affinity for charcoal.

Under these extreme conditions, personal sampling pumps and dual section charcoal tubes have traditionally been used because they provide the required sorbent capacity with back-up capability.

Advances in diffusion sampling technology now allows the industrial hygienist to conveniently and accurately sample organic vapors under extreme conditions. The 3M

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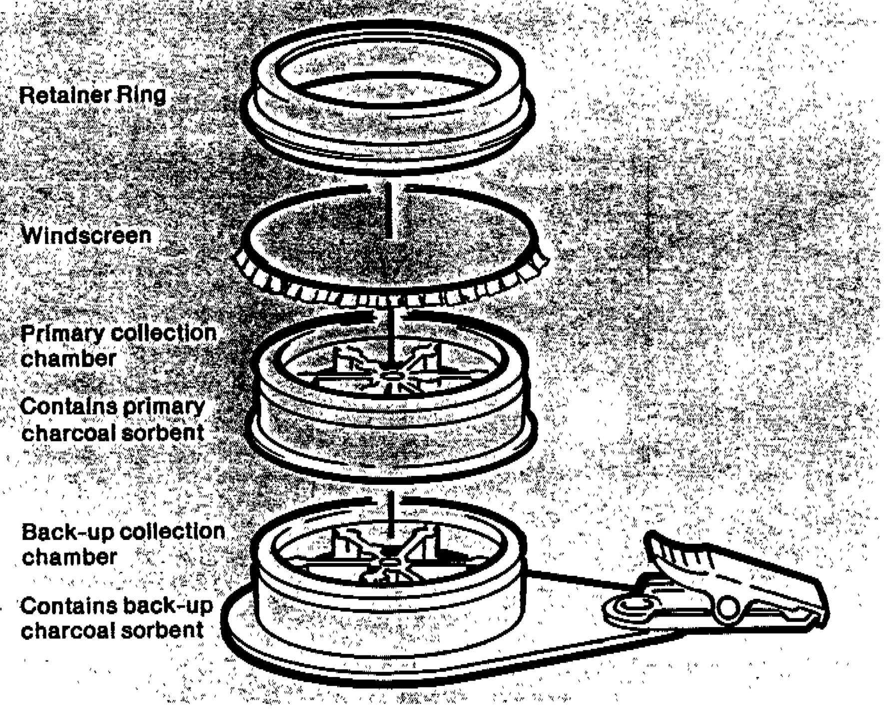
FIGURE 1
3M No. 3520 Organic Vapor Monitor



Organic Vapor Monitor

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brand No. 3520 Organic Vapor Monitor is essentially a single sorbent wafer 3M brand No. 3500 Organic Vapor Monitor to which a back-up section and wafer have been added.

The addition of the second charcoal wafer provides the No. 3520 monitor with up to four times the sampling capacity of the single sorbent No. 3500 monitor. The following is a brief discussion on how the No. 3520 monitor works and how it can be used.

Monitor Design

The design of the No. 3520 monitor (Figure 1) is similar to that of the No. 3500 monitor, with the addition of a second sorbent wafer. Organic vapors pass through the porous windscreen and diffuse through the diffusion chamber to the primary charcoal wafer.

When the primary charcoal wafer's sampling capability for organic vapors is exceeded, the vapors then begin to diffuse through the second diffusion chamber to the secondary charcoal sorbent, where they are collected.

Capacity

The sampling capacity of the primary charcoal wafer is defined as the point at which the weight collection rate is no longer a linear function of sampling time. This is illustrated in Figure 2.

In the No. 3520 monitor, vapors will begin to diffuse to the secondary, or back-up, sorbent when the linear sampling capacity of the primary section has been reached. Since the secondary sorbent is further from the windscreen than the primary sorbent, the vapor molecul s have a longer distance to travel to reach the sorbent, and thus the sampling rate is only about 45 percent of that for the primary sorbent.

The overall linear sampling capacity of the No. 3520 monitor could be up to four times that of the No. 3500 single sorbent monitor. This increase in capacity is due to the decreased sampling rate of the back-up section, and the fact that the primary sorbent will continue to sample after its capacity has been reached (see Figure 3).

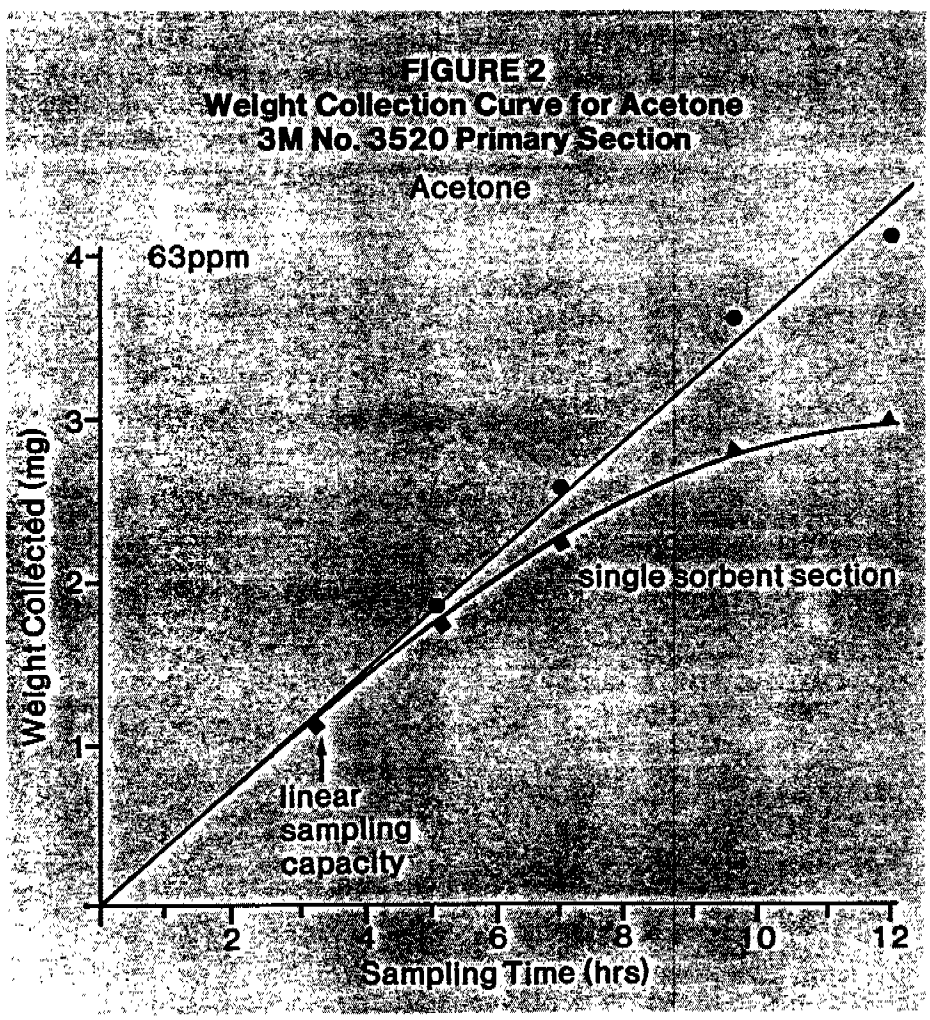
To further illustrate the increased capacity, consider that once breakthrough of the front wafer starts, it will take the back-up wafer at least twice as long as the front wafer to reach its linear capacity due to the 45 percent sampling rate. During that time, the front wafer continues to sample at less than 100 percent efficiency, but the entire monitor is collecting at 100 percent efficiency.

Therefore, the weight collected by the two sorbent wafers within the linear capacity of the No. 3520 monitor could be up to four times the weight collected within the linear capacity of the single wafer No. 3500 monitor. Specifically, compounds for which charcoal has a large capacity at the sampling conditions will be closer to the 3520/3500 weight ratio of four to one, while compounds with a low affinity for charcoal will be closer to a two to one ratio.

The actual linear sampling capacity of the No. 3520 monitor will be dependent on such factors as relative humidity, temperature, specific contaminant, contaminant concentration, competing interfering compounds, changing ambient conditions, etc.

Sample Validity

One of the problems in any sampling method is knowing when the capacity of the device is reached. An advantage of the dual sorbent



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monitor is that as long as the secondary sorbent has not reached its capacity, the capacity of the entire monitor has not been exceeded.

For the No. 3520 monitor, this will be true if the ratio of the weight of vapor on the secondary sorbent (W_S) compared to the weight of vapor on the primary sorbent (W_P) is less than or equal to 0.5. This is similar to the technique used for dual section charcoal tubes.

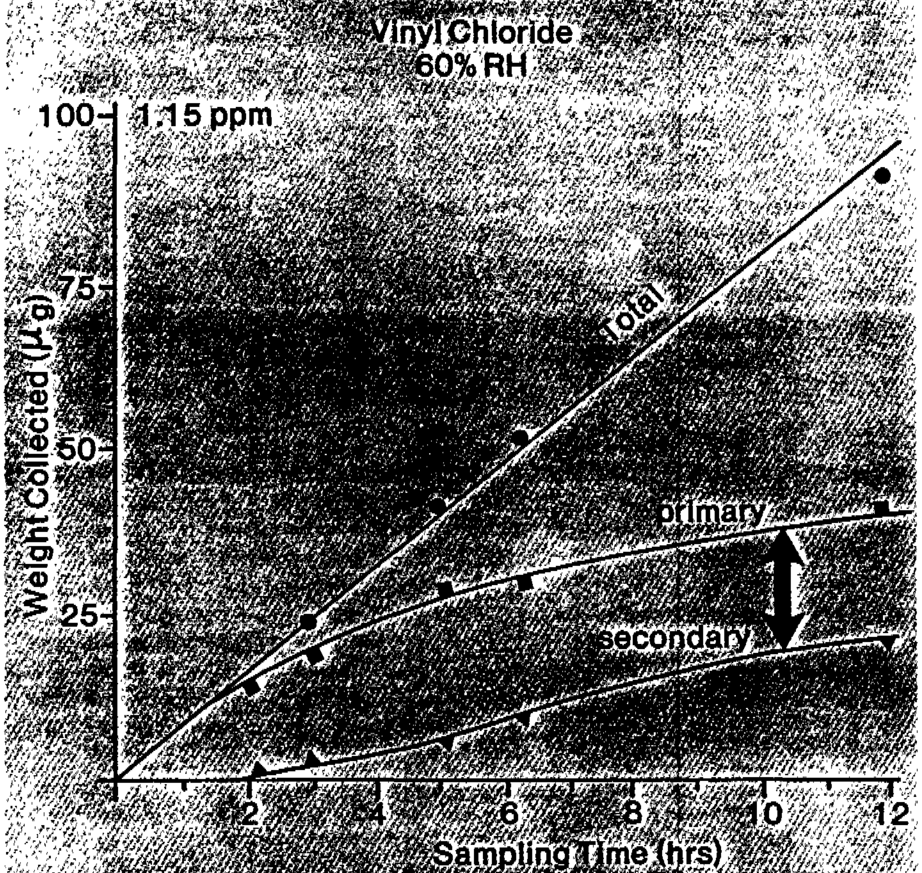
Performance

The performance of the No. 3520 Organic Vapor Monitor has been documented in both laboratory and field studies. Sampling rates for the No. 3500 monitor can be used for the No. 3520 monitor and are listed in the "3M Organic Vapor Monitor Compound Guide."

Overall accuracy of the No. 3520 monitor meets the OSHA accuracy criteria of ± 25 percent at the 95 percent confidence level. Technical reports summarizing both laboratory and field data, as well as the complete sampling and analysis guides are available from 3M.

In a future issue of *JobHealth Highlights*, the effects of humidity and sampling of mixtures will be discussed.

FIGURE 3
Weight Collection Curves for Vinyl Chlorid
3M No. 3520



Double arrows indicate points at which sample is no longer considered valid. (W_S/W_P exceeds 0.50)

Product Information

3M Brand 3750/3751 Formaldehyde Monitors

The Occupational Health and Safety Products Division of 3M has determined that the 3M brand Formaldehyde Monitors 3750/3751 have a shelf life limitation which ultimately may reduce the accuracy of the monitor readings to below the Occupational Safety and Health Administration's (OSHA) ±25 percent accuracy requirement for air sampling devices. The shelf life limitation was identified by 3M as a result of its continuing quality assurance research programs.

Our records indicate that most of the formaldehyde monitors previously sold have been used during the effective shelf life period and produced valid formaldehyde concentration readings. Nevertheless, 3M is requesting that all unused 3750/3751 monitors be returned to 3M for credit. OH&SP sales representatives will be contacting customers with further details.

Additionally, 3M is notifying those users of the 3750/3751 monitors who may be affected by this situation either by letter or by direct contact. Those customers who are not contacted by 3M are not affected.

It is important to note that b - cause the chemistry of the 3M brand Formaldehyde Monitor is unique to this specific monitor, this situation does not apply to other 3M diffusional monitors. The 3M brand Organic Vapor Monitors 3500/3510/3520, the 3M brand Ethylene Oxide Monitors 3550/3551 and the 3M brand Mercury Vapor Monitors 3600/3600A are *NOT* affected and all meet the ±25 percent overall accuracy criteria required by OSHA.

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Gas/Vapor Respirator Prefilter Approvals

A previous issue of *JobHealth Highlights* discussed the NIOSH test requirements for gas/vapor respirators. In many instances, it is necessary to use some type of particulate removing prefilter with the chemical cartridge because a dual gas/vapor and particulate hazard exists. This can occur in operations such as paint spraying or pesticide application. The three basic categories for NIOSH prefilter approvals are: 1) dust/fume/mist 2) paint spray and 3) pesticide.

These prefilters, like the gas/vapor cartridges or respirators with which they are used are approved by NIOSH/MSHA according to the requirements set forth in 30 CFR Part 11. The prefilter/gas and vapor respirator assembly is first tested for its gas and vapor service life according to the requirements referenced in *JobHealth Highlights* Volume I, Number 2. If the assembly passes this test, it is then tested for the particulate contaminant of interest; i.e. dust/fume/mist, paint spray or pesticide.

Dust/Fume/Mist

The test protocols used to make these measurements are detailed in several sections of 30 CFR Part 11. All the dust/fume/mist prefilters can be tested and approved for use in the same categories as the standard dust/fume/mist respirators (see *JobHealth Highlights* Volume I, Number 3).

The prefilters, when tested in combination with the chemical cartridges, must meet the same efficiency requirements as the particulate respirators. The breathing resistance requirements for the combination prefilter and chemical cartridge are slightly higher (see Table 1).

The most common dust/fume/mist prefilters are approved for dusts and mists with an "air contamination level not less than 0.05 mg/m^3," or high efficiency prefilters approved for contaminants with an "air contamination level less than 0.05 mg/m^3." Generally, these prefilters are approved for use with all of the gas and vapor respirators, i.e. organic vapors, acid gas, organic vapor/acid gas or ammonia/methylamine.

Paint Spray

The most widely used prefilter is for paint spray that is used in combination with organic vapor cartridges or respirators. This combination is approved for the gases, vapors, dusts and mists associated with the spray from paints, lacquers and enamels.

NIOSH certification is obtained by testing the organic vapor cartridge for service life per the standard carbon tetrachloride test. Then the prefilter is tested using special enamels and lacquers which are sprayed into a test chamber using a paint spray gun.

Air is drawn through the respirator in this atmosphere to test the prefilter (see Table II). Because of the severe clogging characteristics of this test, the paint spray prefilter is usually lofty on the outer surface to reduce pressure drop with a denser back-up filter for particulate efficiency. This allows the prefilter to meet both the penetration and breathing resistance tests.

Pesticides

Prefilters used for pesticide applications also must be used with organic vapor cartridges. Pesticide prefilters must meet the silica dust and a shortened lead fume test for penetration, plus the breathing resistance requirements shown in Table I. This combination is then acceptable for most pesticides, except for fumigants.

Service Life

Because of the diverse nature of the applications for the combination of cartridges and prefilters, service lives are highly variable. If a lot of particulate is present, it may be necessary to change prefilters before the chemical cartridge

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TABLE I

Chemical Cartridge Respirators(1) Maximum Air Flow Resistance

Respirator Type	Inhalation Initial	Inhalation Final(2)	Exhalati n
Gas & Vapor only	40	45	20
Gas & Vapor & Dust/Mist/Fume	50	70	20
Gas & Vapor & Paints, Lacquers, Enamels	50	70	20
Gas & Vapor & Pesticide	50	70	20

(1) mm water column height at an air flow of 85 liters per minute.
(2) Following service life testing for both gas/vapor and particulates.

TABLE II

Paint Prefilter Approval Tests

	Challenge (mg/m^3)	Air Flow (lpm)	Time (min)	Penetrati n (mg)
Lacquer	95-125	32	156	less than 5
Enamel	95-125	32	156	less than 1.5

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Particulate Filtration Theory

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a. Sedimentation

Larger particles have greater mass, are more affected by gravity and thus fall through the air at a given velocity. In most instances, the turbulence and convection currents in a moving airstream are not enough to support them as they fall. For heavy particles above 3 microns diameter, sedimentation rules their behavior.

b. Inertia

If a moving airstream changes direction and takes a quick bend, particles with enough inertia will cross the stream sideways, sometimes to impact on the nearest obstacle. How much a particle moves out of its former path in a change of airflow direction is based on its size, shape, density and speed.

Inertia affects particles down to about .5 micron. Below this size, particles no longer have enough inertia to move across the airflow streamlines.

c. Diffusion

Air molecules are constantly moving and randomly colliding due to their kinetic energy. In a random system, however, a good share of these molecules may move in the same general direction at the same time. If a particle is placed in the way of these molecules, they will move that particle a distance out of its previous direction. A measure of this movement is the diffusion coefficient.

Particles with large diffusion coefficients are constantly moving within a moving airstream: upstream, cross-stream and downstream. Although this phenomenon greatly affects particles below .3 microns, particles up to 1 micron can also be affected to a lesser degree.

The power of diffusion on particles is shown by the speed by which cigarette smoke can leave its thermal convection currents and fill a room in a matter of minutes.

d. Shape

The shape of a particle can also affect the manner in which it moves in the air. Particles which have non-spherical, irregular shapes will settle differently from spheres.

An asbestos fiber that is .3 microns in diameter and 3 microns long will fall through the air due to its mass the same as a sphere of water that is .8 microns in diameter. The asbestos fiber, due to its shape, will have a diffusion coefficient the same as a sphere of water that is .54 microns in diameter.

Particles in the lungs

The human body "breathing apparatus" is not an efficient filter. A majority of the particles entering the lungs are breathed out again. The capture of particles entering the lungs is dependent on the particle characteristics and the breathing rate and capacity of the lungs.

Above 5 microns the nasal and oral cavities take out particles by impaction and sedimentation with better than 75 percent efficiency. Also, exhalation is always much less efficient in filtering particles than inhalation.

The table below is a representation of the available data on the greatest percent capture of particles in the lungs for mouth inhalation breathing.

Not every particle that enters the lungs, as shown in this example, is captured in the lungs. Depending on the particle size, 30 to 75 percent of the particles will be breathed out again.

Respiratory filters

The most common particulate filters are of two types: absolute and non-absolute. Absolute filters contain pores which are smaller than the particles to be removed. Their main mechanism is screening of the particles. They are expensive, have high flow resistances and clog rapidly.

The common respiratory filters are non-absolute and contain pore sizes many times greater than the particles to be removed. Such filters may be 70 to 99 percent air by

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Particle Diameter	% Capture of Particles in The Lung	Predominate Capture Mechanism
3 microns	70%	Impaction
2 microns	50%	Impaction, Sedimentation
1 micron	35%	Sedimentation
.5 micron	25%	Sedimentation, Diffusion
.2 micron	27%	Diffusion

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Particulate Filtration Theory

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volume. Their main filtration mechanisms take into account how particles behave in moving airstreams.

By placing many small fibers in the path of moving particles, targets are presented into which small particles can blunder and large particles can impact. By using smaller and smaller fibers for the same weight and thickness of filter mat, a large fiber surface area is presented for particle capture by diffusion and impaction.

The addition of electrostatic charges to the fibers and particles also greatly enhance particle capture.

Non-absolute fibrous filters are presently the most economical means for respiratory filtration. They can be designed to achieve particulate removal efficiencies approaching absolute filters with v ry low flow resistances. These low flow resistances can be maintained over a wide range of particle loadings.

Filtration capture mechanisms

In an absolute liquid filter, as particle size is reduced, an abrupt change in filtration-efficiency occurs as the particle diameter reaches the pore size diameter of the filter. This is *not* true for air filtration even for absolute filters.

In air, combinations of capture mechanisms occur at different flowrates and particle sizes to make the use of specially-designed, non-absolute, very low flow resistance filters possible. Each of these mechanisms and their combinations, which make up the sum total filtration efficiency, are well understood.

The ability of researchers to predict the initial filter efficiency with accuracy on laboratory test aerosols is excellent.

To simplify the visualization of the different capture mechanisms, imagine a fiber lying perpendicular to a moving airstream as in Figures 1-4. A good analogy is that the airstreams are lanes on a superhighway, and an obstacle occupying more than one lane has been placed across the path of traffic. Each capture mechanism describes the probability with which a certain vehicle will collide with the obstacle.

a. Interception capture

Interception is the only capture mechanism in which particles do not deviate from their original streamline paths as shown in Figure 1. As the streamlines approach a fiber, they split and compress as they go around the fiber and rejoin on the other side.

If a particle moving along these streamlines comes within one particle radius of the surface of the fiber, it is captured. As particle size increases and occupies more than one streamline, capture becomes more probable.

In our vehicular analogy, a car with the inability to change lanes (rush hour traffic) would end up becoming part of the obstacle, depending upon its size with respect to the obstacle.

b. Sedimentation capture

Sedimentation affects only large particles (2 microns and above). It is a contributor to capture efficiency only at low flowrates. As shown in Figure 2, the particle is affected by gravity, a force completely external to the filter fiber, and crosses the streamlines to be captured by the fiber.

One could imagine a car, affected by a large magnet on one side of the road, crossing lanes and becoming part of the obstacle. The main effect of sedimentation is that it determines which particles enter the respirator by the inhalation airflow deflecting them into the filter from their settling paths in the environment.

c. Inertial impaction captur

When a particle with sufficient inertia encounters an abrupt change in streamline direction as shown in Figure 3, it will cross the streamlines and impact into the fiber. The inertia of the particle depends on its size, density and speed.

In our analogy, a large flat-bed truck loaded with iron pipes could be moving toward our obstacle at too high a speed. The driver would find that the force of inertia is a powerful one as the truck becomes part of the obstacle which small vehicles can easily pass around in their proper lanes.

d. Diffusion capture

Smaller particles are constantly in motion, due to bombardment by air molecules. As shown in Figure 4, the particles can randomly cross the streamlines, and their probability of touching the fiber as they pass is greatly enhanced as their diffusive activity increases.

This random motion of the particle is dependent on its size and the temperature of the air. Its chances of capture are greatly enhanced by a high residence time near a fiber (low flow rates) and the availability of fibers in its path.

On the super-highway, a driver

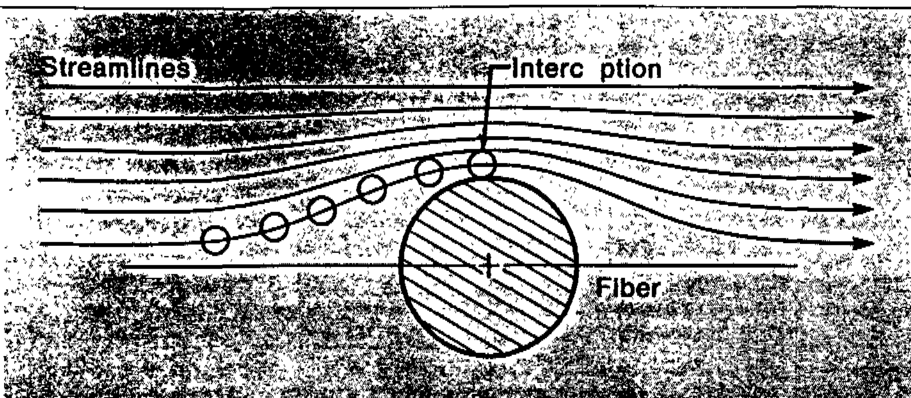

Figure 1. Interception Capture Mechanism

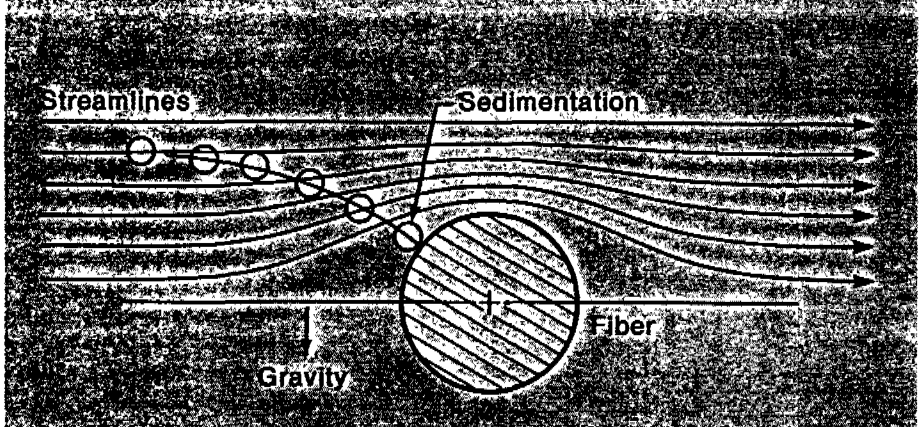

Figure 2. Sedimentation Capture Mechanism

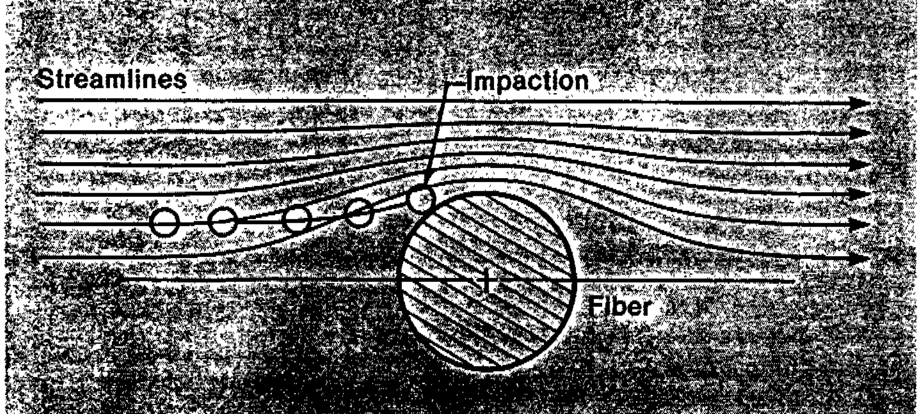

Figure 3. Impaction Capture Mechanism

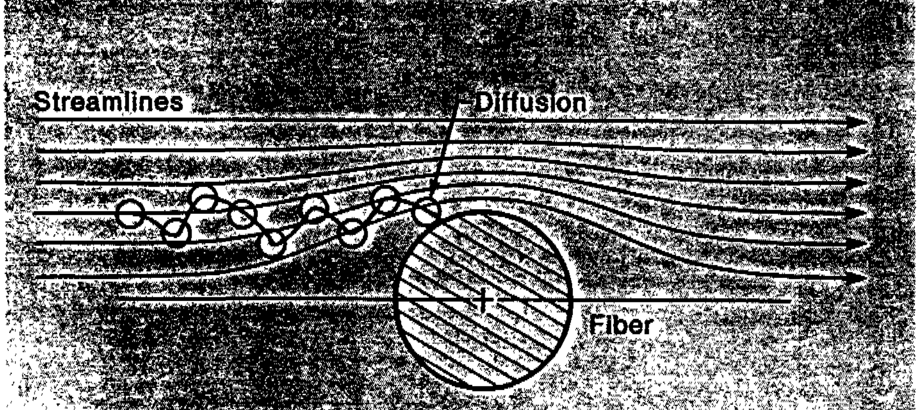

Figure 4. Diffusion Capture M chanism

with an alcohol blood level well above prescribed limits would randomly change lanes while moving in one general direction. The chances of being captured by interception are increased.

e. Combinations

Vehicle capture in the design of a super-highway is not the goal of designers. To minimize such dangers, the speed, weight and size of vehicles and their control ability are taken into consideration. At high speeds a small, heavy car has the same control problems as a large truck of the same mass. The sum total of possible capture mechanisms and their interactions are more important than the close analysis of each.

For a large heavy particle, the combination of inertial impaction and interception is important. For a large, light particle, diffusion and direct interception are important.

For a very small particle diffusion prevails. If each total capture mechanism is calculated to determine its degree of contribution to capture, then a theoretical sum total filtration efficiency may be found.

In the next issue of *JobHealth Highlights* we will discuss the subjects of filtration efficiency versus particle size and the performance of respirators against mechanically-generated dusts, using silica as an example.

Note: These articles are taken from a paper written by Daniel A. Japuntich of the 3M OH&SP Laboratory.

New Product Profile

Training Program Acquaints Employees, Supervisors with Chemical, Physical Hazards

A series of sound/slide and video presentations that inform workers of potential chemical and physical hazards in the workplace are available from 3M's Occupational Health and Safety Products Division (OH&SP).

Hazards Awareness Products educate employees about health and safety conditions related to chemical agents, hazards control equipment and physical stress. The audio/visual presentations help employers to meet employee training requirements, such as those established by Right-to-Know laws.

Hazards Awareness Products are available in packages that include sound/slide presentations or videocassettes.

Hazards Awareness Products are available in complete packages that include: sound/slide or 1/2- or 3/4-inch videocassettes; instructions for use; printed scripts; test questions and answers to help ensure program understanding; and attractive packaging that provides protective storage and easy identification.

Information is presented in factual, scientifically accurate language. The programs are easy to understand and are neither alarming nor inflammatory.

Each Hazards Awareness Product is reviewed by an external advisory council of health and safety professionals. The council helps ensure that the information presented is up-to-date and technically correct. The Hazards Awareness Products represent the compilation of information from sources 3M believes to be reliable. However, it is up to individual users to determine the suitability of each presentation for their specific application.

Hazards Awareness Products are available in three subject areas: chemical hazards; physical stresses; and hazards control equipment.

Examples of audio/visual presentations covering chemicals include:

- Chemical handling.
- Isocyanates.
- Lead.
- Methyl Ethyl Ketone.
- Vinyl Chloride.

Hazards Awareness products covering physical stress include:

- Video Display Terminals — Management.
- Video Display Terminals — Operators.
- Hearing Conservation.

Hazards control equipment programs include:

- Fire and Extinguishers.
- Laboratory Hoods.

Gas/Vapor Respirator Prefilters

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is used to capacity. If a high gas or vapor concentration exists, the cartridges may need to be changed first.

Previous articles on particulate filters and gas/vapor service life discussed when to consider replacing such components. As always, the major criteria used for service life determination are detection of gas/vapor odor or taste, difficult breathing, cartridge damage, or specific limits set by OSHA, the manufacturer or user have been reached. Of course, the final judge of service life is the respirator wearer.

3M offers several prefilter combinations with a maintenance-free gas and vapor respirator line. The No. 8732 prefilter has a dust/mist approval for an "air contamination level *not* less than 0.05 mg/m^3. It can be used with the 3M No. 8712 Organic Vapor Respirator, No. 8714 Acid Gas Respirator, No. 8725 Organic Vapor/Acid Gas Respirator and No. 8727 Ammonia/Methylamine Respirator.

The No. 8741 Paint Spray Respirator consists of the No. 8742 Paint Spray Prefilter, No. 8744 Prefilter Retainer and No. 8712 Organic Vapor Respirator. The No. 8751 Pesticide Respirator consists of the No. 8752 Pesticide Prefilter, the No. 8744 Prefilter Retainer and the No. 8712 Organic Vapor Respirator.

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