6. Lodge, J.P.; Chan, T.L., Eds.: Cascade Impactor Sampling and Data Analysis. American Industrial Hygiene Association, Akron, OH (1986).
7. Cohen, B.S.; McCammon, C.S.; Vincent, J.H., Eds.: Proceedings of The International Symposium on Air Sampling Instrument Performance. Appl. Occup. Environ. Hyg. 8(4):209–424 (1993).
8. Bartley, D.L.: Inhalable Aerosol Samplers. Appl. Occup. Environ. Hyg. 13(5):274–278 (1998).
9. Woebkenberg, M.L.: Direct-Reading Monitoring Devices for Carbon Monoxide. Appl. Occup. Environ. Hyg. 13(8):567–569 (1998).
10. Harper, M.: Diffusive Sampling. Appl. Occup. Environ. Hyg. 13(11):759–763 (1998).
11. Burroughs, G.E.; Tabor, M.E.: Portable Gas Chromatographs. Appl. Occup. Environ. Hyg. 14(3):159–162 (1999).
12. International Organization for Standardization (ISO): Air Quality—Particle Size Fraction Definitions for Health-Related Sampling. ISO Standard 7708. ISO, Geneva (1995).
13. American Conference of Governmental Industrial Hygienists: Particle Size Selective Sampling for Health-Related Aerosols. ACGIH, Cincinnati, OH (1999).
14. Comité Européen de Normalisation (CEN): Workplace Atmospheres—Size Fraction Definitions for Measurement of Airborne Particles in the Workplace. EN481, CEN, Brussels (1993).
15. Leidel, N.A.; Busch, K.A.: Statistical Methods for the Determination of Noncompliance with Occupational Health Standards. DHEW (NIOSH) Pub. No. 75-159; NTIS Pub. No. PB-83-180-414. National Technical Information Service, Springfield, VA (1975).
16. Leidel, N.A.; Busch, K.A.; Lynch, J.R.: Occupational Exposure Sampling Strategy Manual. DHEW (NIOSH) Pub. No. 77-173; NTIS Pub. No. PB-274-792. National Technical Information Service, Springfield, VA (1977).
17. Taylor, D.G.; Kupel, R.E.; Bryant, J.M.: Documentation of the NIOSH Validation Tests. DHEW (NIOSH) Pub. No. 77-185; NTIS Pub. No. PB-274-248. National Technical Information Service, Springfield, VA (1977).
18. Parker, C.D.; Lee, M.B.; Sharpe, J.C.: An Evaluation of Personal Sampling Pumps in Sub-Zero Temperatures. DHEW (NIOSH) Pub. No. 78-117; NTIS Pub. No. PB-279-615. National Technical Information Service, Springfield, VA (1977).
19. Bissette, L.W.; Parker, D.D.: Evaluation of Batteries Used in Sampling Pumps. Final Report. NIOSH Contract 210-75-0080. NTIS Pub. No. PB-83-109-694. National Technical Information Service, Springfield, VA (1975).
20. Tompkins, F.C., Jr.; Becker, J.H.: Evaluation of Portable Direct-Reading H_2S Meters. Report of NIOSH Contract HEW 210-75-0037. DHEW (NIOSH) Pub. No. 77-137. NIOSH, Cincinnati, OH (1976).
21. Parker, C.D.; Strong, R.B.: Evaluation of Portable, Direct-Reading Carbon Monoxide Meters, Part 1. DHEW (NIOSH) Pub. No. 75-106; NTIS Pub. No. PB-273-870. National Technical Information Service, Springfield, VA (1975).
22. Parker, C.D.; Strong, R.B.: Evaluation of Portable, Direct-Reading Sulfur Dioxide Meters, Part 2. DHEW (NIOSH) Pub. No. 75-137; NTIS Pub. No. PB-273-799. National Technical Information Service, Springfield, VA (1977).
23. Willey, M.A.; McCammon, C.S.: Evaluation of Portable, Direct-Reading Hydrocarbon Meters. DHEW (NIOSH) Pub. No. 76-166; NTIS Pub. No. PB-266-439. National Technical Information Service, Springfield, VA (1977).
24. Woodfin, W.J.; Woebkenberg, M.L.: An Evaluation of Portable, Direct-Reading Oxygen Deficiency Monitors. NTIS Pub. No. PB-85-196-442. National Technical Information Service, Springfield, VA (1985).
25. American National Standards Institute/Instrument Society of America: ANSI/ISA - S92.04.01, Part 1 - 1996, Performance Requirements for Instruments Used to Detect Oxygen-Deficient/Oxygen-Enriched Atmospheres (Standard). ISA, Research Triangle Park, North Carolina (1996).
26. Instrument Society of America: ISA-RP92.04.02, Part II-1996, Installation, Operation, and Maintenance of Instruments Used to Detect Oxygen-Deficient/Oxygen-Enriched Atmospheres (Recommended Practice). ISA, Research Triangle Park, North Carolina (1996).
27. American National Standards Institute/Instrument Society of America: ANSI/ISA - S12.15, Part I - 1990, Performance Requirements for Hydrogen Sulfide Detection Instruments (10-100 ppm) (Standard). ISA, Research Triangle Park, North Carolina (1990).
28. American National Standards Institute/Instrument Society of America: ANSI/ISA - RP12.15, Part II - 1990, Installation, Operation, and Maintenance of Hydrogen Sulfide Detection Instruments (10-100 ppm) (Recommended Practice). ISA, Research Triangle Park, North Carolina (1990).
29. American National Standards Institute/Instrument Society of America: ANSI/ISA - S12.13, Part I - 1995, Performance Requirements, Combustible Gas Detectors (Standard). ISA, Research Triangle Park, North Carolina (1995).
30. American National Standards Institute/Instrument Society of America: ANSI/ISA - RP12.13, Part II - 1995, Installation, Operation, and Maintenance of Combustible Gas Detectors (Recommended Practice). ISA, Research Triangle Park, North Carolina (1995).
31. Instrument Society of America: ISA-dS92.0.01, Part 1, Performance Requirements for Toxic Gas Detection Instruments (Draft Standard), Draft 4, March 1997. ISA, Research Triangle Park, North Carolina (1997).
32. Instrument Society of America: ISA-dRP92.0.02, Part II, Installation, Operation, and Maintenance of Toxic Gas Detection Instruments (Draft Recommended Practice), Draft 3, March 1997. ISA, Research Triangle Park, North Carolina (1997).
33. Instrument Society of America: ISA-dS92.02.01, Part I, Performance Requirements for Carbon Monoxide Detection Instruments (50-1000 ppm Full Scale) (Draft Standard), Draft 6, March 1997. ISA, Research Triangle Park, North Carolina (1997).
34. Instrument Society of America: ISA-dRP92.02.02, Part II, Installation, Operation, and Maintenance of Carbon Monoxide Detection Instruments (50-100 ppm Full Scale) (Draft Recommended Practice), Draft 5, March 1997. ISA, Research Triangle Park, North Carolina (1997).
35. Instrument Society of America: ISA-dS92.06.01, Performance Requirements for Chlorine Detection Instruments (0.5-30 ppm Full Scale) (Draft Standard), Draft 6, March 1997. ISA, Research Triangle Park, North Carolina (1997).
36. American National Standards Institute/The Institute of Electrical and Electronics Engineers: ANSI/IEEE C95.1-1982, American National Standard Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz, p. 10. IEEE, New York (1982).
37. American National Standards Institute: ANSI/ISEA 102-1990, American National Standard for Gas Detector Tube Units—Short Term Type for Toxic Gases and Vapors in Working Environments. ANSI, New York (1990).
38. British Standards Institution: Instruments for the Detection of Combustible Gases, Parts 1 to 5. Document BS6020. BSI, London (1981).
39. European Committee for Electrotechnical Standardisation: Electrical Apparatus for the Detection and Measurement of Combustible Gases. Document EN 50054-58. CENELEC, Brussels (1991).
40. Comité Européen de Normalisation: Workplace Atmospheres—General Requirements for the Performance of Procedures for the Measurement of Chemical Agents. EN 482. CEN, Brussels (1994).

41. Comité Européen de Normalisation: Workplace Atmospheres—Requirements and Test Methods for Diffusive Samplers for the Determination of Gases and Vapours. EN 838. CEN, Brussels (1995).
42. Comité Européen de Normalisation: Workplace Atmospheres—Requirements and Test Methods for Pumped Sorbent Tubes for the Determination of Gases and Vapours. EN 1076. CEN, Brussels (1997).
43. Comité Européen de Normalisation: Workplace Atmospheres—Requirements and Test Methods for Short Term Detector Tube Systems. EN 1231. CEN, Brussels (1996).
44. Comité Européen de Normalisation: Workplace Atmospheres—Requirements and Test Methods for Pumps for Personal Sampling of Chemical Agents. EN 1232. CEN, Brussels (1997).
45. Comité Européen de Normalisation: Workplace Atmospheres—Assessment of Performance of Instruments for Measurement of Airborne Particle Concentrations. prEN13205. CEN, Brussels (1999).
46. Comité Européen de Normalisation: Workplace Atmospheres—Measurement of Chemical Agents as Mixtures of Airborne Particles and Vapours—Requirements and Test Methods. CEN/TC137/WG3/N209. CEN, Brussels (2000).
47. U.S. Congress: Titles I, II, III, and IV of the Clean Air Act as Amended in 1990. Public Law 101-549. Washington, DC (November 15, 1990).
48. U.S. Environmental Protection Agency: Revised Requirements for Designation of Reference and Equivalent Methods for $PM_{2.5}$ and Ambient Quality Surveillance for Particulate Matter; Final Rule, 40 CFR Part 53. Fed. Reg. 62: 38763–38854 (1997).
49. Organisation Internationale De Metrologie Legale: OIML International Document D 22, Guide to Portable Instruments for Assessing Airborne Pollutants Arising from Hazardous Wastes. OIML, Paris (1991).
50. Comité Européen de Normalisation: Council Directive 96/62/EC on Ambient Air Quality Assessment and Management (1996).
51. International Electrotechnical Commission: IEC Publication 761-1: 1983, Equipment for Continuously Monitoring Radioactivity in Gaseous Effluents, Part 1: General Requirements. IEC Geneva (1983).
52. International Electrotechnical Commission: IEC Publication 761-2: 1983, Equipment for Continuously Monitoring Radioactivity in Gaseous Effluents, Part 2: Specific Requirements for Aerosol Effluent Monitors. IEC Geneva (1983).
53. International Electrotechnical Commission: IEC Publication 761-3: 1983, Equipment for Continuously Monitoring Radioactivity in Gaseous Effluents, Part 3: Specific Requirements for Noble Gas Effluent Monitors. IEC Geneva (1983).
54. International Electrotechnical Commission: IEC Publication 761-4: 1983, Equipment for Continuously Monitoring Radioactivity in Gaseous Effluents, Part 4: Specific Requirements for Iodine Monitors. IEC Geneva (1983).
55. International Electrotechnical Commission: IEC Publication 761-5: 1983, Equipment for Continuously Monitoring Radioactivity in Gaseous Effluents, Part 5: Specific Requirements for Tritium Monitors. IEC Geneva (1983).
56. International Electrotechnical Commission: IEC Publication 761-6: 1991, Equipment for Continuously Monitoring Radioactivity in Gaseous Effluents, Part 6: Specific Requirements for Transuranic Aerosol Effluent Monitors. IEC Geneva (1991).
57. U.S. Environmental Protection Agency: National Ambient Air Quality Standards for Particulate Matter; Final Rule. Fed. Reg. 62: 38651–38701 (1997).
58. U.S. Environmental Protection Agency: Revisions to the National Ambient Air Quality Standards for Particulate Matter. Fed. Reg. 52:24634–24750 (1987).
59. International Standards Organisation: ISO 2889: 1975, General Principles for Sampling Airborne Radioactive Materials. ISO, Geneva (1975).
60. Mobil Europe Limited: The Mobil Survey (Fifth Cycle) of ISO 9000 and Environmental Certificates Awarded Worldwide. London (August 6, 1996).
61. International Standards Organisation: ISO 8402:1994, Quality Management and Quality Assurance—Vocabulary. ISO, Geneva (1994).
62. Riswadkar, A.V.: ISO 9000, A Global Standard for Quality. Professional Safety, pp. 30–32 (April 1995).
63. Hansen, M.: ISO 9000: Effect on the Global Environmental Safety & Health Community. ASSE, pp. 44–47 (June 1994).
64. Sharifian, A.R.: Reap the Benefits of ISO 9000: Environmental Health and Safety Thrive under Global Standards. Safety and Health, pp. 68–71 (April 1995).
65. Blondin, R.: ISO 9000: The Health and Safety Connection. Accident Prevention, pp. 12–18 (September/October 1993).
66. Allen, H.: ISO 9000 Paves the Way to Global Safety. Safety and Health, pp. 33–37 (March 1994).
67. Mansdorf, Z.: The ISO Man Cometh: Moving the Global Standards. Occup. Hazards, pp. 43–46 (May 1995).
68. Dyjack, D.T.; Levine, S.P.: Development of an ISO 9000 Compatible Occupational Health Standard: Defining the Issues. Am. Ind. Hyg. Assoc. J. 56: 599–609 (1995).
69. Levine, S.P.; Dyjack, D.T.: Development of an ISO 9000-Compatible Occupational Health Standard–II: Defining the Potential Benefits and Open Issues. Am. Ind. Hyg. Assoc. J. 57: 387–391 (1996).
70. British Standards Institution: BS 8800:1996: Guide to Occupational Health and Safety Management Systems. London, United Kingdom (1996).
71. American Industrial Hygiene Association: AIHA Occupational Health and Safety Management System (OHSMS) and Guidance Document. AIHA Fairfax, VA. (May 1996).
72. International Standard Organisation: ISO 9001:1994, Quality Systems—Model for Quality Assurance in Design, Development, Production, Installation and Servicing. ISO, Geneva (1994).
73. International Standard Organisation: ISO 9002:1994, Quality Systems—Model for Quality Assurance in Production, Installation and Servicing. ISO, Geneva (1994).
74. International Standard Organisation: ISO 9003:1994, Quality Systems—Model for Quality Assurance in Final Inspection and Test. ISO, Geneva (1994).
75. International Standard Organisation: ISO 9004-1:1994, Quality Management and Quality System Elements—Part 1: Guidelines. ISO, Geneva (1994).
76. International Standard Organisation: ISO 9004-2:1991, Quality Management and Quality System Elements—Part 2: Guidelines for Services. ISO, Geneva (1991).
77. International Standard Organisation: ISO 9004-3:1993, Quality Management and Quality System Elements—Part 3: Guidelines for Processed Materials. ISO, Geneva (1993).
78. International Standard Organisation: ISO 9004-4:1993, Quality Management and Quality System Elements—Part 4: Guidelines for Quality Improvement. ISO, Geneva (1993).
79. Scott, G.C.; Whitehead, G.M.: Products Liability and Proper Implementation of ISO 9000. Hazard Prevention 29:24–26 (Second Quarter, 1993).
80. Kinder, D.: Process Safety Management: OSHA Standard Parallels Global Quality Efforts. Occup. Health Safety, pp. 47–52 (October 1994).
81. Kozak, B.; Clements, R.: Build Safety into Your ISO 9000 Program. ASSE, pp. 31–32 (September 1995).

Chapter 12

Air Movers and Samplers

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CONTENTS

Introduction

Active air sampling for airborne contaminants requires a system for moving air, a collection method, and a procedure to determine the quantity of contaminant collected. Because occupational exposure limits and air quality standards frequently are expressed in terms of concentrations, a method of determining the volume of air sampled is also needed.

The four principal components in a sampling train are shown in Figure 12-1. The inlet admits the air sample into the train; the collector(s) separates the gas, vapor, or aerosol from the air; the flowmeter measures the rate or total quantity of air sampled; and the pump (air mover) provides the suction required to draw an air sample through the train. Inlet sampling considerations are discussed in Chapter 20. Various types of collectors are described in subsequent chapters. Flowmeters are discussed in Chapter 7.

This chapter will describe the air mover portion of the sampling train and air sampling systems that contain three or four components in a convenient package. The chapter consists of two parts. The first part contains a brief description of the different types of air movers and air sampling systems. The descriptions of air movers have remained the same from previous editions but the air sampling systems have changed considerably over the last decade. New information on these types of samplers is included. The second part consists of tables and figures showing detailed information on a wide variety of commercially available air movers and sampling systems.

The experienced reader may want to proceed directly to the technical data tables that describe the types of air movers or samplers of interest. Students and others may find the basic descriptions of the different types of air movers informative. For the reader faced with the task of choosing or purchasing the most appropriate air sampling system, the Guide to the Selection of an Air Mover or Sampler beginning on page 9 will be helpful.

Air Movers

Air movers are classified according to the means by which an air flow is induced. These fall into three basic groups: volumetric displacement, centrifugal force (or acceleration), and momentum transfer. The following sections briefly describe the operating principles and salient features of many types of air movers within each of these three basic classifications. In particular, Tables 12-1 to 12-5 at the end of this chapter list characteristics for five different types of commercially available air movers. These are:

1. Diaphragm pumps
2. Piston pumps
3. Rotary vane pumps
4. Blowers
5. Ejectors

Information presented in these tables includes the source code, pump model number, dimensions, weight, maximum air flow rate, and motor power requirements. The source code can be used in conjunction with Table 12-11 to determine the company name, address, and telephone number.

Volumetric Displacement

One method of producing movement of a given volume of air is to displace it, either by mechanical means, or by use of a second volume of gas. This principle is the basis of operation for a diverse group of air movers.

Air Displacement

One type of air displacement collector is an airtight flask or rigid-walled vessel in which a hard vacuum has been created. When the vessel is opened at the sampling location, a sample, which is often called a grab sample, that is equal in size to the free volume of the vessel is almost instantaneously collected. The most admirable feature of such a device is its simplicity. Its use is limited mainly by sample size restrictions. Also, care must be taken to prevent loss of vacuum before sampling. For practical purposes, sample size is limited by the portability of the flask, with a normal upper range of approximately 1 to 2 liters. Additional descriptions of this method, the equipment and a list of commercial sources are provided in Chapter 16.

This procedure is not limited to simple collection of air samples for subsequent gaseous analysis. The evacuated flask may contain an absorbing solution in which the desired component of the grab sample may be concentrated for analysis by wet chemical methods. For example, the U.S. Environmental Protection Agency (U.S. EPA) test method for "Determination of Nitrogen Oxide Emissions from Stationary Sources"(1) uses evacuated flasks containing a dilute sulfuric acid-hydrogen peroxide absorbing solution (U.S. EPA Appendix Method 7; see Table 20-7).

Air displacement samples can also be collected without prior evacuation of the flask by simply displacing the air in the flask with sample air. In this case, the flask should be flushed with at least 5-10 volumes of sample air before being sealed, so that the clean air initially inside is displaced completely.

A related method somewhat overcomes the portability problem and allows collection of much larger samples. The collecting vessel is a plastic bag. If it is mounted within a rigid outer container, it can be filled by creating a slight vacuum in the space around the bag. If it is used without an airtight outer container, it can be filled by directly pumping air into the bag, provided that the material being sampled is not absorbed or altered when passing through the pump. Commercial plastic bags are available in a variety of sizes up to 0.3 m^3 and come equipped with several types of leak-proof valves. A list of commercial sources can be found in Chapter 16.

The sample bag method is particularly useful for contaminants that can be analyzed by infrared spectroscopy or gas chromatography. Different types of plastics have been studied for use in this fashion, with the

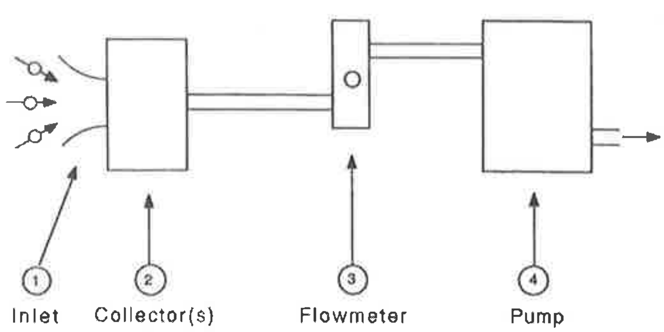

FIGURE 12-1. Principal components of sampling train.

relatively nonreactive fluorocarbons currently in favor. If the bag is to be used for aerosols, it should be foil-lined or have a conductive surface and be grounded. Unless the interaction of the contaminant of interest with the plastic bag, or the possible permeability of the contaminant through the bag, is known or is at least predictable, such bags should be used only for semiquantitative identification. For example, data on such wall losses have been discussed by Posner and Woodfin.[2]

Liquid Displacement

The evacuated flask normally is prepared in the laboratory and carried to the field. A similar method, which can be prepared in the field but does not require a pump, is liquid displacement. A vessel of any convenient size is filled with a liquid in which the suspected contaminant is insoluble. When the liquid is allowed to escape from the vessel, it is replaced by air from the atmosphere to be sampled. Such an air sample is an integrated sample rather than an instantaneous sample because the mass of fluid requires a finite time to empty. In fact, by employing a large vessel with controlled drainage, this method can be used to move air at low flow rates through a sample collector for extended intervals. Additional discussion of this method can be found in Chapter 16.

Diaphragm Pumps

A diaphragm pump, as shown in Figure 12-2, is a device in which a flexible diaphragm of metal or elastomeric material is moved back and forth. The diaphragm is clamped between the pump head and housing, forming a leak-tight seal between the pump chamber and the crankcase. Through the action of a rod or yoke, air in the chamber is displaced on one side of the diaphragm. By using a suitable arrangement of one-way check valves, a variable vacuum is produced in the chamber on the other side of the diaphragm. Mechanical damping is required for more uniform suction. Diaphragm pumps are fairly simple in construction and are used commonly in personal sampler pumps. Diaphragm pumps are oil-free and available in corrosion-resistant materials. They provide contamination-free pumping. Table 12-1 summarizes the characteristics of some commercially available diaphragm-type air movers.

Piston Pumps

Piston pumps are related to diaphragm pumps in that both use a mechanical reciprocating action to provide the motive force. In the piston pump, the piston oscillates in a cylinder equipped with inlet and outlet valves. Because the piston can displace a greater proportion of the air in the chamber above it, piston pumps can provide greater differential pressure or vacuum. In either case, a surge chamber usually is required to smooth out irregularities in flow. In multiple-piston pumps, these irregularities are small and sometimes can be ignored. One new version of the piston pump is the linear-motor-driven free piston, as illustrated in Figure 12-3. This pump uses an electromagnet and return spring to alternately drive the reciprocating free piston. This design results in a compact structure, less vibration, and quieter operation than the conventional piston pump. It also has an oil-less construction. Table 12-2 summarizes the characteristics of some commercially available piston-type air movers.

Rotary Vane Pumps

Rotary vane pumps are used extensively as air movers for portable sampling instruments. There are two basic variants, both having the same operating principle. A rotor revolves eccentrically in a cylindrical housing, with multiple blades on the rotor providing the air-moving drive. Centrifugal force (or springs) keeps the outer edges of the blades in contact with the housing. However, because the rotary motion is eccentric, the vanes must be movable to retain constant contact. One common method is to place the vanes in slots in the rotor (see Figure 12-4). This guided or sliding vane type usually operates at fairly high speeds and it is subject to wear on the blade edge that contacts the casing. Such wear may lead to leakage and reduce capacity. Table 12-3 summarizes the characteristics of some commercially available rotary vane pumps.

Rotary vane pumps, as well as piston pumps, usually are available either in oil-less or lubricated models. In some air sampling procedures, concern may arise about generating contaminants with the sampling apparatus

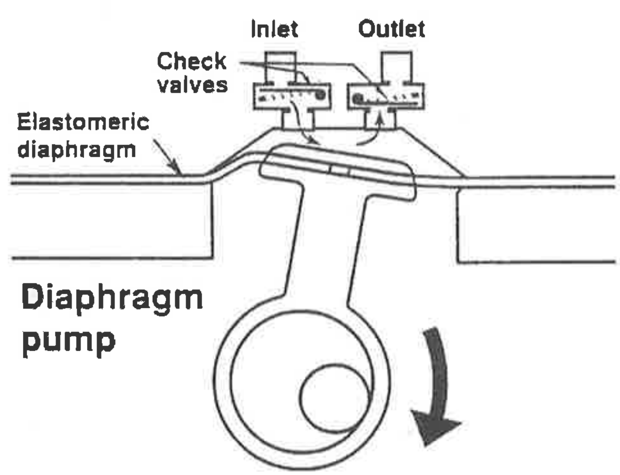

FIGURE 12-2. Schematic diagram of diaphragm pump *(KNF Neuberger)*.

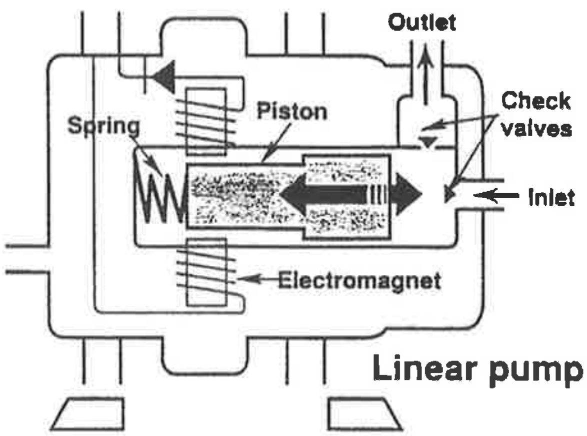

FIGURE 12-3. Schematic diagram of linear-motor-driven free piston pump *(KNF Neuberger).*

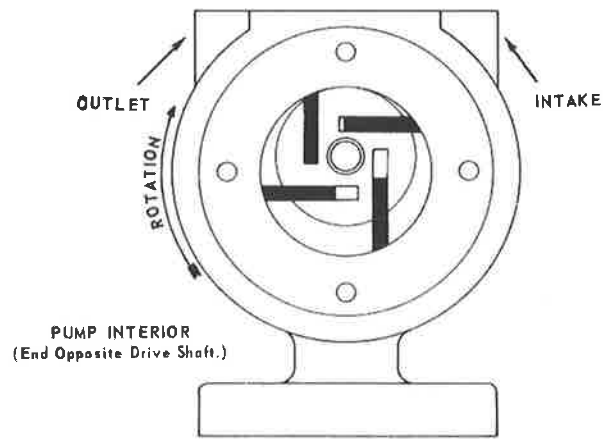

FIGURE 12-4. Schematic diagram showing principle of sliding vane pump operation.

itself. Lubricated pumps can introduce oil mists into the sample if the sample passes through the pump, or if the pump exhaust is resampled. Non-lubricated pumps, which frequently use graphite rings or vanes, can produce carbon dust that may also be an undesirable contaminant. The selection of pump must be based, in part, on the specific air sampling intended.

Gear Pumps

The gear pump is another type of positive displacement air mover. Like a vane pump, it usually is valveless and operates on a rotary principle. The typical gear pump has two shafts, each with a gear. The gears mesh on the interior side and contact the semi-cylindrical casing on the exterior side. The large number of teeth in contact with the outer surface reduces peripheral leakage.

Lobe Pumps

Lobe pumps are similar to gear pumps but use two counter-rotating impellers instead of meshing gears. The impellers can be either a two-lobed, figure-eight-shaped design (see Figure 12-5) or a three-lobed design. As each impeller passes the blower inlet, a volume of gas is trapped, carried through to the blower discharge, and expelled against the discharge pressure. As a result, the volumetric capacity varies little with changes in pressure. Lobe pumps with volumetric capacities from 0.3 to 100 m^3/min. are available.

Hand-Operated Air Movers

Hand-operated air movers include manually actuated piston pumps, bellows pumps, and squeeze bulbs. The piston principle has been employed in several hand-operated air movers. The most familiar of these is the hypodermic syringe, which is used in several commercial instruments and in countless homemade systems. A similar air mover is the hand-operated piston. For industrial hygiene purposes, it is usually calibrated carefully to provide an accurate air volume. This type of pump is often used with direct-reading colorimetric indicators as described in Chapter 17.

Squeeze bulbs or small bellows pumps have been used commonly as air movers on commercial air sampling devices, such as the direct-reading indicator tubes described in Chapter 17, and on several models of combustible gas meters, described in Chapter 18. Squeezing the bulb or bellows expels air through a one-way valve; the subsequent self-expansion of the bulb or bellows allows air to be drawn through the detector. With bulbs, the amount of air drawn by a single bulb compression varies according to the efficiency with which the air was expelled from the previous volumetric stroke. This variation may result in serious errors because the calibrations are based on sampling a constant volume of air. Possible sample size variation is less important in combustible gas meters, which indicate the concentration within the sensing zone (i.e., they are not integrating devices).

An example of a squeeze bulb application is found in the U.S. EPA test method for "Gas Analysis for Carbon Dioxide, Oxygen, Excess Air, and Dry Molecular Weight."(1) This method offers a choice of grab sampling with a one-way squeeze bulb, or integrated sampling with a leak-free pump (U.S. EPA Appendix Methods 3 and 3A; e.g., see Tables 20-7 and Figure 20-9A).

Centrifugal Force

A second basic method of inducing air movement is to produce kinetic energy by means of centrifugal force, with conversion of the resulting velocity pressure to

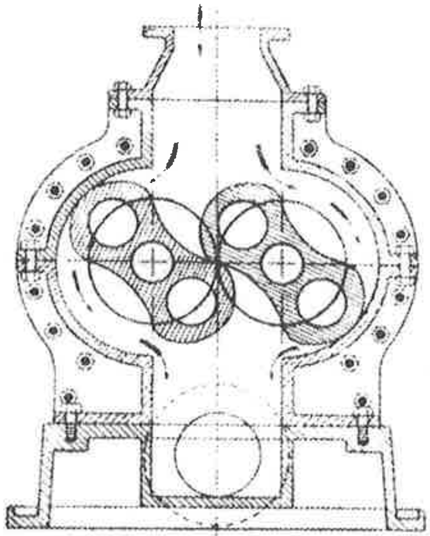

FIGURE 12-5. Schematic diagram showing principle of operation of twin-lubed positive displacement blower.

suction for moving the sampled air. Centrifugal fans that use this approach consist of an impeller and stationary casing, the impeller being a rotary device with vanes. There are two major types of centrifugal fans, either radial flow or axial flow, depending on the direction of air flow through the impeller. Table 12-4 summarizes the characteristics of commercially available centrifugal fans.

Radial-Flow Fans

The term centrifugal fan (or blower), while connoting all types of fans, usually is used in a restrictive sense to indicate just radial-flow fans. These fans are available in three basic types, differentiated by the direction of blade curvature at the delivery edge (see Figure 12-6).

The first of these types is the forward-curved blade fan which has its blade tips curved in the direction of fan rotation. This design usually is more compact, operates at low speeds with less noise than other types, and has a lower initial cost. It is relatively inefficient and not capable of producing high static pressures or high vacuums. These fans are found typically in comfort ventilation systems that have low static pressure or vacuum requirements and where low noise levels are desirable.

The second type is the radial blade fan in which the blades are straight and are aligned along the radii of the fan. This is similar to the old style straight (or paddle-wheel) blade, but the radial blade fan is more compact in design, capable of higher rotational velocity, and slightly more efficient. This type of fan is less prone to clogging than the other types and therefore finds application in systems that handle high particulate mass loads. Unlike the forward-curved fan, radial blade fans operate well in parallel and can produce relatively high static pressures or vacuums.

The third type of centrifugal fan, the backward-curved blade fan, is characterized by blades that curve away from the direction of rotation. Such fans are highly efficient and, because of their high speed capability, are particularly well suited to use with electric motor drives. This type of fan has a distinct advantage over the other two types in that it is difficult to overload the backward-curved fan. Its power requirement peaks at its normal design loading, whereas the power requirements of each of the other types of centrifugal fans continue to increase with increasing flow volume requirements. The disadvantages of this fan design are relatively high noise levels and high susceptibility to clogging.

The backward-curved fan blade is used in several high-volume air samplers. The usual design is to use a 1/2- to 1-horsepower electric motor (AC or DC) to drive a two-stage turbine impeller. (Multiple-staging is required to increase suction.) The exhaust (sampled) air is often used to cool the motor, which imposes a lower flow-rate limit. Some units have separate cooling fans for the motor and therefore can be used with high-resistance filters at lower flow rates. Some representative types of this kind of blower are described in Table 12-4.

Axial-Flow Fans

Axial-flow fans also come in three types: propeller, tube-axial, and vane-axial. These types are named in increasing order of complexity, weight, cost, and static pressure.

The propeller fan is the most common. The fan blades are carried on a small hub in which the motor is often mounted. It can provide high flow volumes and usually operates at or near ambient static pressures. This type of fan is used on some electrostatic precipitator samplers (see Chapter 14), where the flow resistance is both very low and constant.

The tube-axial fan is a propeller fan enclosed in a short cylinder. The fan blades are mounted on a central ring slightly larger than the average propeller fan hub. This unit can operate at moderate static pressures.

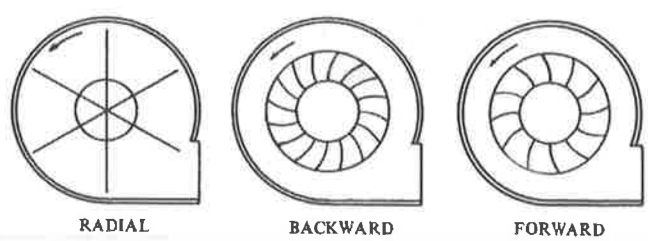

FIGURE 12-6. Curvature of centrifugal fan blades.

The vane-axial fan is a further modification of the tube-axial. It has the same parts, but the cylinder is slightly longer. The extra length accommodates a set of guide vanes that serve to convert the useless tangential velocity component of the discharge into useful static pressure. Vane-axial fans can be either single or multiple stage. In general, vane-axial fans can operate at much higher pressures than tube-axial fans. Because of the high fan speed, the vane-axial fan is sensitive to abrasion of the blades and thus should be used only to move clean air.

Momentum Transfer

A third basic method of inducing air movement is to transfer the momentum of one fluid to another. This process is relatively inefficient, but the equipment involved is very simple and reliable and, in certain cases, particularly well suited for portable sampling units because it does not need electrical power for operation. It has the added advantage of being useful in potentially explosive atmospheres.

A mechanism that utilizes this principle is called an ejector. An ejector consists of a source of high pressure primary fluid, a nozzle, a suction chamber containing a secondary fluid, and a diffuser tube (see Figure 12-7). The primary fluid enters the suction chamber at very high velocity, entraining the available secondary fluid in the chamber and carrying it through the diffuser. It is discharged at a pressure higher than that of the suction chamber. The entrainment of suction chamber secondary fluid reduces the pressure in the chamber and subsequently causes entrainment of the remaining secondary fluid (sampled air).

The driving medium can be steam, high pressure air, water, or any compressible gas. For portable units, a small can of refrigerant can be used to power a compact, low-volume sampler. Mercury or oil diffusion pumps are sometimes used to obtain the optimum vacuum for the transfer of organic fractions from the sampling apparatus to the analytical instruments. Characteristics of some small, commercially available ejector air movers are summarized in Table 12-5.

Air Samplers

The previous discussion has been concerned solely with air movers, with minimum attention to the other three components of the sampling train illustrated in Figure 12-1. An air sampler combines all four functions in a convenient package and is widely used in industrial hygiene practice and indoor or ambient air sampling. Many commercial varieties of air samplers are available, employing many of the air moving devices previously

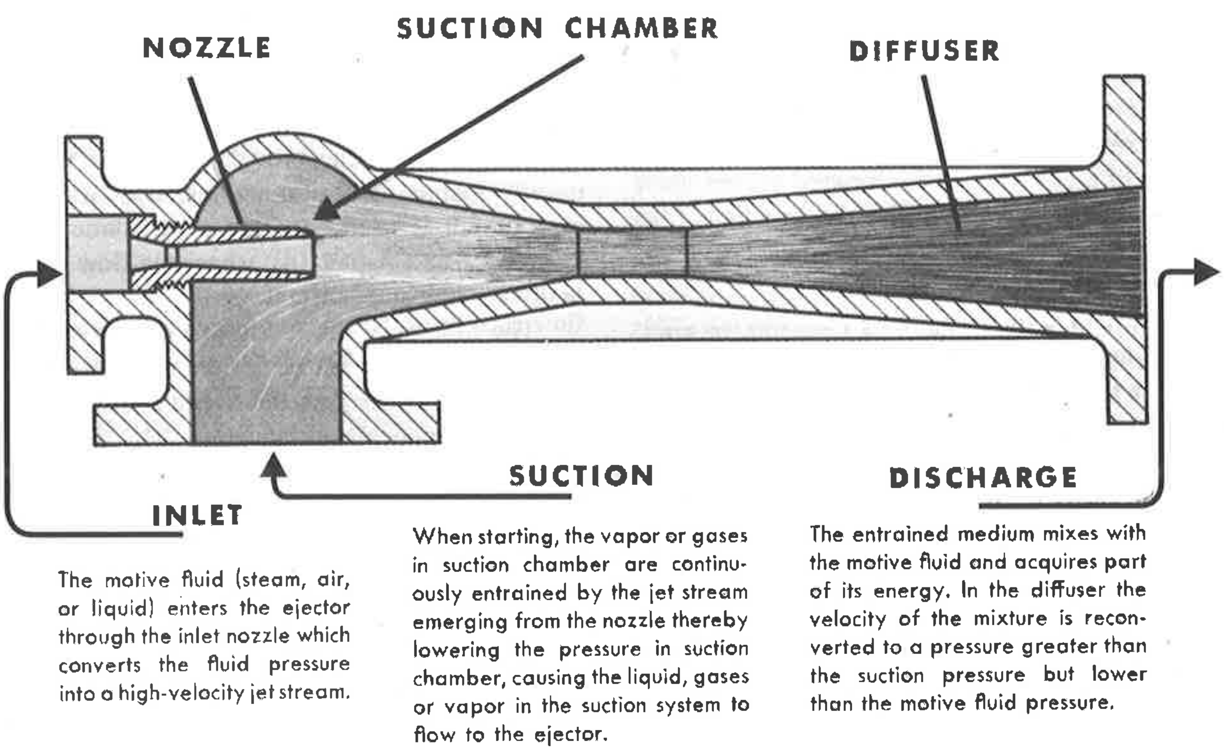

FIGURE 12-7. Schematic di

discussed. Tables 12-6 through 12-10 list characteristics of several classes of commercial air samplers. Table 12-11 provides a list of the commercial sources for the air movers and samplers.

Over the last two decades personal sampling pumps have developed into one of the most used tools of the industrial hygienist and environmental evaluator. The pumps have become smaller, more reliable and more versatile. From large bulky pumps to the now small inconspicuous models, the newer pumps can be calibrated and controlled by internal programs. Feedback control by pressure sensors or by mass flow controllers has advanced their use and application. Multiple flow ranges for manufactured lines of pumps have broadened their use to cover practically all needs for low to medium high flow range: from a few milliliters per minute to 10-20 liters per minute. Pump manufacturers have responded to the requirements for indoor air sampling from the low flow over the long term and up to high flow for shorter term environmental sampling. One can now select the sampling pump for a specific purpose by balancing the features desired against the budgetary limitations: for example, the need for many low priced simple pumps vs. a few more expensive smart pumps.

Categories of Samplers

The listing of samplers presented in Tables 12-6 to 12-10 has been divided into five categories based on the sampling flow rate, source of power, sampler size, and primary application of the sampler. These categories are:

1. Personal sampler: battery powered
2. Low-volume area samplers: battery powered
3. Low-volume area samplers: portable
4. Medium and high volume samplers: portable
5. High volume samplers: with shelters

Flow Range for Each Category

Personal Samplers and Low Volume Area Samplers. Personal samplers generally operate at a sampling air flow rate of up to 5 L/min. and are intended for personal exposure monitoring. Low-volume area samplers typically operate at flow rates in the 3-100 L/min. range. Medium and high volume samplers generally operate at flow rates from 0.1 to 0.3 m^3/min. and 0.3 to 3 m^3/min., respectively, and are most often used for ambient air sampling.

Types of Air Movers for Each Category

Information presented in Tables 12-6 to 12-10 includes the source code, model number, dimensions, weight, air flow-rate range, type of flowmeter, standard sampling attachments (inlets or collection devices), and motor power requirements. The source code can be used in conjunction with Table 12-11 to determine the company name, address, and telephone number.

Many of the air samplers listed in Tables 12-6 to 12-10 are designed to be used in conjunction with a variety of sampling inlets or sample collection devices. The air samplers are not sample collectors by themselves, but provide the air flow through the collectors. Several of the commonly used inlets and collection devices associated with these samplers are listed in these tables. For example, personal sampling pumps are used with charcoal and other sorbent tubes, filters, bubblers, cyclone-filter assemblies for respirable dust sampling, and gas collection bags. Medium- and high-flow area samplers are often used with PM_{10} or $PM_{2.5}$ inlets or collection devices. PM_{10} and $PM_{2.5}$ inlets or collection devices remove particulate matter greater than 10 or 2.5 micrometers, respectively. Detailed discussions of these inlets and devices are provided in later chapters.

A variety of air movers (pumps) are used in the samplers listed in Tables 12-6 to 12-10. Diaphragm pumps are generally used in personal sampler pumps. Low-volume area samplers usually use rotary vane, piston, or diaphragm pumps. Blowers are primarily used in medium- and high-volume samplers.

Flow Measurement in Personal Samplers

Flowmeters are frequently incorporated into the design of the samplers listed in Tables 12-6 to 12-10. The most commonly used integral flowmeters are either a rotameter or a calibrated orifice plate. Numerous other external flow meters such as the soap bubble meter and electronic flow meters can be used to set and calibrate the flow rate. To achieve reliable results from such instruments, a basic understanding of the limitations of these flow measuring devices is necessary. Procedures for calibrating air sampling flowmeters are discussed in Chapter 7.

Rotameters

A rotameter consists of a float inside a tapered vertical tube; the tube cross section increases in area from bottom to top. The position of the float in the tube is governed by establishing an equilibrium between the weight of the float and the force exerted on the float by the velocity pressure of the fluid or gas flowing through the annular space between the float and the tube wall. With [illegible]d the annular area