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Odors From Confined Livestock Production

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EPA REVIEW NOTICE

EPA-660/2-74-023
April 1974

ODORS FROM CONFINED LIVESTOCK PRODUCTION

A State-of-the-Art

by

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ABSTRACT

Current livestock production techniques result in the generation of odors which have become a source of conflict between livestock producers and society. The odorous gases responsible for the nuisance are principally low molecular weight compounds released during anaerobic decomposition of manure. Manure management systems which control or modify this decomposition offer the greatest potential for odor control.

Research to identify the chemical compounds present in odorous air from animal waste degradation has yielded about 45 compounds to date. The amines, mercaptans, organic acids and heterocyclic nitrogen compounds are generally regarded as being of greatest importance. Among the techniques for odor control are: (a) site selection away from populated areas and where adequate drainage exists, (b) maintain the animal areas as dry as possible and prevent the animals from becoming manure covered, (c) select manure handling systems which utilize aerobic environments for manure storage, (d) maintain an orderly operation free of accumulated manure and runoff water, (e) practice prompt disposal of dead animals and (f) use odor control chemicals when short term odor control is necessary, such as when manure storage tank contents must be field spread.

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The technical and editorial assistance of Ted L. Willrich, Extension Agricultural Engineer, and Richard Floyd, Agricultural Experiment Station Editor, Oregon State University, was instrumental in the completion of this report. The material in Section IV on the theories of odor perception was taken, to a large measure, from a literature review paper presented by Clyde L. Barth, Clemson University, during the July, 1970, meeting of the American Society of Agricultural Engineers.

SUMMARY

The phenomenon of olfaction is complex. Several models have been proposed to explain the observations relative to odor perception and identification, yet none of the models are entirely satisfactory. Psychological aspects of odor evaluation compound the difficulties in making objective measurements of either odor strength or odor quality. Correlations between the chemical composition of air and its odor have proven more difficult than anticipated.

Anaerobic decomposition of manure is a stepwise process in which complex organic compounds are degraded to successively smaller, less complex molecules. Since, at a given moment, any or all of these intermediate compounds may be present, the observed odor represents the sum of the individual contributors. Data indicate that the total odor may not represent the simple summation of individual contributors but that extensive interaction is occurring.

Research to identify the chemical compounds present in odorous air from animal waste degradation has yielded about 45 compounds to date. Even though this list is undoubtedly incomplete, it indicates the complexity of the situation and forewarns of the difficulties to be encountered in odor control. The amines, mercaptans, organic acids, and heterocyclic nitrogen compounds are generally regarded as being of greatest odor significance.

The measurement of odors has proven difficult and current techniques are not entirely satisfactory. Odor intensities can be measured by determining the volume of odor-free air required to dilute a volume of odorous air to a barely perceptible level. Both laboratory and field equipment are available for this use. In this technique, the human nose is the detector; therefore, considerable variation due to observer sensitivities and fatigue is common. A liquid dilution technique has been utilized for evaluating the odor of liquids in which odor-free water is used as the dilutant.

Chemical techniques exist for measuring the concentration of many odorous compounds produced by the anaerobic decomposition of manure. The low concentration at which these compounds are odorous in air, however, frequently exceeds the sensitivity of existing analytical techniques. Thus, extensive modification of traditional analytical techniques is necessary. Ammonia, hydrogen sulfide, mercaptans, and volatile organic acids have been quantitatively measured in the air-volatilized material from manure storage tanks.

Although certain odorous gases are known to be toxic to both humans and livestock, the primary concern is one of annoyance or nuisance to humans. Rules and regulations relative to livestock odors are based primarily on the concept of nuisance. Whenever a neighboring property owner feels the odor from an animal production unit is unreasonably interfering with the use and enjoyment of his property, he has the right to initiate legal action to recover damages or to seek an injunction to halt or modify an operation. Both private and public nuisance suits have been heard in the last five years. In some of these cases the judgments have involved major expenses for the livestock producer and, in a few instances, required that a producer cease operation or move to a more appropriate location.

Ammonia has been the most widely studied odorous gas being evolved by anaerobic manure decomposition. The evolution of ammonia is of interest not only because of its odor but also because the potential for reabsorption by nearby water bodies would lead to the possibility of aquatic enrichment. The atmosphere near livestock production units has been measured in enough locations to demonstrate a significant increase in ammonia concentrations in these areas compared to residential or other agricultural areas. The volatilization rate of ammonia is a function of temperature, pH and ammonia content of the material from which it would escape.

Scattered observations have suggested that the odor of manure can be influenced by changing the feed ration of an animal. Sufficient data have been gathered to indicate this is a feasible approach, yet not enough work has been done for this to be considered a viable odor control technique.

Various chemical treatments have been explored for reducing the odor of stored animal manure. Chlorine, lime, potassium permanganate, hydrogen peroxide and paraformaldehyde have been applied to manure for their characteristics of inhibiting anaerobic bacterial activity and their reaction with known odorous compounds. These chemicals have been demonstrated to be temporarily effective when added in sufficient concentration. There are several proprietary odor control chemicals being sold for odor reduction or masking. Their performance has received only limited study and the published results are highly variable.

Soil columns have been studied as a means of removing odorous compounds from air. Their performance under laboratory conditions has been encouraging but they have not been applied to production facilities.

Although complete odor elimination around a livestock operation is not currently within technical and economic limits, there are several principles that have been proposed to minimize odor complaints.[1]

(a) Locate a livestock operation such that close proximity to residential areas is avoided. Although no maximum distances have been established beyond which complaints are not valid, it is desirable to stay away from an urban area, 1600 m (one mile) from housing developments and 800 m (1/2 mile) from neighboring residences. Wind direction and topography are of some importance in most areas. However, in some areas there is sufficient fluctuation in wind direction to make this factor of little help.

(b) Feeding areas and animal pens should be kept dry. The primary source of odor from a livestock operation is that of anaerobic manure decomposition. By keeping manure-covered surfaces dry, this decomposition can be minimized. This same procedure not only is helpful as an odor control scheme, but also is beneficial in the control of water pollution due to runoff and is an aid in fly and insect control.

(c) Manure-management systems should be designed to prevent dirty, manure-covered animals. The warm body of an animal, when covered with wet manure, makes an area of accelerated bacterial growth and odor production. Once produced, the odorous by-products of manure decomposition are quickly vaporized into the air by animal heat.

(d) Appropriate selection of manure storage and treatment devices can be helpful. The use of aerobic systems in general will reduce odor production. Other measures to inhibit anaerobic decomposition such as dry manure storage, chlorine or lime addition, or a cold storage system will reduce odorous gas production.

(e) An orderly scheme of runoff collection and manure handling not only avoids opportunity for water pollution but also promotes better drainage, thus minimizing areas of odor production. In addition, an orderly appearing operation is effective in suggesting a non-offensive situation.

(f) Dead animal disposal requires a definite plan to avoid odors, flies, and severe health risks. Prompt handling, with removal from the site within 24 hours, is required in most areas. Pickup by rendering works is the preferred disposal method where quickly available; otherwise, burial or incineration may be considered.

(g) Odor control chemicals have achieved limited use in livestock operations. Because of the lack of an effective means of evaluating the performance of these materials and their expense, odor control chemical use has been generally limited to short-term applications or use only in particularly offensive areas, such as a manure-storage pit immediately before hauling.

SECTION I

INTRODUCTION TO ODOR CAUSES AND CONTROL

Odors associated with livestock production are generally related to manure handling but other potential odor sources exist. Wet feed, if not promptly removed, makes a contribution to odors as does the decomposition of dead animals if they do not receive proper handling. Animal feeds also have various odors as they are stored and handled before feeding and as they are fed. However, feed odors are not generally regarded as offensive as those from the decomposition of manure.

Manure is a complex mixture of carbohydrates, fats, proteins and their breakdown products. When manure is in a suitable environmental condition during handling, it serves as a substrate for biological growth. This biological growth utilizes the manure as an energy source and yields one of the next succeeding compounds along the metabolic chain. Examples of the biological transformations occurring in manure are shown in Figures 1, 2 and 3. When manure undergoing decomposition has a surface exposed to the atmosphere, volatile products and intermediates will tend to escape into the atmosphere. This is the source of odorous gases and vapors.

One method of avoiding odors is to prevent the formation of odorous breakdown products. Although frequently difficult or even impossible to accomplish in practice, the principle is straightforward: Maintain the manure in an environment unsuitable for the growth of anaerobic microorganisms. This can be done by: (a) providing an aerobic environment, (b) maintaining the moisture content so low that growth is inhibited, (c) controling the pH so that growth is inhibited, (d) adjusting the temperature outside the region of bacterial growth, (e) adding a chemical which inhibits biological growth, or (f) by changing the microbial population so the formation of specific compounds is avoided.

Although difficult as a means to achieve total odor control, each of the above restrictions on microbial growth has been investigated. Each has

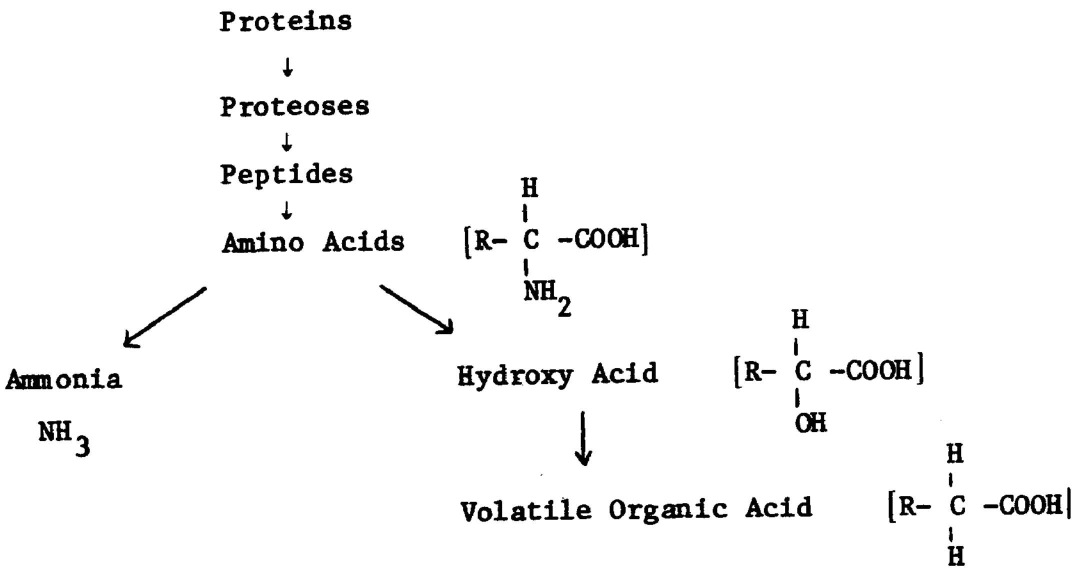


Figure 1. Anaerobic breakdown of proteins

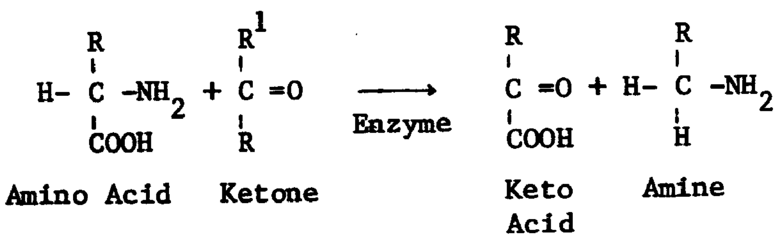


Figure 2. Bacterial transamination

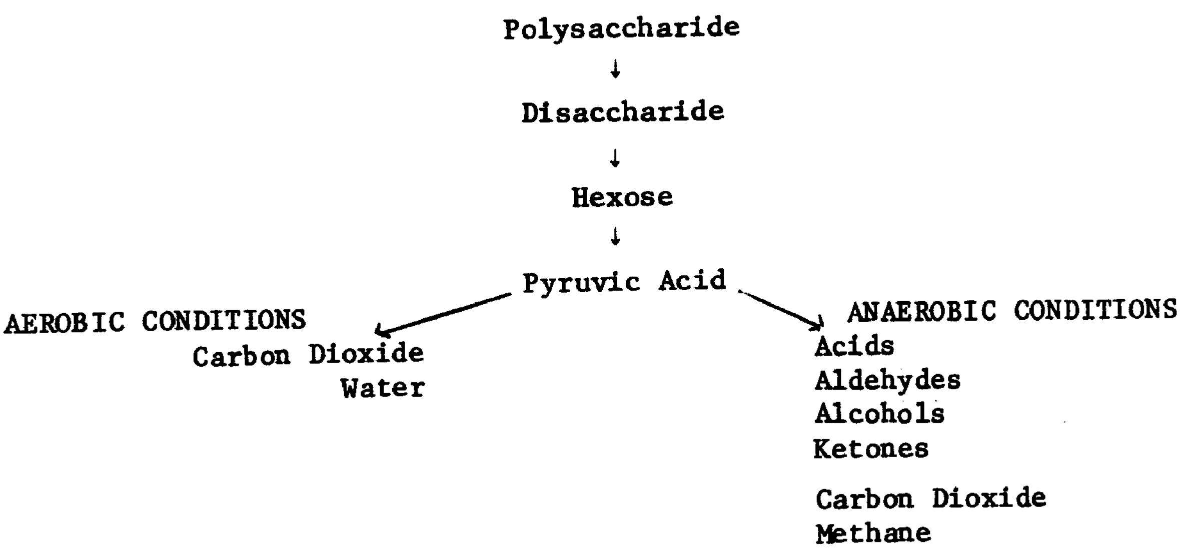


Figure 3. Pathways of carbohydrate decomposition

specific limitations either in terms of technology or cost. However, most are finding application in the control of manure odors as is indicated in Table 1.

Table 1. USE OF RESTRICTIVE ENVIRONMENTS TO CONTROL THE FORMATION OF MANURE ODORS BY ANAEROBIC DECOMPOSITION

Technique	Application	Limitation
Aerobic environment	Oxidation ditch Aerated lagoon	Power and equipment costs
Moisture control	Manure dryers Power ventilated poultry manure pits	Manure transport Control of water leaks
pH adjustment	Lime application	Ammonia release, cost, solids increase
Temperature	Freezing	Cost-handling
Chemical inhibition	Chlorination	Cost
Microbial population adjustment	Digestive aids	Technology

Considerable work has been done to determine the characteristics of animal manures as produced by the specific animal. Summaries of these characteristics are included in Tables 2 and 3. Animal waste characteristics have been determined primarily for use in assessing water pollution effects or the parameters for liquid waste handling. Little attention has been given to analysis of these waste products specifically oriented toward odor production and control.

The odor of fresh manure can be intuitively assumed to be a function of the animal specie, the feed ration being consumed, and the existing microfloral population within the animal intestine. Within these variables would be included the absence or presence of intestinal diseases and specific metabolic disorders of the animal as well as environmental stresses which might be influential in changing the animal's feed utilization. These considerations suggest that there may be great variation in the volatile compounds present within manures from a specific specie. After being voided by the animal, the manure's further decomposition will be influenced by the environment in which it is maintained. At this point, another opportunity for odor control exists. Variables which offer some potential control are moisture condition, dissolved oxygen level, and specific biological controls which might be used to alter the course of decomposition. For any specific metabolic process, other potential means of varying the odor release pertain to the control of volatilization of the odorous compounds, the amount of dilution which occurs, and the proximity of the odor source to the potentially offended persons.

Table 2. CHARACTERISTICS OF FARM ANIMAL MANURES PER THOUSAND LIVE WEIGHT UNITS PER YEAR (POUNDS OR KILOGRAMS)[2]

Animal	N	P_2O_5	K	BOD_5
Dairy	131	36.1	55.8	1.7
Beef	170	26.3	39.4	1.5
Poultry	262	292	134	4.0
Swine	147	66	37	2.1
Sheep	123	43	89	0.7

Table 3. DAILY MANURE PRODUCTION AND CHARACTERISTICS OF LIVESTOCK IN CONFINEMENT, PER THOUSAND LIVE WEIGHT UNITS (POUNDS OR KILOGRAMS)[3]

	Dairy	Beef	Hens	Pigs	Sheep
Raw manure (RM)	88	60	59.0	50	37
Total solids (TS)	9.0	6.0	17.4	7.2	8.4
Total solids, percent RM	10.0	10.0	30.0	14.4	22.7
Volatile solids (VS)	7.2	4.8	12.9	5.9	6.9
Volatile solids, percent TS	80	80	74	82	82
BOD_5	1.7	1.5	4.4	2.1	0.7
BOD_5, percent VS	24	31	34	35	10
BOD_5, percent COD	16	17	28	33	8
Nitrogen, percent TS	4.0	7.8	5.7	5.6	4.0
Phosphoric acid, percent TS	1.1	1.2	4.6	2.5	1.4
Potassium, percent TS	1.7	1.8	2.1	1.4	2.9

SECTION II

HUMAN RESPONSE TO ODORANTS

Although certain odorous gases are known to be harmful and toxic, the principal effect upon humans is one of annoyance or discomfort. The phenomenon of toxicity, although important in the area of industrial hygiene and overall human health, is not generally the problem with respect to livestock waste odors. Specific human health hazards associated with gases which evolved from animal waste are limited to situations in which persons encounter large concentrations of such gases. Particularly hazardous are instances where people enter manure storage tanks without adequate ventilation or situations in which explosive mixtures of methane have been captured within a building and then ignited.

Several gases identified in livestock manure odors are of concern in atmospheres in an industrial setting where people might work. Table 4 lists several gases which may be encountered in an odorous environment and the concentrations which are considered not to be hazardous to human health or safety.

Table 4. CHARACTERISTICS AND PERCEPTIBLE CONCENTRATIONS OF VARIOUS SUBSTANCES IN AIR[4]

Substance	Odor Characteristic	Concentration causing faint odor 10^{-9} g/l
Acetaldehyde	Pungent	4
Ammonia	Sharp, pungent	37
n-Butyl mercaptan	Strong, unpleasant	1.4
Carbon disulfide	Aromatic odor, slightly pungent	2.6
Ethyl mercaptan	Odor of decayed cabbage	0.19
Hydrogen sulfide	Odor of rotten eggs, nauseating	1.1
Methyl mercaptan	Odor of decayed cabbage or onions	1.1
Propionaldehyde	Acrid, irritating odor	2
Propyl mercaptan	Unpleasant odor	0.075

Ammonia has been one of the gases associated with livestock wastes of greatest interest to both researchers and livestock producers. It is produced in relatively large quantities by the anaerobic decomposition of proteinaceous material and by the breakdown of urea. Ammonia has a distinctive odor discernible by most observers at concentrations of approximately 0.037 mg/1[4] or 30 ppm by volume. Other researchers have reported ammonia threshold odors of 46.8 ppm.[5] One complication is that ammonia is seldom encountered independently of other odorous compounds. Several other compounds, particularly the amines, have odor qualities quite similar to ammonia, but are detectable at much lower concentrations. At concentrations of approximately 0.3 - 0.5 mg/1, ammonia acts as an irritant to the eye, nose and throat of humans. At high concentrations it acts as an asphyxiant.[6] Similar reactions have been noted in domestic animals with the additional observation that at even low concentration ammonia tends to interfere with the action of the cilia of the upper respiratory tract.[6]

Hydrogen sulfide has been of concern relative to livestock wastes because of its toxicity to both humans and animals as well as its objectionable odor. Concentrations in excess of 400 ppm have been toxic to man.[7] Similar levels also are responsible for livestock deaths. Hydrogen sulfide poisoning of animals has always been associated with some event such as agitating a manure storage tank which caused the H_2S level to rise up to 1000 ppm for a short period. Chronic H_2S poisoning is not a problem because it is rapidly oxidized to sulfate in the blood.

The most common complaint relative to livestock production is that of odor. Table 5 lists several gases associated with animal waste odors and their perceptible, threshold concentrations. An odor may be intermittent, the usual case, or in certain instances may be continuous. Persons living near livestock production facilities are protected under the law by the concept of nuisance. A nuisance in the legal sense may be summarized as anything which causes an unreasonable interference with the use and enjoyment of property. The various aspects of nuisance relative to livestock production were treated in some detail by Paulson.[8]

Table 5. THRESHOLD LIMIT VALUES* FOR VARIOUS GASES ASSOCIATED WITH ANIMAL WASTE ODORS[9]

Substance	Concentration 10^{-9} g/l
Acetaldehyde	360
Acetic acid	25
Ammonia	35
n-Butyl acetate	710
Butyl mercaptan	35
Diethylamine	75
Dimethylamine	18
Ethylamine	18
Ethyl mercaptan	25
Isopropylamine	12
Methylamine	12
Methyl mercaptan	20
Triethylamine	100

*The Threshold Limit Values refer to airborne concentrations under which it is believed that nearly all workers may be repeatedly exposed without adverse effect.

DOCTRINE OF NUISANCE

Ownership of land includes the right to impregnate the air with odors, dust and smoke, pollute the water and make noises, provided these actions do not substantially interfere with the comfort of others or injure 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 on the right of an owner to use his property as he pleases and is applied to a series of wrongs which may arise from an unreasonable, unwarranted or unlawful use of his property which produces annoyances, inconveniences, discomfort or hurt that the law will presume to be a damage. What constitutes a nuisance in a particular case must be decided 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 it is a ground for a civil proceeding only. In most cases, livestock odor conflicts have been of this latter type.

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 from liability to a neighbor if that business causing the nuisance is unreasonable and constitutes a nuisance. Paulson 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 decided upon the basis of being reasonable or unreasonable.

For the odor of a livestock feeding operation 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.[8] It is not necessary that the odors should be harmful or unwholesome. It is sufficient if they are offensive or produce 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 livestock operation has two courses of action open to him: a suit for damages and a suit to enjoin or abate the nuisance and he may pursue either or both.[8] The remedies of injunction or abatement are generally considered by the courts as being harsh. Normally only that part of the operation which amounts to a nuisance will be abated or enjoined. When the nuisance results only because of the method of operation or manner in which the 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 the annoyance or injury be continuous or recurrent. The use of premises which amounts to 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 party injured is normally allowed to show the best or most advantageous use for which the property is to be used; this is then used as a basis for determining the amount which would be adequate and fair compensation.[8] Punitive damages are allowed only when it can be shown that one has created and persistently maintained a nuisance with a reckless disregard for the rights of others or when he has reason to believe that his act may injure another and does it in deference to 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.[8]

Several court cases involving livestock production odors have been heard in recent years. A limited number of these cases are listed in Appendix B.

The litigation experiences of five livestock and poultry producers were summarized by Willrich and Miner.[10] They listed the major causes of conflicts that precipitated these civil proceedings as follows: noncompliance with zoning regulations; offensive odors exhausted from totally enclosed, mechanically ventilated buildings in which manure and waste feed were decomposing anaerobically; offensive odors released from anaerobic lagoons; offensive odors originating from manure decomposing on open lot surfaces; surface water pollution caused by runoff; or transport of manure from open lots. Other causes included objectionable noises, excessive flies and rodents, manure spillage on a public highway and suspected ground water pollution.

The probability of a livestock or poultry producer becoming involved in court litigation can be minimized by heeding the following suggestions.[10]

(a) The production unit and associated waste handling and disposal facilities must comply with zoning regulations and all other applicable water pollution control and environmental quality regulations.

(b) Provide an adequate separation distance between odor source and the points where the odor could offend others unreasonably and thus constitute a nuisance. Provide an adequate buffer zone for odor dissipation in all directions from the odor source, not just in the prevaling wind direction.

(c) Use waste management methods that minimize release of offensive odors, particularly if the available buffer zone is inadequate for normal dissipation by natural conditions.

(d) Use waste management methods that control the release of potential pollutants into the surface and underground waters and the production of flies, rodents, and other pests.

(e) Avoid or otherwise screen or isolate from public view any unsightliness that might suggest the productional facility could be a source of odor, flies, or other causes of nuisance or material that could cause environmental quality degradation.

(f) Practice the negative golden rule. Don't do to others as you would not like them to do to you.

SECTION III

ANIMAL RESPONSE TO ODORANTS

Because of the difficulties in measuring the strength of odors, no data correlating odors to animal response exists. There has been, however, considerable work reported which establishes the deleterious effects of air pollutants on the health and performance of livestock. This subject was reviewed in great detail by Lillie.[7] The material which follows will deal only with those gases and vapors associated with livestock production and their effect on animals.

AMMONIA

Ammonia in the atmosphere at levels tolerated by man (less than 25 ppm or 17 mg per m^3) does not constitute an air pollution crisis to domestic animals.[7] Higher levels created by poultry kept under poor management practices have been known to produce an eye disorder known as keratoconjunctivitis and to affect the overall performance of poultry, especially with high temperature and high relative humidity. Avian leukosis was not influenced by ammonia. High levels of nutrition counteracted the detrimental effects of ammonia as did proper management and ventilation practices.

A study, conducted by Charles and Payne,[11] indicated that at 18° C and at 67 percent relative humidity the use of atmospheres containing 105 ppm of ammonia (by volume) significantly reduced egg production after 10-weeks exposure. No effects were observed on egg quality. When White Leghorn hens were housed at an environmental temperature of 28° C, body weight decreased. The decrease in live weight was greatest at the high ammonia concentration of 102 ppm and was significant after only one week exposure to the ammonia. Exposure to ammonia further reduced the food intake of the animal as compared to those housed in a low ammonia environment. In a subsequent trial, a high protein, vitamin and mineral diet prevented the onset of harmful effects of ammonia on egg production, even though food consumption fell significantly.

Duroc pigs were subjected to four levels of ammonia air contamination (approximately 10, 50, 100 and 150 ppm by volume) in a study by Stombaugh, Teague and Roller.[12] The trials were conducted under environmental conditions of 21.2^{o} C temperature and 77 percent relative humidity. Ammonia concentrations had a highly significant adverse effect upon feed consumption and average daily gain. However, there was no significant effect upon efficiency of feed conversion.

Preceeding the first trial, Stombaugh, Teague and Roller[12] placed a 30 kilogram (66 pound) gilt in an ammonia concentration of approximately 280 ppm for 36 hours. When first placed in the compartment, frothing of the mouth was observed and there were excessive secretions around the nose and mouth. After approximately three hours, the frothing disappeared. Excessive secretion around the nose and mouth, a short and irregular respiratory pattern, occasional sneezing, and occasional shaking of the head persisted. After 36 hours in this environment, convulsions occured and breathing was extremely short and irregular. At that point the ammonia supply was turned off, and the compartment completely ventilated. Although the pig continued to have convulsions for at least three hours, its condition improved. Seven hours after convulsions ceased, except for occasional sneezing and shaking of the head, the animal appeared completely normal. This experience indicated that an ammonia concentration of 280 ppm was too high to be used in their experiments.

HYDROGEN SULFIDE

Hydrogen sulfide is a highly lethal gas to man and to livestock. Incidents of animal deaths attributable to hydrogen sulfide toxicity have been reported, particularly when manure storage tanks beneath slotted floors have been agitated prior to pumping to a tank truck or an irrigation system. Lillie[7] provides documentation of three instances in which swine were killed while manure storage tanks were being agitated. Measurements have been taken indicating that hydrogen sulfide concentrations after a brief period of agitation can reach concentration in excess of 1,000 ppm which is well over the 500 ppm level considered toxic to humans.

MIXED AIR POLLUTANTS

The effect of a manure storage tank located beneath and vented to an animal confinement facility is to increase the concentration of hydrogen sulfide, ammonia, carbon dioxide and methane within the atmosphere. Agitation of the liquid manure slurry results in a rapid increase of H_2S and CO_2 gases above the levels at which they are normally toxic to livestock. The clinical symptoms of these gas toxicities are: (a) methane becomes explosive in concentrations of five to six percent; (b) CO_2 produces palpitation at the 10 percent level and a narcotic action that often results in death at the 25 percent level; (c) ammonia causes irritation of eyes and respiratory mucous membranes at the 0.01 percent level and becomes a health hazard at a level of 0.05 percent; (d) concentrations of 0.002 to 0.01 percent H_2S irritates the eyes and produces dizziness within 30 minutes, a 0.05 percent level affects the nervous system and death occurs after 30 minutes of inhalation, and inhalation of air containing 0.09 to 0.1 percent H_2S produces instantaneous death.[7]

SECTION IV

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 feel is satisfying, a taste is enjoyable, a scene is beautiful, or a smell is desirable is essentially a personal response based upon our cultural background and our individual disposition of the moment.

The senses of touch, taste, hearing and sight all measure environmental parameters which are also measurable by other techniques as shown in Table 6. The sense of smell is unique in that no mechanical or chemical alternative device exists for measuring the odor. Thus, odor is essentially 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.[13] Moulton[14] 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 preceeded by an understanding of the way the nose functions to distinguish one odor from thousands of others. A simplified sketch of the odor sensation process follows. Information of greater detail may be found in The Chemical Senses by Moncrieff.[15]

Table 6. 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/1, pH unit
Touch	Temperature, hardness	Thermometer	Degree
Smell	Odor	None	None

Figure 4 depicts the nasal cavity in the human head. Inspired air typically travels into the nostrils, through the turbinate area and down the throat to the lungs. Normal breathing will cause 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.

The olfactory nerve cells, shown in Figure 5, are located in the olfactory cleft area. The total olfactory reception area in the adult human is about two square inches. The olfactory cells are long and narrow; they are oriented perpendicular to the surface of the receptor area. The cells are pigmented yellow or yellow-brown. On the exposed end of the nerve cells are five to eight olfactory hairs which extend into or through a mucous layer which coats the surface of the mucous membrane. Surrounding the olfactory cells in the mucous membrane are the sustentacular cells which support and insulate the nerve cells. Axons, originating at each nerve cell, pass through the membrane at the base of the mucous layer and carry a message to the glomeruli.

It is believed that the 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

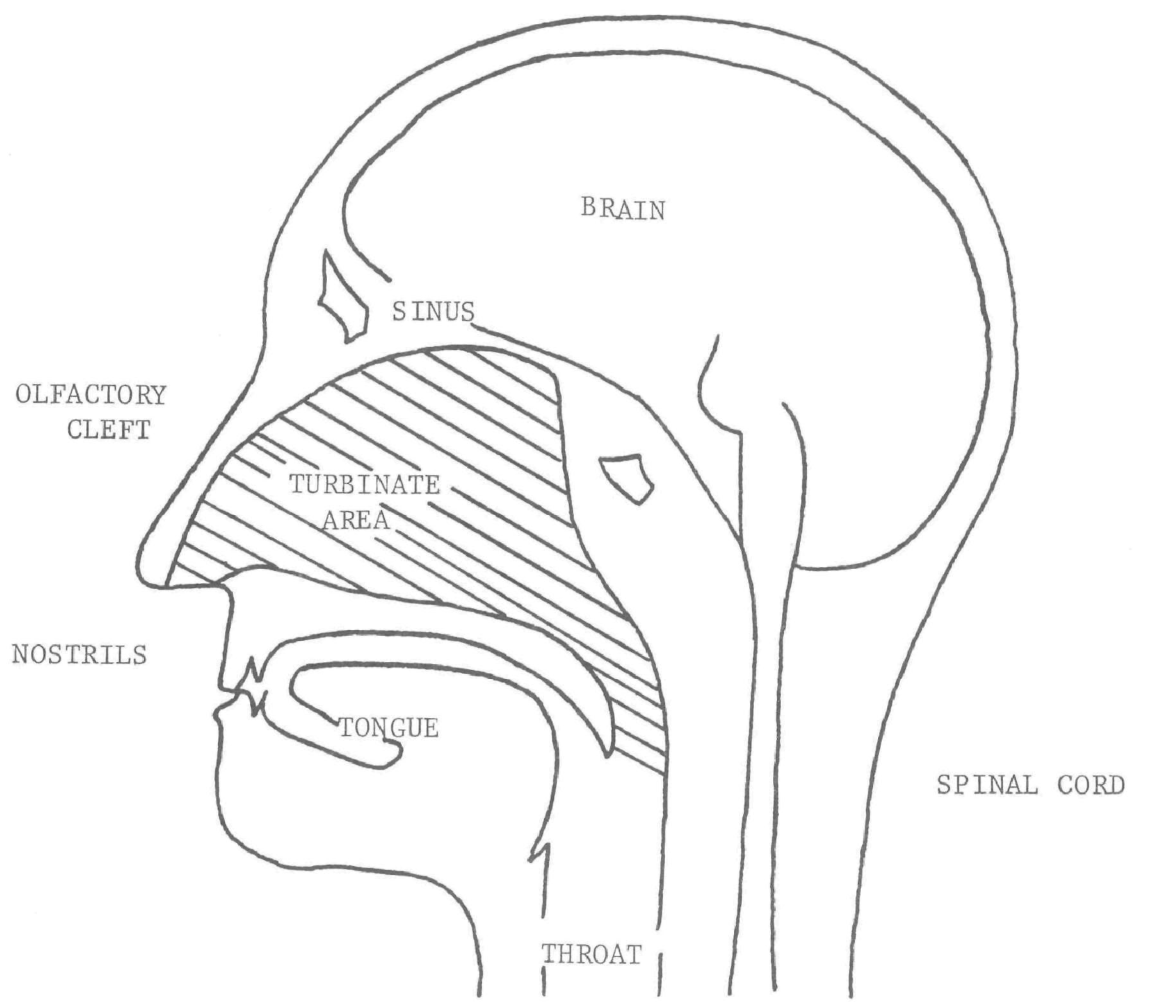


Figure 4. Human nasal cavity

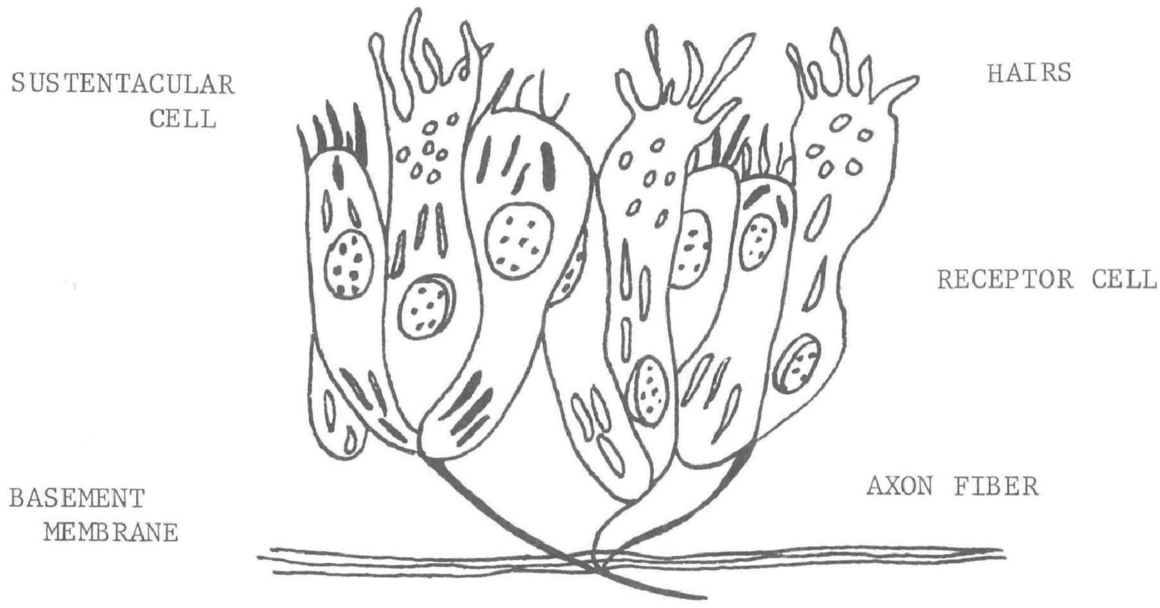


Figure 5. Olfactory mucosa

layer. An excess of the mucus as in the case of a head cold can incapacitate the hairs and the sense of smell. There are different kinds of odor receptor cells--cells that respond to different odor stimuli.

Moncrieff[16] 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 aid 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, and this, according to Moncrieff[15] is only half the story of odor perception. The other half consists of the receptor system and the 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 the 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 on the method by which the "message" of the odorant is transmitted to the olfactory nerve. The 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.[15] 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. (The odorant had been adsorbed onto the receptor cells in the head.) After a short time, the air passing through the head contained a concentration of odorant equal to that entering. (The receptor sites had been saturated and any particles adsorbed only replaced particles desorbed.) The odorant supply was cutoff and the airstream continued to circulate through the nasal cavity until no odorant was detected in the exit air. (The only odorant remaining in the head was adsorbed onto the receptor areas.) 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. (The odorant desorbed from the receptor sites was unchanged. No chemical action had taken place. The process of adsorption is essential in odor perception.)

Events in this experiment are not, however, supported by the contention of Davies[17] that particle retention time on the receptor surface is on the order of 10^{-8} seconds and that a chemical reaction not dependent on the reactivity of the odor molecule occurs.

The stereochemical theory of Amoore[18] 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 the primary odors. Amoore has more recently altered his theory to account for a two-dimensional fit rather than three-dimensional. Molecular silhouette or cross-sectional area is the important steric characteristic of the odorant.[19] Odor perception is initiated by an energy change brought about by the adsorption of the odorant molecule on the olfactory nerve.

The vibrational theory for human olfaction was introduced by Dyson.[20] The theory proposed that odorous substances possess intra-molecular vibrations of such periods as to produce Raman shifts between 1400 and 3500 cm^{-1}.

Since 1954, the idea has been furthered by Wright[21,22] who suggests that the Raman shifts of odorous substances occur at frequencies less than 700 cm^{-1}. It is the vibrations of this range that are most likely to be active at body temperature. The vibrational theory concludes that odorant molecules have "odor-active" molecular vibrations which are best evaluated by both the Raman and infra-red spectroscopy. These important vibration frequencies "fit" specific receptor sites in the nose (along with a steric fit) thus providing the initial stimulus for odor perception.

Davies and Taylor[23] presented the penetration theory. Odor perception according to this theory depends upon two basic parameters:

(a) The partition coefficient of the substance between air and a water-oil interface. This relates to the adsorption-desorption properties of the odorant on the receptor site.

(b) The cross-sectional area of the molecule. This relates to the characteristics of the puncture of the olfactory nerve by the odorant adsorbing on the receptor site.

Odor reception is initiated when the molecule adsorbs onto the olfactory nerve causing a puncture of the surface lipoid membrane. 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. More recent work on the penetration theory by Theimer and Davies[24] has added a third parameter for odor dependence--the length to breadth dimension ratio of the molecule.

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 of 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. American Society for Testing and Materials, "Manual on Sensory Testing Methods,"[25] effectively describes the ground rules for conducting odor strength and quality tests. The manual states the requirements for the physical facilities, the test subjects and the samples to be tested. The 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 the individual tests must be conducted. Such details are dictated by the kind of material and the characteristic of the odorant being judged.

The most common method of measuring odor intensity is by dilution to extinction. The 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 the threshold value. Baker[26] compared four common procedures for determining the 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 of which are blank.

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

The tests were run using two odorants, n-butanol and m-cresol. The results showed that the tests in order of decreasing sensitivity were TT, CS, SP and STD. Baker, however, points out that no test is obviously superior when performed under controlled conditions with trained personnel. Burnett and Dondero[27] reported on a modified procedure for threshold odor determination.

Threshold odor levels are also measured using odor-free air as a carrier and dilution medium. Equipment for the air-dilution method is more intricate and expensive, but the results are more reliable as a measure of true odor intensity. A number of writers have reported on odor threshold determinations with the air dilution procedure.[15,27,28] Suprathreshold odor intensities can be judged directly. The odorous unknown is compared with a similar or like odorant of known intensity. The observer makes an intensity judgment based on the comparison. Jones and Waskow[29] and Stone[30] described methods to utilize this test practice. Either liquid or air-dilution procedures may be used to make the comparisons. Suprathreshold odor-intensity judgments lack the reliability of the threshold level determination.

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

$$2^{OII} = TON \qquad (1)$$

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 to use OII rather than 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. Odor threshold measurements are more objective than suprathreshold measurements. ASTM[25] stated that the minimum number of observers for any test is five since any fewer number places too much dependence on the response of any individual. The subjects must pass a preliminary screening to assure that they are capable of making a normal response to the stimuli to be presented. Swets[31] emphasizes the need to inform the observer as fully as possible concerning the nature of the judgments desired, the test procedure and the controls to be employed. Uncertainty plays a big role in reducing the effectiveness of the subject and, consequently, the validity of the results. Swets further suggests the inclusion of a large number of catch trials (trials which contain no odorant) to insure the certainty of a positive decision.

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 may result from a light, well-ventilated house with little more than the smell of must or feed, or it may have been a highly populated house with poor ventilation, high humidity and concentrated ammonia. One's interpretation could 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. These have been reported by a number of authors.[14,15] Five of these lists are presented in Table 7. Classes of similar qualities are placed on the same line.

Table 7. BASIC ODOR QUALITY CLASSIFICATIONS AS DESCRIBED BY FIVE AUTHORS[15]

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		Camphora-ceous	Camphora-ceous, aromatic
			Minty	Pepper-minty
Empyreumatic	Burnt	Burnt		Almond
Alliaceous	Foul			
Caprylic		Caprylic		
Repulsive				
Nauseating, foetid			Putrid	
		Acid	Pungent	

Qualitative odor testing is widely used in the food and perfume industries. Use of qualitative odor testing in livestock waste research is limited. The test is often made by comparing the unknown with a known odorant of similar or dissimilar quality in paired comparisons. The observer then makes a judgment of the degree of similarity.

Odor-quality testing lacks the desired objectivity of the odor threshold determinations. Quality tests require observer judgments relative to a known odorant and subjectivity is unavoidable. To maximize the validity of the test, the preparations of the physical facilities, the samples, and the subjects as outlined by ASTM[25] are of utmost importance.

LIMITATIONS OF ODOR TESTING

The limitations of odor testing result from the existence of odor phenomena and the preferences (or subjectivity) of the 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 the 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 livestock buildings or yards soon lose the ability to make unbiased odor judgments about odorants similar to those of the immediate environment. The rate of adaptation varies with the strength of the stimulus. Moncrieff[16] demonstrated the effect of adaptation. 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 the 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 the threshold concentration.

Adaptation effects were also reported by Baker[26] who tested the influence of light, background odor on odor-intensity tests. Background odor similar to the odorant tested reduced the OII slightly while a background odor dissimilar to the odorant tested produced a slight increase in the OII.

Fatigue

Fatigue is the result of adaptation. Exposure to a strong odorant may completely exhaust the capability to sense the 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.[13]

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[15] theorized that this effect may result from a substance comprised of more than one recognizable odor where each odor has a different threshold.

Moncrieff[15] reported the concept of limiting intensity. The concept says that the human nose cannot distinguish between odorant concentrations greater than a saturation level. The reasoning behind the concept (which heavily supports the adsorption theory of odor) is that the receptor sites become filled with odorous molecules and an increase in the number of molecules inspired causes no increase in sensation.

Standard procedure for odor threshold testing utilizes serial dilution with each succeeding dilution 50 percent of the one before. Fractional dilution is not justified. Baker[26] reported variability of about one OII unit with the four threshold test procedures that he used. Moncrieff[15] stated that an increase of about 30 percent in odorant concentration is necessary to produce a perceptible sensation.

Both air and liquid dilution media are employed in odor testing. The liquid is usually odor-free water, but alcohol in combination with odor-free water has been used when the odorant was not soluble in water.

Definition of the dilution system and other test conditions are important in reporting results. Sobel[28] stated that different threshold values are obtained from air and water dilution methods for the same odorant.

An awareness of the significance of air and liquid dilution systems is desirable. A water dilution system dilutes the source of the odor until the emitted odor is just detectable. This measures the odor-producing capacity of the odorant. The air dilution system dilutes the odor produced until that odor can just be detected. This measures the strength of the odor produced by the odorant. Both systems have application in studying odor from livestock operations.

Mixtures

Rosen *et al.*[32] 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)	Addition	$R_{A+B} = R_A + R_B$
(d)	Synergism	$R_{A+B} > R_A + R_B$

Work of Baker[26] confirmed examples of additivity, antagonism and synergism.

Jones and Woskow[29] tested the odor intensity of two component mixtures of odorants. They used all possible combinations of three similar odorants and, also, of combinations of three dissimilar odorants. The odor magnitude of the mixes was not additive, nor was it an average of the two components. The odor level of the combinations was somewhere between the sum and the average. This reaction lies in a region not specified by the Rosen *et al.*[32] reactions --- $R_{A+B} < R_A + R_B > \frac{R_A + R_B}{2}$.

Moncrieff[15] described counteraction (the mutual discrimination) of two odors to the extent that they are odorless in combination. Using low concentrations of the odorants they tend to be additive, but with certain combinations of high concentration, the effect was no odor. Guadagni et al.[33] found that the 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, according to Moncrieff,[15] can vary according to the concentration of the components.

Complex mixtures of odorants may not offer the same mysterious range of reactions offered by two-component systems. Complex odorant mixtures have direct application to the field of livestock odors where odors often result from complex biological systems. Guadagni et al.[33] in testing complex systems of up to ten odorants concluded that the reactions were mostly additive rather than synergistic, antagonistic or independent. This would be the anticipated result for complex systems where the more common additive reaction outweighs the other somewhat unusual reactions. In this case, "additive type reaction" refers to one that is additive in nature and not strictly additive as in the reaction stated by Rosen. The interpretation is that (using the two-component reference notation)

$$R_A + R_B > R_{A+B} > R_A \text{ or } R_B$$

Temperature

The recommended temperature for comparative odor testing is 40° C. This temperature was preferred by panelists as compared to temperatures of 21° and 60° C.[26] The lower level produced "dead" samples while the higher level produced some steaming and gave fleeting initial responses (probably due to the extensive removal of the more volatile odorants present). An OII increase of 1.4 units was noted in increasing the diluted odorant test samples from 21° to 60° C.

Other temperature levels for odor testing are reasonable where odor intensity and quality measurements are to be indicative of operative conditions different from 40° C. The odor intensity determination for manure stored under winter conditions might be made at 4° C, while odor levels generated under summer or warm weather conditions might be reported at 20° C. Where odor levels are established strictly for comparative purposes, the standard af 40° C would be desirable.

<u>Anosmia and parosmia</u>

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.[13]

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. The condition is likely to be temporary.[13]

<u>Pungence</u>

"Pungent" has been included as a basic odor type by some authors. This odor is associated with strong acidic and basic smells. Two authors[18,22] proposed that pungence may not, in some cases, be a true olfactory nerve response, but a sensation of pain caused by irritation of the trigeminal nerves in the nasal cavity.

<u>Age</u>

In general, man's sense of smell develops until the age of about 20. The good sense of smell continues until the age of about 50 and then declines. Venstrom and Amoore[34] tested 97 normal subjects to determine the rate of decline of olfactory sensitivity with age. The study showed that man has a 50 percent reduction in the sense of smell in 22 years. This compares with 13 years for a 50 percent reduction in sense of sight, 15 years for sound, 29 years for taste and 60 years for touch.

Moncrieff[15] related that children have a greater tolerance for a fecal odor such as skatole. He also states that man develops a taste for partially-decomposed food such as aged meat and cheese as he grows older. Children rank fruity odors highest for pleasantness while adults prefer fragrant odors.

Sex

Authors are divided on the theory that women are more sensitive, olfactorywise, than men. The case is well stated by the research of Venstrom and Amoore[34] who found that women were about one-quarter OII unit more sensitive to odor intensity than men but that this was not a significant amount for the conditions of their study.

Moncrieff[16] points out that men are more nearly unanimous in their preference for pleasant odors while women are more unanimous in their selection of odors which are unpleasant. Women as a group think culinary odors are more pleasant than men do.

Smoking

Like the battle of the sexes, the question of sensitivity of smokers is unsettled. Again, the work of Venstrom and Amoore[34] gives a good picture of the facts by reporting that non-smokers were about one-fifth OII more sensitive to odor intensity than were smokers but that this was not significant for the conditions of the test. It is necessary, however, that smokers refrain from smoking for 15 minutes before the odor test.

Natural variation

According to Moncrieff[15] olfactory capabilities among healthy persons are fairly uniform. The primary difference is the form of the nasal passages. Additional variations, though slight, can result from any of the myriad diseases and conditions which affect the state of the nasal cavity and olfactory nervous system.

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 the 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. A number of researchers have reported the use of the GLC for odor component identification for livestock wastes.[35,36,37,6,38]

Kendall and Neilson[39] compared the sensitivity of the GLC to the nose. They found that their panelists could detect odorant concentrations 10 to 100 times more dilute than the GLC. Other types of chromatography, though less sensitive, can also be useful in component identification after separation.

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 the odorant with odor-free air prior to inspiration. The meters have been given such names as "osmoscope", "odormeter" and "osmometer". Descriptions and use of these instruments have been made by Stone[30], Moncrieff[15] and Sobel.[28]

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 must 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.

In 1961 Moncrieff[40] developed a mechanical nose. Many refinements were added later.[15] The instrument utilizes a pair of matched thermistors, one of which has a thin protein film placed over it. As an odorant passes over the thermistors, the unbalanced rates of adsorption on the protein film and the glass coating of the other thermistor cause a temperature differential. A flow of current between the thermistors caused by the unequal resistances is measured on a micro-ammeter. Friedman, _et al_.[41] adapted this type of mechanical nose for their work on energy changes associated with odor perception.

In 1964, Rosano and Scheps[42] reported on their efforts to develop an artificial nose. These writers used an instrument which allowed simultaneous study of adsorption and chemical interaction. Their contention was that enzymatic action must be considered in the odor perception process.

These attempts to further understand the function of the human nose and to simulate it have met with some degree of success. Some of the responses of the machines closely resemble those of the nose. It appears, however, that the complexities of the human nose are impossible to duplicate.

SECTION V

RELATIONSHIP BETWEEN ODOR AND pH

To exhibit its characteristic odor, an odorous substance dissolved in water, must escape from the liquid phase. Ionized species have no vapor pressure, thus, only the non-ionized species are effective in odor production. Hydrogen ion concentration is the single most important variable in determining the fraction of a substance in the non-ionized form. Using lime to control the escape, hydrogen sulfide is an applied example of this phenomenon.

Quantification of this characteristic is best achieved by considering the pK values. At a pH equal to the pK, one-half of the compound is present in the non-ionized form. For acidic odorants, a decrease in the pH by one unit causes the fraction of the non-ionized species to increase to 91 percent. Increasing pH values result in the opposite effect. For basic odorants, increasing pH values result in greater quantities being present in the non-ionized fraction, thus in greater volatility. Table 8 includes a tabulation of pH values for various odorants at which the compound is 50 percent ionized.

Table 8. pH VALUES FOR WHICH VARIOUS ODOROUS COMPOUNDS ARE 50 PERCENT IONIZED AT 25° C[43]

Acidic Compounds	pH	Basic Compounds	pH
Acetic acid	4.75	Ammonia	9.25
Butyric acid	4.83	n-Butylamine	3.39
Hydrogen sulfide	7.04	Diethylamine	3.00
Propionic acid	4.87	Dimethylamine	3.30
		Ethylamine	3.33
		iso-Butylamine	3.58
		iso-Propylamine	3.37
		Methylamine	3.36
		Propylamine	3.42
		Triethylamine	3.28
		Trimethylamine	4.20

SECTION VI

DESORPTION OF AMMONIA

Although ammonia is highly soluble in water, an equilibrium exists between the ammonia concentration in water and its partial pressure in air. When manure or manure slurries, high in ammonia, are in contact with air, desorption takes place. The driving force is the partial pressure of ammonia in equilibrium with the liquid concentration; diffusion across the gas film is the rate-limiting process. From these statements, a modified Fick's Second Law expression can be written.

$$dw/dt = Ak_g P_A \qquad (2)$$

where
- dw/dt = rate of desorption
- A = area of gas-liquid interface
- k_g = diffusion coefficient
- P_A = equilibrium partial pressure of ammonia

The term, P_A, which defines the partial pressure of ammonia in equilibrium with the liquid, can be expressed in terms of the ammonia concentration in the liquid and Henry's Law constant for ammonia.

$$P_A = \frac{C_{NH_3}}{H} \qquad (3)$$

where
- C_{NH_3} = ammonia concentration (mg/l)
- H = Henry's Law constant

Only that portion of the ammonia present in the non-ionized (NH_3) form is available for volatilization. The fraction of the total ammonia concentration in the NH_3 form is a function of the pH and temperature. As shown in Table 9 the fraction F of total ammonia concentration present as volatile NH_3 is sufficiently small at pH values less than seven to preclude significant volatilization. Values in Table 9 were calculated from the following relationships:

$$NH_3 + H_2O \rightleftarrows NH_4^+ + OH^- \quad (4)$$

$$K_B = \frac{[NH_4^+]\ [OH^-]}{[NH_3]} \quad (5)$$

$$\frac{[NH_3]}{[NH_4^+]} = \frac{[OH^-]}{K_B} \quad (6)$$

$$F = \frac{[NH_3]}{[NH_4^+] + [NH_3]} = \frac{[OH^-]}{K_B + [OH^-]} \quad (7)$$

$$[OH^-] = \frac{K_w}{[H^+]} \quad (8)$$

Table 9. FRACTION OF TOTAL AMMONIA CONCENTRATION PRESENT AS NH_3 AS A FUNCTION OF TEMPERATURE AND pH*

pH	Temperature (^oC) 10	20	30
7	0.0018	0.0040	0.0081
8	0.018	0.038	0.075
9	0.22	0.30	0.45
10	0.65	0.80	0.89

* Values for K_B and K_w taken from Handbook of Chemistry and Physics[43]

A more useful expression is obtained by combining equations 2 and 3 while substituting

$$\frac{dC_{NH_3}}{dt} = \frac{-Ak_g\ C_{NH_3}}{H} \quad (9)$$

Analytically, measurements of ammonia include both NH_3 and NH_4^+. The sum will be called NH_3^*.

$$C_{NH_3}{}^* = C_{NH_3} + C_{NH_4^+} \quad (10)$$

$$C_{NH_3} = F\ C_{NH_3}^{*} \quad (11)$$

More usefully, equation 9 can be written

$$dC_{NH_3}^{*} = \frac{-Ak_g F}{H}\ C_{NH_3}^{*} \quad (12)$$

Equation 12 is frequently simplified to

$$\frac{dC_{NH_3}^{*}}{dt} = KC_{NH_3} \quad (13)$$

$$K = \frac{-Ak_g F}{H} \quad (14)$$

$$C_{NH_3}^{*} = C_o e^{-Kt} \quad (15)$$

In equations 14 and 15, K is a desorption rate constant. When the natural logarithm of the total ammonia concentration is plotted versus time, the slope of the resulting line is equal to minus K.

FROM LIQUID POULTRY MANURE

Ammonia desorption from liquid poultry manure was studied by Hashimoto and Ludington[44] and the above analysis used to correlate their data. Desorption tanks were formed by inverting 19 1 (5.0 gal.) plastic carboys from which the bottoms had been removed. The tanks were stirred and pH controlled. This work[44] indicated the rate of desorption is highly dependent upon air velocity over the desorbing surface. Values obtained for Ak_g/H from equation 14 ranged from 0.05 to 0.09 per hour at 21° C and 0.037 to 0.061 per hour at 10° C. Using these data, ammonia escaping from the surface of their system at pH 8.0 and 20° C would lower the nitrogen concentration by 3.3 percent per day. At a pH of 9.0 the rate of decrease would be 23 percent per day. Thus pH is extremely important in estimating the rate of ammonia desorption.

FROM CATTLE FEEDLOTS

The escape of ammonia from cattle feedlot surfaces in northeastern Colorado was studied by Hutchinson and Viets[45] by placing dilute acid absorption traps at varying distances from cattle feedlots. Their results, summarized in Table 10, show significantly higher rates of ammonia absorption in the vicinity of feedlots as compared to samples gathered in other rural areas. The absorption of ammonia by the acidified absorbers was twice that of distilled water.

Table 10. MEAN AMMONIA NITROGEN ABSORPTION RATES BY DILUTE ACID TRAPS FROM 27 JULY 1968 THROUGH 27 FEBRUARY 1969 IN NORTHEASTERN COLORADO[45]

Site description	Mean weekly ammonia nitrogen absorption rate kg/ha
No feedlots within 3 km	0.15
Small feedlots (200 head) at 0.8 km	0.34
0.2 km east of 800 head feedlot	0.57
2 km east of 90,000 head feedlot	1.30
0.4 km east of 90,000 head feedlot	2.80

FROM DAIRY PENS

Additional work relative to the volatilization of ammonia from livestock feeding areas was reported by Luebs, Laag, and Davis.[46] Using dilute acid solutions in both air sampling traps and surface traps, they measured the concentration of ammonia plus amine nitrogen in the air near Chino, California. It is in this area that approximately 400 dairies serving the greater Los Angeles area are located. In this 15,500 ha (60-square-mile) area there are 123,000 dairy cows, 7,500 heifers and more than 9,000 calves. Results of their sampling (shown in Table 11) demonstrate the increase of ammonia and amine nitrogen concentration in the dairy area compared to a nearby residential district. In Table 12 average weekly absorption of ammonia plus amine nitrogen by acid surface traps is compared for various areas near Chino, California. Their data indicated that distilled water had an absorption rate equal to 58 percent of that by acid surface traps, thus one may conclude the area near the Chino airport could be exposed to ammonia at a rate up to 220 kg/year/ha (200 lb/year/acre) under the conditions measured.

Table 11. ATMOSPHERIC CONCENTRATION OF DISTILLABLE NITROGEN (AMMONIA PLUS AMINE) NEAR CHINO, CALIFORNIA[46]

Location Sampled	Date	Distillable nitrogen concentration ug/m^3
Brackett Field, 11.2 km (7.0 miles) upwind of dairy area	02-25-71	1
	05-04-71	2
	10-05-71	3
Chino airport in dairy area, 0.8 km (0.5 miles) from cows	02-24-71	39
	03-03-71	37
	03-05-71	46
	10-05-71	69

Table 12. AVERAGE WEEKLY ABSORPTION OF DISTILLABLE (AMMONIA PLUS AMINE) NITROGEN BY ACID SURFACE TRAPS NEAR CHINO, CALIFORNIA, JANUARY 11 TO FEBRUARY 15, 1972[46]

Location	Average weekly absorption rate kg/ha	lb/A
Dairy area, 0.8 km (0.5 miles) from cows	10.5	9.40
Urban area, 11.2 km (7.0 miles) NW of dairy area	0.31	0.28
Poultry and citrus area, 34 km (21 miles) E of dairy area	0.27	0.24
Dryland agricultural area, 51 km (32 miles) E of dairy area	0.20	0.18
National forest, 80 km (50 miles) SE of dairy area	0.02	0.02

Amine nitrogen comprises between five and 10 percent of the total nitrogen absorbed by acid surface traps in the dairy area, according to a limited number of analyses done by Luebs, Laag and Davis.[46] Because the odor of amine compounds is detectable at concentrations less than one ppm in air, they concluded amines were undoubtedly important relative to odors from animal waste.

A direct relationship was found between the concentration of ammonia plus amine nitrogen and the evaporation rate as measured from their sampling traps filled with 0.01 normal sulfuric acid. Thus, these data demonstrate the greater volatilization of ammonia and other distillable nitrogen compounds from dairy corral surfaces as evaporative potential increases. This conclusion was also supported by the fact that the amount of nitrogen measured tended to be higher when air temperature was high and relative humidity was low. Secondly, ammonia concentrations were greater during dry periods after the corrals had been wetted by rain.

FROM ANAEROBIC LAGOONS

An anaerobic lagoon receiving swine waste was analyzed for ammonia desorption by Koelliker and Miner.[47] This lagoon was operated as a flow-through system with a theoretical detention time of about 60 days. The lagoon had a surface area of 2,700 square m (29,000 square ft). A mass balance on the lagoon had indicated that from November 1, 1969 to October 31, 1970, 5,600 kg (12,400 lb) of nitrogen were introduced into the lagoon from the swine waste. During this same period, 2,100 kg (4,700 lb) of nitrogen were removed from the lagoon with wastewater for application to cropland. Because the lagoon water level was lower in 1970 than in 1969, there was a net decrease of 91 kg (200 lb) in the accumulation within the system. Thus, 3,600 kg (7,900 lb) of nitrogen escaped from the system, apparently because of ammonia desorption. Their data for the rate of ammonia desorption were correlated as follows:

$$\frac{d(NH_3\text{-}N)}{dt} = AK(P_l - P_g) \qquad (16)$$

In this expression, K can be approximated by the formula:[47]

$$K = 2.6 \times 10^5 V^{0.8} T^{-1.4} \qquad (17)$$

where

- V = air velocity in ft/second
- T = temperature in degrees Kelvin
- $P_l P_g$ = partial pressures of ammonia in the liquid and gas phases, respectively
- K, the overall rate transfer coefficient has units of pounds/day-square ft-atm

SECTION VII

IDENTIFICATION OF ODOROUS COMPOUNDS

Considerable effort has been expended in identifying compounds evolved by anaerobically decomposing manure. This work has largely involved concentrating the specific chemical gases being evolved into some absorbing solution or condensing trap followed by chromatographic analysis of the accumulated material.

POULTRY MANURE

The odor of fresh and accumulated poultry manure was chromatographically analyzed by Deibel.[48] He found butyric acid, ethanol and acetoin (3-hydroxy-2-butanone) to be the chief volatile components of decomposing manure while fresh manure was found to be devoid of these compounds.

To identify the volatile compounds of odor importance produced by chicken manure, Burnett[35] trapped gases in a collection column submerged in an acetone dry ice bath. A variety of column packings and temperature conditions were used to effect the necessary separations. When 0.5 microliter of prepared condensate was injected directly into the gas chromatograph, six peaks were obtained which were identified as acetic, propionic, iso-butyric, n-butyric, iso-valeric and n-valeric acids. The butyric and valeric acids have very disagreeable odors.

As part of the same project, Burnett[35] also injected chloroform extracts into a chromatograph fitted with an SE-30 column. Indole and skatole were identified by retention time comparisons with authentic compounds. The detection of the nitrogen heterocyclic compounds, indole and skatole, is significant because of the strong, harsh odors of these compounds. Both indole and skatole are very tenacious odorants which tend to cling to clothing and other articles and to persist for long periods. Burnett[35] found approximately 18 times more skatole than indole and concluded that skatole was probably responsible, in part, for the tenacious character of poultry waste odor.

Using additional concentration techniques, Burnett[35] tentatively identified several additional compounds from poultry manure. These were compared with retention times of known compounds and evaluated by an odor panel and postulated to be mercaptans and sulfides. Thus, his conclusion, which is compatible with those of other researchers in this area, indicated that animal manure odors are a complex mixture of organic compounds with characteristics mainly contributed by numerous chemical groups including the organic acids as well as sulfur- and nitrogen-containing compounds.

A direct relationship between odor level and the volatile fatty acid content of liquid poultry manure was found by Bell.[49] Fatty acids were measured according to the procedure outlined in Standard Methods.[50] He suggested an acceptable level based on odor control as being 0.1 percent or less of fatty acids in liquid manure.

The microbiological-chemical changes occurring in poultry manure during storage were studied by Burnett and Dondero.[27] In their studies, dry manure, 75 percent moisture, and wet manure, 85-90 percent moisture, were stored for periods of up to 40 days. They monitored the chemical and biological changes taking place within the stored material as well as the composition of gases produced. They found the uric acid content of dry manure in storage dropped rapidly during the first seven days. The amine nitrogen content of the manure rose during the first seven days and remained at a value of roughly 0.5 mg/g dry weight of manure for the next seven days. Between day 14 and 22 the value dropped back to approximately the initial amine nitrogen concentration. Ammonia evolution was initially low but rose to a maximum value after about six days, then fell again.

A marked increase in odor intensity was noted in the liquid manure after approximately 15 days. The uric acid content fell rapidly as was the case with the dry manure. The ammonia content of the liquid rose rapidly from approximately 100 mg/l at the start of the experiment to a value of approximately 1500 mg/l after 10 days. Beyond this time the ammonia content remained essentially constant. The concentration of soluble sulfides began to rise after approximately 17 days of liquid storage. This increase in soluble sulfides coincided with the dramatic increase in odor concentration. Although methane-producing bacteria were present from the start, they did not begin to proliferate until after 28 days of storage. Their earlier growth may have been inhibited because of the large, volatile organic acid concentration which developed during the early stages of storage. Volatile organic acid concentrations increased to 1600 mg/l by the fourth day and remained at that level or higher for the next two weeks. The volatile organic acid concentration then decreased, allowing the methane bacteria to grow.

A series of studies utilizing White Leghorn laying hen manure was conducted by Ludington, Sobel, and Hashimoto[51] in which 75 g of manure was put into a five gal. carboy for study. In one trial the manure was placed in the carboy without additional water (25 percent solids) and in the second trial the manure was diluted three to one with distilled water and the mixture (6.0 percent solids) was placed in the carboy. Air at the rate of 28.3 l/hr (1.0 cu ft/hr) was passed through the carboys. The exit air was then analyzed for carbon dioxide, ammonia, and hydrogen sulfide. In addition, odor panels made frequent observations on both systems to determine the strength of the odor and the odor characteristics. Both systems produced approximately six g of carbon dioxide daily. The undiluted system released 0.8 g of ammonia per day. The production and release of hydrogen sulfide was larger in the diluted than in the undiluted system. Results of these studies are in Tables 13 and 14.

A study was conducted by Hashimoto[52] in which a manure storage pit beneath caged layers was aerated, using compressed air forced through plastic pipes. Air was released to the liquid manure through 0.32 cm (1/8 in.) holes at 30.5 cm (1.0 ft) spacing along the bottom of the manure storage tank. He recorded the effects upon odor and also the changes of various water quality parameters. With respect to odor control, he found a strong correlation between the odor offensiveness as rated by an odor panel and the ammonia concentration in the room air. In one series of trials in which the tank was initially seeded with established oxidation ditch liquor containing large numbers of nitrifying

Table 13. AMMONIA PRODUCTION BY WHITE LEGHORN LAYER MANURE ADDED DAILY TO A NINETEEN LITER (FIVE GALLON) CARBOY[51]

	System	
	Diluted	Undiluted
Manure feed rate (g/day)	75	75
Water feed rate (g/day)	225	0
Solids content in feed (percent)	25	6
Duration of trial (days)	50	50
Air flow rate (l/hr)	28	28
Ammonia added in manure (g/day)	0.37	0.4
Ammonia added during run (g)	18.5	20
Ammonia in carboy after trial (g)	48	25
Ammonia released to air (g)	3	15
Ammonia content of exit air maximum (micrograms/l)	120	800
Odor:		
Vapor dilution to threshold	1000-2500	1000-2500
Quality	offensive, sour	ammonia-like

Table 14. HYDROGEN SULFIDE PRODUCTION BY WHITE LEGHORN LAYER MANURE ADDED DAILY TO A NINETEEN LITER (FIVE GALLON) CARBOY[51]

	System	
	Diluted	Undiluted
Manure feed rate (g/day)	75	75
Water feed rate (g/day)	225	0
Solids content of feed (percent)	25	6
Air flow rate (l/hr)	28	28
Sulfide added in manure (mg/day)	21.2	21.2
Sulfide added during trial (g)	1.06	1.06
Sulfide in carboy after trial (g)	53.5	5.65
H_2S concentration in air, maximum (micrograms/l)	0.011	0.005
Final pH in carboy	7.5	9.0
Percent sulfide present as H_2S at this pH	20	0.85
Comparative level of offensiveness	high	low

organisms, the ammonia content of the room air was held to less than 2 ppm during the first 100 days of the trial. During this same period the odor level within the room was judged to be very faint. In another trial in which the tank was not seeded, the ammonia concentration of the air averaged eight to 10 ppm during the first 60 days and the odor was judged definite to strong throughout this period. Thus he concluded that nitrification was helpful in odor control and that seeding the manure slurry was beneficial in establishing nitrification during the early stages of the storage.

CATTLE FEEDLOTS

Various attempts were described by Fosnaugh and Stephens[53] to measure odorous compounds in the vicinity of cattle feedlots. Although none of the techniques proved entirely satisfactory, they tentatively concluded that trimethylamine, propylamine, butylamine, and ethyl- or methyl-amine were present in the odorous air near feedlots in concentrations above their odor thresholds. The more promising techniques they described are summarized in Table 15.

Work was reported by Bethea and Narayan[54] concerning the identification of odorous compounds evolved from beef cattle manure. In their initial exploratory work, a small volume of fresh manure was diluted with water and placed in a flask and maintained under aerobic conditions. The gas released from this flask was then passed through a series of selective absorption flasks containing dilute hydrochloric acid, ether, sodium bicarbonate, sodium hydroxide or sulfuric acid. The material from the various absorption flasks was then subjected to chromatographic analysis and the following four classes of compounds were found: alcohols, amines, aldehydes, and esters. The fact that mercaptans and other organic sulfides were not detected may be attributed to the aeration of the manure during the absorption test. Following this work, gas samples were collected from confinement chambers in which a steer was fed 10 kg (22 lb) of a standard roughage concentrate ration daily. The three manure management schemes used were: (a) chamber thoroughly cleaned and washed every day; (b) manure shovelled out daily and no washing; and (c) no cleaning. Air from the chambers was bubbled through four selective absorption traps and these traps analyzed for odorous compounds extracted from the air. The data in Table 16 summarize the results of these experiments. In addition to the compounds listed in Table 16, carbon dioxide, carbon monoxide, ammonia and hydrogen sulfide were reported as present under all three manure management schemes.

In work to analyze amines in the air over a dairy manure sample, White _et al._[37] first conducted a selective absorption of the amine compounds in

Table 15. ODOROUS GAS DETECTION AND IDENTIFICATION SCHEMES EVALUATED BY FOSNAUGH AND STEPHENS[53]

Scheme	Concentration technique	Known compounds tested	Comments
Paper chromatography	1.2 N HCl	amines	Possibly detected trimethylamine near feedlot
Ammonia-amine absorption on silica gel treated with ninhydrin	none	none	Ammonia and amines suggested at concentration less than 1 ppm
Gas chromatography electron capture detector	0.1 N HCl	none	No results
Gas chromatography flame ionization detector	1.2 N HCl	methylamine trimethylamine ethylamine n-propylamine n-butylamine	Presence of amines indicated

Table 16. ODOROUS COMPOUNDS IDENTIFIED FROM THE ATMOSPHERE IN A BEEF CATTLE CONFINEMENT CHAMBER UNDER THREE MANURE HANDLING PROGRAMS[54]

Clean and wash daily	Shovel out daily	No cleaning
Methanol	Methanol	Methanol
Acetaldehyde	Acetaldehyde	Acetaldehyde
Ethanol	Ethanol	Ethanol
iso-Butyraldehyde	2-Propanol	2-Propanol
Ethyl formate	Skatole	Skatole
	Indole	Indole
	Ethyl formate	Ethyl formate
	iso-Butyl acetate	Propionaldehyde
		Methyl acetate
		iso-Propyl acetate
		iso-Propyl propionate
		iso-Butyl acetate

1.2 N HCl. After selective absorption, the solution was neutralized with sodium hydroxide and heated to drive the amine compounds into a super-cooled injection needle. The collected amines were analyzed with chromatographic equipment. The column used was a 3.05 m (10 ft) stainless steel column packed with five percent (by weight) tetrahydroxyethylethylenediamine (THEED) and 15 percent (by weight) tetraethylenepentamine (TEP) on Chromosorb W. A column temperature of 47^{o} C was maintained for these tests. With this approach, they were able to identify trimethylamine and ethylamine in the headspace over both anaerobic and aerated dairy waste.

SWINE MANURE

In early work to identify gases involved in the odor associated with confinement swine buildings, Day, Hansen and Anderson[55] used a U tube submerged in a dry ice-acetone mixture to condense the compounds of interest. The condensate was subjected to spectral analysis. Other qualitative techniques were used to detect hydrogen sulfide and ammonia. They noted that the filter paper preceeding the cold trap was accumulating not only dust but also a strong, objectionable odor characteristic of the swine unit. From these efforts, they identified hydrogen sulfide, methane, carbon dioxide, and ammonia as being present in the buildings.

Work reported by Merkel _et al._[56] utilized a variety of selective absorption techniques followed by chromatographic analyses to identify specific compounds present in the atmosphere of a swine confinement building. Dilute hydrochloric acid was used to absorb ammonia and amines. A mercuric chloride-mercuric cyanide solution was used to absorb sulfur containing compounds. Propylene glycol, which has a high absorption for organic alcohols, was used to isolate those compounds. Carbonyls were collected by using an absorption solution of dichloro methane. Using this procedure they were able to conclude that amines, amides, alcohols, sulfides, di-sulfides, carbonyls and mercaptans were contained in the atmosphere of the swine confinement building in addition to the fixed gases: carbon dioxide, methane, ammonia and hydrogen sulfide. The alcohols specifically identified were methanol, ethanol, N-propanol, iso-propanol, n-butanol, iso-butanol and iso-pentanol. Among the carbonyls identified were formaldehyde, acetaldehyde, propionaldehyde, iso-butyraldehyde, heptaldehyde, valeraldehyde, octaldehyde and decaldehyde. Based upon physiological investigation they concluded that the major constituents of the odor were the amine and sulfide groups.

To check for the presence of carbonyl compounds in a swine building, Hartung _et al._[56] used an absorption column consisting of glass beads, coated with a layer of 2,4 dinitrophenylhydrazone. In making the absorption column, two grams of silica gell were stirred with two ml of the DNPH. The powder was then slurried in carbonyl-free hexane and transferred to the column. Carbonyl-free air was used to evaporate the hexane from the column and then the column was transferred to the swine atmosphere of interest. The air sample was pulled through the column by the use of a vacuum pump and then the column was transferred to the laboratory for carbonyl recovery. Carbonyl-free hexane was used to elute the DNPH derivitive of interest from the column. The eluted material was evaporated to a small volume then placed on thin-layer chromatography plates. Using this technique, the presence of the following carbonyl compounds was shown: ethanal, propanal, butanal, hexanal, acetone, 2-butanone and 3-pentanone. They concluded that propanol, acetone, and 2-butanone probably contributed to the overall odor through additive effects even though only ethanal was measured in concentrations exceeding its threshold odor concentration.

To detect the presence of amines in a swine building atmosphere, Miner and Hazen[6] pumped the air through a solution of five percent acetic acid in water. The ammonia and amines were selectively absorbed from the air while the acetic acid was stripped from the liquid. After a period of aerations, the liquid was subjected to chromatographic analysis. Analyses were conducted using a 4.6 m (15 ft), 0.32 cm (1/8-in.) diameter stainless steel column packed with Porapak Q. This work indicated the presence of methylamine, ethylamine and triethylamine in the air inside a swine building in which manure was being stored beneath partially slotted flooring. Since all three of these compounds have low threshold odor levels, they were judged to be contributing to the odor.

The concentration of various gases in the atmosphere of an enclosed swine building was determined by Lebeda and Day.[57] Air was analyzed under two conditions: (a) when the unit was ventilated at a rate of 1.0 cu m per minute (35 cu ft per minute) per animal and (b) when the forced ventilation had been turned off for six hours. Results of these analyses are given in Table 17. None of the gas concentrations measured reached levels considered harmful to humans.

Table 17. GAS CONCENTRATIONS MEASURED IN AN ENCLOSED SWINE UNIT WHEN VENTILATED AND WHEN VENTILATION HAD BEEN INTERRUPTED FOR SIX HOURS[57]

	Concentration, ppm	
Constituent	Ventilated	Nonventilation for six hours
Ammonia	7.4	18.8
Carbon dioxide	656.0	4,286.0
Hydrogen sulfide	0.09	0.28
Sulfur dioxide	0.026	-

MISCELLANEOUS MEASUREMENTS

The soil atmosphere beneath a cattle feedlot was compared to the atmosphere beneath a cropped field by McCalla and Elliott.[58] They used gas diffusion bottles and then returned the collected samples to the laboratory for a chromatographic analysis. A more reducing atmosphere was present beneath the cattle feedlot as indicated by higher carbon dioxide and methane concentrations as well as lowered oxygen and nitrogen content.

A Burrell gas analyzer with absorption pipettes and oxidation heaters was used by White and Taiganides[37] to measure carbon dioxide, carbon monoxide, oxygen and illuminants. A copper oxide heater was used to measure hydrogen and a catalytic heater was used for the paraffin hydrocarbons. An Orsat gas analyzer was used to measure carbon dioxide, carbon monoxide, and oxygen. These analyses were conducted on gas produced during the pyrolysis of animal manures.

A modification of the chemical oxygen demand analysis as used in wastewater studies was employed by Frus et al.[59] to measure organic gases in a swine building atmosphere. The technique was sensitive to significant changes in odor level and to rates of ventilation within the building. Difficulties with the procedure were associated with reproducibility and variable sensitivity to gases depending upon their solubilities and ease of oxidation.

SUMMARY

The identification of specific gases responsible for livestock and poultry manure odors has proven a difficult and tedious task. Identification of the common and most abundant gases has not satisfactorily explained the observed odors. The research findings indicate that the odorous gases are primarily the end and intermediate products of anaerobic decomposition which have sufficient volatility to escape from the liquid phase.

The primary tool for odorant identification has been gas liquid chromatography. Thin layer chromatography and mass spectroscopy have received limited use. The major limitation in specific compound identification has been the low concentrations at which the odorants are present. Many of the compounds have perceptible odors at concentrations of less than one part per million and less than the minimum detectable concentration of the most sensitive detectors available on gas chromatographs. When highly sensitive detectors have been employed, frequently it has been found that other compounds, present in many times greater concentrations but of less odor significance, tend to interfere with the analyses.

To overcome the problems of detecting these low concentrations, various selective enrichment schemes have been utilized. The use of cold traps in which the odorous gases were passed through a U-tube submerged in a cold liquid, dry ice-acetone or liquid nitrogen has been helpful but suffers from a lack of selectivity. Solid media covered with selective absorbents have been successfully used as have general absorbents which are brought into equilibrium with the odorous gas. Selective liquid absorbents, dilute acid for ammonia and amines, mercuric salt solutions for sulfur-containing compounds, propylene glycol for alcohols and dichloromethane for carbonyls have been most commonly used and with general success.

An examination of the lists of compounds isolated from the air in contact with anaerobically decomposing manure (Table 18) documents the existence of a large number of compounds of potential importance in odorous air. This large list also exemplifies the complexity of odor analysis. This list further explains the variability in characteristics commonly attributed to animal waste odors. Changes in feed rations, animal physiology or manure handling may be expected to alter the quantitative make-up of the volatile by-products of manure decomposition, thus, the exact nature of the odor produced by a livestock operation.

Table 18. COMPOUNDS IDENTIFIED IN THE AIR FROM THE ANAEROBIC DECOMPOSITION OF LIVESTOCK AND POULTRY MANURE

<u>Alcohols (1,8)</u>

- Methanol (1,8)
- Ethanol (1,8)
- 2-Propanol (1,8)
- n-Propanol (8)
- n-Butanol (8)
- iso-Butanol (8)
- iso-Pentanol (8)

<u>Acids (6)</u>

- Butyric (7,6)
- Acetic (6)
- Propionic (6)
- iso-Butyric (6)
- iso-Valeric

<u>Amines (1,2,4,5)</u>

- Methylamine (4)
- Ethylamine (2,4)
- Trimethylamine (2)
- Triethylamine (4)

<u>Carbonyls (1,3,8)</u>

- Acetaldehyde (1,3,8)
- Propionaldehyde (1,3,8)
- iso-Butyraldehyde (8)
- Hexanal (3)
- Acetone (3)
- 3-Pentanone (3)
- Formaldehyde (8)
- Heptaldehyde (8)
- Valeraldehyde (8)
- Octaldehyde (8)
- Decaldehyde (8)

<u>Sulfides (2,6)</u>

- Dimethyl sulfide (2)
- Diethyl sulfide (2)

<u>Nitrogen heterocycles (6)</u>

- Indole (6,1)
- Skatole (6,1)

<u>Esters (1,2)</u>

- Ethyl formate (1)
- Methyl acetate (1)
- iso-Propyl acetate (1)
- iso-Butyl acetate (1)
- iso-Propyl propionate (1)
- Propyl acetate (2)
- n-Butyl acetate (2)

<u>Fixed gases</u>

- Carbon dioxide
- Methane
- Ammonia
- Hydrogen sulfide

<u>Mercaptans (2,6)</u>

- Methylmercaptan (2)

<u>Disulfides (6)</u>

Note: Numbers in parentheses refer to the references below in which identification was reported.

1. R. M. Bethea and R. S. Narayan 1973.[54]
2. R. K. White, <u>et al</u>. 1971.[37]
3. L. D. Hartung <u>et al</u>. 1971[56]
4. J. R. Miner and T. E. Hazen 1969.[6]
5. J. Fosnaugh and E. R. Stephens 1969.[53]
6. W. E. Burnett 1969.[35]
7. R. H. Deibel 1967.[48]
8. J. A. Merkel 1969.[36]

SECTION VIII

MEASUREMENT OF SPECIFIC ODOROUS GAS CONCENTRATIONS

Although a large number of gases have been identified as being released from animal manure during transport, storage, treatment and disposal, only a limited number of these have been routinely measured as parameters of odor intensity. It is the purpose of this section to summarize those procedures in current use so they might be readily available to people working in the area and to aid people utilizing air analyses to more intelligently interpret the data.

AMMONIA

The most widely used method of analysis giving satisfactory results involves selective ammonia absorption followed by color formation using Nessler's reagent. Recommended absorbing solutions include two percent boric acid in ammonia-free water[50] and a diluted sulfuric acid solution made by adding one ml concentrated sulfuric acid to 10 l of water.[60] A measured quantity of absorbing solution is placed in an absorption flask or impinger and contacted with a measured air volume. Using fresh absorbing solution as a blank, the absorbed ammonia is measured by adding Nessler's reagent. Color intensity is best measured at 425 mμ. Directions for the preparation of Nessler's reagent are found in Standard Methods[50] or it can be purchased commercially already prepared. Results are most appropriately expressed as parts per million by volume or micro grams per liter. This method was used by Burnett and Dondero[27] and by Miner and Hazen.[6]

Another technique for estimating ammonia concentrations in air is based on the equilibrium distribution of ammonia in water and in the surrounding atmosphere. At equilibrium, the partial pressure of ammonia in water is equal to its partial pressure in the surrounding atmosphere. The ammonia content of a distilled water containing ammonia can be estimated from a pH measurement, knowing the temperature of the solution and the appropriate dissociation constants. Kowalki *et al.*[61] developed a relationship between ammonia content in water and its partial pressure. Thus, by bringing a distilled water into equilibrium with an air sample containing ammonia, it is possible to estimate the ammonia concentration of the air based upon the ammonia content of the water. The pH of the water can be used as a measure of the equilibrium ammonia content. This general approach was utilized by Koelliker and Miner[47] in estimating the ammonia loss from an anaerobic lagoon. Table 19 represents the calculated pH values of water in equilibrium with various concentrations of ammonia in air.

Table 19. CALCULATED pH VALUES OF DISTILLED WATER IN EQUILIBRIUM WITH VARIOUS AMMONIA CONCENTRATIONS IN AIR AT 20° C

NH_3-N ppm vol.	$P_g = P_L$	pH of water
1	1×10^{-6}	9.5
5	5×10^{-6}	9.9
10	10^{-5}	10.0
50	5×10^{-5}	10.4
100	10^{-4}	10.5
500	5×10^{-4}	10.9

This general technique was utilized by Moum, Seltzer and Goldhaft[62] in devising a quick method for estimating the ammonia content of air. In their procedure, pH test paper is moistened with distilled water and contacted with the air for 15 seconds. At that time, the pH is recorded and, using the data from Table 20, the ammonia content is estimated. Special packets for this purpose, consisting of pH paper, a calibration color card which interprets color directly as ammonia content, and a bottle for carrying distilled water, all in a single case, are marketed by Vineland Laboratories, Vineland, New Jersey.

Table 20. AMMONIA CONCENTRATION (ppm) IN AIR BASED ON THE pH OF A TEST PAPER AFTER 15 SECONDS OF CONTACT[62]

pH	NH_3 concentration
6	0
7	5
8	10
9	20
10	50
11	100+

HYDROGEN SULFIDE

Modifications of the method for analyzing hydrogen sulfide concentrations in wastewater as prescribed in Standard Methods[50] have been widely adopted for gas analysis. In essence, a measured volume of gas is passed through two absorption flasks in series, each containing 100 ml of 0.1 N zinc acetate solution. Similarly, a cadmium hydroxide suspension can be used for the absorption.[63] The hydrogen sulfide reacts to form a zinc or cadmium sulfide suspension. The sulfide content of the suspension may be measured by a titration or a colorimetric procedure.

In the titration procedure, excess 0.025 N iodine solution is added to each of the absorption flasks along with 2.5 ml of concentrated hydrochloric acid. The contents of the flasks are then combined and the excess iodine titrated with 0.025 N sodium thiosulfate. The quantity of iodine utilized in oxidizing the sulfide ion is a measure of the sulfide content of the air.

In the colorimetric procedure, a solution of acidified N, N-dimethyl-p-phenylenediamine oxalate and one of ferric chloride are added to the zinc sulfide suspension. Methylene blue will be formed in proportion to the amount of sulfide present. The intensity of methylene blue color can be estimated or measured using a spectrophotometer at 600 mμ. This procedure is described for use in air pollution studies by Jacobs.[60] Reagents for this procedure are marketed by Hach Chemical Company of Ames, Iowa.

MERCAPTANS

The mercaptans or organic thiols have been identified as a group as being important in animal waste odors. Thus far, they have not been routinely measured by researchers dealing with livestock waste odors but have been detected as being present in the odor given off from cattle feedlots[53] and listed by Merkel, Hazen and Miner[56] and by White <u>et al</u>.[37] as being present in the odors from anaerobic decomposing swine and dairy cattle manures. A method for the quantitative measurement of the mercaptans has been published by the American Public Health Association.[63] In principle, the technique is to absorb the mercaptans by passing a known volume of air through an aqueous solution of mercuric acetate-acetic acid. The collected mercaptans are subsequently determined by a spectrophotometric measurement of the red complex produced by the reaction between mercaptans and a strongly acid solution of N,N,-dimethyl-p-phenylenediamine ferric chloride. The method determines total mercaptans and does not differentiate among individual mercaptans although it is reportedly more sensitive for the lower molecular weight alkane thiols.

The technique is designed to provide a measurement of mercaptans in the range below 200 $\mu g/l^3$ (102 parts/billion). For concentrations above 100 parts/billion, the sampling period can be reduced or the liquid volume increased either before or after aspirating. The minimum detectable amount of ethyl mercaptan is 0.04 $\mu g/ml$ in a final liquid volume of 25 ml. When sampling air at the maximum recommended rate of one l/min for two hours, the minimum detectable mercaptan concentration is 3.9 $\mu g/m^3$ (2.0 ppb methyl mercaptan).

The N,N-dimethyl-p-phenylenediamine reaction is also suitable for the determination of other sulfur-containing compounds including hydrogen sulfide and dimethyl disulfide. The potential for interference from these latter compounds is especially important since all these compounds commonly coexist in odorous air. By appropriate selection of the color formation conditions, the interference from hydrogen sulfide and dimethyl disulfide can be minimized.

The procedure involves collection of the sample by passing air through 15 ml of an absorbing solution of 50 g of mercuric acetate and 25 ml of an absorbing solution of 50 g of mercuric acetate and 25 ml of glacial acetic acid diluted to one l. The sample, after exposure to a known volume of air, is removed from the aspirator, diluted to 25 ml and the color-forming agent added. The color-forming reagent is a mixture of a solution of N,N,-dimethyl-p-phenylenediamine hydrochloride and a solution of ferric chloride hexahydrate. Directions for the mixing and formulation of this color-forming reagent are contained in the reference.[50] A standard mercaptan solution can be made by weighing out an appropriate quantity of lead mercaptide and diluting to an appropriate concentration.

VOLATILE ORGANIC ACIDS

Volatile organic acids are produced as an intermediate breakdown product of carbohydrates. In a well-operating anaerobic digestion system, the volatile organic acids are decomposed as produced and, ideally, never reach such a high concentration as to reduce the overall pH of the solution. Traditionally, when anaerobic digestion systems have failed, an excess of volatile acids has been noted to accumulate, thus monitoring of the organic acid content has been one method for controlling anaerobic digestion. Associated with the accumulation of organic acids has been a sharp change in the odor characteristics of digesting materials. For this reason, it is not surprising that volatile acids are produced during the anaerobic decomposition of animal manures and that they are related to the observed odor characteristics.

There are two methods for the analysis of organic volatile acids: (a) the distillation technique, and (b) the chromatographic technique. The basic philosophy in the distillation technique was summarized by Sawyer.[64] In this procedure, a liquid sample is acidified with sulfuric acid to adjust pH to less than 1.0. At this pH, the volatile acids are in the nonionized form and exert their maximum vapor pressure. They may be distilled from the solution by either direct heating or by steam injection. The direct heating is more rapid but more subject to error than steam injection distillation. The technique involves distillation of the volatile acids and their collection followed by titration with a dilute standard base. Recovery of volatile acid is consistently less than 100 percent using either of these procedures. Thus, it is necessary to determine the efficiency of the particular apparatus being used and to include this efficiency in calculating the final results.

In the partition chromatography technique, a solid absorbant - in this case silicic acid- is placed in a column and a sample of the liquid containing the volatile acids is placed on top of the column.[65] Once the acidified sample is placed on the silicic acid, a mobile phase is passed through the column. The mobile phase is a mixture of chloroform and butanol. This mixture selectively carries with it the nonionized volatile acids which are more soluble in this mixture than in the stationary water phase. The sulfuric acid and other ionized salts, however, are more soluble in the water and so are left behind. The extracted volatile acids are then measured by titration with sodium hydroxide to the phenolphthaline end-point as is done in the distillation procedure.

Both of the above techniques can be modified for the measurement of volatile acids in air. The usual method is to collect a sample by bubbling a measured volume of air through a dilute alkaline solution for the absorption of volatile acids. Once the organic acids from a measured volume of air have been extracted, the absorbing solution is acidified with sulfuric acid and the volatile acid concentration determined by either distillation or by partition chromatography.

SECTION IX

QUANTITATIVE MEASUREMENT OF ODORS

The technological difficulties of quantitative odor measurement are formidable. As explored earlier, odor is essentially a subjective response to the mixture of chemical compounds present in the air. This response is a function not only of the chemical make-up of the air but also is dependent upon 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 which is 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 the threshold concentration.

Similar to the air dilution technique, a liquid dilution technique can be used. A liquid which has an odor can be diluted with odor-free water until the liquid odor is no longer distinguishable from that of odor-free water.[50] Both the air dilution and liquid dilution techniques have been used in evaluating animal waste odors.

In the liquid dilution technique, a sample of the odorous material is mixed with odor-free water. Generally, the diluted sample along with some odor-free samples are then offered to a panel of observers. General technique is to make up a series of five bottles to offer to the panel, two containing a dilution of the odorous material and the other three containing odor-free water. Panel members are asked to mark on their score sheet those bottles which contain the odorous material. By making a series of dilutions and offering them to the odor panel for evaluation, minimum detectable concentration of the material can be determined. By making the liquid dilutions successively greater by a factor of two, those data can be used to determine an odor intensity index (OII). In other words, if the threshold odor was determined to be at a dilution of 15 parts odor-free water to one part of odorous solution, the odor intensity index would be four. The other means of expressing this information would be as the threshold odor number (TON). Threshold odor number is equal to two raised to the odor intensity power. Using this approach, Sobel[28] measured the odor intensity index and threshold odor number of a series of diluted chicken manure samples stored over a period of six weeks. The odor intensity of undiluted manure remained essentially constant at nine or a threshold odor number of 512. For manure diluted three to one, he found the initial odor intensity index to be equal to nine but after the first week the odor of this material increased so that at the end of three weeks he measured an odor intensity index of 15 or a threshold odor number of 32,768.

The vapor dilution technique involves actual dilution of odorous air with odor-free air. Using this technique, Sobel[28] measured the dilution which is the ratio of the volume of odorous air divided by the volume of odor-free dilution air which is offered to the observer. The dilution as used in this technique is essentially equivalent to the threshold odor number of liquid measurements. Using this approach, he again demonstrated that the odor of diluted manure was considerably more intense than the odor of undiluted manure. He also concluded that the quality of the odor from the diluted manure was considerably more offensive to the panel than the ammonia-like odor from undiluted manure.

The odor of stored dairy cow manure was studied by Barth, Hill and Polkowski.[66] By using various aeration rates, they were able to produce a variety of odor intensity indexes as well as variable concentrations of volatile acids, ammonia, and hydrogen sulfide. Their results are summarized in Table 21. From these studies correlations were developed relating the concentrations of the three odorants in the liquid manure to the observed odor intensity index. Those relationships are as follows:

$$OII = 3.04\ C_{VOA}^{0.20} \qquad R = 0.92 \qquad (18)$$

$$OII = 0.64\ C_{NH_3}^{0.46} \qquad R = 0.71 \qquad (19)$$

$$OII = 11.5\ C_{H_2S}^{0.09} \qquad R = 0.80 \qquad (20)$$

$$OII = 2.70\ (C_{VOA}^{0.21}\ C_{H_2S}^{-0.01}) \qquad R = 0.72 \qquad (21)$$

$$OII = 10.88\ (C_{VOA}^{0.28}\ C_{NH_3}^{-0.04}) \qquad R = 0.94 \qquad (22)$$

$$OII = 10.2\ (C_{VOA}^{0.37}\ C_{NH_3}^{0.38}\ C_{H_2S}) \qquad R = 0.95 \qquad (23)$$

Where

OII = odor intensity index

C_{VOA} = concentration of volatile organic acids (mg/l)

C_{NH_3} = concentration of ammonia (mg/l)

C_{H_2S} = concentration of hydrogen sulfide (mg/l)

R = correlation coefficient

It is noted that the most favorable correlation between odor intensity and odorant concentration exists with respect to the volatile organic acids. The inclusion of ammonia and hydrogen sulfide did little to improve the fit.

SCENTOMETER

Field measurements of odor intensity are difficult because of the lack of an overall acceptable measuring device and because of the inability of people to accurately describe odors. One device on the market for the estimation of odor intensity is the scentometer.[67] The scentometer is essentially a rectangular, plastic box containing two air inlets (one for each activated charcoal bed) and four odorous air inlets; 0.159, 0.318, 0.635 and 1.27 cm (1/16, 1/8, 1/4 and 1/2 in.) in diameter.[67] The odorous inlets are directly connected with a mixing chamber and the nasal outlets. See Figure 6.

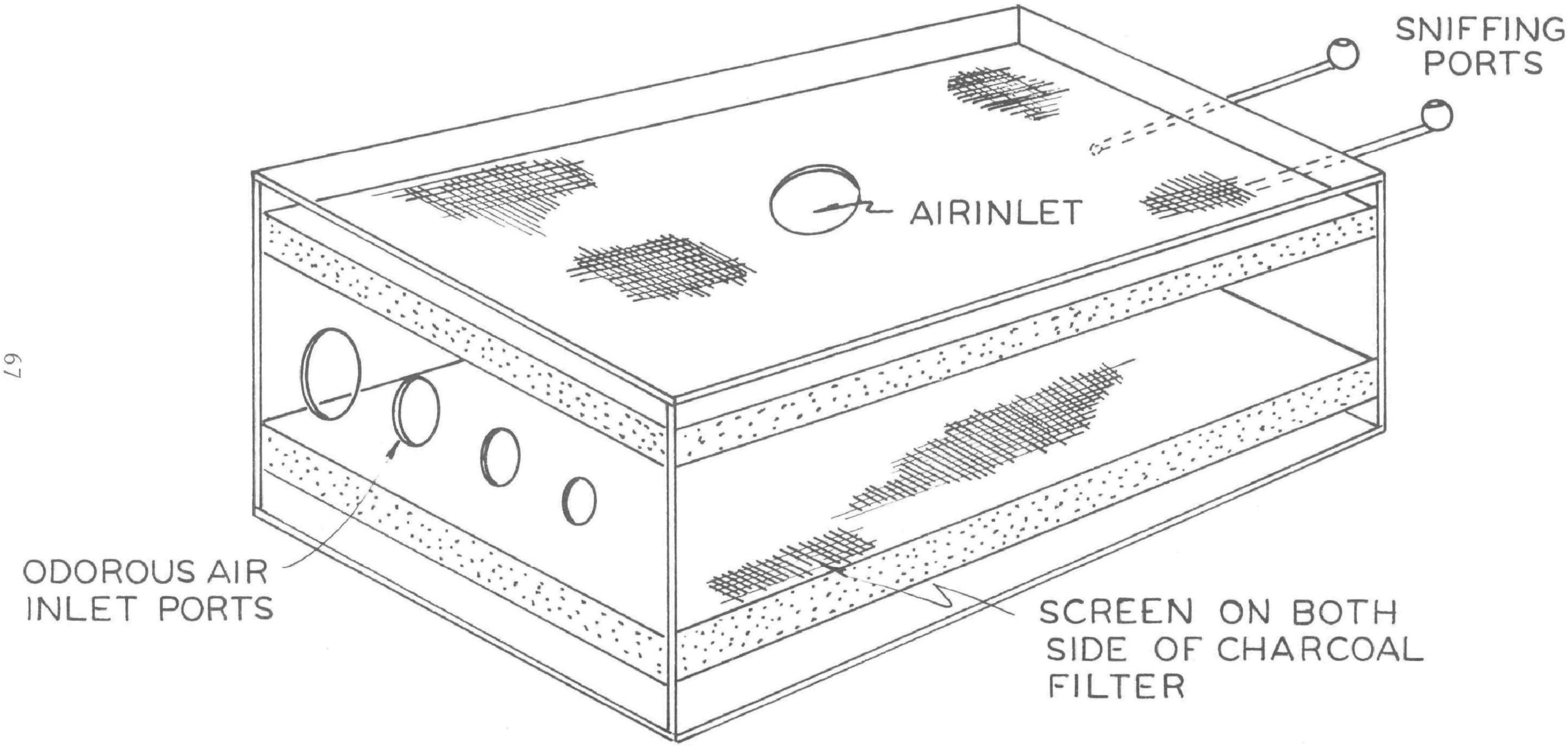
Table 21. ODOR INTENSITY INDEX AND ODOROUS COMPONENTS IN THE SUPERNATANT OF LIQUID DAIRY MANURE RECEIVING VARIOUS RATES OF AERATION[66]

Unit	Aeration Rate, cc/min	Aeration Depth cm	Week	Odor Intensity Index	Odorous components in liquid: V.O.A., mg/l	NH_3-N mg/l	H_2S-S* mg/l	pH
2	400	36	1	10.0	309	340	.30	8.21
			2	8.5	512	448	a	.51
			3	11.0	481	473	a	8.63
			4	12.0	724	632	.20	8.56
			5	13.0	1182	785	b	8.57
3	300	43	1	9.0	275	341	.20	8.22
			2	8.0	565	484	a	8.61
			3	10.0	588	547	a	8.65
			4	11.5	678	512	.10	8.63
			5	12.0	900	840	b	8.55
6	0	0	1	14.5	1566	510	6.6	7.24
			2	16.5	3290	660	13.8	7.15
			3	15.5	3950	843	11.7	7.14
			4	14.0	4940	1007	23.5	7.08
			5	16.0	6900	1444	b	6.69
7	300	20	1	8.5	238	396	.30	8.33
			2	9.8	634	476	.30	8.47
			3	10.0	733	570	1.50	8.50
			4	11.0	988	735	.90	8.47
			5	12.0	3740	1108	b	8.24

*Definition of symbols: a. Insufficient component present to give positive result.
b. No determination made.

In field operations, the observer takes the scentometer where the 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

FIG. 6 SCENTOMETER [67]



is that any air entering his nostrils under these conditions will have passed through the activated charcoal beds and be odor free. Once his 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 smallest 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 the filtered air in definite proportions so that recording the port or ports that were opened at the time he first detected an odor provides a measure of the dilutions required to reach the odor threshold. Table 22 provides a correlation between the ports which are open and the calculated dilution which is entering the nostrils of the observer. By having 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

Table 22. DILUTION TO THRESHOLD VALUES WITH VARIOUS PORTS OPEN ON A SCENTOMETER WHEN AN ODOR IS BARELY DETECTABLE[67]

Dilutions to Threshold	Odorous Air Inlets*			
	1.27 cm (1/2 in.)	0.635 cm (1/4 in.)	0.318 cm (1/8 in.)	0.159 cm (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
2.00	0	x	x	x
5.55	x	0	0	0
5.75	x	0	0	x
6.75	0	x	0	x
7.00	x	0	x	x
27.00	x	x	0	0
31.00	x	x	0	x
170.00	x	x	x	0

*Definition of symbols: x indicates port is covered
0 indicates port is open

inability of the observer to detect small differences in odor intensity.

In discussing the scentometer, Huey et al.[68] stated that their experience had shown that odors above seven dilutions to threshold would probably cause complaints while those measuring 31 dilutions to threshold could be described as a serious nuisance if they persist for a considerable length of time. The scentometer was described in a paper by Rowe[69] 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 of odor to be considered a strong odor.

The scentometer has received rather widespread application in animal waste odor evaluation.[10] In spite of its application, however, there are several basic limitations to this approach. Being a personal observation, the sensitivity of the observer is highly important in determining the values achieved with the instrument. Although sniffing through the scentometer with the odorous air ports closed is designed to restore normal sensitivity to the observer, complete restoration of the smell sensitivity may not occur rapidly enough to obtain meaningful results. The charcoal bed can become saturated and not give a complete odor removal from the air breathed when all the ports are closed. Since there is no indicator to show the carbon is saturated, misleading results may be obtained under these conditions. Intermittent odors which are 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 get 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 straight forward technique to quantify odor quality. Most frequently, odor quality is described by comparison to some common odorant with which the reader or listener is familiar or to a sensation with which he is familiar. For example, White *et al.*[37] used the following terms to describe the odorous components of dairy waste: foul, sweetish, acetate, nutlike, pungent, and musty. In describing the odor of the various fractions of poultry manure odor, Burnett[35] 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.[70] He asked a panel of odor evaluators to select a number from one to 10 indicating the degree of offensiveness of the samples. A nonoffensive odor was marked as zero, a very strong offensive odor was ranked as 10, a definite offensive odor was six and a faint offensive odor was four. 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 X

FECAL ODOR AS AFFECTED BY FEED ADDITIVES

The effects of various feed additives on swine fecal odor were studied in three feeding trials at Texas Tech University by Ingram et al.[71] In each trial, pigs were assigned to five treatments, three replications or pens per treatment with four or five pigs per replicate. Fecal samples were composited from any three of the pigs in each replication and immediately evaluated by olfactory panels in trials one and two and by panels and column chromatographic analyses in trial three. Gas-liquid separation was a qualitative measurement of primarily the organic amines, skatole and indole. Composition of the basal diet is shown in Table 23.

Table 23. COMPOSITION OF BASAL DIET FOR ANIMALS ON FECAL ODOR STUDY[72]

Ingredient	Percent, air-dry
Grain sorghum	66.0
Soybean meal (44%)	30.0
Salt	0.5
Defuor. phosphate	1.5
$CaCO_3$	0.5
Premix (vitamin-mineral)	1.5

Treatments for trial one and the results are shown in Table 24. The feeding period was 14 days duration, using four-week-old-pigs. The treatments were basal; dry Lactobacillus acidophilus in a wheat bran carrier and mixed into two feedings per day of five g each; lyophilized yeast culture at five percent of the diet, replacing grain sorghum; L. acidophilus cultured in whole milk with an average of 2.9×10^{10} viable cells per ml and mixed into the feed twice daily at the rate of 175 ml each time; and last, activated charcoal at five percent of the diet, replacing grain sorghum. Two panels of 11 participants and 31 participants scored the fecal samples for volatile matter on a scale of one through 10, one being not objectionable through 10, extremely objectionable.

Table 24. TREATMENTS AND RESULTS - TRIAL 1. TEXAS TECH UNIVERSITY SWINE FECAL ODOR STUDY[72]

Treatment	Odor score
Basal	7.6
Dry lacto (10 g)	7.5
Yeast (5%)	7.4
Wet lacto (350 ml)	7.2
Charcoal (5%)	6.7

Orthogonal mean comparisons resulted in a significant difference between the basal and dry lacto treatments versus five percent charcoal in reduction of volatile matter.

Table 25 shows treatments and results for trial two. The feeding period was 10 days in length and the pigs from trial one were rerandomized for the second trial. Olfactory observations were made by two panels of 23 and 27 participants. There were no significant differences among the treatment means.

Table 25. TREATMENTS AND RESULTS -TRIAL 2. TEXAS TECH UNIVERSITY SWINE FECAL ODOR STUDY[72]

Treatment	Odor score
Basal	6.5
Sagebrush (5%)	6.3
Wet lacto (300 ml)	6.3
Whole milk (300 ml)	6.2
Charcoal + Wet lacto	5.9

Table 26 summarizes treatments and olfactory panel results for trial three. Three panels of 60 participants each evaluated fecal samples for trial three. The feeding period lasted 21 days and used four-week-old pigs.

Table 26. TREATMENTS AND RESULTS - TRIAL 3. TEXAS TECH UNIVERSITY SWINE FECAL ODOR STUDY[72]

Treatment	Odor score
Basal	6.5
Wet lacto (300 ml)	6.5
Charcoal (2%)	6.8
Yeast (2%)	6.5
Dry lacto (10 g)	6.7

No significant mean differences were detected by the olfactory panel. Fecal samples in trial three also were used for some gas chromatographic analyses. A sample of air from just above the feces was used.

By the end of the second week, as shown in Table 27, chromatographic analyses indicated a marked reduction in volatile matter of feces for the yeast and dry lacto treatments.

Table 27. CHROMATOGRAPHIC RESULTS AFTER 2 WEEKS - TRIAL 3: TEXAS TECH UNIVERSITY SWINE FECAL ODOR STUDY[72]

Treatment	Peak Height Ratio	% Reduction
Basal	1.00	--
Wet lacto (300 ml)	0.83	17
Charcoal (2%)	0.95	5
Yeast (2%)	0.28	72
Dry lacto (10 g)	0.07	93

The peak-height ratio was used as a comparison between each treatment and the basal diet - involving measurement of the height of each peak on the chromatogram and then using peak height as the denominator. The percent reduction indicates the decrease in volatile matter for each dietary treatment as compared to the basal diet.

Table 28 indicates the percent reduction in volatile matter of the feces from pigs in trial 3 after 21 days of feeding.

Table 28. CHROMATOGRAPHIC RESULTS AFTER 3 WEEKS - TRIAL 3; TEXAS TECH UNIVERSITY SWINE FECAL ODOR STUDY[72]

Treatment	Peak height ratio	% Reduction
Basal	1.00	--
Wet lacto (300 ml)	0.61	39
Charcoal (2%)	0.72	28
Yeast (2%)	0.07	93
Dry lacto (10 g)	0.003	99

Results indicate a significant reduction in volatile matter between the basal treatment versus the yeast and dry lacto treatments. The volatile matter detected was primarily skatole and indole.[72]

In summary, these data indicate that a lyophilyzed yeast culture and a commercial preparation of Lactobacillus acidophilus reduced the skatole and indole content of feces of young pigs, but that the changes in volatile matter content were not detected by olfactory panelists.

Based upon limited feeding trials at Colorado State University,[73] sagebrush, as a feed additive, was reportedly effective in reducing feedlot odor. The effectiveness was attributed to the volatile oils being carried through to the manure.

CHEMICAL TREATMENT OF MANURE TO CONTROL ODORS

Several investigators have sought a procedure whereby some relatively inexpensive chemical could be added to manure to achieve odor control. One technique has been to add a chemical or mixture of chemicals which will halt anaerobic decomposition. A second approach, to gain temporary odor control, is to oxidize the odorous compounds present in a slurry. Although they will be replaced with continued decomposition, this may allow time for the manure to be applied to cropland or otherwise moved so that odors are not critical.

CHLORINE AND LIME

Day[74] evaluated chlorine and lime as possible means to deodorize liquid hog manure. In these tests, the chemicals were added to manure storage tanks as the manure accumulated. It was determined that the daily chlorine demand of hog manure was 50 g per 50 kg (0.1 lb per 100 lb) pig. When a pit was treated at this rate, odor was eliminated and when the solids were dewatered on a sand bed, they, too, were odorless. This amount of chlorine was costly (63 cents per hog/month), however, and the method was not pursued. In a similar study, lime was added to the manure to raise the pH to 11. Whenever the pH dropped to nine, more lime was added. The lime treatment was also effective in eliminating odors by inactivating anaerobic bacteria. The daily lime requirement was reported as 80 g per 50 kg (0.16 lb per 100 lb) pig. The lime treatment, although less expensive than chlorine, was estimated as 10 cents per hog per month and increased the quantity of solids to be handled.

Hydrated lime, added to manure in amounts between five and 20 percent, was found to effectively deodorize poultry manure and to materially reduce the nitrogen loss upon storage, according to a study by Yushok and Bear.[75] They suggested that since most soil would benefit by additional lime, the cost of the lime required for deodorization could be charged against the soil on which the manure was to be applied and not be a direct cost to odor control.

The addition of sodium hydroxide to liquid poultry manure at a concentration of 0.9 percent was effective in preventing the development of objectionable odors according to Benham.[76] This treatment also resulted in a reduction in the number of total aerobic bacteria and coliforms. The application of the equivalent of 23 cu m (6,000 gal.) of poultry manure containing this concentration of sodium hydroxide/acre of grassland was not found to produce harmful effects on the grasses studied. The cost per bird per month was estimated to be in the range of one to two cents. Thus, it would cost $3,000 to $6,000 annually for a 25,000 layer operation to use sodium hydroxide for odor control according to this study.

POTASSIUM PERMANGANATE

Potassium permanganate ($KMnO_4$) is a powerful oxidizing agent, in part because of its ability to undergo several different reaction paths. Permanganate (MnO_4^-) solutions are most effective as oxidizing agents (and, therefore, in odor control) in acid solution, next in alkaline solution, and least effective in neutral solution.

Three different oxidation reactions can take place, depending on the pH of the solution:

In strong acid (pH < 2): $MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{++} + 4H_2O$

In "more neutral solutions" (pH 3-11) $MnO_4^- + 4H^+ + 3e^- \rightarrow MnO_2 + 2H_2O$

In strongly alkaline solutions (pH 11) $MnO_4^- + e^- \rightarrow MnO_4^{--}$

The most effective reaction, in a practical sense, is the second of the above because the solutions are essentially noncorrosive. For all three reactions, the reaction rate will increase with increasing temperature, with increasing $KMnO_4$ concentration, and with increasing concentration of oxidizable impurities. Also, the rate of reaction increases as the pH varies from neutral in either direction.

Potassium permanganate has been suggested for odor control around livestock production facilities since 1964 when its use was reported by Faith.[77] The oxidizing capabilities of potassium permanganate when used in gas-scrubbing devices were documented by Posselt and Reidies.[78] In their studies, air containing various odorants was passed through a pair of gas-washing bottles in parallel. One gas-washing bottle contained a one percent solution of potassium permanganate at a pH of 8.5; the other bottle contained distilled water at a similar pH. Under these conditions, they compared the threshold odor numbers of the effluents from the two bottles when various odorous organic compounds were being passed through the solutions. They evaluated the use of potassium permanganate for the oxidation of various mercaptans, other sulfur-containing compounds, amines, phenols and other organic odorants. In each case they found significant reduction in the threshold odor number was achieved by passing the gases through potassium permanganate compared to passing them through distilled water. Potassium permanganate is being marketed by Carus Chemical company for use in odor control applications (See Appendix A

HYDROGEN PEROXIDE

The use of hydrogen peroxide has been proposed for various waste treatment applications. Hydrogen peroxide (H_2O_2) is commercially available as an aqueous solution ranging from three percent for use as a disinfectant in first aid up to 98 percent solutions. Its primary application is as an oxidizing agent. Hydrogen peroxide decomposes to form water, molecular oxygen, and an accompanying release of heat. Strong solutions, greater than eight percent H_2O_2, are considered corrosive and must be handled in specially selected materials.

Dairy manure

The use of hydrogen peroxide for the treatment of dairy cow manure was described in a report by Hollenbach.[79] In the first trial, 19 l (5.0 gal.) of 50 percent hydrogen peroxide were diluted and pumped at the rate of 2 l (1/2 gal.) per minute into liquid manure tanks while the circulating pump was used to provide mixing and circulation of the entire 89 cu m (24,000 gal.) of manure in the system. Sufficient hydrogen peroxide was added to provide a total concentration of 100 ppm in the mass. Their notes were as follows:

prior to agitation and hydrogen peroxide addition, a pleasant silage or animal type odor emanated from the vent and no hydrogen sulfide was detected. Immediately upon agitation the sulfide concentration rose to 150 ppm and a strong sulfide odor was evident. Within 30 minutes, when about half the hydrogen peroxide had been added, the sulfide concentration in the air dropped markedly and most of the odor had disappeared. After one hour, when the full 100 ppm of hydrogen peroxide had been added, no sulfide was detected and only a moderate ammonia odor remained. When the agitation was discontinued for 18 hours and then resumed, the hydrogen sulfide level and the gases were at the initial level before the hydrogen peroxide addition. Thus, the hydrogen peroxide was, in their view, a temporary but effective odor control technique under these conditions.

In a second trial, Hollenbach[79] added hydrogen peroxide as in the earlier trial but immediately thereafter added a second similar quantity. He found the additional hydrogen peroxide resulted in a further decrease in the odor of the manure storage pits. Sixteen hours later, the sulfide concentration had risen and was similar to that prior to treatment. Some foaming difficulties were also reported during the second trial when the larger peroxide additions were made. Hollenbach felt this foaming could be prevented by adding a less concentrated peroxide solution. At the 100 ppm concentration used in the test about 6.0 1 (1.7 gal.) of 50 percent hydrogen peroxide at a cost of about $3.90 would be required to eliminate the sulfide type odors from a 37.8 cu m (10,000 gal.) manure storage tank.

In a study to test the effectiveness of hydrogen peroxide in treating dairy cattle manure odors, O'Neill[80] used hydrogen peroxide at concentrations of 10 and 15 percent, adding sufficient hydrogen peroxide to provide 50 to 220 ppm. When hydrogen peroxide was added at 50 ppm, the odor improvement was only limited. The sulfurous odors were removed but strong animal and ammoniacal odors were apparent. With the 100 ppm treatment, the strong animal odor was replaced by a strong silage odor with vestiges of ammonia. Using 125 ppm, only a silage odor was evidenced. Sulfides were determined at levels greater than five ppm in the manure slurry before treatment but were reduced to zero by the hydrogen peroxide treatments at levels greater than 100 ppm. No foaming problems were encountered during these evaluations.

Swine manure

The use of hydrogen peroxide for the control of swine manure odors was described in a report by O'Neil.[80] In this study, pig manure slurry was treated with 10 percent hydrogen peroxide at levels of 115 and 275 ppm. The hydrogen peroxide was fed into the open end of the discharge pipe as the manure was pumped from a holding pit into a 5.3 cu m (1,400 gal.) liquid manure tank. Hydrogen sulfide levels were reduced to zero in the gas over the manure slurry under both test conditions. The investigator, however, thought that superior odor control was obtained using the 115 ppm dosage. The reason for this increased effectiveness was judged to be primarily because of the effective mixing that took place in that trial. Atmospheric hydrogen sulfide was at a level of 10 ppm for the holding tank but was reduced to zero in the tank spreader after treatment.

Poultry manure

Field trials were conducted by Kibbel, Raleigh and Shepherd[81] at a large poultry farm that regularly received complaints from neighbors about the extremely foul and unpleasant odor when chicken manure slurry was spread on the fields. Sufficient hydrogen peroxide to attain levels of 100, 150 and 175 ppm based on total slurry weight was added to the discharge side of a pump used to transfer a five percent to 10 percent solids slurry from the collection pit under the birds to a 5.3 cu m (1,400 gal.) tank truck equipped to field spread the manure promptly for its plant nutrient values. An area 3 m (10 ft) wide and 400 m (0.25 mile) in length was used for manure application from each level of hydrogen peroxide treatment. Each test strip was separated from the adjacent test zones by 30 m (100 ft). The farm manager and two Extension Service representatives from Pennsylvania State University determined the overall quality and type of odor by sense of smell. Hydrogen sulfide specifically was determined quantitatively with a Hach test apparatus. Additional checks were made 18 hours later to determine the efficiency and persistence of the treatments.

All three hydrogen peroxide levels of 100, 150 and 175 ppm virtually eliminated the presence of hydrogen sulfide and reduced the odor of the chicken manure significantly. No differentiation could be made among the manures treated with the several hydrogen peroxide levels. The offensive chicken manure odor remained significantly reduced in the test plots compared to the control (non-treated) plots on the second and third day after application.

PARAFORMALDEHYDE

The use of flaked paraformaldehyde for the treatment of animal waste to control odors was studied by Seltzer, Moum and Goldhaft.[82] Paraformaldehyde is a mixture of polyoxymethylene glycols containing 90-99 percent polymerized formaldehyde and is available as powder, granules or flakes. Its chemical formula is $HOH_2C\text{-}(O\text{-}CH_2)_n\text{-}CH_2OH$. It is very slowly soluble in cold water.

Paraformaldehyde liberates formaldehyde gas as it decomposes. The flake form liberates the gas most slowly of the various available forms. The loss rate of paraformaldehyde is affected by temperature as indicated in Table 29. The rate of paraformaldehyde decomposition is also increased

Table 29. PERCENT WEIGHT LOSS OF FLAKE PARAFORMALDEHYDE WHEN EXPOSED TO AMMONIA-FREE AIR AT VARIOUS TEMPERATURES[82]

Time	5° C	22° C	38°C
1 day	-	1.3	3.1
2 days	-	2.8	6.5
3 days	-	4.6	10.2
4 days	-	6.7	13.5
1 week	0.09	13.3	26.2
2 weeks	1.2	22.2	34.5
3 weeks	1.8	28.9	39.8
4 weeks	2.2	31.9	42.8
5 weeks	2.7	34.0	46.0
6 weeks	3.0	37.8	48.8

by the presence of ammonia as is indicated in Table 30. The reaction of formaldehyde with ammonia gas occurs as follows:

$$6\ CH_2O + 4\ NH_3 \rightarrow C_6H_{12}N_4 + 6\ H_2O \qquad (24)$$

Table 30. PERCENT WEIGHT LOSS OF FLAKE PARAFORMALDEHYDE IN PRESENCE OF AMMONIA GAS FROM CHICKEN MANURE AT 22° C[82]

Days on test	0.5 g paraformaldehyde over 100 g manure	1 g paraformaldehyde over 100 g manure	3 g paraformaldehyde over 100 g manure	1 g paraformaldehyde over no manure
1	13.1	5.2	0.7	3.1
2	37.1	19.7	5.9	
3	48.8	33.7	15.1	5.4
4	77.1	38.3	21.2	6.0
7	Residue identified as hexamethylene tetramine	58.1	27.1	8.9

At ordinary temperatures this reaction is rapid and proceeds to completion. The end product of the reaction, hexamethylene tetramine, is a white, powdery, odorless material.

To test the effectiveness of paraformaldehyde in controlling poultry manure odor, Setlzer et al.[82] prepared six 3.8 l (1.0 gal.) plastic bottles by adding 100 grams of feces to each. Ten ml of water also were added to each bottle to provide adequate moisture. Paraformaldehyde flakes were added to the bottles in the amounts of 0.5-7.0 g. The pH of the air over the manure was measured as an indication of the ammonia content. Results of this experiment are shown in Table 31.

After 12 days of this experiment a 1.0 g manure sample was removed from each of the test bottles and subjected to bacterial counting on brain heart infusion agar. Plates were incubated at 37° C for four days and the counts shown in Table 32 were obtained. As part of this test, the manure was also

Table 31. AMMONIA CONTENT (PPM) OF HEADSPACE GAS OVER 100 GRAMS OF CHICKEN MANURE TREATED WITH VARIOUS LEVELS OF PARAFORMALDEHYDE[82]

Days on test	Quantity of paraformaldehyde added, g					
	0	0.5	1	3	5	7
1		0	0	0	0	0
2	100	1	0	0	0	0
5	100	10	1	0	0	0
7	100	50	10	0	0	0
9	100	100	100	0	0	0
14	100	100	100	0	0	0
21	100	100	100	0	0	0
28	100	100	100	0	0	0

Table 32. BACTERIAL COUNTS OF MANURE SAMPLES ON BRAIN HEART INFUSION AGAR AFTER 11 DAYS OF EXPOSURE TO VARIOUS QUANTITIES OF PARAFORMALDEHYDE[82]

Quantity of paraformaldehyde added per 100 g manure, g	Number of organisms per g of manure
0	2.2×10^9
1	1.64×10^8
3	1×10^3
7	0

analyzed for nitrogen concentration. It was found that the paraformaldehyde had been effective in reducing nitrogen loss. The Kjeldahl nitrogen concentration in the untreated samples was 1.39 percent. That in the bottle containing three percent paraformaldehyde contained 1.75 percent. Paraformaldehyde, when used as a manure additive, was indicated by these tests to be effective in reducing the evolution of both ammonia and hydrogen sulfide. In addition, it tended to reduce the number of viable bacteria within the sample. Among the limitations of paraformaldehyde is its toxicity to animals if they ingest more than the toxic dose. In addition, formaldehyde as evolved from the flakes has an odor itself.

Paraformaldehyde flakes are sold under the brand name Methogen by Vineland Laboratories of Vineland, New Jersey.

SECTION XII

USE OF SOIL FILTERS TO REMOVE ODORANTS

The use of soil beds for odor control was reported by Carlson and Leiser.[83] 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 107 l per min per sq m (0.35 cu ft per min per sq ft) of soil surface were reduced to an imperceptible level in 81 cm (32 in.) of soil. For a flow rate of 103 l per min per sq m (0.34 cu ft per min per sq ft) and a hydrogen sulfide concentration of 9.5 ppm, 90 percent of the hydrogen sulfide was removed in the first 46 cm (18 in.) of soil. Effectiveness of the soil beds in removing the hydrogen sulfide did not diminish during a three-month test period. A soil filter for the removal of odors from a Mercer Island pumping station in Washington has been in successful operation for three years.

As an outgrowth of the earlier work, Carlson and Gumerman[84] proposed a system for the treatment of odorous gases. Their system included a perforated tile system through which the 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 that is sacrificed in the active biological growth which occurs. They suggested a plant with a shallow root system which would meet the above goals but not interfere with the gas distribution piping system.

Investigating soil columns as a means of removing odor, Gumerman and Carlson[85] proposed a two-stage process: an absorption and a rejuvenation. The rejuvenation or oxidation stage requires the presence of oxygen. In designing a soil column for the absorption of H_2S, they listed the following considerations:

(a) Detention time

(b) Temperature

(c) Quantity of H_2S

(d) Initial H_2S concentration

(e) Gas flow rate

Hydrogen sulfide was removed by both wet and dry soil columns. For the wet columns, absorption seemed to be the responsible mechanism. Better removals were obtained at pH 8 than at either pH 4.0 or 5.8, suggesting that the hydrosulfide ion HS, not H_2S, is the active specie. Removal was enhanced by the presence of Cu^{2+}, Fe^{3+}, Zn^{2+} and Ni^{2+} ions at the soil surface.

Hydrogen sulfide removals were more efficient in dry than in wet soils. The dry soil reactions were postulated to be a two-stage surface catalyzed process.

H_2S removal: $MO_X + H_2S \rightarrow MS_X + H_2O$ (25)

MO_X is the cation oxide present at the removal site

Rejuvenation: $2\ MS_X + XH_2O \rightarrow 2MO_X + \text{Sulfur}$ (26)

The limitation on the number of possible rejuvenations is caused by the steric hindrance from deposition of sulfur at the removal site. The same metal ions as listed for the wet soil system are desirable for the dry system.[85]

The use of soil filters for the removal of animal waste odors was investigated by Burnett and Dondero.[27] They based their initial trials on the earlier work of Carlson and Leiser[83] and Gumerman and Carlson[85] and found that, indeed, the use of soil columns was effective in removing both hydrogen sulfide and ammonia from the head-space 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 occured throughout a three-month, continuous testing period. They further found that when the soil columns dried, the ammonia removal efficiency dropped rapidly. Thus, to be fully effective, the moisture content of the soil must be maintained. By mixing manure with the soil prior to using it in the column, the moisture-holding capacity was increased. As a result of their 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 0.61 m (2.0 ft) deep, 0.61 m (2.0 ft) wide and 276 m (903 ft) long would be required to deodorize the air. This is equivalent to 2.55 l (0.0903 cu ft) of soil per bird.

As a part of this study, Burnett and Dondero[27] attempted to determine the pressures required to force air through the soil columns at various depths. The columns they were using were 15 cm (6.0 in.) diameter plexiglass with a shallow layer of gravel just above the gas inlet. For untreated soil they were using, a back pressure of 13 cm (5.0 in.) of water was sufficient to cause 30 l (1.1 cu ft) per min of air to pass through a 0.61 m (24 in.) depth of soil. For the soils to which some manure had previously been added, this pressure was reduced to approximately 6.4 cm (2.5 in.) of water under the same conditions. Thus, one may expect wide variations in the pressures required to gain the necessary volumetric gas flow.

SECTION XIII

USE OF PROPRIETARY ODOR CONTROL CHEMICALS

When two odorants are mixed the resultant has a different odor from that of the original components, even though no chemical reaction may take place. When the odor of the mixture is more pleasant than that of one of its components, the process may be considered to be a method of odor control by which an unpleasant odor (malodor) is mixed with another substance (controlling agent). Such processes are called odor counteraction, odor masking, odor cancellation, odor neutralization or reodorization. The specific meanings of some of these terms are discussed below.

The literature contains early reference to "odor pairs", odorous gases in proportions that make the mixture odorless or nearly odorless; for example, rubber and cedarwood, musk and butter almond, skatole and coumarin, and butyric acid and oil of juniper. These original odor measurements were dilution-to-threshold ratios and the reduction in these values resulting from mixing a malodor with a controlling agent is called "odor counteraction". Odor counteraction is considered to be the phenomenon whereby odor intensity, however measured, is reduced by adding a non-chemically-reactive controlling agent to a malodor.

The term "odor cancellation" implies complete counteraction or reduction to an odorless condition. "Odor neutralization" is also used in this sense, although the chemical implication of this term (as in acid-base neutralization) may be confusing. No generally accepted physiological mechanism explains this phenomenon; some investigators question its reality. In the absence of a generally accepted scale of odor intensity, it is difficult to say what "nearly odorless" really means.

When a malodor is changed in quality by mixing with a control agent, especially when the change is so extreme that the malodor is rendered unrecognizable, the process is called "odor masking". To the extent that masking makes a malodor less objectionable, it is a method of odor control. Odor control by masking and by counteraction have similar operational requirements and are frequently indistinguishable from each other in practice, even though their objectives are presumably different.

Several chemicals are available to livestock producers to control odor. These chemicals, although seldom sold on the basis of composition but on the basis of brand names and specific company formulations, are generally thought to behave in one of several ways. Chemicals are sold which will modify the pH or in some other way inhibit biological degradation. These chemicals are thus designed to inhibit odorous gas formation. A second group of chemicals commonly called masking agents have a particular odor of their own and are designed to overcome the manure odor with the odor of the chemical additive. Counteractants, as the name implies, are generally mixtures of aromatic oils selected to counteract the odor of the components in the waste. Another group, the deodorants, is a formulation designed to eliminate the malodor of the waste generally without adding an additional covering odor. The final classification is the digestive deodorant which is generally a combination of enzymes and aerobic and anaerobic bacteria designed to modify the biological process of degradation in such a way as to alter the odorous compounds produced.

Deibel[48] performed odor abatement studies on liquid poultry waste using a number of chemicals and proprietary compounds. Additions of sodium chloride up to eight percent (weight/volume) or of commercially available powdered bacterial starter cultures (digestive deodorants) to the waste as well as direct ozone treatment failed to abate the odor. Addition of lime abated the odor for seven to 10 days, but after one week, the strong odor of ammonia was readily detected regardless of the lime concentration. The addition of hypochlorite to the waste caused the evolution of chlorine gas, presumably from the reaction of the hypochlorite and uric acid. The addition of 50 ppm of chloramine-T rapidly deodorized the manure, but the odor returned within 24 hours. The cost of treating the waste with chloramine-T immediately prior to removal and spreading of the manure was computed to be $5,000 annually for a 25,000-bird operation.

A report from England[86] regarding the addition of odor control compounds to liquid poultry manure indicated that good odor control could be achieved by the use of the commercial masking agent added directly to the manure slurry at the rate of 25 to 50 ml per cu m (one to two pints per 10,000 gal.) prior to spreading. Costs for such treatment were estimated at three to nine cents per cu m ($1.20 to $3.60 per 10,000 gal.) of liquid manure.[86]

A study was conducted by Burnett and Dondero[86] in which a variety of masking agents, counteractants, deodorants, and digestive deodorants were evaluated - first in a laboratory study, then in a field operation - to determine their effectiveness. Odor panels were used to evaluate the similarity of the odor of treated manure samples receiving various concentrations of the odor chemicals. For evaluation of the chemical counteractants, the deodorants, and masking agents, 500 ml of the waste was placed in a screw cap quart jar. Each jar then received a quantity of the chemical being tested. The quantities ranged from zero to 3.2 g of the appropriate chemical per jar. For the evaluation of the digestive deodorants, which required an incubation period for action to take place, the waste sample was placed in the jars, the chemical added, and then the material allowed to incubate at room temperature for 28 hours. A sample was withdrawn and placed in the test vial.

Data were collected in terms of an index of similarity (D). This index is defined as the square root of the sum of the squared differences between the panel ratings for the nine concentrations of chemical and the control. Thus, the D index was a measure of the effectiveness of the odor control chemicals. A low value indicated lack of effectiveness and a high index meant the treated liquid manure was highly dissimilar to untreated liquid manure. Their results indicated that some chemicals were effective in controlling the odors immediately after addition to the waste. This would be equivalent to adding odor control chemical to a storage pit immediately before spreading the waste on cropland. The masking agents and counteractants were found to be most effective odor control products, deodorants were moderately effective, and digestive deodorants were least effective. The cost of treating liquid poultry manure with an effective animal odor control product (masking agent) was estimated to be 37 cents per cu m ($14.00 per 10,000 gal.) of liquid manure based upon brief field study. A list of odor control product manufacturers was included in their report. That list is given in Table 33, along with additions which have become available since then.

Table 33. MANUFACTURERS OF ODOR CONTROL PRODUCTS FOR USE IN CONTROLLING MANURE ODORS [36,87]

Agriaids, Inc.
Div. of Flavor Corp.
of America
3037 N. Clark St.
Chicago, Ill. 60657

Airkem, Inc.
P.O. Box 203
Commerce Rd.
Carlstadt, N.J. 07072

Albert Verley & Co.
124 Case Drive
S. Plainfield, N.J.
07080

Allied Chemical Corp.
Solvay Process Div.
40 Rector Street
New York, N.Y. 13209

Blenders, Inc.
6964 Main St.
Lithonia, Georgia

Chloroben Chem. Corp.
Belleville Turnpike
Kearny, N.J. 07032

Dodge & Olcott, Inc.
P.O. Box 273
Old Chelsea Sta.
New York, N.Y. 10011

Florasynth, Inc.
900 Van Nest Ave.
P.O. Box 12
Bronx, N.Y. 10462

Fritzsche Bro., Inc.
76 Ninth Ave.
New York, N.Y. 10011

Givaudan Corp.
321 W. 44th St.
New York, N.Y. 10036

Gland-O-Lac Co.
19th & Leavenworth
Omaha, Nebraska

International Flavors
& Fragrances, Inc.
521 W 57th Street
New York, N.Y. 10019

Kalo Company, The
Quincy, Ill. 62301

Martin Bio-Chem
710 E. Southern Ave.
Mesa, Arizona 85201

Miles Chemical Co.
1127 Myrtle St.
Elkhart, Ind.

Nilodor Co., The
60 E. 42nd Street
New York, N.Y. 10017

Noville Essential
Oil Co., Inc.
1312 Fifth Street
North Bergen, N.J.
07047

Orbis Products Corp.
475 Tenth Ave.
New York, N.Y. 10018

Perry Brothers, Inc.
61-12 32nd Ave.
Woodside, N.Y. 11377

Reliance Chem. Co.
P.O. Box 19343
Houston, Texas 77024

Rhodia, Inc.
600 Madison Ave.
New York, N.Y. 10022

S.B. Penick & Co.
100 Church St.
New York, N.Y. 10007

Sep-Ko Chemicals, Inc.
3900 Jackson St. N.E.
Minneapolis, Minn.
55421

Somis Chemical Co.
Somis, California

U.S. Gypsum Co.
300 W. Adams St.
Dept. 139
Chicago, Illinois

Vineland Laboratories, Inc.
Vineland, N.J.
08360

SECTION XIV

WASTE MANAGEMENT TECHNIQUES TO MINIMIZE ODORS

Because of technical difficulties in odor measurement and the large number of variables involved, only limited data exist relating odor production and specific manure handling techniques. There has developed, however, an extensive collection of observations relating odors with waste handling practices. Most of these observations were made incidental to other studies and thus are scattered throughout the total accumulated literature. An overview indicates that certain operations are most likely to be sources of odor.

OPEN LOTS

Animals have traditionally been raised outside in much of our country. When raised in a sufficiently low density to allow a vegetative ground cover to be maintained, little odor was produced. The manure was widely dispersed and during warm weather dried rapidly. Odorous compounds that were released were diluted sufficiently to avoid odor problems. Nutrients in the urine and feces were incorporated into the soil resulting in a labor-, odor- and pollution-free manure management system.

Increased animal density, as found in cattle feedlots, hog lots and some poultry operations, results in eliminating the vegetative ground cover and the advent of manure management. The water pollution potential of such operations has been well documented and need not be of concern in this report. The odor potential of outdoor confinement units is largely related to manure management, but the operator has definite limits because of climatic and geographical limitations. When the manure accumulated on the soil surface is wet (70 percent moisture or above) anaerobic decomposition is possible. When the manure is both wet and warm, anaerobic bacteria flourish, and odors are likely to occur. Coupled with odor release from the lot surface is the tendency of animals to lie or roll in the wet manure for its cooling effect. A manure-covered animal perhaps represents the epitome of odor generation because heat of the animal stimulates bacterial metabolism.

Site selection and facility design are of paramount importance in controlling odors of this type. Good drainage and proper orientation to achieve the maximum drying rate are important. Feedlots in areas of the country with low, summer rainfall have definite advantages in this respect. Adequate slope is also helpful in maintaining a dry lot. Slopes of four to six percent are generally preferred for unsurfaced lots. Concrete-surfaced lots may have a lesser slope and still be satisfactory. The use of concrete pavement around feeders and waterers in areas of heavy animal usage also can be helpful in promoting a dry lot. Mounds are frequently used to provide animals a dry place to lie down if drainage is marginal.

An unroofed feeding pen can be operated in a manner to minimize the extent of anaerobic decomposition. Regrading to eliminate poor drainage that develops from animal activity can speed manure drying in those areas. Prompt repair of leaking waterers is another method. Manure removal frequency has been suggested as an odor control technique but is limited during wet periods. Odor control chemicals have been used by some operators but their results are difficult to predict and chemicals are often expensive.

Of greatest importance with respect to site selection is proximity to other commercial operations, recreational areas and homes. Although no legally defined distances exist beyond which odors of nuisance level will not occur, separation is of great value in achieving natural odor dilution. Nuisances have been established in courts at distances of 300 m (1,000 ft) downwind from operations where anaerobic storage tanks were uncovered and vented to the atmosphere. Thus, a 0.8 km (0.5 mile) separation from residences is a desirable minimum. Greater distances from communities, housing developments, commercial areas, parks or other points where people are likely to gather are appropriate.

Visual screening, landscaping, or other means to eliminate the suggestion of a potential odor source are often helpful in avoiding odor complaints. The untidy appearance of a livestock operation can be detrimental because of the subjective nature of odors and the fact that people are subject to suggestion of odors.

In discussing techniques for the control of odors from cattle feedlots, Paine[88] described the odors as being due to the anaerobic decomposition of manure on the feedlot surface. Also listed as odor-contributing areas were the retention basins used to collect feedlot runoff. The key to odor control was described in terms of controlling the oxygen and moisture content of the organic materials which produced the odor. Maintaining the feedlot surface with an overall slope between 2.0 and 4.0 percent to remove excess moisture from the pens and to prevent low spots which accumulate moisture were suggested. Mounds were recommended in flat feedlots which otherwise would not provide adequate drainage or a dry, clean spot for animals to rest. The addition of straw or other fibrous material was suggested where better footing is required in wet manure and also to reduce the moisture content. Sprinkling the feedlot surface during dry weather was recommended to control dust and to increase aerobic manure decomposition. Methods suggested for minimizing odors associated with manure holding ponds included solids removal prior to allowing the water to enter and the use of surface aeration equipment. When manure must be stockpiled prior to disposal, the use of long, narrow rows was suggested. Such rows are compatible with available composting equipment and are helpful in the control of fires.

CONFINEMENT BUILDINGS

Confinement livestock production has many potential economic and labor utilization advantages. To capitalize on these advantages, a higher degree of sophistication is required in planning, design, construction and operation than when range or pasture production is utilized. Odor production is related to several aspects of the system and, therefore, needs to be considered in the overall planning process. Just as in the case for unroofed systems, site selection and visual considerations are of paramount importance.

ANIMAL-MANURE SEPARATION

The initial manure management operation which has an important influence on odor production is separating the animal from its manure. If manure remains in the pen with animals, they will inevitably pick up a portion of it on their bodies and increase the odor-generating surface. The warmth of their bodies contributes to the decomposition and an odorous building results. Several schemes have evolved for rapid separation of animals and manure.

Among the most common are slatted floors and frequent-flushing, solid-floor systems. Each of these concepts has worked satisfactorily and when properly designed and operated can provide clean animals. Slatted floors may be used in the entire pen area or in a limited area, partially slatted. Although more expensive, the totally slatted floors have more reliably provided clean animals. Flushing systems are highly varied in their design, ranging from manual, daily hosing of the floor to automatically flushing gutters and alleyways which are designed to promote defecation in the flushed area.

Caged poultry systems overcome this problem by having the cages suspended so that droppings pass immediately through the cage floor to a storage or drying area. When poultry is raised in a floor system, the floor frequently serves as the storage area. Under this system the manure pack is managed to limit the moisture level so that anaerobic decomposition does not occur. Litter is the frequent aid used to achieve this end.

MANURE STORAGE

From a biological point of view, hence an odor point of view, storage of manure cannot be realistically separated from treatment. In liquid and semisolid storage systems, biological activity continues throughout the storage period unless inhibited by low temperature or some alternate biological restraint. In typical, manure storage tanks, anaerobic decomposition is continually in progress but in a container not specifically designed for that purpose. For example, Miner[2] suggests that for an anaerobic lagoon a volume of 12.5 l per g (200 cu ft per lb) of volatile solids per day should be provided. In a storage tank designed for swine wastes, 30 days storage, 1.56 cu m of storage volume per kg of animal (25 cu ft of storage volume per thousand pounds of animal) would retain the waste. This is equivalent to 0.26 l per g (4.2 cu ft per lb) of volatile solids added per day. Thus, it is consistent that the odor of manure storage tanks is typical of overloaded lagoons or septic tanks.

Most odor complaints are related to manure storage and, thus, the great majority of research data available concerns this source. Of particular concern are the gases and odors released upon agitation of a manure storage tank. When a storage tank beneath a slatted floor is agitated, animals over the tank are subject to high concentrations of gaseous products of decomposition. Animals have been killed under these conditions.

One step to reducing odors from manure storage tanks has been to locate the tanks outside the building and to keep them covered which inhibits the escape of gases from the liquid surface. By having the storage tank outside the building, hazards to the animals from gas release upon mixing are reduced but the difficulty in getting manure into the tank is increased.

An additional method of reducing odor from manure storage tanks is to reduce the storage period. Both research and field observations indicate the odor intensity and offensiveness increase with storage period.

Inhibition of anaerobic metabolism during storage can be effectively used to reduce odors. Among ways to accomplish this are: (a) adding sufficient oxygen to maintain aerobic conditions, usually by aeration; (b) reducing the moisture content to inhibit degradation (drying); and (c) inhibition of biological activity by chemical means.

In aeration for odor control, aerobic activity is the main mode of degradation. Although the gaseous by-products of aerobic degradation have not been as extensively studied as those from anaerobic treatment, they are generally nonodorous and, therefore, not objectionable. The gases are more highly oxidized in nature. The most common aerobic storage device in use is the oxidation ditch. The design and operation of oxidation ditches were described by Miner.[2] Aerated lagoons also are aerated storage devices.

Drying manure as a means of reducing odors and volume has received widespread application in the poultry industry. Basically, the cages are suspended over a manure storage pit into which the droppings fall. Sufficient ventilation is provided in the pit to dry the manure. By following this procedure, it is possible to obtain extended storage periods. Diligent, operator control is required, however, to prevent water spills or other extraneous water from entering the pit and exceeding the drying capacity of the ventilation system.

Several attempts have been made to find chemicals that will prevent odor production for addition to manure storage tanks. These are treated in considerable detail in Section IX. Thus far, none of the materials suggested have been fully satisfactory or at a price that was acceptable.

ANAEROBIC LAGOONS

Anaerobic lagoons have been used in animal waste management systems for the last ten years. Originally they were conceived as a treatment and disposal device, but it soon became evident that in all but the most arid regions lagoons filled and the removal or discharge of effluent was necessary. Secondly, it was also determined that effluent from an anaerobic lagoon was not of suitable quality to discharge to most streams and the most acceptable alternative was to apply the effluent to cropland. Thus, the anaerobic lagoon also must be regarded as having a primary storage function and achieves considerable solid breakdown to liquid during the storage. Because of this action, the lagoon effluent is generally more amenable to pumping than fresh manure and can, therefore, be applied to cropland using conventional irrigation equipment.

The odor of anaerobic lagoons has been described throughout the range of nonoffensive to highly offensive. A primary cause of objectionable odors from lagoons is organic overload. When a lagoon contains a large concentration of fresh manure which is high in easily decomposable organic matter, the acid-forming bacteria proliferate and produce a large concentration of odorous intermediates including organic acids. The methane-forming bacteria, whose role is to convert organic acids to methane, grow less rapidly than the acid-forming group. As long as this imbalance exists, odorous compounds will accumulate in the water and some will escape to the air. If the imbalance is severe, the methane-forming bacteria will be inhibited in their growth and the odorous condition may persist. Such overloads may be the result of either faulty design, inadequate volume, or poor management. Overloads are particularly common in the spring when the lagoon, which has been receiving manure all winter, finally warms sufficiently for acid-forming bacteria to attack the accumulated manure. Again, there is a rapid production of organic intermediates and an insufficient number of methane formers to utilize them.

The intensity and duration of objectionable odors from anaerobic lagoons can be minimized by providing an adequate water volume so the spring surge in organic acid concentration will be diluted. Overloaded conditions also are avoided by adding wastes frequently rather than in large quantities at irregular intervals. Parallel, rather than series, operation of multiple lagoons makes more uniform use of the lagoon available, hence reducing the tendency to cause overload.

Even with good design and proper management, however, anaerobic lagoons will still produce an odor. Whether this odor production is acceptable will depend upon other environmental factors such as the proximity to neighbors and the general odor criteria of the area.

SECTION XV

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SECTION XVI

APPENDICES

APPENDIX A

PARTIAL LIST OF PROPRIETARY ODOR CONTROL CHEMICALS FOR LIVESTOCK WASTES

Manufacturer:	The Kalo Co. 2620 Ellington Rd. Quincy, Ill. 62301
Product:	Kalo K. O.
Type:	Digestive deodorant, dry powder
Application rate:	3 lb/1,000,000 gal. Lagoon waste 0.5 lb/ton manure 0.5 lb/10,000 sq ft floor area
Cost:	$1.50/lb in 500 lb lots (3-70)
Product:	Kalo O. M.
Type:	Odor maskant, liquid concentrate
Application rate:	Applied by diluting 1 cup to 50 gal. water, oil, or insecticide and spraying
Cost:	$5/pint in 100 pint drum
Manufacturer:	Carus Chemical Co. 1500 Eighth St. La Salle, Ill. 61301
Product:	Cairox (potassium permanganate)
Type:	Odor oxidant
Application:	1. Spray a 1 percent solution on feedlots at 20 lbs/acre 2. Mix 5 lbs of Cairox per 1000 gal. liquid manure or spray a 1 to 4 percent solution on tank at the same rate
Manufacturer:	Nilodor, Inc. 7740 Freedom Ave., N. W. North Canton, Ohio 44720
Product:	Nilodor Superconcentrate

Type:	Odor neutralizer
Application:	Concentrate volatilizes from an automatic dispenser. One dispenser every 10 ft of wall
Cost:	$39.15 per qt in 4 qt lots (11/72)
Product:	Nil-O-Sol
Type:	Nilodor plus detergent
Application:	Dilute 1 qt to 16-32 gal. as a cleaning solution
Manufacturer:	Vineland Laboratories, Inc. 2285 E. Landis Ave. Vineland, N.J. 08360
Product:	Methogen
Type:	Reacts with ammonia, fumes bacteriocidal
Application:	1 lb methogen per 100 lbs manure
Manufacturer:	Wayne Animal Health Aids Allied Mills, Inc. 110 N. Wacker Drive Chicago, Illinois
Product:	Wayne D-ODOR #1
Type:	Bacteria culture and enzymes
Application:	Product is placed in water suspension and applied to manure-covered surfaces where slurries are not the problem. One ounce per 1000 sq ft weekly
Product:	Wayne D-ODOR #2
Type:	Bacteria culture and enzymes
Application:	Water suspension is applied to manure slurries or other liquids at the rate of 1 lb per 10,000 gal. of material.

Manufacturer:	Game Slatted Floor Co. Box 3 Ransom, Illinois 60470
Product:	Solution "101"
Type:	Odor maskant
Application:	Dispensed into the air with a "Pig Puff" dispenser.
Cost:	Pig Puffs: $79.50 each Solution "101": $7.95/gal.

APPENDIX B

SUMMARY OF SELECTED COURT CASES RELATIVE TO LIVESTOCK ODORS

1966 Law Suit Against a Dairy Operation in Washington by Urban Neighbors.

The dairy was on land zoned for general uses with the operation of a dairy farm permitted. The land had been used as a dairy farm for many years and until three years earlier the herd was approximately 50 animals. The land across the street to the south, zoned suburban agricultural, had been divided into approximately five-acre tracts for homes. The area was typical of those found on the boundaries of a city.

Those who complained had not recently moved into the area, but most had been there a number of years. The principal complaint of the 18 plaintiffs was that because of the intensified operation of the dairy in the last three years, odors arising from it had become a nuisance. The herd number had been increased to 200.

In an effort to solve the problem created by the waste of the dairy animals, the defendants constructed a large concrete holding tank. All manure was washed into the tank, reduced into a liquid state, and pumped into a lagoon. An earlier attempt to dispose of the liquid manure by spraying it on the fields was abandoned because of the odors created and because drift from the spray fell on adjoining properties. Those who complained asserted that nauseous odors were emitted from the lagoon. The relief sought was an injunction from maintaining the open lagoon.

The witnesses testified that the odors were intensely offensive, and that when the weather was pleasant and conducive to outdoor activities that it was impossible to carry on these activities because of these odors from the lagoon. Certain neighbors called by the defendants testified that they were not greatly affected by odors since their homes tended to be to the side of prevailing wind patterns.

The judge made some effort to examine the area and on three occasions drove on the streets. On each occasion, the weather was cold and the wind rather brisk but unpleasant odors could be detected. On one occasion, by closer inspection on foot in the neighborhood of the lagoon, some effort was made to ascertain the presence of the offensive odors and some unpleasant odor was noted which was different in quality, and subjectively more offensive than that generally associated with manure from cattle. The court was of the opinion that if the odors emitted by the lagoon were of that intense quality, those in the vicinity, indeed, would be substantially affected to an unbearable degree.

The problem arose because the increased number of cattle had increased the manure disposition problem far beyond that which existed when the dairy was smaller. The defendants have invested about $300,000 in their operation. They have experimented with manure disposal. They tried to dispose of it by spraying it on the pasture and abandoned this method at substantial cost to themselves because of problems which spraying created. They have not attempted to use the lagoon system and have constructed a lagoon into which they pump about 100 cu m (27,000 gal.) of liquid manure every two days.

The thrust of the testimony of the expert witnesses was that when they visited, the lagoon seemed to be operating satisfactorily, and they detected no unusual odors. However, all seemed to agree, that lagoons are still experimental and there is a great deal to be learned from them.

From the evidence, the judge found that the operation of the lagoon constituted a nuisance because of the odors which it emitted from time to time. Evidently, at times it had not functioned properly and there was no reason to suppose that the condition would not recur. He continued the case for four months, thereby withholding final judgment, to permit the defendants to attempt to further cope with this problem by means of their own choosing, and suggested that they investigate the possibilities of chemical additives; of aeration by the discharge of air in pipes in the body of the lagoon; of the introduction of algae, if appropriate; of enlargement of the lagoon system so that overload would not occur, or by such other means as their own investigation might suggest.

In court action four months later (in April 1966), a new attorney for the dairy owner advised the abandonment of the lagoon and the installation of a series of dug rectangular pits to receive the manure. Black polyethylene film is used as a cover for the pits. It was the contention of the attorney, who has a background of chemistry, that the pits would act as anaerobic ones and that plastic covers would confine odors.

Patz versus Farmegg Products, Inc. (1970).

This was a civil action for injunctive relief and to recover damages sustained on account of a private nuisance. The case was heard in the District Court, Webster County, Iowa, during 1970.

Farmegg Products, Inc. purchased 1.63 ha (4.0 acres) of land in 1969 that had a common boundary with a 100 ha (240 acre) farm owned and operated by Mr. and Mrs. Patz. FPI constructed two buildings to grow chickens to laying age on the four acre tract. These were totally-enclosed, mechanically ventilated buildings, each confining about 43,000 birds in cages suspended over 25 cm (10 in.) deep pits. Air exchange was provided by the ventilation system to promote manure drying and coning so that the pits could retain the manure produced during the 22 week growing cycle.

At the beginning of each growing cycle, in January and in July 1970, feed and water spilled by the baby chicks and spilled water from malfunctioning waterers caused excessive moisture in the manure and wasted feed retained in the pits. The combination of a high ambient temperature required for young chicks and a low air exchange rate to maintain a high indoor temperature produced more concentrated odorous gases in the fan-exhausted air.

The Patz residence is located about 300 m (1,000 ft) west-northwest from the nearest exhaust fan. The Patzes complained about offensive odors and dust exhausted from the buildings and about manure spillage on the public road in front of their home.

Evaluation of climatic data by defendant's counsel indicated that the probability of odor detection in the Patz house yard would be about one percent of the time.

Having heard the evidence, the Court found that odors coming from the poultry buildings were offensive, that they were injurious and dangerous to the health and comfort of the plaintiffs and thus interfered with the plaintiffs' right to use and enjoy their residence, and that the invasion of private rights was substantial and intentional; i.e., the decision to use the existing system of manure handling without giving consideration to the distance between the plaintiff's house and the poultry buildings. For the purpose of determining the defendant's liability for damages, the court found the conduct of the defendant to be unreasonable.

The court awarded $20,000 in permanent damages to the plaintiffs, and enjoined the defendant from hauling manure upon the highway abutting the plaintiffs' premises in such a manner that there was risk of spillage on the highway. The request for injunctive relief, except as indicated in the preceding sentence, was denied.
Reference: Patz versus Farmegg Products, Inc., Civil No. 43257 (Iowa Dist. Ct., Webster Co., Dec. 2, 1970).

Hardin Co. versus Gifford Feed Lots, Inc. (1968).

This case, heard in the District Court, Hardin County, Iowa, during 1968, concerned a public and private nuisance and noncompliance with zoning regulations.

A land tract of about 12 ha (30 acres) was purchased in 1966, and a commercial feedlot was constructed in an old gravel pit on this land. Gravel had been mined from the pit before 1930. Use of the tract before 1965 was to graze, feed and water a few horses and cattle. The landowner constructed two cattle pens and a shed in the gravel pit in 1965. Gifford Feed Lots, Inc. expanded the facilities to 10 pens with a combined capacity of about 1,200 head on about two ha (five acres) in 1966. The actual number kept there ranged from 500 to 1,100 head.

Located in the old gravel pit, the feedlot area was poorly drained even though the lot area was graded. Shallow drainage ditches were constructed to collect and convey drainage water to a point from where the pooled water was pumped to two lagoons located at points of higher elevation. Manure removed from the feedlot was stockpiled near the rim of the gravel pit for later field-spreading on adjacent cropland owned by others.

The feedlot was located 240 m (800 ft) northwest of Gifford, an unincorporated village of about 100 people. Gifford residents complained of offensive odors, flies, and noise from bawling cattle and trucks. They were also concerned about possible contamination of shallow wells in the village.

Having heard the testimony, the Court found that the odors and flies constituted a public and private nuisance that could not be abated by measures proposed by the defendant. The court also found that Hardin County had been zoned in 1965 and that the use of lagoons violated the zoning regulations. An injunction was decreed by the Court. No appeal was perfected. Reference: Hardin Co. versus Gifford Feed Lots, Inc., Civil No. 62-160 (Iowa Dist. Ct., Hardin Co., Dec. 23, 1968).

Trottnow Versus Kullmer (1968).

This case was for damages and an injunction to abate alleged nuisance created by offensive odors from a poultry house owned by Kullmer. The case was heard in the district court of Iowa, Benton County, during 1968. The poultry house in question was constructed in 1966 to accommodate 12,800 hens. A second, similar house was constructed during March, 1967, thus, two similar buildings are involved. Manure from the buildings was mechanically scraped into one of two large manure holding pits. Manure was scraped into the pits at weekly intervals or more frequently. Water from the chicken waterers also was collected in the manure storage pit and on occasion excess water was added to the manure to ease the scraping problem. The two manure pits had holding capacities between 2-1/2 and 3-1/2 weeks production. Rather than have the pits filled, usual operating procedure was to pump manure to a 5.7 cu m (1,500 gal.) mobile tank for transport to cropland. The defendants owned 31 ha (77 acres) on which this manure was applied and some manure was applied to neighbors' farmland. The Trottnow home is the only home within 0.8 km (1/2 mile) of the chicken houses. The Trottnow farmhouse is 58 m (190 ft) directly west of the closest chicken house.

The major complaint involved in the lawsuit was the odor emanating from the chicken houses themselves. Each building had ten 0.91 m (36 in.) exhaust fans on the sides and the ends of the buildings. All are thermostatically controlled and operate continuously during warm weather.

The odors from the chicken house being blown to the Trottnow property were particularly bothersome to tenants of the property. They presented testimony to the discomfort which they suffered and indicated the odors were having an adverse effect upon their health. The tenant and his wife eventually moved from the property and drove back and forth to do the work.

The judge found the chicken laying business was a substantial nuisance to the owner and occupants of the Trottnow dwelling and specified certain operational requirements that were to be met by the Kullmers. These included changes in the ventilation system, the manure handling system, and manure application practices. In addition, he specified they would provide some method of preventing noxious odors which would unreasonably pollute the air at the Trottnow farm buildings. He maintained control of the case and indicated that if additional problems were evident that impartial observers should be obtained to make impartial observations as to whether or not the odors were objectionable. Finally, the judge concluded that Mrs. Trottnow had not at that point suffered compensable damages but the tenants of her property had, in fact, suffered such. A sum of $1,365 was awarded, based upon their medical expenses and additional living cost occasioned by the odors.
Reference: Trottnow versus Kullmer. Civil No. 23482 (Iowa Dist. Ct., Benton Co., Aug 3, 1967).

Edwards versus Black (1968).

Mr. Black operated a commercial cattle feeding operation in a rural area near Audabon, Iowa. A group of 19 adjacent property owners charged that the offensive odors, flies, and noise adversely affected their properties. The jury found that no nuisance existed in this case and declared the confinement operation was a reasonable use of property in that locality.

The verdict indicated:

1) the area in which the feedlots were located was primarily an agricultural area;
2) in spite of the numerous homes in the area, the feedlot was a reasonable use for that area;
3) the odors had not polluted the air in and around the plaintiff's properties;
4) the defendant had not used his property so as to endanger the health of the plaintiffs;
5) the operation and maintenance of the feedlot did not constitute a nuisance nor result in damages to the plaintiffs;
6) the operation of the feedlot did not constitute a continuing nuisance

The decision was reached primarily on the basis of location. Although some consideration was given to distance from the residences as an element of location, the more important consideration was the character of the surrounding area. Thus, because the surrounding area was predominantly rural, the facility was judged as being properly located.

Reference: Iowa Law Review. 1971. "Ill blows the wind that profits nobody:" Control of odors from Iowa livestock confinement facilities. 57(2):451-505. Edwards versus Black. Civil No. 15235-J28-170 (Iowa Dist. Ct. Montgomery Co., November 5, 1968).

Spencer Creek Pollution Control Association versus Lane Feedlots (1970).

This case was brought by an association of residents and land owners against a cattle feedlot near Eugene, Oregon. The complaints were of surface water pollution, groundwater pollution, odors, spread of animal disease, unsightliness, and insect and rodent infestation. The plaintiffs sought monetary damages and an injunction to preclude cattle raising on the property.

The feedlot had capacity for approximately 1,000 head and expansions were proposed to increase this to 1,500 head. The operation included the feeding of beet top silage during a portion of the year which contributed to the odor and drainage problems.

After lengthy testimony and argument, the following orders were decreed:

1) Runoff of contaminated water to be kept from the nearby creek.
2) No more than 600 head of cattle were to be maintained on the property.
3) The amount of beet silage to be fed was limited.
4) Continued efforts to reduce odor escape were required.
5) Damages were awarded to the various plaintiffs in amounts ranging from $15 to $1,850.

Reference: Spencer Creek Pollution Control Association versus Organic Fertilizer Co. Case No. 96125. Circuit Court for the State of Oregon for Lane County. August 25, 1970.

Crandall versus Biergans (1972).

In this case the plaintiffs were seeking damage payment and an injunction against W. M. Biergans who constructed a swine finishing barn on his property in 1965. They claimed that the swine operation constituted a private nuisance because obnoxious odors and toxic gases emanating from the barn were carried by the prevailing wind to the plaintiffs' property. Secondly, it was asserted that the Michigan Environmental Protection Act of 1970 had been violated because of air pollution.

The swine building in question, 37 m (120 ft) long by 10 m (32 ft) wide had a partially slatted floor. A manure storage tank 2.44 m (8.0 ft) wide and 1.83 m (6.0 ft) deep ran the length of the building along the center line. Manure, removed from the storage tank by a vacuum tank wagon, was spread on the defendant's cropland as a crop fertilizer. Four 46 cm (18 in.) exhaust fans were mounted along the east side of the confinement barn to provide ventilation.

In his opinion, the judge concluded that (a) the swine building was in an area zoned agricultural and it was a farming area, and (b) the defendants were conducting their operation in a husbandlike manner and were not negligent in their maintenance.

The court decided in favor of the defendants. They were not maintaining a nuisance. On the basis of the evidence presented, the injury suffered by the plaintiffs was not of such a substantial nature as to warrant an injunction against the swine operation or the relocation of the barn as long as the defendant continued his operation in a careful and husbandlike manner and used such odor control products or devices as are economically feasible.

With respect to the Environmental Protection Act, the court determined there were no standards to judge this operation with respect to odors, therefore, it did not serve as a basis for any relief to the plaintiffs.

Reference: Crandall versus Biergans. Michigan Circuit Court, Clinton County, File No. 844. February 14, 1972.

Warden versus Sinning (1970).

This was a civil action seeking damages and injunctive relief because of a private nuisance caused by offensive odors from a hog operation. The case was heard by a jury in the District Court, Marshall County, Iowa, during 1970.

Mr. and Mrs. Leonard Warden, the plaintiffs, live on a grain and livestock farm in a home that is located directly across the road from the farmstead on the Sinning property. Mr. Warden has lived on his property 46 years.

The Sinning property is also a grain and livestock farm. A totally-enclosed, mechanically-ventilated hog finishing building was built in 1967 on the property about 100 m (325 ft) southwest and across the road from the Wardens' home. The building housed about 500 hogs on a partially-slotted floor, with a liquid manure pit below the floor. Manure pumped from the pit was spread on the Sinning farm.

Having heard the testimony, the jury failed to reach a verdict and was dismissed.

A post-trial agreement between the two parties was reached on November 1970. The Sinnings agreed to clean and fill the pit so that it could not be used to store animal waste, and further agreed that no confinement type of livestock raising would be conducted on their 65 ha (160 acre) farm within 0.8 km (0.5 mile) of the Warden home so long as the Wardens maintained a residence on their existing farm.

This agreement by the Sinnings is binding also on their heirs, successors and assignors. However, it does not prevent the Sinnings from using the hog finishing building for purposes other than for the confinement of livestock or poultry or prevent them from the reasonable feeding of hogs, cattle, or other livestock on any part of their property in any ordinary manner other than by confinement.

Reference: Warden versus Sinning, Civil No. 30403 (Iowa Dist. Cr., Marshall Co., May 25, 1970).

Winnebago Co. versus Fluegel (1970).

This case was heard by a judge in the Circuit Court, Winnebago County, Ill., during 1969. Plaintiffs included the County of Winnebago and eight intervening plaintiffs who were owners of property in close proximity (usually less than 1.6 km (1.0 mile) to the property owned by the defendant, David A. Fluegel.

A request for injunction was tried on two counts: (a) that the use of the Fluegel property as a cattle feedlot was unlawful since it was contrary to the zoning ordinance, and (b) that the cattle feedlot was both a public and private nuisance because of odors, flies, other insects, bacteria in the air and nitrates in the groundwater that existed because of the feedlot operation.

The Fluegel property was located in an area that had been classified as an "agricultural district" in 1942. Fluegel purchased the 10 ha (24 acre) property in 1969 and proceeded to construct a commercial feedlot. The intention was to construct a circular, funnel-shaped feedlot area on about 1.6 ha (4.0 acres). The circular, concrete-surfaced area would be divided into 12 pie-shaped pens, with all pen surfaces sloping toward the center of the circle. A shed was to be constructed in each pen. The completed feedlot was planned to confine about 2,800 head.

The circular feedlot area was graded from property boundary to property boundary across the narrower width of the land tract. A portion of the area was concrete surfaced and sloped to drain to a sump in the center of the circle. The sump drained to an earthen pit through a corrugated metal pipe. Accumulated storm runoff was pumped from the pit and trucked off the Fluegel property on at least one occasion; 1,400 cattle were placed on the half-circle. The manure disposal plan was to truck the solid manure to a Wisconsin-based composting operation.

The previous owner of the land tract was a cattle feeder. A silo, hay shed, cattle shed, and some cattle lots existed on the property when Fluegel purchased it. Testimony indicated the previous owner had finished as many as 400 cattle at one time.

Having heard the testimony, the Court found that the defendant was operating a commercial cattle feedlot in an Agricultural Use District, which feedlot was not a stock farm, a domestic animal-breeding operation, or a use commonly classed as agricultural, but was found to be a stockyard or a use substantially similar to that of a stockyard as defined under Industrial Zoning. Therefore, the defendant was found in violation of the zoning ordinance.

The decree further found the feedlot to be a public nuisance because of the imminent danger of contaminating groundwater, of actual pollution of surface water which escaped to nearby properties, of the existence of offensive odors with no effective means to control or abate the odors, and of substantially contributing to the fly population. The feedlot was found a private nuisance also. The defendant was permanently enjoined from using the premises as a cattle feedlot after March 1, 1970. An appeal was not perfected.

Reference: Winnebago Co. versus Fluegel, Chancery No. G-19425 (Ill. Cir. Ct., Winnebago Co., Jan. 31, 1970).

Bower versus Hog Builders, Inc. (1970).

This was a civil action to recover damages and seeking an injunction because of a private nuisance. The case was heard by a jury in the District Court, Platte County, Missouri, during 1969.

The plaintiffs were Mr. and Mrs. Glenn Bower and Mr. and Mrs. Frank Bower. The Bower families live on adjacent farms of 23 and 22 ha (58 and 55 acres). They had lived on their farms for 20 years or longer.

Hog Builders, Inc., the defendant, purchased a 56 ha (139 acre) tract across the road north from the Glenn Bower property in 1965 and constructed facilities for producing hog breeding stock. Eleven hog buildings with a combined capacity of about 3,800 head were constructed in 1965 and 1966. Open lots for hog confinement on the HBI property covered about 12 ha (30 acres).

All buildings were totally enclosed and mechanically ventilated with partially-slotted floors over 1.2 m (4.0 ft) deep liquid manure pits. Pit contents were emptied into anaerobic lagoons. Eight lagoons, with a combined surface area of about two ha (five acres) were constructed between 1965 and 1969. Lagoons were enlarged or added as needed to store from three to four years' manure production.

Plaintiffs' testimony indicated that some lagoon overflow or release of lagoon contents with subsequent flow across the Frank and Glenn Bower properties occurred on several occasions. On one occasion, a dislodged plug on one lagoon drainpipe permitted a large volume of lagoon-stored waste to flow across the Glenn Bower property, through his stock watering pond, and into a creek. Conservation Agent Paul Tichnor testified that he observed dead fish in both pond and creek on different occasions.

Runoff from about 4.9 ha (12 acres) of hog lot area drained across the Glenn Bower property and through the larger of Glenn Bower's two ponds according to the natural flow of water. However, eroded soil and manure from the hog lot filled the road ditch below the lot so that the road was overtopped by runoff water. This permitted hog lot drainage to flow into the smaller, second pond on the Glenn Bower property and near the vicinity of his shallow, house well.

The Glenn Bower home was located about 250 m (800 ft) from the closest anaerobic lagoon and a somewhat lesser distance from the hog lot. The Frank Bower residence was located a greater distance from these odor sources. Both Bower families testified as to how obnoxious odors from the HBI property affected the uses and values of their properties.

According to wind direction frequencies, odor would be transported from the HBI property toward the Bower properties from 16 to 31 percent of the time, varying from month to month based on an evaluation of Kansas City weather data made by an expert witness for the plaintiffs.

Having heard the evidence submitted during the proceedings, the Court awarded $46,200 in actual damages and $90,000 in punitive damages to the Bower families. The greater amount went to the Glenn Bower family who suffered the greater damage. The presiding judge had excluded an injunction as a possible choice.

The decision was appealed. After reviewing the case, the Supreme Court of Missouri upheld the District Court's decision in December 1970.

Reference: Bower versus Hog Builders, Inc. 461 S. W. 2d 784 (Mo. 1970).

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16. ABSTRACT

Current livestock production techniques result in the generation of odors which have become a source of conflict between livestock producers and society. The odorous gases responsible for the nuisance are principally low molecular weight compounds released during anaerobic decomposition of manure. Manure management systems which control or modify this decomposition offer the greatest potential for odor control.

Research to identify the chemical compounds present in odorous air from animal waste degradation has yielded about 45 compounds to date. The amines, mercaptans, organic acids and heterocyclic nitrogen compounds are generally regarded as being of greatest importance. Among the techniques for odor control are: (a) site selection away from populated areas and where adequate drainage exists, (b) maintain the animal areas as dry as possible and prevent the animals from becoming manure covered, (c) select manure handling systems which utilize aerobic environments for manure storage, (d) maintain an orderly operation free of accumulated manure and runoff water, (e) practice prompt disposal of dead animals and (f) use odor control chemicals when short term odor control is necessary, such as when manure storage tank contents must be field spread.

(Miner - Oregon State University)

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Odor, *Livestock, *Legal aspects, Cattle, Hogs, Poultry, Hydrogen sulfide, Ammonia	*Olfaction, *ammonia desorption, *Livestock manure, *Manure, Odor control	05A 05C 05D

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