AT-90-15-1

#4730

NEEDS AND PRECAUTIONS FOR THE USE OF DUST COLLECTORS IN INDUSTRIAL ENVIRONMENTS

T.H. Kuehn, Ph.D., P.E.
Associate Member ASHRAE

D.Y.H. Pui, Ph.D.
Member ASHRAE

ABSTRACT

Recent advances in dust collector performance measurements and system modeling are reviewed. Unresolved issues are discussed to stimulate future research efforts related to industrial dust collector performance and operation.

INTRODUCTION

Dust collectors are necessary to minimize the amount of dust released into the atmosphere and in some cases back into the industrial work environment when recirculated air systems are used with nuisance dust. Dust concentrations downstream of a collector should be categorized into total and respirable dust quantities for human health considerations. A review of the necessary instrumentation for workplace sampling was given by Phalen et al. (1986).

Modern dust collectors often utilize pulsed air for cleaning the media and, therefore, operate on an intermittent basis. Detailed studies of the transient performance of a cartridge dust collector were given by McDonald et al. (1986). The laboratory test methodology was summarized by Liu et al. (1986).

The authors conducted ASHRAE RP-531 to determine the performance of typical dust collectors available for industrial applications (Kuehn et al. 1989). This study consisted of laboratory measurements of dust collector fractional efficiency and pressure drop, field measurements of dust collector efficiency, and the development of a computer model to predict the indoor respirable nuisance dust concentration for industrial air-cleaning systems that use recirculated air. The results are summarized in two ASHRAE technical papers (Fay et al. 1989; Bergin et al. 1989).

The objectives of this paper are to summarize the state of the art of techniques for measuring the performance of industrial dust collectors and subsequent data analysis, to identify topics for future research, and to make recommendations for quantitative comparisons of performance.

DESCRIPTION OF NEEDED RESEARCH

Several issues are unresolved regarding the specification and use of dust collectors in industrial environments. These issues have been categorized into the following four subject areas:

1. Development of standard test methods
2. Establishment of performance parameters
3. Parametric studies of dust collectors
4. Supporting studies

Each of these topics is discussed in the following sections.

Development of Standard Test Methods

Standardized test methods are needed to ensure that a uniform procedure is used by all manufacturers for rating the performance of similar units. Different rating procedures may be required for different collector designs, such as for electrostatic precipitators for which a procedure suitable for baghouse units may not be appropriate.

Dust collection efficiency is the most important parameter to measure in a rating test. In high-efficiency units, it is more appropriate to list the collector penetration, which is 1.0 minus the collection efficiency. The collection efficiency, or penetration, is affected by the challenge aerosol loading and size distribution, the air velocity through the collection media or through the unit, and the method used to clean the unit. The air pressure, length of cleaning pulses, and cycling time of the cleaning process all affect the collector's performance for pulse-cleaned units. The shaker action and cycling time influence the operation of shaker units. The best method of comparing upstream and downstream dust concentrations is to use the same method or instrument, which eliminates calibration bias and the cost of a second measurement unit. In high-efficiency collectors, the downstream concentration is very low. Therefore, traditional gravimetric sampling procedures can require a considerable amount of time. For example, a gravimetric sample usually requires the accumulation of between 10 and 100 micrograms of material for an accurate weight-change measurement. A collector with a downstream dust concentration of 0.01 mg/m^3 that is sampled at 1 cfm (4.73x10^{-4} m^3/s) through a filter will require between one-half and six hours for sufficient weight measurement. Measurements should be made over a sufficiently large number of cleaning cycles to provide representative results. Fluctuations in downstream concentration as a result of pulsed-air cleaning are shown in

T.H. Kuehn and **D.Y.H. Pui** are Associate Professors, Department of Mechanical Engineering, University of Minnesota.

Figure 1. Similar results are obtained from other types of cleaning.

The test method reported in McDonald et al. (1986) and Liu et al. (1986) and used in ASHRAE RP-531 (Kuehn et al. 1989) is sufficiently general to apply to nearly all types of industrial dust collectors. A schematic diagram of the apparatus is shown in Figure 2. This method—a variation of it—is recommended as the test method that should be adopted for rating industrial dust collector units. The re provide the fractional collection efficiency of the unit ur test in addition to the total collection efficiency for either or respirable dust.

The energy use of a collector is another impor parameter that should be measured in a rating test. T two largest energy uses are the fan power required to o come the pressure drop through the unit and the auxilia

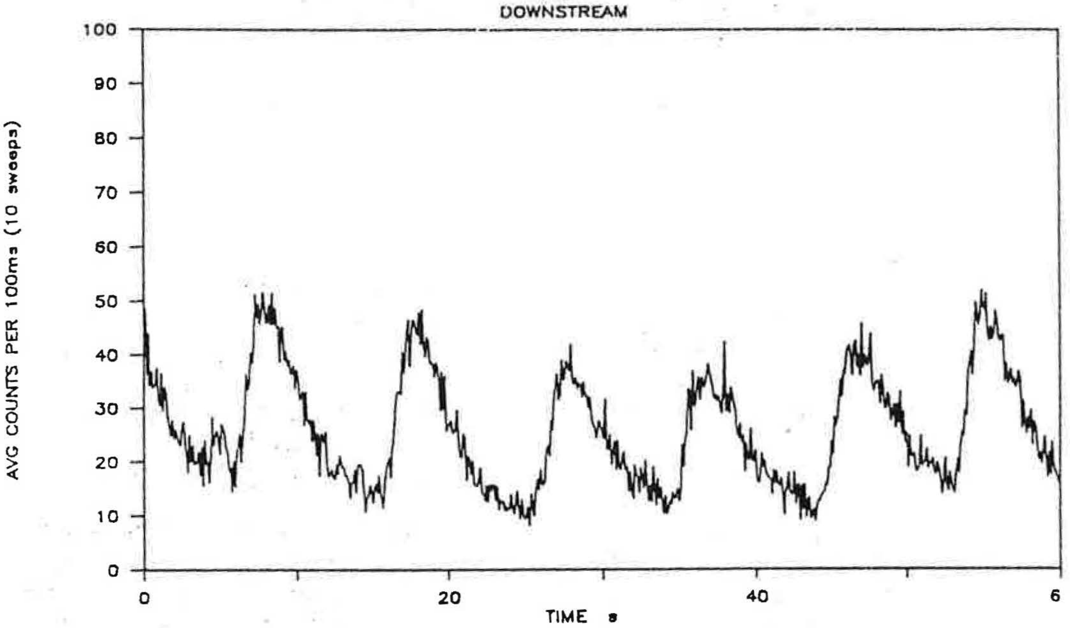

Figure 1 *Short-term fluctuations in particle count downstream of a dust collector with pulsed-air cleaning*

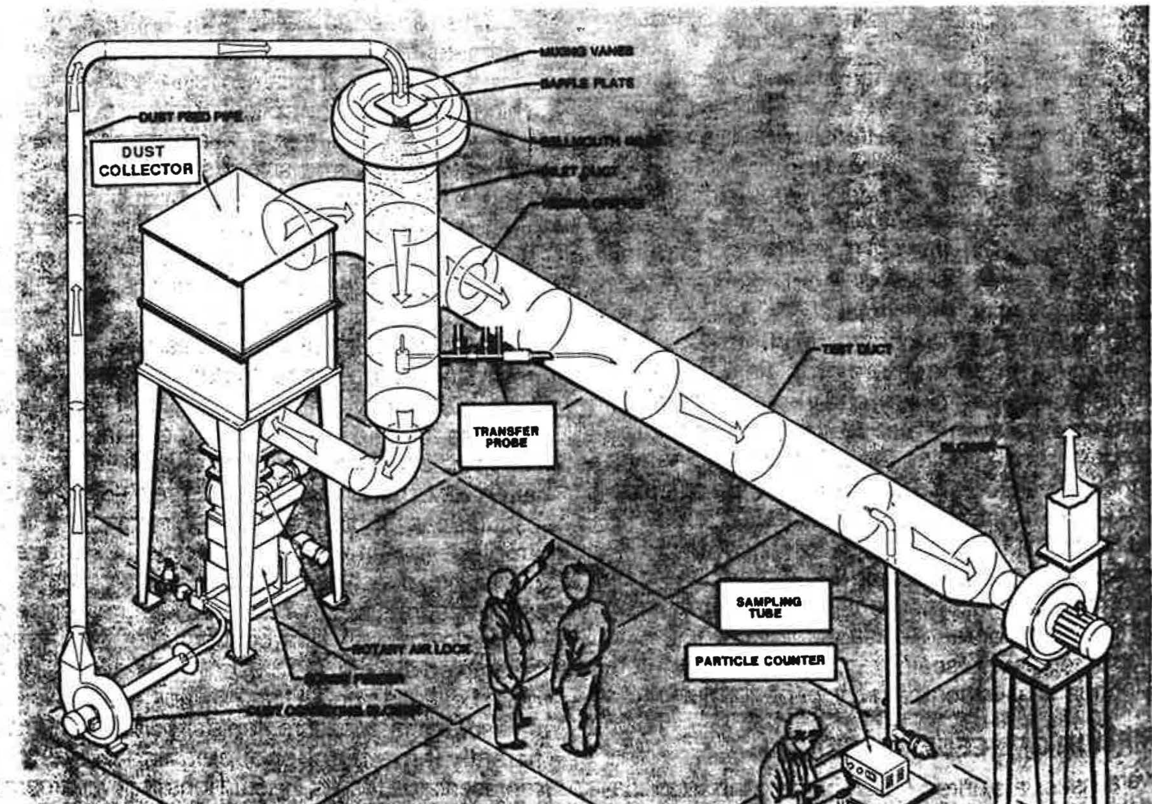

Figure 2 *Schematic diagram of experimental dust collector test facility*

power required to operate the unit itself, such as power required to compress the air in a pulse-cleaned unit or the mechanical power required in a shaker unit. The power measurements should be time averaged to account for the deviations caused by cleaning cycles and other transient processes such as start-up.

The sound level of units with self-contained blowers should also be measured. These units may be mounted in sound-sensitive areas, such as near school buildings or at small factories where sound levels are a concern. A tone-adjusted A-weighted scale would be appropriate, as other types of HAVC equipment use this scale.

Establishment of Performance Parameters

Several performance parameters can be defined to rate the unit for collection efficiency, energy use, and sound level. The collection efficiency is better expressed as the penetration, which is defined as

$$P = 1\text{-}\eta = m_d/m_u = C_d/C_u \qquad (1)$$

where:

P = penetration
η = collection efficiency
m_d = downstream mass flow
m_u = upstream mass flow
C_d = downstream dust concentration
C_u = upstream dust concentration

The penetration is the fraction of the aerosol mass upstream of the unit that penetrates through the unit. It is equal to the ratio of the aerosol mass concentration downstream divided by the aerosol concentration upstream. This is a more convenient method of describing the performance of modern high-efficiency collectors. For example, a collector with a penetration of 10^{-5} would have a collection efficiency of 99.999%.

The theoretical minimum fan power requirement to overcome the pressure drop through the unit is equal to the airflow rate through the unit multiplied by the pressure drop across the unit ($Q\ \Delta$ Pressure). Although the pressure drop information alone is useful when designing the air-handling system, the user must convert the pressure drop data to fan power requirement when specifying the fan required for a particular unit.

The auxiliary power requirement, W, can be determined by test, usually by metering the electric power required by the supporting equipment. Examples include air compressor requirements for pulse-cleaned units, power requirements for shaker-cleaned units, and the electric power required to operate electrostatic precipitators.

Sound levels can be rated using a variety of scales with the results given in dB. The tone-corrected A-weighted scale is used for other types of HVAC equipment and is part of standard testing procedures. Such measurements should be made on units with self-contained blowers. Sound levels for remote fans should be available from the fan manufacturer.

Although the individual performance parameters listed above are useful, combined parameters are often more indicative of the relative performance of comparable units. For example, the coefficient of performance (COP) or energy efficiency ratio (EER) are common performance parameters used for refrigeration and heat pump equipment. These parameters are simply the ratio of the system's capacity (or desired output) to the required power input. Similar performance parameters can be defined for industrial dust collectors. One such parameter is the figure of merit, which is defined as

$$FOM = -\log \text{Penetration}/\Delta\ \text{Pressure} \qquad (2)$$

This is the ratio of the dust penetration through the unit divided by the pressure drop imposed on the air passed through the unit. The higher the collection efficiency, the larger the numerator, and the lower the pressure drop, the smaller the denominator. Each will cause the performance of the unit to increase and result in a larger value for *FOM*.

Another rating parameter can be defined as the ratio of the dust penetration through the unit divided by the total power required to operate the unit. This performance rating factor (*PRF*) can be written as

$$PRF = -\log \text{Penetration}/(Q\ \Delta\ \text{Pressure} + W) \qquad (3)$$

The smaller the penetration or the lower the energy use, the higher the performance rating factor for a particular unit. This performance parameter has a meaning similar to the EER of an energy conversion device, such as a heat pump, in that the desired output is in the numerator and the minimum amount of energy required to operate the device is in the denominator.

Parametric Studies of Dust Collectors

The laboratory measurements performed in ASHRAE RP-531 were restricted to a given set of operating conditions. The objective of that study was to evaluate the performance of dust-collectors as installed and operated according to current practice. A number of questions regarding dust-collector operation remain. A series of parametric studies should be undertaken to resolve some of these questions. The parameters to be studied are summarized in the following paragraphs.

Challenge Aerosol The previous study considered a single aerosol size distribution, loading, and steady upstream concentration. Distributions of different size may have a significant effect on the collector's capture efficiency. A collector receiving dust from a variety of sources may perform differently from the same collector receiving dust from a single source. In the field measurements performed in ASHRAE RP-531, the two collectors receiving talc dust had much higher penetration values than the collectors tested with other types of dust. This may signify the importance of the type of dust in addition to its nominal size distribution.

The upstream dust concentration was fixed in the previous study at 1 grain/ft³ (2.29 gm/m³). This resulted in a given cake formation time, cleaning process cycle, penetration, and pressure drop. A change in the dust loading is expected to change all these items.

The collectors tested were all new and just received from the factory. The collectors were loaded until a nearly steady-state operation was achieved. The tests did not consider transient loading due to dust generation processes being started, stopped, or altered. Night shutdown and restart were not evaluated. Transient loading, shutdown, and restart should all be evaluated and compared with the current steady-state data.

Air Velocity The air velocity through the media or air-to-cloth ratio was specified by the manufacturer for the previous tests according to the challenge dust size distribution and upstream concentration. The velocity was not changed, as may occur in practice when the number or type of dust sources are changed. The air-to-cloth ratio is expected to have a pronounced effect on both the penetration results and the pressure drop through the unit.

Cleaning Process All the cartridge and baghouse units tested previously used pulsed air to clean the filter media. The air pressure and cleaning frequency were prescribed by the individual manufacturer. As a result, a wide variety of cleaning cycles was used. Figure 3 shows the effect of pulse dwell time on the pressure drop of one of the cartridge units tested. The media were conditioned for the initial 20 hours without pulsing. The pressure drop through the unit increased dramatically during this time. From 20 hours to 255 hours, the pulse-cleaning cycle was initiated every 30 seconds with a pulse pressure of 90 psi (620 kPa). The pressure drop continued to increase but at a much slower rate. After 255 hours, the pulse dwell time was reduced to 10 seconds. The pressure drop increased much more slowly and appeared be approaching a steady value. The particle penetration also changes with pulse rate. The pulse pressure and dwell time should be chosen to minimize both penetration and pressure drop under a given set of operating conditions. It is not clear whether this optimum cleaning process can be determined from existing data.

Filter Media A variety of filter media was tested in the earlier study. As with all filtration devices, the type, density, and thickness of the media play an important role in collector performance. The best media to use may depend on the size distribution and loading of the upstream aerosol.

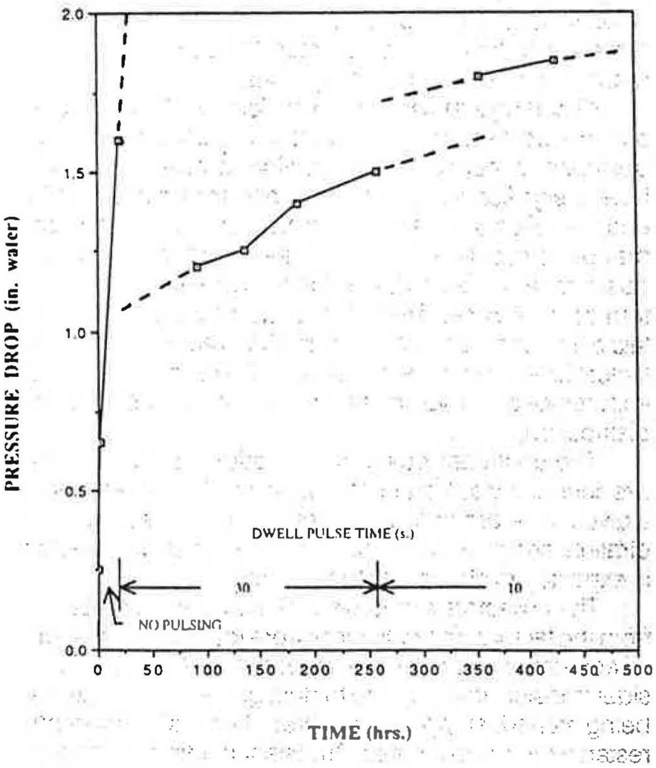

Figure 3 *Pressure drop vs. pluse dwell time for a cartridge dust collector during start-up*

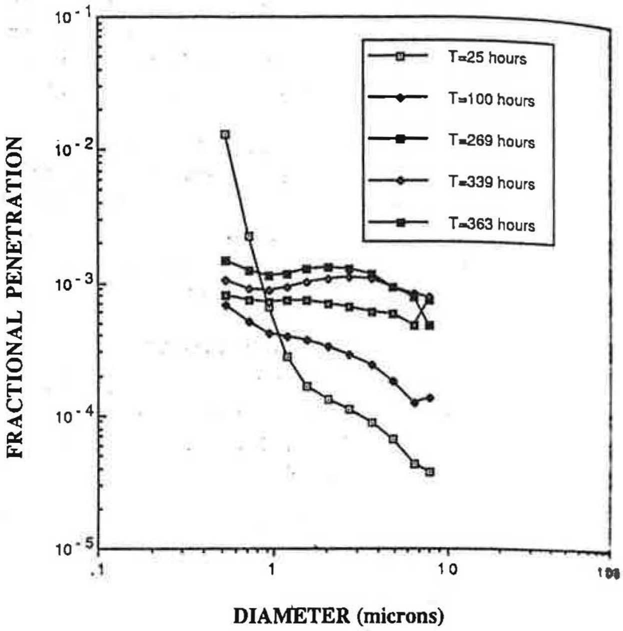

Figure 4 *Fractional particle penetration vs. time for a baghouse collector during start-up*

It would be useful to test a variety of media on different challenge aerosols to determine the best media to specify for various applications.

Long-Term Performance No collector was tested for more than 500 hours in the previous tests. The pressure drops appeared to be nearly steady near the end of the tests, but the particle penetration data were not stabilized. Figure 4 shows the fractional penetration for one of the baghouse units tested. Other units exhibited similar characteristics. The initial curve at 25 hours after start shows a fairly high penetration for submicron particles but a low penetration for particles larger than 1 micron in size. However, at later times, the penetration of the larger particles continues to increase. The final penetration distribution may require significantly more time to reach than was available in the earlier tests. The mechanism that causes the increase in large particles downstream is not resolved. If the mechanism could be determined, perhaps a redesign of the unit could help eliminate this potential problem. This trend may also help to explain the larger penetrations measured with the units in the field than with the new units tested in the laboratory.

In summary, a single unit should be tested under a variety of operating conditions for an extended period of time to perform some of the parametric tests suggested here. The results of such a study would provide collector manufacturers and users with considerably more information than currently exists in the literature concerning dust collector operation under conditions that more closely resemble real field experience.

Supporting Studies A number of parameters required in the dust concentration model developed in ASHRAE RP-531 are very loosely determined at the present time. However, these parameters have a strong influence on the final results of the modeling and the conclusions that can be drawn. One such parameter is the dust size distribution and generation rate from the various industrial processes associated with dust collectors. Very little information exists in the literature concerning this topic. A number of field measurements should be undertaken to increase the data base of dust generation processes to make the model more widely applicable.

The associated gases generated in industrial processes should also be considered. A more complete air recirculation model should include both dust and gas concentrations to ensure that all appropriate OSHA and NIOSH indoor limit concentrations are met with a particular air recirculation system.

Hood capture efficiency data are also scarce. The hood capture efficiency was found to be one of the most important parameters in controlling the indoor dust concentration levels when using recirculated air. Different hood designs, airflow rates and particle sizes, and initial particle velocities should be considered.

Dust collectors may not provide adequate worker protection in the case of a filter leak or some other malfunction. The type and location of sensors to detect unacceptable levels of dust should be evaluated. Such sensors could use smoke detector technology for many applications, provided the threshold value was set at an appropriate level. These sensors could be placed in the clean air duct downstream of the collector and could actuate dampers and shutdown procedures.

SUMMARY

This paper summarizes the work performed in ASHRAE RP-531 and presents a number of issues that are not resolved concerning the use of industrial dust collectors in air recirculation systems. Parametric studies of dust collectors and work on other system components, such as hoods and sensors, are outlined. These additional studies would help manufacturers and system designers construct and operate industrial air-cleaning systems that meet applicable OSHA and NIOSH guidelines with a minimum amount of energy use and operating cost.

REFERENCES

Bergin, M. H.; Pui, D. Y. H.; Kuehn, T. H.; and Fay, W. T. 1989. "Laboratory and field measurements of fractional efficiency of industrial dust collectors. *ASHRAE Transactions*, Vol. 95, Pt.2.

Fay, W. T.; Kuehn, T. H.; Pui, D. Y. H.; and Bergin, M. H. 1989. "Dust concentration modeling for industrial operations." *ASHRAE Transactions*, Vol. 95, Pt. 2.

Kuehn, T.H.; Pui, D.Y.H.; Bergin, M.H.; and Fay, W.T. 1989."Dust collector recirculation for industrial processes." Final Report, ASHRAE RP-531.

Liu, B.Y.H.; Pui, D. Y. H.; Schaller, R. E.; McDonald, B. N.; and Johnson, T. W. 1986. "An optical particle counting system for testing industrial pulse-cleaned cartridge dust collectors." *Part. Charact.*, Vol. 3, pp. 68-73.

McDonald, B.N.; Schaller, R.E.; Engel, M.R.; Liu, B.Y.H.; Pui, D.Y.H.; and Johnson, T.W. 1986. "Time resolved measurements of industrial pulse-cleaned cartridge dust collectors. *Fluid Filtration: Gas*, Vol. 1, R. Raber, ed. ASTM STP 975, pp. 241-256.

Phalen, R.F.; Hinds, W.C.; John, W.; Lioy, P.J.; Lippmann, M.; McCawley, M.A.; Raabe, O.G.; Soderholm, S.C.; and Stuart, B.O. 1986. "Rational and recommendations for particle size-selective sampling in the workplace." *Appl. Ind. Hyg.*, Vol. 1, pp. 3-14.

DISCUSSION

G. Smarr, Sunbelt Engineering Group, Atlanta, GA: The efficiency of dust collectors is not 99.99%—it's more like ±95%.

T.H. Kuehn: Dust collectors with clean filters have 95% efficiency; however, the efficiency rapidly improves with loading time. This is due to the additional filtration media provided by the dust cake built up on the clean filter media. We found in our previous study (ASHRAE RP-531) that, after about 100 hours of loading with a calcium carbonate powder, the collection efficiency exceeds 99.99% for a typical cartridge or baghouse dust collector. In eight field measurements, we found that the efficiency varied from 93.6% to 99.9% with an average of 98.1%. The differences may be due to changes in operating parameters, dust types, loading, and problems in installation and maintenance.

C. Clemance, Senior Project Engineer, 3M Canada, Inc., London, Ontario: Were bags inspected physically prior to or after tests for physical defects? Please discuss the use of off-line vs. on-line pulse-cleaning to extend the life of the bags and/or to improve their performance.

Kuehn: Yes, in the laboratory measurements, we were able to inspect the bags before and after tests for physical defects. Unfortunately, we were not allowed to do so in the field measurements. We have no experience in off-line pulse-cleaning, as all the pulse-cleaned units we tested used in-line cleaning. Off-line cleaning has the advantage of reducing the average downstream dust concentration, but may involve longer dwell time or more complex airflow control.