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MONITORING OF PARTICULATES IN RECIRCULATED AIR

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Abstract

The various categories of particulate monitoring instruments are identified along with criteria for successfully monitoring particulates in recirculated exhaust air. Each category of instruments is evaluated against these criteria as part of a selection process for identifying the optimum instrumentation. The selected categories are then further examined in terms of their advantages and limitations. Some general comments are also made with regard to the selection of instruments to monitor gaseous pollutants in recirculated exhaust air.

INTRODUCTION

While listening to several of the previous papers presented at this symposium and the discussions which ensued, there seemed to be some question as to the definition of monitoring in the context of recirculated air. Therefore, I would like to begin this presentation with my understanding of the definition of monitoring:

> The direct readout of the concentration of a subject contaminant on a real-time or continual basis. This is differentiated from the term sampling, which involves manual analytical/weighing procedures.

Please note that this definition does not specify the point of measurement. This provides the latitude of considering either in-duct monitoring at a point or points prior to the release of recirculated air into the work environment, or area or personal monitoring directly in the work environment.

Although the primary emphasis of this paper is to be particulate monitoring, gaseous monitoring is also discussed. Since this latter topic includes over 350 compounds listed in the Federal Register, only a brief presentation about monitoring gaseous substances, which is applicable "across the board" yet not so general as to become trite, will be included. The focus of the presentation will be discussion of the varying monitoring applications for which commercial instruments currently exist, those parameters to be considered in evaluating and selecting instruments for monitoring recirculated air, and some selection hints.

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GENERAL DISCUSSION OF GASEOUS AND PARTICULATE MONITORING

Table 1 lists the five primary measurement domains in which monitoring instruments are currently utilized. These instruments are typically designed for use in a specific domain and should not be casually utilized in alternative environments. The selection of a commercial instrument for monitoring one or more substances in air should be based on a careful evaluation of the relevant measurement parameters. These parameters are listed in table 2 and include both independent and dependent parameters. The independent parameters relate to the monitoring environment, whereas the dependent variables are related to the monitoring instrument itself.

It should also be noted that some of these parameters impact more on specific airborne contaminants than others. For example, the nature and degree of air movement and particle size distribution are of more concern when monitoring particulates than with gaseous substances. The overall message, therefore, is to be careful in selecting instrumentation. Make sure that the instrument design and sensing principle you are considering is compatible with your mon-

Table 1. Five primary measurement domains.

1.	Outside (ambient) air
2.	In-plant air
3.	Stack (stationary source) emissions
4.	Automotive exhaust (mobile source) emissions
5.	Ventilation ducts

Table 2. Measurement parameters.

Independent	
•	Concentration range of pollutant
•	Condition of effluent (temperature, humidity, pressure, interference agents, etc.)
•	Movement (velocity, turbulence) of air being monitored
•	Particle size distribution
•	Chemical composition
Dependent	
•	Instrument sensing method
•	Instrument design

itoring requirements. There are many qualified consulting organizations available to assist in the selection process and I encourage you to use them to augment your in-house capabilities when necessary.

CATEGORIES OF PARTICULATE MONITORING INSTRUMENTS

In order to assess the suitability of utilizing commercially available instruments to monitor particulate contaminants in recirculated exhaust air, a listing of candidate instrumentation was prepared. Table 3 presents these general categories of particulate monitoring instruments along with some of their respective manufacturers. This listing of manufacturers is not meant to be all inclusive nor should it be considered an endorsement of their products. An attempt is made, however, to identify the major suppliers of each instrument category to provide the reader with a starting point in the event that more specific information is desired.

As table 3 illustrates, there are seven general categories of particulate monitoring instruments available. Light scattering instruments are subdivided into particle counters, which count the number of individual airborne particles in a measured air sample by size range, and nephelometers or photometers, which measure the general scattering of light by particles in a volume of air. In the latter case, the resulting signal can be related to the mass concentration of the particles over a discrete particle size range, knowing the density of the particles.

The second category is opacity monitors, which measure the degree of opaqueness of particulates in a gas stream. An optical receiver measures the amount of light that is transmitted through the airborne particulates from a light source. The degree of opacity is dependent upon the size distribution and optical properties of the particulates being monitored.

Optical tape samplers, the third category, is similar in principle to opacity monitors except that the particles are collected on a filter tape prior to the measurement of light transmission. The resulting Coefficient of Haze (COH) signal is also dependent on the physical and optical properties of the collected particulates.

The fourth category, called electrical methods, is comprised of three subcategories. The first, electric charge transfer, involves the impaction of a particulate against an electrically conductive sensing element resulting in a small current. The current is then amplified and converted into a voltage readout. The mobility analyzer, the second subcategory, utilizes electrostatic techniques for particle detection. The entering aerosol is electrostatically charged with a number of ions proportional to its size. The charged particles are caused to flow to a current sensor that measures the total collected charge and displays the results in digital or analog format. The third subcategory, ionization gauges, more commonly known as smoke detectors, draws an aerosol into a chamber, resulting in a reduction in the detected ionization current within the chamber.

Condensation nuclei counters comprise the fifth category of particulate measurement instruments listed in table 3. This instrumentation is designed to detect and measure submicron airborne particles. The air being sampled is

Table 3. General categories of particulate monitoring instruments.

A. Light scattering instruments

  1. Particle counters--count individual particles by size
     Bausch & Lomb, Climate, Royco, Particle Measuring Systems
  2. Nephelometer or photometer--general scattering of a volume of air
     Leitz Tyndallometer, MRI, Weathermeasurer

B. Opacity monitors

     Lear Siegler, RAC, Dynatron

C. Optical tape samplers

     RAC, Bendix, GCA

D. Electrical methods

  1. Electric charge transfer
     Ikor
  2. Mobility analyzer
     TSI
  3. Ionization gauge
     (only smoke detection and alarm instruments commercially available)

E. Condensation nuclei counters

     Environment One Corporation

F. Piezoelectric mass monitors

  1. Collection by electrostatic precipitation
     TSI
  2. Collection by impaction
     Celesco

G. Beta attenuation mass monitors

  1. Collection by impaction
     GCA
  2. Collection by filtration
     GCA, Philips, Frieseke Hoepfner

drawn through a humidifier and then into a cloud chamber in which water is condensed upon the submicroscopic particulates to produce a cloud of micron-sized droplets. The degree of attenuation of a light beam by this cloud is then sensed and recorded.

The sixth category of instruments utilizes piezoelectric techniques to detect and monitor particulate mass concentration. Particles are collected either by electrostatic precipitation or impaction on a vibrating quartz crystal and the change in resonant frequency is measured as the particles are collected. The results can be displayed as an analog output or in digital format.

The last category, beta attenuation instruments, collects the sample on a substrate either by filtration or impaction. The mass is then determined by the degree of attenuation or absorption of beta radiation passing through the sample from a radioactive source (located above or below the collected sample) as measured by a sensor such as a geiger detector located at the opposite side of the substrate.

CRITERIA FOR INSTRUMENT SELECTION

The several categories of particulate monitoring instruments discussed above have each been developed for use in a specific domain and for measuring specific parameters that include: concentration by number of particles; concentration by mass; submicron particle measurement; respirable particle measurement; the measurement of large particles only; etc. The application under discussion, however, has its own set of unique requirements and the objective is to best match the performance specifications of these instruments with such requirements.

In order, then, to meet this objective, a set of six selection criteria was developed and is presented as part of table 4. The first criterion is that the mode of operation be real-time or continual. The reasoning is that the selected monitor must have a fast response time to changes in contaminant levels so that corrective action can be initiated and completed before unacceptable workplace concentrations are reached.

The second criterion is that the instrumentation must perform accurately within a concentration range which brackets the TLVs for the particulate contaminants being monitored. Focusing in on the TLVs for silica-containing, nuisance, and other common particulate contaminants, these ranges are:

$$0.1 - 15 \text{ mg/m}^3 \text{ or } 2 - 5 \text{ mppcf}.$$

Please note that although there are parallel mass concentration and particle count standards in the Occupational Safety and Health Administration (OSHA) regulations, these are not interchangeable. In fact, it is very likely that you may be meeting one standard, but be out of compliance with another.

Because of the above dichotomy, a third criterion specifies that the mass concentration standard be the one recognized, and therefore requires that the output from the selected instrumentation be directly related to mass concentration. The rationale here is that OSHA and Mining Enforcement and Safety Administration (MESA) have widely adopted gravimetric (mass concentration) techniques as their methods of compliance and that the results from any instrument selected for this application should be directly compatible with these compliance methods.

The next two criteria relate to the aerodynamic particle size ranges for respirable and total dust. If only respirable dust is being measured, the selected instrument should be capable of collecting and monitoring the particle size range which penetrates a respirable cyclone precollector. The upper particle size associated with this range is 10 µm. If total dust is to be measured, however, the monitoring device should be capable of measuring the same particle size range as the total dust compliance or reference method. This method, as specified by OSHA, involves the use of an inverted closed-faced 37-mm filter at a flow rate of 2 l/min. This author was, however, unable to

Table 4. Categories of particulate monitoring instruments vs. selection criteria.

Criteria	Categories of particulate monitoring instruments				
	Light scattering particle counter	Nephelometer	Opacity monitors	Optical tape samplers	Electric charge transfer
Mode of operation (real time or continual)	Real time or continual	Real time	Real time	Continual	Real time
Concentration range (0.1-15 mg/m^3 [2-50 mppcf])	Up to 100 mppcf	0.01-100 mg/m^3	Above 10 mg/m^3	Less than 50 mg/m^3	0.02-2 x 10^5 mg/m^3
Particle size range--respirable (up to 10 micrometers)	0.3-10 micrometers using cyclone	Up to 5 micrometers	Respirable range cannot easily be segregated	Down to 0.3 micrometers	Respirable range cannot easily be segregated
Particle size range--total (up to 20 micrometers[?])	0.3 ->10 micrometers	Insensitive to large particles in presence of small particles	Insensitive to large particles in presence of small particles	Down to 0.3 micrometers	Down to approximately 1.0 micrometer
Units of readout (mass concentration)	Particles/ft^3	mg/m^3	Percent opacity	Coefficient of Haze (COH)	Proportional to gr/scf for constant density, particle size distribution
Attention and maintenance level (minimal)	Low	Low	Low	Low	Low
Alarm signaling capability (yes)	Yes	Yes	Yes	Yes	Yes

(continued)

Table 4 (con.)

Criteria	Categories of particulate monitoring instruments: Mobility analyzer	Condensation nuclei counter	Piezoelectric and electr. precip.	Piezoelectric and impaction	Beta attenuation and impaction	Beta attenuation and filtration
Mode of operation (real time or continual)	Real time	Real time	Continual	Real time or continual	Continual	Continual
Concentration range (0.1-15 mg/m³ [2-50 mppcf])	>2,000 mppcf	Up to 1,000 mppcf	0.1-10 mg/m³	0.001-2.0 mg/m³	0.02-150 mg/m³	0.005-300 mg/m³
Particle size range--respirable (up to 10 micrometers)	0.005-5 micrometers	Below 0.3 micrometers	Up to 8 micrometers	0.1-10 micrometers with cyclone	0.4-10 micrometers using cyclone	<0.1-10 micrometers using cyclone
Particle size range--total (up to 20 micrometers[?])	0.005-5 micrometers	Below 0.3 micrometers	Up to 8 micrometers	0.1-100 micrometers	0.4-20 micrometers	<0.1-100 micrometers
Units of readout (mass concentration)	Particles per cm³	Nuclei/cm³	mg/m³	mg/m³	mg/m³	mg/m³
Attention and maintenance level (minimal)	Low	Low	High-frequent cleaning of crystal required	High-frequent cleaning of crystal required	Low	Low
Alarm signaling capability (yes)	Yes	Yes	Yes	Yes	Yes	Yes

determine from discussions with NIOSH personnel and other experts in aerosol measurement the upper end of the aerodynamic particle size range sampled via this method. Best estimates seem to suggest that this level would be under 20 μm. Consequently, up to a 20-μm detection capability is specified as the criterion for total dust monitoring, pending additional information.

The last two criteria require that the attention and maintenance level of the instruments be minimal and that the instrumentation offer alarm signaling capability. These are essential requirements to insure reliable long-term operation in industrial environments, as well as the ability to quickly respond in the event that excessive concentrations occur.

COMPARISON OF INSTRUMENT CATEGORIES AGAINST SELECTION CRITERIA

Table 4 compares the various categories of particulate monitoring instruments against the seven selection criteria discussed above. The information in this table was compiled from data sheets and brochures of instrument manufacturers, as well as from published information and discussions with scientists and engineers familiar with the design and application of these instruments.

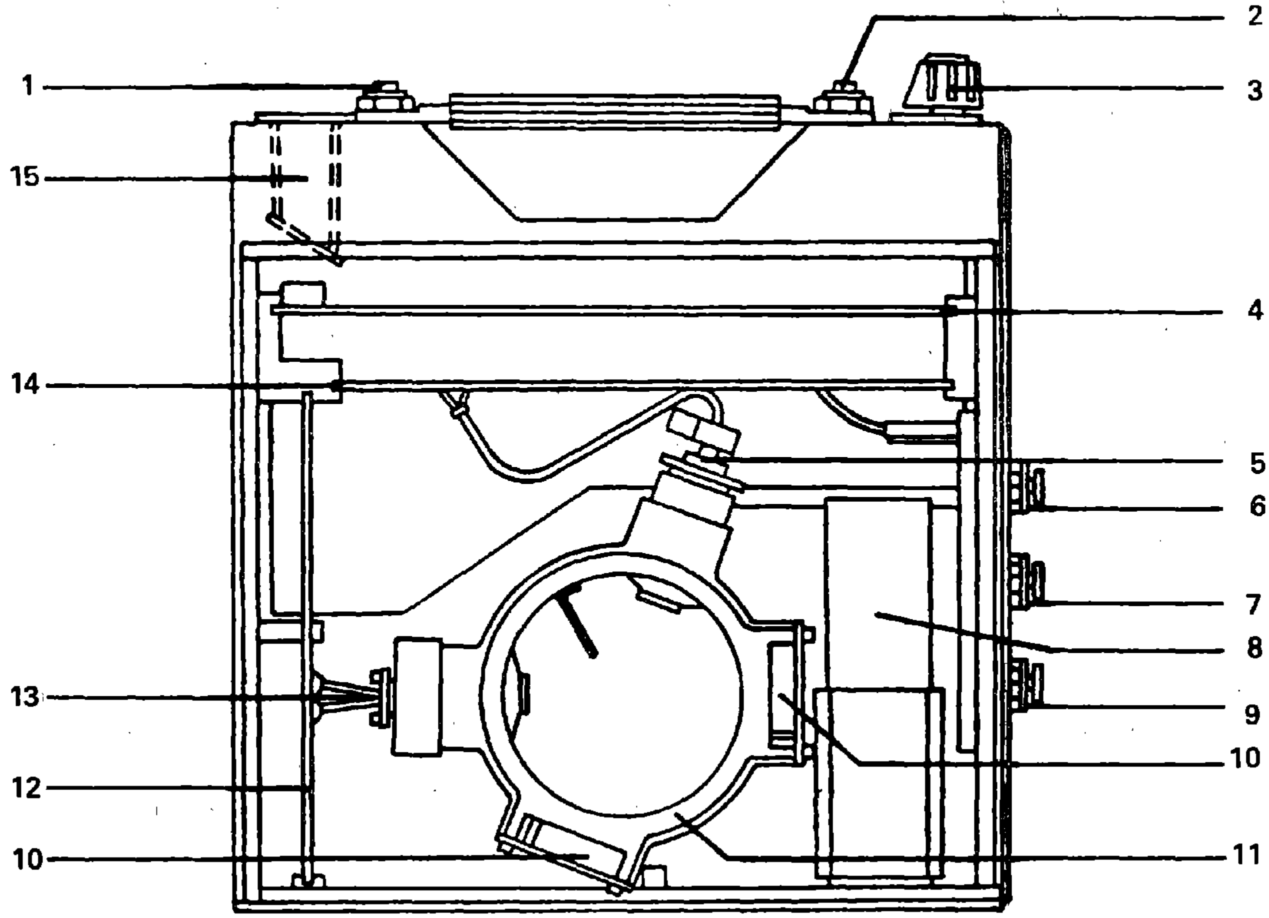
For each category of instruments, the performance specifications pertaining most to the selection criteria are listed. In those cases where there is a definite mismatch between the criteria and performance specifications, a "box" is drawn in to signify this mismatch. The instrument categories best suited to monitoring particulates in recirculated air are those where the performance specifications are most compatible with the selection criteria and where no significant mismatches exist.

This evaluation indicates that two classifications, the nephelometer and beta attenuation, should be further considered in monitoring recirculated air. Both these instrumentation categories are discussed below.

A FURTHER EXAMINATION OF THE NEPHELOMETER

As an example of this category of particulate monitoring instrumentation, a schematic of the Tyndallometer, is shown in figure 1. This instrument, manufactured by Leitz in West Germany, is designed for in situ measurements as the sensing chamber is positioned directly in the dust-laden air to be sampled. A luminescence diode (wavelength 0.94 μm) serves as the light source, and a silicon diode receives the light scattered in an angle of 70°. A direct digital display or analog output is available. As outlined in table 5, an advantage of this unit is that it does perform in situ measurements, obviating the need for a pump to draw a sample into the unit. Also, low maintenance and a direct digital readout in mg/m^3 are other benefits.

Although the Tyndallometer is basically insensitive to variations in particle size within the range of about 0.4 to 5 μm, the presence of submicron particles will tend to overwhelm the instrument, resulting in excessively high results. Conversely, the Tyndallometer is relatively insensitive to the presence of larger particles (above 5 μm), resulting in readings biased on the low side. Also, the unit is calibrated for a specific mass density and care should be taken in applications where variations in density can occur.



1 Key
2 Balancing key for zeroing
3 Range switch (measuring mode switch)
4 a.c. converter
5 Photo diode
6 Data output
7 Analogue output
8 d.c. converter
9 For mains units or battery connection
10 Light trap
11 Measuring chamber
12 Operating control
13 Glow diode
14 Amplifier
15 Digital measured value display

Figure 1. Schematic of the Tyndallometer manufactured by Leitz.

Table 5. Further examination of the nephelometer.

Advantages	
	• In situ measurement
	• No moving parts--low maintenance
	• Direct digital display in mg/m^3
Limitations	
	• Insensitive to particles much above 5 micrometers
	• Presence of ultra fine particles can bias results upward
	• Assumes a specific particle mass density

A FURTHER EXAMINATION OF BETA ATTENUATION PLUS IMPACTION

The Model RDM-301 Recording Dust Monitor manufactured by GCA Corporation is an example of this category of particulate monitoring instrumentation. A photo of the unit is shown in figure 2. Dust is collected by impaction as a "spot" on a coated Mylar disc capable of advancing automatically after each cycle with a capacity of 450 samples per disc. A carbon 14 source is utilized as the beta-emitting isotope and the sensor is a Geiger Mueller Detector. The cycle time is programmable from 1 to 99 minutes.

As shown in table 6, the basic advantage of the RDM-301 is that the measurement principle is directly proportional to mass and a digital tape printout directly in mg/m^3 is provided. Also the unit can be operated for several shifts without attention. The two primary limitations of the unit for this application are that particles below 0.4 µm in aerodynamic diameter are not collected and therefore not measured; secondly, if in-duct monitoring is required, the sample has to be extracted via a probe with the concomitant possibility of some particle losses within the probe.

FURTHER EXAMINATION OF BETA ATTENUATION PLUS FILTRATION

To illustrate this category, a photograph of the Model APM, Aerosol Mass Monitor, is presented in figure 3. This instrument, manufactured by GCA Corporation, collects the dust sample on a high-efficiency filter and measures the mass by beta radiation attenuation. As listed in table 7, the incremental advantage of this approach vs. collection by impaction is that the filter collects particles across the entire particle size spectrum for measurement. Also, a novel flow control system maintains a constant flow. This specific instrument also has been successfully field tested for monitoring particulates in recirculated air from baghouses by the major asbestos producers in Quebec. The primary limitation of this unit is the need to extract the air sample via a probe if in-duct monitoring is required.

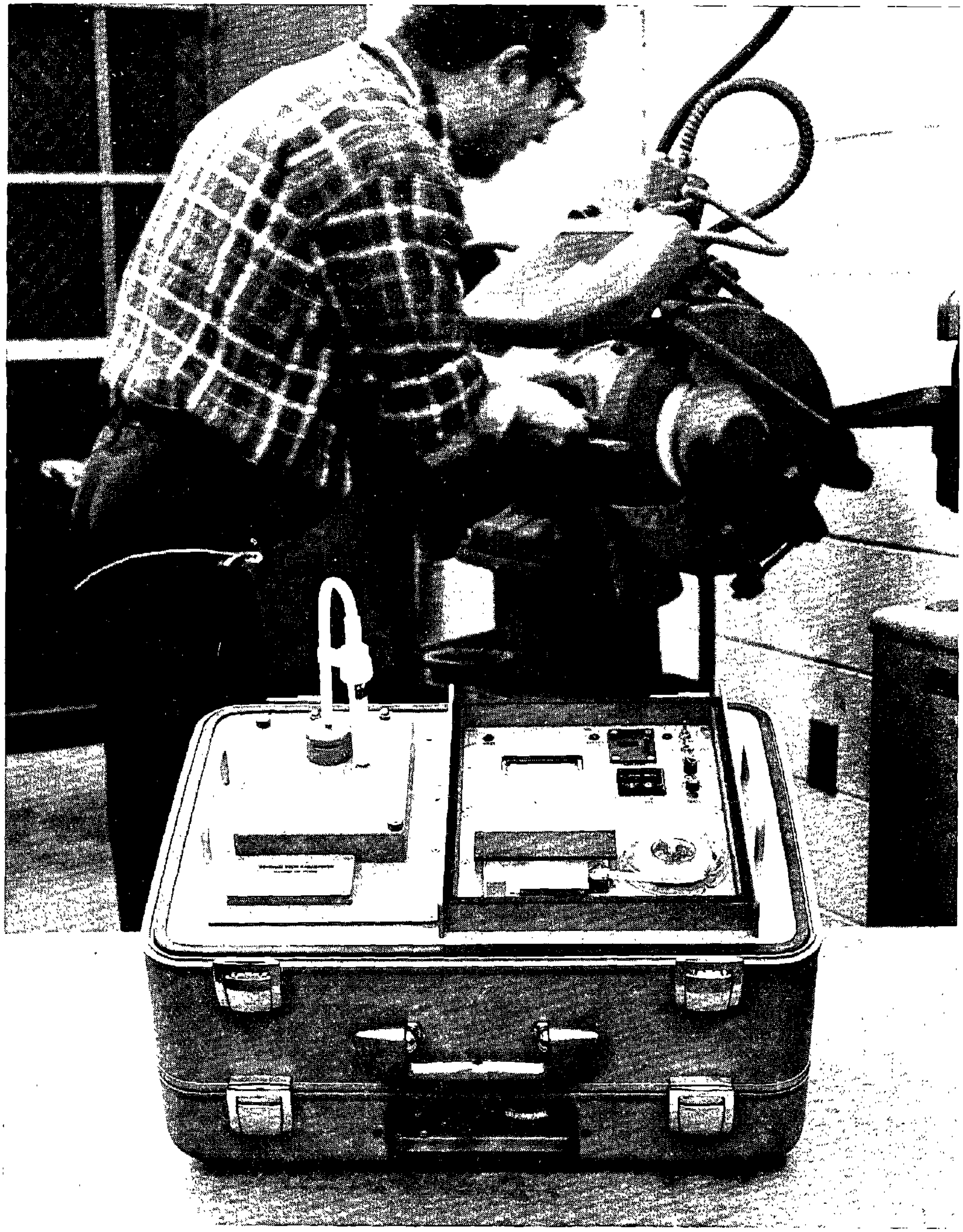


Figure 2. Photo of model RDM-301, recording dust monitor manufactured by GCA Corporation.

Table 6. Further examination of beta attenuation plus impaction.

Advantages

- Direct readout in mg/m^3
- Attenuation of beta radiation directly proportional to mass
- Can be operated for several shifts without attention

Limitations

- Mass contribution of particles below 0.4 microns (aerodynamic diameter) not measured
- Sample extracted from duct via probe

Table 7. Further examination of beta attenuation plus filtration.

Advantages

- Direct readout in mg/m^3
- Attenuation of beta radiation directly proportional to mass
- High-efficiency filter collects particles across entire particle size spectrum (<0.1-100 micrometers) for measurement
- Constant flow control
- Field tested downstream of baghouses by major asbestos producers in Quebec

Limitations

- Sample extracted from duct via probe

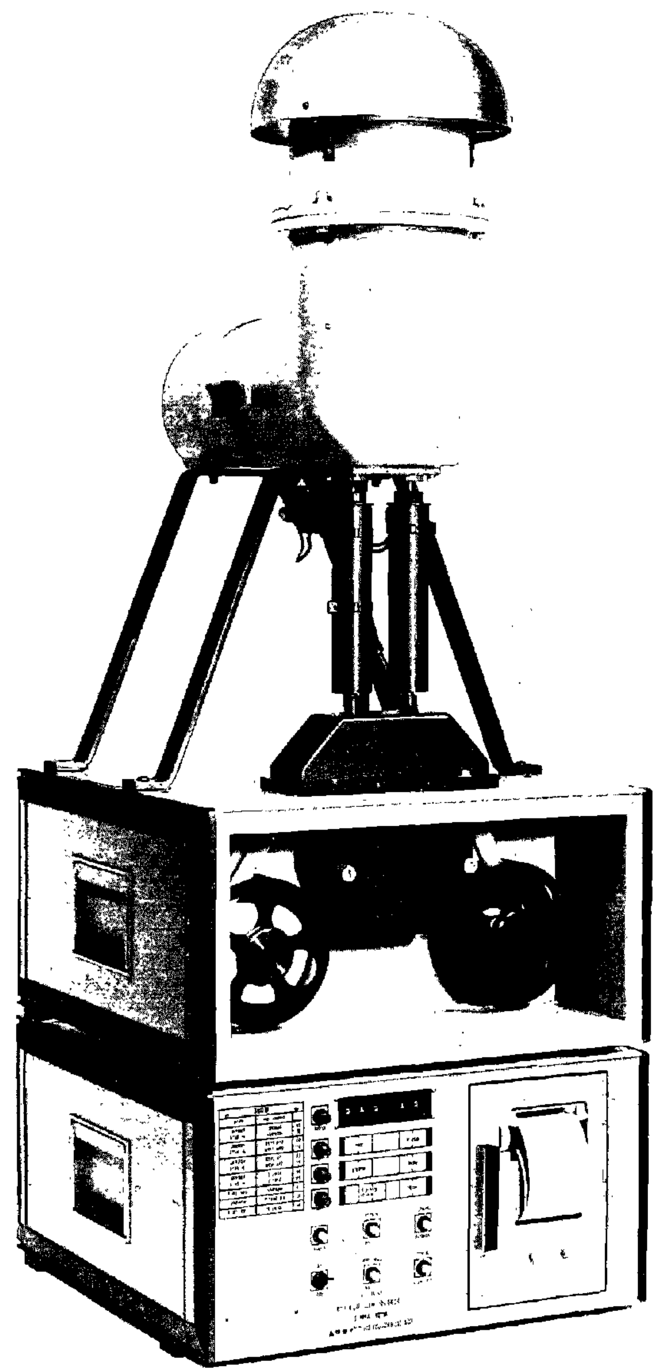


Figure 3. Model APM, aerosol mass monitor (pump module not shown) manufactured by GCA Corporation.

DISCUSSION

MR. WILLIAM HUELSEN (American Foundrymen's Society, Des Plaines, Illinois): I've heard that on the beta attenuation instruments where you use the disc which is coated with a vaseline-like material, that for warm or hot gas conditions the vaseline will begin to run and the sample will disperse and will give you a false reading. Is this correct? If it is correct, what are the temperature limitations?

MR. CHANSKY: Bill, the answer to that question is that the standard type of commercial instrumentation is designed to be operated up to temperatures of approximately 100° F, and if you do bring such instrumentation into an environment where you have temperatures exceeding that level, the phenomenon that you discussed will take place. However, there are several coating materials that can be used that have different viscosities, and we know of several that are suitable for high temperature applications, so this is not an intrinsic limitation. You do have a choice in terms of the type of coating material you select, and certainly for high temperature applications (above 100° F), the commercial coating would not be recommended.

MR. SCOTT STRICOFF (A. D. Little, Inc., Cambridge, Massachusetts): In the context of recirculation, I don't think that it is always true that you require a real-time monitor. We went through that several times this morning, and I think a lot of the people in the room also believe that in some, if not many, industrial recirculation systems, there are potential situations where real time isn't a requirement. It all depends on the specifics of the location and contaminants, the airflows, and a lot of other things.

MR. CHANSKY: What is required? What would be the replacement for real time?

MR. STRICOFF: It all depends on how quickly you get into a dangerous situation. If all you're dealing with is nontoxic dust, it may be perfectly adequate if the area is sampled once a day. It depends on the situation.

The second point is regarding output, and the virtues of mass versus count. I don't disagree with what you said in general terms, although, again, for this particular kind of an application it may be sufficient in some situations where you know what your expected values are, particularly where you're looking at ducts, to just look for an "off-spec" kind of a situation, and look for a change. If that is what you're looking for, then the units you're looking at are not that significant.

MR. CHANSKY: I would say that if you're looking simply for a type of instrument for your application, you're absolutely correct. In terms of something which monitors on a continual, not continuous but continual basis, where you're acquiring data not only on whether you're exceeding the levels or not, but also on what the levels are, for recordkeeping purposes and whatever else that might be required, then mass concentration may be more desirable. Again, to use the terminology you used, I would like to think of these more as guidelines, and I'm sure there are many exceptions that can be mentioned.

MR. LARRY BULLOCK (Envirex, Milwaukee, Wisconsin): I was wondering why you might have excluded devices which are specific for contaminants in your criteria? I think in some applications where exhaust might be, some mechanics are interesting and might be useful.

MR. CHANSKY: Currently, of course, there is no continuous real-time particulate monitor that gives you mass concentrations specific to a given constituent. The way to get around that is by being very conservative, and by knowing what the range of concentration is of a specific constituent existing in your facility. For example, I know Joe Medved up in Saginaw, in central foundry of GM; his people have done a study using personal monitors where they've taken a number of samples periodically and come up with a very good handle on the range of silica levels at various locations in his plant. They can say with confidence that, for example, 95 percent of the time the silica level would not exceed 15 percent in location X. They'll then select a TLV based on this upper silica level. You may be hurting yourself more than is necessary, but the conservative approach in this particular application would probably be recommended, although again, you have to consider each case individually.

MR. BRUCE MENKEL (Bruce Menkel Consulting Engineers, Dayton, Ohio): Question about the application of GCA model APM in Canada, downstream of the bag houses in the asbestos: is that a recirculation operation emission?

MR. CHANSKY: Yes, recirculation emission and ambient air, both. They are recirculating a certain percentage of air back to the workplace. What that percentage is, I'm not sure. I don't know the percentage, but up in Canada, it is mighty cold, and during the wintertime they do recirculate air, returning from the bag house back into the plant.

MR. MENKEL: Use of the APM, are they monitoring just on a concern with bag breakage, or are they also into fiber?

MR. CHANSKY: No, they are using the nephelometer as an indication of bag breakage, but with the APM they are using it as a continual monitor to assure themselves at any time they are not exceeding some preset levels for asbestos. Now again, I don't know how much asbestos is in the mass sample, but they assume 100 percent asbestos, and for those of you interested, please write your comments and I will be able to give you the names of the people most knowledgeable in the Province of Quebec on the program.

MR. DON SCARBROUGH (Nordson Corporation, Amherst, Ohio): Question on your determination of respirable technique: I presume you're using nylon mat cyclone. Can you comment upon the effect of your results of having electrostatic charge borne upon the particulate matter?

MR. CHANSKY: Let me preface any comments I make by saying that this piece of plastic has probably had more money spent on it per pound or per ounce than anything else I can think of in evaluating a specific tool. There have been studies, and I can't specifically name them, on the effect of electrostatic charge on the cyclone. I would be happy to find out for you and get back to you, but GCA has not been involved in any studies of that type.

MR. WILLIAM HEITBRINK: Several years ago, a coworker, Bruce Almich, studied the effect of electrostatic charge upon the nylon cyclone's penetration and found some effects. The cyclone's penetration was affected slightly and the reproducibility of the data was affected. Details of this study can be found in the AIHAJ, vol 35, pp 603-611 (1974). Caplan et al. found that charge had no effect upon cyclone performance. A report of their work can be found in the AIHAJ, vol 38, pp 162-173.

Earlier you mentioned that the captive efficiency of the Millipore 37-mm filter holder has never been fully evaluated. I believe that this is true for all industrial hygiene air sampling devices used to measure total aerosol. The effect of ambient air velocity upon capture efficiency has received very little attention. Some literature which contains relevant experimental data is as follows:

1. Breslin and Stein, 1975, Efficiency of Dust Sampling Inlets in Calm Air, AIHAJ 36: 576-583.

2. Raynor, 1970, Variation in Entrance Efficiency of a Filter Sampler With Air Speed, Flow Rate, Angle, and Particle Size, AIHAJ 31: 294-304.

3. Ogden and Wood, 1975, Effect of Wind on the Dust and Benzene-Soluble Matter Captured by a Small Sampler, Annals of Occupational Hygiene 17: 187-195.

Because these references do not contain specific data on the effect of orientation and wind speeds between 50 and 200 ft/min upon the capture efficiency of the closed-face 37-mm filter holder, NIOSH plans to study these effects contractually.

MR. CHANSKY: For those of you familiar with the Davis criteria for sampling aerosols, estimates of largest particle to be sampled using a personal filter are less than 10 mm. However, there are other criteria that set the upper level much higher than 10 mm. Speaking to some of the NIOSH people directly and asking them the question, they, as you indicated, don't know, and you verified you will be conducting a study this year. Is that correct?

MR. HEITBRINK: Yes.

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FOREWORD

These proceedings of the symposium on "The Recirculation of Industrial Exhaust Air" are submitted under Contract No. 210-77-0056 to the National Institute for Occupational Safety and Health of the U.S. Department of Health, Education, and Welfare. The symposium was held in Cincinnati, Ohio, on 6-7 October 1977.

The objective of this symposium was to discuss the development of technical criteria for the recirculation of industrial exhaust air. With emphasis on the protection of the worker's health, technical subject matter discussed included: (1) decision logic for determining recirculation feasibility; (2) design and performance guidelines for recirculation systems; (3) availability of air cleaning and monitoring systems; and (4) maintenance guidelines.

Mr. Robert T. Hughes, Chemical Agents Control Section, Control Technology Research Branch, Division of Physical Sciences and Engineering, National Institute for Occupational Safety and Health, Cincinnati, Ohio, was the Symposium General Chairman.

Mr. Alfred A. Amendola, Control Technology Research Branch, Division of Physical Sciences and Engineering, National Institute for Occupational Safety and Health, Cincinnati, Ohio, was the Symposium Vice-Chairman and Project Officer.

Mr. Franklin A. Ayer, Manager, Technology and Resource Management Department, Center for Technology Applications, Research Triangle Institute, Research Triangle Park, North Carolina, was the Symposium Coordinator and Compiler of the proceedings.