minimum or theoretical odor-free air requirement for dilution of odors to acceptable or threshold values. There are no reliable data available to indicate whether such ventilation standards for controlling smoke, odor, and irritation effects are in fact adequate to protect a nonsmoker from possible effects of nicotine and other poisonous smoke ingredients of unknown toxicological thresholds.

Ventilation requirements are frequently controlled by governmental ordinance. The Chicago Ventilation Code,[4] is an example. In this code a table of requirements is given for various applications. The values may be considered as practical empirical values in excess of the minimum theoretical requirements. For instance, in offices a minimum of 0.6 cfm of outdoor air *must be supplied by mechanical ventilation* per square foot of floor area. With air conditioning the code requirement for outdoor air is reduced to one-third, with two-thirds recirculated. When an effective adsorption device, *such as an activated carbon adsorber, is used to remove odors,* the outdoor air requirement may be reduced to 15 percent of the code requirement. In some other localities, 100 percent recirculation is acceptable under certain conditions.

ODOR REMOVAL BY ABSORPTION

Some odors are conveyed on liquid and solid particles having vapor pressures. Filters, electrical precipitators, sonic *flocculators, washers, scrubbers, condensate cooling coils,* and absorption equipment are sometimes applicable in removing these particulates.

The decontamination of a stream of odorous air by washing it with a liquid depends for its effectiveness on two processes. The first is to obtain contact of the air with the absorbing solution. The second involves the dispersal of the contaminating gases into the washing liquid, with or without chemical reaction, and their consequent removal from the air stream. When physical solution without chemical reaction is involved, the partial pressure of the odorous gas in equilibrium with the solution of such gas in the washing liquid begins to increase as soon as the decontamination process starts and builds up to a maximum value when the liquid becomes saturated. Thus, treatment of an effluent by physical absorption alone cannot operate at 100 percent efficiency.[5]

Solution with chemical reaction, however, may offer a specific means for deodorizing a given effluent. Examples of chemical reactions which may effectively be used in treatment of reactive odorants include neutralization of acids and bases and oxidation (permanganate, hypochlorite, chlorine, chlorine dioxide) of reducing substances. In some cases, recovery of valuable by-products may be possible. Finally, decontamination by washing also involves the problem of disposal of the liquid wastes.

Many types of equipment have been developed for odor removal by physical or chemical absorption. Special equipment and solutions are developed by manufacturers to remove specific odorants or contaminants.

ODOR REMOVAL BY ADSORPTION

Any gas or vapor will, to some degree, adhere to any solid surface at ordinary or low temperatures. This phenomenon is called adsorption.

In adsorption gases and vapors (the adsorbates) are collected in a condensed state upon the surfaces of the solid which is called the adsorbent. These surfaces include not merely *those comprising the exterior of the adsorbent but also all* the surfaces of the vast network of extremely minute channels and sub-microscopic pores within the body or structure of the adsorbent. For this reason, only certain specific solids whose structures include such highly convoluted surfaces can be of any practical use in adsorption. The cumulative magnitude of the surfaces of such solids is enormous. It has been estimated, for example, that the aggregate area of the surfaces in one pound (54 to 62 cubic inches) of granular activated carbon approximates 140 acres or nearly one-quarter square mile.

This significant adsorptive characteristic is possessed not alone by carbons, charcoals and chars, but also by such materials as zeolite, silica, alumina, mica and some others. All these differ widely in the number and kinds of substances they adsorb, as well as in the amount of sorbed substances *they will retain. In general, the siliceous, metallic* oxide and active earth types of adsorbents are electrically polar—that is, their molecular structure contains an unsymmetrical electron distribution. Since polar substances have strong attraction for one another and since water is highly polar, the polar adsorbents mentioned above retain water in preference to most other fluids and are, therefore, incapable of adsorbing non-aqueous gases efficiently from a humid atmosphere. For use in air recovery, however, which requires a sorbent to extract very small quantities of a variety of gases and vapors from either dry or humid air during a very brief interval of contact, specially processed carbon of high activity, dense structure and suitable hardness has alone been found to be adequate. Such activated carbon, being non-polar and hence electronically symmetrical in structure, has no particular affinity for moisture and preferentially adsorbs organic gases and vapors.[6]

In physical adsorption, the attraction of the sorbent (carbon) for the sorbate does not involve chemical reaction, and the heat liberated by the adsorption of the gas or vapor is approximately that which would be liberated by the simple condensation of the same kind and quantity of gas or vapor. The degree of attraction is influenced by the molecular characteristics of the sorbate which, in turn, are related to its critical temperature and boiling point. These factors, there*fore, provide tentative criteria for predicting the degree of* adsorption to be expected.

True gases, for example, having critical temperatures well below −50 C and boiling points below −150 C are practically nonadsorbable at ordinary temperatures. This, because the extreme mobility of their relatively light molecules, creates an escaping tendency greatly exceeding the attractive force of the carbon. Such true gases include hydrogen, nitrogen, oxygen, carbon monoxide and methane.

Low boiling vapors having critical temperatures between approximately 0 C and 150 C and boiling points between −100 C and 0 C have a lesser escaping tendency and are, therefore, moderately adsorbable. These vapors include ammonia, ethylene, formaldehyde, hydrogen chloride and hydrogen sulfide. The adsorptive capacity of activated carbon for such vapors at ordinary temperatures is, however, inadequate to insure their practical elimination in air purification. The adsorptive capacity of the carbon for some of these vapors can be increased by special impregnation.

When the air-entrained impurities are high boiling vapors (above 0 C), usually odorous, their molecular escaping tendencies are low and the physical adsorptive capacity of the carbon for them is very great. It is this phenomenon which makes air recovery so effective because the types of contaminants common to air pollution, particularly in the in*habited areas or enclosures, are almost entirely vapors in this* category. They include most organic compounds, such as

hydrocarbons, alcohols, esters, aldehydes, ketones, organic acids, nitrogen and sulfur compounds and many *inorganic* vapors. Physical adsorption is an ideal and, in fact, the only practical method for removing low concentrations of such vapors from air on a commercial scale.

Another *approximate criterion for predicting* the absorbability of gaseous or vaporous substances is molecular structure. The adsorptivity of gaseous substances increases progressively with their molecular size. Thus, with vapors comprising a *regular organic series,* such as the hydrocarbon or the alcohol series, each member of the series is sorbed more readily than the next lower or lighter member. As a practical rule for air purification, any gas or vapor whose molecule *contains fewer* than three atoms independent of hydrogen is not practically adsorbable. There are some exceptions to this, such as bromine, iodine and methyl bromide molecules. Note how this rule eliminates the practical use of physical adsorption for removing true gases and low-boiling vapors like ammonia (NH_3), ethylene (C_2H_4), formaldehyde (HCHO), hydrogen chloride (HCl).

Carbon Reactivation

When the carbon has reached its practical saturation in service, it must be reactivated. This can be done in place, or by the manufacturer, whichever is economically feasible. As the retentive capacity of the carbon is an inverse function of the temperature to which it is exposed, reactivation consists essentially of heating the carbon in a controlled atmosphere until the adsorbed gases and vapors are removed by desorption, displacement or oxidation. The reactivation atmosphere may be an inert gas, superheated steam, or combustion gas of carefully controlled composition. The ultimate temperature necessary will depend upon the boiling points and critical temperatures of the sorbed substances and on the nature of the reactivation atmosphere. In general, a temperature of *1000 F* or higher is required to completely release all of the gases and vapors accumulated by the carbon in ventilating service.

Use of Activated Charcoal

Activated charcoal often may be effectively used for control of atmospheric pollution,[7] or for control of odors, gases and vapors in air-conditioned spaces. In connection with heating, cooling, and ventilating of enclosures, *it permits one* or more of the following results.

1. Increased well being and efficiency of personnel by removing stuffiness and irritating vapors.
2. Recirculation of all or part of the *ventilating air,* saving heat in winter and refrigeration in summer.
3. Purification of outdoor air required for ventilation or pressuring.
4. Ventilation of spaces, such as toilets, not conveniently connected to central ventilating, heating, or cooling systems.
5. Use of one circulating system for all rooms no matter what odors are released in the individual areas.
6. Elimination of odors from air exhausted to the atmosphere.
7. Recovery of values from vapors present in the space.
8. Increased safety by removing combustible or toxic vapors.
9. Elimination of toxic gases resulting from military or industrial emergencies.

In recirculation systems, air is blown through a bed of activated charcoal or past surfaces of activated charcoal. If there is a high rate of air-turnover for uniformity or heat transfer purposes and a relatively low rate of odor release, *only part of the air need pass through an activated charcoal* bed—or the entire flow can go through a partial bypass type of filter and obtain the advantages of low resistance and low *first cost.*

Outdoor air is not pure in most industrial and urban locations and may not be suitable for ventilation purposes. In the case of an atmospheric or military emergency, ventilation with unpurified outdoor air presents exceptional hazards. For purifying outdoor air, exhaust air, or air in recirculation systems with high odor level, the activated charcoal filter should have high purification efficiency for each passage of air.

Quantity of Charcoal Required

There are three main steps in applying activated charcoal to the control of odors in a specific application.

1. Determination of the amount and type of odor in terms of pounds of activated charcoal required per year.
2. Analysis of the cost of activated charcoal purification and the benefits to be received.
3. Settling such application details as air circulation rate, activated charcoal filter type, distribution of air flow, and installation details.

The amount of activated charcoal needed to purify a given space depends on the types of contaminants, the *amount to* be removed (which depends on the concentration, the proportion of the time the concentration is present, the uniformity of vapors in the space, and related factors), and the type of activated charcoal used.

The adsorption capacity of a charcoal can be determined by the standard government accelerated chloropicrin test. A high quality charcoal would have a 50 minute break through *time by this test. Another test* method is the determination of the activity and retentivity with carbon tetrachloride. The selection and use of the test method appears to be influenced by the application, the nature and origin of the charcoal and the manufacturer's preference. Chars made from various materials such as nut shells, hard woods, coal, and petroleum can be used for relatively good adsorption, depending on the materials and process methods employed. There is no industry code of standard performance.

Each odor control situation requires a certain activated charcoal adsorption capacity per year to satisfactorily do the job. The required quantity of adsorbent can be supplied in the form of permanent-type factory-reactivated cells, or the disposable type. The air might pass through a small area of a thick charcoal filter or a larger area of a thin charcoal bed. The amount of activated charcoal required per year might be supplied, for example, in the form of a filter containing twice the yearly requirement which is reactivated every second year, or in throw-away filters having a six month life and containing half the yearly requirement. In designing an adsorption system, the calculation of the amount of charcoal should be based on removing *100 percent of the odor* and on the manufacturer's performance rating of the charcoal.

The most difficult problem in applying any type of air purification is determination of the quantity and type of *contaminants that must* be removed. With this information the quantity of activated charcoal can be determined easily. Often a shortcut can be taken to combine the two into one step.

Six empirical methods will be discussed. One or more of these is applicable to every situation. It is best to calculate the amount of charcoal required by several methods, if applicable, and compare the results. The six methods are:[8]

A. *Knowledge or analytical* determination of specific odor-causing compounds and their amounts.