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Control of Odors From Anaerobic Lagoons Treating Food Processing Wastewaters

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CONTROL OF ODORS FROM ANAEROBIC LAGOONS TREATING FOOD PROCESSING WASTEWATERS

by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Envuronmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these ends both efficiently and economically.

This report reviews the physical chemistry involved in odor release from liquid surfaces, mechanisms of odor perception, and techniques currently employed for odor measurement. These concepts and data are applied to anaerobic lagoons as presently being used to produce a low cost, energy-efficient device for treatment of organic wastes. Field experiences are related in which meat packing plant lagoons presented a problem due to odor complaints.

Finally, the technology is identified which must be developed in order for anaerobic lagoons to receive societal sanction. A research plan is presented to evaluate one proposed solution to the technology need. For further information on the subject, contact H. Kirk Willard, Chief, Food and Wood Products Branch.

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ABSTRACT

Anaerobic lagoons are used for the treatment of meat packing wastes in most areas of the country. They are a relatively low cost means of achieving BOD reduction. Although lagoon effluent is not suitable for stream discharge, it is amenable to further treatment or to land application.

One of the most serious limitations of anaerobic lagoons in this application is odor production. Odor complaints have been widespread but have been most frequent in areas of high sulfate waters and during start-up. There has been little specific research effort devoted to anaerobic lagoon odor control.

This report assembles existing information relative to odor control associated with anaerobic lagoons used in the meat packing industry and identifies opportunities for productive research. It provides a basis for approaching the overall problem in a comprehensive fashion. This report identifies six research techniques which could make significant contributions toward solving the odor problems.

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SECTION 1

INTRODUCTION

Anaerobic lagoons have been identified as low-cost means of treating meat plant wastes. They have achieved widespread application throughout this country and much of the world. The greatest application has been to small- and medium-sized packers; however, anaerobic lagoons have been utilized for several larger packing plants.

Anaerobic lagoons are basically engineering earthen basins which detain waste while it undergoes anaerobic bacterial decomposition. The rate of decomposition is a function of organic matter concentration and temperature. Since meat packing wastes typically include significant proportions of hot water, they respond well to lagoon treatment.

One of the most frequent problems mentioned relative to anaerobic lagoons is odor. Being an anaerobic biological process, the end products are highly reduced components. Typical constituents are ammonia, methane, hydrogen sulfide, and carbon dioxide. Other intermediates involved in the decomposition of many by-products include amines, mercaptans, alcohols, ketones, and other more complex organic compounds. Therefore, anaerobic lagoon contents are a solution of input, intermediate breakdown products, and end products of bacterial decomposition.

In order for an odor problem from an anaerobic lagoon to arise, a series of events must occur. The odorous compound must be discharged to the lagoon or be formed within the lagoon by anaerobic biochemical processes. The odorous compound must volatilize and escape from the lagoon surface. The volatile odorous gas must be transported from the lagoon surface to the proximity of people. And finally, there must be people to serve as receptors who are offended by the smell they perceive.

The chain of events necessary for an odor problem to arise also provides a key to the control of odors. Remedial measures which halt or modify any one or more of the events leading to odor problems can be expected to decrease or change perceived odor intensities.

The purpose of this report was to assemble existing information concerning anaerobic meat packing plant waste treatment lagoon odors in a single location and to draw from this information guidance in effective odor control technology development.

SECTION 2

DOCTRINE OF NUISANCE

Ownership of land includes the right to impregnate the air with odors, dust and smoke, pollute the water, and make noise, provided these actions do not substantially interfere with the comfort of others or hamper the use and enjoyment of their property. Whenever a person uses his land in such a way as to violate this principle, he may be guilty of maintaining a nuisance. Thus, the doctrine of nuisance acts as a restriction and is applied to a series of wrongs which may arise from unreasonable, unwarranted or unlawful use of property to produce annoyance, inconvenience, discomfort or hurt that the law will presume to be a damage. What constitutes a nuisance in a particular case must be decided based upon the facts and circumstances of that instance.

Nuisance has been classified as either public or private. A nuisance is said to be public when the public at large or some considerable portion of it is affected or when the act is done in violation of law. When a public nuisance is involved, legal action may be brought by a public official. A private nuisance generally affects only one person or a specific number of persons and is grounds for a civil proceedings only.

The fact that a business is carried on carefully and in accordance with the ordinary methods employed in that business does not relieve the owner or person responsible for liability to a neighbor if that business is unreasonable and constitutes a nuisance. Paulson (1967) states that a livestock feeding operation, in itself lawful, is not a nuisance per se. When it interferes with another's use and enjoyment of property or injures that property, it may become a nuisance by virtue of the way it is maintained or operated. The precise degree of discomfort that must be produced to constitute a nuisance must be determined upon the basis of being reasonable or unreasonable.

For an odor to be considered a nuisance, the stench must be offensive to the senses and materially interfere with the comfortable enjoyment of property within the area (Paulson, 1967). It is not necessary that the odor be harmful or unwholesome. It is sufficient if it is offensive or produces such consequences, inconvenience or discomfort as to impair the comfortable enjoyment of property by persons of ordinary sensibility.

A person who suffers damages or feels that he suffers damages because of the odor of a livestock operation has two courses of action open to him: a suit for damages, or a suit to enjoin or abate the nuisance--and he may pursue either or both. The remedies of injunction or abatement are generally considered harsh by the courts; normally, only that part of the operation which amounts to a nuisance will be abated or enjoined. When the nuisance results solely because of the method of operation or manner in which business is conducted, the decree will be formed only to prevent that particular method or manner rather than prohibiting completely the use of the property by the person creating the nuisance. It is an essential element for injunctive relief that annoyance or injury be continuous or recurrent. The use of premises which create a nuisance may be enjoined, however, if it reasonably appears that such annoyances or injury will be recurrent.

To be liable for actual damages one need only create or commit a nuisance. The injured party is normally allowed to indicate the best or most advantageous use of his property; this is then used as a basis for determining the amount which would be adequate and fair compensation (Paulson, 1967). Punitive damages are allowed only when it can be shown that one has created and persistently maintained a nuisance with reckless disregard for the rights of others, or when one has reason to believe that his act may injure another and does it in defiance of the rights of others. The mere commission of an act justifying an award of actual damages is not sufficient to justify the award of punitive damages as a penalty.

SECTION 3

THEORY OF ODOR PERCEPTION

Each of the five senses is used to bring us information about our environment. The ability to touch, taste, hear, see and smell brings us into contact with our external world in such a way as to give us a better understanding of its status and changes. The response to these senses is essentially a personal reaction. Whether a sound is pleasant, a feeling satisfying, a taste enjoyable, a scene beautiful, or a smell desirable is fundamentally an individualized response based upon cultural background and momentary disposition of the individual.

The senses of touch, taste, hearing and sight all measure environmental parameters also measurable by other techniques as shown in Table 1. The sense of smell is unique in that no mechanical or chemical alternative device exists for measuring odor. Thus, odor is largely a subjective phenomenon for which no quantitative standard of comparison exists.

The human nose is the basic detector in odor analysis. It may be supplemented in some cases by other instruments, but there is no replacement for it even though the complexities of its functioning are not thoroughly understood (Barth, 1970). Moulton (1965) stated that the final approach in odor and flavor identification is "a bioassay based on stimulation of the human nose. But the behavioral response of a man is not a simple objective index of olfactory sensitivity. It is the end product of a complex flow of interacting events, molded by the needs and experiences of the individual--by the input of many classes of information. Yet, in the last analysis, there is no adequate substitute." Measurement of odor intensity and quality must be preceded by an understanding of the way the nose functions to distinguish one odor from thousands of others.

Inspired air typically travels into the nostrils, through the turbinate area and down the throat to the lungs. Normal breathing causes only a small portion of the air to reach the olfactory cleft and the olfactory nerves, located high in the nasal cavity. A "sniff," characterized by a short burst of air inspired at a rate greater than normal breathing, brings about extensive turbulence and diffusion to all parts of the cavity. Odor sensation is much more obvious from a concerted sniff than from the normal breathing rate.

TABLE 1. THE HUMAN SENSES, EXAMPLES OF PARAMETERS MEASURED AND ALTERNATE INFORMATION SOURCES

Sense	Parameter measured	Alternate device	Unit of measurement
Sight	Color, intensity	Colorimeter, light meter	Wave length, lumens
Sound	Pitch, intensity	Tuning fork, microphones	Frequency, decibels
Taste	Saltiness, sour	Chemical titration pH	mg/l, pH unit
Touch	Temperature, hardness	Thermometer	Degree
Smell	Odor	None	None

The olfactory nerve cells are located in the olfactory cleft area. The total olfactory reception area in the adult human is about two inches square. Olfactory cells are long and narrow, and are oriented perpendicular to the surface of the receptor area; cells are pigmented yellow or yellow-brown. There are different kinds of odor receptor cells--cells that respond to different odor stimuli. On the exposed end of the nerve cells are five to eight olfactory hairs extending into or through the mucous layer which coats the surface of the mucous membrane.

It is believed that olfactory hairs are the means of reception of the "signal" of the odorous molecule. A chain of events follows which instantaneously gives odor perception. The hairs are kept moist by the mucous layer. An excess of mucus, as in the case of a head cold, can incapacitate the hairs and, thus, the sense of smell.

Moncrieff (1966) describes the mechanism of olfaction in six stages:

(a) The molecules of a volatile substance are continually lost to the atmosphere.
(b) Some of the molecules, inspired with air into the nasal cavity, are directed to the olfactory receptors. The air of a sniff is beneficial but not essential.
(c) The odorous molecules are adsorbed on appropriate sites on the olfactory nerve cells.
(d) The adsorption is accompanied by an energy change.
(e) An electric impulse, generated by the energy change, travels from the olfactory receptor to the brain.
(f) The brain processes the information and transmits the sensation of smell.

MECHANISMS OF PERCEPTION

A precise relationship between chemical composition and odor would make it possible to predict accurately the odor of an unknown compound or to formulate a compound with a required odor. Recent findings have shown that odor is closely associated with molecular configuration, but this, according to Moncrieff (1967), is only half the story of odor perception. The other half consists of the receptor system and brain of the person doing the smelling.

An acceptable odor theory must account for odor phenomena. Some of these are listed here:

(a) Only volatile substances are odorous.
(b) Air movement into the nasal cavity is necessary to feed the receptors.
(c) If air movement in the nasal cavity stops, odor sensation vanishes.
(d) Water, though having the characteristics of other odorants, has no odor.

(e) Gases such as oxygen and nitrogen have no odor.
(f) Exposure to an odor produces a high initial response and a declining response with continued contact. (Adaptation)
(g) A strong odorant completely exhausts the capacity to perceive odor in two to three minutes. (Fatigue)
(h) A change in odor sometimes occurs on dilution of the odorant.
(i) Some animals have a better developed sense of smell than humans.
(j) Isomers (having the same chemical composition) have widely differing smells.
(k) Compounds having widely differing chemical compositions have similar smells.
(l) Some odorants are perceived at a concentration of one millionth that of others.

The theories of odor perception differ essentially in the method by which the "message" of the odorant is transmitted to the olfactory nerve. Primary theories have proposed (a) chemical reaction, (b) physical adsorption, and (c) molecular vibration as the cause of initial stimulus.

The chemical theory can be largely discounted on the basis of work done on a freshly severed sheep's head (Moncrieff, 1967). An odorant was passed through the nasal cavity of the head and collected and analyzed after passage. The first collection of air which had carried the odorant into the sheep's head contained none of the odorant. After a short time, the air passing through the head contained a concentration of odorant equal to that entering. The odorant supply was cut off and the airstream continued to circulate through the nasal cavity until no odorant was detected in the exit air. After a period of time, up to several hours, the air flow was again started. No odorant was added. The discharged air again contained the odorant in its original form. No chemical action had taken place. The process of adsorption is essential in odor perception.

The stereochemical theory of Amoore (1963) was first introduced in 1952. This theory was based upon a fit between an odor molecule and a "socket" at the receptor site in the nose. Seven types of receptor sites were proposed to serve the seven primary odors--ethereal, camphoraceous, musky, floral, pepperminty, pungent, and putrid. Other odors resulted from combinations of primary odors. Amoore has more recently altered his theory to account for a two-dimensional rather than three-dimensional fit. Molecular silhouette of cross-sectional area is the important steric characteristic of the odorant (Amoore et al., 1967). Odor perception is initiated by an energy change brought about by adsorption of the odorant molecule on the olfactory nerve.

Residence time of the odorant substance on the nerve is on the order of 10^{-8} seconds. The time required for the puncture to heal is longer--on the order of 10^{-4} seconds. In the interval between desorption and healing of the puncture, an exchange of Na^+ and K^+ ions occurs. This exchange, brought about by an excess of Na^+ on the exterior and K^+ on the interior of the membrane, is the stimulus for the olfactory perception process.

These theories are the basis for most of the research related to olfactory perception in recent years. Two points of agreement exist in these theories: (a) the process is initiated with the adsorption of the odorant molecule on the olfactory nerve, and (b) the cross-sectional properties of the molecule are a controlling factor. Again, the primary difference is the manner by which the characteristic odor of the molecule is translated to the olfactory nerve. It is feasible that all these theories might be involved in the actual odor perception reaction.

Finally, the odorant substance must possess certain characteristics if it is to be subject to the theories presented: (a) the substance must be sufficiently volatile that molecules can be transported to the nasal orifices, (b) solubility in the lipoid material of the mucous membrane is essential (solubility in water is helpful), and (c) the odorous substance must be able to be adsorbed onto the sensory nerve.

ODOR STRENGTH

Accurate characterization of an odor includes reference to its strength, or intensity, and its quality. ASTM Special Technical Publication No. 434, "Manual on Sensory Testing Methods" (ASTM, 1968) effectively describes the ground rules for conducting odor strength and quality tests. The manual states requirements for physical facilities, test subjects, and samples to be tested. Kinds of tests that may be applied are discussed along with procedures for analysis of the data. The manual does not, however, describe the detailed procedure by which individual tests must be conducted. Such details are dictated by the kind of material and characteristic of odorant being judged.

The most common method of measuring odor intensity is by dilution to extinction. An odorant is diluted with an odor-free medium until its odor can no longer be detected. The greatest dilution at which the odorant is just barely detectable is termed its threshold value. Baker (1964) compared four common procedures for determining threshold value of an odorant in odor-free water dilution:

- (a) Standard Method, STD: five flasks containing serial dilutions plus one "catch trial" blank;
- (b) Consistent Series, CS: five flasks containing serial dilutions plus two blanks;
- (c) Triangle Test, TT: three flasks at each dilution level, two which are blank; and

(d) Short Parallel, SP: two flasks at each dilution level, one of which is blank.

Tests were run using two odorants, n-butanol and m-cresol. Results showed that the tests, in order of decreasing sensitivity, were TT, CS, SP and STD. However, Baker points out that no test is obviously superior when performed under controlled conditions with trained personnel.

Odor intensities are stated in terms of odor intensity index, OII, or threshold odor number, TON. The two values are related, according to the equation

$$2^{OII} = TON$$

OII is defined as the number of times an odorant must be diluted by half with odor-free medium until the threshold is reached. TON is defined as the greatest dilution of the odorant with odor-free medium until the threshold is reached. Most writers seem to prefer OII to TON. Certainly an OII value of 15 is less cumbersome and easier to grasp than the equivalent TON value of 32,768.

Odor intensity testing can be objective in nature if a sufficient number of qualified, properly prepared observers are used and procedures and conditions of the test are standardized. ASTM (1968) states that the minimum number of observers for any test is five, since any fewer places too much dependence on the response of any one individual. Subjects must pass a preliminary screening to assure that they are capable of making a normal response to the stimuli to be presented.

ODOR QUALITY

Odor quality references are often made by comparing the odor with an odor that is familiar. The odor is "like coffee," "like new-mown hay," or "like a characteristic poultry odor." The judgment of "characteristic poultry" would depend on past experiences. This recollection could result from a light, well-ventilated house with little more than the smell of must or feed to a highly populated house with poor ventilation, high humidity, and concentrated ammonia. One's interpretation might include a wide range of quality values.

Many attempts have been made to produce a list of basic odor classes that would describe the qualities of all other odors. Five of these lists are presented in Table 2. Classes of similar qualities are placed on the same line.

Qualitative odor testing is widely used in the food and perfume industries; however, use of qualitative odor testing in waste treatment research is limited. The test is often made by comparing an unknown with a known odorant of similar or dissimilar

TABLE 2. BASIC ODOR QUALITY CLASSIFICATIONS AS DESCRIBED BY FIVE AUTHORS (MONCRIEFF, 1966)

Zwaardemaker 1895	Henning 1916	Crocker and Henderson, 1927	Amoore 1952	Davies 1965
Ambrosial			Musky	Musky
Balsamic or fragrant	Flowery, resinous	Fragrant	Floral	Floral, cedary
Ethereal	Fruity		Ethereal	Ethereal, fruity alcoholic
Aromatic	Spicy		Camphoraceous	Camphora-ceous, aromatic
			Minty	Pepper-minty
Empyreumatic	Burnt	Burnt		Almond
Alliaceous	Foul			
Caprylic		Caprylic		
Repulsive				
Nauseating, foetid			Putrid	
		Acid	Pungent	

quality in paired comparisons. The observer then judges the degree of similarity.

Odor quality testing lacks the desired objectivity of odor threshold determinations. Quality tests require observer judgments relative to a known odorant and subjectivity is unavoidable.

LIMITATIONS OF ODOR TESTING

The limitations of odor testing arise from the existence of odor phenomena and the preferences (or subjectivity) of observers. The sources of these limitations will be discussed individually. It should be apparent how each limitation can enter into the interpretation of odor test results.

Adaptation

Adaptation is the adjustment of the observer to an odor stimulus. The level of sensation diminishes with time even though the stimulus is applied at a steady rate. Observers who enter the vicinity of lagoons soon lose the ability to make unbiased odor judgments about odorants similar to those of the immediate environment. Rate of adaptation varies with strength of the stimulus. Moncrieff (1966) demonstrated adaptation as follows: a subject who first took a sniff of pure acetone could recognize nothing less than 5.0 percent acetone with a second sniff. This is 170 times threshold concentration. The effect of a dissimilar odor was not so great--after smelling pure acetone, n-butanol could be recognized at 0.06 percent, or 12 times threshold concentration.

Fatigue

Fatigue is the result of adaptation. Exposure to a strong odorant may completely exhaust the capability to sense odor. Fatigue develops gradually, with an exposure of two to three minutes required for total exhaustion. Recovery after removal of the odorant requires about the same length of time. Fatigue is selective--that is, fatigue to one odor will reduce sensitivity to similar odors, but does not produce fatigue for all odors.

Odorant Concentration

Changes in odor quality sometimes occur due to dilution. For example, concentrated furfuryl mercaptan has a nauseating odor but is reminiscent of the aroma of coffee when greatly diluted.

Moncrieff (1967) reported the concept of limiting intensity, which states that the human nose cannot distinguish between odorant concentrations greater than saturation level. The reasoning behind this concept (which heavily supports the adsorption theory of odor) is that receptor sites become filled with odorous molecules and an increase in the number of molecules inspired causes no increase in sensation.

Mixtures

Rosen et al. (1962) listed four possible reactions for mixtures of two individually odorous components. In these equations, R_A is the odor stimulus of component A, R_B is the odor stimulus of component B, and R_{A+B} is the odor stimulus from the combination of components A and B.

(a) Independence $R_{A+B} = R_A$ or R_B

(b) Antagonism or counteraction $R_{A+B} < R_A$ or R_B

(c) Additions $R_{A+B} = R_A + R_B$

(d) Synergism $R_{A+B} > R_A + R_B$

Moncrieff (1967) described counteraction (the mutual discrimination) of two odors to the extent that they are odorless in combination. Using low concentrations of the odorants they tended to be additive, but with certain combinations of high concentration, the effect was no odor. Guadnagni et al. (1963) found that combination of sub-threshold concentrations of odorous components produced suprathreshold mixtures.

Without prior knowledge, the quantitative and qualitative outcome of the reaction of the combination of two components is unpredictable. In addition, the type of reaction can vary according to the concentration of the components.

Anosmia and Parosmia

Anosmia (odor-blindness) is a condition which affects about 10 percent of the population. Partial anosmia--anosmia for a group of similar odors--is more common than complete anosmia. Partial anosmia is much more likely to exist without the knowledge of the afflicted person.

Parosmia (perversion of odor) is a second type of olfactory disease: the parosmatic senses a different odor than the one put before him. The perverted odor is often an unpleasant one. But the condition is likely to be temporary.

Pungence

"Pungent" has been included as a basic odor type by some authors. This classification is associated with strong acidic and basic smells. Pungence may not be a true olfactory nerve response, but a sensation of pain caused by irritation of the trigeminal nerves in the nasal cavity.

SUPPLEMENTARY INSTRUMENTS

The gas-liquid chromatograph, GLC, has been the most important instrument in supplementing the capabilities of the human nose in odor research. While the nose can best determine quality and intensity of simple and complex odor combinations, the GLC can best fractionate and quantify the odorant components involved. The capabilities of one do not replace the capabilities of the other. Advancing technology has made possible increased sensitivity of the GLC and, therefore, greater capacity to identify the trace quantities of odorants in complex materials.

Odormeters of various forms have been developed to assist in test work. The meters are of the general form that can make the necessary dilutions of odorant with odor-free air prior to inspiration. The meters have been given such names as "osmoscope," "odormeter" and "osmometer."

Development of a "mechanical nose" which would eliminate errors of natural variation and subjectivity in the human nose would greatly advance odor research. The most important obstacle in such a development continues to be the lack of understanding of the odor perception process of the human nose. Even so, several researchers have made efforts to duplicate the human nose.

SECTION 4

QUANTITATIVE MEASUREMENT OF ODORS

The technological difficulties of quantitative odor measurement are formidable. Odor is essentially a subjective response to the mixture of chemical compounds present in air. This response is a function not only of the chemical make-up of the air but also of the psychological disposition of the observer as well. Evaluation of an odor is thus a complex physiological and psychological process and it is little wonder that techniques for quantitative measurement of odors have been fraught with difficulty. Two separate aspects of odor can be identified: strength or intensity, and quality.

ODOR STRENGTH

Odor strength or intensity is the more direct and easily measured of the two aspects. The current concept is that each odor source may be diluted sufficiently with odor-free air to be indistinguishable from odor-free air by the human nose. That concentration barely distinguishable from odor-free air is termed the threshold odor. The strength of an actual odor can be defined in terms of the number of dilutions with odor-free air required to reduce the odor to threshold concentration.

Similar to the air dilution technique is a liquid dilution method. In this technique, a sample of odorous material is mixed with odor-free water. Generally, the diluted sample along with some odor-free samples is offered to a panel of observers. The general technique is to make up a series of five bottles for the panel, two containing a dilution of odorous material, the other three containing odor-free water. Panel members are asked to mark on their score sheets those bottles which contain the odorous material. By making a series of dilutions and offering them to the odor panel for evaluation, minimum detectable concentrations of the material can be determined. By making liquid dilutions successively greater by a factor of two, resulting data can be used to determine an odor intensity index (OII). In other words, if threshold odor were determined to be diluted 15 parts odor-free water to one part odorous solution, the odor intensity index would be 4. A second means of expressing this information would be a threshold odor number (TON), which is equal to two raised to the odor intensity power.

SCENTOMETER

Field measurements of odor intensity are difficult because of the lack of an overall acceptable measuring device and the inability of people to accurately describe odors. One device on the market for the estimation of odor intensity is the scentometer. The scentometer is essentially a rectangular, plastic box containing two air inlets (one for each activated charcoal bed) and four odorous air inlets (1/16-, 1/8-, 1/4- and 1/2-inch in diameter). The odorous inlets are directly connected to a mixing chamber and the nasal outlets (see Figure 1).

In field operations, the observer takes the scentometer where odor intensity is to be measured. He places the device to his nostrils, covering the odorous air inlet ports with his fingertips and breathes through the instrument to adjust his sense of smell to odor-free air. The concept is that any air entering his nostrils under these conditions will have passed through the activated charcoal bed and be odor-free. Once the observer's sense of smell has become acclimated to odor-free air and his sense of smell rested to the point of maximum sensitivity, the ports are opened in successively larger diameters beginning with the 1/16-inch port. He continues in this manner until an odor is first detected coming through the device. The design is such that odorous air is mixed with filtered air in definite proportions so that recording the port or ports opened at the time an odor was first detected provides a measure of the dilutions required to reach the odor threshold. Table 3 provides a correlation between the ports which are open and the calculated dilution entering the nostrils of the observer. With a combination of ports open, it is possible to estimate odor dilutions through thresholds ranging from 1.47 to 170. Measurements made with more than one port open, however, are subject to question because of the frequent inability of the observer to detect small differences in odor intensity.

In discussing the scentometer, Huey et al. (1960) stated that their experience had shown that odors about seven dilutions to threshold would probably cause complaints while those measuring 31 dilutions to threshold could be described as a serious nuisance if they persisted for a considerable length of time. The scentometer was described in a paper by Rowe (1963), in which he indicated that it required about ten times the perceptible odor threshold to give a definite sensation of odor and another tenfold increase to be considered a strong odor.

The scentometer has received rather widespread application in animal waste odor evaluation. In spite of its application, however, there are several basic limitations to this approach. The sensitivity of the observer is highly important in determining the values achieved with the instrument. Although sniffing through the scentometer with odorous air ports closed is designed to restore normal sensitivity, complete restoration of sense of smell

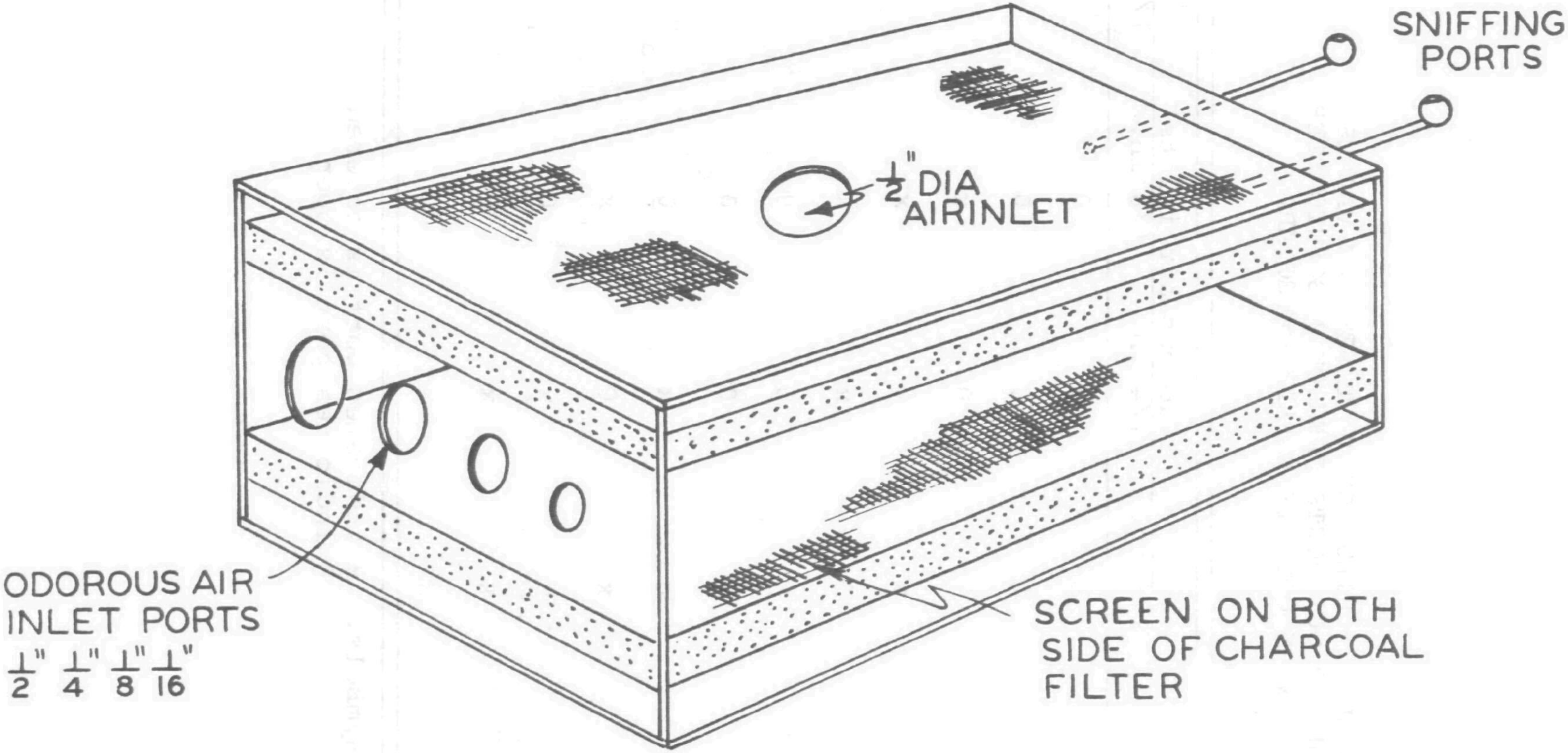

Figure 1. Scentometer

TABLE 3. DILUTION TO THRESHOLD VALUES WITH VARIOUS PORTS OPEN ON A SCENTOMETER WHEN AN ODOR IS BARELY DETECTABLE

Dilutions to threshold	Odorous air inlets[1]			
	1/2 in.	1/4 in.	1/8 in.	1/16 in.
1.47	0	0	0	0
1.49	0	0	0	x
1.55	0	0	x	x
1.88	x	0	x	0
2.0	0	x	x	x
5.55	x	0	0	0
5.75	x	0	0	x
6.75	0	x	0	x
7.0	x	0	x	x
27.0	x	x	0	0
31.0	x	x	0	x
170.0	x	x	x	0

[1]Definition of symbols: x indicates port is covered
0 indicates port is open

may not occur rapidly enough to obtain meaningful results. The charcoal bed can become saturated and not give complete odor removal from air breathed when all ports are closed. Since there is no indicator to show if the carbon is saturated, misleading results may be obtained under these conditions. Intermittent odors common in animal waste, particularly when observations are made some distance from the odorous source, present additional difficulties and require use of the scentometer over a considerable period to obtain representative data. In spite of these limitations, however, the scentometer is a useful device, and is being used by some regulatory agencies.

ODOR QUALITY

In contrast to odor strength, which can be quantitatively evaluated, there is no straightforward technique to quantify odor quality. Most frequently, odor quality is described by comparison to a common odorant or sensation with which the reader or listener is familiar. For example, White et al. (1971) used the following terms to describe the odorous components of dairy waste: foul, sweetish, acetate, nutlike, pungent, and musty. In describing the odor of various fractions of poultry manure odor, Burnett (1969) used the following words: rotten egg, rotten cabbage, onion-like, putrid, butter-like, and garlic.

An alternative method to evaluate odor quality was used by Sobel (1971). He asked a panel of odor evaluators to select a number from one to ten, indicating the degree of offensiveness of the samples. A nonoffensive odor was marked as 0, a very strong offensive odor was ranked as 10, a definite offensive odor was 6 and a faint offensive odor was 4. He also asked panel members to select suitable descriptors from the following list to describe the odor of the sample: mold, musty, fish, stagnant water, sulfide, rotten egg, petroleum, earth, yeast, ammonia, grain, feed, sour, fermented, and cabbage. Using this approach, he was successful in differentiating the offensiveness of an odor and the odor strength.

SECTION 5

RELEASE OF AMMONIA AND HYDROGEN SULFIDE FROM LIQUID SURFACES

Wastewaters of both human and industrial origin contain sulfurous and nitrogenous compounds which have been implicated as contributing to odor production. Under anaerobic conditions, these compounds are typically converted to their most reduced states, hydrogen sulfide and ammonia. The evolution of these compounds has been investigated from a physical chemistry perspective in work summarized in a paper prepared by C. N. Click and J. C. Reed, entitled "Atmospheric Release of Hydrogen Sulfide and Ammonia from Wet Sludges and Wastewaters." Their material has been utilized in this discussion where it is pertinent to the release of odorous materials from anaerobic meat packing plant lagoons.

HYDROGEN SULFIDE IN WASTEWATER

The evolution of hydrogen sulfide (H_2S) from sewage has been documented frequently for sewers and sewage works. Gravity sewers and force mains may produce soluble sulfide buildup to the point of odor nuisance, sewer corrosion and toxicity. Gravity sewers are less subject to sulfide production than force mains since more oxygen is available in gravity sewers and oxygen must be virtually absent from sulfide accumulation. Oxygen will eventually cause previously formed sulfides to be converted to soluble non-volatile sulfates. Iron and other heavy metals form insoluble suspensions of sulfides which are not normally available for reaction of H_2S.

In most wastewaters, sulfides are usually present in both organic and inorganic forms. The organic "sulfides" are not measured by the usual wastewater tests, but they may contribute to nuisance conditions either by being odorants (such as mercaptans, thioethers, and disulfides), or by contributing soluble "inorganic" sulfides via biological degradation. Inorganic sulfides may be measured by the standard wastewater tests but not all of the inorganic sulfides may be available for H_2S formation because as noted above, some heavy metals form insoluble sulfides.

The threshold of taste/odor detection of H_2S is reported to be between 1.0×10^{-5} and 1.0×10^{-4} mg/l in water (Pomeroy and Cruse, 1969) and to be about 4.7×10^{-4} ppm in air (Leonardos et al., 1969) where ppm is by volume. The threshold limiting value (TLV) for H_2S in air is 10 ppm, but various studies (WPCF, 1969) have reported that 100 to 300 for one hour is the maximum tolerable short-time exposure or even that 300 ppm can cause death in a short time. The low concentrations of taste/odor detection practically guarantee that odor nuisances exist before toxicity problems can occur and sometimes before noticeable corrosion results. Unfortunately, the higher (greater than 10 ppm) concentrations render the olfactory sense ineffective very quickly, so workers are not continuously reminded of the danger.

AMMONIA IN WASTEWATER

The evolution of ammonia (NH_3) from wastes is possible. Meat packing wastes contain nitrogen in several forms. Most is derived from the breakdown of the organic materials, urea and protein. The thresholds of odor detection and recognition of ammonia have been reported (Stahl, 1973) to be between about 0.04 and 47 ppm. It is interesting that although the 1972 TLV for ammonia was given as 50 ppm, proposed changes would reduce the TLV to 25 ppm.

HYDROGEN SULFIDE EVOLUTION AND pH

Substances that react in aqueous solution to accept or donate electrons (and consequently donate or accept protons) dissolve to a degree dependent upon solution pH and their dissociation constant (K). For an acid the equilibrium dissociation constant, K, is defined by the dissociation equation, which for H_2S is:

$$H_2S \rightleftarrows HS^- + H^+ \tag{1}$$

The subsequent dissociation of the bisulfide ion (HS^-) into a second proton and sulfide ion with a second constant need not concern us because neither the bisulfide nor sulfide ion ($S^=$) has an odor or vapor pressure itself. Ionization as in equation (1) removes the reactive gas from gas-solubility considerations. Equation (1) gives K_1 by definition:

$$K_1 = \left[H^+\right]\left[HS^-\right]/\left[H_2S\right] \tag{2}$$

where $[\ ]$ symbolizes concentration in mol/l.

By rearranging equation (2) and substituting the definition for pH and pK (analogous to pH), we obtain:

$$pH = pK_1 + \log \left[HS^-\right]/\left[H_2S\right] \tag{3}$$

Equation (3) is the relationship between the pH of a solution of hydrogen sulfide and the concentrations of the dissolved gas (H_2S) and the bisulfide ion (HS^-) in solution.

Defining the total soluble sulfide concentration (before reacting) as C_1 and f_1 as the fraction dissociating at equilibrium, the concentrations become $H_2S = (1 - f_1)\ C_1$; $HS^- = H^+ = f_1C_1$. Substituting these values in equation (3) and taking antilogs:

$$(f_1) = 10 \exp\ (pH - pK_1)/\left[1 + 10 \exp\ (pH - pK_1)\right] \quad (4)$$

and

$$(1 - f_1) = 1/\left[1 + 10 \exp\ (pH - pK_1)\right] \quad (5)$$

Equation (4) gives the bisulfide ion and (5) the gaseous hydrogen sulfide fraction for a solution with any total soluble sulfide concentration as a function of solution pH. Equations (4) and (5) thus give the fraction of dissociated and undissociated hydrogen sulfide, respectively.

Equations (4) and (5) show that at a given temperature, the percent dissociation of a reactive gas is controlled entirely by the system pH (providing there are no competing reactions) and can be calculated for chosen values of pH from the pK alone. For hydrogen sulfide, $pK_1 = 7.02$ at 25 $^{\circ}C$ and thus at a solution pH of 7.02.

$$(1 - f_1) = 1/(1 + 10^{0.0}) = \tfrac{1}{2} = 0.5 \quad (6)$$

When solution pH = pK the solute is 50 percent undissociated (gas) and 50 percent dissociated (ions). Increasing acidity (low pH) will result in higher values of $(1 - f_1)$ or undissociated H_2S over wastewater solutions.

AMMONIA EVOLUTION AND pH

The relationship between the evolution of ammonia and pH is analogous to that for hydrogen sulfide. Consider the equilibrium reaction between ammonium ion and gaseous ammonia:

$$NH_4^+ \rightleftarrows NH_3 + H^+ \quad (7)$$

If the original concentration of ammonia is C_2, and f_2 is the fraction reacting, at equilibrium we have:

$$K_2 = \left[NH_3\right]\left[H^+\right] / \left[NH_4^+\right] \quad (8)$$

$$pH = pK_2 + \log \left[NH_3\right] / \left[NH_4^+\right] \quad (9)$$

$$f_2 = 10 \exp\ (pH - pK_2)/\left[1 + 10 \exp\ (pH - pK_2)\right] \quad (10)$$

where K_2 = the equilibrium dissociation constant for ammonium ion.

Equation (10) is analogous to (4) but equation (10) gives the fraction (f_2) of undissociated ammonia (gas) present whereas equation (4) gives the fraction (f_1) of dissociated sulfide (ions) present.

SOLUBILITIES OF UNDISSOCIATED GASES

Henry's Law states that the solubility of a gas in a liquid is directly proportional to the partial pressure of the gas over the liquid for ideal solutions. Providing there is no reaction between solute (gas) and solvent (water), Henry's Law should be followed reasonably well for the dilute solutions encountered in waste treatment. Henry's Law may be written:

$$P = Hx \qquad (11)$$

where P = vapor pressure of gas in equilibrium with solution
H = Henry's Law "constant," pressure per mol fraction, usually atmospheres/mol fraction
x = mol fraction of undissociated solute in the liquid phase.

Equation (5) provides the fraction of total soluble sulfide present in solution as undissociated (gaseous) H_2S as a function of pH and, coupled with a knowledge of the total soluble sulfide concentration (C_1), can be used to calculate the mol fraction of gaseous hydrogen sulfide in solution:

$$x_1 = \frac{(1-f_1)C_1/32.06}{(1-f_1)C_1/32.06 + (s.g.)10^6/18.02} \qquad (12)$$

where x_1 = mol fraction hydrogen sulfide gas in solution
$(1-f_1)$ = fraction of total sulfide present in solution as gas
C_1 = total soluble sulfide concentration in solution, mg/l
s.g. = specific gravity of water at temperature, t.

Substituting (5) into (12) and the result into (10), we have:

$$P_{H_2S} = H_1 \frac{\left\{1/\left[1+10\ \exp(pH-pK_1)\right]\right\} C_1/32.06}{\left\{1/\left[1+10\ \exp(pH-pK_1)\right]\right\} C_1/32.06 + (s.g.)10^6/18.02}, \text{ atm} \qquad (13)$$

From (13) one can estimate the concentration of gaseous hydrogen sulfide (C_{g1}) in the air over the wastewater at constant temperature, since at one atmosphere:

$$C_{g1} = 10^6(P_{H_2S}/1.0), \text{ vol ppm,} \qquad (14)$$

$$*C_{g1} = 10^6 (32.06/29.0) P_{H_2S}/1.0, \quad \text{(as "sulfide") wt ppm} \tag{15}$$

Analogously, equation (10) provides the fraction of total ammonia-N present in solution as undissociated NH_3 (dissolved gas) as a function of pH and, coupled with a knowledge of the total ammonia-N concentration, can be used to calculate the mol fraction of ammonia in the solution (x_2):

$$x_2 = \frac{f_2 C_2/14.01}{f_2 C_2/14.01 + (s.g.)\ 10^6/18.02} \tag{16}$$

where x_2 = mol fraction ammonia gas in solution
f_2 = fraction of total ammonia-N present as gas
C_2 = concentration of total ammonia-N in solution, mg/l
s.g. = specific gravity of water at temperature, t.

One can estimate the concentration of gaseous ammonia (C_{g2}) in the air over the wastewater at constant temperature since at one atmosphere:

$$C_{g2} = 10^6 P_{NH_3}/1.0, \text{ vol ppm,} \tag{17}$$

or

$$*C_{g2} = 10^6 (13.01/29.0) P_{NH_3}/1.0, \quad \text{(as ammonia-N) wt ppm} \tag{18}$$

TEMPERATURE EFFECTS

When gases dissolve in water, there is generally given off some "heat of solution and mixing" (ΔH); consequently, heating aqueous solutions of gases tends to drive gases out. In water and wastewater studies, the most common application of this fact occurs in tests for dissolved oxygen (DO).

EQUILIBRIUM DISSOCIATION CONSTANT

The temperature effect on equilibrium dissociation constants (K) is variable but the relationship may be approximated by the Van't Hoff equation. Although linear over a limited range, the best temperature correlation (Dean, 1973) for the range 32 to 120 ^oF is the form:

$$pK = A + B/T + C/T^2 \tag{19}$$

where T = ^oR.

In the case of ammonia, a similar expression was derived (Dean, 1973):

$$pK_2 = 0.2401 + 4756/T + 41097/T^2 \qquad (20)$$

The pK's of ammonium ion and hydrogen sulfide decrease with increasing temperature. Thus the K's of NH_4^+ and H_2S increase with increasing temperature and equations (1) and (7) are forced to the right.

Referring to equations (1) and (7), one can see that H_2S tends to dissociate into $HS^- + H^+$ whereas NH_3 tends to be formed from the dissociation of NH_4^+ into $NH_3 + H^+$ as the temperature increases (that is, as the respective K's increase). Thus these effects are opposite, and increasing temperature at constant pH increases the proportion of NH_3 gas in solution but decreases the proportion of H_2S gas. Figure 2, a plot of the fraction undissociated gas (for both H_2S and NH_3) versus pH for several temperatures, shows this effect graphically. Referring to Figure 2 at pH 7, H_2S is about 75 and 50 percent undissociated at 40 and 80 ^oF, respectively whereas at pH 10, NH_3 is about 55 and 85 percent undissociated at 40 and 80 ^oF, respectively.

LABORATORY RESULTS

A series of laboratory studies concerning hydrogen sulfide production in anaerobic lagoons was conducted by Gloyna and Espino (1969). Their model was based on units 58 cm in diameter and 175 cm deep. Illumination was provided 12 hours daily. Four independent variables were investigated: organic surface loading rate, detention time, surface loading rate of sulfate, and influent sulfate concentration. Results are shown in Table 4. Based upon these data, an empirical relationship of the following form was devised:

$$S^= = a \begin{pmatrix} \text{BOD surface} \\ \text{loading rate,} \\ \text{lbs/acre-day} \end{pmatrix} + b \begin{pmatrix} SO_4^= \text{ influent} \\ \text{concentration,} \\ \text{mg/l} \end{pmatrix}$$
$$= c \begin{pmatrix} \text{detention time,} \\ \text{days} \end{pmatrix} + d \qquad (21)$$

where $S^=$ = sulfide concentration, mg/l
a = -0.011
b = 0.025
c = -0.08
d = 3.3

These coefficients were based on the model they used and a temperature of 25 ^oC. This equation was further refined to correlate the data in the form:

$$S^= = \Big[0.0001185 \text{ (BOD surface loading rate)} - 0.001655 \text{ (detention time)} + 0.0553\Big]\ SO_4^= \qquad (22)$$

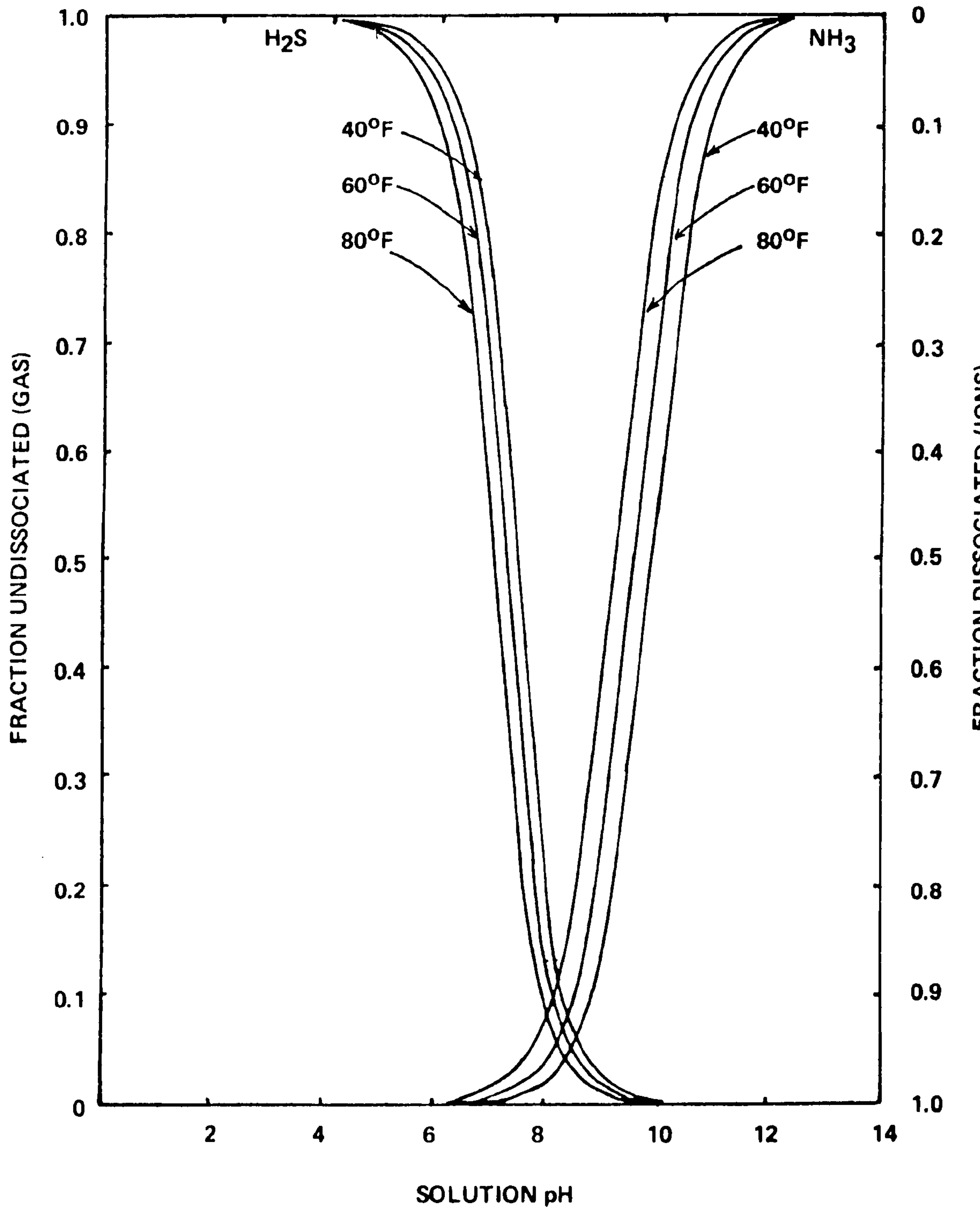

Figure 2. Effect of Solution pH on Fraction Dissolved Reactant Dissociated (Ionized).

TABLE 4. RESULTS OF LABORATORY ANAEROBIC LAGOON STUDIES TO PREDICT SULFIDE CONCENTRATIONS (GLOYNA AND ESPINO, 1969)

Test #	BOD load[1]	SO_4 conc., mg/l	SO_4 load[1]	Detention time, days	Sulfide concentrations, mg/l
1	136	23	11	30	0.432
2	68	23	11	30	0.500
3	136	23	23	15	0.12
4	136	206	94	30	4.29
6	68	200	188	15	6.36
7	136	400	188	30	8.76

[1]Pounds per acre-day

Furthermore, Gloyna and Espino (1969) defined the rate of hydrogen sulfide transfer from the liquid to the atmosphere using the Fickian relationship:

$$q = k(c - c_{eq}) \qquad (23)$$

where q = mass rate of exchange
k = diffusion constant
c = hydrogen sulfide concentration
c_{eq} = hydrogen sulfide concentration at equilibrium.

A series of tests was conducted in model lagoons to measure the hydrogen sulfide escape rate. Experiments were conducted in basins 175 cm deep, having a surface area of 188 sq cm. So long as pH of the basins was less than 4.5, there was essentially no HS^- nor $S^=$ to confound the issue. Under these conditions, the data could be analyzed as follows:

$$\frac{dc}{dt} = -k\frac{A}{V}c \qquad (24)$$

$$\frac{dc}{c} = -k\frac{A}{V}dt \qquad (25)$$

$$\ln c = \ln c_o - k\frac{A}{V}t \qquad (26)$$

where c = hydrogen sulfide concentration, mg/l
c_o = initial hydrogen sulfide concentration, mg/l
t = time, hr
A = surface area, m^2
V = liquid volume, m^3
k = hydrogen sulfide escape rate, m/hr.

The value of the calculated rate was approximately 0.006 m/hr for tests with low pH, low wind movement, and no waves. Wind effects, waves or other agitation would be expected to increase k values.

Based upon these experiments and the equations developed, Gloyna and Espino established design levels of sulfide in the lagoon as 4 mg/l. Detention time or loading rates may be adjusted to meet this criterion.

SECTION 6

ANAEROBIC LAGOON DESIGN AND OPERATION

The anaerobic lagoon is the treatment process most widely used at meat and poultry plants. The anaerobic process is especially suited to the concentrated hot wastewaters from these plants. The process utilizes anaerobic bacteria, which function in the absence of free oxygen to break down organic wastes. The lagoon is usually deep and covered with a blanket of floating sludge.

The anaerobic lagoon has obtained greater than 90 percent BOD_5 reduction, with highest removals during warm weather. The process has minimum capital and operating costs, is simple to operate, and shows visible treatment results; mechanical equipment is not necessary and treatment processes can withstand the shock loadings common to the industry. The anaerobic lagoon has given high removal efficiency with and without sludge recirculation.

There are two potential problems in the selection of anaerobic lagoons for meat packing wastes: odor emission, and high ammonia concentrations in the effluent. Ammonia is toxic to fish, and fish kills due to ammonia in meat plant discharges have been documented. However, reduction of protein to ammonia is a reaction that cannot be avoided in biological systems. The problem is that the concentration of ammonia in anaerobic lagoon effluents requires selection of additional treatment processes to remove the ammonia.

Anaerobic lagoons are designed with a low surface area to volume ratio to conserve heat and minimize surface re-aeration. Depths of 10 feet or more are desirable. Economic considerations and maintaining several feet above groundwater usually limit depths to less than 18 feet. The volume is based on organic loading and designs range from 12 to 25 pounds of BOD_5 per 1,000 cubic feet with 15 pounds BOD_5/1,000 cubic feet being common. The anaerobic lagoon at the Reeves plant in Ada, Oklahoma, has a water depth of 10 feet and an organic loading of 12 pounds BOD_5/1,000 cubic feet (Witherow, 1976). Average removal efficiencies for BOD_5, TSS, and FOG were 92, 84 and 95 percent, respectively.

The parameters used in determining municipal sewer rates are generally BOD, TSS, and oil and grease. The BOD and TSS concentrations at the Reeves plant were below 200 mg/l except on rare occasions (Witherow, 1976). Oil and grease analyses made on the effluent showed concentrations were well below the 100 mg/l limit commonly used by municipalities. The high percent removal and consistency of effluent concentration from the anaerobic lagoon resulted in an effluent which would meet common limitations for discharge to a municipal treatment plant.

Discharge of an effluent with high hydrogen sulfide concentrations to a municipal system will damage concrete sewers and structures unless precautionary devices are installed. Hydrogen sulfide, with its characteristic rotten egg odor, can be detected at low concentrations. At the demonstration facilities, the sulfate concentration in the water supply was 4 mg/l and a hydrogen sulfide odor could not be detected. Other septic odors could only be detected within 50 feet of the anaerobic pond in the downwind direction.

Most of the effluent ammonia concentrations were between 65 and 85 mg/l at the Reeves plant (Witherow, 1976). The conversion of protein to ammonia increased the concentration of ammonia three-fold through the anaerobic pond.

Oil and grease concentrations in the raw waste and effluent of the Reeves plant averaged 514 mg/l and 16 mg/l, respectively, which shows limited loss in the packinghouse and high reduction in the anaerobic pond (Witherow, 1976). A grease cover did not form on the anaerobic pond, which indicates grease was being digested in the pond. Some consideration was given to mixing grease and straw on the surface of the lagoon to form a cover to reduce heat loss. This was not done and temperature reduction through the pond was high during part of the winter when water temperature dropped to around 10 ^{o}C. Insignificant changes in removal efficiencies were noted during this period. In a colder climate there are greater advantages for a cover to reduce heat loss and maintain biological activity.

The anaerobic lagoon can produce an effluent suitable for discharge to a municipality, but it will not produce an effluent suitable for discharge into a surface water without further treatment in an aerobic process. Aerobic processes are those that maintain dissolved oxygen in the water.

SECTION 7

FIELD EXPERIENCE

In an attempt to identify specifically documented odor problems related to anaerobic lagoons serving meat packing plants, it was necessary to contact personnel who have had immediate experience. No reports were found in the literature which specifically documented odor problems or their solution.

DOCUMENTATION OF ODOR PROBLEMS

Odors in the proximity of a meat packing lagoon near Sweetwater, Texas, were made by Dr. John M. Sweeten (personal communication, Texas A & M University, 1976). In connection with that lagoon, odor measurements were made utilizing the scentometer. Downwind of the anaerobic lagoon three readings were made indicating an odor intensity of 31 dilutions to threshold. The odor was described as a mixture of normal, musty lagoon odors sparked with releases of putrid odors whenever large bubbles or mats of scattered floating solids were surfacing. The lagoon at the location has a volume of 97,000 ft^3 and a daily BOD_5 input of 310 pounds for a loading of 3.2 pounds BOD_5/day/1,000 ft^3. This is not a high loading rate; however, in conjunction with the high sulfate concentration in the city water (218 mg/l), problems were created. In this particular case, aerators have been suggested as a potential remedy.

Odor measurements were also made in the vicinity of an anaerobic meat packing plant lagoon near Eagle Pass, Texas, (Sweeten, personal communication, Texas A & M University, 1976). Odor intensities adjacent to the lagoon were 31 dilutions to threshold. At a distance of 0.75 miles downwind, odors were detectable at a concentration of two dilutions to threshold.

In discussing an anaerobic lagoon for the treatment of meat packing plant wastes in New Zealand, Rands and Cooper (1966) identified "one of the main criticisms of open, large scale, anaerobic digesters as being the liability arising from the association of hydrogen sulfide with digester gas." Other trace constituents such as mercaptan and amine-type volatiles joined with hydrogen sulfide to produce a difficult-to-define "pond" odor. "Uncontrolled meat waste digesters have attracted considerable attention in New Zealand in the past because of blackened house paint, sometimes at distances of several miles from the source." (Rands and Cooper, 1966).

At Moerewa, New Zealand, odor control is dependent on as continuous a scum cover as possible on the sludge pit (Rands and Cooper, 1966). The scum cover effectively blankets all unpleasant odor, but how much of this is purely physical retention and how much oxidation of sulfide as gases permeates the porous scum mat is not yet known. But the latter process appears to play an important part in reducing gaseous sulfide.

The effectiveness of the scum mat in reducing the escape of hydrogen sulfide to the atmosphere was demonstrated by tests carried out over the surface of the digester using a Drager Gas Detector held four inches above the water or scum surface. The concentration of hydrogen sulfide above the scum, which was about one inch thick, averaged 0.35 mg/l/v/v compared with concentrations of 2.0 to 15.0 mg/l over scum-free areas (Rands and Cooper, 1966).

"Despite many attempts, the collection of a representative sample of gas reaching the surface of an open digester has so far presented insuperable difficulties. Any negative pressure used in collection increases gas evolution and even collection under a bell jar can encourage increased solution of carbon dioxide. This is suggested by the analysis of a sample gas collected in this way and analyzed by the Chemical Inspector, Department of Health, Auckland, with the results shown in Table 5." (Rands and Cooper, 1966).

TABLE 5. ANALYSIS OF A GAS SAMPLE COLLECTED IN A BELL JAR OVER AN ANAEROBIC MEAT PACKING WASTE LAGOON IN NEW ZEALAND (RANDS AND COOPER, 1966)

Gas	Concentration, percent by volume
Hydrogen sulfide	0.4
Carbon dioxide	7.0
Methane	85.0
Oxygen	0.6
Nitrogen and undetermined	7.0

A continuous record of the concentration of hydrogen sulfide in the air was kept at the treatment plant close to the digesters and sedimentation tanks from March to November, 1965 by a paper tape sampler using lead acetate-impregnated paper. Another sampler was placed at the outlet of the oxidation pond to the river and a continuous record was kept there from March to June, 1965.

The highest concentration was an isolated peak of 0.11 mg/l but of the total number of readings at intervals of two hours, 1,897 were nil and 389 positive with an average of 0.2 mg/l. Similar results were obtained from the other sampler, although an occasional high of 0.20 mg/l at night indicated a local anaerobic "boil" from the digester under still air conditions.

The experience gained from these records has shown that maintenance of gas lines, a continuous scum layer on digesters, as little disturbance of the digester surface as possible, and sufficient wind to disperse odors without disturbing surface scum are important details of odor-free operation (Rands and Cooper, 1966).

A municipally owned anaerobic lagoon (Monmouth, Illinois) receives waste from a Swift and Company packing house killing an average of 8,000 head per day at maximum capacity. This plant discharges between 1 and 1.5 million gallons of liquid waste per day to a treatment system with a BOD_5 ranging from between 600 to 700 pounds per day. The anaerobic lagoon has a surface dimension of 400 by 260, which is covered by a hypalon cover. At this plant, the gas is not utilized; it is burned off as produced.

Mr. Robert Merwin, Plant Operator, indicated they have found it a successful operation. They do not attempt to store gas beneath the cover but keep it burned off as produced. Their cover has neither ropes nor cables but is a free-floating device; the goal is to have the cover rest directly upon the water. The major problem, according to Mr. Merwin, is that excess grease and fat tend to form a scum and stick to the cover.

The cover for the Monmouth, Illinois, anaerobic meat packing waste lagoon was manufactured and installed by Globe Liner of Long Beach, California. Mr. Bill Kays of that company reported that Globe Liner has manufactured and installed over 90 covers and that they are working satisfactorily. It is his opinion that the success enjoyed by Globe Liners has been largely due to his company's special skills both in design and fabrication of covers.

This particular cover is fabricated from a hypalon resin produced by Dupont and Company of Louisville, Kentucky. Although they do not serve meat packing lagoons other than the Monmouth, Illinois, currently in operation, they have several meat packing lagoon covers under design. In discussing the cost of hypalon covers which might be installed, Mr. Kays pointed out that it is difficult to determine a representative cost; however, he was able to indicate that the typical cost per square foot for a moderately large lagoon is in the neighborhood of $1.75 to $2.50 per square foot. This price does not include the gas collection system nor unusual installation or production difficulties. According to his recollection, the Monmouth cover was installed for a cost of approximately $1.90 per square foot three years ago.

Mr. James Chittenden, Vice-President of Research and Development, Texas Amarillo Systems Company, was contacted relative to his experience with respect to meat packing anaerobic lagoon covers. Mr. Chittenden has been involved with meat packing lagoons for some time and has been watching the Monmouth, Illinois, operation with considerable interest. He reports that his firm is currently designing an anaerobic lagoon to be located in Arizona which will be provided with a cover for a plant killing 1,400 animals per day. This plant will utilize water with a sulfate content of 390 mg/l. It is his design that the lagoon will produce an average of 100 cubic feet per minute of gas having a heating value of 650 Btu/lb. He anticipates the system will, therefore, be sufficiently large to justify the purchase of a boiler to utilize the gas for heat production. Anticipated cost of the cover is to be in the range of $250,000.

The University of Illinois has used a "Controliner," Model 90, Environetics Company, as an anaerobic swine manure lagoon liner and cover for two years (Waldo, 1976). This unit provides total containment of both liquids and gases. Prior to installation of the unit, both odor and mosquito problems existed. Periodic analyses of gases within the Controliner were performed by gas chromatography and are summarized in Table 6. As the table shows, methane content of the gas is a sensitive function of temperature.

TABLE 6. COMPOSITION OF GASES INSIDE THE CONTROLINER AT UNIVERSITY OF ILLINOIS SWINE FARM (WALDO, 1976)

Date	Constituent, percent			
	CO_2	O_2	N_2	CH_4
September 1, 1976	34.8	2.5	20.7	42
September 15	45.0	4.5	10.5	42
October 4	42.0	2.0	10.5	48
October 17	18.0	12	45	25
October 24	25	4	46	25
December 5	5.6	19	72	2.9
March 19, 1977	11.7	17.2	71	4.8
April 1	6.8	19.0	73	1.2
April 23	50	9.7	39	1.2
July 29	20	10	49	21

SECTION 8

PROBLEM ANALYSIS

Odors are a complex subjective phenomenon. Odor problems arise when neighbors or other people who live, work or recreate in the vicinity of a source of air emissions register complaints or otherwise bring pressure against an operation. Legal recourse is available for property owners whose use of their property has been unreasonably restricted due to odors. Where large groups of people have been offended, public nuisance suits have been filed seeking operational restrictions or actual plant closure.

Anaerobic lagoons, which have proven to be low cost effective waste treatment devices, are especially prone to emit odorous gaseous compounds. By its very nature, the anaerobic process degrades complex organic compounds in the absence of oxygen to less complex compounds of increasing volatility. Both the end products and intermediate breakdown products contribute to odor production. Odor problems have been observed to be more severe when the water supply has a high sulfate concentration. This observation suggests hydrogen sulfide and related sulfur-bearing compounds are important in the observed odor intensities.

In discussing odors from anaerobic lagoons serving meat packing plants, J. A. Chittenden (1977) made the following comments:

1. No anaerobic lagoon should be used if the sulfate concentration of incoming fresh water is in excess of 200 mg/l. As a matter of fact, I am reluctant to consider anaerobics at sulfate concentrations above 100 mg/l. The hydrogen sulfide generated by the anaerobic action of concentrations above 100 mg/l produces odors that travel for miles downwind of the treatment system.

2. The loading on the anaerobic should range from 15 pounds BOD/1,000 ft^3 to 25 pounds BOD/1,000 ft^3. Loading significantly out of the range, either higher or lower, results in poor anaerobic lagoon performance. This imposes a high load on the subsequent aerobic phases, causing these to become septic and generate odors.

3. Start-up of the anaerobic lagoon remains a black art. No one system is quite like another. There are several things to watch and consider.

a. I see the anaerobic at start-up with primary digester sludges from a municipal treatment system. This helps get suspended solids up at start-up and appears to give the bugs a headstart. Forty or fifty thousand gallons of sludge is not too much.

b. In one case the acid-forming bacteria predominated during start-up and the methane-forming bacteria could not get started. As a result, pH dropped to around 5.0 rather than the near 7.0 pH realized from a well-functioning anaerobic lagoon. Several additions of the stoichiometric amount of lime were required to overcome the acid formers, but inside of a week the methane formers began to function and BOD fell into the desired range.

c. The sludge cover on the anaerobics forms, in my opinion, as a result of the flotation effect from the gas formed during anaerobic decomposition. Sufficient gases are not generated until the suspended solids environment in the bottom strata of the anaerobics is well-established. This takes time--as much as four months in cold weather. Bypassing grease recovery systems does nothing to enhance cover formation. I have had some limited success in promoting cover formation by flowing chopped straw on the surface of the lagoon. The straw sinks after three or four weeks and must be re-applied, but it does help.

The comments made by Mr. Chittenden typify current odor control technology. There has been very little research done having direct odor control objectives. Much of the knowledge about odor control from anaerobic meat packing wastes has been a spin-off from waste treatment studies.

As indicated earlier, problems result when the following odor production steps occur:

1. Odorous compounds enter or are formed in the anaerobic lagoon.

2. Odorous compounds existing in the lagoon volatilize and escape to the overhead air.

3. Once free to the air over an anaerobic lagoon, the odorous gas mixture must be transported downwind to a location where it is judged offensive or otherwise undesirable. This transport must occur so the odorous air arrives at the point of objection before it has been diluted beyond the threshold concentration, oxidized to non-odorous species, absorbed by intervening vegetation or structures, or reacted with other airborne compounds to attenuate its odorous nature.

The above odor production steps provide the basis for most odor control procedures. Possible odor control alternatives are outlined as follows:

1. Prevent entry or formation of odorous components

    Pretreatment with chemicals to remove or tie up odorous precursors - sulfur

    Inhibit anaerobic decomposition
    - Aeration
    - Sterilization

    Alter environmental conditions to prevent the formation of odorous components

2. Prevent the escape of odorous components

    Maintain an effective scum layer

    Install an impermeable cover

    Chemically treat to prevent volatilization
    - Precipitation
    - pH adjustment

3. Prevent transport of volatilized odorants from lagoon to neighbors

    Use of vegetative barriers

    Use of scrubbing screens

    Select lagoon site remote from habitation and recreation sites

SECTION 9

RESEARCH NEEDS

Odors from anaerobic lagoons used in the treatment of meat packing wastes are a significant environmental problem. In areas where lagoons are used, odors present a nuisance problem resulting in citizen complaints and property damage. In other locations, anaerobic lagoons are rejected in the design process, forcing the selection of more expensive and energy-intensive processes.

The control of anaerobic lagoon odors offers an opportunity for technology application with measurable pay-off. Research techniques have been devised which have the needed sophistication to make significant contributions.

Among the specific needs are the following:

> Identification of the specific compound with the goal of identifying means of eliminating it from water and air.
>
> Identification of potential chemical treatment processes for removing or precipitating odorous components.
>
> Evaluating means of forming scum layers using synthetic materials as well as low-density waste components.
>
> Measuring the effectiveness of various scum layers in terms of thickness and composition.
>
> Evaluation on a significant size scale of various cover materials and fabrication techniques to achieve a minimum cost system with appropriate useful life and resistance to physical and chemical damage.
>
> Evaluation of physical and chemical processes involved in odorous compound transport with the goal of effectively designed odor control barriers.

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APPENDIX

RESEARCH PROPOSAL

One objective of this report preparation was to identify research needs in the control of odors from food processing lagoons. The proposal generated was submitted to the Environmental Protection Agency in September, 1977.

Title: Development of a Permeable Cover to Control Odor

Principal Investigator: Dr. J. Ronald Miner, Professor and Head
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Oregon State University
Corvallis, Oregon 97331
Telephone: 503 754-2041

Project Period: 2 years

Budget: $66,800

OBJECTIVES OF THIS PROJECT

This project has as its overall objective the development of information which will allow the design and construction of a floating permeable cover to be placed on odorous liquids to reduce or eliminate the escape of odorous gases. Although the need for and application of this information is widespread, it has particular application to odor problems in the meat processing and livestock production industries. Anaerobic lagoons and, consequently, odor problems are also of concern in fruit and vegetable processing plants, dairies, potato processing plants and rendering facilities. Permeable covers have the potential of being a satisfactory solution to odor problems wherever odorous liquids are stored in open tanks or reservoirs.

Anaerobic lagoons are a low cost technique for the treatment of organic wastewaters. They typically achieve 70 to 85 percent BOD reduction at a very low level of energy consumption. Certain industrial and commercial wastes are particularly amenable to this form of treatment including those discharging a warm water with a high BOD concentration. Frequently, however, the use of anaerobic lagoons is rejected in favor of more expensive and energy-consumptive techniques due to the inability to control odor releases.

Odor problems are particularly severe from anaerobic lagoons in which sulfate ion concentration of the untreated waste is in excess of 100 mg/l.

The overall objective will be approached by pursuit of the first three of the following four procedural steps:

1. Develop criteria for a permeable cover to control odor emissions from an anaerobic liquid surface.

2. Investigate various materials such as foams, beads, natural zeolites and other inert buoyant materials from which one might fabricate a floating lagoon cover.

3. Evaluate the cost effectiveness of floating permeable covers as a means of odor control from anaerobic liquid surfaces.

4. Demonstrate the effectiveness of floating permeable covers in an existing odorous lagoon.

RESULTS AND BENEFITS EXPECTED

This project is designed to provide a cost effective technique for the control of odors from anaerobic lagoons and other anaerobic liquid surfaces. The only alternatives currently available are expensive impermeable covers which encase the entire lagoon surface and require a separate gas treatment scheme or abandonment of the anaerobic lagoon process in favor of more expensive and/or energy-intensive processes such as aeration basins, aerated lagoons, or automated anaerobic digesters.

The most obvious benefit is decreased odor in the proximity of anaerobic lagoons; however, the real benefits are in the area of wastewater treatment. By making open anaerobic treatment processes environmentally acceptable, the cost of wastewater treatment is reduced, hence, high levels of BOD removal become economically achievable. Furthermore, since anaerobic lagoons require considerably less energy input than alternate forms of treatment, development of an effective odor treating cover has a significant impact upon the energy consumption of environmental quality protection.

Beyond direct application of these research results to the food processing, livestock production and other concentrated organic waste-generating industries, these research activities are of a sufficiently basic nature to have widespread application wherever it is desirable to control organic gas escaping from liquid surfaces. The theory and practices involved will have an impact on the art of pollution abatement. Due to the proposed involvement of graduate and undergraduate students, there will also be measurable educational benefits.

APPROACH

The proposed project is consistent with previous work of the principal investigator and represents a timely progression of his previous work. The attached list of publications reflects the nature of his previous research relative to odor control technology. The timeliness of this work is further supported by current environmental and social concern over odor and other nuisance pollutants.

Background

Anaerobic lagoons have been demonstrated to effectively reduce organic pollutants. They accomplish this removal with minimum capital and operating costs. They are simple to operate, require no mechanical equipment, and the process can withstand shock loadings. In meat packing plant waste treatment, Chittenden et al. (1) report BOD, grease and suspended solids removals in excess of 80 percent. Similar removal efficiencies have been reported in the treatment of other wastewaters. The major disadvantage of anaerobic lagoons is the odor resulting from the process, which can be particularly severe when sulfate concentration in the water supply is high. Wherever sulfate concentrations are in excess of 100 mg/l, odor problems are a subject of concern. Specific case histories in which odor problems were encountered from meat processing lagoons were reported by Chittenden et al. A similar accounting of odor problems from livestock production was provided by Miner (2).

Costs of using an anaerobic lagoon or aeration were compared for a 2.88 mgd waste flow meat packing plant in Illinois (1). The anaerobic-aerobic combination was approximately $1.4 million less expensive to build than a completely aerobic system. A floating flexible membrane to cover with a gas burner was proposed at an additional cost of $369,000. Thus, if an effective permeable cover can be developed at a cost of $3 per square foot or less, a net initial cost saving can be accomplished.

There is ample evidence in both the literature and common experience to support the basic premise of this proposal: namely, that slow diffusion of odorous gases through either a chemically or biologically active layer will result in absorption and oxidation of odorous demonstrations in normal experience, including the lack of perceptible odors over buried putrescible wastes or over septic tank disposal fields.

The use of soil beds for odor control was reported by Carlson and Leiser (3). Their tests indicated that odor reduction was affected by microorganisms in the soil rather than by ion exchange, chemical combination or oxidation. Moist loam soils were found to have the greatest odor removal possibilities. Over a three-month test period, hydrogen sulfide gas concentrations of 15 ppm at a flow rate of 0.35 ft^3/min per square foot of soil surface were reduced to an imperceptible level in 32 inches of soil. For a flow rate of 0.34 ft^3/min per square foot in a hydrogen sulfide concentration of 9.5 ppm, 90 percent of the hydrogen sulfide was removed in the first 18 inches of soil. Effectiveness of soil beds in removing hydrogen sulfide did not diminish during a three-month test period. A soil filter for the removal of odors from a Mercer Island, Washington, pumping station has been in successful operation for several years.

As an outgrowth of the earlier work, Carlson and Gumerman (4) proposed a system for the treatment of odorous gases. Their system included a perforated tile system through which odorous gases were blown. Above the tile system, the soil was covered with a greenhouse to facilitate year-round plant growth. The role of the plants within the system was to keep the structure open, to utilize some of the excess sulfur, and to replenish the soil organic matter sacrificed in the active biological growth that occurred. They suggested a plant with a shallow root system which would meet the above goals but not interfere with the gas distribution piping system.

The use of soil filters for the removal of animal waste odors was investigated by Burnett and Dondero (5). They based their initial trials on the earlier work of Carlson and Leiser (3) and Gumerman and Carlson (6) and found that, indeed, the use of soil columns was effective in removing both hydrogen sulfide and ammonia from the headspace gas over decomposing poultry manure. They found that for ammonia concentrations of up to 200 ppm, removals of 100 percent were obtained, and for hydrogen sulfide concentrations of 22 to 100 ppm, more than 95 percent removal occurred throughout a three-month continuous testing period. They further found that when the soil columns dried, ammonia removal efficiency dropped rapidly. Thus, to be fully effective, the moisture content of the soil must be maintained. By mixing manure with soil prior to using it in the column, the moisture-holding capacity was increased. As a result of this work, they made some tentative suggestions as to the area required for odor removal. Assuming a 40,000-layer operation, they suggested that a trench two feet deep, two feet wide and 903 feet long would be required to deodorize the air. This is equivalent to 0.0903 cubic feet of soil per bird.

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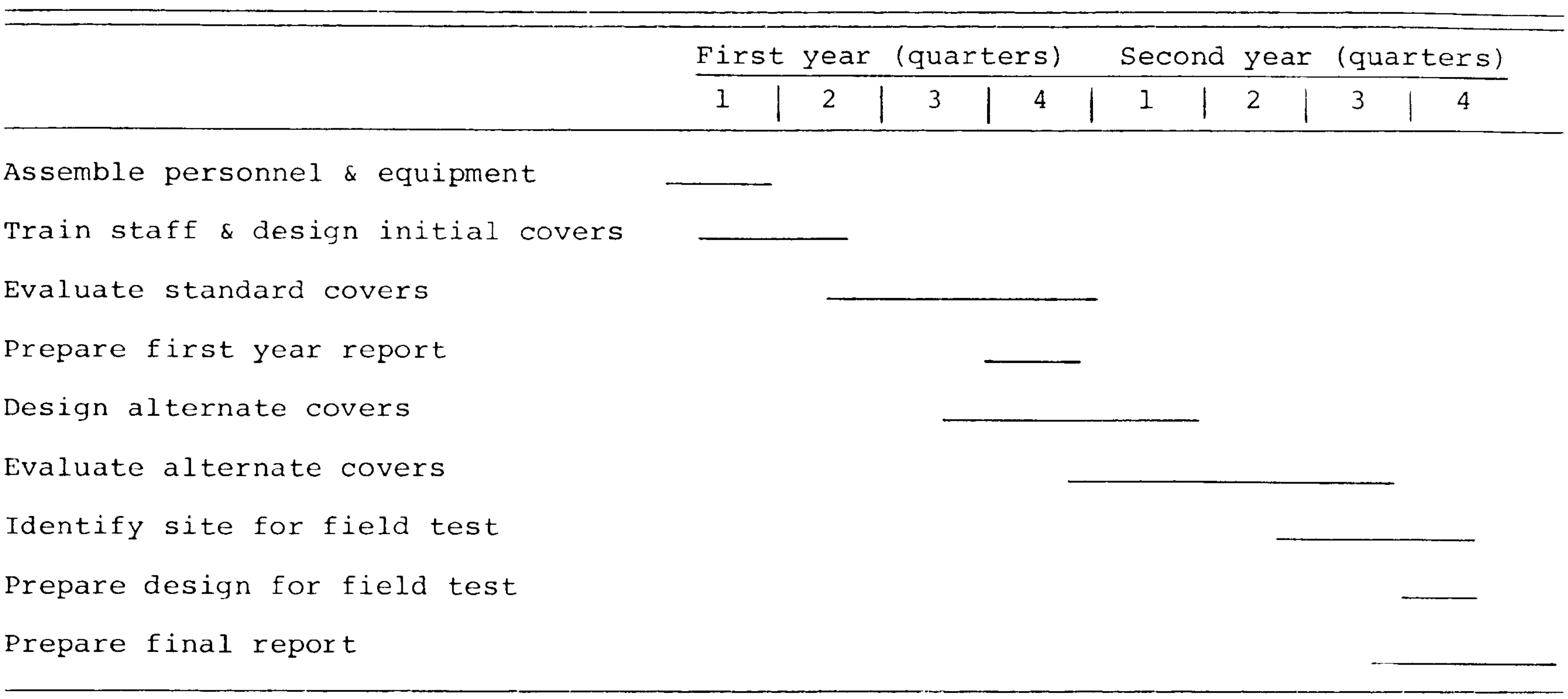
WORK PLAN

The first step in this project is evaluation of the basic process which will be accomplished by fabricating circular pads of dense fiberglass filter materials ranging in thickness from one to six inches. They will be fabricated into a circular configuration to fit snugly inside the plastic lined 55-gallon drums proposed for simulating the lagooning process. Twelve barrels will be used initially. They will be filled with cattle manure for the first trial, then with a simulated meat packing plant waste for the second. For both trials, one-third of the barrels will be spiked with sulfates to provide a net sulfate ion concentration of 100 mg/l and an equal number to 300 mg/l. Effectiveness will be evaluated by measuring the ammonia and hydrogen sulfide evolution rates and by scentometer evaluations made at the rim of the barrel.

Based upon the results of the initial trials, alternate techniques of fabricating permeable lagoon covers will be evaluated. The materials discussed in the detailed objectives will be included. The goal during this phase of the effort will be to identify those basic physical characteristics which define the effectiveness of a lagoon cover; however, there is likely an additional factor relating to the distance of travel by the gas phase. Once these questions are resolved, covers made of different materials with standard levels of odor abatement can be defined. From this point, it is possible to calculate the cost effectiveness of alternate designs. The next ingredient is the long term usefulness of specific covers, which will be determined using the model lagoons described above. The schedule for accomplishing the various tasks is shown in Figure 1.

FIGURE A-1. TIME SCHEDULE FOR PROGRESS OF THE PROJECT



REVIEWS

The proposal was evaluated by six technical reviewers who have extensive experience on the subject. A summary of this review follows.

Mr. //// /. /////////, of the Environmental Protection Agency, aided the development of this proposal over the year and had previously developed a research proposal with similar, but less extensive, objectives. He finds the overall project design, available resources, project period, and budget satisfactory. He states the principal investigator's background and experience are ideal. His concerns are the brevity of the design and the developmental nature of the project. This development requires exploration for more effective material for odor reduction.

Dr. /. /. ///, Agricultural Engineering Professor at the ///////// // ////////, was selected at random to review the proposal. He states that the project's objectives are of interest to the EPA mission and that the project could contribute significantly in control of odor and use of low cost waste treatment. He knows of no overlap of the proposed project with other work, but mentioned that some research on alternate control techniques has been undertaken. He states that the project period, resources, and facilities are adequate, and that the principal investigator has the needed background and training and has a long successful record of research in the area. Dr. /// makes two suggestions: (1) the model lagoon should be operated through a range of expected temperatures for expected seasonal variations, and (2) continuous loading and discharge of waste be used in the experiment to more nearly simulate actual conditions.

Dr. //// /. ///////, Dean, College of Engineering, ////////// // ///////////, was asked to review the project because of his research in odor control using soil systems. Dr. /////// accurately describes the objectives and recommends the area of work. He states, "Not a great deal of work has been done in the area proposed." He describes the budget as sufficient to get the project under way and states a second stage (year) of work should be undertaken if progress shows worthwhile results. He further states a third stage of field evaluation is needed if the developed system is feasible. Dr. /////// writes the background information is reasonable, but he would like more details on the proposed work. He later states such project details could not be expected until the principal investigator has funds sufficient to allocate time to the project. He has several specific concerns or suggestions. These are: (1) use of 55-gallon drums for digesters will cause problems "because of iron, temperature, current, and depth perturbations"; (2) the development of a permeable cover should include more materials of a biologically active or amenable base; the possibility for a joint soil-glass fiber system or a styrofoam log with soil interface system for breathing of odorous gases is suggested.

Dr. /// ///////, Extension Agricultural Engineer, ///// //////////// ///////// ///////, was selected to review the proposal because of his publications and experience in control of odors from anaerobic lagoons and feedlots. Dr. /////// strongly recommends that EPA fund this grant, which will provide significant information on the control of odors. He noted that in his state, 45 percent of all air pollution complaints involve odors, and that anaerobic lagoons are an efficient and cheap method of waste treatment, but are often the leading cause of odors found around livestock feeding operations. Dr. /////// writes, "No organized research has yet dealt with the use of permeable covers as a means of odor abatement." He thinks "a permeable floating cover for lagoons is a unique approach widely applicable to thousands of existing feeding operations." He states the principal investigator is one of the best qualified researchers in the U. S. to conduct an investigation of the type proposed. He feels the two-year project period and the budget are appropriate, finds no major weakness with the proposal, and lists as one of its strong points the use of plastic-lined 55-gallon drums to simulate lagooning.

Mr. /. /. //////////, Vice-President for Research, /////, has been responsible for design of a number of meat packing waste treatment systems for a large meat packer. He writes that the project is sound and the benefits to EPA appreciable. He describes anaerobic lagoon operations and lists three specific benefits of the project to these operations: (1) it would allow the use of anaerobic lagoons treating waters with sulfate concentrations above 100 mg/l; (2) it would be beneficial during the start-up period of an anaerobic lagoon when odorous emissions are commonly experienced regardless of sulfate concentrations; (3) it would be useful in case of intermittent loading to the anaerobic lagoon due to seasonal operation of the plant (common in the food industry). The benefits would be not only to control odor by maintaining a cover during plant shutdowns, but also during re-introduction of waste. He knows of no similar work being conducted, except on impermeable covers (which he describes as too costly, except in the case of very high sulfate waters). He thinks the staff, support facilities, project period, and project budget are adequate. The strengths of the project are the use of 55-gallon drums as digesters, the use of 12 digesters, and the range of sulfate concentrations at 1, 100, and 300 mg/l. The weakness of the project is finding an acceptable medium to act as a permeable cover. He suggests that insulated thermostatically controlled barrels (drums) be used to maintain constant temperature and constant gas production. He states that even if the project fails to produce an acceptable cover material, demonstrating a relationship between odor emissions and surface area per unit of cover would justify this study.

Mr. /. /. //////, Research Chemist with the //////// ///////
//////// /////////// ///., New Zealand, was requested to review the project because of his two publications on the subject. ////// repeats the objectives without describing their benefits. His seven page review includes description of his research and observations, as well as that of others, on the subject. The more pertinent points follow. The length of operation necessary to form a scum crust and become odor-free varies between 4 and 12 months. These crusts may reach one to three feet in thickness, and at one anaerobic lagoon, cleaning was necessary every six months to a year. (These conditions usually occur when paunch manure is discharged to the lagoon). At another anaerobic lagoon, a 1/4- to 1/2-inch crust was maintained for odor control and acted as a biological filter with action due partly to iron bacteria in symbiotic association with red and green photosynthetic sulfur bacteria. He states that the proposed use of a cheap porous material may be necessary to form a satisfactory scum mat for odor control and suggests the addition of cattle and sheep paunch material (a practice strongly opposed by EPA and cost factors since the presence of BPT and BAT discharge limitations).

Mr. ////// writes the proposal gives a well-rounded approach and that the materials listed are worth investigating. He ranks the principal investigator as high caliber, and the organization and support facilities as ideal. The project period and budget are adequate, but he suggests the project time could be longer. He considers the central theme a valid one and recommends selecting materials for the cover that can be easily removed and replaced. He continues saying that on large lagoons when sludge buildup or maintenance is needed, a dragline is a simple means of solids removal, and for this reason a non-rigid cover material would be better. He concludes that use of 55-gallon drums is sound and generation of a fibrous cover can stop odors.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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15. SUPPLEMENTARY NOTES

Project Officer: Jack L. Witherow, Food and Wood Products Branch--Corvallis, Oregon

16. ABSTRACT

Anaerobic lagoons are used for the treatment of meat packing wastes in most area of the country. They are a relatively low cost means of achieving BOD reduction. Although lagoon effluent is not suitable for stream discharge, it is amenable to further treatment or to land application. One of the most serious limitations of anaerobic lagoons in this application is odor production. Odor complains have been widespread but have been most frequent in areas of high sulfate waters and during start-up. There has been little specific research effort devoted to anaerobic lagoon odor control. This report assembles existing information relative to odor control associated with anaerobic lagoons used in the meat packing industry and identifies opportunities for productive research. It provides a basis for approaching the overall problem in a comprehensive fashion. This report was submitted in fulfillment of Contract No. CC691935-J by the Agricultural Research Foundation of Oregon State University under the sponsorship of the U. S. Environmental Protection Agency. It covers the period July 1, 1976 to December 31, 1976, and work was completed as of December 31, 1976.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Odors	Anaerobic Lagoon Meatpacking Food Processing Industry Anaerobic Digestion Wastewater Treatment	13B

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