EVALUATION OF ODOR-REDUCING COMMERCIAL PRODUCTS FOR ANIMAL WASTE

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(ABSTRACT)

Six odor-reducing commercial products were tested for their efficacy in reducing odors from dairy and swine wastes. A sensory panel method was utilized for odor evaluations, in which the panel played an important part. Comparisons between products were made for agitated and unagitated conditions and effect of storage time (three weeks in which experiments were performed). Cotton pieces tied to the mouth of the sample jars were useful in absorbing the odors. Odor-treated jars were observed and evaluated by panel members. The odors were rated on a discrete scale of 0-5, with ‘0’ being no odor and ‘5’ the highest odor level of dairy or swine waste.

The products were analyzed for their effectiveness on dairy and swine wastes separately. The “General Linear Model” was used for data analyses, and all the products were compared for their effectiveness under each waste storage condition and elapsed storage time.

Each product was able to reduce odors. For both dairy and swine wastes, one product stood out and was very effective, whereas another product was less successful. Unagitated storage conditions of swine waste favored the product performance. Unagitated storage conditions were also found to be better for most of the products; only two products were slightly better in effectiveness under agitated storage conditions. The effect of storage time on product-effectiveness for each product for both dairy and swine waste varied. Odor levels from unagitated swine waste was very low in the beginning, but became worse with increasing storage time. Dairy waste in unagitated conditions had slightly higher levels of odors in the beginning, but became a little less with increasing storage time.

Under the conditions of this study, it can be recommended that: 1) P2 has a better chance in reducing odors, 2) in general, unagitated conditions favor the reduction in odor levels, and 3) dairy waste should be treated in the first few days following collection, whereas swine waste should be treated when it is old. Testing of these products in actual field conditions would provide stronger support for these findings.

ABSTRACT

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1 INTRODUCTION

Most modern livestock operations concentrate animals together, to reduce cost of production. In North Carolina, 10,000 hogs in a single operation are common. Similarly in Texas, 50,000-100,000 beef cattle, in a single feedlot are not unusual (Meadows, 1995). In the same study, it was reported that a single broiler chicken farm in Arkansas could have as many as 400,000 birds. These operations can very often be found near the processing plants, to keep the cost of transportation low. The result is concentration of large number of animals in very small areas. Meadows (1995) reported that in North Carolina, 80% of the total hogs are concentrated in about 700 swine operations, which is only 10% of the total swine farms in the state. This concentration is responsible for large amounts of manure generated in relatively small areas. According to the same report, 46.5 million dairy and beef cattle in the U.S. produce 500 million tons of waste, annually. Sixty million hogs, and 7.5 billion chickens and turkeys produce 100 million tons and 300 million tons of wastes, respectively (Meadows, 1995). The collection, storage, transportation, treatment and disposal of manure are major causes of odor problems from these units. An increase in public awareness about emissions from the animal production units is making the problem of odor more noticeable. This has resulted in many lawsuits against animal producers (Miner and Stroh, 1976). According to Pain (1994), 4000 odor related complaints from farms are reported each year in Wales, England.

The sensation of odor is subjective and thus varies from person to person. Exposure to unpleasant odors can be a serious threat to the sense of well being (NRC, 1979). Malodors can cause nausea, headache, loss in appetite and sleep, irritation of the eyes and nose, and other health related concerns. Researchers claim that presence of malodors can cause erratic behaviors in animals and can effect their behavior pattern.

In animal housing, the odorous gases are evolved from freshly deposited or stored manure and urine. Liquid manure handling systems (LMHS) are popular for the collection and storage of manure as the handling of manure is easy (White et al, 1971). However, LMHS create more odor-related problems than solid waste handling systems.

The National Research Council (1979) has suggested three main principles for odor control: 1) control of volatile compounds, 2) inhibition of anaerobic decomposition, and 3) physical confinements of odors. Treating animal waste with chemical additives is one way of dealing with odors from stored manure that conforms with the first principles of odor control. Low cost and ease of application has made them of interest to animal producers (Li et al, 1996).

Many studies have been done in the past, and are going on at present, to test the efficacy of these chemical additives. The results have been mixed and mostly unsatisfactory. A study by Muehling (1979) proved all 22 tested products a failure. However, efforts to make these odor control products more and more effective are constantly in progress, and manufacturers are now claiming that their products are more effective, environmental-friendly, affordable, and safe.

1.1 OBJECTIVES

This study was conducted to test six odor-reducing commercial products (ORCP). The objective was to observe the following:

1. Effectiveness of the products on dairy and swine wastes;

2. Effectiveness of the products on agitated and unagitated waste conditions; and

3. Effect of storage time on the effectiveness of the products.

2 REVIEW OF LITERATURE

2.1 PHYSIOLOGICAL AND PSYCHOLOGICAL REACTIONS TO MALODORS

Malodorous compounds from animal buildings and feedlots usually are accompanied with irritants, allergic substance, bacteria, and other pathogens (Cone and Shusterman, 1991). Such odorous compounds can affect the state of well being in humans as well as in animals (NRC, 1979).

The sense of smell triggers when the molecules of the odorous compounds get trapped in the nasal mucous overlaying the olfactory epithelium. These molecules then make contact with the olfactory receptor cells (Shusterman, 1992). The olfactory nerve that mediates odor perception penetrates the cribriform plate, which separates the cranial cavity from the nasal cavity and also gives rise to bilateral patches of the olfactory epithelium (Shusterman, 1992). The trigeminal or the fifth cranial nerve helps in recognizing irritation or pungency in both taste and smell (Shusterman, 1992). The trigeminal system mediates many protective responses to chemical irritants.

Many unfavorable responses may be caused by exposure to malodors. These may include nausea, headaches, disturbed sleep, shallow breathing, loss in appetite, irritation of nose eyes and throat, and many more (NRC, 1979). A reduction of respiratory rates along with rhinitis, lacrimation, and cough were reported in experimental animals (Shusterman, 1992). In humans, development of bronchoconstriction due to exposure to lower respiratory tract irritants, were reported. It was also found that individuals with bronchial asthma are highly susceptible to odors (Shusterman, 1992). Prolonged exposure to irritants at high levels may cause the development of tracheobronchitis, chemical pneumonitis, or non-cardiogenic pulmonary edema (Shusterman, 1992). The National Research Council (1979) claims that some odorous compounds cause decrease in heart rate, blood vessel constriction, and alteration in the size of cells in the olfactory bulbs present in the brain. It was found that, when constantly exposed to a single odorant for a long period of time, morphology of some cells in the olfactory bulbs of rats was altered. However this change was reversible (NRC, 1979). Many methods of performance measurement have been proposed as indicators of annoyance.

In a study conducted at the Duke University Medical Center, it was established that moods of people living downwind from hog operations was adversely affected (Meadows, 1995). People working in these environments are most at risk, as they constantly breathe dust from waste and feed. They are prone to asthma, bronchitis and even chronic pulmonary diseases (Meadows, 1995).

2.2 ENVIRONMENTAL IMPACT

There is another adverse effect of livestock waste, which is less understood. This includes effects of global warming and atmospheric deposition of nitrogen, (Meadows, 1995). Large amounts of greenhouse gases are evolved from animal waste lagoons. Ammonia is also evolved from livestock waste, which volatilizes into the environment from the lagoon surface or from the spraying of waste onto fields (Meadows, 1995).

2.3 *ODOR REGULATION*

Regulations for pollution exist both at state and federal levels. At the federal level, responsibility to enforce laws lies with the Environmental Protection Agency (EPA). Minimal pollution tolerance levels are set by the EPA, which the states must enforce. If the states fail to comply with the EPA standards the federal government takes the role of regulating pollution for them (Levi and Matthews, 1977). States can develop more strict regulations, that can be above the minimal tolerance level set by the EPA, (Levi and Matthews, 1977).

The Common Law

Odor nuisance is defined as 'odor emissions at such concentrations and duration, that may cause any interference whatsoever with the normal usage or enjoyment of any property' (Sweeten and Akabani, 1994). Nuisance law varies from state to state, and generally takes two types of liabilities into consideration, namely 'Private' and 'Public' nuisance (NRC, 1979). A private nuisance related to odor is one in which rights of few people are violated. In this case, lawsuits between private parties are usually enforceable (Sweeten and Akabani, 1994). Since the precedent William Aldred's Case in 1611, which was the first recorded odor related case in the court of law private-nuisance actions about odors have taken an important place in common law (NRC, 1979). To make a case related to private nuisance, the plaintiffs must establish that there is an interference with her/his use of land due to malodors for which the defendant is responsible (NRC, 1979). The plaintiffs must show causality, but there is no need to show negligence or recklessness on the defendant's part (NRC, 1979). A person with too sensitive sense of smell can find very small concentration of odors offensive, so nuisances of this kind must be judged by the standards of the ordinary and normal sense of smell. The plaintiffs must balance their interests against those of the defendant's. To make an effective case, plaintiffs must show that her interests are more at risk (NRC, 1979).

Public nuisance is created when rights of all members of public are invaded. Many difficulties encountered in the cases of private nuisance are avoided in public nuisance litigation, and they work as a powerful tool for odor regulation. Public authorities can take actions in cases of public nuisance. Private parties need not expend their resources for this purpose. To claim offense through public nuisance litigation, it is required must be proven that genuine public rights have been violated, not merely rights of large number of individuals. On the other hand, it is not necessary to show that the whole community has suffered, but that interference with the exercise of public rights is present (NRC, 1979).

Odor Standards

The Tenth Amendment of the United States Constitution provides the states with the power of regulating any environmental pollution (Bermberg, 1994). In general this amendment empowers the states to "regulate within constitutional limits, private conduct and occupation for the promotion of order, safety, health, morals and general welfare" (Bermberg, 1994). When dealing with the regulation of odors, all the states encounter the same fundamental question: "What is an acceptable level of odor emission?" As defined by Cone and Shusterman (1991), "odor free air is the air, which is passed through a drying agent followed by two successive beds of activated carbon." The Environmental Protection Agency (EPA) of the United States has no federal standards for odors in particular, and the 1990 Federal Clean Air Act does not deal with odors

(Sweeten and Akabani, 1994). However, Section 108(a)(1), of the Clean Air Act puts forward three conditions for listing pollutants that will be subject to federal ambient standards. Any pollutant must be listed if it lies in any one of the following categories (NRC, 1979):

- The emission of the pollutant is either the cause of air pollution or is contributing to it;
- It is imposing some threat to the public health and welfare;
- It's presence in the ambient air must result from numerous or diverse mobile or stationary sources and/or;
- The administrator decides that an regulating air-quality criterion for any particular pollutant is a must, even if the other two conditions are met.

After a particular pollutant is added to this list, the air-quality criteria must be issued within one year (NRC, 1979). Under section 109(a)(2), of the Clean Air Act, these criteria should be accompanied by national primary and secondary ambient air quality standards for a pollutant. These standards are considered uniform nationwide by the EPA (NRC, 1979). Primary standards are those which have an adequate margin of safety to protect public health, and are established on the basis of administrators' judgement. Secondary standards are set at levels that are required to protect public welfare from any known or expected harmful impact that can be caused by the presence of such pollutants in the ambient air (NRC, 1979). This act indicates establishment of federal standards for a pollutants at the discretion of federal government (NRC, 1979).

The Environmental Protection Agency has also set emission standards for regulating specific industries, and mostly these emission standards are devised for sulfurous gas emission (Shusterman, 1992). In San-Francisco Bay area, the local authorities have established emission standards for five types of chemicals, namely di-methylsulfide, ammonia, mercaptans, phenolic compounds and trimethylamines.

Some states have established ambient air quality standards, for the purpose of regulating odorant exposures (Shusterman, 1992). In California, the abatement of odor nuisance does not necessarily require any proof of lasting physiological impairment among residents of the affected area. The state has adopted a per-hour ambient air quality standard for hydrogen sulfide (0.03 ppm). This level is based on the assumption that H_2S becomes annoying to at least 40% of the population at five times its mean odor detection threshold (Shusterman, 1992). In another study Shusterman (1992) found that a concentration of 0.0001-ppm (0.14 µg/m3) caused headaches, upper respiratory tract irritation, eye irritation, and nausea and that 0.00001-ppm of various mercaptans also caused these symptoms.

Right to Farm Statutes

In the later part of the 1980's, 'right-to-farm' statutes were passed (McNitt and Pratt, 1996). These laws protect agricultural operations against legal nuisance actions, except in limited circumstances. Most of the Right to Farm Statutes were guided by the Idaho legislature; this legislative act is as follows (McNitt and Pratt, 1996):

> "The legislature finds that agricultural activities conducted on farmland in urbanizing areas are often subjected to nuisance lawsuits, and that such suits encourage and even force the premature removal of the lands from agricultural uses, and in some cases prohibit investment in agriculture improvements. It is the intent of the legislature to reduce the loss to the state of its agricultural operations those may be deemed to be a nuisance,"

This legislation then went on to protect certain agricultural activities from lawsuits, by the following provision:

> "No agricultural operation shall be or become a nuisance, private or public, by any changed condition in or about the surrounding nonagricultural activities after the same has been in operation for more than one year, when the operation was not a nuisance at the time the operation began; provided, that the provision of this section shall not apply whenever a nuisance results from the improper and negligent operation of any agricultural operation-----," (McNitt and Pratt, 1996).

Texas also too passed a law that narrows the possibilities of lawsuits. This law states that:

> "No nuisance actions may be brought against an agricultural operation that has lawfully been in operation for one year or more, prior to the date on which the action is brought, if the conditions or circumstances complained of as constituting the basis for the nuisance action have existed substantially unchanged since the established date of operation. This subsection does not

restrict or impede the authority of this state to protect the public health, safety and welfare-------," (McNitt and Pratt, 1996).

"The right to farm statutes reduce the chances of any jurisdiction for odor related conflicts. Most typically these statutes provide restriction of initiation of lawsuits only to circumstances where a significant change occurs in an operation, or there is negligence or breaking of the law. These statutes allow suits against operations which are in existence for less than a year" (McNitt and Pratt, 1996).

2.4 NORTH CAROLINA SCENARIO

The hog industry of North Carolina tripled in size from 1991 to 1995, and was reported by Meadows (1995) to be the fastest growing in the country. In 1994, the state was reported to be raising about 7 million pigs, second only to Iowa (Vukina et al, 1996).

Meadows (1995) reported that, according to the 'Swine Odor Task Force' North Carolina, spraying of wastes causes the fine particles to drift through air, spreading odor to greater distances. North Carolina has more odor problems and stricter odor regulation than any other state. The following sections describe how this state resolves the odor complaints.

Negotiation

When a dispute arises between a farmer and neighboring landowners, it is settled through direct negotiation. These disputes can be settled if the parties agree to change the siting, modify the operations improve management practices or offer some compensation. For example, in Harnett

County, NC, fifteen livestock companies agreed upon siting swine and poultry operations (Vukina et al, 1995). In order to maintain a balance between the farming operations and the non-farming population of the state, a memorandum of understanding (MOU) was implemented in January 1993. According to this MOU, new swine operations and waste treatment facilities must be at least 1000 feet away from any residential, public or business areas (Vukina et al, 1995). After a year most farmers had acted according to the guidelines in the MOU (Vukina et al 1995).

Litigation

If the settlement cannot be reached in an informal fashion, the party affected can file a nuisance lawsuit to resolve the issue (Vukina et al, 1995). "Nuisance Law" is based on the principle of 'reasonableness.' The Supreme Court of North Carolina defines 'reasonableness' as a "question of fact to be determined in each case by weighing the gravity of the harm to the plaintiff, against the utility of the conduct of the defendant." This is the premise of nuisance law, and accordingly all property owners have a right to use and enjoy their property reasonably. If any property owner is found to be using her/his property in a manner that adversely affects, the reasonable use of neighboring owner property, then the affected party has the right to sue for monetary damages and an injunction to stop the objectionable activities. If the offending property is not located in an appropriate area or if the maintenance or operation is not proper, the nuisance law can be pursued (Vukina et al, 1996).

If the plaintiffs are successful in their suit, they may receive equitable relief, compensations for damages, or a combination of the both (Vukina et al, 1996). Monetary damages are also very common as compensation in private nuisance suits. Damage is calculated according to the permanence of the nuisance; a temporary nuisance is one that can be corrected at a reasonable cost, whereas a permanent nuisance involves low damages compared to the cost of abatement (Vukina et al, 1996). In the case of a permanent nuisance, the defendant can buy her/his rights to continue with the activities by paying for the damages to the plaintiff (Vukina et al, 1996).

To protect the state from the loss of its agricultural resources through nuisance laws, North Carolina also implemented the "Right to Farm Statutes." This limits the circumstances under which agricultural operations can be considered to be a nuisance (Vukina et al, 1996). Right to Farm Statutes of North Carolina establishes that the agricultural operations in existence for over a year cannot become a nuisance because of changes in the locality (Vukina et al, 1996). This law also prohibits local government officials, from enacting ordinances that would otherwise classify these operations as nuisances. However, this law does not protect new operations, or operations which create nuisance out of negligence (Vukina et al, 1996).

Regulation

Safety and health laws attempt to limit workers exposure to certain gases like ammonia, which are present in swine wastes (Vukina et al, 1996). These regulations do not help the neighbors with their complaints. Federal and state environmental laws in the state do not regulate the problem of odor from swine facilities, directly. In 1992, North Carolina adopted new regulations provided by the state's Environmental Management Commission. Hog operations with more than 250 animals in a confined facility are now required to register with the Division of Environmental Management (Vukina et al, 1996). In addition owners of these facilities must file and implement an approved waste management plan by the end of 1997. The same is true with operations with other animals too, but the threshold for the number of animals differs from species to species (Vukina et al, 1996).

The Swine Farm Siting Act, passed by the house requires new swine facilities to be located at least 1,500 feet from any residential area; 2,500 feet from any school, hospital or church; and 100 feet from the boundary of any property (Vukina et al, 1996).

2.5. ODOR REGULATIONS IN OTHER STATES

Since 1972, odor has been regulated in Texas by the Texas Air Control Board, now a part of Texas Natural Resource Conservation Commission (Sweeten and Akabani, 1994). Under the Texas Clean Air Act, building new cattle feedlot for more than 1000 animal units requires a construction permit. The rule also applies when an existing feedlot is to be expanded (Sweeten and Akabani, 1994). Obtaining a construction permit involves review of site suitability, design, and methods to reduce odor and particulate emission. The Texas Natural Resource Conservation Commission issues a construction permit on the basis of an application that includes a description of the facility from an engineering point of view, odor emissions, and waste management facilities and control methods (Sweeten and Akabani, 1994). In additions to this, residents of the nearby area (where the construction is proposed) are informed and given a chance to review the situation and comment (Sweeten and Akabani, 1994). After the construction is complete, the operator must apply for the operating permit, which is issued only when there is a successful implementation of odor control practices, mentioned in the construction permit (Sweeten and Akabani, 1994).

2.6 ODOR SOURCES

In a livestock operation, the odor sources vary they may come from feed materials, fresh manure and/or stored manure. Pain (1994) has described three major sources of odor production: 1) Land-Application of Waste, 2) Livestock Buildings and 3) Waste Storage Facilities.

Odors from land application of wastes can be generated during the spreading of waste is done, and after the waste is land applied. Waste is applied to fields by machines that spray it in liquid form, and slurry droplets may be thrown high in the air in aerosol form. These aerosols often carry odor to long distances from the field. In England, emissions from this source are the most common, and cause most complaints (Pain, 1994). According to Pain (1994), odor concentrations were measured between 1059 and 2020 odor units/m^3 for cattle and pig waste, respectively. Measurements were based on the air samples collected from behind the plume of slurry while waste was being land-applied. The concentration of odor from this type of operation is very much dependent on the speed and size of the tanker and ambient wind speed on the day of application. Pain (1994) discovered that in the first hour after the waste was land-applied, the highest concentrations of odor are experienced. The concentrations drop rapidly to much lower levels, and then persist for 36 to 60 hours (Pain, 1994). The change in odor concentrations usually follows an exponential decay curve, as high odor emissions drop down to very low levels within a small duration of time (Pain, 1994). Odors from pig slurry are reportedly to be more offensive than those from cattle. The other factor, effecting odor is extraction of slurry from the bottom of the storage tank. Odor emissions are higher from slurry extracted from the bottom of the tank since volatile fatty acids accumulate at the bottom of the tanks (Pain, 1994).

Anaerobic degradation of proteinaceous wastes, feed, bedding material, skin, hair, feces and urine causes the emission of odor from livestock buildings. The concentrations of odor from buildings are chiefly dependent on the design and management of the building. The techniques of waste handling system and management influence the emission of odor from livestock buildings tremendously (O'Neill and Phillips, 1991). In an effort to study the manure gases in livestock houses, Skarp (1975) discovered that:

Main manure gases are carbon dioxide, methane, ammonia, and hydrogen sulfide.

Gases released from solid wastes are lesser in quantity.

Only liquid pig manure releases H_2S in measurable quantities when left standing.

When liquid manure is disturbed, in the process of pumping and mixing, sometimes H_2S is released at harmful levels.

O'Neill and Phillips (1991) reviewed the causes of odor production from livestock buildings, and mentioned four major sources of odors, namely: waste removal, floor design, bedding material, and ammonia emissions. Pain (1994) tested the additional sources of ventilation system and waste storage facilities.

Waste Removal

Animal manure constitutes the major proportion of waste from any animal facility, and since it is biologically active, its composition changes with time. Anaerobic decomposition is understood to produce more odors than the aerobic decomposition process. When manure is left on the floor for a long period of time, anaerobic decomposition takes place, increasing the concentrations of odors (O'Neill and Phillips, 1991). Odor emission in the livestock buildings is less if the slurry is removed at shorter intervals (Pain, 1994 and O'Neill and Phillips, 1991). Liquid manure produces more odors, as the biological activities are higher than in dry manure.

Floor Design

Waste removal is largely dependent on the design of the floor. Odor emissions increase with an increase in the exposed surface of the waste, which is dependent on the floor design (Pain, 1994). Ni et al., (1996) discussed different ways for reducing ammonia emissions from animal houses, and studied the status of floors and their relation to ammonia emission rates. Two effective measures taken for odor-reduction were: 1) removal of slurry at short intervals, and 2) use of waterproof coatings on the floor surface to allow urine to flow away. Ni et al., (1996) related the rate of ammonia emission from slatted floor pig houses, to the proportion of non-slatted floor surface, which was covered by swine waste. They found that ammonia emission is a function of total pig weight and room temperature. A linear relationship between the floor factor and the rate of ammonia emission was established in this study, which means that high floor factor affects ventilation rate and room temperature, which increases the emission of ammonia.

Bedding Material

The amount of bedding material removed along with the manure determines the nature of the waste. Straw and wood shavings are the most common bedding materials. They both absorb moisture and keep the manure dry, which may help reduce the odor concentrations (O'Neill and

Phillips, 1991). Farmyard manure (FYM) is the organic fertilizer produced when straw is used as a bedding material. Decay of straw produces odors that are more acceptable than slurry because straw has a physical structure, which encourages thermophillic aerobic decomposition. However, composting of FYM requires regular turning of the material to encourage aerobic processes, keeps odors low (O'Neill and Phillips, 1991).

Ammonia Emissions

Concentrations of ammonia near livestock feedlots have been found to be significantly higher in comparison to other agricultural operations (Miner et al, 1975). Ammonia is produced in animal houses due to bacterial and enzymatic processes taking place in the decomposition of nitrogen compounds in the animal excreta, especially urine (Hartung and Phillips, 1994). Ammonia is the highly reduced form of nitrogen, and has a sharp, pungent and irritating odor (Miner and Hazen, 1969). Amines are compounds that are closely related to ammonia that are also produced due to decomposition of animal waste. The odor of amines is similar to ammonia, but has severe and longer lasting effects than ammonia (Miner, and Hazen, 1969).

Ventilation System

Ventilation systems in animal houses are necessary for providing a healthy environment for the animals and for an economical feed conservation ratio (Pain, 1994). Ventilation influences odor evolving from animal feedlots as higher ventilation rate increases the drying rates of the manure and dry manure is less offensive. Flow pattern and temperature gradient are the two most important properties of any ventilation system. It is reported that proper use of these two factors in pig houses encourages the animals to drop dung over the slatted part of the floor to keep the areas where they lie cleaner (Pain, 1994). The odor in air passing over the waste depends on the rate of formation of the odorous compounds and on the air volume flow rate. High flow rates dilute the concentration of odor within a building, but increase the odor emission rates (Pain, 1994). Thus, without a proper ventilation system, the odor concentrations and odor mission both are affected.

Waste Treatment

The method of handling or treating waste effects the concentration of odor significantly. Undesirable odors mainly result from anaerobic bacterial activities, so the control of odor can be achieved by suppressing these activities (O'Neill and Phillips, 1991). Some of the methods used for this purpose are reduction of moisture content, temperature, variation in the pH of the waste, and application of bacteriocides. These treatments reduce odor or at least change the composition of the compounds present in the odorous gases, this makes them less offensive (O'Neill and Phillips, 1991). It was found in some studies that increase in concentrations of ammonia increased with infrequent cleaning of slurry, and high amount of solids in animal houses. Similarly emission of hydrogen sulfide increased when slurry was agitated (O'Neill and Phillips, 1991).

Waste Storage

Odor emissions from waste storage are influenced by the size and dimensions of the waste storage facility, the type of waste, period of storage and environment (Pain, 1994). The factors affecting odor concentration from waste storage are pH levels, percent solids, ammonia and amine release rates and volatile fatty acids (Janni et al., 1980). The pH level of the waste affects the release of volatiles; the lower the pH level, the greater is the release rate of odorous gases. When the solid content of waste was high in liquid manure, there was an increase in the release rates of gases due to high microbial activities. The release of ammonia is also directly related to the initial solid concentration of the waste (Janni et al., 1980).

2.7 MECHANICS OF ODOR EMISSION

Odor emissions from livestock production units involve complicated mechanisms (Miner, 1980), and are mainly a result of bacterial activities (Barth and Polkowski, 1974). The bacteria present in animal wastes use the small amount of oxygen present and develop anaerobic conditions and generate offensive odors. Under aerobic conditions, the odors are not offensive but rather musty or earthy (White et al., 1971).

Volatile organic acids like butyric acids are detected in stored poultry manure. Presence of amines in low concentrations is common in swine waste, but amines vaporize easily and are offensive to humans at low concentrations, thus their contribution to the problem of odor is significant (Barth and Polkowski, 1974).

Certain microorganisms present in the waste and some chemical reactions taking place in animal waste produce gases, and this has shown some correlation to the odor intensity (Barth and Polkowski, 1974). Main components of animal manure are proteins, carbohydrates, fats, ammonia and hydrogen sulfides. Odorants arising from these components include:

Proteins → ammonia, volatile organic acids, hydrogen sulfide and mercaptans

Carbohydrates → alcohols, aldehydes, ketones, volatile organic acids

Fats→ volatile organic acids, alcohols

Ammonia + alcohols→ amines

H_2S + alcohols → mercaptans

2.8 COMPOSITION OF ODOROUS GASES

Miner (1975) reported 40 compounds that were odorous. Sweeten and Akabani (1994) identified at least 60 volatile compounds found in gases emitted from animal wastes. The highest figure was given by O'Neill and Phillips (1992), who reported 168 odorous compounds, of which 30 are detectable at very low concentrations. Of 10 compounds with the lowest odor detection thresholds, 6 contained sulfur. Several compounds could not be identified for their odor threshold levels, but their chemical structure suggests that they have very powerful odors.

2.9 ODOR PARAMETERS

Odor production is affected by bioengineering parameters such as temperature, pH, electrode-potential and aeration (White et al., 1971). These parameters are discussed briefly in the following paragraphs:

Temperature

In the warmer part of the year, odor production is comparatively higher than in the colder months. There are two main reasons for this. First, the vaporization rate increases with the rise in temperature, and secondly, the rate of biological activities increases including the increase in the enzymatic activities. The van't Hoff's rule states that, with every 10°C rise in temperature, the rate of biological activity doubles (White et al., 1971). Ammonia releases also increase with a rise in temperatures combined with appropriate pH levels (Hartung and Phillips, 1994).

Hydrogen ion concentration (pH)

Hydrogen-ion concentration, or pH, also has an impact on the activity of microorganisms and enzymes. Bacteria have optimum pH ranges at which they produce odorous gases at a higher rate. Decarboxylation of amino acid takes place at an optimum pH range of 4 to 5, when amines and sulfur compounds are released. Deamination, the process in which ammonia and some organic acids are produced, takes place at higher pH levels (White et al., 1971). In another study by Hartung and Phillips (1994), it was discovered that greatest emission of ammonia takes place between pH 7 and 10. When the pH is below 7, very small quantities are released. When anaerobic conditions are maintained, sulfate ions are reduced to sulfides. The equilibrium for H_2S, and ions HS and S^- depends on the pH. When pH levels are maintained at 8 and above, sulfur exists as HS^- and $S^=$; and the amount of H_2S is almost nil. But when pH levels drop below 8, rapid formation of non-ionized H_2S takes place, which is 80% complete as the pH reaches 7, thus creating serious odor problems.

Electrode Potential (Eh)

Reduction of organic matter takes place in the process of anaerobiosis, and low electrode potential is characteristic of the process of anaerobiosis. It has been reported in many cases that high negative values of Eh are proportional to the intensity of odor. For instance, value of Eh for sulfate reduction must be –200 mV, whereas for methane bacteria in sludge digestion, the optimum value is between –265 to –295 mV.

Aeration

Aeration rates are related to electrode potential. If aeration rates are low, Eh is lower, thus increasing the odor intensities. Aeration rates high enough to maintain aerobic conditions result in CO_2, H_2O, NO_3 and SO_4 as end products of decomposing waste, all of which are odorless.

2.10 ODOR MEASUREMENT

The emission of odor becomes a nuisance under the following conditions: 1) odor intensity, concentration or strength is beyond a tolerance level; 2) odor detection within a particular time period is frequent; 3) the odor persists for a long time; and 4) the odor is offensive. There are five basic approaches to measure odors (Ritter, 1981):

- Identification of odorous gases;
- Measurement of the concentration of odorants;
- Measurement of the intensity of odor by vapor dilution;

- Odor intensity measurement by liquid dilution;

- Ranking the odor intensities by an arbitrary scale.

These approaches can be classified as either analytical or sensory measurements. Each is discussed in detail in the following paragraphs.

Analytical Methods

Odor in the air is usually a result of various odorants. Analytical measurements are useful in measuring concentrations of these odorants, specifically ammonia, and hydrogen sulfide (NRC, 1979). The sensitivity of the analytical method used must be greater than the human nose, and should be capable detecting odors at very low concentrations. As a general rule, analytical sensitivity down to 0.1ppb (vol./vol.) should be adequate for any odorant (NRC, 1979). Some of the analytical methods used in the detection of livestock odors are discussed as follows.

Wet Chemical Method

The wet chemical method of identifying odorous compounds involves several absorption techniques. This method is frequently used for concentrating and identifying hydrogen sulfide and other odorous sulfur compounds (Elliott et al., 1978).

Measured volumes of air are passed through trapping solutions, which are basically heavy metal salt solutions. When these solutions come in contact with the H_2S present in the air, they form insoluble metal precipitates. In some previous work volatile nitrogenous compounds from swine manure were collected in acetic acid, and efforts were made to trap gases from beef manure in a series of columns containing water, diluted hydrochloric acid (HCl), sodium bicarbonate ($NaHCO_3$) and concentrated sulfuric acid (H_2SO_4). From these trappings, amines, amides, acids, alcohols esters, carbonyls (ketones and aldehydes) sulfides and mercaptans were separated (Elliott et al., 1978).

Gas Chromatography

In comparison to wet chemical methods, detection sensitivity is better in gas chromatography (GC) methods (Elliott et al., 1978). Grab samples of air are taken in glass syringe with Teflon plungers, or in special glass cylinders. The samples are then carried to the laboratory for analysis. The gases present in the sample are identified with the help of two chromatographic columns, which are packed with materials of different polarity or solubility alongwith pure compounds for characterization of behavior, which help in confirming the chemical species (Elliott et al., 1978).

Identification of volatiles requires that the samples have the following characteristics (White et al., 1971):

- The sample collected should represent all types and concentrations of volatiles present in the environment from which the sample is collected. This includes even those volatiles that are below their odor threshold limits;
- A minimum amount of water should be concentrated with the volatile compounds; and
- The air sample collected should be in a form so that it can be easily injected into the gas chromatograph.

Sensory Methods

According to Sobel (1972), the human nose is an acceptable instrument for sensing odor. Similarly, Sweeten and Akabani (1994) stated that sensory methods are the most valid way of odor evaluation. Before discussing any of the sensory techniques, it is necessary to become acquainted with certain definitions, given by NRC (1979) regarding odor terms.

Odor Intensity: The intensity of odor as perceived, regardless of the knowledge of the concentration of the odorant or dilution of the sample needed to eliminate odor.

Odor Threshold: When the odor sample is progressively being diluted, the intensity of odor decreases and comes to a point when it is barely detectable. This dilution level is the odor threshold.

Hedonic Tone of Odor: The scale at which the pleasantness or unpleasantness of the odor is rated. This value is difficult to evaluate, because an odor found to be pleasant by one could be unpleasant for another.

Odor Unit: As defined by Benforado et al. (1969), 'odor unit' is the ratio of the cubic feet of clean air needed to dilute each cubic feet of odorous air, such that 50% of the odor panel members do not detect any odor in the diluted mixture.

Sensory methods that are used for odor evaluation include olfactory methods, supra-threshold referencing and dilution to threshold methods (Sweeten and Akabani, 1994). In the olfactory method of odor evaluation, a panel is presented with the diluted odor samples. The panel then rates each sample on the scale given (Sweeten and Akabani, 1994). Supra-threshold referencing allows each panelist to compare the intensity of the diluted air to a known concentration of a reference compound. The Butanol olfactometer is a very useful instrument that is employed for this method (Sweeten and Akabani, 1994). Dilution to threshold methods, mix gaseous odorous samples with clean air. Diluted samples of air manner are then presented to the panel members. The flow rate is controlled and the number of dilutions is changed. The panelists must determine if they can detect odor at that particular level of dilution. The stronger the odor, the higher the dilution level required for the determination, of the threshold level. Odor detection by this method can be achieved with the help of the syringe-dilution method, the scentometer and the dynamic olfactometer (Sweeten and Akabani, 1994).

These sensory evaluation methods differ, but they generally are carried out in five steps (Sweeten and Akabani, 1994): collection of samples, dilution of sample and presentation before the panelist, response, interpretation of the response, and results.

Odor Sampling

Odor sampling can be done in two ways: static and dynamic sampling. Static sampling involves collecting the samples of odorous air in the field from the odorous sources or any other locations of interest and then storing and transporting the samples, prior to analyses. Teflon, Tedlar or Mylar plastic bags have very low absorptive characteristics, and thus are considered suitable for collection of odorous gases (Sweeten and Akabani, 1994).

In dynamic air sampling, continuous sampling and analyses of the ambient odor samples is carried out and there is no need of storage (Sweeten and Akabani, 1994). In this method, the olfactometer and panelists are taken to the field. A stream of odorous air enters the mixing chamber, where a stream of clean air is also supplied to dilute the odorous air (Sweeten and Akabani, 1994).

Panel

Screening of panelists is not needed, and as many panelists as possible should be employed if the objective of an odor study is to measure the presence of odor, odor sensitivity distribution, and mean odor detection threshold of large number of people (NRC, 1979). But for some odors, some individuals are found to be less sensitive than the average population, and thus screening of the panelists becomes necessary.

Panel size is also an important issue in the sensory testing of odor. The National Research Council (1979) suggests that a panel size of at least 9 to 10 people is the smallest acceptable. Sweeten and Akabani (1994) reported that the acceptable panel size generally ranges from 3 to 20 panelists. The same report suggests that if the panel size is 5 or less, two or three replications should be used. Sobel (1972) used a panel size of 10, whereas in another study by Al-Kanani et al., (1992) panel size varied from 10-14. Riskowski et al., (1991), used 12-18 panel-members.

The training of panelists becomes important when the need is to identify fine differences between the odors. When the only task of the panelists is to identify the presence of odor, odor intensity or odor threshold, no training whatsoever other than how to record the requested information is needed (NRC, 1979).

Panel selection involves the screening of the candidates based on their abilities to differentiate odors at low intensities, to concentrate on more than one type or quality of odor, to understand the testing process, and to show satisfactory behavior while the tests are in progress (Wittes and Turk, 1969). Tests that can be employed for screening candidates are (a) triangle test, (b) intensity rating test, and (c) multicomponent-odor-identification test.

The extent of human errors and variability in data are immense, however, for sensory evaluation of odor human nose is indispensable. Humans can be biased easily by visual stimuli, or their sensitivity can be reduced under some circumstances (NRC, 1979).

Wilby (1969) has done a study on the variation in recognition threshold of a panel and found that, in successive tests, odor threshold for a particular compound varies for an individual and is dependant on her/his physical and mental condition, or change in ambient conditions. He also reported that the range of odor threshold determined by all the observers varied for different compounds. Foster (1968) has focused on the limitation of subjective measurement of odor. He states that the principal sources of variability are as follows:

- *Subject or observer* can be different in intelligence, motivation, sensitivity, adaptation quality, any prior training, or psychological setup;
- *Situations* like the odor level, appearance of the sample, surrounding environment, social influence by the experimenter or other observers, temperature humidity;
- *Treatment* (anything which the experimenter does to the observers), type of instructions, order of samples presented;

- *Task* familiarity, meaningfulness, duration of exposure to the odor, difficulty in judging the odors;

Despite the sources of variability encountered in the subjective measurement of odor with a panel, Foster (1968) asserts that panel data should be evaluated just as any physical measurement. He further reiterates that humans are still the best instruments for odor measurement given the right experimental conditions.

Instruments and Devices for Odor Measurement

Odor measurement requires many instruments and devices to which assist in the measurement and assessment of odor. Some of these are mentioned and discussed below.

Butanol Olfactometer

The Butanol Olfactometer provides panelists with a method of quantifying ambient odors. This is done by comparing the perceived intensity of undiluted odor samples with the intensity of different concentrations of 1-butanol (1-butyl alcohol, C_4H_9OH) in air (Sweeten and Akabani, 1994). The Butanol olfactometer delivers accurate dilutions of 1-butanol, which is the reference compound to which the intensity of the measured odor is compared. The intensity of the 1-butanol must be kept constant throughout the test. Sweeten and Akabani (1994) state that, according to ASTM (1975), 1-butanol is used as the standard compound because it is readily available, is high in purity, less toxic, highly stable and it has an agreeable odor.

Dynamic Olfactometer

The dynamic olfactometer is a device that has many advantages over other dilution to threshold methods (Sweeten and Akabani, 1994). It is more statistically reliable and has better reproducibility. In addition, the stimuli to panelists are even and consistent, and panelists need less training.

Several dynamic olfactometers have been developed, but there is no universally accepted instrument (Sweeten and Akabani, 1994). Although olfactometers work differently, some features common to all include (Sweeten and Akabani, 1994):

- Presentation of a mixture of odorous and clean air by blending them at controlled flow rates and known dilutions;
- Use of pumps and flowmeters that allow an infinite number of dilutions;
- Minimum contact of olfactometer surfaces with the odorous air, to avoid adsorption and desorption of the odorants;
- Threshold level of individual and entire panel members is tested on the basis of a series of dilutions using a standard reference odor such as 1-butanol;
- Measurement odor in terms of dilutions to threshold levels, which is basically measurement of odor concentration.

Different olfactometers available are *Misco (Sanders) Olfactometer, T04 (Mannebeck) Olfactometer*, *Dynamic Triangle Olfactometer*, *Hemeon Olfactometer*, *Dravnieks/ASTM*

Dynamic Forced Choice Olfactometer and *QDPI Dynamic Forced Choice Olfactometer* (Sweeten and Akabani, 1994 and NRC, 1979).

Scentometer

The Scentometer is a device for odor estimation in ambient air, and can be easily used in field operations (Miner, 1975). This device is essentially a plastic box, with two glass smelling ports, activated carbon filters, and several holes of different sizes in the box (NRC, 1979).

The operator inserts the nosepieces in his nostrils and breathes only the air, which is deodorized by carbon filter. When his sense of smell gets adjusted to the odor-free air, he opens the ports of odorous air. At first the port of smallest diameter is opened and if odor is not perceived a port of bigger diameter is opened. This process goes on until odor threshold is reached (NRC, 1979). Different ports can also be used to obtain different dilution ratios of the odorous air to odorless air (Miner, 1975).

Odormeter

The Odormeter is a device that was developed by Hemeon Associates (Air Pollution Research Engineers PA) (Hemeon, 1968). The Odormeter consists of two stages of dilution that are identical. In the first stage, the air with raw odor is admitted through a tube. This tube has a flowmeter with a scale range of 0.1 to 0.7 cfm. Air is drawn from the surrounding environment at rates indicated by the flowmeter. Flow of odorous gas is maintained by a primary valve whereas, the dilution air stream is controlled by other valves, which are regulated by knobs that can be controlled by the panel members. The primary stage is used for dilution levels ranging from 30 to 400; for higher dilutions a second stage is used (Hemeon, 1968).

Ifeadi et al. (1975) designed a system for quantitative measurement of odor generated from dairy manure. The whole system consisted of 1) a dairy waste generator, 2) a sample collector, 3) an odor transfer system, 4) an injection system, 5) a gas chromatograph and 6) a chemical ionization mass spectrometer. For sensory evaluation, two more additions were made to this system: 1) a dilution train, and 2) sniffing hoods. Dorling (1976) employed bag sampling and dynamic dilution techniques for odor intensity measurement.

2.11 PRINCIPLES OF ODOR CONTROL

The three main principles for odor control as suggested by NRC (1979) are: control of volatile compounds, inhibition of anaerobic decomposition, and physical confinement of odors.

Control of Volatile Compounds

Some volatile compounds present in feed and manure can be converted to less volatile forms. This can be achieved by controlling pH and by using chemicals and biological conversion processes. Miner (1980) suggests that the addition of lime can adjust the pH of the manure above 9.5, which decreases H_2S emissions. Addition of paraformaldehyde to the manure converts ammonia to less volatile chemical hexamethylene tetramine (Miner, 1980). Under aerobic treatment of wastes in oxidation ditches and aerated lagoons, sulfides convert to form sulfates, which are less odorous (Miner, 1980).

Inhibition of Anaerobic Decomposition

Dry conditions in feedlots improve oxygen permeation through the surface. This helps in maintaining aerobic conditions, which results in reduction of odorous gases. If slurry in liquid systems is aerobic, the odorants evolved are reduced. Oxidation ditches and aerobic lagoons are two practices that help in the inhibition of anaerobic processes that take place in the manure. Low temperatures also inhibit anaerobic bacterial decomposition of waste. However, this factor is best accomplished when site and climatic conditions are favorable (NRC, 1979).

Physical Confinements of Odors

The third and last principle of odor control is restriction of odorous gases within an area or structure. Covered manure storage tanks and aerobic treatment effectively confine odorous gases. Providing air exchange over waste slurries reduces the concentration of volatile gases. Incineration of gases escaping the enclosed tanks is another way of avoiding the dispersion of odorous gases into the environment. Liquid scrubbing and soil column absorption are also helpful in controlling gases escaping from waste storage (NRC, 1979).

Methods of Odor Control

One can encounter various technological difficulties while controlling odor (Miner, 1977). However, good management practices and maintaining hygienic conditions can reduce odor to significant levels (Pain, 1994). Some of these practices are discussed in the following paragraphs.

Site Selection

Factors considered in selecting the site for livestock production units are transportation, feed supply, and zoning regulations (Miner, 1980). Most of the time, the potential residential areas are overlooked. Wind direction is important while selecting a site for a livestock production unit. However, the direction of wind changes throughout the year. Considering that downwind location is best for the location of any livestock unit is not sufficient, in fact the deciding factor should be based on the percentage of time the wind blows from the source to the point in question throughout the year. Odors can be transported a mile or more toward downwind locations in appropriate climatic conditions (Miner, 1980).

Feed Additives

This method is the best choice if control of odor must be done at the source rather than treating the manure. Odors can sometimes be reduced by modifying the feed ration as there is a direct relationship between feed and the quality of odor (Ritter, 1981). It was found that addition of charcoal at the rate of 5% of the total ration caused significant reduction in swine odor (Ritter, 1981). Lyophilized yeast, sagebrush, whole milk, and dry and wet lacto were also tested for odor control, and were found to reduce emissions of indole and skatole, but there was no reduction in odor intensity. In a different study, Ritter (1981) found that 2% calcium bentonite in feed ration of cattle reduced odors. A fungalamylase enzyme added to the ratio at the rate of 0.05g/Kg reduced the odors also (Ritter, 1981).

In a study done in the Netherlands, Peet-Schwering et al. (1996) found that ammonia emissions are lowered in swine houses when a low protein diet is combined with low cost housing management. Similarly, Sutton et al (1996) compared corn-soy diets with protein deficient diets, supplemented diets, standard commercial diets and excess protein diets. They found that standard commercial diets often exceed the amino acid requirements and thus volatile ammonia emissions are in excess. They concluded that diet supplemented with amino acids in required quantities reduces nitrogen in the excreta. Similar results were obtained in another study by Turner et al., (1996) and Hartung and Phillips (1994).

Feedlot Management

Proper operation and management of feedlots also offer an alternative for odor control. Overflowing manure storage tanks, broken scrapers, leaking water sources and ruptured retention ponds are common causes of odor problems in feedlots (Miner, 1980). Well-drained feedlots with watering systems that do not overflow and runoff facilities draining in remote areas are effective in reducing odors.

In confined units, the cleaning of the feedlot surfaces is critical (Pain, 1994). Frequent scrapping and flushing of manure from feedlot surfaces and maintenance of dry conditions are advisable. Studies indicate that, when residence time of feces and urine on the feedlot surfaces is short, fewer odors are generated. In pig houses, it is very hard to keep surfaces dry, and frequent removal is harder to achieve than in poultry houses. In dairy cattle feedlots, urine is the main cause of ammonia emissions, so removal of wastes from the feedlots on half-hourly basis is helpful. This can be achieved efficiently by flushing systems, as flow systems and surface scrapping leave a film of urine on the surface, and are time consuming (Hartung and Phillips, 1994).

Manure Covers

Li et al. (1997) studied odor control using covers. The covering materials used in the study were straws, cornstalk, Leka-rock, substitute Leka rocks, mesh with film, and aerated bubbles. Straw reduced odor emission significantly, whereas cornstalks were not so effective, Leka rock and substitute Leka rock showed very good results. Mesh and film used proved useless, and odor reduction was up to 90% with the use of aerated bubbles. Filson et al. (1996) studied wood shavings, peat moss, wheat straw, barley straw, fishnets, plastic bubble sheets, plastic bottles and various combinations of other products. Only barley straw was reported to be effective in reducing odor emission.

Treatment of Waste

Treatment of waste is the most common method used to reduce odor concentrations. Some of the methods of treatment are separation, anaerobic digestion, aerobic treatment, and composting.

Separation

Two separation methods are separation of feces from the urine and water, and mechanical separation of slurries before storing. Pain (1994) reported the use of a filter belt installed below the slats of floors in hog houses, for the separation of feces from urine. He further stated that 35% of feces and urine is separated as solids, whereas the liquid flows to a storage tank.

Mechanical separation improves the handling and storage conditions of the slurry and results in slurries that can be pumped. Dry matter content of waste from 3-9% is suitable for employing this method (Pain, 1994). Removal of coarse solids such as hair, grit, bedding materials and larger undigested residues in the manure are the objective of this kind of separation.

Aerobic Treatment

Aerobic treatment is very successful in reducing odors from slurries with over 3% dry matter. The degree of odor control depends on the treatment time. Aerobic conditions are maintained with the help of aerators. But, aeration is an energy intensive process. During aeration, air input to the aeration vessel or reactor is controlled by redox potential or dissolved oxygen concentration (Pain, 1994). Goodrich and Petering (1997) have developed a new aerobic animal waste treatment system, 'Teritary Oxygen Activated Sludge Treatment' (TOAST), which is operational on a hog farm in Minnesota. This system is reported to reduce odors effectively, and the emissions are reported to be at least half from that of untreated manure.

Anaerobic Treatment

Anaerobic treatment is applied to slurries with dry matter content of up to 6-8% (Pain, 1994). A reduction of 93% of volatile fatty acids is reported by Pain (1994). In the same study, it was reported that odor concentrations fell significantly for digested versus undigested pig slurry. Zhang et al, (1996) studied surface aeration of anaerobic lagoons and found it to be an effective method for odor control.

Composting

The objective of composting is production of stable products without odor that can be packed, stored and used as fertilizer. The moisture content of the manure should be 40-60% and the C:N ratio should be maintained at 30:1 (Pain, 1994).

Odor Control Amendments

Addition of odor control amendments to manure storage tanks or animal feeding areas have gained popularity in recent years (NRC, 1979). Due to low cost, ease and flexibility of application, they have been of interest to producers and researchers (Li et al., 1996). Materials which have potential for odor control are those which can prevent the release of odorous compounds, inhibit the process of odor generation, or mask odors (NRC, 1979). A number of products have been used since 1960s, but a majority have been ineffective (Ritter, 1981).

Masking Agent

Masking agents are blends of aromatic oils, which have strong odors of their own, that help in covering malodors. Since masking agents are organic in nature, they are broken down by bacteria present in the manure and soon lose their effectiveness. The use of masking agents is prevalent in the petroleum industry (Ritter, 1981). Masking agents were neither satisfactory nor economically feasible for long term use (NRC, 1979). Ritter (1981) reported mixed results for masking agents. Burnett and Dondero (1970) found that masking agents were quite effective, partially masking odors from liquid manure dairy manure. Odors from poultry manure were controlled if masking agents were applied in concentrations of 25-30 mL/m^3, before the slurry was spread. On the other hand, they were ineffective with pig slurry.

Chemical Deodorants

Chemical Deodorants are of two types, oxidizing agents and disinfectants. Oxidizing agents transform odorous compounds into less offensive ones by chemical oxidation, whereas disinfectants alter or eliminate the bacterial activities responsible for the production of odor (Ritter, 1981).

Oxidizing Agents

Oxidizing agents like potassium permanganate, paraformaldehyde, ozone, potassium nitrate, hydrogen peroxide and *Ozene* are potential odor control chemicals that have been tested extensively (Ulich and Ford, 1975). Ritter et al. (1975) also tested hydrogen peroxide and found it useful in eliminating H_2S.

The National Research Council (1979) reported different application rates of potassium permanganate for the reduction of odors. Spreading of 22 kg/ha of potassium permanganate in cattle feedlots was found effective by one group of scientists, whereas 28 g/Kg of manure totally suppressed odors from manure. Burnettt and Dondero (1970) found that spraying of aqueous solution of potassium permanganate of strength 1%, at the rate of 20 lb/acre, proved satisfactory for the treatment of poultry waste lying on the floor. Potassium permanganate reduced the COD content of liquid dairy and swine wastes, from 13,400 µg/L to 5930 µg/L after 24 hours of treatment (Ritter and Eastburn, 1980). According to Ulich and Ford (1975), 14 grams of potassium permanganate per 500 grams of manure sample reduced odor levels lower than required for it to be barely perceivable. The use of potassium permanganate was determined to be the least expensive of the four compounds (potassium permanganate, potassium nitrate, hydrogen sulfide, and *Ozene*) tested.

The amount of potassium nitrate needed for complete suppression of malodorous gases proved to be much more costly than potassium permanganate. The quantity used to completely suppress odors was 49g/500g of manure. The cost of potassium nitrate was found to be at least 1.1 times more expensive than potassium permanganate (Ulich and Ford, 1975).

Hydrogen peroxide suppressed sulfurous gases at all levels, and the most effective quantity was 82 milliliters/500g of manure. This was slightly more expensive than potassium permanganate (Ulich and Ford, 1975). Cole et al., (1975) found 500 ppm of H_2O_2 effectively reduced the sulfides and odor levels to a very low level. Sulfide levels came lower than 10 mg/L, which is a reduction of 90%.

Ozene is the brand name of a formulation of orthodichlorobenzene. This product is slightly more expensive than potassium permanganate. The quantity of *Ozene* needed to suppress sulfurous gases at all levels was found to be 60 milliliters/500g of manure (Ulich and Ford, 1975).

Ozonation is another method of oxidizing the odors to less offensive levels. Ozone is a very powerful oxidizing agent produced from dry gas with an electric discharge generator or by the use of ultra violet light (Watkins et al, 1996). Ozone destroys odors by (a) killing the microorganisms that produce odors, thus controlling the production rate of odorous metabolites, and (b) oxidizing the odorous metabolites produced by anaerobic processes, thus reducing their concentrations Watkins et al., 1996).

Disinfectants

A study done by Ritter (1981) indicated that a disinfectant containing orthodichlorobenzene helped in improving the odor quality from swine waste, but did not alter the odor strength. This compound was not very effective in reducing sulfides or other odors from dairy or swine manure in the long term. Chlorine is a very effective disinfectant but it is not economical to use. Formaldehyde and paraformaldehyde reduced ammonia and H_2S evolution by decreasing the number of viable bacteria. Formaldehyde is not too favorable to use as it can be toxic to animals if ingested and has a strong odor of its own (Ritter, 1981).

Counteractant

Counteractants are similar to masking agents, but instead of masking odors they neutralize them. They are also a mixture of aromatic oils, like masking agents, and are easily degraded by the bacteria in the manure. Their use is more popular in the petroleum and chemical industry (Ritter, 1981).

Digestive Deodorant

Digestive deodorants are cultures of bacteria and enzymes that eliminate odors by biochemical digestive processes. These are probably the most popular agents used in the livestock operations. Bregdoll (1975) reported that odors and other harmful gases were successfully removed in most of the livestock units studied. Miner and Stroh (1976) found that, of two digestive agents, both were effective in reducing ammonia emissions, but there was no decrease in odor intensities. Bregdoll (1975) conducted an experiment on the use of digestive cultures and concluded that:

- For achieving odor reduction from bacterial cultures and enzymes, it is necessary that they be sprayed evenly on the surface;
- Water with chlorine levels above 3-5 ppm has a detrimental effect on bacterial culture enzymes effectiveness;
- The spraying and spreading equipment should be free from disinfectant, insecticides or other harmful chemicals;
- The use of bacterial cultures can be optimized if aeration is provided while applying them in a lagoon. Temperature is also critical for increasing bacterial activities;
- When mixed before application cultures should not be left in the spraying equipment for long to avoid decrease bacteria count;
- For the first few days of treatment of a badly overloaded lagoon with bacterial cultures, the ammonia emissions will increase as the bacteria are in the process of breaking down organic matter.

Absorbent

Adsorptive materials have achieved some success in odor control. These are products with large surface areas so that they absorb the odor particles. Activated carbon, silica gel and active alumina are absorbents used to filter ventilated air from animal houses. Activated carbon in powdered form at the concentrations of 2000-5000 ppm was to be ineffective on odors (Ritter, 1981). Two natural zeolites were also found to be effective in reducing the evolution of odor, but were not as effective in reducing the odor intensity (Miner and Stroh, 1976).

Summary

The livestock industry is huge in the U.S. and is growing day by day. Recent shifts to larger production units have resulted in greater confinement of animals for efficient management. This proved to be economical and energy efficient, but the accumulation of waste in smaller areas has intensified odor problem. With the increase in public awareness, the number of complaints and law enforcement cases are on the rise. There are laws that can be enforced by private or public parties. Right to farming statutes protects certain farming operations from litigation. EPA has set some odor standards for certain pollutants, but states may set more strict standards.

Malodors are constituted from irritants, allergic substances, bacteria and other pathogenic messengers. Odor has many health impacts on humans and animals. Decline in sleep and appetite, nausea, and irritability is some common results of odor exposure. In tests done on animals, it was found that odor molecules can be carried to the brain and can cause a reduction of size in some brain cells.

Subjective sensation of odor varies from person to person, depending on individual sensitivity. Various methods can be used for odor measurement. Two basic techniques used are analytical and sensory. The analytical technique usually is used to identify and measure the compounds, which are causing odor. The sensory approach is dependent on a panel of individuals with a normal sense of smell.

Odor from livestock units originates from land-application of waste, livestock buildings and waste storage facilities. National Research Council suggests that odor can be controlled by three principle approaches: 1) control of volatile compounds, 2) inhibition of anaerobic decomposition, and 3) physical confinement of odors. The problem of odor can be avoided by judicious planning strategies like proper site selection, suitable design criteria, and good management.

Odor control amendments are used extensively, as they are low in cost and easy to use. These amendments are materials, which have potential for odor control, can prevent release of odorous compounds, and inhibit the process of odor generation or mask their odors. These products can be classified in the categories of oxidizing agents, disinfectants, masking agents, deodorants, absorbents, counteractants, or digestive cultures of bacteria or enzymes. These additives have achieved very little success up to the present time. More and more products are launched in the market every year with claims of improved quality and performance. Research programs to explore the effectiveness of these products are in progress.

3 MATERIALS AND METHODS

3.1 BACKGROUND

Odor-reducing commercial products (ORCP) are popular with the livestock producers due to low cost, ease and flexibility of application. These products are materials that can control odor by preventing the release of odorous compounds, inhibiting the process of odor generation or masking them. Many ORCP are marketed at present, but their effectiveness has been ambiguous in the past. Various studies have been conducted to establish the credibility of these products. This study is another effort to examine six products for their effectiveness in reducing odors from agitated and unagitated dairy and swine wastes.

It has been established in literature review that the human nose is the best instrument for sensing odor, and sensory methods are the most valid way of odor evaluation. One person cannot be the deciding factor for something as subjective as odor, as people differ in their sensitivity. A cumulative effect on a population of individuals can determine whether an odor is offensive or not. Based on these factors, odor evaluation in this study was done using sensory methods, in which olfactory techniques were applied. Odor evaluation was done with the help of a panel of individuals, who evaluated the odor intensity of the treated samples.

This experiment began on June 16, 1997, and lasted till July 23, 1997. The treatment of wastes was carried out in the Bioprocessing Laboratory of the Biological Systems Engineering Department, Virginia Polytechnic Institute & State University. Panel evaluation of the treated manure was done in Room #117 in Seitz Hall. The room used for this purpose is spacious and adequately ventilated with four exhaust fans.

3.2 *COLLECTION AND STORAGE OF WASTES*

Collection of dairy waste started on June 16, 1997 and that of swine waste on June 17, 1997. Dairy cattle and hog wastes were collected from the feedlots of the Dairy Center, and the Swine Center of Virginia Tech. in the mornings before they were cleaned. The two waste types were collected in 6-gallon buckets and then transported to the Bioprocessing Laboratory, and deposited in to larger storage containers, kept outside the laboratory in a shaded area. The storage containers utilized for deposited manure were heavy-duty, 170L, plastic trashcans (Figure A-1 (a), 1(b)).

About 19L of waste was collected at a time, and collections were divided in two equal parts to be kept in agitated and unagitated conditions. The raw wastes were collected from the animal feedlots every other day for two weeks, till the raw waste in each storage container reached, about one-third its capacity. Each time with the addition of waste some water was added to maintain the consistency of waste in a typical storage tank. By the end of the collection period, the containers were filled with to 75% their capacities. After this period no fresh waste was added to the storage containers, as one of the objectives of the study was to observe if there was any difference in the odor levels as the wastes aged.

Odor emissions from waste storage tanks often differ between agitated and unagitated conditions. Therefore, in this study product effectiveness was tested under agitated and unagitated storage conditions. To emulate the agitation process, wastes were agitated to observe if uniform mixing of the waste had any effect on the odor levels. During the course of this experiment wastes were regularly agitated every third day, manually, for 15 minutes. This was done in order to mix the wastes thoroughly, breakdown the solids to finer particles and uniformly distribute them in lower and upper levels of the container. At the time of treatment uniform mixture of the waste were extracted from the storage container. Under unagitated conditions the solids tend to settle down to the bottom of the container as no mixing up of the waste takes place. To observe the effect on odor levels under unagitated conditions waste was left undisturbed. Although, some mixing of air could have taken place at the time of adding fresh waste to the collection bins. Waste supernatant was extracted for treatment purposes.

3.3 DESCRIPTION OF WASTES

Dairy waste was high in moisture content, so the consistency of the manure was very loose. Urine accumulation overnight also increased the moisture in the waste. Raw waste had a distinct and sharp smell. Since the cattle were fed in open feedlots, the waste had a moderate amount of feed mixed in it. The manure had a large amount of undigested feed material in it, some of which may have been presented because of feed spills, as these were open feedlots.

In the swine facility, the waste was collected from concrete feedlots. The manure was dry and compact and the smell was not too offensive at the time of collection. Undigested feed material in the raw waste was high. Urine did not mix very well with the manure, and drained immediately, as the floor was sloped. Odor from the swine waste became offensive when water was added to the waste. No bedding materials were used on the floor of any of the animal housing.

3.4 SAMPLE TREATMENTS

Six commercial products were tested on agitated and unagitated dairy and swine wastes. Each product was provided by its manufacturer along with a protocol on how to use them and in what quantity. Wastes for treatment were extracted from the large storage containers and placed in 3.78L glass jars, which had been previously acid-washed, as shown in Figure A-2. The jars were painted black, to minimize the visual impact of the manure on the panel members.

Treatment of the wastes was done inside the Bioprocessing Lab building. The wastes were treated with the odor-reducing commercial products according to the product recommendations. At each sampling period, twelve samples were withdrawn from a single type of waste (dairy or swine) and were treated: six from the agitated waste storage and six from unagitated waste storage. Treatments on dairy waste were carried out each Monday from July 7 to July 23, 1997, and swine waste was treated every Wednesday, during the same period. Each week dairy and swine wastes were treated once, so over a period of three weeks a total of 64 treatments were completed.

3.5 ODOR-REDUCING PRODUCTS

The brand names and chemical compositions of the products available for this experiment were kept confidential. To maintain this confidentiality the products are identified as P1, P2, P3, P4, P5 and P6. Each of these products had different estimated time periods for achieving the goal of odor reduction. Since this study was a relative and comparative study of the performance of these products, to maintain uniformity all of them were tested for their effectiveness over an equal period of time.

Application of Products

The waste samples were extracted in 1-gallon jars from the large storage containers (Figure A-3). The products were prepared according to directions indicated and applied to the wastes at 12 noon, at least four hours before panel evaluation began.

Product 1 (P1)

This product is a digestive culture available in powdered form. According to manufacturer's recommendations 30 grams should be measured and mixed with 100 ml of tap water, to rehydrate the bacteria and allow cell growth which would accelerate the procedure of odor reduction from wastes. After this, 10 ml of this solution should be used to treat 3.785 liters of waste sample.

Product 2 (P2)

A brief manufacturer's instruction suggested that a dilution rate of 38.35 grams of this product is adequate per 3.785 liters of water. This amount (38.35 grams), of this product was applied directly to 3.785 liters of waste to test its effectiveness. The product is not classified into any category by the manufacturer. The product has a very strong odor and the waste was noticed to change its color after few hours of treatment, so it is concluded that it is a chemical deodorant, which oxidized the odorous gases to less odorous ones.

Product 3 (P3)

This product is a enzymatic catalyst. The protocol for this product suggested the dosage on the basis of tests done in Iowa State. According to this study, the manure must be diluted to 4% solids, and 2 ml of the product was mixed with 100 ml of water to treat 4.64 liters of waste. Since the waste to be treated was 3.785liters, the solution needed was approximately 1.6 ml, which was mixed with 80 ml of water prior to application.

Product 4 (P4)

This product is a biochemical product which has a combination of vitamin precursors of plant and animal origin. From the information about the product it is understood that it is a biologically balanced stimulant, which derives energy from decomposing waste materials by oxidizing the organic gases like ammonia, hydrogen sulfide, carbon monoxide, and sulfur. The suggested application rate was 9.59 grams for 18.93 liters of waste. According to the instructions, 1.92 grams was sufficient for treating 3.785 liters of waste. For testing purposes, 9.59 grams of the product was used. As suggested in the manufacturer's directions, one part of the solution was mixed with nine parts of water and sprayed on the surface of the waste.

Product 5 (P5)

The recommended application rate for this powdered product is 45.4 grams per 37.85 liters of waste. For application to 3.785 liters of waste, the amount of product was about 45.3 grams. The product was applied directly to the waste. There was no information available about the product category.

Product 6 (P6)

This product is a culture of aerobic microbes. The recommended application method for this product is similar to product P3. The manure must be diluted to 4% solids. As with product P3, 1.6 ml of the product was mixed with 80 ml of water and applied to the waste.

3.6 OBSERVATIONS

After the wastes were treated, they were immediately transferred to a panel sniffing room in the Biological Systems Engineering building at least two hours prior to panel evaluation. Here the sample jars were arranged in a random order on tables (Figure A-3). The mouths of the jars were covered with wet cotton swatches immediately. Cotton is an absorbent fabric and serves as an alternate system for the purpose of detecting odors, they were first used by Miner and Licht (1980). By the time the panel arrived, adequate time had passed for the odor to be absorbed in the fabric.

Odor Evaluation Panel

Participation as a panel member was voluntary, students from the BSE Department formed the panel. National Research Council (1979) suggests a panel size of at least 9 to 10 people. In this study panel size varied from 12 to 24 at different times.

There are many tests available, which can be employed for screening the candidates for panel, but as the panel participation was limited, no such tests were employed. The panel members were asked to provide information on the evaluation form. The readings of some panelist were discarded if it was reported that they had colds, allergies, or had a meal less than an hour before a odor-evaluation session. As this study did not require panelists to identify finer differences between the odors, no training was necessary. The only task of the panelists was to identify the presence of odor and odor intensity.

Odor Evaluation

Panelists began odor evaluation on the samples for odor intensity at 4 P.M. The panelists recorded their information about each treated sample in a data collection form (Figure 1), and followed instructions provided to them. The form was developed from similar form developed by Ritter et al. (1975) and Sobel (1972).

On the form there were certain questions which had to be answered by the panelists to find their physiological conditions. After the panelists completed the upper portion of the form, they proceeded to take observations. They wore a disposable glove on the hand they used to open the jar lids, so that direct contact can be avoided. The observations began with the panelists first

Name of the panelist: --

Sex: M/F Date: ---/---/ 97 Time: -------

At what time did you last eat something: -------

At what time did you last smoke: ------- At what time did you last chew gum: -------

Are you wearing any perfume or any other fragrance: Yes / No

Are you suffering from cold today: Yes / No

Observations

Rating scale: 0 to 5, Water: '0' and Raw waste: '5'

Mark (√) the rating of odor for corresponding Sample number:

Observation #	Sample #	0	1	2	3	4	5
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							

Figure 1. Odor Evaluation Form.

smelling coffee, which helped remove traces of any previous odors from the olfactory senses (Dhandpani, 1997). They waited for 35 to 35 seconds for the coffee to be effective. There were two jars marked '0' and '5' for their reference, where '0' was rated for no odor and '5' for highest level of odor for any waste, the panelists smelled these jars to understand the two odor levels on which they had to base their observations. It is important to mention here that at the time when treatment was done on dairy waste the reference odor jar rated '5' was dairy and same was the case for swine waste. The observations were taken by lifting the lids of the jars with the gloved hand and smelling the treated samples from a distance of 6-8 inches, the panelists spent about 20 seconds to determine the levels of odors before marking down their observation. In case, a panelist became confused at any point about the odor level she/he could come back to the reference jars and smell the jars before going any further. If the panelist felt that her/his sense of smelling was saturated she/he could smell some coffee and then proceed. FigureA-4 shows the panel members taking observations.

4 RESULTS AND DISCUSSION

The six odor reducing commercial products were tested for their effectiveness on dairy and swine wastes under agitated and unagitated storage conditions. The protocols provided by the manufacturers were followed for treating the wastes. Observations were taken for treated wastes using a discrete scale of 0 to 5, where the value ‘0’ refers to no odor and ‘5’ to highest odor.

4.1 STATISTICAL ANALYSIS

Since the reference odor value of ‘5' was different for dairy and swine wastes, the data collected for both wastes were analyzed separately and product-effectiveness for dairy waste was not compared with swine wastes. The General Linear Model (GLM) procedure was utilized to examine if there were differences in odor levels due to: products; waste conditions; waste storage time; and interactions between these three factors. The GLM procedure was performed using SAS (SAS, Inc., 1997). For comparing the product effectiveness, graphical and statistical techniques were used. Least square means (LSM) of the raw data were used to minimize the sum of squared errors. The Tukey-Kramer multiple comparison test was performed to compare overall effectiveness of each product under the two waste storage conditions. The trends of odor change over the three week periods were also analyzed using MINITAB (Minitab Inc., 1996).

The ‘Analysis of Variance (ANOVA)’ table obtained from the GLM procedure was used to answer the following questions:

1. Did the products differ in their overall effectiveness?

2. Did the odor levels change over time?

3. Was there any difference due to panel members?

4. Was there an interaction between product and waste storage condition?

5. Was there an interaction between waste storage condition and storage time?

6. Was there an interaction between product and storage time?

A total of six hypotheses were tested for examining the factors and interactions for each waste type. Three hypotheses were tested to examine the significance of three factors: products, storage time, and panel. Since the 'Error Degree of Freedom' for waste storage conditions was zero, the effect of this factor on odor level was considered statistically indeterminable. After ascertaining the significance of the factors and their interactions, the next step was to compare the effectiveness of the six products. For each waste, four separate sets of pair-wise comparisons were made to evaluate the differences in products for: overall effectiveness; effectiveness in agitated storage conditions; effectiveness in unagitated storage conditions; and effectiveness in agitated versus unagitated storage conditions. All the statistical tests were performed at 0.05 significance level (α). Results for factors and interactions tests as well as the multiple comparison tests are discussed separately for dairy and swine wastes in the following sections.

Product Effectiveness for Dairy Waste

Factors and Interactions

The results for hypotheses testing for factors and interactions for the dairy waste are presented in Table 1. The product factor was found to be statistically significant indicating that each product was different than the other in its odor reducing potential (p-value = 0.0001). This was expected considering the fact that there were differences due to product type (masking agents, chemical deodorant, counteractants, digestive deodorant or absorbents), formulations, and recommended dosage. Time was also found to be a statistically significant factor in governing the odor levels indicating that odor levels at the three times (week 1, week 2, and week 3) were statistically different (p-value = 0.0007). Odor changes over time can be attributed to various factors such as bacterial activity, storage time, and waste storage condition. Panel was also found to be a statistically significant factor meaning that observations for the same treatment varied from person to person (p-value = 0.0001). This is expected in light of the fact that people differ in their odor perception. The interaction between waste condition and product, was found to be statistically significant (p-value = 0.0004, Table 1), suggesting that each product worked differently under the two waste storage conditions. Interaction between product and waste storage time was also significant (p-value = 0.002), indicating that product effectiveness changed with time. Similarly, significant interaction (p-value = 0.0182) between waste condition and waste storage time was also found. This significant interaction reveals that the odor levels changed with time for both the storage conditions.

Table 1. Hypothesis testing of main factors and their interactions on dairy waste.

Source of Variability	Hypothesis	p-value	Decision
Products (1, 2, 3, 4, 5, 6)	Ho: No differences in odor levels due Products H_1: Differences in odor levels due to products	0.00010	Difference in odor levels due to products
Storage time (Week 1, 2, and 3)	Ho: No differences in odor levels in the three weeks of storage H_1: Differences in odor levels in the three weeks of storage	0.0007	Difference in odor levels in the three weeks of treatment
Panelists (1---29)	Ho: No differences in observations made by panelists H_1: Differences in observations made by panelists	0.0001	Difference in each panelist observation
Condition of wastes * Products	Ho: No differences due to interaction between condition of wastes and products H_1: Differences due to interaction between condition of wastes and products	0.0004	Interaction present
Condition of wastes * Waste storage time	Ho: No differences due to interaction between condition of wastes and time of treatment H_1: Differences due to interaction between condition of wastes and storage time	0.0182	No interaction present
Product * Waste storage time	Ho: No differences due to interaction between products and waste storage time H_1: Differences due to interaction between products and Waste storage time	0.002	Interaction present

Comparisons of Product Effectiveness

As mentioned before, four sets of pair-wise comparisons were made for dairy waste. Results from these comparisons are discussed in the next four sections.

Comparison of Overall Effectiveness

For evaluating the differences in overall effectiveness of products, composite LSM were computed and are shown in Figure 2. Among all the six products, P2 and P4 were the only products which reduced the overall odor levels by more than 50%. P6 seemed to be least effective in reducing the odor levels (39% reduction).

Results for Tukey-Kramer multiple comparison tests for overall effectiveness are tabulated in Table 2. It can be observed from Table 2 that, with an exception of P2, P1 was statistically equal to all the other products. This result is in consonance with the LSM of odor levels presented in Figure 2. Pair-wise comparison of P2 with other products revealed that it was equal only to P4. Similar comparison of P3 revealed that it was equal to P1, P4, and P5 in its odor reducing potential. The odor reduction achieved by P4 was found to be statistically equal to P1, P2, and P3. P5 reduced the odor to a similar level as compared to P1, P3, and P6. However, odor reduction potential of P6 was the same as P1 and P5 but was different than P3. Overall it can be inferred that only P1, P3, and P4 were always found to be equal in their odor reduction potential.

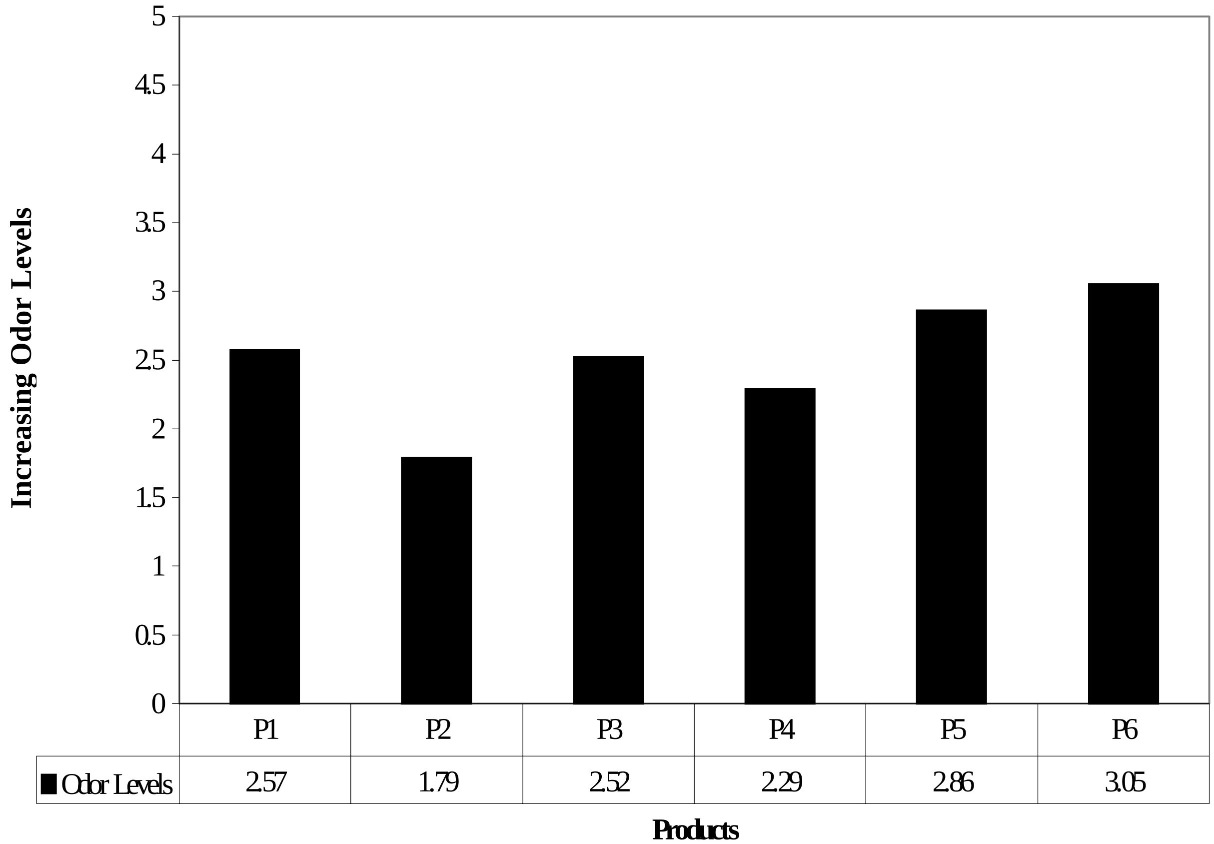


Figure 2. Overall product effectiveness on dairy waste.

Table 2. Tukey-Kramer multiple comparisons between products for dairy waste.

Odor levels (Least-Square Means)		Comparisons to other Products (p-values)					
		P1	**P2**	**P3**	**P4**	**P5**	**P6**
P1	2.57		NE* (0.0004)	E (0.9997)	E (0.6383)	E (0.5990)	E (0.0956)
P2	1.79	NE (0.0004)		NE (0.0014)	E (0.0837)	NE (0.0001)	NE (0.0001)
P3	2.52	E (0.9997)	NE (0.0014)		E (0.8093)	E (0.4124)	NE (0.0448)
P 4	2.29	E (0.6383)	E (0.0837)	E (0.8093)		NE (0.0218)	NE (0.0005)
P5	2.86	E (0.5990)	NE (0.0001)	E (0.4124)	NE (0.0218)		E (0.9133)
P6	3.05	E (0.0956)	NE (0.0001)	NE (0.0448)	NE (0.0005)	E (0.9133)	

*** Comparisons marked with letter 'E' represent equalities and those with 'NE' show inequalities among products.**

Comparison of Effectiveness Under Agitated Storage Condition

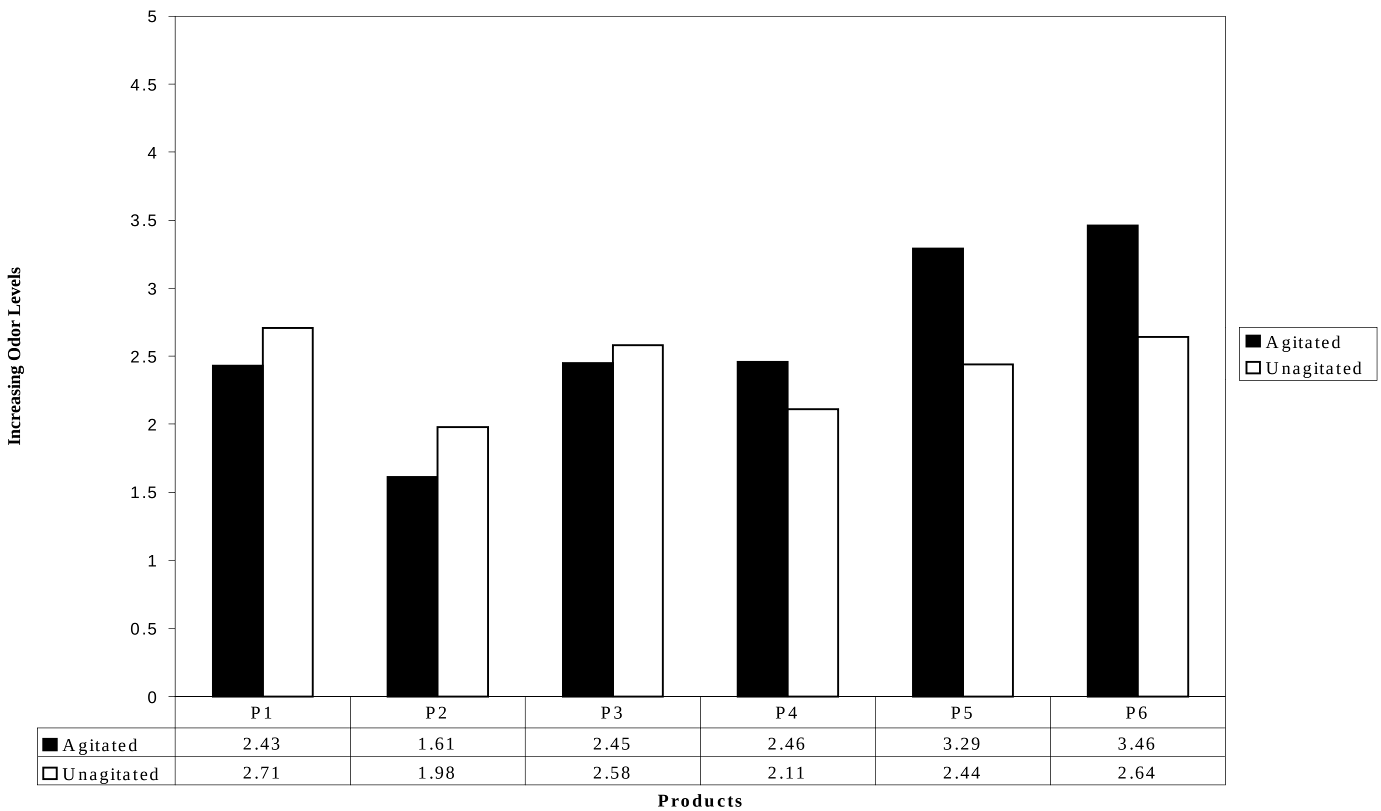
It has already been established that the products performed differently in agitated and unagitated storage conditions. Therefore, the multiple comparisons were performed on the odor data obtained from the two waste storage conditions and are discussed separately. Figure 3 is the graphical representation of least-square means of odor levels for agitated and unagitated waste conditions. Results for Tukey-Kramer tests for agitated storage conditions are presented in Table 3.

From Figure 3, it is clear that P2 reduced odors to lowest levels (68% reduction). P1, P3, and P4 were able to reduce odors approximately 50%. P5 and P6 appeared to be least effective, since both the products reduced odors to less than 35%. Comparing these results (Figure 3) with that obtained for overall effectiveness of products (Figure 2), it can be seen that the order of odor reduction achieved by different products was similar.

Examination of Table 3 shows that P1 had the same effectiveness as P2, P3, and P4, but was different from P5 and P6. P2 was found equal to P1 and P3 in its odor reduction potential. P3 was equal to all the products except P6. P4 was equal to P1, P3 and P5, whereas P5 had the same effectiveness level as P3, P4 and P6. P6 had the same effectiveness as P5. Among all the products, P1, P2, and P3 were interchangeably equal to each other.

Comparison of Effectiveness Under Unagitated Storage Condition

Multiple comparison tests presented in Table 4 revealed that the LSM of odor levels induced by the products under unagitated storage conditions were statistically equal. This inference was



	P1	P2	P3	P4	P5	P6
Agitated	2.43	1.61	2.45	2.46	3.29	3.46
Unagitated	2.71	1.98	2.58	2.11	2.44	2.64

Figure 3. Effect of waste storage conditions on dairy waste.

Table 3. Tukey-Kramer multiple comparisons between products for dairy waste under agitated storage conditions.

Odor levels (Least-Square Means)		Comparisons to other Products (p-values)					
		P1	**P2**	**P3**	**P4**	**P5**	**P6**
P1	2.43		E* (0.0693)	E (1)	E (1)	NE (0.0387)	NE (0.0038)
P2	1.61	E (1)		E (0.0526)	NE (0.0467)	NE (0.0001)	NE (0.0001)
P3	2.45	E (1)	E (0.0526)		E (1)	E (0.0561)	NE (0.0062)
P4	2.46	E (1)	NE (0.0467)	E (1)		E (0.0581)	NE (0.0064)
P5	3.29	NE (0.0387)	NE (0.0001)	E (0.0561)	E (0.0581)		E (1)
P6	3.46	NE (0.0038)	NE (0.0001)	NE (0.0062)	NE (0.0064)	E (1)	

***Comparisons marked with letter 'E' represents equalities and those with 'NE' show inequalities among products.**

Table 4. Tukey-Kramer multiple comparisons between products for dairy waste under unagitated waste storage condition.

Odor levels (Least-Square Means)		Comparisons to other Products (p-values)					
		P1	**P2**	**P3**	**P4**	**P5**	**P6**
P1	2.71		E* (0.1543)	E (1)	E (0.4455)	E (0.9959)	E (1)
P2	1.98	E (0.1543)		E (0.4345)	E (1)	E (0.8153)	E (0.2779)
P3	2.58	E (1)	E (0.4345)		E (0.7986)	E (1)	E (1)
P4	2.11	E (0.4455)	E (1)	E (0.7986)		E (0.9815)	E (0.6359)
P5	2.44	E (0.9959)	E (0.8153)	E (1)	E (0.9815)		E (0.9997)
P6	2.64	E (1)	E (0.2779)	E (1)	E (0.6359)	E (0.9997)	

*** Comparisons marked with letter 'E' represents equalities and those with 'NE' show inequalities among product .**

supported by Figure 3, since these values for all the products can be observed to be little different from each other.

Agitated vs. Unagitated Comparison

Effectiveness of each product under agitated storage conditions was compared to all the products including itself under unagitated storage conditions. The results are presented in Table 5. It was observed that P1, P2, P3, and P4 had equal odor reduction potential for both the storage conditions. P5 reduced odor to 34% under agitated conditions, but its odor reduction potential was higher under unagitated storage conditions (51%). Similarly, odor reduction potential of P6 increased significantly from 31% for agitated conditions to 47% for unagitated conditions. The odor reduction potential of each product under agitated storage conditions was compared to those of other products under unagitated conditions (Table 5). Since results of these comparisons do not reveal any important information, they are not discussed.

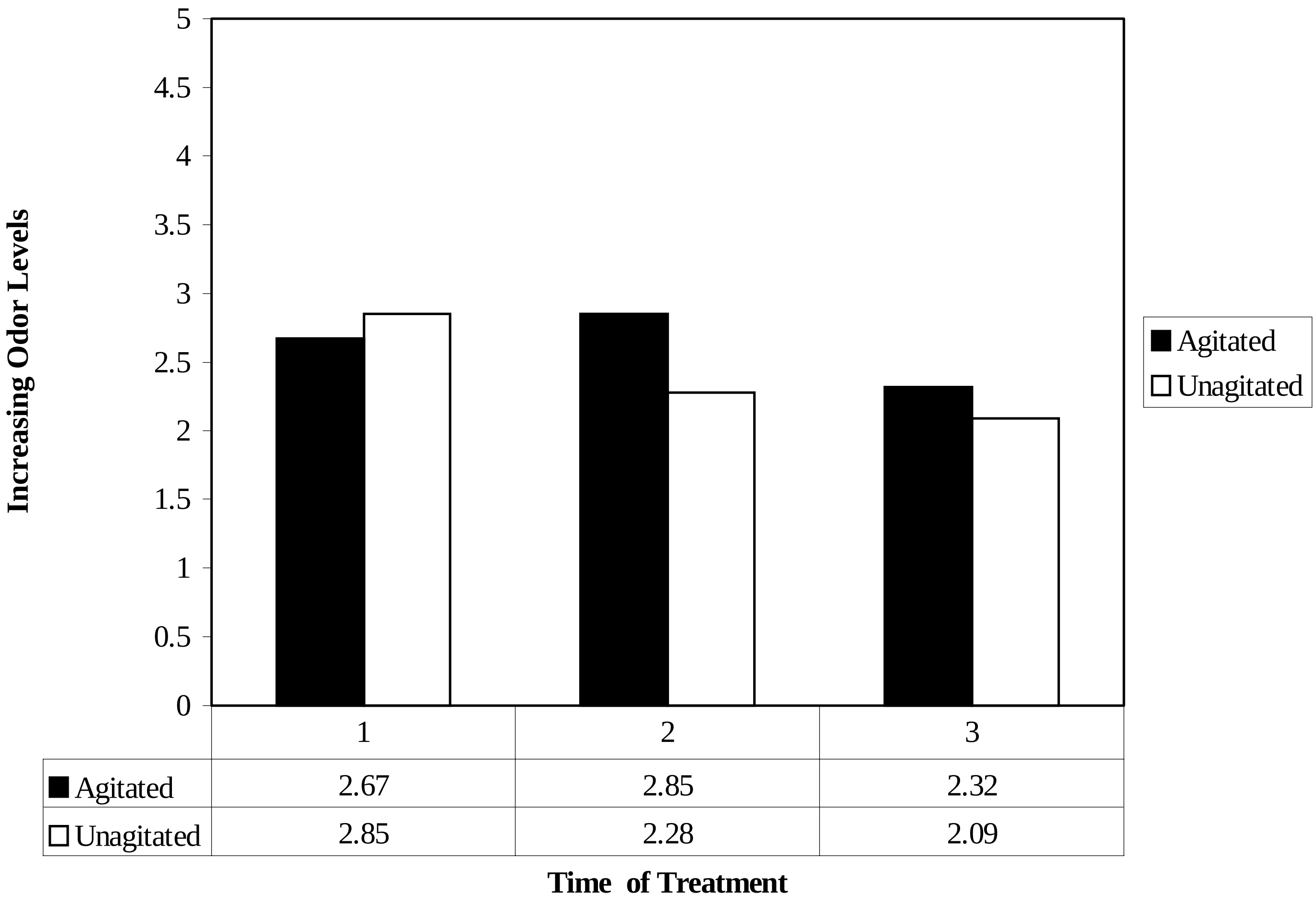
Effect of Storage Time on Odor Levels

As mentioned earlier, odor evolution from dairy waste was affected by the waste storage time. Least square means of odor levels from dairy wastes at the three events of treatments are presented in Figure 4. Odor reduction in week 1 reached 46% for agitated waste, but increased in the last week of study (53%). Similarly, unagitated storage conditions exhibited 43% odor reduction in the first week of treatment, but showed increased reduction levels (week 2 = 54% and week 3 = 58%) in the later two weeks. Observation of Figure 4 suggests that odor level was higher from unagitated dairy waste than from the agitated condition at the beginning of the study,

Table 5. Tukey-Kramer multiple comparison between agitated and unagitated dairy waste for product effectiveness.

Products under Agitated Condition	Comparisons to other Products under Unagitated Condition (p-values)					
	P1	**P2**	**P3**	**P4**	**P5**	**P6**
P1	E* (0.9936)	E (0.8431)	E (1)	E (0.9865)	E (1)	E (0.9995)
P2	NE (0.0014)	E (0.9582)	NE (0.0103)	E (0.7427)	E (0.0642)	NE (0.0041)
P3	E ((0.9978)	E (0.7886)	E (1)	E (0.9749)	E (1)	E (0.9999)
P4	E (0.9982)	E (0.7689)	E (1)	E (0.9665)	E (1)	E (0.9999)
P5	E (0.5192)	NE (0.0001)	E (0.1979)	NE (0.0004)	NE (0.0397)	E (0.3390)
P6	E (0.1464)	NE (0.0001)	NE (0.0328)	NE (0.0001)	NE (0.0049)	E (0.0629)

*** Comparisons marked with letter 'A' represents equalities and those with 'NE' show inequalities among products.**



	1	2	3
Agitated	2.67	2.85	2.32
Unagitated	2.85	2.28	2.09

Figure 4. Odor levels from dairy waste at three times of treatments.

but decreased over time. This can be attributed to differences in microbial activities in the two storage conditions, and retention time.

The trend analyses (Figure 5 and 6) results show that the dairy waste reflected a quadratic trend for both waste conditions. Although for unagitated conditions a quadratic trend was found to be more befitting, a decreasing linear trend seemed more appropriate.

Trends in Product Effectiveness

Products action was different from one treatment event to the other. Figure 7 presents the least-square means of odor levels for each product at the three times of treatments in graphical form. P2 can be observed to have achieved the highest odor reduction level in week 1(58%) and week 2 (66%). However, P6 was not as effective as the other products throughout the study period, although it improved with time. P3 and P5 also improved in effectiveness levels as the waste storage time increased. The trend in the odor reduction potential of P4 was notable. In week 1, P4 reached an average level of odor reduction (53%), but in week 2 its effectiveness was as low as P6 (39%). However, in the last week the odor reduction potential of P4 was the highest among all the products (70%).

The trends of product effectiveness with time are presented in Figure 8. P1 and P4 showed a quadratic trend over time. The effectiveness level for P1 was at its best in the second week, but P4 was least effective at this time. The rest of the products improved over time, hence showed a decreasing linear trend.

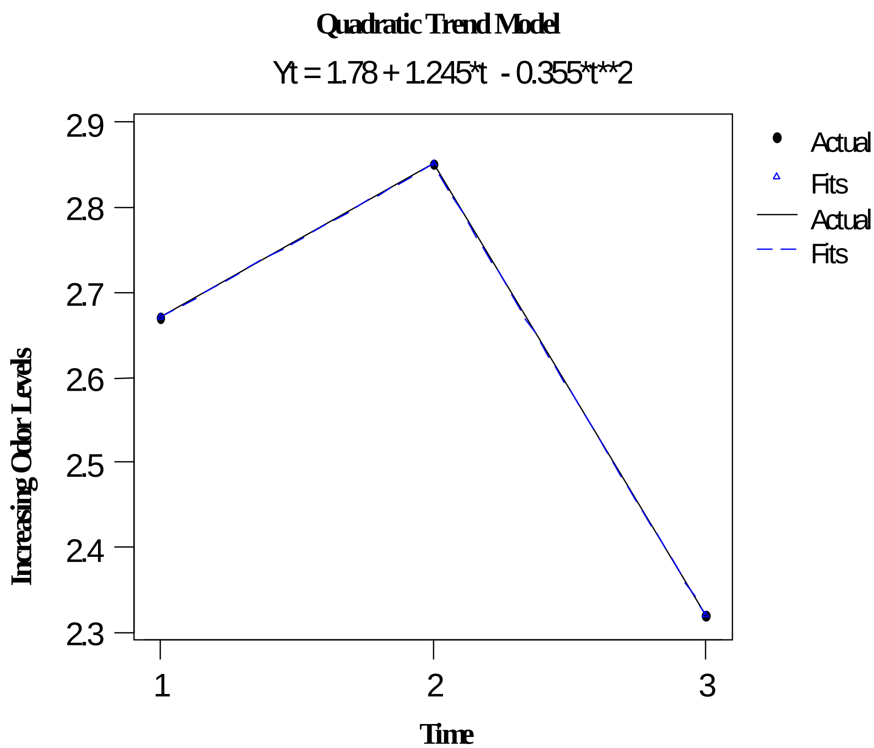


Figure 5. Trend analysis for agitated dairy waste

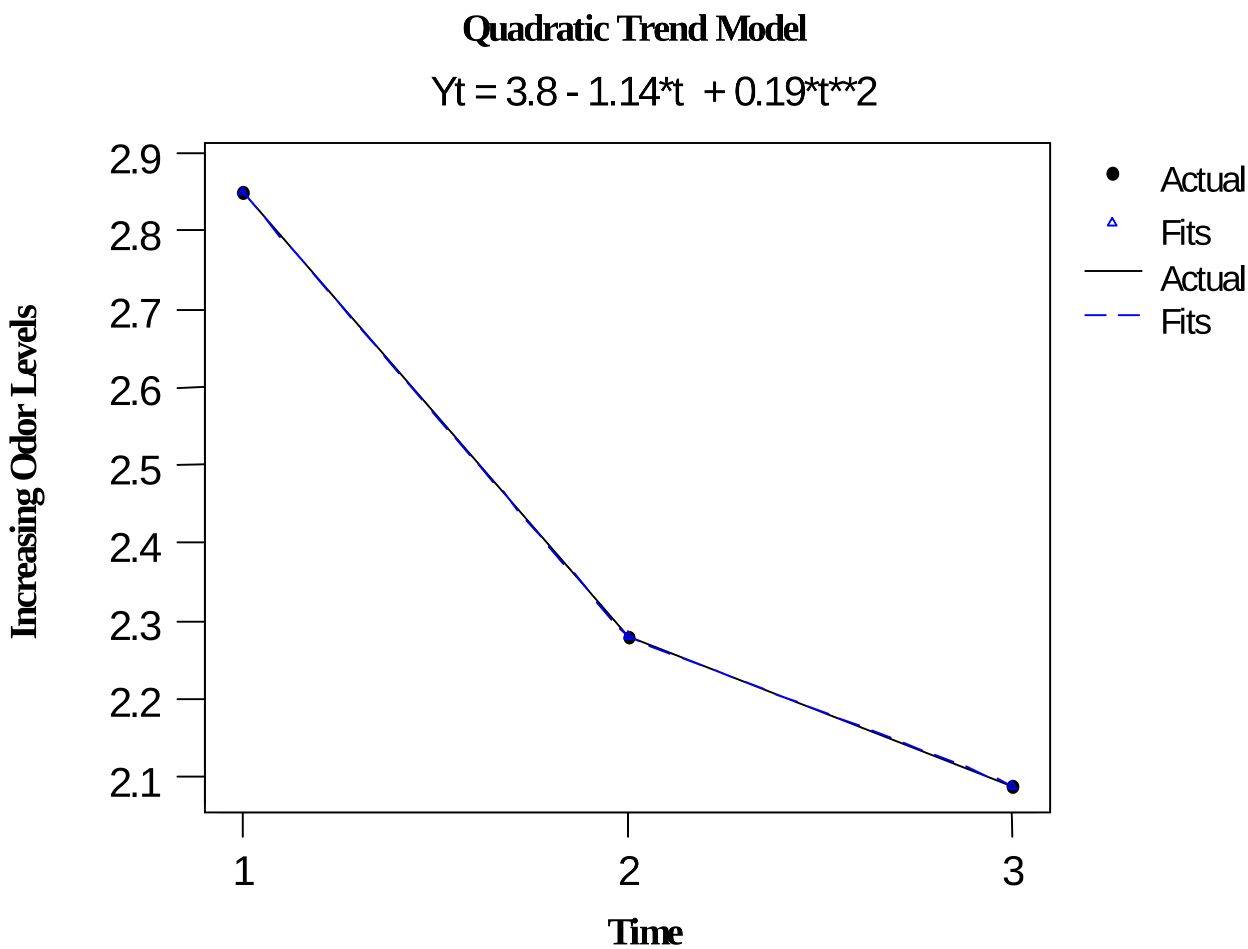
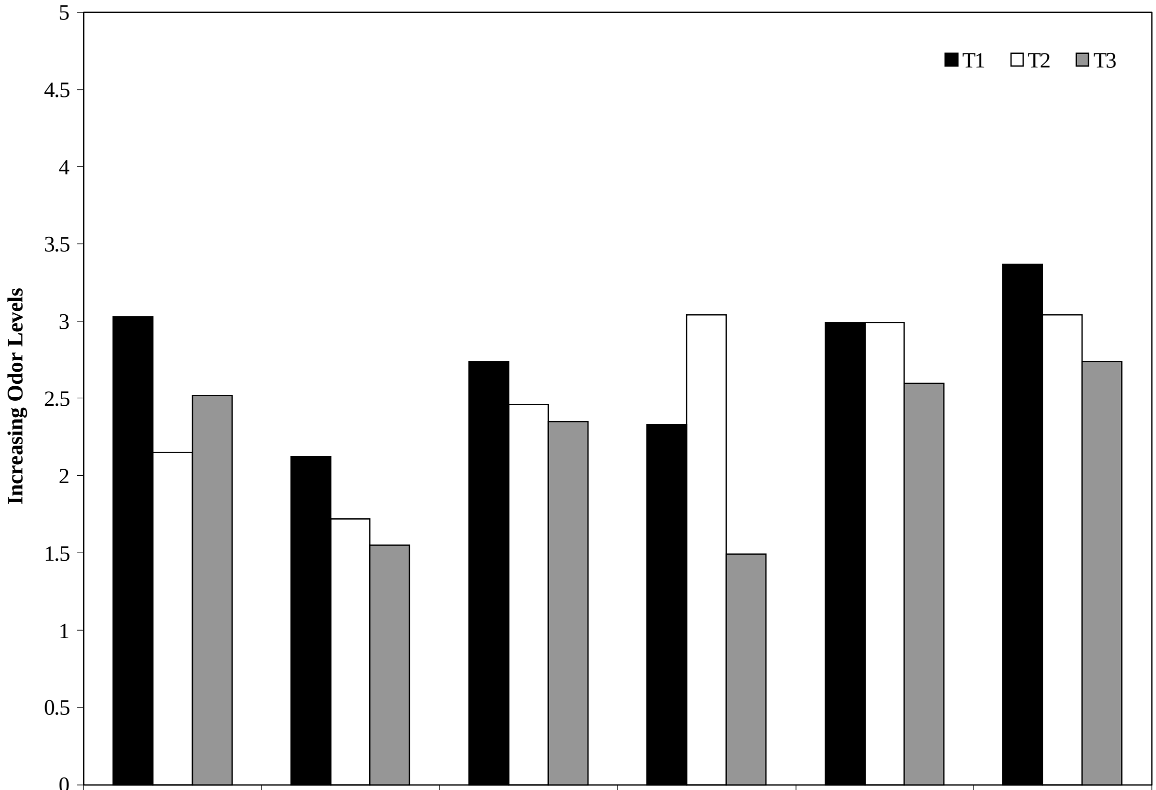


Figure 6. Trend analysis for unagitated dairy waste.



	P1	P2	P3	P4	P5	P6
T1	3.03	2.12	2.74	2.33	2.99	3.37
T2	2.15	1.72	2.46	3.04	2.99	3.04
T3	2.52	1.55	2.35	1.49	2.6	2.74

Figure 7. Product effectiveness on dairy waste at three times of treatment.

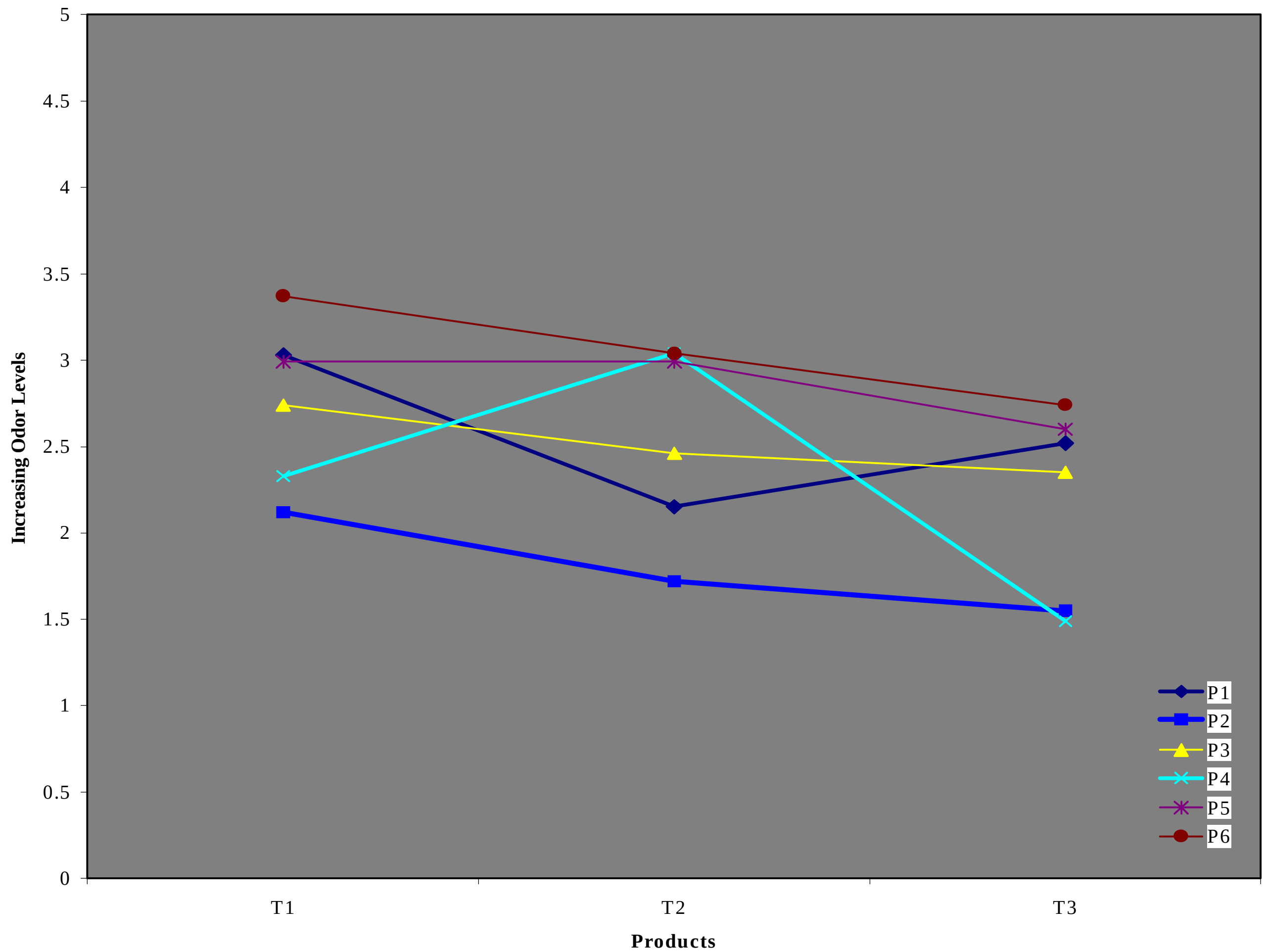


Figure 8. Trends in product effectiveness for dairy waste.

Product Effectiveness for Swine Waste

Factors and Interactions

The results for hypotheses tested for determining the presence of factors and interactions are presented in Table 6. As with dairy waste (Table 1), the three factors examined were product, storage time, and panelist which were all found to be significant at $\alpha = 0.05$ for swine waste (Table 6). All the three null hypotheses for testing the interactions were rejected, and it was concluded that statistically significant interactions were present between: waste storage conditions and products; waste storage conditions and storage time; and storage time and products (Table 6).

Comparisons of Product Effectiveness

Similar to dairy waste, four sets of Tukey-Kramer multiple comparison tests were performed for swine waste. A discussion of these comparisons follows.

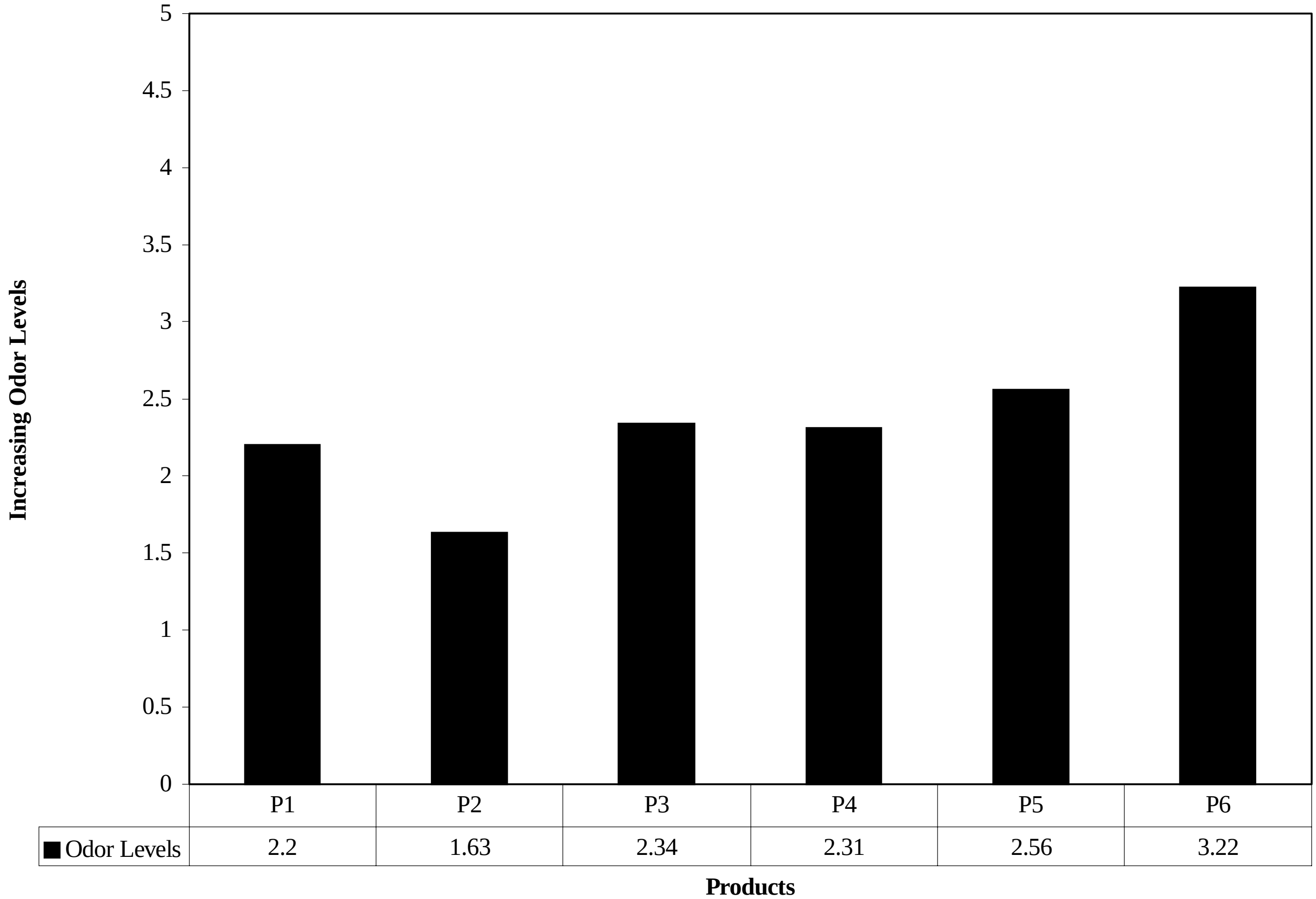
Comparison of Overall Effectiveness

Figure 9 shows the LS mean of overall values for odor levels achieved by each product. As shown in Figure 9, all but one product (P6) was able to reduce the odor levels by approximately 50% or more. P6 was able to reduce the odor levels only by 36% and therefore was least effective in reducing the odor levels.

Results for Tukey-Kramer multiple comparisons for overall effectiveness are presented in Table 7. Examination of Table 7 reveals that there are no pair-wise differences among P1, P3, P4, and

Table 6. Hypothesis testing of main factors and their interactions for swine waste.

Source of Variability	Hypothesis	p-value	Decision
Products (1, 2, 3, 4, 5, 6)	Ho: No differences in odor levels due Products H1: Differences in odor levels due to products	0.0001	Difference in odor levels due to products
Storage time (1, 2, 3)	Ho: No differences in odor levels in the three weeks of storage H1: Differences in odor levels in the three weeks of storage	0.0015	Difference in odor levels in the three weeks of treatment
Panelists (1---40)	Ho: No differences in observations made by panelists H1: Differences in observations made by panelists	0.0001	Difference in each panelist observation
Condition of wastes * Products	Ho: No differences due to interaction between condition of wastes and products H1: Differences due to interaction between condition of wastes and products	0.0001	Interaction present
Condition of wastes * Waste storage time	Ho: No differences due to interaction between condition of wastes and Waste storage time H1: Differences due to interaction between condition of wastes and Waste storage time	0.0001	Interaction present
Product * Waste storage time	Ho: No differences due to interaction between products and Waste storage time H1: Differences due to interaction between products and Waste storage time	0.0001	Interaction present



	P1	P2	P3	P4	P5	P6
Odor Levels	2.2	1.63	2.34	2.31	2.56	3.22

Figure 9. Overall product effectiveness on swine waste.

Table 7. Tukey-Kramer multiple comparisons between products for swine waste.

Odor levels (Least-Square Means)		Comparisons to other Products (p-value)					
		P1	**P2**	**P3**	**P4**	**P5**	**P6**
P1	2.2		NE* (0.003)	E (0.949)	E (0.984)	E (0.1834)	NE (0.0001)
P2	1.63	NE (0.003)		NE (0.0001)	NE (0.0002)	NE (0.0001)	NE (0.0001)
P3	2.34	E (0.949)	NE (0.0001)		E (0.9999)	E (0.7021)	NE (0.0001)
P4	2.31	E (0.984)	NE (0.0002)	E (0.9999)		E (0.566)	NE (0.0001)
P5	2.56	E (0.1834)	NE (0.0001)	E (0.7021)	E (0.566)		NE (0.0003)
P6	3.22	NE (0.0001)	NE (0.0001)	NE (0.0001)	NE (0.0001)	NE (0.0003)	

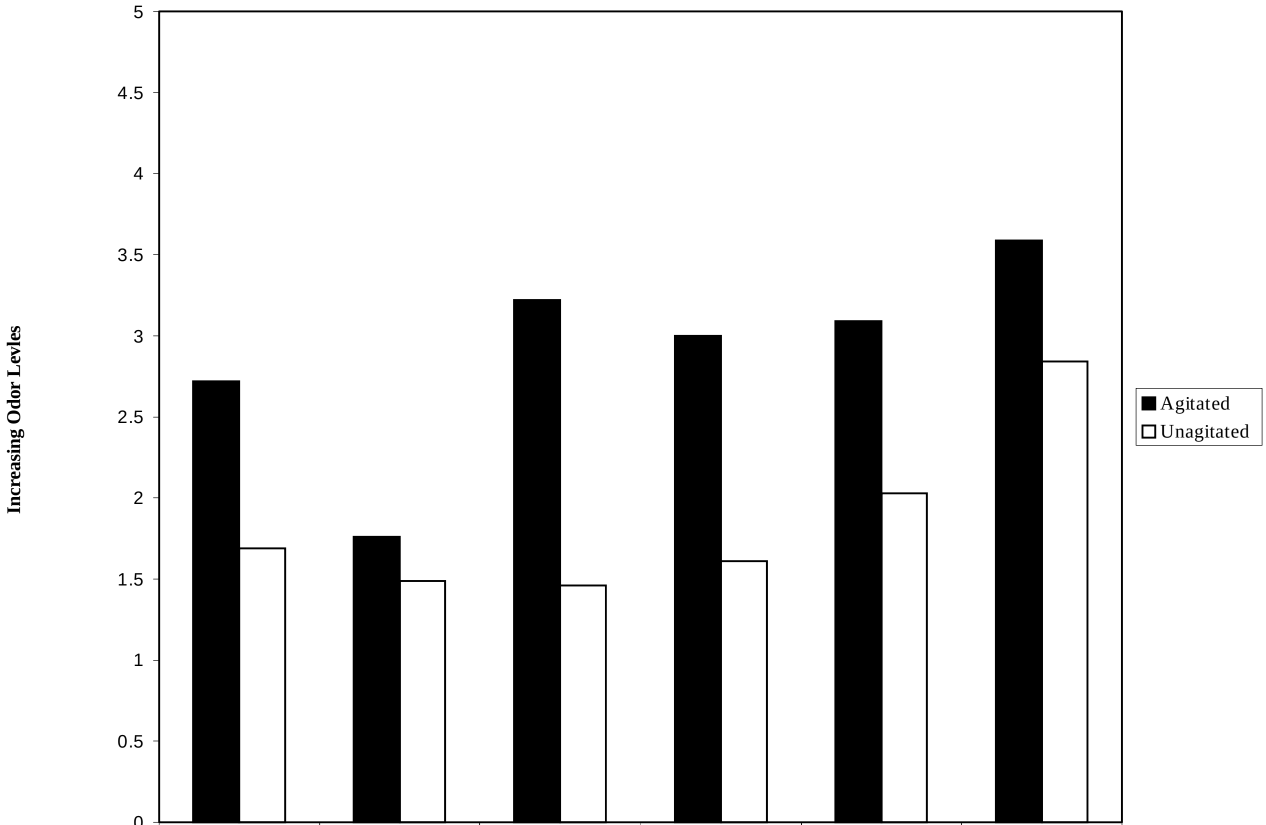
*** Comparisons marked with letter 'E' represent equalities and those with 'NE' show inequalities among products.**

P5. This was to be expected since the differences in odor levels achieved by these products were less than 0.36. P2 and P6 were different from all the products as well as from each other. Uniqueness of P2 was expected since the odor level reduction achieved by this product was approximately 0.6 units or more than other products. Uniqueness of P6 can also be explained by the fact that all the other products were able to reduce the odor levels by more than 0.6 units or more as compared to P6.

Comparison of Effectiveness Under Agitated Storage Condition

Odor reductions achieved by the six products are shown graphically in Figure 10 for both agitated and unagitated conditions. Examination of LSM for agitated storage conditions reveals that, among all the products, only P2 was able to reduce the odor levels by more than 50% (65% reduction) (Figure 10). P6 was the least effective product since it achieved odor reduction of 28%. All the remaining products, namely P1, P3, P4, and P5 were able to achieve odor reduction in the range of 35 to 45%.

Results of Tukey-Kramer multiple comparison tests for agitated storage conditions are presented in Table 8. Odor levels achieved by P1, P3, P4, and P5 were statistically equal to each other. This was expected since these four products achieved the similar levels of odor reduction (35 to 45%). P2 and P6 were found to be statistically different from each other as well as from all other products. Comparison of multiple comparison test results for overall effectiveness (Table 7) and for agitated conditions (Table 8) reveals an interesting point: similarities and differences obtained for overall effectiveness and effectiveness under agitated conditions are same (Tables 7 and 8).



	P1	P2	P3	P4	P5	P6
■ Agitated	2.72	1.76	3.22	3	3.09	3.59
□ Unagitated	1.69	1.49	1.46	1.61	2.03	2.84

Products

Figure 10. Effect of waste storage condition on swine waste.

Table 8. Tukey-Kramer multiple comparisons between products for swine waste under agitated storage conditions.

Odor levels (Least-Square Means)		Comparisons to other Products (p-value)					
		P1	**P2**	**P3**	**P4**	**P5**	**P6**
P1	2.72		NE* (0.0007)	E (0.4844)	E (0.9774)	E (0.8533)	NE (0.0035)
P2	1.76	NE (0.0007)		NE (0.0001)	NE (0.0001)	NE (0.0001)	NE (0.0001)
P3	3.22	E (0.4844)	NE (0.0001)		E (0.9981)	E (1)	E (0.8456)
P4	3.00	E (0.9774)	NE (0.0001)	E (0.9981)		E (1)	E (0.2166)
P5	3.09	E (0.8533)	NE (0.0001)	E (1)	E (1)		E (0.4733)
P6	3.59	NE (0.0035)	NE (0.0001)	E (0.8456)	E (0.2166)	E (0.4733)	

*** Comparisons marked with letter 'E' represents equalities and those with 'NE' show inequalities among products.**

Comparison of Effectiveness Under Unagitated Storage Condition

Examination of results of unagitated storage conditions show odor reduction achieved by all the products were lower than those achieved under agitated storage conditions. P3 was found to be the most effective product with an odor reduction potential of 71%. However, P2 was a close second, with 70% odor reduction level. All the other products were able to reduce odors in a range of 60 to 68%. P6 had the least effectiveness level, as it was able to reduce odors to 43%.

Multiple comparison tests results for unagiated storage condtions are presented in Table 9. These results revealed that, with an exception of P6, there was no significant difference in the effectiveness levels of all the other products. This result could be related to the above mentioned inferences, as differences in odor reduction levels for P1 through P5 was no more than 0.5 units. The difference between the odor reduction level of P6 and other products was at least 0.8 units.

Agitated vs. Unagitated

On examining Figure 10, it was found that: P1 reduced odors 1.03 units less under unagitated storage conditions, than it did under agitated storage conditions; P2 showed a slight increase in its odor reduction potential from agitated to unagitated conditions (from 65% to 70%); P3 showed highest level of difference from 36 to 71%; and P4, P5 and P6 too had an improved odor reduction level for unagitated storage conditions.

Each product under agitated storage conditions was compared to all the products including itself under unagitated storage conditions. The results are presented in Table 10. Statistical comparisons can be compared to the above mentioned results. P2 was the only product, which

Table 9. Tukey-Kramer multiple comparisons between products for swine waste under unagitated waste storage condition.

Odor levels (Least-Square Means)		Comparisons to other Products (p-value)					
		P1	**P2**	**P3**	**P4**	**P5**	**P6**
P1	1.69		E* (0.9994)	E (0.9971)	E (1)	E (0.9158)	NE (0.0001)
P2	1.49	E (0.9994)		E (1)	E (1)	E (0.3761)	NE (0.0001)
P3	1.46	E (1)	E (1)		E (0.9999)	E (0.2780)	NE (0.0001)
P4	1.61	E (1)	E (1)	E (0.9999)		E (0.7427)	NE (0.0001)
P5	2.03	E (0.3761)	E (0.3761)	E (0.2780)	E (0.7427)		NE (0.0108)
P6	2.84	NE (0.0001)	NE (0.0001)	NE (0.0001)	NE (0.0001)	NE (0.01080	

*** Comparisons marked with letter 'E' represents equalities and those with 'NE' show inequalities among products.**

Table 10. Tukey-Kramer multiple comparison between agitated and unagitated swine waste for product effectiveness.

Products under Agitated Condition	Comparisons to other Products under Unagitated Condition (p-value)					
	P1	**P2**	**P3**	**P4**	**P5**	**P6**
P1	NE* (0.0002)	NE (0.0001)	NE (0.0001)	NE (0.0001)	NE (0.0718)	E (1)
P2	E (1)	E (0.9886)	E (0.9708)	E (0.9999)	E (0.9851)	NE (0.0001)
P3	NE (0.0001)	NE (0.0001)	NE (0.0001)	NE (0.0001)	NE (0.0001)	E (0.8625)
P4	NE (0.0001)	NE (0.0001)	NE (0.0001)	NE (0.0001)	NE (0.0006)	E (0.9999)
P5	NE (0.0001)	NE (0.0001)	NE (0.0001)	NE (0.0001)	NE (0.0001)	E (0.9920)
P6	NE (0.0001)	NE (0.0001)	NE (0.0001)	NE (0.0001)	NE (0.0001)	NE (0.0271)

*** Comparisons marked with letter 'E' represents equalities and those with 'NE' show inequalities among products.**

achieved equal effectiveness level for both storage conditions. All the other products improved significantly, in their effectiveness from agitated to unagitated storage conditions.

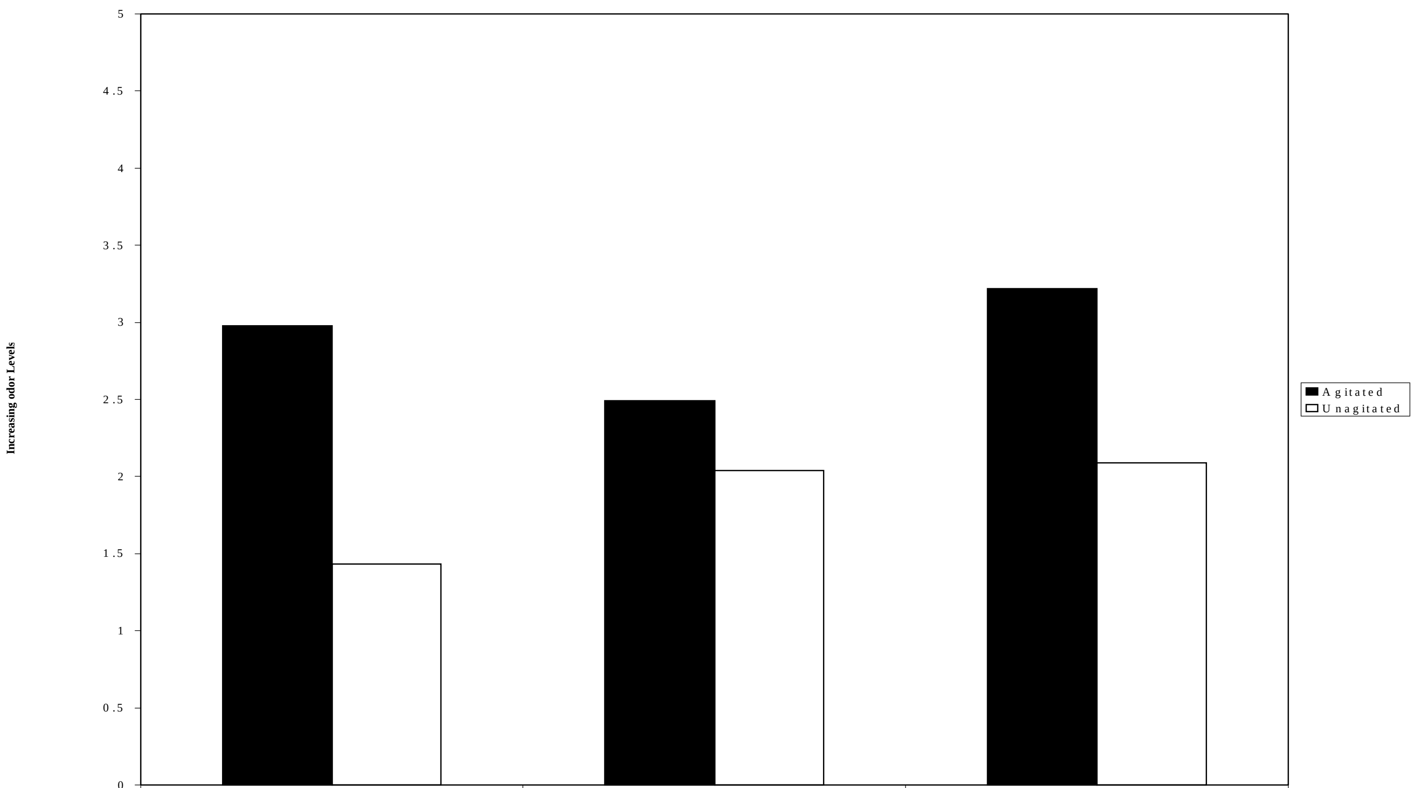
Effect of Storage Time on Odor Levels

Least square means of odor levels from swine wastes at the three events of treatments are presented in Figure 11. Week 1 showed a decrease of 40% in odor levels, but was much lower in the second week of study (50%). Odor reductions in the third week was only 36%. Unagitated storage conditions exhibit 71% odor reduction in the first week of treatment, but as the week passed odor reduction levels decreased to 59% and 58% in the later two weeks. Observation of Figure 11 suggests that odor levels were always higher from agitated swine waste than from unagitated storage condition.

The trend analyses (Figure 12 and 13) show that a quadratic trend best fitted odor levels for both storage conditions, but a glance at the LSM for unagitated storage conditions shows that, as time passed, there was an increase in odor levels.

Trends in Product Effectiveness

Figure 14 represents the LSM of odor levels achieved by each product in the three week test period. The products which were more effective in the first week were P1, P4, and P5. P2 had equal odor reduction levels in the first two weeks (72%), but its effectiveness dropped to 0.7 units in the last week. Despite a drop in its effectiveness level, P2 remained the most effective of all the products at all times. The odor reduction level of P6 was between 25 to 45%, which was



	1	2	3
Agitated	2.98	2.49	3.22
Unagitated	1.43	2.04	2.09

Products

Figure 11. Odor levels from swine waste at three times of treatment.

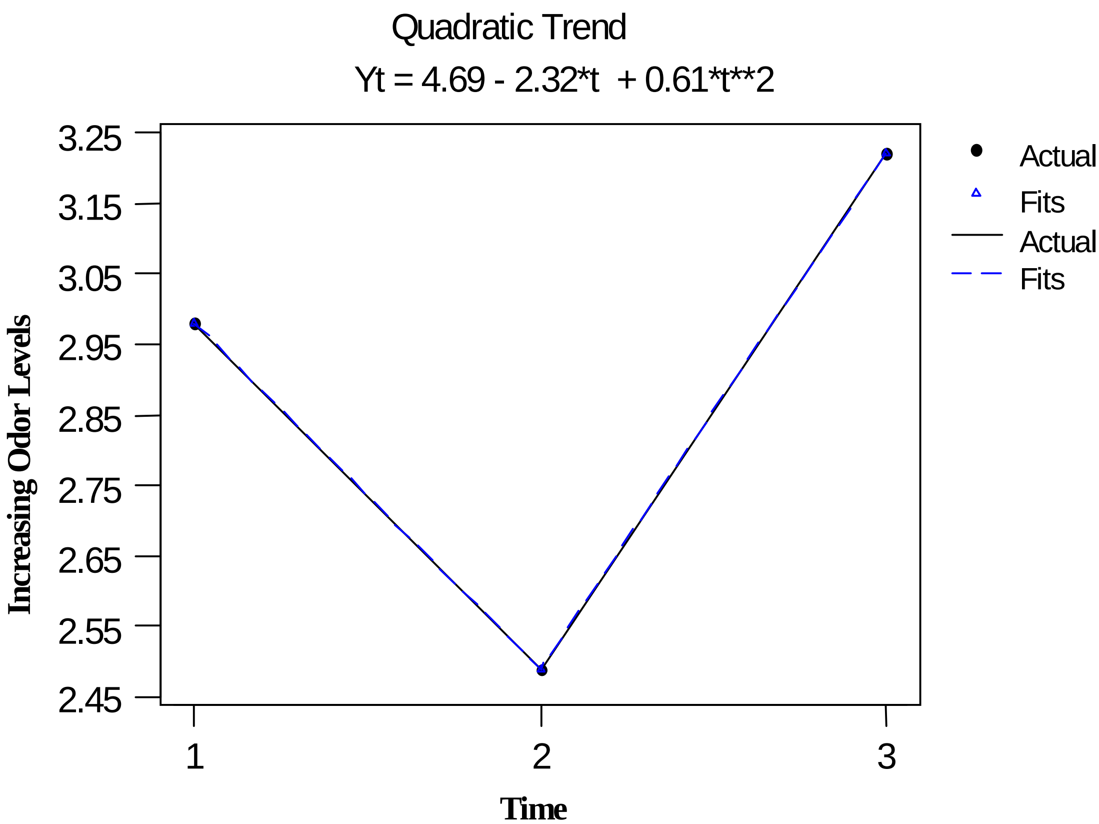


Figure 12. Trend analysis for agitated swine waste.

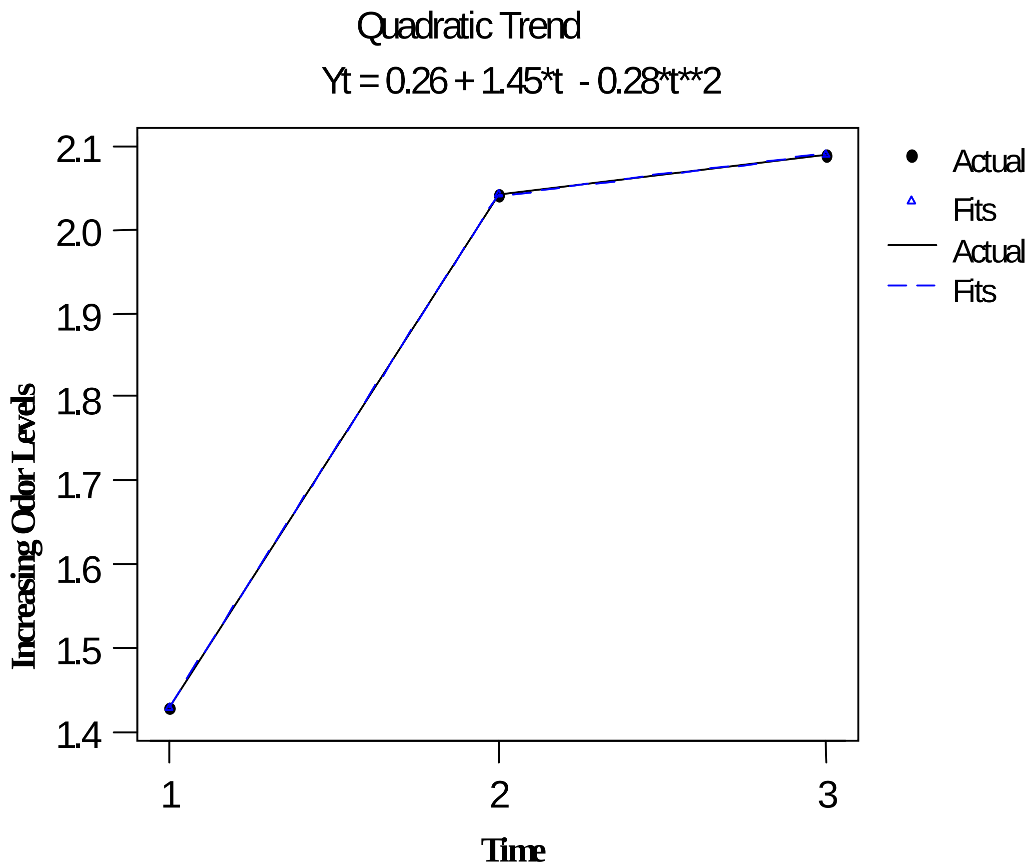
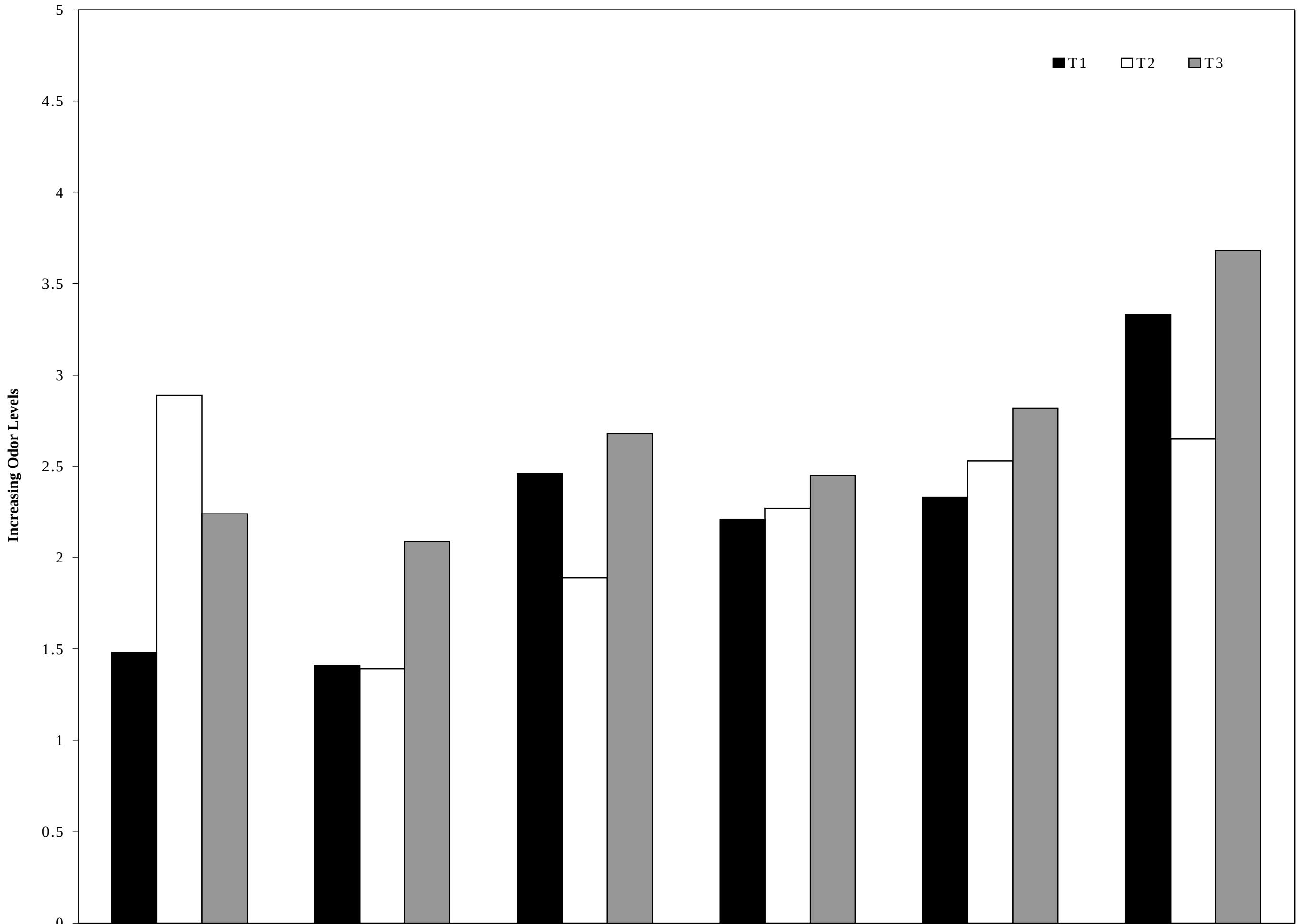


Figure 13. Trend analysis for unagitated swine waste.



	P1	P2	P3	P4	P5	P6
T1	1.48	1.41	2.46	2.21	2.33	3.33
T2	2.89	1.39	1.89	2.27	2.53	2.65
T3	2.24	2.09	2.68	2.45	2.82	3.68

Products

Figure 14. Product effectiveness on swine waste at three times of treatment.

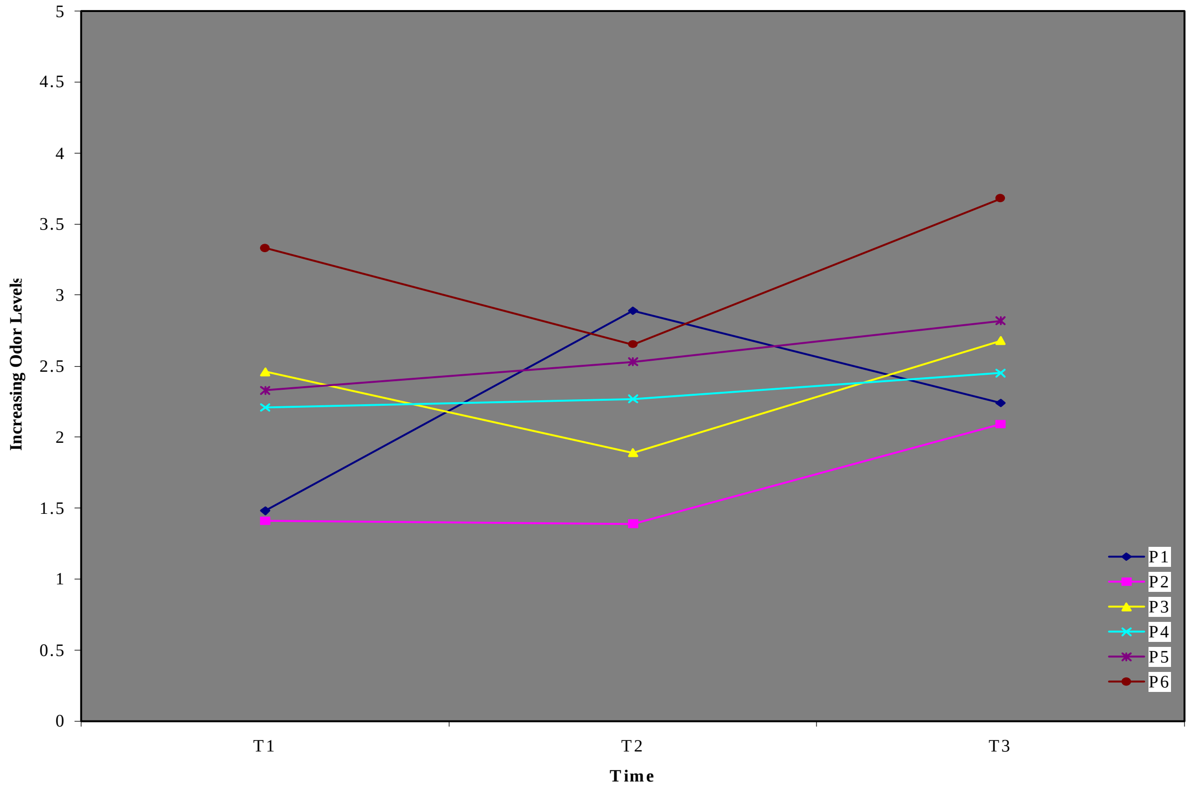


Figure 15. Trends in product effectiveness for swine waste.

the lowest among all the products. All the products except P1 were the least effective in the last week of treatment.

The trend analyses for the products are shown in Figure 15. Quadratic trends of P1, P3 and P6 can be distinctly observed. P2, P4 and P5 were concluded to have reduced odors to same levels at each treatment event, as all of them produced almost straight lines for the plotted values.

A review of the results for both dairy and swine wastes show that P2 reduced odors to the lowest level among all products, and P6 had the highest odor level after treatment. All the other products were somewhere between these two products. Since dairy waste is different from swine waste, no comparisons between the two wastes could be made directly. It is hard to conclude whether the products had better action on dairy or swine waste, but it is relevant to say that unagitated waste storage conditions for swine waste are preferred, but for dairy waste this sort of inference can not be made (Figures 3 and 10). The likely reason can be that microbial activities are more dynamic in agitated conditions due to higher oxygen content than in unagitated conditions.

The trend of product effectiveness of each product was also found to be different for the two wastes which brings us to the conclusion that the response of each product on dairy and swine waste was different. Agitated storage conditions for dairy waste were found favorable for P1, P2 and P3 as compared to unagitated storage conditions. P1 and P3 are digestive and enzymatic cultures, respectively, which are basically an amalgam of many aerobic bacteria. These kind of products work better in an environment stimulated with oxygen, which are induced by agitation of waste. Thus, product-effectiveness was enhanced under agitated conditions. P2 is an oxidizing agent, and more oxygen helps this product achieve odor reduction at a faster pace than the others. P4, P5 and P6 worked better under unagitated conditions. These products may have worked better under unagitated conditions since these conditions the solids tend to settle to the bottom of the tank, thus making the waste supernatant to be treated more dilute in nature. Thus, odor evolution from dairy waste foregoes any particular trend corresponding to storage conditions. Product category (masking agent, chemical or biological deodorizer) seems to be the decisive factor for product effectiveness under the two storage conditions. Swine waste was high in solids content since feces contained much undigested feed material. Solids would take more time to break down and decompose, which can be a probable reason why the odor emissions were of less offensive nature from unagitated swine waste. Thus storage conditions for swine waste have a distinct effect on product effectiveness.

Agitated conditions for both dairy and swine waste indicated a quadratic trend. Dairy waste showed peak odor levels in the second week of the study. The most reasonable explanation can be the height of microbial activity during the second week of waste storage. However, swine waste showed an opposite trend, as odor levels were found to be the lowest at the time of the second treatment event.

Unagitated storage conditions showed the opposite trend on dairy waste (↓) and swine waste (↑) (Figures 6 and 13). Dairy waste was more uniformly distributed, and seemed to be constituted of smaller particle size, thus the settling time of solids would be longer. More solid content suggests higher microbial activity and, hence, enhancement in odor evolution rates and levels. As the solids settled to the bottom of unagitated dairy waste, the supernatant to be treated became dilute in nature. This seems to be a probable explanation for the decrease in odor levels from unagitated dairy waste.

Odor levels from swine waste were not offensive in the beginning of the study, but got worse in the later weeks. Although, swine waste was constituted of more solids which may have settled rapidly, yet as the weeks progressed the rate of solid decomposition may have increased, thus increasing odor levels.

5. SUMMARY AND CONCLUSION

After a comprehensive literature search, the sensory method for odor evaluation was selected for the purpose of this study. Since odor sensation can vary from person to person and its quality is decided on the basis of the majority of the population, a large panel is very useful for its evaluation. For this study, the panelists were asked to identify the presence and intensity of odor. Products were code named P1, P2, P3, P4, P5 and P6 to maintain the confidentiality of the manufacturer. Wastes were collected in 170L containers. Dairy and swine waste were stored under agitated and unagitated conditions, and treatments were carried out twice a week for both dairy and swine waste. The data collected by the panel members were analyzed using various statistical tools, and the following conclusions were reached.

5.1 DAIRY WASTE

- In overall test of effectiveness of products, product P2 was found to be the best in reducing odor levels under all the conditions studied. On the other hand, P6 was the least effective, and the rest of the products were somewhere in between P2 and P6.these two.

- Multiple comparisons between products reflected that for overall effectiveness:

  - P1 = P3, P4, P5, and P6,

  - P2 = P4,

  - P3 = P4 and P5,

- P4 = P1, P2, and P3,
- P5 = P1, P3, and P6,
- P6 = P1 and P5.

♦ Storage conditions had an effect on product effectiveness, but there was no indication that one condition was more favorable than the other for all the products. Some products responded better for agitated conditions (P1, P2, and P3), and the others worked better under unagitated conditions.

♦ Multiple comparisons for product effectiveness under agitated conditions yielded the following results:

- P1 = P2, P3, and P4,
- P2 = P1 and P3,
- P3 = P1, P2, P4, and P5,
- P4 = P1, P3, and P5,
- P5 = P3, P4, and P6, and
- P6 = P5.

♦ For unagitated conditions, all the products were found to be equal to each other.

- Products were also compared interchangeably for the two storage conditions and product effectiveness under agitated conditions with the following results:
  - P1 under agitated storage conditions (A) = P1, P2, P3, P4, P5, and P6 under unagitated storage conditions (U),
  - P2 (A) = P2, P4, and P5 (U)
  - P3 and P4 (A)= P1, P2, P3, P4, P5, and P6 (U),
  - P5(A) = P1, P3, and P6 (U), and
  - P5 (A) = P1 and P6(U).
- Odor levels for both storage conditions were statistically different from one week to the other. The trends were analyzed to investigate any effect of time. Quadratic trends were found to best fit the data for both storage conditions, but a decreasing linear trend for unagitated conditions was found more appropriate.
- Product effectiveness was examined for the trends, and it was discovered that P1 and P4 had a quadratic trend whereas the others showed a decreasing linear trend.

5.2 SWINE WASTE

- In overall effectiveness P2 produced the lowest odor levels and P6 induced higher odor levels than the other products.

- Multiple comparisons for overall effectiveness revealed the following results:
  - P1 = P3, P4 and P5,
  - P2 had a different effectiveness level from all the other products,
  - P3 = P1, P4, and P5,
  - P4 = P1, P3, and P5,
  - P5 = P1, P3, and P4 and
  - P6 was not equal to any of the other products.
- Storage conditions showed a distinct effect on odor levels. Lower odor levels were induced by all products under unagitated storage conditions.
- For agitated storage conditions, comparisons between products revealed the following results:
  - P1 = P3, P4, and P5,
  - P2 was different from all the other products,
  - P3 = P1, P4, P5 and P6,
  - P4 = P1, P3, P5, and P6,
  - P5 = P1, P3, P4 and P6, and

- P6 = P3, P4, and P5.

- Under unagitated conditions, multiple comparisons between products revealed that all the products had an equal level of effectiveness, except P6, which was different from other products.

- When the products were compared interchangeably under agitated and unagitated storage conditions, the following results were achieved:

  - P1 (A) was not equal to any other product or itself under unagitated conditions,
  - P2 (A) = P1, P2, P3, P4 and P5 (U),
  - P3 (A) = P6 (U),
  - P4 (A) = P6 (U)
  - P5 (A) = P6 (U), and
  - P6 (A) was unequal to any other product under unagitated storage conditions or itself.

- Statistical analysis revealed that odor levels for both storage conditions changed over time. Trends were analyzed to investigate the effect of time, and quadratic trends were found to best fit the data for both storage conditions.

- Trends for product effectiveness were examined and it was observed that P1 P3, and P6 had a quadratic trend. Odor levels induced by P2, P4, and P5 had little or no difference for all the three treatment events.

5.3 *OVERALL CONCLUSIONS*

- It can be concluded from this study that the products in general were effective in reducing odors from both dairy and swine wastes.

- For both dairy and swine wastes, P2 successfully reduced odors to very low levels. However, none of the products were able to totally eliminate odors. The odor levels induced by P6 were not as low as was desired. The other products were rated average in their effectiveness.

- Storage time affected the odor levels from both dairy and swine waste, for both storage conditions. Agitated conditions exhibited a quadratic trend for both waste types, although the trends were in contrast to each other.

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APPENDIX

Figure A-1 (a). Dairy waste.

Figure A-1 (b). Swine waste.

Figure A-2. Transfer of waste in treatment jars.

Figure A-3. Treatment samples in the odor sniffing room.

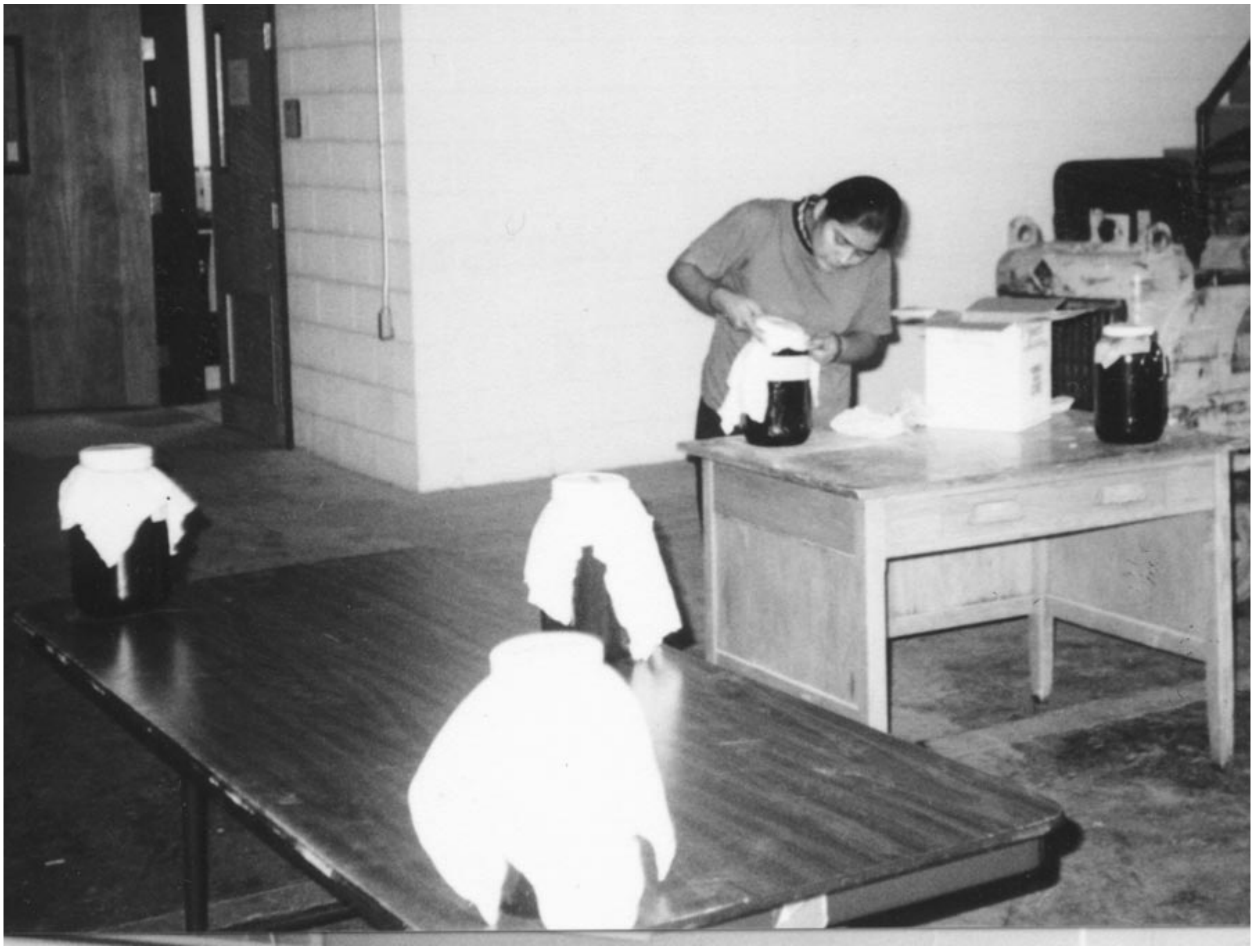

Figure A-4. Odor evaluation session.

VITA

I Shuchi S. Shukla was born to Shakuntala and Akhilesh K. Misra in Allahabad India. I grew up in Allahabad under the supervision of my Grandmother. In 1990, I earned the Degree of B. Tech in Agricultural Engineering, from Allahabad University, India. I worked as a Design Engineer for Sonmati Engineering Works, India from 1990-1991. I was a Degree Apprentice Trainee from 1991-1992, in the Minor Irrigation Division, Government of India. I earned a Post-Graduate Diploma in Industrial Pollution Management, in 1993 from National Institute of Management, India. I joined the Biological Systems Engineering Department for the Master's Program in the spring of 1996.