INVESTIGATIONS IN THE CONTROL OF ODORS FROM CONFINED BEEF CATTLE FEEDLOTS

by

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PREFACE

The primary objective of this research was to assemble and index all known available information, develop new technology, and report methods of controlling odors from confined feedlots. Included was the objective of determining the effectiveness of various chemical spray applications. Following cataloguing, the literature was screened to narrow the parameters and determine the most feasible control methods. Good housekeeping, combined with the application of odor control material to the manure, was determined to be an economically feasible method of odor control from open, confined beef cattle feedlots. Laboratory testing indicated two materials were highly effective in reducing odors.

In preparation of this report, extensive use was made of individual expertise and pertinent literature. A conscientious effort has been made to credit and cite all source material.

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CHAPTER I

INTRODUCTION TO CONFINED ANIMAL ODOR PROBLEMS

Cattle feedlots undoubtedly antedate written history. Probably, the first feedlot was established shortly after cattle were first domesticated. Mention is made of "the fatted calf" in the Bible. Cattle feedlots are among the more important operations in American agriculture today. Cattle and calf sales gross more cash than the combined sales of cotton, corn, wheat, peanuts, tobacco, and rice (100). Cattle feedlot operations are an especially important industry on the Texas High Plains. Total current feeding capacity in the area is over 2,000,000 head. Since most of the constituents consumed in the ration are grown and much of the slaughtering is carried out within the area, it is evident that the indirect economic impact is much greater than the direct.

Pollution from agricultural enterprises has only recently been recognized by the general public. Where pollution was recognized, it was usually a localized phenomenon affecting few people and considered a necessary evil. Agriculture was viewed as one of the few industries which maintained or even improved the quality of the environment. This view of agriculture is changing rapidly. One state has even passed a law regulating the amount of sediment which can be carried in storm water runoff from agricultural land. Similar laws are under consideration by other state legislatures.

In the past, large accumulations of domestic animal wastes did not exist. Animal populations, in general, were widely dispersed and wastes were recycled through the soil as a source of plant nutrients. Until the advent of chemical fertilizers, animal manures were valuable by-products of livestock feeding. Today, chemical fertilizers have largely supplanted animal manures as sources of plant nutrients because of the lower costs. Current technology in animal production, in combination with economic factors, has moved in the direction of concentrating ever expanding numbers of animal units in one area. At present, in contrast to many other animal production operations, many cattle feedlot operations are in the open. The Northeast and Midwest are moving toward enclosed animal feeding units; however, the trend in the Southwest is still toward open feedlots. This is readily understandable as climatic analysis has shown the optimum areas for open feedlots operating on a year-round basis to be the Southern Great Plains, desert Southwest, and portions of California (22).

The trend toward concentrated cattle feeding started shortly after World War II. It took until the mid 1950's for the trend of concentrated animal production to develop to the point that an awareness of the pollution potential of animal wastes was recognized. Even then, there was no measure of the magnitude of the problem. It wasn't until the early 1960's that these data were developed, but even then the data related mostly to water pollution. This is readily understandable because standard methods for water quality analysis have been developed and practiced for some time. (40)

Air pollution was a different matter. Baseline data were not available. While some methodology was available, there were no standards, and often data could not be correlated. This is particularly true in the case of odors. Odor perception is highly subjective and variable. The biological system producing odors by decomposing manure is highly variable and extremely complex. Active work to isolate, identify, and measure manure odor components has been going on since the early 1960's. Identification of some odorous components was rapid. One of the early reports on these components was by Day et al. (26) in 1963. Hydrogen sulfide and ammonia were odorous gases identified in a swine building. The identification of these odors, however, did not account for the utter foulness of the stench.

Merkel et al. (65) gave three reasons for controlling odors from animal feeding operations:

1. To prevent possible damage to structural components of the feeding operation.
2. To prevent the toxic effects of individual compounds or combination of compounds on workers and/or animals.
3. To be esthetically pleasing to owner and neighbors.

Item one is self-explanatory and will not be discussed further except to say that some gases, hydrogen sulfide for example, are highly corrosive to metals and may cause rapid deterioration of concrete and paints.

That lethal gases are produced by the decomposition of manure is no longer subject to debate (65). Increased susceptability to disease and a reduction in performance are possible subletheal effects. Lillie (54) published a literature survey concerning the effects of many air pollutants on domestic animals. The effects of hydrogen sulfide, ammonia, carbon monoxide, and some hydrocarbons are of particular interest since they are known decomposition products of animal wastes under some conditions. Seltzer et al. (91) cited several cases of the adverse effects of ammonia and other manure gases on poultry and other animals. Taiganides and White (98) discussed the effects of certain gases generated by decomposing animal excreta on human and animal health. They presented a table concerning the effects of some noxious gases and information regardingmethods to prevent adverse effects on humans and animals from such gases.

Urban growth has and will probably continue to expand into the rural areas. Urban and rural residents are not prepared to accept insults of poorly operated, carelessly constructed, or improperly designed operations. The use of good housekeeping and husbandry was the key factor in the decision, handed down by a county circuit court judge, not to issue an injunction against a hog production operation. The injunction was denied so long as economically feasable odor control devices or products were used and the operation was run in a husband-like manner. The operation was located in an area zoned for agriculture. Commercial practices were implemented which, while common, did not eliminate all odors. The plaintiff was not able to establish that wrongful or unreasonable use was being made of the property. (80) There is no location to which the feedlot operator can move to escape this phenomenon. It is, however, apparent that environmental pollution will not be acceptable in any animal production area in the future (67). Odors are the most frequent complaint directed at animal production in the near-urban locations. At the present time, it appears that the primary basis for regulating odors from animal production is to eliminate an unacceptable nuisance. Carbon monoxide, which is odorless, is a toxic gas produced by decomposing manures. It is suggested in a large quantity of literature that many odorants from the decomposition of animal excreta are not physically harmful at levels which are psychologically intolerable (40). Actual physiological damage to neighbors from animal waste odors has not been proven in court; however, nuisance and property damage have been proven (33, 67, 105). A discussion of nuisance and tresspass was given by Willrich and Miner (105). They gave a brief account of five recent nuisance cases heard in civil court. Two cases involved both private and public nuisance as well as noncompliance with zoning regulations, whicl the other three involved only private nuisance. Of the cases reported, tow cases involved cattle, two swine, and one poultry. Feedlots in theese cases were not considered to be agricultural operations, but rather industrial operations.

Miner et al. (68) suggested a program of rural zoning which would set aside specific areas for livestock production where the odors would be acceptable. Lack of effective land use regulation has led to court cases where the fact that the livestock producer was there first gave no protection against judgements.

Currently, most odor control is only subject to indirect government control through zoning. At least nineteen states have regulations defining odor as an environmental pollutant. Similar regulations are under consideration in five other states. Nine of the nineteen employ qualitative control standards, while nine employ quantitative standards, and only three employ both in their regulations. Four of the states do not define any control standard. Quantitative measurement is usually by odormeter and qualitative is by inspections, panels, and random sampling (8). While the Environmental Protection Agency has given no recommended limits for odorous emissions, the Texas Air Control Board is considering issuing standards for odorous emissions within a year (97). In addition, local ordinances are becoming more specific and quantitative. In many instances, excessive odor is defined in terms of volumes of odor-free air required to dilute one volume of odorous air to a level which is not objectionable. Any odor is rated as unacceptable in quality, if a stated percentage, typically thirty per cent, of the exposed people find it to be objectionable (29).

In addition to the control of emissions as odors, certain components may have specific emission limitations placed on them for other reasons. It was found that open water surfaces in close proximity to feedlots had ammonia adsorption rates which were as much as twenty times greater than open water surfaces not similarly situated. This indicates that ammonia volatization from the surfaces of feedlots is a significant contributor to the nitrogen enrichment of surface water in the feedlot vicinity. No apparent seasonal correlation of the ammonia absorption rate was found even though both volatilizing and absorbing surfaces were completely frozen during soem periods. A belief was advanced that the absorption rate is a function of the moisture status of the volatilizing surfaces. Peaks of maximum absorption occurred when rapid drying was taking place on feedlot surfaces. Minimum absorption was generally found to occur during periods of low evaporation and periods of precipitation (44). During a laboratory study under simulated feedlot conditions, Stewart (95) found that the quantity of nitrate accumulated and ammonia volatilized depended upon the soil moisture content. In this study, five milliliters of urine was added to each twenty-one cm^2 of soil. This is equivalent to the average urine excreted by steers with a stockage rate of one animal per seventy-five ft^2. The total added to the soil columns, which had been previously wetted with distilled water, represented approximately twelve inches for continuous stocking. Under these conditions, about sixty-five per cent of the urine was converted to nitrate and less than twenty-five per cent was lost as ammonia. When five milliliters of urine was added every fourth day, over 90% of the added nitrogen was volatilized as ammonia. This rate of addition also gave a moisture loss in excess of 90% before the next addition.

CHAPTER II

CHARACTERIZATION OF ANIMAL WASTE ODORS

Many different methods have been used in attempts to characterize the odorous components of animal manure decomposition. There are certain characteristics of odors which are known. An odor is an effect, the result of the stimulation of an individual's olfactory region. Odorants or odorous substances are the materials producing the stimulus (109). Only substances which are volatile are odorous; however, many volatile substances do not have odors. Substances having the same chemical composition (isomers) have very different odors. Substances having very different chemical compositions may have similiar odors. Some odorous substances must have a concentration of a million times greater than others in order to be detected by smell. Variation in the concentration of an odorant may cause a change in the quality of the odor. A high initial reaponse is produced on initial perception of an odor followed by a declining response with continued contact. Total loss of perception may happen in some cases. Air movement must take place in the nasal cavity for odors to be perceived. (9)

Only substances having the form of fine mists, gases, or vapors can be smelled. Sensitivity of the human olfactory organ varies widely for different odorants (51). Odors can, however, be associated with solid particulate matter. Burnett (19) collected particulate matter from a poultry laying house. A panel of at least eight people determined that the dust carried a "chicken house" odor. The odors dissipated after standing for at least 12 hours at room temperature or being dried at 100°C, thereby indicating that they were due to one or more volatile compounds. When these volatiles were subjected to chromatographic analysis coupled with organoleptic evaluation, a number of compounds had strong odors. Since no individual compound had the typical "chicken house" odor, the assumption was made that the typical odor was a blend of several odorous materials.

Most physiological responces, including odor intensity, follow the Weber-Fechner Law, i.e. the sensation is proportional to the log of the stimulus (23). Stated another way, the intensity of an odor is proportional to the log of the concentration. Therefore, odorant concentration must be reduced by a factor of ten to effect a reduction in the odor intensity of two, or a factor of one hundred to effect a reduction of four, etc. (109). From this it is easy to see that methods for reducing odors must be extremely effective.

Odor intensities may be expressed in several ways. Typical are the Threshold Odor Number (TON) and the Odor Intensity Index (OII). The following equation relates the two values:

$$TON = 2^{OII}$$

The number of times an odorant must be diluted by half with an odorless agent until the odor is just detectable (threshold) is the Odor Intensity Index. The greatest dilution of an odorant with an odorless agent until the odor is just detectable is the Threshold Odor Number (9). Odor Intensity Index seems to generally be preferred as it is simpler to express. A Threshold Odor Number of one means that an air sample is odorless. Threshold Odor is an attempt to quantify the least amount of a substance to produce an odor that can be detected under a specific set of conditions, including that of the testor. This definition is based on four known facts:

1. A weak odor will not be noticed in the presence of a strong odor.

2. An unrecognizable odor will be produced by the blending of two odors of equal strengths.
3. Awareness of an odor will be diminished by constant contact.
4. The like or dislike of an odor is affected by past experience. (85)

Some compounds are extremely odorous. This is particularly true for amines, organic sulfur compounds, and some organic acids. Sulfur compounds have commonly been used as odorants for fuel gases for many years. One of these, tertiary butyl mercaptan, is detectable at less than one tenth of one part per billion. Another powerful odorant is trimethylamine, which is very similiar to the odors of cattle feedlot areas (94). Table I lists the Threshold Odor levels of some odorants which have been identified as components of odors from decomposing animal manures.

TABLE I (52)

ODOR THRESHOLDS IN AIR

COMPOUND	ppm. BY VOLUME
Trimethylamine	0.00021
Dimethyamine	0.047
Monomethylamine	0.021
Ammonia	46.8
Hydrogen Sulfide	0.0047
Ethyl Mercaptan	0.001
Acetic Acid	1.0
Butryic Acid	0.001
Formaldehyde	1.0

Odormeters have been developed which assist in odor measurement. These instruments have taken various forms, but all make the necessary dilutions of odorous air with odor free air before inhalation. Osometer, odormeter, osmoscope, scentometer, olfactometer, and olfactoscope are some of the names which have been given these instruments. Several odormeters are described by Moncreif (70) of which the first and most famous was built by Zwaardemaker in 1895. A very important apparatus in odor research has been the gas-liquid chromatograph. The gas-liquid chromatograph can best separate and quantify odorants while the human nose can best determine the quality and intensity of simple or complex combinations of odorants. The capabilities of one compliments the other rather than one supplanting the other (9). Kendall and Neilson (47) compared the sensitivity of the human olfactory organ to that of the gas-liquid chromatograph. Ten to one hundred times greater odorant concentrations were necessary for detection by the gas-liquid chromatograph than for organoleptic detection.

Subjectivity is unavoidable in odor quality testing. Observer judgements in relation to a known odorant is required if testing is not to be on the basis of pleasant or unpleasant. It is widely thought that there are primary odors just as there are primary colors. All odors are made up of the primaries or combinations of the primaries (9). Primary odors have not been identified, but the number of primary odors has been estimated to run as high as twenty-seven (2).

The chemical oxygen demand (COD) test used in water pollution measurements was modified to measure the COD of the atmosphere of a swine confinement chamber. (35) Sobel (93) adapted an odor evaluation rating method to manure handling and treatment using organoleptic techniques. Bentsen and Bethea (14) gave a description of a computer program which will aid in the qualitative and quantitative analysis of unknown samples by gas chromatography. Moum *et al*. (73) used pH paper impregnated with 6 - 11 indicators to identify and indicate the quantity of ammonia in animal quarters. Schutz (90) has devised a method of odor measurement called a matching standards technique.

Organic materials are composed of carbon, hydrogen, oxygen, sulfur, nitrogen, and phosphorus. The final oxidation or decomposition products are carbon dioxide (CO_2), water (H_2O), sulfate ($SO_4^{=}$), Nitrates (NO_3^{-}), and phosphates $PO_4^{\equiv}$). All of these compounds are odorless. Merkel et al. (65) detailed the decomposition of organic material under anaerobic conditions. Protein breaks down to simpler substances, ie. proteoses, peptones, peptides, ammino acids, and ultimately to ammonia and volatile organic acids such as acetic, butyric, propionic, and formic. Different sulfides and mercaptans may also be expected because some ammino acids contain sulfur. Starches and cellulose decompose to glucose, a form of sugar. Sugars degrade to organic acids, aldehydes, ketones, and alcohols. Fats are esters of glycerol, which is a trihydroxy alcohol. Hydrolysis to alcohols and the corresponding fatty acids is the first step in fragmentation of fats. Aceitc acid is cleaved from these acids and those produced by the deamination of ammino acids. Certain bacteria utilize acetic acid as an energy source and produce carbon dioxide and methane as end products. Organic acids, aldehydes, sulfides, simple hydrocarbons, alcohols, ammonia, methane, and carbon dioxide can be expected form the breakdown of animal wastes. Alcohols and acids react with ammonia to form amines and amides. Acids, aldehydes, and alcohols react with hydrogen sulfide to form thioacids, thiols, and mercaptans. Ketones are reaction products of alcohols and acid.

There are certain additional factors which should be considered about the compounds to be expected as off gases from degrading wastes. Vapor pressure is one of these as the material must be in a gaseous state for an odor to be detected. Vapor pressure generally varies inversely with the molecular weight for a specific homologous series. The water solubility of compounds is also important. Methane, while odorless, has negligible solubility in water at ordinary pressures and escapes immediately upon production. The pH affects the solubility of many compounds. Under conditions of high pH, hydrogen sulfide is mostly dissociated and present as H^+ and HS^- ions so little odor is detectable. If the pH is lowered, ionization decreases and the odor of hydrogen sulfide is readily detected.

Deibel (27) and later Burnett and Dondero (21) related the production of offensive odors in batch lots of diluted and undiluted poultry manure to changes in the chemical and microbial composition. Deibel's work also indicated that excreted enzymes were not a factor in odor production. Burnett and Dondero proved that pure cultures of bacteria produce ammonia and hydrogen sulfide from sterile poultry manure substrate.

Ludington and Sobel (58) found that the release and production of odors and gases differed in diluted and undiluted poultry manure. Diluted manure was found to produce more hydrogen sulfide and ammonia than undiluted; however, a significantly larger quantity of ammonia was released from the undiluted manure. Production of hydrogen sulfide was considerably greater in the diluted chicken manure than in the undiluted; however, its release was only about twice as fast. Both systems released comparable strength odors, but the quality was vastly different. The predominate odor from the undiluted manure was ammonia, which was relatively inoffensive. By comparison, the odor from the liquid manure was very offensive. Liquid dilution can be used to measure the odor strength of manures and dilution with odor free air can be used to measure the strength of the released gases (60). According to Sobel (93), the offensiveness of the odor appears to be proportional to the logarithm of the moisture content in the measurement of odors from animal manures.

Table II lists volatile components which have been identified as decomposition products by various researchers. Stephens (94) suggested that the lower molecular weight amines, particularly trimethylamine, are among the more obnoxious odorous gases in cattle feedlot air. White et al. (104) considered dimethyl sulfide to be the main component of odors from the anaerobic decomposition of dairy cattle waste. Tests by Merkel et al. (65) indicated that mercaptans, sulfides, amines, and ammonia had potential for being significant odorous compound in the atmosphere of an enclosed swine feeding operation. Alcohols and carbonyls were judged to be unimportant. Miner and Hazen (69) found the ammonia concentration to be below threshold in a swine confinement building. This indicated that ammonia is unimportant in the odors from swine areas or that its effects are additive. Burnett (18) indicated that sulfur compounds, amines, and organic acids were important malodorous components of the decomposition of poultry manure.

TABLE II

VOLATILE DECOMPOSITION PRODUCTS OF ANIMAL MANURES

COMPONENT	REFERENCE
Fixed Gases	
Hydrogen Sulfide	10, 18, 26, 58, 64, 103
Ammonia	10, 18, 26, 58, 64, 69
Carbon Dioxide	26, 64
Methane	26, 64
Carbon Monoxide	64
Nitrogen Compounds	
Amines	64, 94
triethyl	69
ethyl	10, 69, 104
trimethyl	94, 104
methyl	10, 69
indole	18, 58, 76

TABLE II CONTINUED

COMPONENT	REFERENCE
<u>Nitrogen Compounds Continued</u>	
Amines Continued	
skatol	18, 58, 76
dimethyl	10
diethyl	10
Amides	64
<u>Volatile Organic Acids</u>	
Acetic	10, 58, 64
Propionic	10, 58, 64
Butyric	10, 58, 64
Iso-butryic	18
Valeric	10, 18, 58
Iso-valeric	18
<u>Alcohols</u>	
Ethanol	64, 65, 76
Methanol	64, 65, 76
Propanol	64, 65
Iso-propanol	64, 65
Butanol	64, 65
Iso-butanol	64, 65
Iso-pentanol	64, 65
<u>Sulfur Compounds</u>	
Sulfur Compounds	94
Mercaptans	10, 58, 64, 65
methyl	18, 103, 104
ethyl	18
n-propyl	18

TABLE II CONTINUED

COMPONENT	REFERENCE
Sulfur Compounds Continued	
Sulfides	10, 18, 58, 64, 65
methyl	18
disulfides	10, 64, 65
diethyl	103, 104
dimethyl	104
Carbonyls	
Aldehydes	
acetaldehyde	39, 64, 76
decaldehyde	64, 65
formaldehyde	64, 65
heptaldehyde	64, 65
hexaldehyde	39
iso-butyraldehyde	64, 76
octaldehyde	64
propionaldehyde	39, 64, 76
valeraldehyde	64, 65
butyaldehyde	39, 65
Ketones	
acetone	39, 64, 76
diketone	58
2-butanone	39
3-hydroxy-2-butanone (diacetyl)	18
3-butanedione (acetoin)	18
3-pentanone	39

TABLE II CONTINUED

COMPONENT	REFERENCE
Esters	
Ethyl Formate	76
Isopropyl Propionate	76
Propyl Acetate	103, 104
Butyl Acetate	103, 104
Isopropyl Acetate	76
Isobutyl Acetate	76
Methyl Acetate	76

CHAPTER III

LITERATURE REVIEW OF ODOR CONTROL

With the passage of the Federal Air Quality Act of 1967, there remains little doubt that the emmission of odorous effluents will have to be abated. Current technology has given us a large quantity of equipment, chemicals, and other products to choose from in the development of odor control systems. The following literature review provides a survey of many attempts, both successful and unsuccessful, at odor abatement.

HOUSEKEEPING

Moorman (72) stated that housekeeping consisting of a regular manure removal program plus strict attention to carcass removal, feed spoilage, and water drainage can alleviate odor problems at cattle feedlots. Wright (108) cited an example where housekeeping improvements alleviated odor problems. Faith (31) gave the primary means of odor control in cattle feedlots as housekeeping and sanitation. Continuous manure removal and pen cleaning were necessary if the pen was paved. On earth lots where manure was allowed to accumulate, it was kept aerobic by scarifying and then removed when the depth became too great for penetration. Miner (67) stressed the importance of housekeeping. An animal-raising operation must be an orderly enterprise. Rats, flies, and other pests must be controlled. If grounds are cluttered with abandoned machinery, buildings in disrepair, and the area overgrown with weeds, a nuisance condition will be expected to exist. When operations are neat and well maintained, small environmental violations are more apt to be overlooked. Ludington *et al.* (59) conducted tests to determine the effect of manure removal and moisture removal on odor offensiveness from poultry facilities. Odor offensiveness was evaluated by a panel. Removing moisture reduced the odor level in all tests. No significant difference was found for different methods of daily manure removals at the one per cent and five per cent levels of significance. There were significant differences between all methods of daily removals and storage of diluted and undiluted manure. There were also significant differences between the stored diluted and undiluted manures. It was concluded that manure management systems which remove moisture from manure, or remove the manure from the poultry house daily will cause the least problems with odors.

Environmental chamber experiments by Narayan (76) showed the effect of waste handling and sanitation on the type and number of odorous compounds found. The chamber housed a 500 pound steer. Three management schemes were carried out for periods of one week each. The management schemes were:

1. Wash and clean the chamber thoroughly each day.
2. Remove solid waste daily by shoveling with no washing.
3. Cleaning completely eliminated.

Under the first management scheme, only a few odorous compounds were found which were not particularly offensive. Indole and skatol, two very odorous amines, were found during the second management scheme. There was a threefold increase in the number of odorous compounds during the no-cleaning phase. The peak heights of the chromatogram indicated the concentration of the odorants increased with time.

SCRUBBING

Hedrich (41) reported that gas washing was tried, unsuccessfully in an attempt to control odors from sludge drying equipment at a Pasedena, California, sewage treatment plant. Wright (108) gave a brief description of absorption. Liquid scrubbing of air for odor removal has a practical and a historical basis according to Bosworth and Bardukin (17). The quantity of odor stripped by scrubbing has been shown to be a function of the quantity of odorant in the air, the solubility of the odorant in the absorbent, the quantity of surface available for mass transfer and the velocity of air through the scrubber. Emmanuel (30) gave a description of the use of a scrubber for the control of malodors from feedlots, manure piles, and rendering plants. Experimental data were deemed a necessity in determining the cost for a particular application. Shrode (92) related descriptions of plain and oxidative scrubbing with emphasis on the use of potassium permanganate. A table was given describing the reaction of several compounds with potassium permanganate. Bethea (15) discussed odor control by gas washing and scrubbing. Hicks (42) used a 12.5 ft. deep rock filter and a 10 ft. deep Flocor filter to scrub odiferous air in a sewage treatment plant. Reductions in odorant concentrations of greater than 90% were attained.

ADSORPTION

Bethea (15) reported that activated carbon could be an effective and economical method of odor control. Careful design of the carbon adsorption beds was considered necessary to avoid displacement. Monitoring was considered a necessity because some odorants are adsorbed more strongly than others. Activated carbon varies in adsorptive capacity from lot to lot. Hedrich (41) reported that attempts to adsorb odors from sewage sludge drying operations onto charcoal filter beds gave no improvement. Wright (108) briefly discussed the adsorption process. Santry (85) stated that hydrogen sulfide can be removed by adsorption on activated carbon. Even with regeneration, Sawatani (87) reported that odor adsorption by activated carbon was too expensive for use in poultry, swine, and fishery operations in Japan. Shrode (92) described the use of activated carbon and other adsorbents for odor control.

Gumerman and Carlson (37) reported that hydrogen sulfide and ethyl mercaptan can be removed by sterile loam soil. They suggest that a soil filter can be designed for the removal of these gases. The gases were removed with the soil either wet or dry, but the mechanism of removal differed for the two cases. Dry soil was found to be more efficient.

CHLORINE

Hedrich (41) stated that atmospheric oxidation of malodors with chlorine was unsuccessful. From three to nine pounds of chlorine per pound of hydrogen sulfide were required for the elimination of hydrogen sulfide from sewage in a series of field tests. The average requirement was 5.3 pounds (81). According to Santry (85), chlorine has been used for the control of hydrogen sulfide in sewers. Chlorine was quite expensive for this purpose. Deibel (27) tested sodium chloride in concentrations as strong as eight per cent without total loss of odor in poultry manure. Hammond et al. (38) tested the use of chlorine to supress odors from hog manure. Based on laboratory tests, chlorine was added at the rate of 0.1 pound active chlorine per 100 pounds of hog per day. Only traces of ammonia could be detected and there was less hydrogen sulfide production than in a limed pit used for comparison. The cost of chlorine was estimated to be about ten times that of lime; however, about half the amount of chlorine used was shown to be effective in reducing odors. The chlorine was also effective in the control of rodents and maggots in the building. Sawatani (87) did not find chlorination to be a practical process for odor elimination from poultry, swine, and fishery operations. Chlorination is one method of hydrogen sulfide control in common use. The following equation describes one reaction of hydrogen sulfide and chlorine: $H_2S + Cl_2 \rightarrow 2HCl + S$. The theoritical quantity of chlorine to react with a pound of hydrogen sulfide for this reaction is 2.1 pounds; however, excess chlorine must be present for this reaction to occur. When excess chlorine is present, another reaction also takes place. $H_2S + 4Cl_2 + 4H_2O \rightarrow H_2SO_4 + 8HCl$. By this reaction, 8.4 pounds of chlorine is required to react with one pound of hydrogen sulfide. (34)

OZONATION

Hedrich (41) stated that two ozone generators were installed in an attempt to oxidize odors. Thirty-two grams (18.1 ft.^{3}) of ozone was injected into the discharge of 7,000 cfm of air. Inadequate improvement was noted. Deibel (27) reported that direct ozonation of poultry manure was unsuccessful in abating odors. Bauch and Burchard (12) described the une of ozone in treating toxic and strong smelling liquid effluents. The use of ozone reduced oxygen demand, but not all organic materials were oxidized. A striking reduction of odors occurred. Nakano (75) reported that ozonation was used successfully for the treatment of sewage digestion odors in Nagoya, Japan. This system handles 560,400 cfm of air. A four second residence time for reacting and mixing 0.37 pound of ozone per hour decreased ammonia concentrations by 60%. The cost of operation was $290.00 for the year of 1968. The common components of sewage odors were not detectable in the effluent air stream. Okuno (79) discussed the mechanism by which ozone destroys sulfurous compounds, lower molecular amines, and acids. Reactivity was determined by measuring the quantity of residual ozone and monitoring the reaction products by gas chromatography. Not all odorous components can, however, be removed by ozone oxidation. Some odorous substances were found to react faster than others. Baba (7) gave information on using ozonation as a control technique for odors from human sewage. Comparative cost data were presented for thermal and catalytic incineration, adsorption, chlorination, and ozonation. Ozonation was shown to be the least expensive.

Sawatani (87) did not consider ozonation to be a practical process for elimination of odors from poultry, swine, and fishery operations. The deodorization of air by reaction with ozone is not possible according to studies by Huch _et al_. (43). According to kinetic theory, only slow reaction rates were predicted. In order to verify that no novel reactions were taking place, deodorization of air from a swine barn and a poultry house was attempted under carefully controlled conditions. Revelant differences between the gas before and after treatment could not be detected. Nascent oxygen generation, a variation of ozone treatment was attempted. The effectiveness of the reaction chamber was the same whether the ultraviolet light source was turned on or off. Elliot (29) stated that ozonation was most effective in the reduction of organic odorants. Dosage requirements depended upon retention time, humidity, and temperature. Bethea (15) discussed the use of ozone for odor control. A suggested program for further research was given in addition to comparative costs for oxonation and other methods of odor control. Scarlet (88) discussed the possibility of using ozone in enclosed feeding areas or of treating the effluents from such areas.

INCINERATION

Experiments showed that odorants from a sludge drying operation could be oxidized by thermal incineration with a stack temperature in excess of 1,000° F. A horizontal furnace gave satisfactory deodorization, but was replaced by a vertical furnace because of operational difficulties. The vertical furnace, while satisfactory from an odor control standpoint, was very expensive to operate. A reversing heat exchanger furnace was being built at the time of publication in attempt to reduce costs. (41) Incineration by open flare burning, direct flame combustion, and catalytic combustion was discussed by Shrode (92). Bethea (15) also gave a discussion of odor control by incineration. Because of high costs, incineration was considered to be a last resort method of odor control. Mills and Danielson (66) discussed the use of thermal incineration for control of odors from an enclosed cattle feeding operation. Operating costs for a 100-head feeding operation were estimated to be $5.00 per hour without heat reclamation. Heat reclamation would have resulted in a considerable reduction in costs. Estimated capitol costs were $10,000 to $15,000. Catalytic oxidation (48) in open air may solve sulfide odor problems. The oxidation technique was reported to be effective for odors of hydrogen sulfide, methyl mercaptan, and other alkyl mercaptans.

Alaxon SRM, said to be a mixture of organic and inorganic compounds, was the key to the process.

ORTHODICHLOROBENZENE

Orthodichlorobenzene was used for hydrogen sulfide control with good results at dosages as low as 1.5 parts per million. The Los Angeles County Sanitation district found that 40 parts per million was necessary to reduce the hydrogen sulfide generation by 50%; however, a poor point of application was used. It was noted that orthodichlorobenzene exhibited a remarkable ability to mask other odors. (81) Deibel (27) found that Chloramine - T, at a concentration of 50 ppm., deodorized liquid poultry manure in ten minutes; however, it was effective for only about 24 hours. The spraying of 300 gallons per acre of a 1% solution of Ozene, the brand name of a formulation of orthodichlorobenzene, was recommended for the control of feedlot odors. It was also recommended that the lot be empty when sprayed, the feed not be contaminated, and the spraying be repeated at regular intervals. (1)

LIME

Yushok and Bear (110) reported that odors from solid poultry manure were greatly reduced when quicklime was used as a preservative. Because of difficulty in the handling of quicklime, the decision was made to compare its effects with that of hydrated lime. Similiar drying and deodorizing effects were observed for both products. The primary effect of either product was to slow the decomposition rate of the manure. A bactericidal effect was noted.

Santry (85) reported that a lime slurry had given good control of hydrogen sulfide in sewers in Los Angeles County, California. Deibel (27) found that lime added to liquid poultry manure initially decreased both odors and bacterial growth. Initial pH was about ten, but decreased to seven or eight regardless of the amount of lime added. The odor of ammonia was readily detected at high pH values. Hammond et al. (38) studied the use of lime in supressing odors from hog manure. Hydrated lime was added to the manure at rates of 0.154 and 0.158 pounds per day. This maintained the pH at nine or above. Hydrogen sulfide and carbon dioxide production were reduced, but methane and ammonia production were not appreciably changed by the addition of lime.

POTASSIUM PERMANGANATE

Faith (31, 32) reported that potassium permanganate gave satisfactory results in the control of feedlot odors provided good sanitation was maintained. Good housekeeping, including frequent manure removal and scarification of the manure pack to provide aerobic conditions, had not reduced odors to a satisfactory level at a feedlot in Southern California. Various chemicals and proprietary compounds were tested in an attempt to further reduce odors. Potassium permanganate, applied in a dilute water solution, was found to be most effective. The one percent solution was sprayed in order to apply potassium permanganate in amounts of twenty pounds per acre. Jedele and Andrew (46) reported that fifty thousand gallons of liquid manure were rendered odorless by the use of potassium permanganate. The reported cost was nearly as much as that needed to provide continuous operation of an oxidation rotor.

Posselt and Reidies (82) investigated potassium permanganate solutions to determine their effectiveness in the destruction of odors caused by a number of organic and inorganic compounds. Potassium permanganate was shown to be effective for the abatement of esters, mercaptans, phenol and its derivitives, thioacids, and amines. Where the odor intensities were not reduced, often the characteristics were changed from sickening to tolerable or even pleasant smelling. Some gases, including ammonia, had a very slow reaction with the solution.

SODIUM HYDROXIDE

Benham (13) reported that objectionable odors were prevented for 28 days by the addition of sodium hydroxide to a two to one mixture of water and poultry manure. The final concentration was 0.9% by weight. Total aerobic bacteria and coliforms were reduced in numbers.

PHOSPHORIC ACID

Lasalle and Launder (50) reported that poultry manure was immediately deodorized, denatured, and stabilized upon introduction into a weak solution of phosphoric acid. The dilute acid solution was maintained at a pH of 3.5 to 4.0.

HYDROGEN PEROXIDE

Laboratory tests have shown that hydrogen peroxide eliminates atmospheric and sewage hydrogen sulfide at near stoichiometric levels. Field tests were conducted in various parts of the country with the same results. At pH's near neutral, hydrogen peroxide reacts with hydrogen sulfide according to the following formula:

$$H_2O_2 + H_2S \rightarrow 2H_2O + S \text{ (86)}$$

There are also indications that hydrogen peroxide acts as a selective bacteriacide in the case of sulfate reducing bacteria. (34)

NITRATES

McKinney and Conway (62) used laboratory reactors to treat sodium acetate and an industrial waste substrate using nitrates as a source of oxygen. Analysis for ammonia, nitrites, nitrates, and dissolved oxygen showed that the nitrates were completely reduced to nitrogen gas. This reduction took place without any buildup of ammonia, nitrites, or dissolved oxygen. It was shown that of the oxygen atoms available in the nitrate molecule, 2.5 were available for the oxidation of organic matter. There were no odors generated by the nitrate-fed reactor. Hydrogen sulfide in sewers has been controlled with zinc sulfate and sodium nitrate, but the cost has generally been prohibitive (85).

DIGESTIVE DEODORANTS

Deibel (27) tested several digestive deodorants and found them to be ineffective in odor reduction. Of the forty-four formulations of odor control agents tested by Burnett and Dondero (20), the two digestive deodorants were found to be the least effective. Ludington and Sobel (58) reported that of the forty commercially available odor control products evaluated, digestive treatments, i.e. bacterial and enzyme starter cultures, were the least effective.

MASKING AND COUNTERACTING

Wright (108) discussed masking and counteracting as two of five methods proven for the control of odors. Masking is the superimposition of a pleasing odor over an unpleasant odor. Certain factors of importance in the selection of masking agents are that they persist under conditions of use, can be used with moderate strength, and do not cause odor fatigue. The last item was especially important since the loss of perception of one odor will not necessarily result in the loss of perception of the odor being masked. Counteraction is the antagonistic reaction of two or more odorants with the olfactory sensory system causing a reduction in the intensity of both. Potentially toxic compounds should not be treated with masking or counteracting agents since the chemical makeup of the offensive agent is not changed.

Moorman (82) stated that odor counteraction from air or ground spraying gave additional control where housekeeping had not been successful in eliminating odor problems. Satisfactory control of odors from feeding, pens, storage sites, and during manure handling had usually been attained by counteractant systems.

A commercial masking agent was reported to have given good odor control during spreading of poultry manure slurry. Two pints of the agent per 10,000 gallons of waste were added to the slurry. (83)

Burnett and Dondero (20) found that good control of odors from liquid poultry manure was obtained by the use of commercial masking agents. Forty-four formulations of masking agents, counteractants, and deodorants were laboratory tested and rated according to their effectiveness in controlling odors. Masking agents were found to be most effective in control, with counteractants second, and deodorants least effective. Field tests were carried out using the masking agent judged most effective in laboratory tests. Good odor control was attained during spreading. Costs were estimated to be $0.63 per 450 gallons of liquid manure.

Ludington and Sobel (58) reported that forty commercially available odor control products were evaluated by an organoleptic test for the control of odors from liquid manure. No completely satisfactory odor control product was found. Deodorants were moderately effective. The most effective were found to be masking agents and counteractants. Masking agents in oil were spread in thin surface layers on manure collected in pits. Offensive odors were effectively controlled, but as the manure concentration increased, more frequent applications of the control agents were required. Prevention of the formation of odorous compounds was recommended rather than control attempts. A method of manure handling which reduced moisture content was suggested as the best means of preventing odor formation.

AERATION

Ludington (56, 57) studied odor production and degradation of poultry manure with no aeration and excess aeration. The use of ORP for control purposes allowed continuous monitoring of conditions from anaerobic to aerobic. Monitoring of ORP could also readily be incorporated into an automatic system to control aeration.

Chicken manure was stored at ORP's of 0, -150, -300, -400 millivolts, and with no aeration. Manure stored with aeration produced no hydrogen sulfide, while that stored with no aeration produced hydrogen sulfide.

Bloodgood and Robinson (16) found that while dairy cattle manure added to aerobic storage reactors was objectionably odorous, there were no objectional odors from the reactors. A slight "earthy" odor could be detected within a foot of the reactors. It was concluded that the odor problem normally associated with spreading would be alleviated by this type of storage system.

The production of the six principal odorants identified by White (103) were either diminished or eliminated by aeration. The odorants were also diminished or eliminated when the electrode potential was raised by direct electrical current being imposed on the waste. Increasing the pH also reduced odors, but not to as great an extent as raising the electrode potential or aeration.

Barth and Polkowski (11) tested the concept of using a surface aerated faculative lagoon for the storage of dairy cattle waste. The primary purpose of surface aerating the lagoon was to reduce the odors and reduce hazards from hydrogen sulfide and methane production. Effective odor reduction was attained by the use of surface layer aeration. A twenty to twenty-four inch depth of aeration was found to be desirable. The surface layer was maintained with a dissolved oxygen level greater than 1 ppm and a pH greater than 8.

According to Converse, *et al*. (25) a relatively odorless condition, compared to anaerobic digestion, can be attained in liquid hog manure utilizing aeration, but without maintaining a dissolved oxygen residual. The aeration must be used to maintain the oxidation-reduction potential (E_{cal}) between -300 and -340 millivolts and the pH between 7.7 and 8.5. The average air flow required to maintain these conditions was 216 cubic feet per pound of five day BOD.

According to White *et al.* (104), an electrode potential (E_{cal}) of -200 mv was required for the reduction of sulfates. Good methane production required an electrode potential of from -265 mv to -295 mv. The electrode potential was raised by aeration too low to maintain aerobic conditions. Raising the electrode potential decreased odor production.

Ogilvie and Dale (78) reported that short term aeration of dairy cattle manure produced an odorless liquid which could be used for irrigation. Soluble organics were converted to cell material; however, much of the increase was negated by oxidation if the aeration extended beyond twenty hours. Odors were not created by the waste following irrigation.

Moore *et al.* (71) conducted research on the use of an oxidation ditch to treat cattle feeding waste in Minnesota. Based on the waste treatment factor alone, it was considered to be one of the more expensive treatment systems in use today. Odors were not a problem. Larson and Moore (49) stated that the oxidation ditch's role as a management system will be limited to that of collection, partial treatment, and temporary odorless storage. It was anticipated that land disposal will be used for secondary and complete treatment. Results indicated the oxidation ditch's use should be limited to warm confinement units. Jedele and Andrew (46) reported the production of high quality protein for refeeding by the use of an oxidation ditch. The oxidation ditch was also reported to be a proven method for odor control; however, further treatment was required for the overflow.

Mahoney *et al.* (63) found that beef cattle allowed 25 $ft.^2$ on slotted floors had the same rate of feed conversion as those allowed 100 $ft.^2$ on conventional dirt lots. Close confinement offers an improved physical environment, automated feeding, and manure handling and storage with better control of flies and odors.

Clayton and Feng (24) described a system for the reuse of treated effluent for flushing the waste from a dairy barn. The system was designed for a six-month operation without cleanout. After sixty-two weeks of operation, there was only slight odor in the effluent.

DEHYDRATION

According to Ludington (55), odor and dust were the main problems encountered in the operation of a poultry manure dehydration plant. Burning at 1,200° F was recommended for the destruction of the odorous fumes. A heat exchanger was recommended to cut costs since fume incineration was expected to use almost as much fuel as the dehydration process. Scholz (89) reported that odor and dust were controlled in the dehydration process by temperature control and scrubbing the gas through a liquid manure holding and evaporation basin. This also achieved maximum heat utilization.

FILTRATION

Eby and Willson (28) conducted tests of plastic foam filter pads as a means of capturing odor-carrying dusts from force ventilated poultry houses. The pads were effective in the elimination of the characteristic poultry odor, but the odor of ammonia was not abated. This method was deemed impractical because of the short life and high initial cost of the filter material.

Willson (107) related the results of a study on the use of a baffle impingement filter for dust and odor control from force ventilated poultry houses. The filters utilized the natural stickiness of the dust; however, the effects of a water spray ahead of the filters were also determined. Filtering the dust from the air reduced the strength and changed the character of the odor. Complete removal was achieved with the sprays operating until the wash water had been recirculated for a month with a buildup of ammonia in excess of 40 ppm.

COMPOSTING

Willson (106) also reported that no odors were given off from composted dairy cow manure during handling and storing after completion of composting. Dairy manure required a 40% minimum moisture content for composting; however, moisture contents above 55% resulted in anaerobic activity and the generation of malodors. The compost batches usually had strong odors before being turned. When dried compost was used to reduce the initial moisture content to 55%, the odors were substantially reduced. In addition, the ability to attract flies was lost.

RATION MODIFICATION

Nakano (74) found that incorporation of 0.1% to 0.2% by weight of humic acid into chicken feed rendered the manure odorless. Odors were substantially reduced in ten days and virtually eliminated in twenty days. Thirty days were required to obtain similiar results with dogs. Both Bethea (15) and Scarlet (88) discussed the possibility of humic acid being added to the feed ration to prevent odors from cattle feedlots.

Grant (36) conducted experiments with a naturally occurring material similiar to soft coal. Since there appeared to be little doubt that the fecal matter produced by cattle which were fed the material was essentially odor free, the primary purpose of the research was to determine if any harmful residue from the material was retained in the meat of the animal.

Matsuhima (84) discovered that the inclusion of a small amount of sagegrush in feedlot rations eliminated or reduced odors.

Ground sagebrush was added to the rations of three groups of steers at the rates of 0, 1, and 2 pounds per day. No significant difference in feed efficiency was noted. The oils from the sagebrush acted as a bactericide or a bacteriostat on the odor-producing organisms in the animals' digestive tracts.

According to Anthony (3), the refeeding of fecal matter gave the feedlot operator an economic incentive to clean the lot each day. This recycling of unutilized feed material reduced feed costs. In addition, water pollution from feedlot runoff was decreased and odor problems were reduced. Scarlet (88) discussed refeeding of fecal matter and stated that consumer resistance to this practice might develop.

METEOROLOGY

Norstedt and Taiganides (77) developed an air quality model to estimate the potential for odor problems from land-spreading of animal wastes. They considered meteorological control to be potentially effective for reducing odor problems from land spreading operations. The most critical factors in the dispersal of odors were found to be wind speed and diffusion conditions. The consideration of meteoroligical conditions was recommended to minimize odor effects when planning daily manure spreading. The consideration of wind speed and direction especially was recommended.

Sweeten (96) discussed climatic factors in relation to feedlot location and management for odor control. He stated that manure removals should be managed so as to have the least amount on the lot surface when there is the greatest probability for rainfall and temperature effects to create odorous conditions. He further stated that the ideal placement for a feedlot is away from population centers in the wind direction which has the least probability of occurrance, and that odorant concentrations downwind from a feedlot are an inverse function of the wind speed so that when the wind speed is doubled, the concentrations are reduced in half. He also discussed the turbulance and stability conditions and gave the effect of distance on these conditions.

PARAFORMALDEHYDE

Seltzer et al. (91) experimented with the effect of paraformaldehyde on chicken feces. The paraformaldehyde prevented the build-up of ammonia gas for twenty-eight days. The formaldehyde gas which was released also acted as an antimicrobial agent. Manures treated with ten per cent paraformaldehyde retained approximately double the nitrogen and ten times the amount of sulfur as untreated manures. In another test, flies did not deposit eggs in paraformaldehyde treated manure while doing so in untreated control manure.

CHAPTER IV

DISCUSSION OF ODOR CONTROL MEASURES

There are but two basic methods of odor control. These are interference with the olfaction process and reduction in the concentration of the odorant. Our ability to interfere with the olfactory process is limited because of lack of knowledge about how the process works. Masking and counteracting are the only two means at present by which we can interfere with the olfactory process.

Masking and counteracting are two of the three techniques of odor control which can have universal application to confined animal feeding situations. These two techniques of odor control will be discussed together because of their many similarities. Masking agents simply cover one odor with a different, hopefully more desirable, odor. The principle of odor counteraction entails the mixing of two or more odorants in proportions which will result in the reduced detectability of each. Low initial costs, negligible space requirements, and the unestablished need to confine odors in order to treat them are advantages associated with masking and counteracting. Disadvantages result from the fact that odorous molecules are simply commingled with other odorous molecules and the resultant blend may create a more objectionable odor than the original odorous molecules. Odor fatigue, the loss of perception of an odorant, may be created by the odorant used in treatment without a corresponding loss of perception of the odorant being treated. In addition, the odorous molecules may become separated from the masking or counteracting molecules by atmospheric dispersion. Caution should be used to prevent the masking or counteracting of odorants when they are present in toxic concentrations.

Reduction in the concentration of the odorant is the second basic method of odor control. Several basic processes are available to accomplish odorant concentration reduction. Within each process, there may be one or more feasible techniques. Since some materials or actions affect more than one type of process, they will be discussed under the process classification where it is felt the primary effect lies. The basic processes for reduction of odorant concentration are process modification, oxidation, absorption, and adsorption.

PROCESS MODIFICATION

Housekeeping is one of the odor control techniques included in the technique of process modification and is the third technique which can have universal application to confined animal feeding operations. It is one of the primary techniques of odor control practiced by most feedlot operators. Good housekeeping, i.e., clean-up of old feed, prompt removal of dead animals, planned removal of manure, etc., is usually all that is required to effectively control odors except during rainy periods and atmospheric inversions when additional measures may be required. One other aspect of housekeeping, moisture control, deserves discussion. Pens should be sloped to provide good drainage. A commonly recommended slope is about four per cent; however, this should be the minimum with the maximum not exceeding ten per cent. Such slopes will allow excess moisture to move rapidly out of the pen areas and will help prevent sinkholes in which anaerobic conditions can develop. Common grading equipment can be used to reshape the manure pack to achieve these slopes when they are not provided in the feedlot design. The surface should be maintained in a smooth condition. A shallow porous aerobic blanket of loose manure should be about one inch thick and should not exceed two inches in thickness.

While excess moisture results in odor problems, too little moisture results in dust problems and can aggrevate the next period of excess moisture. Only minimum degradation of the manure will have taken place during the dry period; therefore, when the manure is reconstituted, rapid anaerobic degradation will take place. Twenty-five per cent is the minimum moisture content the surface of the feedlot should be allowed to reach while fifty per cent is the maximum desirable moisture content (96).

Orthodichlorobenzene has been used to prevent odors from sewers and waste treatment facilities. Orthodichlorobenzene, in very low concentrations inhibits the growth of sulfate splitting and possibly other types of bacteria; thereby preventing the generation of hydrogen sulfide and other odors. The spraying of orthodichlorobenzene has also been recommended to control feedlot odors (1).

An air quality model has been developed which can be used to evaluate the nuisance potentials from land spreading. (77) A method and an example have been given of how to determine the best direction to locate a feedlot from a population center in relation to wind direction. Methods for determining average wind velocities for a location have been given. Odorant concentrations downwind from a feedlot have been shown to be an inverse function of wind speed so that when the wind speed doubles, the concentration is halved. A nomogram is available for calculating the decrease in odorant concentration with distance downwind from a feedlot (96). Odor intensity appears to vary directly with the humidity. The probability of wind speed, wind direction, precipitation, and frequency of inversion should be considered in planning the location. Statements by Miner (67) and Sobel (93) indicated some odors are psychosomatic in orgin. In other words, people smell what they expect to smell. If an operation gives an attractive, orderly appearance, there is much less chance of odor complaints than if the appearance is unattractive. Trees are suggested as a means of screening feedlots from view when they are located in close proximity to roads or other public access areas. The problem of people's blaming one operation for causing an odor when it is a different operation causing the odor is in the same general category.

Ration modification is a second form of process change which can affect odor production from feedlots. Many feedlot operators have commented that waste from cattle fed other grain is less odorous than the waste from cattle fed milo (99). Also the greater the percentage of nutrients that an animal can extract from the total digestable nutrients consumed, the less nutrients there will be to support bacterial growth. Feed conversion on the basis of total digestable nutrients can be an important factor in the control of feedlot odors. Anthony has authored several papers concerned with the direct refeeding of manure. He (3) developed a systematic plan for harvesting manure and using it in rations for cattle and found that cattle fed manure had average daily gains equal to or better than those fed on manure-free rations. Anthony (4) also discussed the production and feeding of wastelage. Wastelage is a low moisture silage produced from feedlot manure and ground grass hay. In addition, Anthony (5) recovered feed and nutrients from cattle manures by mixing with water. The mixture was dewatered and the solids remaining were used for feed. The wash water was allowed to settle, forming an interface. The layer below the interface was used as a liquid feed for swine or dried and fed to cattle as a solid. Anthony (6) also mixed fecal residue from steers fed a high grain mixture at 40% by weight with a base feed mixture. This mixture was fed to three yearling steers. The animals consumed the feed well and no detrimental symptoms resulted from the feeding. Excellent daily gains and feed conversions were noted. Problems associated with the refeeding of animal manures are consumer acceptance and approval of the appropriate regulatory agencies.

Odor control by the use of feed additives appears to be particularly attractive. Nakano (74) reported that humic acid is effective in the control of odors from poultry and canine manures. "Humic acid has been defined as the alkali-soluble, acid-insoluble fraction of humus, while fulvic acid is the alkali-soluble, acid-soluble fraction" (102). As cattle are ruminants, feed additives which are effective in the control of odors from the fecal matter of animals with simple stomachs, may not be effective in the control of odors from the fecal matter of ruminants. Bethea (15) described a comprehensive research program for evaluating the potential of humic acid as an effective odor control agent in cattle feeding operations. Methods for determining the actual control agent, whether total humic acid or one component, were discussed. Mention was made of the necessity for evaluation of side effects from the feeding of humic acid. According to Grant (36), a naturally occurring material similar to soft coal is a proven odor control feed additive. Research is underway to evaluate side effects. The feeding of sagebrush for odor control purposes is being evaluated at Colorado State University (84). This would be particularly attractive to cattlemen in areas where sagebrush has been a nuisance requiring the expenditure of considerable money and effort for control. Cattle on sagebrush-infested ranges undoubtably consume some sagebrush without apparent ill effects. Sagebrush is also a staple in the diet of wild ruminant species. For these two reasons, sagebrush would not be expected to have an adverse effect on beef animals or leave harmful residues in the meat. Since the Colorado research has already indicated that feed efficiency is not affected by the feeding of up to two pounds of sagebrush per day, it would appear that a plant previously considered to be a range nuisance has a potential for becoming a valuable, but probably low cost, feed supplement with the capabilities of controlling odors.

Housing feeder cattle on slotted floors is not a new idea. Slotted floors were developed to facilate waste handling in areas where animals were already enclosed in shelters as protection against the weather. In areas not requiring this type of protection, slotted floors could be used without enclosure. Flushing by the use of a dosing syphon can be used to transport the waste to a clarification basin for suspended solids removal. The clarified liquid can be aerobically treated to control odors and reused for additional flushing. As an alternative to aerobic treatment, dilute phosphoric acid can be added to the supernatant to deactivate the bacteria, thereby preventing degradation and subsequent production of odors (50). There are many reasons to recommend the use of phosphoric acid. In addition to being completely odorless, the use of phosphoric preserves total nutrient values. The material may be stored in the wet or dry state without loss of nitrogen until the optimum time for soil application. It can be applied on fallow alkali soil without neutralization. If application to a crop is desired, the waste can be neutralized with anhydrous ammonia to provide a high grade fertilizer. Because of the total preservation of nutrients, lighter applications will be required and excessive salt buildup in the soil will not occur. With this type of system there would be no dust, insect, or rodent problems. In addition, the problem of runoff would be negligible. Modifications of this system can be applied to many existing open feedlots with minimum investment.

OXIDATION

Incineration is one process commonly used for odor control by industry. Direct flame combustion, catalytic oxidation, and open flare burning are the typical incineration methods used. In direct flame combustion, odorous gases are fed into an oil or gas fired burner and mixed with sufficient oxygen for combustion. Temperatures required for complete oxidation usually range from 1,000° F to 1,500° F and the retention time required is usually less than one second. Complete oxidation usually results in deodoration; however, partial combustion may increase the odor.

Incineration is too expensive for many industries unless the heat can be recovered and utilized. Much lower temperatures are needed for direct flame burning. The temperature range is usually between 500° F and 1,000° F. Loss of catalytic activity and the costs of furnaces and catalysts are the main drawbacks of this type of system. It is mandatory that the surfaces of catalysts be active since the oxidation takes place on the exposed surface. Metallic vapors and particulate matter in the air stream are the main reasons for loss of catalyst activity. The third method of incineration is open flare burning and is suitable only when highly combustionable gases must be disposed of rapidly (92). Incineration of odorants from cattle feeding operations would require that the feedlots be enclosed. Thus the heating of the large volumes of air necessary for odor control purposes would be uneconomical and would render incineration unsuitable as an odor control measure for feedlot operations (15, 66).

Chemical oxidation of atmospheric odorants is limited to three materials: Alaxol SRM (48), chlorine, and Ozone. The atmospheric catalyst, alaxol SRM, was only reported to be effective for sulfur compounds. Chlorine is highly toxic and corrosive. It would be necessary to maintain very close control of the quantity released during treatment. Reported research does not indicate success where its use for treatment has been attempted. It is felt that the use of chlorine in a feedlot situation is more dangerous and complicated than most operators would be willing to undertake even if successful. Ozone is a powerful oxidizing agent which is rapidly gaining favor for disinfecting and deodorizing wastewaters. The reported use of ozone for deodorization of air is ambigious and contradictory. Excellent results at low cost have been reported by some while poor or no results have been reported by others. The reaction products of ozone oxidation has been reported by Okuno (79). Other researchers have proven theoretically that the deodorization of air by ozonation is impossible. Experiments were conducted in which the theoretical proof was shown to be correct. Hutch et al. (43) Stated that ozone was reported to be effective in odor control because of masking and anesthetizing properties. Bethea (15) discussed the proposed use of ozone to control the odors from a cattle feeding operation. Such an operation would, of course, have to be enclosed. The possibility of the use of ozone to deodorize and stabilize the manure was also discussed. The direct application of ozone to manure for the control of odors was unsuccessfully attempted by Deibel (27). Due to the contkoversy, the only way in which ozonation could be recommended for the control of feedlot odor would be on a performance graranteed basis.

Potassium permanganate, hydrogen peroxide, and some chlorine compounds have the ability to chemically oxidize odorous substances before they are emmitted to the atmosphere. Potassium permanganate is the oxidizing agent most commonly used in feedlot odor control at present. Enough satisfactory results have been reported to indicate that potassium permanganate may be an effective odor control agent when properly applied. Potassium permanganate has been used as an antiseptic as well as an oxidizing agent. Faith (32) has theorized that initial odor reduction is achieved by the rapid oxidation of odorous material and that there is a subsequent alteration of the bacterial population so that odor producing bacteria are inhibited. The manganese dioxide produced by the reaction of potassium permanganate adsorbs partially or unoxidized odorants as an added benefit (92). Manganese dioxide is a black powder which imparts a black color to runoff from treated feedlot and may create a disposal problem of its own. Manganese is an important trace element for most crops, but is toxic in excess concentrations. If manure is applied to the soil, the manganese can be either beneficial or harmful. Expert advice should be sought from a soil scientist as to the maximum quantity which can be applied to cropland without adverse effects.

Hydrogen peroxide is well known as an oxidizing agent and widely thought to be an effective antiseptic. In actuality, its capability as an antiseptic is limited (101). No reported use as a feedlot odor control agent has been discovered. Hydrogen peroxide has been used for the control of hydrogen sulfide at less cost than chlorine, which is more commonly used. Some evidence also exists that hydrogen peroxide acts as a selective bactericide in the case of sulfate reducing bacteria.

Chlorine and many chlorine compounds are also powerful oxidizing and disinfecting agents. Their use in water and waste water treatment is well known. Objections to the use of chlorine have already been cited. Chlorine compounds have been shown to be effective in the control of odors from animal wastes (27, 38). An adverse effect is that chlorine compounds sometimes react with ammonia to release chlorine gas. Chlorine compounds are quite expensive and probably only suitable for the treatment of wet spots.

Oxidation may also be biological. Aerobic biological oxidation results in highly oxidized odorless end products, namely CO_2, H_2O, NO_3^-, $SO_4^=$, and $PO_4^=$. Biological oxidation may take place in either a fluid or a solid bed process. Biological oxidation in fluid beds has commonly been used for the treatment of municipal and industrial sewage. Examples of these processes are oxidation ditches, aerated lagoons, and faculative lagoons. With the exception of oxidation ditches under slotted floors, the use of the fluid bed process use is not directly applicable to the control of odors from the feedlot proper. Transfer of the material to the treatment process in necessary. The oxidation ditch has been reported to be a proven but highly expensive method of odor control (46). Mechanically aerated faculative and aerobic lagoons can be highly effective for odorless storage of runoff from feedlot areas. Effective odor control was attained in a pilot scale test of faculative aerated lagoons (11). Short term aeration has also been reported to be effective. Short aeration has also been shown to prevent odor before, during, and after land spreading where soil surface application was used for final treatment (78).

The solid bed process of biological oxidation is commonly known as composting. Biological oxidation in the form of on-site composting may be one of the ultimate answers to the odor problem in beef cattle feedlots. Feedlot wastes are being composted without odor generation at present. Present lot design is not capable of accommodating composting equipment currently being manufactured. Serious consideration should be given to the accommodation of composting equipment in new feedlot design. With proper moisture control, feedlot cleaning may be almost completely eliminated. The half life of manure volatiles from beef cattle fed a high roughage ration was shown to be four months in environmental chamber tests (61). Shorter half lives can be expected from manures from cattle fed high concentrate rations. Assuming a half life of four months as a conservative figure, less than 2% of the volatile manure components will be left in two years. All the materials which were oxidized to their final degradation products would not be available for microbial decomposition when excess water is received. In addition, the nitrates which are formed become a source of oxygen under anaerobic conditions. Certain bacteria have the capability to utilize the oxygen in nitrates and liberate nitrogen gas. Nitrogen gas, odorless and comprising about 78% of the atmosphere, cannot be considered a pollutant. Chemical feeding of oxygen in the form of nitrates to prevent odors in sewage treatment lagoons has been used for many years. Dissolved oxygen, nitrates, and sulfates are the sources of oxygen used in biological oxidation in the order of preference. Sulfates will not reduce to sulfides as long as dissolved oxygen or nitrates are present (62). Any form of nitrate except ammonium nitrate is satisfactory; however, sodium nitrate has adverse effects upon the soil. Digestive deodorants, i.e. enzymes, starter cultures, etc, are advertised as having the capability to control odors. However, three researchers reported them to be ineffective (27, 58, 71).

ADSORPTION

To some degree, any vapor or gas will adhere to a solid surface at ambient or lower temperatures. This is a mechanical, not a chemical process and is called adsorption. While there are some specific use adsorbents, activated carbon is the only practical one for the control of odors. Because activated carbon is non-polar, it adsorbs vapors and organic gases in preference to water. There is, however, a high installation cost for activated carbon filters. Economics often limit their use to gas streams containing less than 5 ppm of odorant material unless product recovery is involved (92). Sawatani (87) considered activated carbon adsorption to be too expensive for the control of animal waste odors. Bethea (15), however, felt that activated carbon adsorption could be an effective and economical method of control.

Chemically impregnated adsorbents can also be used to destroy odorous material. Oxidizing agents or catalysts can be impregnated on activated carbon or other material. This can be surface impregnation as the reaction takes place on the surface. Various catalysts can be impregnated to provide a continuously oxidative absorbent. Some catalysts provide intermittent operation. When the absorbing capacity of the activated carbon is depleted, the carbon is heated to provide a catalytic surface oxidation of the pollutant (92).

At least one type of soil is capable of adsorbing some sulfur compounds (37). The only practical use of soil as an adsorbent for manure odors at the present is when the manure has been placed beneath the soil in some type of land application process. Adsorption may then be an effective economical means of controlling cattle feedlot odors provided the feedlots are enclosed.

ABSORPTION

Absorption may be a practical odor control process when odorous substances are soluble, emulsiable, or capable of reacting chemically. The most common form of absorption is scrubbing. Water is the easiest liquid to use in a washer or scrubber, but unfortunately, many of the odorous manure gases have limited solubility in water. Even ammonia, which is readily soluble in neutral or acid waters, soon reaches a saturation concentration. The addition of oxidizing reagents to water forms effective absorbing solutions. Chlorine dioxide, chlorine, sodium hypochlorite, lime water, and potassium permanganate are possible reactive scrubbing reagents (109). Reactive scrubbing should give easily removable non-odorous complexes, or inert precipitates which are disposed of easily. (15)

Another variation of absorption to remove ammonia is paraformaldehyde. Ammonia reaction has long been used in the chemical industry for the destruction of waste formaldehyde. Paraformaldehyde combines with ammonia to form hexamethylenetetramine, a low volatile, odorless solid. Paraformaldehyde also reacts with urea. The products of this reaction are many and varied and depend on the relative concentrations of the two reactants. All reaction products break down more slowly than urea. It is not known whether amines enter into reaction with formaldehyde, but the formation of secondary amines is inhibited. Paraformaldehyde also alters the bacterial composition of the manure and prevents loss of sulfur. An added benefit is that flies do not breed in paraformaldehyde treated manure (91). Appropriate government agencies have not approved the use of paraformaldehyde in actual contact with food animals. The use of absorptants in the control of feedlot odors is then limited to the control of odors from enclosed feeding areas, or from manure not in contact with the animals.

SUMMARY OF FEASIBLE TECHNIQUES

Despite the many techniques available for controlling odors, only a limited number have applicability for odor control in conventional open feedlots. Housekeeping, consisting of planned removal of manure, prompt removal of dead animals, effective control of moisture, etc., is and must remain the primary means of control if satisfactory odor levels are to be economically maintained. Meteorological control, within its limitations, can be expected to be effective in open lot control. Masking and counteracting can be expected to have only limited effectiveness. Ration modification, while desirable from many aspects, is still in the experimental stage. Chemical oxidation, by the use of potassium permanganate, hydrogen peroxide, and chlorine compounds, may prove to be effective. Biological oxidation may also be an effective odor control technique. The application of orthodichlorobenzene to the manure pack also appears to have potential for odor control.

CHAPTER V

EXPERIMENTATION

On the basis of the literature search, personal experience, and other considerations, seven materials were selected for testing. The seven materials were potassium permanganate, potassium nitrate, paraformaldehyde, hydrogen peroxide, Ozene, Formula 2, and a digestive deodorant. These materials were felt to have a high probability of modifying the production of odorous gases. Lime and chlorine compounds were excluded from the tests because adequate information on their effects was already available. The optimum conditions for the production of odorous gases are a fairly deep accumulation of manure with moisture conditions equal to that of a slurry.

DESCRIPTION

The method of Narayan (76), modified by the substitution of nitrogen gas for purified air, was used to simulate the optimum conditions for the production of odorous gases. Fresh manure was collected from a minimum of three animals. After mixing, 500 grams of the manure was slurried in 2 liters of water in a 5 liter bottle. Nitrogen, a non-reactive gas, was bubbled through this mixture at a low rate for 72 hours. This provided a mild stirring action. The volatile gases produced from the manure were swept by the nitrogen through a selective absorption system which trapped and concentrated the odorous gases. The selective absorption system of Merkel *et al*. (65) was modified by using a cadium hydroxide suspension for the absorption of hydrogen sulfide (45). The selective absorbents used and the gases absorbed are given in Table III. The selective absorbents were then colorimetrically analyzed to determine whether the various classes of odorous gases were present. The reaction and absorption system is shown schematically in Figure 1.

TABLE III

ABSORBENT	GASES ABSORBED
1.2N Hydrochloric Acid	Amines, Ammonia
Cadium Hydroxide Suspension	Hydrogen Sulfide
3% w/v Mercuric Chloride	Disulfides
4% w/v Mercuric Cyanide	Mercaptans

Preliminary testing showed that all classes of odorous gases, except hydrogen sulfide, were present in detectable quantities at the end of a 24 hour reaction period. Further testing showed hydrogen sulfide was produced in 48 hours about half the time and was always produced in 72 hours.

To verify that the same gases were produced without the addition of moisture, the 500 grams of manure was distributed on four pieces of screen wire in the reaction vessel. Nitrogen gas, saturated with water vapor, was introduced at the bottom of the reaction chamber and allowed to sweep upward around the manure. The off gases were selectively absorbed as previously outlined. The same gases were found to be present from this solid manure as from the liquid manure.

During the preliminary testing, propylene glycol was used in a fifth gas washer to selectively absorb alcohols and carbonyls. When the fifth trap was disconnected, it was noticed that the gaseous effluent was not odorous and no complaints were received from other people working in the room. Upon disconnecting one or

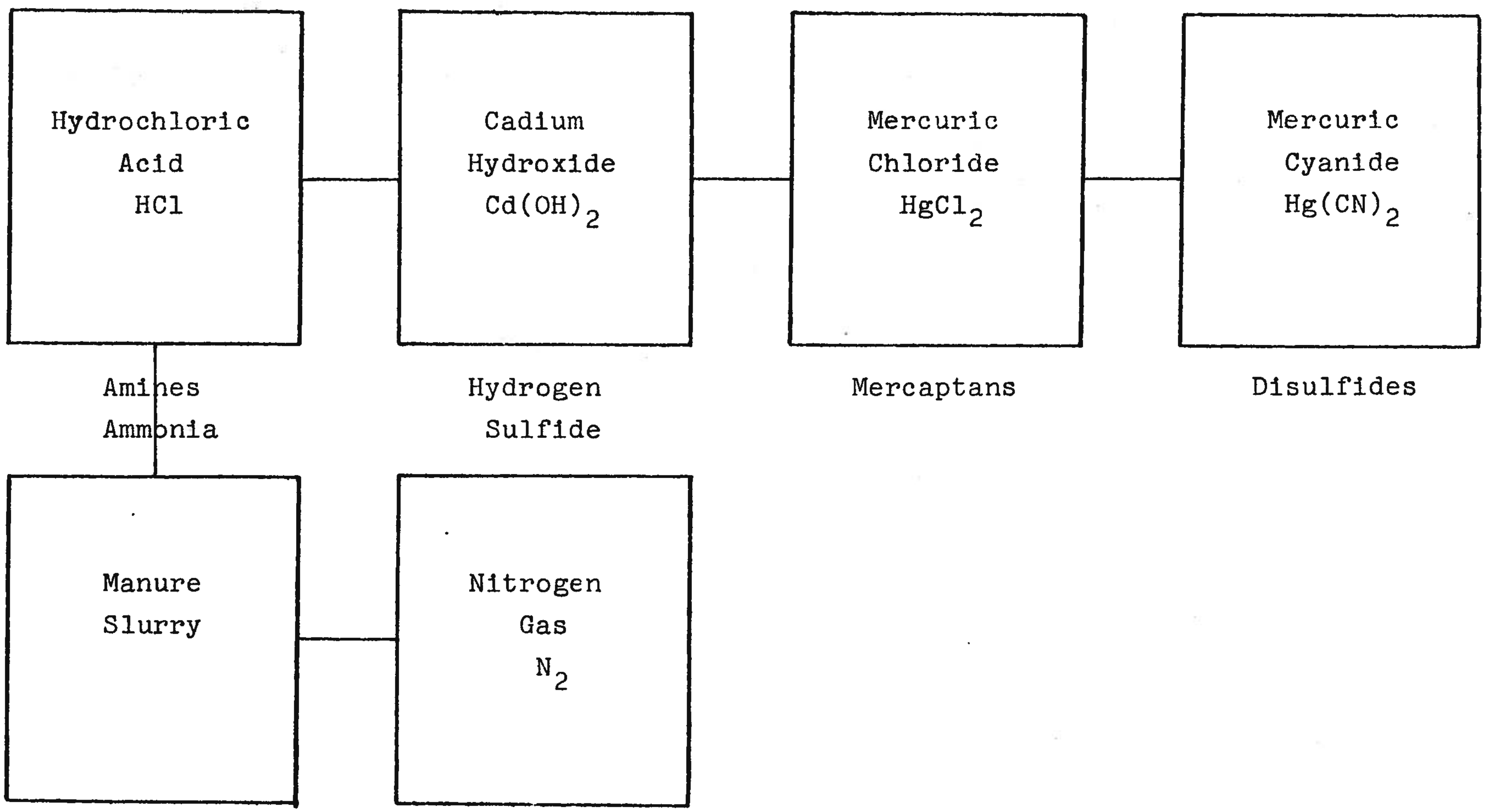

Figure 1.--Reaction and absorption system

more additional traps, obnoxious odors were noticed immediately, and complaints were received from other personnel working in the room. After further experimentation, alcohols and carbonyls were concluded to be unimportant in feedlot odors and their absorption was discontinued.

Following the procedural testing, qualification testing of the seven materials was carried out. One hundred grams of solid, or one hundred milliliters of liquid, test material was added to the manure slurry. If favorable results were obtained in the qualification testing, the amount of test material was successively halved for further testing.

DATA

Tables IV through XI give the colorimeter readings obtained from the selective absorbents from the slurry experiments. Included are experiments in which various quantities of the test material were added to the manure slurries, and control experiments in which no test material was added to the manure slurries. Transmittance of above 90% indicates that none of the gas tested for was present in detectable quantities, even after the 72 hour concentration periods. As the quantity of gas which has been absorbed increases, the per cent transmittance decreases.

TABLE IV

POTASSIUM PERMANGANATE

Quantity (grams)	100	50	20	10	5
ABSORBENT	PER CENT TRANSMITTANCE				
Hydrochloric Acid	98	95	91	84	93
Cadium Hydroxide	100	98	97	98	100
Mercuric Chloride	95	96	99	100	98
Mercuric Cyanide	100	99	97	98	100

TABLE V

POTASSIUM NITRATE

Quantity (grams)	100	50	25	10	5
ABSORBENT	PER CENT TRANSMITTANCE				
Hydrochloric Acid	100	95	82	79	85
Cadium Hydroxide	100	100	96	99	100
Mercuric Chloride	97	98	100	98	99
Mercuric Cyanide	100	96	100	98	100

TABLE VI

PARAFORMALDEHYDE

Quantity (grams)	100	50	25	10	5
ABSORBENT	PER CENT TRANSMITTANCE				
Hydrochloric Acid	100	96	61	77	65
Cadium Hydroxide	100	97	97	98	97
Mercuric Chloride	98	95	100	100	99
Mercuric Cyanide	100	97	99	97	100

TABLE VII

HYDROGEN PEROXIDE

Quantity (milliliters)	100	50	20	10	5
ABSORBENT	PER CENT TRANSMITTANCE				
Hydrochloric Acid	100	89	12	87	91
Cadium Hydroxide	100	93	94	100	100
Mercuric Chloride	99	88	98	97	96
Mercuric Cyanide	97	91	95	98	100

TABLE VIII

ORTHODICHLOROBENZENE (OZENE)

Quantity (milliliters)	100	50	20	10	5
ABSORBENT	PER CENT TRANSMITTANCE				
Hydrochloric Acid	100	80	90	72	92
Cadium Hydroxide	98	97	100	100	100
Mercuric Chloride	100	98	98	100	99
Mercuric Cyanide	100	97	100	99	100

TABLE IX

FORMULA 2

Quantity (milliliters)	100	50	20	10	5
ABSORBENT	PER CENT TRANSMITTANCE				
Hydrochloric Acid	45	56	5	20	16
Cadium Hydroxide	90	98	90	96	98
Mercuric Chloride	94	96	99	100	95
Mercuric Cyanide	92	100	96	95	100

TABLE X

DIGESTIVE DEODORANT

Quantity (milliliters)	100
ABSORBENT	PER CENT TRANSMITTANCE
Hydrochloric Acid	27
Cadium Hydroxide	4
Mercuric Chloride	20
Mercuric Cyanide	32

TABLE XI

CONTROL

ABSORBENT	PER CENT TRANSMITTANCE			
Hydrochloric Acid	18	31	24	38
Cadium Hydroxide	52	60	60	65
Mercuric Chloride	35	43	33	48
Mercuric Cyanide	37	41	41	44

DESCRIPTION

Because complaints about odors are the results of the sense of smell, the human nose is the ultimate judge as to the effectiveness of an odor control method. For this reason, the organoleptic test described by Sobel (93) was used for further evaluation of the odor control materials. This test consists of zero to ten rating scales for both presence and offensiveness of odors. The members of the odor panel were also asked to describe the odor. Several possible terms which might be used for the description were listed, or a term of the panelist's choice could be used. Sample instruction and data sheets are shown in Figures 2 and 3.

Manure was collected from a concrete surfaced feedlot. The manure on the lot was approximately 2 inches deep. Since it had previously rained for several days, the manure for the first test was in a fairly wet condition. After mixing, 2 pounds were placed in each of nine cans, forming a 2 inch deep layer. Paper sacks, with the same number and size of holes punched in them, were used to cover the cans to prevent visual prejudice of the panelists. Potassium permanganate, paraformaldehyde, Ozene, and the digestive deodorant were applied at previously recommended rates. Hydrogen peroxide and potassium nitrate were applied at rates equivalent to the cost of the potassium permanganate. Formula 2 was arbitrarily

Rate the samples as to the presence of odors and the odors as to offensiveness according to the following scale using sample "0" as having an 0 rating.

Presence				Offensiveness
No Odor	-	0	-	No Offensive Odor
		1		
Very Faint	-	2	-	Very Faint Offensive Odor
		3		
Faint	-	4	-	Faint Offensive Odor
		5		
Definite	-	6	-	Definite Offensive Odor
		7		
Strong	-	8	-	Strong Offensive Odor
		9		
Very Strong	-	10	-	Very Strong Offensive Odor

Describe the odor of each sample by giving an appropriate descriptive term. Possible terms that might be used are given in the list below or you may use a term of your choice which you feel properly describes the odor.

mold, musty	earth
fish	yeast
stagnant water	ammonia
sulfide, rotten eggs	grain, feed
petroleum	sour, fermented
sweet, carmel	rotten cabbage, mercaptans

Figure 2.--Instruction sheet

Study ______________________ Name ______________________

Day ______________________ Date ______________________

PRESENCE RATING	OFFENSIVENESS RATING	SAMPLE	ODOR DESCRIPTION
___	___	1	____________
___	___	2	____________
___	___	3	____________
___	___	4	____________
___	___	5	____________
___	___	6	____________
___	___	7	____________
___	___	8	____________
___	___	9	____________
___	___	10	____________

Thank you for your time

Figure 3.--Rating sheet

applied at the same rate as the digestive deodorant. Except for hydrogen peroxide and paraformaldehyde, the odor control materials were applied by spray in a 1% water solution. The hydrogen peroxide was applied without dilution, and the paraformaldehyde flakes were simply sprinkled on the surface of the manure. Application rates and costs are given in Table XII. The unit costs of the materials, while believed to be realistic, are subject to price fluctuations. The per acre rates were considered as one treatment unit and are so referred to in further discussion in this report. Panel members were drawn from personnel in the Agricultural Engineering Building. Panelists were not screened, but some were eliminated for lack of perception. Each panel consisted of a minimum of ten people. The same people were used as panelists whenever possible.

TABLE XII

MATERIAL	QUANTITY PER ACRE	UNIT COST	COST
Potassium Permanganate	20.0 lb.	$1.54/lb.	$ 30.80
Potassium Nitrate	20.0 lb.	1.54/lb.	30.80
Paraformaldehyde	2,178.0 lb.	0.50/lb.	1,078.11
Ozene	3.0 gal.	3.38/gal.	10.12
Hydrogen Peroxide, 10%	12.4 gal.	2.48/gal.	30.80
Formula 2	5.9 gal.	5.95/gal.	35.10
Digestive Deodorant	5.9 gal.	unknown	-----

Following the placement of manure in the cans, one-fourth inch of water and one treatment unit of test material was applied to the manure. Approximately twenty-four hours later, the odor panel conducted the first evaluation. An additional treatment unit of test material was applied, except for the paraformaldehyde. After another 24 hour period, the odor panel again conducted an evaluation. Five days later, the manure in each can was mixed and, except for the paraformaldehyde, three treatment units of test material were applied. The odor panel again conducted an evaluation one day later. As controls, two of the nine cans had no test material added to them and one can containing clean wet sand was used as a check.

DATA

Table XIII shows the odor panelists' evaluations for presence and offensiveness of odors during the organoleptic tests. Responses between panelists were highly variable. Individual responses as to presence and offensiveness generally paralleled each other. Table XIV is a tabulation of the most frequently used descriptive terms for each treatment.

TABLE XIII

AVERAGE VALUES FOR PRESENCE AND OFFENSIVENESS

	TEST I		TEST II		TEST III	
	P.	O.	P.	O.	P.	O.
Potassium Permanganate	3.1	3.3	3.3	3.4	2.7	2.7
Potassium Nitrate	2.5	2.6	3.9	3.9	4.7	4.2
Paraformaldehyde	3.3	3.2	5.1	5.0	2.7	2.6
Hydrogen Peroxide	3.6	3.6	3.0	3.0	4.6	4.5
Ozene	5.4	6.0	2.9	3.4	3.0	2.9
Formula 2	6.2	6.2	5.1	5.1	4.4	4.4
Digestive Deodorant	4.1	4.5	3.0	3.1	4.6	4.1
Control A	4.1	4.5	4.0	3.8	4.4	4.4
Control B	4.7	5.1	4.9	4.2	4.2	4.2

P = Presence O = Offensiveness

TABLE XIV

MOST FREQUENTLY USED DESCRIPTIVE TERMS

Treatment	Sour, Fermented	Musty, Mold	Yeast	Sulfur Compound Rotten Cabbage or Eggs	Sweet	Rotten	Stagnant Water	Ammonia
Potassium Permanganate	9	4	3	1	3	0	3	1
Potassium Nitrate	13	3	3	2	1	2	1	1
Paraformaldehyde	8	4	5	2	3	2	1	1
Hydrogen Peroxide	13	2	3	1	0	1	1	1
Ozene	8	4	1	3	4	1	2	2
Formula 2	15	3	2	2	0	2	1	3
Digestive Deodorant	12	8	2	2	0	0	2	1
Control A	12	4	3	1	0	4	1	2
Control B	13	4	2	5	2	1	0	0

CHAPTER VI

ANALYSIS AND DISCUSSION OF RESULTS

The slurry experiments showed that six of the seven materials tested, favorably altered the release of odorous gases. All six of these materials suppressed the release of sulfurous compounds at all levels tested. The materials had varying capabilities for suppressing the release of amines and ammonia. The data for amines and ammonia was plotted as shown in Figures 4 through 9.

The quantity of odor control agent was plotted as the abscissa and the per cent transmittance was plotted as the ordinate. The per cent transmittance was then linearly regressed on the amount of odor control material according to the method of least squares. (53) The estimated regression equation used is as follows:

$$Y_x = a + b(x - \bar{x})$$

with Y_x the estimated average value of the transmittance for any quantity of odor control material applied; a is the arithmetic mean of the values of transmittance; x is any amount of odor control material, and $\bar{x}$ is the average of odor control material. The estimate of b is given by the equation

$$b = \frac{\Sigma(x - \bar{x})(y - \bar{y})}{\Sigma(x - \bar{x})^2}.$$

The details of the calculation for potassium permanganate are shown in Table XV.

TABLE XV

LEAST SQUARES CALCULATION

x	y	$x-\bar{x}$	$(x-\bar{x})^2$	$y-\bar{y}$	$(x-\bar{x})(y-\bar{y})$
5	93	-32	1,024	.8	-25.6
10	84	-27	729	-8.2	221.4
20	91	-17	289	-1.2	20.4
50	95	13	169	2.8	36.4
100	98	63	3,969	5.8	365.4
Σ185	461	0	6,180	0	618.0

$$\bar{x} = \frac{\Sigma x}{n} = \frac{185}{5} = 37$$

$$a = \bar{y} = \frac{\Sigma y}{n} = \frac{461}{5} = 92.2$$

$$b = \frac{\Sigma(x-\bar{x})(y-\bar{y})}{\Sigma(x-\bar{x})^2} = \frac{618}{6,180} = .1$$

$$\begin{aligned} Y_x &= a + b(x-\bar{x}) \\ &= 92.2 = .1(x - 37) \\ &= .1x + 88.5 \end{aligned}$$

This equation and those developed for the other materials which suppressed the release of odorous gases were then plotted on Figures 4 through 9. The point where the line represented by the equation crosses the 90% transmittance line is the estimate of the average amount of odor control material to totally suppress the release of nitrogenous and sulfurous gases.

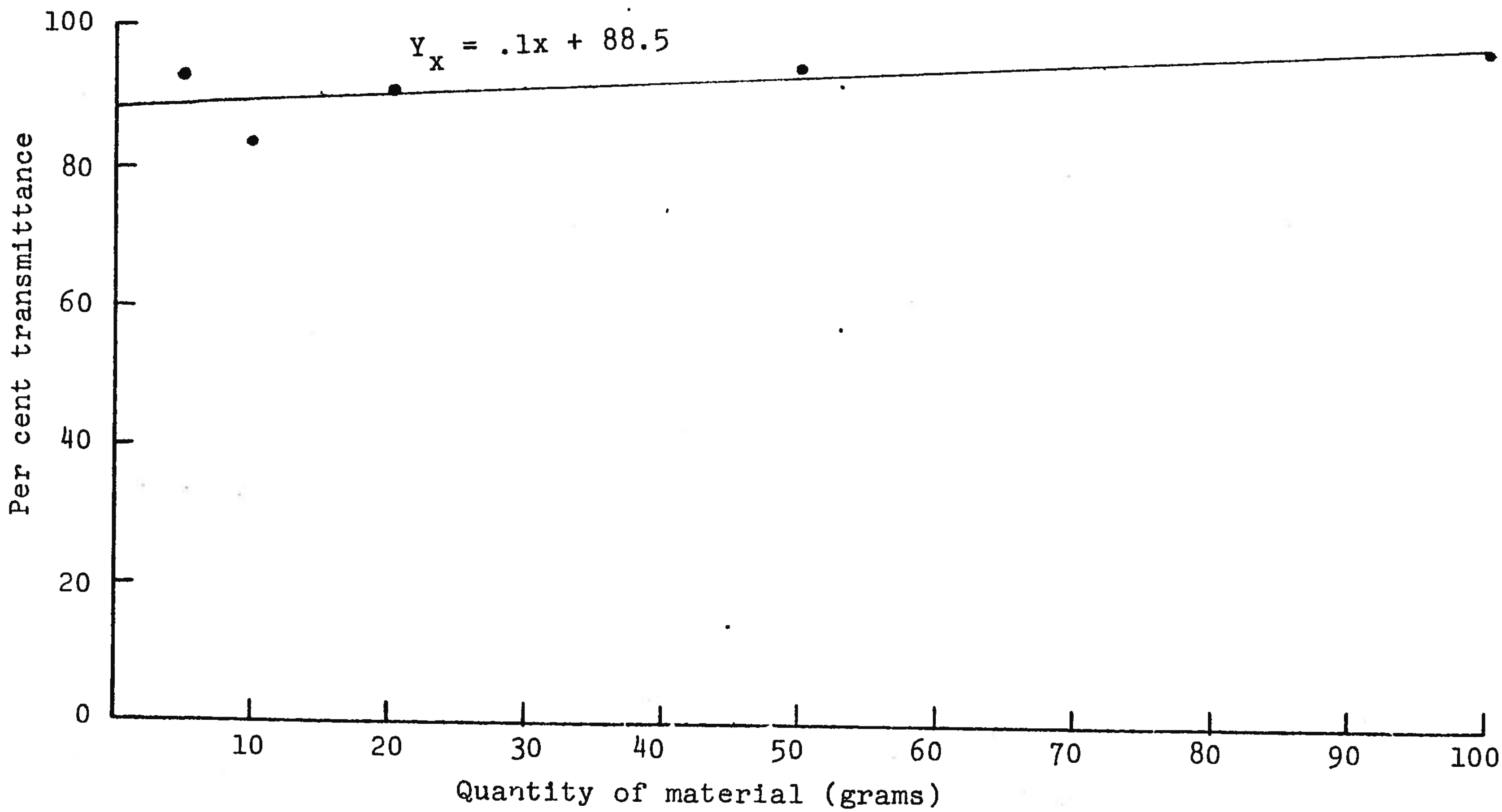

Figure 4.--Potassium permanganate

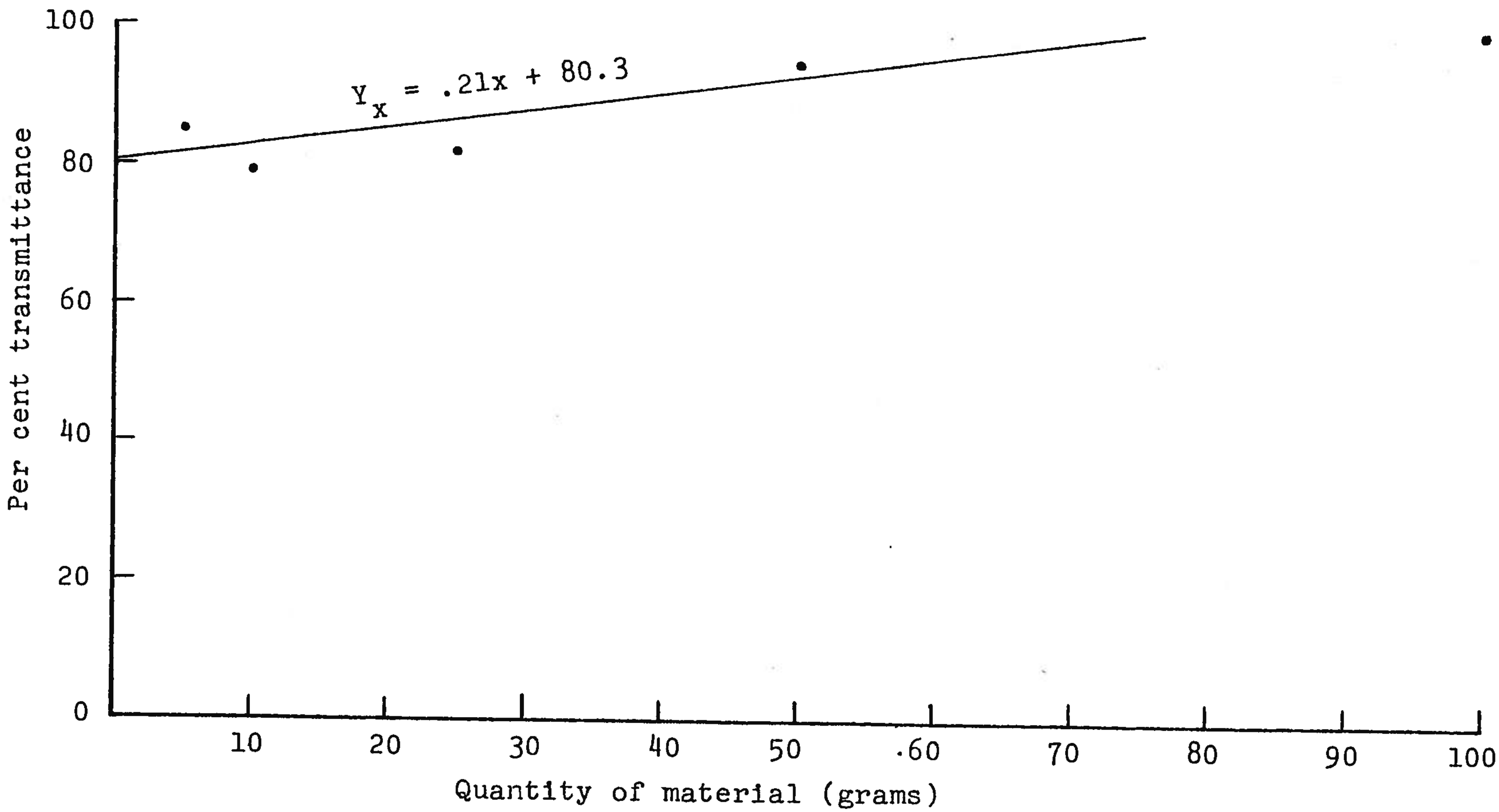

Figure 5.--Potassium nitrate

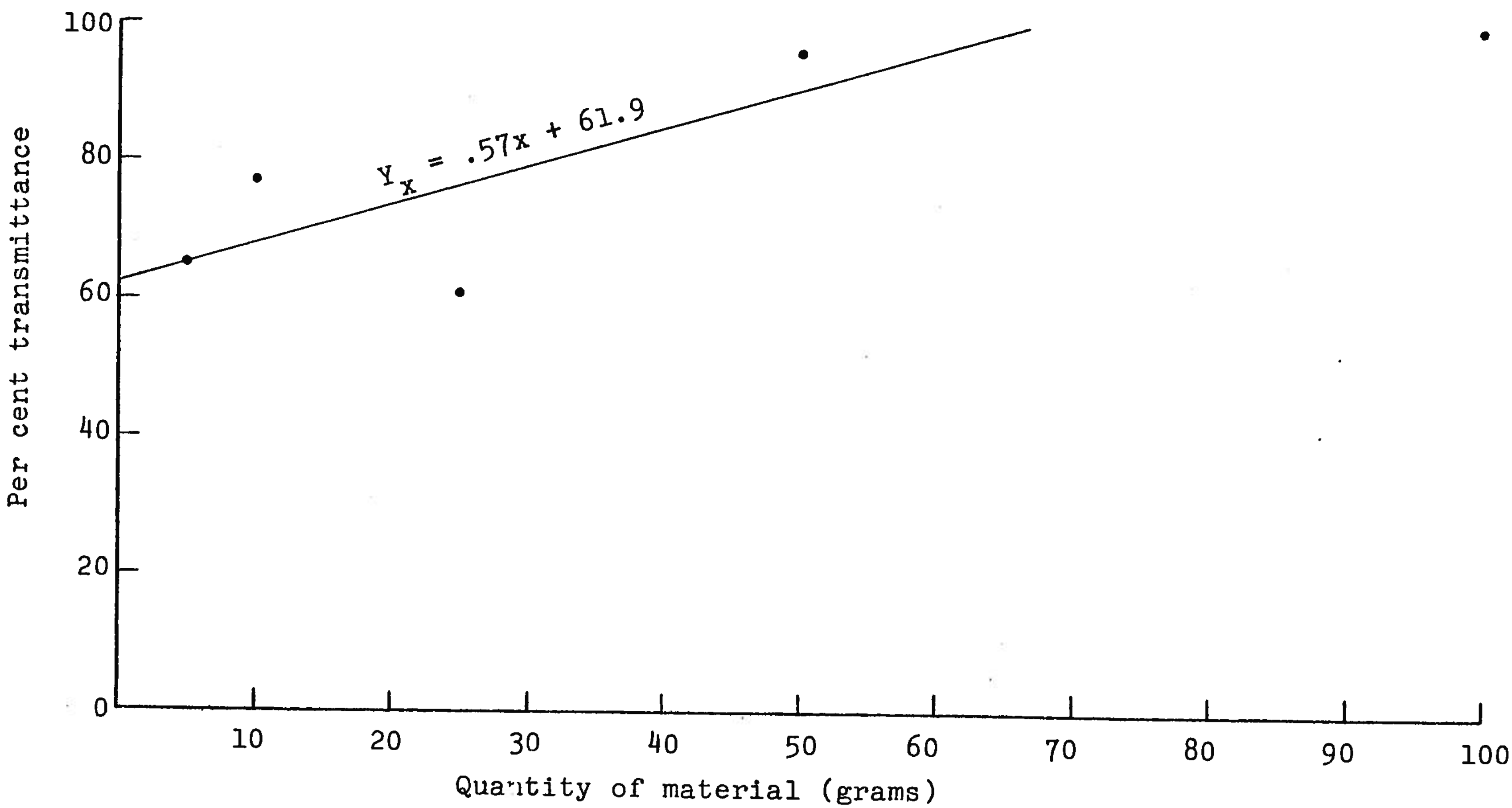

Figure 6.--Paraformaldehyde

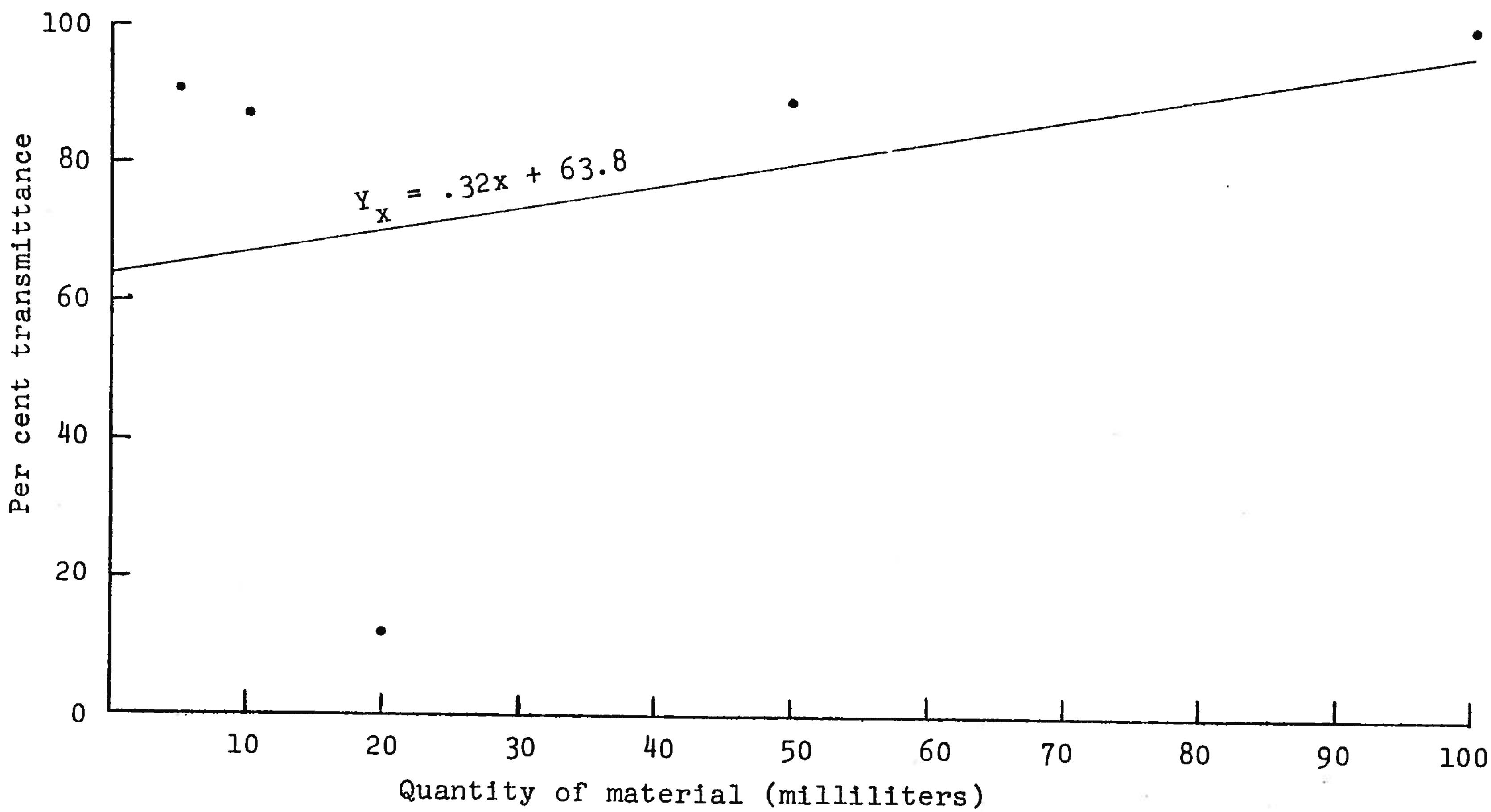

Figure 7.--Hydrogen peroxide

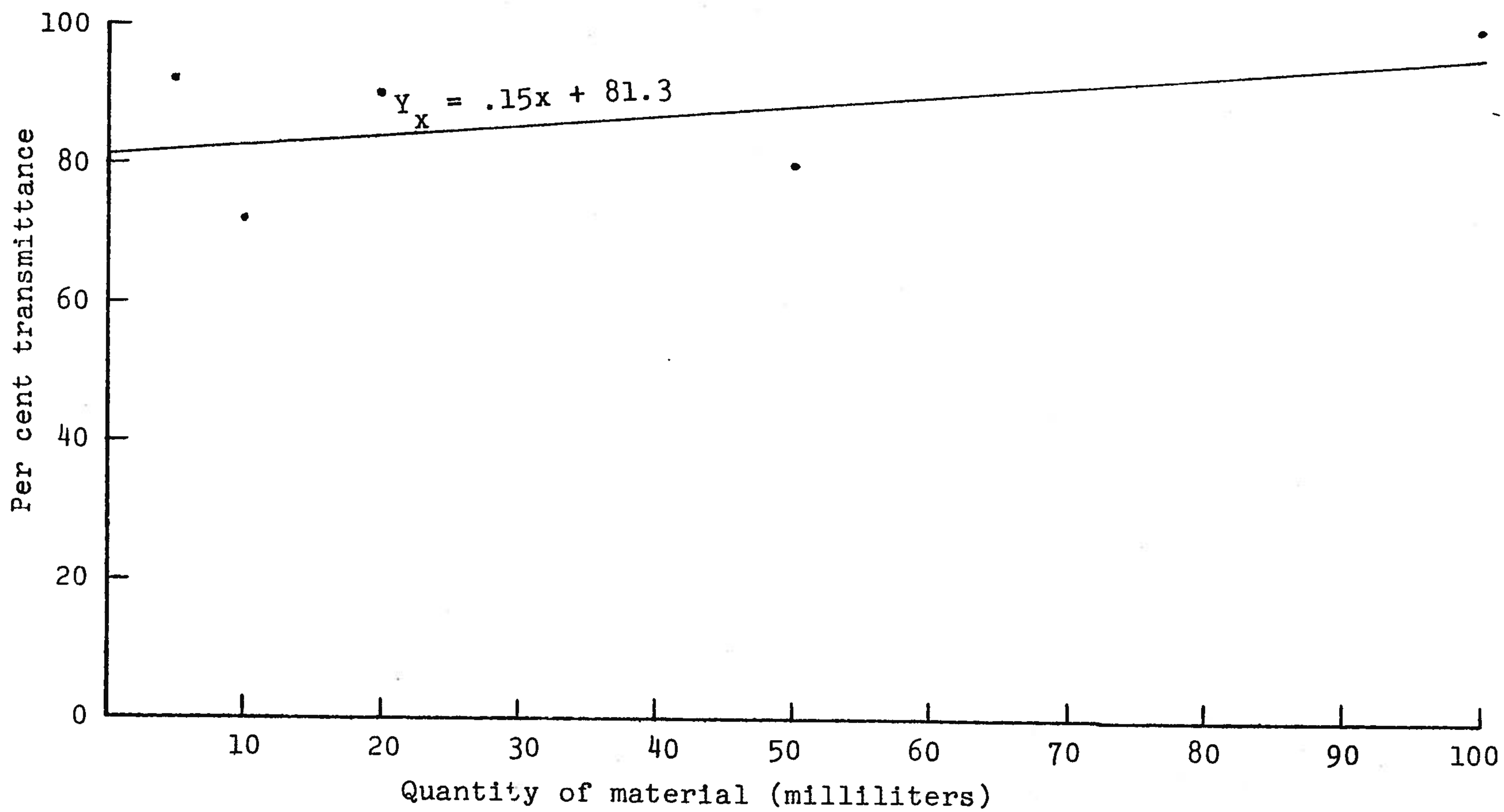

Figure 8.--Ozene

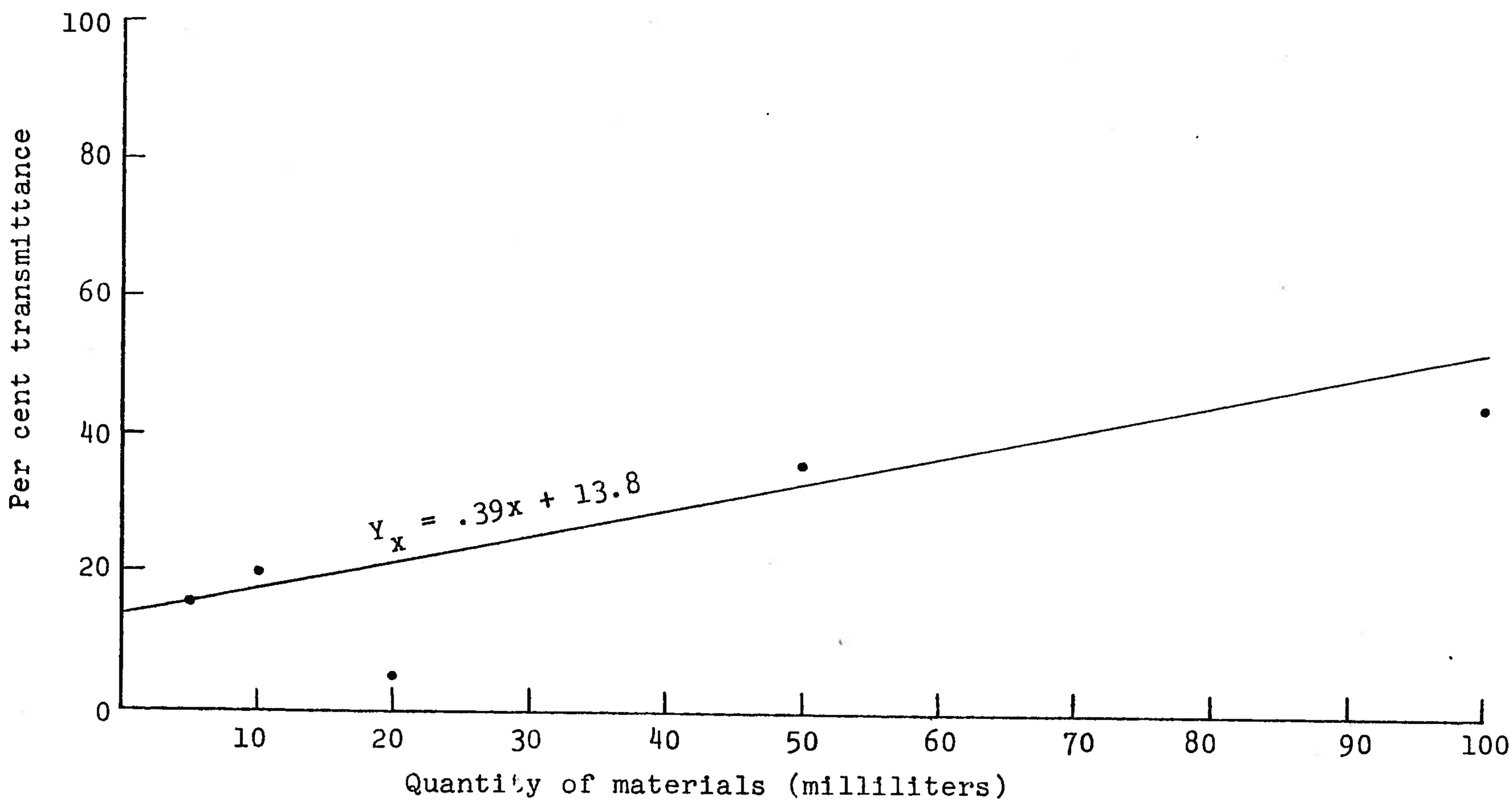

Figure 9.--Formula 2

POTASSIUM PERMANGANATE

Potassium permanganate was found to be the most economical of the seven materials considered in these tests for totally suppressing the release of the important malodorous gases. Potassium permanganate suppressed the release of sulfurous gases at all levels in the slurry experiment tests. The quantity of potassium permanganate required to totally supress the release of the important malodorous gases was estimated to be 14 grams per 500 grams, or 56 pounds of potassium permanganate per ton of manure. The cost for this quantity of potassium permanganate would have been $86.24. While this was the least cost of any material considered in these tests, it was still judged to be excessive by present day standards. Organoleptic testing showed that potassium permanganate was effective in the reduction of malodors in much lower quantities than required for their elimination. The panelists' average ratings for presence and offensiveness for manure treated with potassium permanganate was 3.0 and 3.1. These were lower average ratings than achieved by the other test materials. Potassium permanganate was judged to be effective in the control of cattle feedlot odors when applied at the rate of twenty pounds per acre in a 1% water solution. At current prices, the cost for this application was estimated to be $30.80; however, this is 1.5 times the cost to achieve comparable results with Ozene.

POTASSIUM NITRATE

Potassium nitrate was estimated to be a much more expensive method of odor control than potassium permanganate or Ozene. Potassium nitrate suppressed the release of sulfurous gases at all levels in the slurry experiments. The quantity of potassium nitrate to totally suppress the release of the important malodorous gases was estimated to be 38 grams per 500 grams, or 152 pounds of potassium nitrate per ton of manure. The cost for this quantity of potassium nitrate would have been $234.08, which is 2.7 times the cost to achieve comparable results with potassium permanganate.

Organoleptic testing did not indicate effectiveness at the levels tested. While the panelists' evaluation for presence and offensiveness during the first test was lower than that for the other materials under test; the panelists' reaponses indicated an increase in both presence and offensiveness with time.

PARAFORMALDEHYDE

Paraformaldehyde was estimated to be a slightly more expensive technique of totally suppressing the release of the important malodorous gases than potassium permanganate. Paraformaldehyde suppressed the release of sulfurous gases at all levels in the slurry experiments. The quantity of paraformaldehyde to totally suppress the release of the important malodorous gases was estimated to be 49 grams per 500 grams, or 197 pounds of paraformaldehyde per ton of manure. The cost for this amount of paraformaldehyde would have been $97.71, which is 1.1 times the cost to achieve equivalent results with potassium permanganate. Organoleptic evaluations were somewhat ambigious, but did not indicate effectiveness under the conditions of the test.

HYDROGEN PEROXIDE

Hydrogen peroxide, 3% weight per volume, was estimated to be a more expensive means of totally suppressing the release of the important malodorous gases than potassium permanganate. Hydrogen peroxide suppressed the release of sulfurous gases at all levels in the slurry experiments. The quantity of hydrogen peroxide to totally supress the release of the important malodorous gases was estimated to be 82 milliliters per 500 grams, or 39.3 gallons of hydrogen peroxide per ton of manure. The estimated cost for this quantity of hydrogen peroxide would have been $97.46, or 1.1 times the cost to attain equivalent results with potassium permanganate. Organoleptic evaluations were somewhat ambigious, but did not indicate effectiveness at the level tested.

OZENE

Ozene, the brand name of a formulation of orthodichlorobenzene, was estimated to be a slightly more expensive method of totally suppressing the release of the important malodorous gases than potassium permanganate. Ozene suppressed the release of sulfurous gases at all levels in the slurry experiments. The quantity of Ozene to totally suppress the release of the important malodorous gases was estimated to be 60 milliliters per 500 grams, or 28.8 gallons per ton of manure. The cost for this amount of Ozene would have been $97.00, or 1.1 times the cost to attain equivalent results with potassium permanganate. Organoleptic testing showed that Ozene was effective in the reduction of malodors in much lower concentrations than required for thier elimination. The panelists' average rating for presence and offensiveness of manure treated with one treatment unit of Ozene did not indicate effectiveness. The addition of a second treatment unit achieved good control. The estimated cost for two treatment units of Ozene was $20.24.

FORMULA 2

Formula 2 was estimated to be a very expensive method of odor control. Formula 2 suppressed the release of sulfurous compounds at all levels in the slurry experiments. The quantity of Formula 2 to totally suppress the release of the important malodorous gases was estimated to be 193 milliliters per 500 grams of manure, or 92.5 gallons of Formula 2 per ton of manure. The cost for this quantity of Formula 2 would have been $550.38, or 6.4 times the cost to achieve equivalent results with potassium permanganate. Organoleptic testing did not indicate effectiveness at the levels tested. The panelists' average rating for presence and offensiveness of manure treated with Formula 2 exceeded that for manure receiving no treatment. Panelists' responses, however, indicated a decrease in both presence and offensiveness with an increase in time and the concentration of Formula 2.

DIGESTIVE DEODORANT

The digestive deodorant, i.e. bacterial enzyme culture, when applied to the manure slurry did not prevent the release of any of the malodorous gases for which tests were conducted. Some gases were produced in larger quantities than when no odor control material was applied to the manure. Organoleptic testing did not indicate effectiveness.

CHAPTER VII

SUMMARY AND RECOMMENDATIONS

SUMMARY

The literature review indicated different authors obtained a variety of results from common treatments. The manure age appeared to be a prominent factor in this discrepency; therefore, laboratory experimentation and evaluation became a necessity. Samples of 500 grams of manure under simulated feedlot conditions were used for this purpose. Preliminary tests confirmed the previously reported detection of all classes of odorous gases except hydrogen sulfide within 24 hours. Further tests revealed hydrogen sulfide detection within 72 hours.

Based on several considerations, 7 control materials were selected for testing. After satisfactory procedural testing, qualification testing of the 7 materials was carried out. One hundred grams of solid, or one hundred milliliters of liquid, test material was added to the manure slurry. If favorable results were obtained in the qualification testing, the amount of test material was successively halved for further testing.

The human nose is the most effective means of detecting odors. For this reason, an organoleptic test was used for further evaluation of the odor control materials. Each panel conducting the test consisted of a minimum of 10 people. The same people were used as a panel whenever possible.

The evaluations indicated that six of the seven materials considered in the tests suppressed the release of sulfurous compounds at all levels tested. The six materials, however, showed varying capabilities to suppress the release of amines and ammonia. Two of the materials were effective in the reduction of malodors in much lower concentrations than required for their elimination.

Potassium permanganate and Ozene were judged to be the most economical of the seven materials considered in the tests to totally suppress the release of the important odorous gases. In addition, both were effective in the reduction of the odors in much lower concentrations than required for their elimination. Potassium permanganate and Ozene were estimated to significantly reduce malodors when sprayed in a 1% water solution at rates of 20 pounds and 6 gallons per acre reapectively. The estimated costs of these applications were $30.80 and $20.24 per acre.

Hydrogen peroxide, paraformaldehyde, potassium nitrate, and Formula 2 were judged to be more expensive means of totally suppressing the release of the important malodorous gases. In addition, organoleptic testing did not indicate effectiveness at the levels tested.

The digestive deodorant was not found to prevent the release of any of the malodorous gases for which tests were conducted. Some gases were produced in larger quantities than when no odor control material was applied to the manure. Organoleptic testing did not indicate effectiveness.

Sulfurous compounds, amines, and possibly ammonia were shown to be important components of cattle feedlot odors. Both liquid and solid manures were found to produce the same classes of odorous gases. Housekeeping, combined with the application of odor control material when necessary, was judged to be an economically feasible method of controlling feedlot odors. Potassium permanganate and Ozene were found to be the most economical odor control materials considered in these tests.

RECOMMENDATIONS

The importance of good housekeeping cannot be over stressed if satisfactory feedlot odor levels are to be maintained at reasonable costs. Waste feed, particularly in a wet condition, should be cleaned up and disposed of immediately. Dead animals should be disposed of at least daily. If a feedlot appears to be an attractive, orderly, and efficient operation, there is much less chance of complaints about odors than if the appearance is unattractive. Trees and other shrubbery can be used to screen a feedlot to improve appearances, particularly when a feedlot abuts a road or other public access area.

Pen cleaning should be done on a scheduled basis. The schedule should be based on the average meteorological conditions of wind speed and direction which offer the best probability for the dispersion of odors. The ideal period between manure removals appears to be less than a week. Such a schedule would rarely, if ever, be practical for conventional open feedlots. If pens cannot be cleaned on a weekly basis or less, there is probably no benefit to cleaning them more than 2 times a year on the Great Plains. Theoretically, the twice yearly cleaning should take place before the summer months when rainfall and temperature generate maximum levels of odor and the winter months when evaporation is at a minimum. If, however, experience has shown there are worse odor problems at other times of the year, the pen cleaning should take place before these times. When practical, only the surface, aerobic layer of manure should be removed.

Moisture control is probably the most important aspect of housekeeping. A shallow, porous, aerobic blanket of loose manure, less than two inches thick, should be maintained on the lot surface at all times except during or immediately following rains. Beneath this blanket, the manure pack should be firm and well consolidated, thereby forming a barrier to the deep penetration of moisture. The moisture content of the blanket should be maintained between 25% and 50% whenever possible. Stockage rates and pen cleaning should be adjusted to maintain these conditions if necessary. During long, hot, dry periods, it may become necessary to add supplemental moisture to maintain these conditions and prevent dust. The pens should be sloped to provide good drainage and the lot surface should be maintained in a smooth condition. The minimum slope should be 4% and the maximum should not exceed 10%. These slopes will help prevent the development of surface depressions where moisture can collect and anaerobic conditions can develop. Where adequate slopes have not been provided for in the feedlot design, common grading equipment can be used to reshape the manure pack to achieve rapid movement of excess moisture out of the pen area. If it is desirable to improve footing during rainy periods, fibrous material such as stalks or straw can be added to the surface of the manure pack. The fibrous material inproves aerobic degradation by providing air passageways in addition to binding the manure pack together. The overflow of water troughs must be prevented. Broken water lines must be repaired immediately and wet manure removed if a boggy condition has developed.

Odors from runoff holding ponds can be controlled by the settling out of solids in sedimentation basins or channels upstream of the main retention pond. The ponds should be dewatered as soon as practical. Additional odor control can be attained by the use of chemicals or aeration. If it is necessary to stockpile manure, the stockpiles should be constructed in long narrow rows. Access lanes for trucks and other equipment should be left between the rows. Stockpiling of this type readily allows for fire control and the use of composting equipment. The stockpiles must be located in a well drained area with the sides sloped and the top crowned.

During rainy periods, potassium permanganate or Ozene* can be applied to achieve additional odor control. These materials should be sprayed on the manure in a 1% water solution. The spray must neither contact the animals nor contaminate the feed and water. Twenty pounds of potassium permanganate should be applied per acre. The estimated per acre cost of material for this application is $30.80. Six gallons of Ozene should be applied per acre. The estimated per acre cost of material for this application is $20.24. Potassium permanganate and Ozene should not be applied together. In a related experiment, it was found that the potassium permanganate oxidized the Ozene. If it is desired to apply both, the potassium permanganate should be applied forst with a minimum time lapse of 24 hours before application of the Ozene. A week should elapse following the application of Ozene before applying potassium permanganate.

If these recommendations are followed, it is believed that satisfactory odor levels can be maintained at reasonable costs.

*Ozene is the brand name of a particular formulation of orthodichlorobenzene. The use of the brand name in this report is no endorsement of this formulation as being more or less effective than formulations by other manufacturers, but is simply the formulation with which this research was conducted.

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