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ASHV-7

HEATING VENTILATING AIR CONDITIONING GUIDE 1944

AN INSTRUMENT OF SERVICE PREPARED FOR THE PROFESSION—CONTAINING A

Technical Data Section

OF REFERENCE MATERIAL ON THE DESIGN AND SPECIFICATION OF HEATING,
VENTILATING AND AIR CONDITIONING SYSTEMS BASED ON—THE TRANS-
ACTIONS—THE INVESTIGATIONS OF THE RESEARCH LABORATORY AND CO-
OPERATING INSTITUTIONS—AND THE PRACTICE OF THE MEMBERS AND
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CHAPTER 28

Air Pollution

Classification of Air Impurities, Dust Concentrations, Air Pollution and Health, Occlusion of Solar Radiation, Smoke and Air Pollution Abatement, Dust and Cinders, Nature's Dust Catcher

THE particulate impurities which contribute to atmospheric pollution include carbon from the combustion of fuels, particles of earth, sand, ash, rubber tires, leather, animal excretion, stone, wood, rust, paper, threads of cotton, wool, and silks, bits of animal and vegetable matter, and pollen. Microscopic examination of the impurities in city air shows that a large percentage of the particles are carbon.

CLASSIFICATION OF AIR IMPURITIES

The most conspicuous sources of atmospheric pollution may be classified in various ways, as dusts, fumes and smoke. In Fig. 1, the classification is by particle size, but recent practice favors differentiation by method of formation. Thus, *dusts* are composed of particles produced by disintegration of larger material, as by crushing or grinding, whereas *fumes* are produced by condensation, and *smoke* consists of the finer carbon particles resulting from incomplete combustion. Similarly, *mists* are formed by the breaking up of liquids and *fogs* by condensation of vapors. There is as yet, however, no general agreement on these terms.

Dusts tend to settle without agglomeration, fumes to aggregate and smoke to diffuse. Particles which approach the common bacteria in size—from 1 to 10 microns—are difficult to remove from air and are apt to remain in suspension unless they can be agglomerated by artificial means. The term fly-ash is applied to solid ashy material, usually finely divided, that is a constituent of the effluent gases from coal-fired furnaces. Cinders denote the larger solid constituents which may be entrained by furnace gases.

Particles larger than 10 microns are unlikely to remain suspended in air currents of moderate strength, but settle out by gravity at speeds dependent upon the shape, size and specific gravity of the particle and upon the wind velocity. These larger particles are of major interest to the engineer in the solution of nuisance problems; on the other hand, it is mainly the smaller particles that are of hygienic significance. A notable exception to this size limitation in the latter case is the common hay-fever producing pollen such as that from ragweed. Pollen grains may be anything from fragments 15 microns or less in diameter to whole pollens 25 microns or more in size.

CHAPTER 40

Industrial Exhaust Systems

Classification of Systems, Hood Design Principles, Requirements for Suction and Velocity, Duct System Design, Collectors, Resistance of System, Efficiency of Exhaust Systems, Types of Fans, Protection Against Corrosion

IN many industries some type of exhaust system designed to collect and remove dusts and fumes is essential to the efficiency, economy, and safety of operation. General design information is included in this chapter which is intended to relate primarily to industrial exhaust systems.

CLASSIFICATION OF SYSTEMS

In general there are two basic layouts of exhaust systems, the central and the multiple unit system. In the central system a fan is located near the center of operations with a piping system radiating to the various machines to be served. In the multiple unit system, which is sometimes employed where the machines to be served are widely scattered, or where the operations are apt to be independent or intermittent, small individual exhaust fans are located at the center of the machine groups or at each machine. The unit arrangement has the advantage of flexibility.

Exhaust systems are also classified by the means employed to collect the material. The dust or refuse may be collected and controlled by enclosing hoods or open hoods with positive inward air movement or by exhausting the general air of the room. With some classes of machinery it is not feasible to hood the machines closely and in these cases open hoods over or adjacent to the machines are provided to collect as much as possible of the dust and fumes. This class includes such machines as rubber mills, package filling machinery, sand blast, crushers, forges, pickling tanks, melting furnaces, and the unloading points of various types of conveyors.

The open hoods should be placed as close to the source of dust or fumes as possible, with due regard to the movements of the operator and should be placed so that the operator is in no case in the path of the exhausted material. When the hood must be placed at some distance above the machine it should be large enough to cover a large area as diffusion is usually quite rapid.

Some consideration should be given to the natural movement of the fumes. For those that are lighter than air, the hood may be over or above

the machine; and where a heavy vapor, or dust-laden air at ordinary temperature is to be removed, horizontal or floor connections are sometimes preferable. In many cases there are convection currents and other atmospheric disturbances in the work room which should be given consideration. These disturbances diminish the tendency of dusts and fumes to settle from the room air because of their density.

In another class of operation the main objective is to prevent the escape of dust into the surrounding atmosphere, the removal of some dust from the machine or enclosure being merely incidental. The dust-creating apparatus is enclosed within a housing which is made as tight as practicable, and sufficient suction is applied to the enclosure to maintain an inward air leakage, thus preventing escape of the dust. While the exhaust system is required to handle only the air which leaks in through the crevices and openings in the enclosure, yet in many installations leakages are very high and great care is required to obtain satisfactory results with a system of this kind. The inward-leakage principle is utilized for controlling dust in the operating of tumbling barrels, grinding, screening, elevating, and similar processes.

Certain dust and fume producing operations are best carried on by isolating the process in a separate compartment or room and then applying general ventilation to this space. The compartment or room in which the work is performed should be as small as is consistent with convenience in handling the work. The ventilating system should be designed so that a current of clean air is drawn across the work in such a manner as to carry the dust or fume away from the operator and out of the work space. Another method of accomplishing the control of this type of installation is the dilution method. In this case sufficient clean air is introduced generally into the work space to dilute the contamination to a safe level.

HOOD DESIGN PRINCIPLES

The first step in the design of an exhaust system is to determine the number and size of the hoods and their connections. No general rules, however, can be given since hood and duct dimensions are determined by the characteristics of the operations to which they are applied. When a tentative decision regarding the set-up has been made, it is then necessary to obtain the suction and air velocities required to effect control. At this point the designer must rely upon the prevailing practice and on such physical data relating to hoods, duct systems and collectors as are available. The fan speed must be sufficient to maintain the estimated suction and air velocities in the system. In general, the most important requirements of an efficient exhaust and collecting system are¹:

1. Hoods, ducts, fans, motors and collectors should be of adequate size and type.
2. The air velocities should be sufficient to control and convey the materials collected.
3. The hoods and ducts should be placed so as not to interfere with the operation of a machine or any working part.
4. The system should do the required work with a minimum power consumption.

¹For more detailed requirements refer to Fundamentals Relating to the Design and Operation of Exhaust Systems, 29-1936 (American Standards Association), Industrial Code Bulletin Nos. 10 and 12 (New York State Labor Department), Principles of Exhaust Hood Design, by J. M. DallaValle (U. S. Public Health Service, 1939).

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5. When inflammable dusts and fumes are conveyed, the piping should be provided with an automatic damper in passing through a fire-wall.

6. Ducts and all metal parts should be grounded to reduce the danger of dust explosions by static electricity.

7. The design of an exhaust system should afford easy access to parts for inspection and care.

REQUIREMENTS FOR SUCTION AND VELOCITY

The removal of dust or waste by means of an exhaust hood requires a movement of air at the point of origin sufficient to carry it into a collecting system. The air velocities necessary to accomplish this depend upon the physical properties of the material to be eliminated and the direction and speed with which it is thrown off. If the dust to be removed is already in motion, as is the case with high-speed grinding wheels, the hood must be installed in the path of the particles so that a minimum air volume may be used effectively. It is always desirable to design and locate a hood so that the volume of air necessary to produce results is as small as possible. This will reduce the size of equipment and power required by the system and also the heating load requirements in the winter.

Air Flow from Static Readings

The static suction at the throat of a hood is frequently used in practice as a measure of the effectiveness of control. Where the hood coefficient is known the volume of air flow through any hood may be determined from the equation:

$$Q = 4005 f A \sqrt{h_t} \quad (1)$$

where

Q = volume of air flow, cubic feet per minute.

A = area of connecting duct, square feet.

h_t = static suction measured 3 diameters from throat of hood, inches of water.

f = orifice or restriction coefficient which varies from 0.6 to 0.9 depending on the shape of the hood.

An average value of f is 0.71, although for a well-shaped opening a value of 0.8 may be used. The factor f is determined from the equation:

$$f = \sqrt{\frac{h_v}{h_t}} \quad (2)$$

where h_v is the velocity head in the connecting duct.

The static suction is not a good measure of the effectiveness of a hood unless the area of the opening and the location of the operation with respect to the hood are known. This is clearly indicated by Equation 3 which shows that the velocity at any point along the axis varies approximately inversely as the square of the distance. However, this formula coupled with Equation 1 should serve to indicate the velocity conditions to be expected when operations are conducted external to the hood opening.

Design Based on Total Air Flow

Where the foregoing factors are not known, the usual method of designing an exhaust system is to base the air flow through the system on

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TABLE 1. RATES OF FLOW THROUGH BRANCH PIPES WOODWORKING MACHINES

PIPE DIAMETER, IN.	AIR VOLUME, CFM
3	200
4	350
5	550
6	800
7	1100
8	1400

TABLE 2. BRANCH PIPE SIZE FOR WOODWORKING MACHINE HOODS

TYPE OF MACHINE	SIZE, IN.		NO. OF BRANCHES	MINIMUM DIAMETER, IN.		
	Min.	Max.		BOTTOM BRANCH	TOP BRANCH	OTHERS
Self feed table saw			2	5	4	
Other single saws	18	18	1 1		4 5	
Saws with Dado Head			1		5	
Band saws		2	2	4	4	
	2	3	2	5	4	
	3	6	2	5	5	
Disc sanders		18	1	4		
	18	28	1	5		
	26	32	2	4	4	
	32	38	2	5	4	
	38	48	3	5	4	4
Triple drum sanders		30	1	7		
	30	36	1	8		
	36	42	1	9		
	42	48	1	10		
Single drum sanders: (area in sq in.)		350	1	4 ^a		
	350	700		5		
	700	1400		6		
	1400	2800		7		
Horizontal belt sanders		9	2	5	4	
	9	14	2	6	4	
Vertical belt sanders		6	1	4		
	6	9	1	5		
	9	14	1	6		
Jointers		8	1	4		
	8	20	1	5		
Single planers		20	1	5		
	20	26	1	6		
	26	36	1	7		
Tenoner			2	5	5	

^aNot over 10 in. diameter.

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TABLE 3. RATES OF FLOW THROUGH BRANCH PIPES GRINDING AND BUFFING WHEELS

PIPE DIAMETER, IN.	AIR VOLUME, CPM
3	225
4	400
5	600
6	900
7	1200

rates of flow through each hood which have been found by experience to provide adequate control. For woodworking systems the rates of flow given in Table 1, calculated on the basis of a branch velocity of 4000 fpm, are adequate for control. Using these air flow rates, Table 2 gives the size of pipe connections to be used with the more common woodworking machines. Properly designed grinding and buffing wheel hoods have been found to be adequately controlled when the rates of air flow given in Table 3, calculated on the basis of a branch velocity of 4500 fpm, are used. Table 4 gives the minimum branch pipe sizes to be used on the more common sizes of grinding and buffing wheels.

In some states grinding, polishing and buffing wheels are subject to regulation by codes. (See Standards Chapter 48.) The static suction requirements, which range from $1\frac{1}{2}$ to 5 in. water displacement in a U-tube, must be followed in such states although in several instances they may appear to be excessive. Frequently, in these operations, a large part of the wheel must be exposed and the dust-laden air within the hood is thrown outward by the centrifugal action of the wheel, thus counteracting useful inward draft. This tendency may be diminished by locating the connecting duct so as to create an air flow of not less than 200 fpm past the lower edge of the wheel.

Controlling Air Velocities

Exact determinations of hood control velocities are not available, but it is safe to assume that for most dusty operations they should not be less

TABLE 4. BRANCH PIPE SIZES FOR GRINDING AND BUFFING HOODS

TYPE OF WHEEL	WHEEL SIZE DIAMETER, IN.		MAXIMUM		BRANCH PIPE MINIMUM DIAMETER, IN.
	Min.	Max.	Width In.	Area Sq In.	
Grinding	9	18	1	30	3
	18	24	3	175	4
	24	30	4	300	5
	30	36	5	500	6
	36	42	6	700	7
Disc Grinding	20	20	---	300	4
	20	30	---	---	5
Buffing Polishing and Scratch Brushing	8	8	2	50	$3\frac{1}{2}$
	16	16	3	150	4
	24	24	4	300	5
	30	30	6	600	6

than 200 fpm at the point of origin. For granite dust generated by pneumatic devices, velocities from 150 to 200 fpm, depending on the type of hood used, are recommended as sufficient for safe control². Considering the character of the industry, air velocities of this order may be extended to similar dusty operations. The method for approximately determining these velocities in terms of the velocity at the hood opening is given in Equation 3.

No set rule can be given regarding the shape of a hood for a particular operation, but it is well to remember that its essential function is to create an adequate velocity distribution. The fact that the zone of greatest effectiveness does not extend laterally from the edges of the opening may frequently be utilized in estimating the size of hood required. Where complete enclosure of a dusty operation is contemplated, it is desirable to leave enough free space to equal the area of the connecting duct. Hoods for grinding, polishing and buffing should fit closely, but at the same time should provide an easy means for changing the wheels. It is advisable to design these hoods with a removable hopper at the base to capture the heavy dust and articles dropped by the operator. Such provisions are of assistance in keeping the ducts clear. Air volumes used to control many dust discharges may often be reduced by effective baffling or partial enclosure of an operation. This procedure is strongly urged where dusts are directed beyond the zone of influence of the hood.

Axial Velocity Formula for Hoods

When the normal flow of air into a hood is unobstructed, Equation 3 may be used to determine the air velocity at any point along the axis³:

$$V = \frac{0.1 Q}{x^2 + 0.1 A} \quad (3)$$

where

V = velocity at point, feet per minute.

Q = volume of air handled, cubic feet per minute.

x = distance along axis, feet.

A = area of opening, square feet.

Velocity Contours

It is possible by use of a specially constructed Pitot tube⁴ to map contours of equal velocity in any axial plane located in the field of influence. It has been found that the positions of these contours for any hood can be expressed as percentages of the velocity at the hood opening and are purely functions of the shape of the hood⁵.

Further, the velocity contours are identical for similar hood shapes when the hoods are reduced to the same basis of comparison. These facts are applicable to all hood problems so that when the velocity contour

²Control of the Silicosis Hazard in the Hard Rock Industries. I. A Laboratory Study of the Design of Dust Control Systems for Use with Pneumatic Granite Cutting Tools, by Theodore Hatch, Philip Drinker and Sarah P. Choate. (*Journal of Industrial Hygiene*, Vol. XII, No. 3, March, 1930).

³The Control of Industrial Dust, by J. M. DallaValle (*Mechanical Engineering*, Vol. 55, No. 10, October, 1933).

⁴Studies in the Design of Local Exhaust Hoods, by J. M. DallaValle and Theodore Hatch (*A.S.M.E. Transactions*, Vol. 54, 1932).

⁵Velocity Characteristics of Hoods under Suction, by J. M. DallaValle (*A.S.H.V.E. TRANSACTIONS*, Vol. 38, 1932, p. 387).

distribution is known, the air flow required can be determined. Fig. 1 shows the contour distribution in two axial planes perpendicular to the sides of a rectangular hood with a side ratio of one-half. The distribution shown is identical for all openings with a similar side ratio provided the mapping is as shown in the figure. The contours, of course, are expressed as percentages of the velocity at the opening.

Low Velocity Systems

On multiple installations of the same operation it is often possible to institute a great saving in power cost by designing an exhaust system

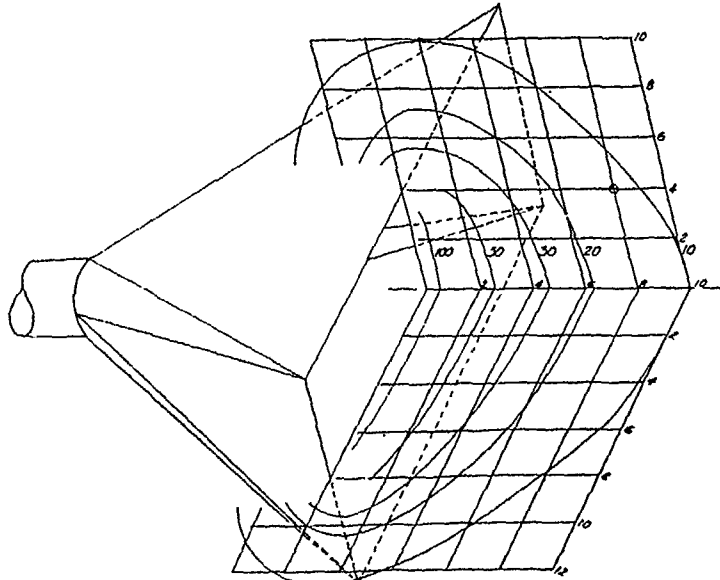


FIG. 1. VELOCITY CONTOURS FOR A RECTANGULAR OPENING WITH A SIDE RATIO OF ONE-HALF. CONTOURS ARE EXPRESSED AS PERCENTAGES OF THE VELOCITY AT THE OPENING

using low velocities in the main ducts. Such a system for use in grinding and shaping porcelain has been described⁶. In these operations, the separate machines are grouped around a central plenum chamber and exhausted by means of a low pressure fan connected to the plenum. In this case a power saving of over 90 per cent was obtained. A similar design technique has been described⁷ for use in ventilating plating tanks.

Large Open Hoods

Large hoods, such as may be used for electroplating and pickling tanks, should be sub-divided so the area of the connecting duct is not less than

⁶Low Velocity Exhaust Systems, by Theodore Hatch (*Heating and Ventilating*, October, 1940, p. 27).

⁷Tank Ventilating Power Costs Cut by Low Velocity Systems, by William B. Harris (*Heating and Ventilating*, July, 1942, p. 42).

one-fifteenth of the open area of the hood. Frequently, it will be found necessary to branch the main duct in order to obtain a uniform distribution of flow. *Canopy hoods* should extend 6 in. laterally from the tank for every 12 in. elevation, and wherever possible they should have side and rear aprons so as to prevent short circuiting of air from spaces not directly over the vats or tanks. In most cases, hoods of this type take advantage of the natural tendency of the vapors to rise, and air velocities may be kept low. Cross drafts from open doors or windows disturb the rise of the vapors and therefore provision must be made for them. The air velocities required also depend upon the character of the vapors given off, cyanide fumes, for example, requiring an air velocity of approximately 75 fpm on the surface of the tank and acid and steam vapors requiring velocities as low as 25 to 50 fpm. The total volume of air flow necessary to obtain these velocities may be approximately determined from the equation:

$$Q = 1.4 PDV \quad (4)$$

where

Q = total volume of air handled by hood, cubic feet per minute.

P = perimeter of the tank, feet.

D = distance between tank and hood opening, feet.

V = air velocity desired along edges and surface of tank, feet per minute.

Lateral Exhaust Systems

The lateral exhaust method, as developed for chromium plating⁴, is applicable in many instances in preference to the canopy type hoods. The method makes use of drawing air and fumes laterally across the top of vats or tanks into slotted ducts at the top and extending fully along one or more sides of the tanks. The slots are 1 in. wide and for effective ventilation a 2000 fpm exhaust air velocity at the slot face is advisable. In addition, the duct should not be required to draw the air laterally for a distance of more than 18 in. and the level of the solution should be kept 6 to 8 in. below the top of the tanks.

It has also been determined that a similar control may be used for tanks wider than 3 ft when the same velocity (2000 fpm) is maintained through a slot which is increased $\frac{1}{4}$ in. for every foot of width greater than 3 ft. When these slots must be extended more than 6 ft in length some method of spreading the flow is necessary to provide even air flow distribution through the entire slot length. This can be accomplished by tapering the slot, which incidentally will add to the resistance of the system. A more economical approach is to place properly spaced vanes in the side ducts, or to branch the side ducts⁵.

The flexible exhaust tube method may be advantageously used for removing dust or fumes. Flexible tubes having one end connected to an exhaust system and a slotted hood attached to the other end may be shaped at will to fit in with industrial processes without affecting the ease

⁴Health Hazards in Chromium Plating, by J. J. Bloomfield and William Blum (*U. S. Public Health Report*, Vol. 43, No. 26, September 7, 1928).

⁵New Data for Practical Design of Ventilation for Electroplating, by W. P. Battista, Theodore Hatch and Leonard Greenburg (*Heating, Piping and Air Conditioning*, February, 1941, p. 81). Ventilation of Plating Tanks, by Allen D. Brandt (*Heating, Piping and Air Conditioning*, July, 1941, p. 434).

of operation. Efficient dust or fume removal may be had with use of relatively small exhaust volumes. This type of system may be used on swing grinders, portable grinding wheels, soldering operations, stone cutting, rock drilling, etc.

Spray Booths

In the design of an efficient spray booth, it is essential to maintain an even distribution of air flow through the opening and about the object being sprayed. While in many instances spraying operations can be performed mechanically in wholly enclosed booths, the volatile vapors may reach injurious or explosive concentrations. At all times the concentrations of these vapors, and particularly those containing benzol, should be kept well below 100 parts per million in the breathing zone of the worker. Spray booth vapors are dangerous to the health of the worker and care should be taken to minimize exposure to them.

It is recommended in the design of spray booths that the exhaust duct be located at the end of the booth opposite the opening. In front of this duct should be placed baffle plates which will cause a uniform air velocity distribution across the frontal area. The air volume should be sufficient to maintain a velocity of not less than 100 fpm over the open area of the booth (150 fpm is preferable where benzol or lead is present in the paint) and the vapors should be discharged through a suitable stack to permit dilution. It is good practice to pass the fumes or vapors through baffle type washers or scrubbers designed for efficient spray removal.

Hoods for Chemical Laboratories

Hoods used in chemical laboratories are generally provided with sliding windows which permit positive control of the fumes and vapors evolved by the apparatus. Their design should offer easy access for the installation of chemical equipment and should be well lighted. Air velocities should exceed 50 fpm when the window is opened to its maximum height.

Kitchen Hoods

The length and width of kitchen hoods should be such as to extend beyond the extreme projection of the ranges, broilers, etc., over which they are installed. The minimum projection or overlap should be 12 in. Where space conditions permit, range hoods should be about 2 ft high so as to provide a reservoir to confine momentary bursts of smoke and steam until the exhaust system can evacuate the hood. As in the case of industrial hoods, range hoods should be located as low as possible to increase their effectiveness.

In general the amount of air to be exhausted from restaurant range hoods is at the rate of 100 fpm per square foot of face area. Thus, a hood 4.5 ft wide by 30 ft long has a face area of 135 sq ft, which multiplied by 100 fpm velocity results in a total air quantity to be exhausted of 13,500 cfm. In some cases where the application is principally frying and where it is not practical to install a hood 2 ft high it is recommended that the face velocity be increased from 100 to 150 fpm, depending on peak load conditions in the kitchen. Exhaust connections to range hoods should always be made at the top and back of hoods, and should be spaced pref-

erably not more than 6 ft apart and be rectangular in shape with the long side parallel to the back of the hood. Exhaust openings into range hoods should be designed to maintain a velocity of 1500 to 1800 fpm.

An approved fire damper with fusible link should be (and is required by code in many states) installed in the main exhaust duct or branch adjacent to the range hood. Should there be more than one hood connected to a common duct, then the branch duct to each hood should be provided with a fire damper. Access doors should be provided at the fire damper for purpose of inspection, cleaning or for renewal of fusible link. All exhaust piping to range hoods, commonly called grease ducts, should be provided with tight fitting cleanout doors of adequate size to permit easy removal of grease.

Hoods over steam tables should be of similar construction to range hoods. In determining the necessary amount of air to be exhausted it is considered good practice to design such hoods with a face velocity of 60 to 70 fpm. Hoods over dishwashing machines are usually relatively small and generally 1500 to 2000 cfm per hood is allowed, which is equivalent to a velocity of approximately 100 fpm per square foot of face area. Range hoods in diet kitchens are constructed the same as restaurant range hoods but with less exhaust air per square foot of face area, depending upon the nature of the food cooked.

Hoods are not often used in private residences unless they are quite large and the consideration of expense is not important. For such residences the hoods should be designed on the same basis as diet kitchens. Most all residence kitchens can be effectively and economically ventilated by the installation of a built-in kitchen ventilator, which should be located in an outside wall and in close proximity to the kitchen range. It has been found that the capacity of the built-in kitchen ventilator should be at least 350 cfm regardless of the size of kitchen. This can be justified on the basis that the smaller the kitchen the more concentrated the heat will be thus requiring a more rapid rate of air change. Standard size built-in kitchen ventilators are generally available in three sizes, namely 350, 500 and 800 cfm. The proper size to use will depend on design conditions and available wall space.

DUCT SYSTEM DESIGN

In designing a duct system it is necessary to recognize a few fundamental principles (see also Chapter 32). Knowing the quantity of air required, the size of the duct may be computed from Equation 5:

$$A = \frac{Q}{V} \quad (5)$$

where

A = cross-section area of duct, square feet.

Q = air quantity to be handled by the duct, cubic feet per minute.

V = velocity of air, feet per minute.

Air Velocities in Ducts

Where it is necessary to transport the particulate material collected in an exhaust system, minimum carrying velocities must be maintained in the

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TABLE 5. GAGES OF METALS FOR EXHAUST SYSTEM

DUCT DIAMETER, IN.	GAGE OF METAL	
	Dust	Non-Corrosive Fumes, Vapors and Gases
8 or less.....	20	24
9 to 18.....	18	22
18 to 30.....	16	20
30 or more.....	14	18

ducts preceding the collector. It has been found that good design results when air velocities in horizontal runs are not less than 3000 fpm or not greater than 5000 fpm. When the dust being carried is organic and other than wood flour, or similar material, a velocity of 2500 fpm is adequate. The velocity in vertical piping should be increased 25 per cent over the minimum required for transport in horizontal ducts.

For duct systems wherein the air has no dust or solid load, a lower velocity is desirable, which may range from 1200 to 2000 fpm. In view of the fact that the horsepower required by a system depends directly on the resistance and the resistance is a function of the velocity, economical design requires velocities of this magnitude.

The equal friction method is generally used for designing a duct system as this insures equal resistance to air flow in all branches throughout the system (see Chapter 32). Long main ducts do not generally provide the most economical layout. Where it is necessary to ventilate a large number of machines, or machines which are widely separated, it is desirable to locate the fan at approximately the center of the system. With this arrangement it is possible to choose a fan which will deliver the required air quantity against a lower resistance pressure, and this will generally result in a horsepower saving.

When a system carrying dust is designed with an oversize main duct to allow for future extension, the air velocity may be found to be too low to carry the dust, and serious plugging may occur. In this case it is desirable to install an orifice in the end of the pipe to allow for the lower air quantity.

Construction

The ducts leading from the hoods to the exhaust fan should be constructed of sheet metal not lighter than is shown in Table 5. The piping should be free from dents, fins and projections on which refuse might catch.

All permanent circular joints should be lap-jointed, riveted and soldered, and all longitudinal joints either grooved and locked or riveted and soldered. Circular laps should be in the direction of the flow, and piping installed out-of-doors should not have the longitudinal laps at the bottom. Every change in pipe size should be made with an eccentric taper flat on the bottom, the taper to be at least 4 in. long for each inch change in diameter. All pipes passing through roofs should be equipped with collars so arranged as to prevent water leaking into the building.

The main trunks and branch pipes should be as short and straight as

possible, strongly supported, and with the dead ends capped to permit inspection and cleaning. All branch pipes should join the main at an angle of not greater than 45 deg, the junction being at the side or top of the larger end of a transformation piece. Branch pipes should not join the main pipes at points where the material from one branch would tend to enter the branch on the opposite side of the main.

Cleanout openings having suitable covers should be placed in the main and branch pipes so that every part of the system can be easily reached in case the system clogs. Either a large cleanout door should be placed in the main suction pipe near the fan inlet, or a detachable section of pipe, held in place by lug bands, may be provided.

Elbows and hoods should be made at least two gages heavier than straight pipe of the same diameter, in order to enable them to withstand the additional wear caused by changing the direction of flow. Elbows should preferably have a throat radius of at least one and one-half times the diameter of the pipe.

Every pipe should be kept open and unobstructed throughout its entire length, and no fixed screen should be placed in it, although the use of a trap at the junction of the hood and branch pipe is permissible, provided it is not allowed to fill up completely. The passing of pipes through firewalls should be avoided wherever possible, and floor sweep connections should be so arranged that foreign material cannot be easily introduced into them.

At the point of entrance of a branch pipe with the main duct, there should be an increase in the latter equal to their sum. Some state codes specify that the combined area be increased by 25 per cent. While this is not always good practice and is frequently done at the expense of a reduced air velocity, it is often done where future expansion of the exhaust system is contemplated.

Duct Resistance

The resistance to flow in any galvanized duct riveted and soldered at the joints may be obtained from Fig. 2, Chapter 32. The pressure drop through elbows depends upon the radius of the bend. For elbows whose centerline radii vary from 50 to 300 per cent of pipe diameter, the loss may be estimated from Table 6. It is sometimes convenient to express the resistance of an elbow in terms of an equivalent length of duct of the same diameter. Thus with a throat radius equal to the pipe diameter the resistance is equivalent to a section of straight pipe approximately 10 diameters long, while with a throat diameter radius $1\frac{1}{2}$ times the dia-

TABLE 6. LOSS THROUGH 90-DEG ELBOWS

ELBOW CENTER LINE RADIUS IN PER CENT OF PIPE DIAMETER	LOSS IN PER CENT OF VELOCITY HEAD
50	75
100	26
150	17
200 to 300	14

meter, the resistance is apparently the same as that of seven diameters of straight pipe.

COLLECTORS

The most common method of separating the dust and other materials from the air is to pass the mixture through a centrifugal or *cyclone* collector. In this type of collector the mixture of the air and material is introduced on a tangent, near the cylindrical top of the collector, and the whirling motion sets up a centrifugal action causing the comparatively heavy materials suspended in the air to be thrown against the side of the separator, from which position they spiral down to the tail piece, while the air escapes through the stack at the center of the collector.

The diameter of the cyclone should be at least 3.5 times the diameter of the fan discharge duct. When two or more separate ducts enter a cyclone, gates should be provided to prevent any back draft through a system which may not be operating. Cyclones working in conjunction with two or more fans should be designed to operate efficiently at two-thirds capacity rating.

If a cyclone is used to collect light dusts such as buffing wheel dusts, feathers and lint, the exhaust vent should be large enough to permit an air velocity of 200 to 500 fpm. This will require a cyclone of larger dimensions than given for the foregoing general case.

When a high collection efficiency is desired, or the material is very fine, multi-cyclones may be used. These are merely small cyclones arranged in parallel which utilize the principle of high centrifugal velocity to attain separation. The capacities and characteristics of this type of separator should be obtained from the manufacturers.

Dust Filters

Filters are used when the material collected by an exhaust system is valuable or cannot be separated efficiently from the air with an ordinary cyclone. They are also employed when it is desirable to recirculate the air drawn from a room by the exhaust system, which otherwise might entail considerable loss in heat. Bag filters which are properly housed should be operated under suction. *Bag houses* used in the manufacture of zinc oxide and other chemical products are operated on the positive side of the fan.

Wool, cotton and asbestos cloths, and paper are commonly used as filtering mediums. When woolen cloths are employed, the filtering capacities vary from $\frac{1}{2}$ to 10 cfm per square foot of filtering surface, depending on the character of the material collected. The rates for cotton and asbestos cloths are lower. The type of filter cloth and the rates of filtration depend, of course, on the material to be collected and the fan capacity. The time increase of resistance varies with the amount of material permitted to build up on the surface of the filter and can be determined only by experiment. The limits of the increase may be regulated by adjustment of the shaking or cleaning mechanism. These limits may be regulated further according to the capacity of the fan and the effective performance of the hoods and the duct system.

For additional information on dust and cinders, see Chapter 29, Air Cleaning Devices.

RESISTANCE OF SYSTEM

The maintained resistance of the exhaust system is composed of three factors: (1) loss through the hoods, (2) collector drop, and (3) friction drop in the duct system.

The loss through the hoods is usually assumed to be equal to the suction maintained at the hoods. Where possible the resistance of the particular collector to be used should be ascertained from the manufacturer.

Friction drop in the pipes must be computed for each section where there is a change in area or in velocity. Find the velocities in each section of pipe starting with the branch most remote from the fan. The friction drop for these sections can be determined by reference to Table 6 and Fig. 2, Chapter 32. Total friction loss in the piping system is the friction drop in the most remote branch plus the drop in the various sections of the main, plus the drop in the discharge pipe.

TABLE 7. ACCEPTED STANDARDS FOR TOXIC CONCENTRATION OF FUMES, DUSTS AND MISTS^a

FUMES	MILLIGRAMS PER CUBIC METER
Cadmium oxide.....	0.1
Chlorodiphenyl.....	1.0
Lead or oxides of lead.....	0.15
Mercury or mercury compounds.....	0.1
Pentachloronaphthalene.....	0.5
Trichloronaphthalene.....	5.0
Zinc oxide.....	15.0
DUSTS	MILLION PARTICLES PER CUBIC FOOT ^b
Asbestos.....	5
Cement.....	100
Gypsum.....	100
Lead or compounds of lead.....	0.15 ^c
Manganese.....	6 ^c
Marble.....	100
Silica (more than 70 per cent free silicon-dioxide).....	5
Silica (more than 10 per cent free silicon-dioxide).....	10
Silica (less than 10 per cent free silicon-dioxide).....	100
MISTS	MILLIGRAMS PER CUBIC METER
Chromic acid.....	0.1
Sulphuric acid.....	5.0

^aAdapted from Safe Concentrations of Certain Common Toxic Substances Used in Industry, by M. Bowditch, C. K. Drinker, P. Drinker, H. A. Haggard, and H. Hamilton (*Journal of Industrial Hygiene and Toxicology*, Vol. 22, No. 6, June, 1940). Industrial Code Bulletin No. 35 (New York State Labor Department). Study of Asbestosis in Asbestos Textile Industry (*U. S. Public Health Bulletin* No. 241, 1938). Chronic Manganese Poisoning in an Ore Crushing Mill (*U. S. Public Health Bulletin* No. 247, 1940).

^bDetermined by light field or equivalent technique.

^cMilligrams per cubic meter.

CHAPTER 40. INDUSTRIAL EXHAUST SYSTEMS

TABLE 8. CORROSION RESISTING MATERIALS FOR EXHAUST SYSTEMS^a

MATERIAL	ACID ^b															
	ACETIC		CHROMIC		HYDRO-CHLORIC		HYDRO-FLUORIC		NITRIC		PHOS- PHORIC		SUL- PHUROUS		SUL- PHURIC	
METALS	Dil.	Conc.	Dil.	Conc.	Dil.	Conc.	Dil.	Conc.	Dil.	Conc.	Dil.	Conc.	Dil.	Conc.	Dil.	Conc.
Aluminum.....	Good		Fair		Poor		No Data		Poor		Good		Poor		Poor	
Magnesium and Alloys.....	No Data		Good		Poor		No Data		Poor		Good		No Data		No Data	
Lead and Lead-Coated.....	Poor		Good		Poor		Poor		Poor		Poor		Good		Good	
Moly Alloy (60 Ni—20Mo— 20 Fe).....	Good		No Data		Fair		No Data		Poor		Poor		No Data		Good	
Monel Metal.....	Fair		Poor		Fair		Poor		Good		Fair		Poor		Good	
Bronze.....	Poor												Good			
Silicon Iron.....	Fair		Good		No Data		Fair		Poor		Good		Good		No Data	
Stainless Steel (18 Cr— 8 Ni).....	Good		Good		Poor		No Data		Good		Poor		Good		Poor	
Enameled Steel.....	No Data		No Data		Good		Poor		Good		Poor		No Data		Good	
MISCELLANEOUS																
Asbestos Comp.....					Good except against strong acids and alkalis											
Wood.....	Some woods are decomposed or softened faster than others.															
Rubber.....									Poor							
Plastic.....	In general plastics resist weak acids and are decomposed by concentrated acid.															

^aStandard Practice Sheet No. 115 (Division of Industrial Hygiene, New York State Labor Department).

^bAcid mists in air are more corrosive than as liquid in storage tank. Galvanized iron not resistant to acid.

^cStainless steel of (24 Cr—10 Ni) fairly resistant at low temperature for HCl and H₂PO₄.

^dUnder most conditions.

^eAt room temperatures.

EFFICIENCY OF EXHAUST SYSTEMS

The efficiency of an exhaust system depends upon its effectiveness in reducing the concentration of dusts, fumes, vapors and gases below the safe or threshold limits¹⁰.

Too much emphasis cannot be placed on the necessity of testing exhaust systems frequently by determining the concentration of atmospheric contamination at the worker's breathing level. Commonly accepted values of threshold limits for usual atmospheric contaminants, such as fumes, dusts and mists are given in Table 7. Similar data covering gases and vapor will be found in Chapter 28.

TYPES OF FANS

Manufacturers generally provide special fans for the collection of various industrial wastes. These are available for the collection of coal

¹⁰Criteria for Industrial Exhaust Systems, by J. J. Bloomfield (A.S.H.V.E. TRANSACTIONS, Vol. 40, 1934, p. 353).

dust, wood shavings, wool, cotton and many other substances. When substances having an abrasive character are conveyed, the fan blades and housing should be protected from wear. This may be accomplished by placing a collector on the negative side of the fan or by lining the housing and blades with rubber.

PROTECTION AGAINST CORROSION

The removal of gases and fumes in many chemical plants requires that metals used in the construction of the exhaust system be resistant to chemical corrosion. A list of the materials which may be used to resist the action of certain fumes is given in Table 8. Hoods and ducts, when short, may frequently be constructed of wood and be quite effective. Rubberized paints are available and may be applied as protective coatings in handling such gases and fumes as chlorine and hydrochloric acid.