

fact that the k_{d_w} values for the factory scale tanks are not precise, the correlation for the several scales of operation is excellent. This is in agreement with the recently published data of Wise (6).

Discussion and Conclusions

The data show that the primary scale-up factor for submerged aerobic fermentors of conventional design is the oxygen absorption rate, which is defined as $k_{d_w}P$ when air is employed as the source of oxygen. This analysis has been limited to fully baffled vessels provided with agitation, the primary function of which, therefore, is to deliver oxygen from the gas phase to the liquid phase. A secondary function of the agitators is to overcome liquid-mycelia diffusion resistances and to account for satisfactory heat transfer coefficients at the broth-heat transfer surface of the fermentor.

Proper design of large scale units of the type described in this paper requires that a suitable $k_{d_w}P$ be experimentally determined through correlation of fermentation yield *vs.* $k_{d_w}P$ measured in small scale equipment for any given fer-

mentation, with the proviso that the small scale units be fully baffled and geometrically similar to the contemplated production units (4, 5). From this point the scale-up involves the following steps:

1. Select an operating pressure, thus fixing P .
2. Select an air flow sufficient to supply the peak molar oxygen demand of the broth, but not so high as to cause excessive foaming. A safe starting point would be to set the air flow to correspond to five times the peak molar oxygen demand of the broth. The peak oxygen demand can be determined readily by oxygen-uptake studies as detailed in a previous paper in this series (2).
3. If more than one sparging impeller is employed, multiple sparging is good practice for the most effective use of mixing energy to achieve a given oxygen absorption rate. Then, the tank must be considered as divided into separate units, each provided with one sparged impeller. Thus, the value of V_s for each section will be the volumetric air flow through the sparger of that section divided by the free cross-sectional areas of the section.
4. Determine the shaft horsepower per gallon required from Figure 5. As k_{d_w} and V_s have been established, this can be obtained readily. This defines the power

which must be delivered by each sparged impeller at the fixed V_s .

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VAPOR CONCENTRATION Control in Closed Spaces

AMOS TURK

Connor Engineering Corp., Danbury, Conn.

Maintaining a low but very constant concentration of a given vapor in a space is very difficult in a static system, especially because of adsorption factors. A dynamic method for establishing such a vapor concentration has been developed, in which vapor is introduced into the space by evaporation of a liquid from a container of specific dimensions, while the space air is continuously ventilated or purified. An equilibrium is established, giving a constant vapor concentration. An equation is derived in which the vapor concentration is expressed in terms of the vapor pressure of the liquid, the dimensions of the container from which the liquid evaporates, the volume of the space, the mutual air-vapor diffusion coefficient, the barometric pressure, and the rate of air purification or ventilation. The method may be applied to control of vapor concentrations for olfactory measurements, treatment of perishables with fungicidal vapors, and other uses.

IT IS OFTEN IMPORTANT to maintain a low but constant concentration of a particular vapor in a space—for example, stored fruit may be protected from fungus diseases by a very small concentration of a toxic vapor in the storage atmosphere. When such a method is used, it is essential to prevent the concentration of the toxic vapor from reaching the point where it becomes dangerous for plants or humans. It is therefore necessary to set up a system in which the desired low vapor concentration is reliably maintained.

In studying the migrations of insect

pests it may be revealing to determine how strongly a particular plant odor influences the insects' travels, either as an attractant or as a repellent. If this can be determined experimentally in the laboratory, it affords priceless information which is a valuable aid in the strategy of the fight against the insect pest, and in predicting or controlling its habits. To set up such laboratory tests, however, it is necessary to duplicate and maintain the marginal odors often present in nature. Such odors are produced by extremely low concentrations of vapors (4). This is essentially a study in

insect olfaction. Similar experimental problems are involved in studies of human olfaction.

To set up a low vapor concentration in a space merely by a single "shot" of the required gas is ineffective because the gas quickly dissipates, with nothing to take its place. Even when there is no ventilation, the adsorption of vapors on various solid surfaces causes rapid dissipation when the initial concentration is very low. The problem can be solved by setting up a system in which the required vapor is continuously injected into the space and simultaneously re-

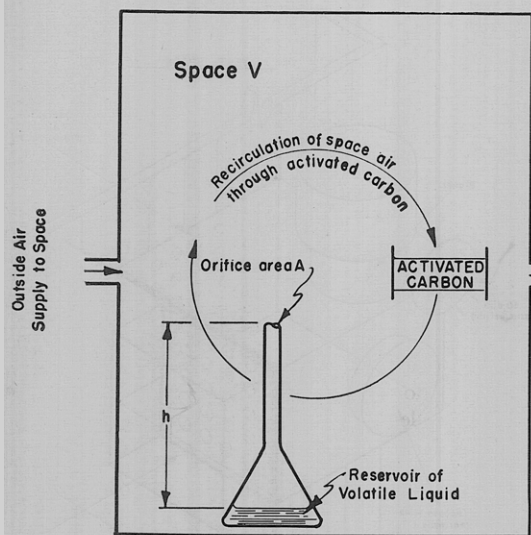


Figure 1. Vapor equilibrium system

moved from it at a controlled rate. This sets up a dynamic equilibrium which results in a constant vapor concentration even at very low levels.

To accomplish this effect in a controlled manner, the required vapor is generated by evaporation at constant temperature and atmospheric pressure, and allowed to diffuse through a controlled path, and to emanate from an orifice of specified area. The method of gaseous diffusion is one of the most reliable for controlling delicate gas transfer. The opposing process which operates simultaneously—the controlled removal of the gas or vapor from the space—is accomplished by circulating the air in the space continuously through beds of activated carbon, which removes all foreign atmospheric gases or vapors by adsorption.

The system may be schematically represented as shown in Figure 1. The equation representing the rate of evaporation of a liquid from a container (3) is

$$\Gamma = -\frac{nD}{h} \log_e \left(1 - \frac{n_{10}}{n} \right) \quad (1)$$

where

Γ = stream density, number of molecules of vapor of volatile liquid crossing 1 sq. cm. of area of plane perpendicular to concentration gradient per second, at h cm. above liquid surface

D = mutual vapor-air diffusion coefficient

n = molecular density of air-vapor mixture, number of molecules per cc. in gas phase

n_{10} = molecular density of vapor at surface of volatile liquid

Then

$$\frac{n_{10}}{n} = \frac{P_v}{P}$$

where

P_v = vapor pressure of volatile liquid, mm.

P = barometric pressure, mm.

Substituting this vapor pressure ratio

for the ratio of molecular densities, and using common logarithms,

$$\Gamma = -2.303 \frac{nD}{h} \log \left(1 - \frac{P_v}{P} \right) \quad (2)$$

Now, let

Γv = volumetric stream density (cc. per second) from orifice

then

$$\Gamma v = \Gamma A$$

(volume of one molecule)

$$\Gamma v = \Gamma A/n$$

where

A = orifice area, sq. cm.

$1/n$ = volume of one molecule, cc.

Substituting for the value of Γ in Equation 2,

$$\Gamma v = -2.303 \frac{AD}{h} \log \left(1 - \frac{P_v}{P} \right) \quad (3)$$

Equation 3 gives the rate at which vapor is diffused into the space.

To express the rate at which the vapor is removed from the space, let

V = volume of space, cc.

C_v = concentration of vapor, p.p.m., in the space when equilibrium is reached

R = rate of ventilation in space, in air change per second, sec.⁻¹

Then the rate at which the vapor is leaving the space is $10^{-6} C_v R V$. But, at equilibrium, this is equal to the rate of input of vapor, Γv . Therefore

$$\Gamma v = 10^{-6} C_v R V \quad (4)$$

and, substituting for Γv from Equation 3 and solving for C_v ,

$$C_v = -2.303(10)^6 \frac{AD}{hRV} \log \left(1 - \frac{P_v}{P} \right) \quad (5)$$

or

$$A/h = -\frac{4.34(10)^{-6} C_v R V}{D \log \left(1 - \frac{P_v}{P} \right)} \quad (6)$$

This equation, for a given volatile liquid of known vapor pressure, P_v , and diffusion coefficient with air, D , evaporating into a space, V , at a known barometric pressure, P , supplied with purified air a definite rate, R , fixes the dimensions of an evaporation container, A/h , so that a desired concentration, C_v , is obtained in space V .

For the purposes of supplying purified air at a fixed rate, R , the extraction of impurities from air by recirculation through activated carbon is equivalent to replacing the air in the space with fresh outside air in the same ratio (5). Therefore, the value of C_v (Equation 5) will be the same regardless of whether R is supplied by activated carbon-air purification of recirculated air, or by outside air ventilation, or by both methods simultaneously, so long as the same total rate of contaminant-free air is supplied to the space. If the equipment for air purification by activated carbon operates at an efficiency less than 100%, the

same value of R can nevertheless be satisfied by processing a quantity of air equal to the necessary rate of supply of contaminant-free air divided by the adsorption efficiency. The adsorption efficiency of commercial equipment for air purification is about 95%; therefore, to obtain R air changes per unit time the capacity of such equipment must be sufficient to process $VR/0.95$ unit volumes of space air per unit time.

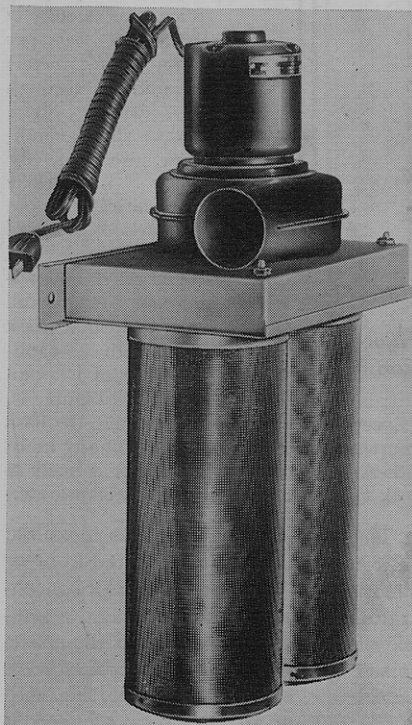
In actual practice the substitution of activated carbon purification of recirculated air for outdoor air ventilation is often not only optional but desirable or mandatory. When the space under consideration is mechanically refrigerated, it is manifestly prohibitive in cost to supply large quantities of outside air ventilation. The use of activated carbon adsorption is then economical. In other cases—e.g., olfactory measurements—the outside air may not be sufficiently free of extraneous vapors or odors, in which case the use of carbon adsorption is mandatory.

Ethyl Mercaptan Vapor

An experiment was set up to apply these principles to the establishment of a weak, constant odor of ethyl mercaptan (ethanethiol) in a space. Because the odor threshold concentration is very low and this substance has a powerful stench, such an objective is not easily obtained by ordinary methods. This is reflected in the widely divergent values reported for its odor threshold concentration.

The space used was a clean, empty commercial walk-in cooler of wood construc-

Figure 2. Equipment for air purification



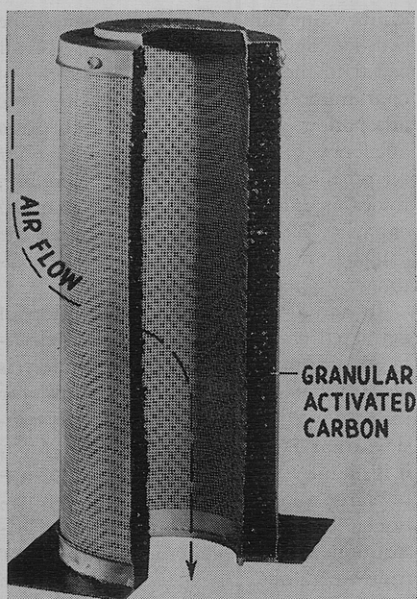


Figure 3. Cutaway view of activated carbon canister

tion, provided with gravity coil refrigeration, of 160-cubic-foot capacity, and maintained at 29° F. This space was provided with activated carbon air purification. The purification equipment used was a commercial unit (Dorex Air Improver, Connor Engineering Corp., Danbury, Conn.) consisting of dual perforated adsorption canisters filled with activated carbon and assembled integrally with a motor-driven air blower (Figure 2). Each canister (Figure 3) contained 1.7 pounds (3100 grams) of granular activated carbon, suitable for gas adsorption, arranged in a uniformly dense 0.7-inch (1.8-cm.) cylindrical bed. The blower circulated air

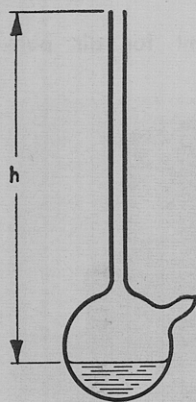


Figure 4. Diffusion flask

(Except for the capillary opening, the flask must be sealed without joints of any kind; otherwise some mercaptan odor is likely to leak through by dissolving lubricants, etc.)

The odor in the space was measured in terms of the dilution required to bring the space air to its threshold odor concentration. For odor measurement, a sample of air was removed from the space, mixed with a known volume of odorless outside air, and smelled. Starting with 100% outside air, the ratio of odorous

space air to odorless outside air was increased stepwise until odor first became apparent. This approach to threshold from the odorless side eliminates adaptation error. The mixing equipment (Figure 5) contained two plates, each with 25 holes which could be corked. The total quantity of air supplied to the smeller was 10 cubic feet per minute, sufficient to simulate actual sniffing of a gaseous space. At the start of the test, the 25 holes to the odorous space were corked, and the 25 holes to the outside were open. Dilution was then decreased stepwise by corking one outside hole and uncorking one hole to the odorous space. The total quantity of smelled air was thus never changed. Then,

$$\frac{\text{Concn. of odorant in space}}{\text{Threshold odorant concn.}} = \frac{25}{\text{No. of openings to odorous space}}$$

The odorant concentration in the space may then be most conveniently controlled by regulating h , and should be inversely proportional to it. Figure 6 shows a straight-line plot of

$$\frac{\text{Concn. of odorant in space}}{\text{Threshold odorant concn.}} \text{ vs. } \frac{1}{h}$$

If the other factors in Equation 5 are known, this method gives a new approach to the determination of odor threshold concentrations which is not likely to suffer from gross adsorption errors.

The same general method has been applied to the establishment of controlled bromine concentration in a space to inhibit ethylene-stimulated acceleration of lemon respiration (6), ethylene-produced injury to growing orchids (7), and mold disease of tomatoes (2).

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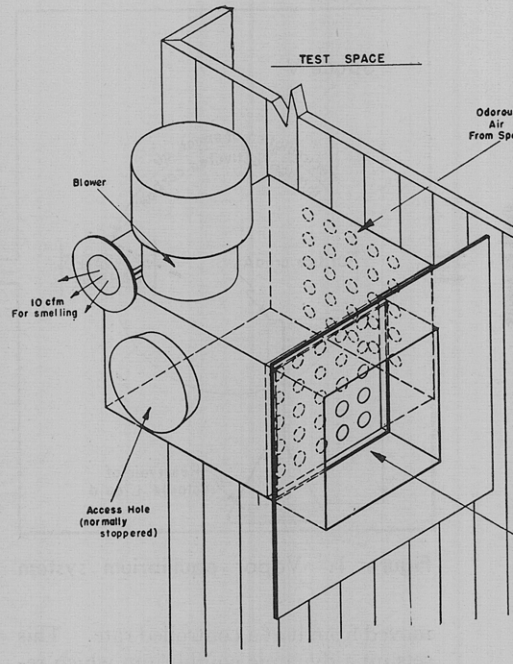


Figure 5. Air proportioner

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Figure 6. Relative odorant concentration vs. reciprocal of diffusion path

