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Development of procedures for assessment and documentation of odorous impacts on a community.

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NOTICE

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DEVELOPMENT OF PROCEDURES FOR ASSESSMENT AND DOCUMENTATION OF ODOROUS IMPACTS ON A COMMUNITY

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ABSTRACT

There is an increasing need to develop procedures for assessing the impacts of odorous emissions on communities surrounding stationary sources. The formulation and implementation of regulations depend on the availability of acceptable sampling techniques and objective measurement procedures.

This report deals with the development of objective measurement procedures through which odorous impacts can be evaluated in terms of detection, discrimination and complaint potential thresholds as well as degrees of complaint related to concentrations of a major component or indicator of an odorous source emission. This work emphasizes the need for both sensory and analytical measurement of odors.

Health aspects of odors in terms of their effects on the general public have been reviewed. The need for control regulations has been emphasized. Current methods of measurement of public reactions to odors in terms of spontaneous complaints and social surveys have been discussed. Traditional sensory dimensions of odorous materials, such as detectability, intensity, hedonics and quality have been described briefly. New dimensions defined as discrimination thresholds, complaint potentials and degrees of complaint have been introduced. Several methods of data analysis used for the evaluation of odor detection thresholds were examined through application to two samples of n-butanol. Panels of 7 and 10 people working with a six level IITRI ternary forced-choice dynamic olfactometer were presented with initial

concentrations of 99.46 and 52.06 ppm n-butanol during three trials. The Hall-Ellis Ranking and Modified Dravnieks methods were also applied to the evaluation of discrimination thresholds of the odorous samples. It was found that single evaluations of detection or discrimination thresholds by either methods would always be within ± 50% of the mean of six trials. The effect of successful guessing on the magnitude of detection thresholds was examined in terms of the principle of maximum likelihood estimation of one, two and three trials of panel responses. The discrimination threshold obtained by this method always falls between the detection and discrimination thresholds evaluated by the currently used models. The mean discrimination threshold of n-butanol for six trials was found to be 0.65 ± 0.25 ppm measured as butane equivalent. It would appear that the magnitude obtained from one trial would be sufficiently reliable for most practical purposes, since any subsequent trials would not produce threshold values better than ± 40% of the mean of six trials.

The models were also applied to practical situations involving emissions from a fast food restaurant and vegetable oil odors generated in the laboratory. The use of oleic acid as the major component for the measurement of sensory properties of odorous emissions from fast food restaurants is suggested. The application of the Major Component Odor Impact Model was demonstrated through the assessment of the impact of fish odors, in terms of triethylamine content, using a portable Miran Infrared General Purpose Gas Analyzer. The use of triethylamine or ammonia as a major component for the measurement of sensory properties of fish odors is recommended.

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I: INTRODUCTION

It is estimated that more than 50% of the complaints related to air pollution deal with exposures to odors (1). Extensive studies with animals show that some odorants can induce marked physiological and morphological changes. Some are recognized as cardiovascular and respiratory effects (1). Consequently, there are possibilities that expressions of irritation or annoyance by humans exposed to odorous air pollution could be due to similar physiological changes.

Although it is now becoming apparent that odors can have more serious effects than just creating nuisance reactions, to date, there are no regulations regarding odorous source emissions or ambient standards in most of the Canadian provinces due to a lack of technology for the measurement and control of odors.

The Environmental Protection Act of 1971 and its regulations, specify that "there shall not be contaminants emitted into the atmosphere which

i. cause impairment of the quality of the natural environment for any use which can be made of it

ii. cause harm or material discomfort to any person" (Section 14).

The regulations also indicate that "no person shall emit contaminants that

i. cause discomfort to persons

ii. cause loss of enjoyment of normal use of property

iii. interfere with the normal conduct of business

iv. cause damage to property (O. Reg. 15 Section 6).

This lack of regulatory strategy can be attributed to the many problems inherent in any attempted control program not specifically related to odors. In practice, the existence of an odor pollution problem must be established before any steps towards control can be attempted. Reliable relationships between ambient odor levels and odor annoyance thresholds for different communities must be determined before ambient odor standards can be established. The scentometer and ASTM syringe methods (2) currently used by environmental agencies are considered to be inadequate for regulatory purposes. There has been a general trend towards the dynamic olfactometric approach. Although considerable research has been focussed on odor measurement technology, there is still a basic need for the development of sensory methods that are capable of measuring odors objectively and reliably and yielding results that can be related to community annoyance.

The current philosophy expressed by most air pollution control agencies in the U.S.A. is to concentrate on those sources which cause the majority of citizen complaints. The list of offenders includes

i. pulp mills, kraft mills, wood products
ii. land fills, dumps, open burning
iii. fruit and vegetable processing
iv. fisheries and fish processing facilities
v. petroleum and natural gas refining, asphalt production
vi. rendering, meat packing, slaughter houses, tanneries
vii. fertilizer plants

viii. sewage and human waste treatment plants

ix. feed lots and stock yards

x. incinerators

xi. coffee roasting and spice processors

xii. commerical restaurants and dry cleaning operations

xiii. paint, varnish and lacquer producers and handlers

xiv. coating applications (paint coating, baking and drying)

xv. diesel (and other mobile source) exhausts.

It is significant to appreciate that since most citizen complaints are related to a relatively few source categories, a successful regulatory strategy devised for one could provide a frame work for the others.

Recognizing the obstacles to the successful implementation of odor regulations, the objectives of the present investigation were to

i. examine the current methods of determining odor threshold values using the five or six level dynamic ternary forced choice olfactometric technique

ii. examine the objectivity of current approaches to the evaluation of the existance of an odor pollution problem

iii. develop a fast and simple procedure for determining not only detection but also discrimination and complaint potential thresholds, as well as degrees of complaint profiles by a panel of judges representing an affected community

iv. account for the magnitudes of the uncertainities introduced into threshold determinations through successful guesses by panelists in making decisions during dynamic ternary forced choice olfactometry

v. apply currently used and newly developed models for odor threshold evaluations to practical situations involving emissions from a fish processing plant and fast food restaurants

vi. investigate the practicality of applying one or two major components as indicators of odor levels and representing the sensory properties of an odorous sample in terms of the concentration of the major component(s).

Chapter II deals with the health aspects of odors in terms of their effects on the general public. It emphasizes the need to measure citizen responses to odorous stimuli and implement regulatory strategies to deal with practical situations.

Chapter III discusses the various sensory properties of odors including the new concepts defined during this program.

The currently used models for evaluating odor threshold data are discussed in Section IV along with the Impact Model developed during this project to provide a comprehensive picture of any odor pollution problem.

Chapter V describes the experimental phase of the program. The major component approach is particularly important in terms of regulatory standards concerning odors emitted from fish processing operations.

Chapters VI, VII and VIII are devoted to the results, discussion of results, conclusions and recommendations.

II. LITERATURE SURVEY

The perceived connection between odors and disease has resulted primarily from an actual association between disease and poor hygiene. When hygiene is poor, both odors and the incidence of disease are high. Throughout the last century, standards of hygiene have improved significantly; however, odors from industrial sources have increased during this time. Since the ambient atmosphere is still unpleasant, an average citizen could infer that risks to his health have not been reduced.

A. Health Aspects of Odors

Some odors (for example, the putrid smell of rotting flesh and the smells of vomitus and raw sewage) cause most individuals to withdraw from the odorant sources. If forced to endure them for more than a few seconds, people will often report adverse physiological reactions such as headache, dizziness and nausea (1). Studies with experimental animals show that some odorous materials may damage tissue (3,4), but there is no direct evidence of the same phenomena in man due to lack of research in this area.

Persons who live in malodorous environments report adverse somatic symptoms. For example, Winneke and Kastka (5) found that the majority of persons living within 1 km of a tar oil plant in Duisburg, Germany, and an insulation plant in Cologne, Germany, experienced occasional to frequent periods of "odor-induced"nausea and headache. Arguments against the conclusion that these adverse reactions resulted directly from the odor sensations must account for the immediacy of the reported reactions.

One or two inhalations of the malodorous air surrounding many industrial operations will often induce nausea (1), just as one or two inhalations of rancid leftovers in the home can cause nausea. Odors rated as neutral or pleasant within a proper context may create annoyance when present at the wrong times. Odors often regarded as unpleasant, irrespective of context, may generate nothing more serious than annoyance. However, to categorize all negative reactions to community odors as annoyance, trivializes the problem of odor pollution. Some industrial odorants produce conditions that are simply too revolting and sickening to warrant the designation of annoyance which is defined as (6) an effect which may not be "demonstrably pathogenic", but which involves a negative factor for an individual's comfort and well being. Even if odors do not cause recognizable pathogenic changes, the symptoms of nausea, headache, and dizziness seem to transcend annoyance. Due to the lack of objective verification and measurement of these common symptoms, victims of odor pollution, particularly those exposed only briefly, are medically ignored (1).

Groups that are particularly susceptible to odor pollution are asthmatics and individuals with pre-existing respiratory and cardiovascular diseases and allergies. Prolonged exposure to foul odors usually evokes reactions in people that can range from uneasiness, discomfort, irritation and anger to violent physiological manifestations, including circulatory and respiratory effects, nausea, vomiting and headaches severe enough to lead to prostration (1). Consequently, the regulation of substances that are released to the atmosphere and are of public concern for no other reason than their characteristic foul odor is a necessary function of air pollution control agencies (1).

B. Effects of Odors on the General Public

The foul odors most commonly encountered are associated with emissions from poorly designed and badly operated sewage treatment facilities, rendering and fish meal plants, cattle feed lots, farms with garbage-fed pigs and a variety of rubber, petroleum and chemical manufacturing operations, including wood pulping (1). Although these processes may not be responsible for any diseases or infirmities, they do deprive neighbouring citizens of complete mental, social and physical well being.

Many people show distaste and annoyance when exposed to foul odors of moderate or even low intensity, but they are not prepared to express their reactions. Exposures to odorants that have unpleasant characteristics are often associated with a small number of chronic and persistent complainers, plus a majority of indifferent neighbours. Without substantial citizen reaction, the air pollution control officer experiences great difficulty in deciding whether a situation merits official control action in the face of an odor exposure that may be considered trivial (1). Normally exposure to odors constitutes a matter of public concern when the intensity, duration, character and degree of unpleasantness of an odor create concerted public reaction.

Since responses to odors have been measured subjectively, to date, it has been hypothesized that objectivity could be attained by monitoring some somatic responses mediated by the central nervous system that might be closely related to the perceived annoyance. Although measurements have been proposed for monitoring central nervous system activity, their validity is yet to be established (3,6).

C. <u>Need for Regulations to Control Odors</u>

Odorous substances may have adverse effects on the public simply because they are perceived as malodorous and also because they are actually harmful substances (1). Consequently, controlling a malodor may also serve, in whole or in part, to reduce the harm that is caused directly by the substance itself. The nature of a regulatory program, including choice of standards and enforcement tools, depends largely on what is known about the properties of an odor and on the technology available for measuring and controlling it. It has been well documented (7) in the U. S. A. that 50% of all citizen complaints to local air quality agencies are associated with odors. Not much can be done to rectify the sources of complaints because there is little objective documentation of odor levels. For example, a rendering plant was said to be responsible for "a putrid smell which brings tears to the eyes of nearby residents, drives them from their yards to the protection of their homes and robs them of their sleep" (8). In another case, odors from the defendants' chicken-processing plant made the plaintiffs unable to eat their meals without nausea" (9). Prolonged and repeated exposure to offensive odors in a third case made people "very irritable, upset and nervous" and promoted one witness to move to another town "because of the stink" (10).

Without quantitative measurements, citizen reactions can be considered only in terms of nuisance type violations. The American nuisance law is the oldest and most pervasive source of regulations for controlling odors. However, regulations based on more scientific approaches are needed (1). The nuisance law encompasses two distinct fields of liability, termed "public nuisance" and "private nuisance".

A public nuisance is created when a right common to all the members of society is invaded, as for example, enjoyment of a park. A private nuisance involves an invasion of a private party's interest in the use and enjoyment of his land.

1. Private Nuisance

To rate a nuisance level, an odor must cause substantial annoyance by the standards of the ordinary, reasonable person living in that locality. Consequently, an unusually sensitive person may find it impossible to establish a nuisance on the basis of odor pollution in an industrialized neighbourhood, partly because the odor is characteristic of the locality and because it is considered harmless by most residents of the area. However, the odors from a well maintained horse barn may be deemed a nuisance in a residential community where the average home owner is not used to the smell of manure (11). The fact that an odorous activity substantially impairs another's right to the use and enjoyment of land does not automatically subject a polluter to liability. The plaintiff who is troubled by odors will usually find himself without a remedy. He has to establish that the harm to him is greater than what he should be required to bear without compensation. A private plaintiff may have difficulty making such a showing, especially against an industrial source on which the local economy depends. Even if he successfully demonstrates that he is entitled to compensation, the usual remedy would be an award of damages rather than an injunction forcing the defendant to abate the offending odor (1).

2. <u>Public Nuisance</u>

The public nuisance action avoids many of the previously discussed difficulties, but has limitations of its own as a tool for odor regulation. An action can be initiated by public authorities since public nuisance is usually a crime at common law. However, problems with evidence, inertia or bias on the part of the enforcing authority can stand in the way of forceful public litigation (1). Although it need not be shown that the whole community has suffered, it must be established that the alleged nuisance interferes with some exercise of public rights. The strength of the case depends mainly on the number and reliability of witnesses who testify to the existence of the nuisance.

3. Nuisance as a Private and Public Concern

When disagreeable odors are dispersed widely enough to interfere seriously with public comfort, they also infringe on the right of private individuals to use and enjoy land affected by the emission source. This makes the nuisance a private as well as a public concern. Injury to health, such as persistent nausea and headaches, is usually considered sufficiently harmful in the U. S. A., to form the basis for a legal suit (1). Testimony from affected residents of the community initiates official investigation and public prosecution of cases that would otherwise be left to the law of private nuisance (1). Consequently, to control odors, regulations and standards are needed to establish limitations both on emission sources and maximal ambient air concentrations for the major components identified as the most likely causes of industrial odor in any region.

The ordinance proposed by Copley International Corporation (12) relies on public attitude surveys to establish a community odor problem. Odor panels consisting of randomly selected residents from the affected community and a control group drawn from a nearby odor-free community of similar socio-economic characteristics would be used to identify an odor problem. If a significantly greater proportion of residents in the affected community than of residents in the control community are bothered by odors, then an odor problem has been established.

The most important impact of a majority of odor problems is community annoyance (1). Objective measurement of annoyance is essential to the success of a regulatory strategy for odor control (1). It should be understood that reported surveys in any area will respond to shifts in community attitudes over time, especially when abatement of some odorant sources makes others become more recognizable.

D. Measurement of Public Reaction to Odors

Annoyance is a common reaction of inhabitants in communities where unpleasant odors are encountered (6). Decision on when to control unpleasant odors and what degree of control to exert, has been dependent upon the choice of methods (1). Two approaches have been used for this purpose. One relies on spontaneous complaints and the other on social surveys.

1. Spontaneous Complaints

Many complaints are initiated spontaneously by citizens in a community. Almost all grievances are received by telephone and handled by inspectors or clerical personnel. Most U. S. agencies maintain records of odor complaints on some type of standard form.

Odor complaint data have been used (12) to

i. alert local authorities that odors were detected at specific times and locations and that possible odor problems exist

ii. help determine whether local laws governing odors have been violated

iii. describe the conditions under which odors were detected and to enumerate the effects of odors experienced by the persons who complained

iv. help identify the offending odor sources, so that steps can be taken to eliminate the odor problems.

Environmental and enforcement agencies have used odor complaints as measures of community reactions in several different ways (12,13). In certain jurisdictions in the U. S. A., local laws require that a specific number of complaints be received before initiation of enforcement procedures. Since complaints represent an inexpensive means of gathering information, other methods of measuring community reaction are considered to be too elaborate and expensive for purposes of enforcement. The use of odor complaints provides a simple and straightforward approach to exerting pressure on the people responsible for the sources of offending odors.

In general, very few citizens register formal complaints with authorities with respect to any environmental problem (6). A study of annoyance created by aircraft noise showed that the main characteristics distinguishing complainants from non-complainants were related to education, value of their home and membership in organizations. On this basis the number of complaints received by officials may reflect not so much the amount of discomfort experienced by the exposed population, but its social class composition and level of community organization (14,15). However, studies have shown that persons who volunteer their opinions may tend to overstate their concern (16). This does not mean that all petitions are unreliable, but possibly that community-initiated actions are likely to contain unmeasurable bias. Social surveys, however, when conducted by properly trained persons, can be used to estimate the true feelings of an average citizen in a community by including controls for bias.

2. Social Surveys

The enforcement of public nuisance laws is usually decided on the basis of the number of persons who have complained. These laws are applicable to widespread odor situations, but not to localized odor problems where a few persons are affected or in cases where the odors are transient and the complaints cannot be validated. Without validation of citizen complaints by a recognized enforcement agency, courts often consider community reactions as biased or eccentric (1).

To avoid these problems, social survey methods, also called public opinion or public attitude surveys, are proposed (1). This method involves asking questions whether

i. odors have been perceived

ii. odors have caused annoyance and under what conditions.

Questions about the backgrounds of the respondents are added to characterize those who state that they have been bothered. Additional questions about other forms of pollution are included, if the main interest in odors is to be de-emphasized to those being surveyed.

An important task is to define the region affected by an odor, in terms of a "test area". The socio-economic characteristics of the test area should be examined by referring to published census information. The names and addresses of the families living in the test area must be obtained. In order to design a questionnaire that will provide the information needed to achieve the survey objective, it is necessary to consider

i. the way the questionnaire is to be administered
ii. each question with respect to its ability to communicate and elicit accurate information
iii. instructions for interviewers
iv. instructions for the respondents if the questionnaire is to be self-administered
v. pretesting the questionnaire in a community similar to the one where it is to be used
vi. changes in the questionnaire and in the instructions for administering it, if necessary, on the basis of the results of the pretest.

Throughout the survey, precautions should be taken to control bias. For example, a sample of completed questionnaires should be validated by non-interviewing personnel. A number of new respondents should be contacted, and the questionnaire should be administered to them. Random selection of the residents or workers to be contacted, careful design and pretest of the questionnaire, thorough training of interviewers, validation of completed interviews, and interviews of new respondents are some of the precautions that can be taken to avoid bias.

Simultaneous surveys should be conducted in a matching odor-free community designated as the "control area". Comparison of the results serves several purposes. Assuming that people in both areas have equal rights to odor-free air the comparison provides an equitable basis for a legal decision. Critical evaluation of results from the test and control areas permits an estimation of two attitudes.

Several criteria should be used to select the control area (17). It is important that the control area

i. be free of odor as much as possible. This implies that the local air pollution control agency should not have received any odor complaints from people living or working in the area during the past 12 months

ii. be close to the test area, preferably within 10 miles of it

iii. have similar access to heavily travelled roadways

iv. be within approximately the same distance from commercial or industrial establishments

v. median incomes and gross rents not differ from those in the test area by more than 20% ,

vi. median number of rooms per housing unit not differ from that in the test area by more than 10%.

The major objections voiced by enforcement agencies that have used this approach are generated by the cumbersome procedures required (12). To reduce time, effort and money, the design of a brief questionnaire and a plan requiring as few as 60 interviews to reach a decision has met with some success (17). However, even this effort requires at least one week of interviews and about $1500 each time the method is used.

3. Comparison of Spontaneous Complaint and Social Survey Methods

Of the two methods used to measure the social effects of odors, the social survey approach is recognized by scientific groups as the better one (1). According to the Fourth Karolinska Institute Symposium on Environmental Health (6), spontaneous complaints such as letters to newspapers or health authorities may indicate the existence of annoyance. However, population survey techniques for determining annoyance, when properly and expertly developed, can be applied to yield valid and significant evaluations of annoyance.

4. Dosage Approach

Air pollution control officials have expressed an urgent need for the development of more straightforward procedures providing quantitative measures of ambient or source odorant dosages, instead of subjective human responses (1). An objective dosage approach would define a performance standard that could be evaluated at the stack or an ambient air standard that could be quantified in the community. This procedure would provide practical advantages of convenience, reproducibility and proof of violation or compliance with regulations. In order to relate odor concentrations or dosages to community reaction, dose-response relationships must be developed (1). Since people differ in their responses, it has become traditional to define the 50% thresholds as the minimal concentrations at which half the subjects in a population respond to, discriminate, or get annoyed by an odorant. This definition is also in accordance with the "median effective dose", ED_{50} used in toxicological work.

III. DEVELOPMENT OF ODOR DOSAGE-RESPONSE DIMENSIONS

Odorous source emissions and ambient air normally contain large numbers of odorous components. Consequently, the odor sensations commonly experienced in a community are due to mixtures of odorants rather than single chemicals. The concentrations and properties of the component compounds determine the character of any odorous stimulus. Because of the complex nature of typical odorous emissions a neighborhood odor problem must be considered in terms of

i. analytical techniques that identify sample components and their concentrations

ii. sensory techniques that measure human responses to odor samples.

Analytical data are more precise than sensory evaluations. As a result they are useful in identifying odor sources, plotting the dispersion of odorous emissions under complex meteorological and topographical conditions and in selecting emission abatement methods for odor reduction.

The traditional sensory dimensions for describing any odor have been detectability, intensity, hedonics and quality (18).

1. Detectability

Detectability is the threshold concentration at which a specific fraction, usually 50%, of a panel of human judges can detect the presence of the odor under investigation. Although this value is often determined by successful guessing on the part of members of a panel, the effect of such guesses has not been taken into account in the past.

2. Intensity

Intensity refers to the magnitude of perceived sensation (19). According to Steven's Law, intensity is related to concentration according to

$$I = K C^n,$$

where

I = subjective intensity

C = stimulus concentration

K,n = constants

3. Hedonics

Hedonics refers to the degree of pleasantness or unpleasantness of an odor (20).

4. Quality

Quality is used to describe the differentiating character and degree of odor similarity to other odors, which can be readily recognized by panelists.

5. Additional Odor Dimensions

Until very recently, no significant attempts were made to express odors in terms of their real life dimensions which have direct impact on a community, as complaint potential thresholds and degrees of complaint.

During this program, a procedure has been developed for the simultaneous evaluation of detection, discrimination, complaint potential (or annoyance) thresholds and degrees of complaint of an odor.

a. Discrimination Threshold

The concept of a discrimination threshold has been introduced to account for the level at which panel members are sure, beyond a doubt, about the presence of an odor.

b. Complaint Potential

The complaint potential or annoyance threshold has been developed to express the level at which any fraction (usually 50%) of the panel members would be annoyed when exposed to an odor for a specific period of time, usually, an average period of 8 hours.

c. Degree of Complaint

A scale of 0 to 10 has been suggested as a means of expressing the degrees of complaint at different fractions of panel responses.

d. Major Component Measurement

Gas Chromatographic separation of odorous sample components with subsequent mass-spectrometric identification of the sequentially eluted components, from their ionized molecular fragmentation spectra, has been used to "finger-print" complex odorous samples. Recently Shibamoto et al. (21) identified forty-four of seventy-three compounds in sukiyaki volatiles obtained from beef, heated with vegetables and seasonings (sugar and soy sauce) using gas-liquid chromatography/mass spectrometery. However, these methods are very expensive (22) and mainly suitable for exploratory research rather than routine monitoring. Consequently, the gas chromatographic/mass spectrometric approach has limited applications since the integrity of an odorous sample can not be preserved if it can not be evaluated in the field without storage and transport (1). There are also difficulties resulting from inadequate sample sizes and ambiguities in interpretations (23).

Due to the limitations of the gas chromatographic/ mass spectrometric techniques with respect to routine monitoring of odors for regulatory purposes it would be useful to develop procedures for relating the analytical and sensory dimensions of a complex odorous mixture in terms of one or more potential chemical indicators that could be monitored with some form of portable instrumentation. The viability of this approach is suggested by the fact that, although in many cases of odorous air pollution a large number of odorants are present, only a few are responsible for the characteristic odor of a complex mixture. For example, aromatic and oxygenated organic compounds typify diesel exhausts (24,25), while organic acid groups and methyl sulphides are associated with rendering plant emission (26). The extensive investigations conducted by Pyysals and Suihko (27) into the role of specific volatiles associated with the sensory characteristics of mushrooms indicate that 1-octene-3-one was one of the most potent compounds with an odor threshold of 0.004 ppm.

In the present program, the practicality of relating analytical and sensory dimensions of an odorous mixture in terms of a major chemical component was examined in terms of fish odors emitted by a typical fish processing plant. Fish, like meat, is composed of protein, oil and water. Most fish is transported over considerable distances for processing and sale. Even when stored in ice, bacterial and enzymatic degradation occurs and off-flavours can develop to such a degree that the fish can become inedible (28). Investigators have attempted to identify and quantify volatile flavour compounds from naturally-spoiling fish tissue. This research has provided considerable data on the identification of classes of chemicals such as amines (29, 30, 31, 32, 33); acids (34, 35), carbonyls (36, 37), sulphur compounds (38, 39), aromatics (40) and total volatiles (30). Of the many individual chemicals that have been identified, the most prominent are triethylamine, trimethylamine, ammonia, acrolein, butyric acid, indole, methyl mercaptan, dimethyl-sulfide and hydrogen sulfide (1).

After an extensive analysis of fish odors, triethylamine was selected as the basis of measurement of fish odor levels. A portable single beam infrared analyzer with field monitoring capabilities was used for the analytical measurement of triethylamine concentrations in fish odor samples. The sensory dimensions of the same fish odors were evaluated using a recently developed five dilution-level olfactometer. The responses from panelists provided detection, discrimination and complaint-potentials at different dilution levels in terms of fish odor concentrations based on the major component at each level. The degrees of complaint for each dilution level were averaged for the entire panel and related to the concentration levels on the same coordinate system.

IV. DEVELOPMENT OF MODELS FOR EVALUATING ODOR THRESHOLDS

The human odor detection spectrum can be subdividied into three regions (1). At sufficiently high dilutions, odor detection by many people is almost impossible. On the other hand, at low dilutions, odors can be easily detected by most humans. Between these two extremes, there is an intermediate region where odor detection may or may not be possible depending on the sensitivity of the individual sense of smell. Because of the variability of the human nose, an odor threshold cannot be considered as a definite property of a pure or complex odorant, as is for example, a vapor pressure defined by the temperature of any liquid.

A number of parameters influence the results of odor threshold determinations (1). Although individual sensitivities to odors can differ by a factor of 20 or even more, these variations are still within the limits of normal probability of distribution in the population. Differences in personal judgment criteria and in design of sample presentation, anticipation effects, olfactory fatigue, lack of verification that an odor was perceived when the panelist stated that it was, can influence the final results. The multiple sample, forced choice, ascending-concentration design is essentially free of most of these problems and is economical of the panelists' time (1). Measurement methods that use dynamic mixing and controlled rate of sample delivery are more suitable than the static methods such as the ASTM syringe-dilution test for sample handling in that they minimize adsorption losses and provide better control of the rate of sample delivery to the nose. The rate of sample delivery to the nose has a great effect on the odor threshold of an odorous sample. The optimum rate has not yet been standardized. Different methods of panel data analysis can also influence threshold values.

Unless all factors that can affect odor thresholds are standardized, widely different values are likely to be reported for the same samples by different researchers.

The traditional methods of data analysis for the determination of odor detection thresholds have been the

i. Hall-Ellis Ranking, and

ii. Modified Dravnieks

techniques.

A. Hall-Ellis Ranking Method

According to this approach, responses by panelists are transmitted from a ternary forced choice six level dynamic triangle olfactometer (41) through a signal box to the panel leader, who records them on a pre-printed form which is shown in Figure 1.

The first dilution level at which any panel member makes a correct choice and continues to be correct is taken to be the correct judgment level. In the event that a panelist is correct at all levels, or wrong at all levels, a hypothetical dilution level that is higher by the appropriate geometric ratio than the highest dilution level available or lower by the appropriate geometric ratio than the lowest dilution level, is taken to be

Sample: 52.06 ppm n-butanol measured as THC butane equivalent

Evaluation Date: July 11, 1980 RESULT: Log ED_{50} = 2.10 ED_{50} = 125.9 (O.U.) = 0.42 ppm

Cons. No.	Panelist	Dilution Level Number 1	2	3	4	5	6	"7"	
	Correct Choice Would Be: (t = top, c = center, b = bottom)	C	B	C	C	C	C		← from connections in olfactometer
	Panelist Indicated:								
1	DANA	T	C	B	T	C	C		
2	KIM	T	B	B	C	C	C		
3	ROB	T	B	B	C	C	C		
4	MARY	T	T	B	T	C	C		
5	LAG	B	B	T	B	C	C		
6	NAG	T	C	C	C	C	C		
7	MEH	C	T	C	C	C	C		
8	PRA	T	T	C	C	C	C		
9	MOH	B	C	B	C	C	C		
10	PAL	B	B	C	C	C	C		
Frequency Tally			1	3	3	3			← how many begin to detect
Average Rank			1	3	6	9			← from frequency count

For Rank Count:

- 1 — #2
- 2, 3, 4 — #3
- 5, 6, 7 — #4
- 8, 9, 10 — #5

X = Plotting Value		-1.33	-0.60	+0.11	+0.91			← from average rank and table
Y = Log(Tolerance Level)		2.92	2.45	1.98	1.50	1.07		← average of Log(Dil. Fact.)

Dilution Level No.	<1	1	2	3	4	5	6	"7"	
Log(Dilution Factor)		3.16	2.69	2.20	1.75	1.30	0.85		←from flow calibration

Plot Y versus X
Y at X=0 is Log ED_{50}

Panel Leader E. Poostchi

FIGURE 1: ED_{50} Evaluation Form By Hall-Ellis Ranking Method Using a Six Level Dynamic Triangle Olfactometer

the correct judgement level for the panelist.

The evaluation of the frequency of detection by panelists at each dilution level can be discussed in terms of the data in Figure 1. Since one panelist detected the odor at the second level, the frequency tally for level No. 2 is 1. Three panelists began to detect the odor at level No. 3. Consequently, the frequency tally at level No. 3 is 3, and so forth.

The next step is to convert the frequencies to average ranks. The small column of numbers under the heading "For Rank Count" is provided for this conversion. The level No. 2 is the first occupied in the tally by one panelist only. This corresponds to an average rank of 1. Level No. 3 is occupied by three panelists. These correspond to ranks 2, 3 and 4, or an average rank of

$$\frac{2 + 3 + 4}{3} = 3$$

Similarly level Numbers 4 and 5 are ranked accordingly.

The average rank numbers are converted to plotting values corresponding to the appropriate panel sizes using Table I. For instance, the plotting value is -1.33 for an average rank of 1, when the panel size is 10. These plotting values correspond to x coordinates. The y coordinates are found by taking averages of the logarithms of the dilution factors.

To evaluate ED_{50} (odor detection threshold) as an average response from the panel, the y coordinates are plotted against corresponding x coordinates. The best straight line is drawn through the graphical representation by using the least squares

Average Rank	Number of Panelists				
	6	7	8	9	10
1.0	-1.07	-1.15	-1.22	-1.28	-1.33
1.5	-0.79	-0.89	-0.97	-1.04	-1.10
2.0	-0.57	-0.67	-0.77	-0.84	-0.81
2.5	-0.37	-0.49	-0.59	-0.67	-0.75
3.0	-0.18	-0.32	-0.43	-0.52	-0.60
3.5	0	-0.16	-0.28	-0.39	-0.47
4.0	+0.18	0	-0.14	-0.25	-0.35
4.5	+0.37	+0.16	0	-0.13	-0.23
5.0	+0.57	+0.32	+0.14	0	-0.11
5.5	+0.79	+0.49	+0.28	+0.13	0
6.0	+1.07	+0.67	+0.43	+0.25	+0.11
6.5		+0.89	+0.59	+0.39	+0.23
7.0		+1.15	+0.77	+0.52	+0.35
7.5			+0.97	+0.67	+0.47
8.0			+1.22	+0.84	+0.60
8.5				+1.04	+0.75
9.0				+1.28	+0.91
9.5					+1.10
10.0					+1.33

TABLE I: Conversion of Average Rank Numbers to X-Coordinate Plotting Values (41) technique. The y value at x=0, corresponds to log ED_{50}, from which the average effective dosage is obtained. To express the ED_{50} in terms of ppm, the original concentration is divided by the number of odor units obtained from the plot. This method calls for only one trial with seven to ten panelists.

B. Modified Dravnieks Method

This technique was developed as an alternative to the Hall-Ellis Ranking approach, in order to avoid plotting the panel response data (42). Basically it involves estimation of the individual maximum likelihood threshold for each panelist and calculating from these values a geometric mean threshold for the entire panel.

For example, consider that a panelist makes the set of judgments corresponding to I/C/I/C/C/C , where the first response from the left is for level No. 1 (highest dilution) and the last is for level No. 6 (lowest dilution). Capital C represents a correct choice of port at any dilution level whereas a capital I, an incorrect choice. Since this panelist made three correct judgments consistently from the fourth level onwards, the usual statistical assumptions (42) imply that this particular individual would be capable of making a correct judgment somewhere between the third and fourth levels, if the instrument provided finer subdivision of dilution levels. Consequently, the most likely dilution threshold for this panelist would be the geometric mean of the dilution factors for levels 3 and 4.

If a panelist misses at the lowest dilution factor available

(D), it is assumed that a correct choice would be made at a higher concentration (that is at a lower dilution level). Consequently, a hypothetical dilution factor (of $\frac{D}{3}$) is postulated as the best estimate. Similarly if a panelist has made correct choices throughout all dilution levels, a hypothetical dilution factor, which is three times the highest dilution provided by the instrument is taken as the best estimate. The individual dilution threshold for each panelist is obtained by taking the geometric mean of the level beyond which the subject has consistently made correct choices and the previous level. The logarithm of the individual dilution threshold of each panelist is also determined. The ED_{50} value of the panel is calculated by adding the logarithms of the individual thresholds, dividing by the number of panelists and taking the antilogarithm of the result. This method is also based on only one trial by seven to ten panelists.

C. Development of Probability Model

The Hall-Ellis Ranking and Modified Dravnieks methods for the determination of odor detection thresholds depend on forced choice decisions by panelists who often resort to guess work for their responses. Neither approach accounts for the uncertainities experienced by panelists while making their choices. To minimize the effect of guessing during the determination of an effective dosage for an average panel member, the concept of discrimination threshold was introduced. The discrimination threshold is defined as the level at which 50% of a panel can distinguish between the odor and non-odorous air with certainty. Both the Hall-Ellis and Modified Dravnieks methods were applied to the data defining the dilution levels at which panelists were sure about the presence of the odor under investigation. Because panelists are required to be positive about the presence of an odor the discrimination threshold approximates the recognition threshold defined as the level at which 50% of a panel can recognize the character of the odor. In practice, the experimentally determined value is probably an overestimation of the true discrimination threshold of the panel because individuals often tend to recognize the odor character before expressing certainty of detection. Consequently, to determine an estimate of the true discrimination threshold based on all panelist responses and to account for successful guesses, the development of a probability model (43, 44) was initiated.

In the current program, a probability model has been proposed on the basis of the maximum likelihood estimate method for one, two and three trials of sample presentation of the same odorous material to the same panel members. The maximum likelihood estimation method has been used since it is regarded as a standard of reference in many cases where estimates of population parameters are sought (45).

1. Derivation of Pertinent Expressions

For every dilution level, the panel members can be considered to fall into two distinct populations. Those who are sure about the presence of the odor at any dilution level can easily identify which port is delivering a stimulus. On the other hand, panelists who are not positive about the presence of the odor, have to make a guess.

If $\hat{a}$ represents the estimate of the proportion of people who are sure about their choices at any dilution level and any number of trials (true discriminators), then $(1 - \hat{a})$ is the proportion of pure guessors. For a forced ternary choice technique, the proportion of panelists who are correct once out of only one trial (no wrongs) will be

$$W_o/1 = \hat{a} + \frac{1}{3}(1 - \hat{a})$$

The proportion of panelists who are correct twice in two trials (no wrongs out of 2) will be

$$W_o/2 = \hat{a} + (\frac{1}{3})^2 (1 - \hat{a})$$

In general, the proportion of panelists who are correct K times out of K trials (no wrong in K trials) will be

$$W_o/K = \hat{a} + (\frac{1}{3})^K (1 - \hat{a})$$

Similarly, the proportion of panelists who are wrong at any one level will be expressed in terms of once for one trial by,

$$W_1/1 = \frac{2}{3}(1 - \hat{a})$$

twice for two trials by,

$$W_2/2 = (\frac{2}{3})^2 (1 - \hat{a})$$

and, three times for three trials, by

$$W_3/3 = (\frac{2}{3})^3 (1 - \hat{a})$$

In general, the proportion of panelists who are wrong r times out of K trials for a ternary forced choice situation will be

$$W_r/K = \binom{K}{r}\left(\frac{2}{3}\right)^r\left(\frac{1}{3}\right)^{K-r}(1 - \hat{a})$$

where r = 1,2,3, ... K

and
$$\binom{K}{r} = \frac{K!}{(K - r)!\ r!}$$

2. One Trial Ternary Forced Choice

In a ternary forced choice technique, the proportion of panelists who are correct once in one trial will be,

$$W_o/1 = \hat{a} + \frac{1}{3}(1 - \hat{a})$$

which reduces to

$$W_o/1 = \frac{2\hat{a} + 1}{3} \qquad (1)$$

and the proportion of panelists who are wrong once in one trial, will be

$$W_1/1 = \frac{2}{3}(1 - \hat{a}) \qquad (2)$$

Equations 1 and 2 give the expected values of $W_o/1$ and $W_1/1$. The observed magnitudes of $W_o/1$ and $W_1/1$ are obtained through actual experimentation.

The method of the maximum likelihood estimate (44) involves multiplication of the logarithm of the number expected in each class (Equations 1 and 2) by the number observed ($W_o/1$ and $W_1/1$), summation for all classes and determination of the expression for the unknown parameter ($\hat{a}$) for which the sum is a maximum. Accordingly the sum, S, becomes

$$S = W_o/1 \log\left(\frac{2\hat{a} + 1}{3}\right) + W_1/1 \log \frac{2}{3}(1 - \hat{a})$$

For this sum to be a maximum, differentiation with respect to

$\hat{a}$ and subsequent equation to zero, yields

$$\frac{2\ W_o/1}{2\ \hat{a} + 1} - \frac{W_1/1}{1 - \hat{a}} = 0$$

which on rearrangement gives

$$\hat{a} = \frac{2\ W_o/1 - W_1/1}{2(W_1/1 + W_o/1)} \qquad (3)$$

Equation 3 provides the maximum likelihood estimate of $\hat{a}$ for one trial for each dilution level based on the observed values of $W_o/1$ and $W_1/1$ at those levels. A plot of log concentration of odorant versus $\hat{a}$ determined for each dilution level provides the true discrimination threshold of the panel in terms of the odorant concentration corresponding to $\hat{a} = 0.5$.

3. Two Trial Ternary Forced Choice

For two trials in a ternary forced choice situation, the proportion of panelists who are correct both times out of two trials will be,

$$W_o/2 = \hat{a} + \left(\tfrac{1}{3}\right)^2 (1 - \hat{a})$$

from which

$$W_o/2 = \frac{8\hat{a} + 1}{9} \qquad (4)$$

The proportion of panelists who are wrong once out of two trials will be,

$$W_1/2 = \frac{2!}{1!\ 1!} \times \frac{2}{3} \times \frac{1}{3} \times (1 - \hat{a})$$

or

$$W_1/2 = \frac{4}{9}(1 - \hat{a}) \qquad (5)$$

and, the proportion of panelists who are wrong both times out of two trials will be

$$W_2/2 = \frac{2!}{0!\ 2!}\left(\frac{2}{3}\right)^2 (1 - \hat{a})$$

which is equivalent to

$$W_2/2 = \frac{4}{9}(1 - \hat{a}) \qquad (6)$$

Equations 4, 5 and 6 give the expected values of $W_o/2$, $W_1/2$ and $W_2/2$. The observed values of $W_o/2$, $W_1/2$ and $W_2/2$ are obtained through actual experimentation. Application of the method of maximum likelihood estimate (46) to the sum, S, for two trials, gives

$$S = W_o/2 \log\left(\frac{8\hat{a} + 1}{9}\right) + W_1/2 \log \frac{4(1 - \hat{a})}{9} + W_2/2 \log \frac{4(1 - \hat{a})}{9}$$

from which

$$\hat{a} = \frac{8\ W_o/2 - W_1/2 - W_2/2}{8(W_o/2 + W_1/2 + W_2/2)} \qquad (7)$$

Equation 7 gives the best estimate of $\hat{a}$ at each dilution level on the basis of two trials providing experimentally determined values of $W_o/2$, $W_1/2$ and $W_2/2$ at those levels.

A plot of log concentration of odorant versus $\hat{a}$ determined for each dilution level, yields the true discrimination threshold of the panel in terms of odorant concentration corresponding to $\hat{a} = 0.5$.

4. Three Trial Ternary Forced Choice

For the case of the three trial, ternary forced choice situation, the proportion of panelists who are wrong a specific number of times can be developed using the general expression,

$$W_r/K = \binom{K}{r} \left(\frac{2}{3}\right)^{r} \left(\frac{1}{3}\right)^{K-r} (1 - \alpha)$$

where W_r/K is the proportion of panelists who are wrong r times out of K trials, and

$$\binom{K}{r} = \frac{K!}{(K - r)!\, r!}$$

Consequently, the proportion of panelists who are wrong once out of three trials, will be

$$W_1/3 = \frac{3!}{2!\ 1!} \left(\frac{2}{3}\right)^{1} \left(\frac{1}{3}\right)^{2} (1 - \alpha)$$

which reduces to

$$W_1/3 = \frac{2(1 - \alpha)}{9} \qquad (8)$$

and the proportion of panelists who are wrong twice out of three trials, will be given by

$$W_2/3 = \frac{3!}{1!\ 2!} \left(\frac{2}{3}\right)^{2} \left(\frac{1}{3}\right) (1 - \alpha)$$

which simplifies to

$$W_2/3 = \frac{4(1 - \alpha)}{9} \qquad (9)$$

The proportion of panelists who are wrong all three times out of three trials, becomes

$$W_3/3 = \frac{3!}{0!\ 3!} \left(\frac{2}{3}\right)^{3} \left(\frac{1}{3}\right)^{0} (1 - \alpha)$$

which is equivalent to

$$W_3/3 = \frac{8(1 - \alpha)}{27} \qquad (10)$$

The proportion of people who are correct in all three trials, becomes

$$W_o/3 = \hat{a} + \left(\frac{1}{3}\right)^3 (1 - \hat{a})$$

which reduces to

$$W_o/3 = \hat{a} + \frac{(1 - \hat{a})}{27} \tag{11}$$

Application of the method of the maximum likelihood estimate (46), gives the sum, S, for the three trials, in the form

$$S = W_1/3 \log \frac{2(1 - \hat{a})}{9} + W_2/3 \log \frac{4(1 - \hat{a})}{9} + W_3/3 \log \frac{8(1 - \hat{a})}{27} + W_o/3 \log \left(\frac{26\hat{a} + 1}{27}\right)$$

The process of differentiation with respect to $\hat{a}$, and equating to zero, lends to

$$-\frac{W_1/3}{1 - \hat{a}} - \frac{W_2/3}{1 - \hat{a}} - \frac{W_3/3}{1 - \hat{a}} + \frac{26\ W_o/3}{26\hat{a} + 1} = 0$$

which ultimately reduces to

$$\hat{a} = \frac{26\ W_o/3 - W_1/3 - W_2/3 - W_3/3}{26(W_o/3 + W_1/3 + W_2/3 + W_3/3)} \tag{12}$$

Equation 12 gives the maximum likelihood estimate of $\hat{a}$ for each dilution level based on the observed values of $W_o/3$, $W_1/3$, $W_2/3$ and $W_3/3$ at those levels.

A plot of log concentrations of odorant versus $\hat{a}$ determined for each dilution level, provides the true discrimination threshold of the panel in terms of odorant concentration corresponding to $\hat{a} = 0.5$.

D. Development of Odor Impact Model

All of the three previously described models have their merits and limitations. For example, both the Hall-Ellis and Modified Dravnieks approaches have been applied only to the evaluation of odor detection thresholds based on 50% panel responses. Neither model provides measures of other fractional responses which could be useful for the development of an overall picture of the impact of an odor pollution problem on a community. They are also not designed to evaluate complaint potential profiles or degrees of complaint of an odor by a panel of judges representing the affected community.

Although the Probability Model can, in principle, provide discrimination thresholds for $0 \leq \hat{\alpha} \leq 1$, it also fails to develop any information related to the impact of an odor stimulus on a neighbourhood or a panel of judges in terms of complaint levels or degrees of complaint which are the most important dimensions for defining an odor pollution problem in a locality.

In order to account for and evaluate these essential odor dimensions, a fast, simple and acceptably accurate method of presenting an overall view of an odor impact on a community was developed during this program. This new approach provides a practical procedure for routinely evaluating all the essential odor dimensions including detection, discrimination and complaint potential thresholds as well as degree of complaint profiles. An existing or potential neighbourhood odor impact can now be assessed in the laboratory by a panel of judges representing a community where an odor source is or will be located.

Basically, the newly developed procedure involves an extension of the currently used principle of ternary forced choice detection threshold determination with a five or six level dynamic olfactometer. In addition to identifying the ports which they perceive to be emitting odorous material, panelists are also required to specify the levels at which they are sure, beyond a doubt, about the presence of the odor. Furthermore, panel members are provided with a preprinted form on which they are asked to indicate at which dilutions (concentrations) they would complain if they were exposed to similar odorous stimuli for an average period of eight hours and to rate the degree of complaint at each level on a scale ranging from 0 to 10, using zero as no complaint and 10 as the maximum measure of annoyance.

The first dilution levels beyond which individual panelists make continuous correct choices are taken as the basis for the evaluation of the detection threshold profile, relating fractional panel responses to different odor levels as illustrated by curve I of Figure 2.

The odor discrimination threshold profile is based on the first dilution levels (concentrations) from which the panel members continue to be certain about the presence of the odor. Curve II of Figure 2 illustrates the location of a typical discrimination threshold profile with respect to the detection threshold profile.

Similarly the dilution levels (concentrations) at which

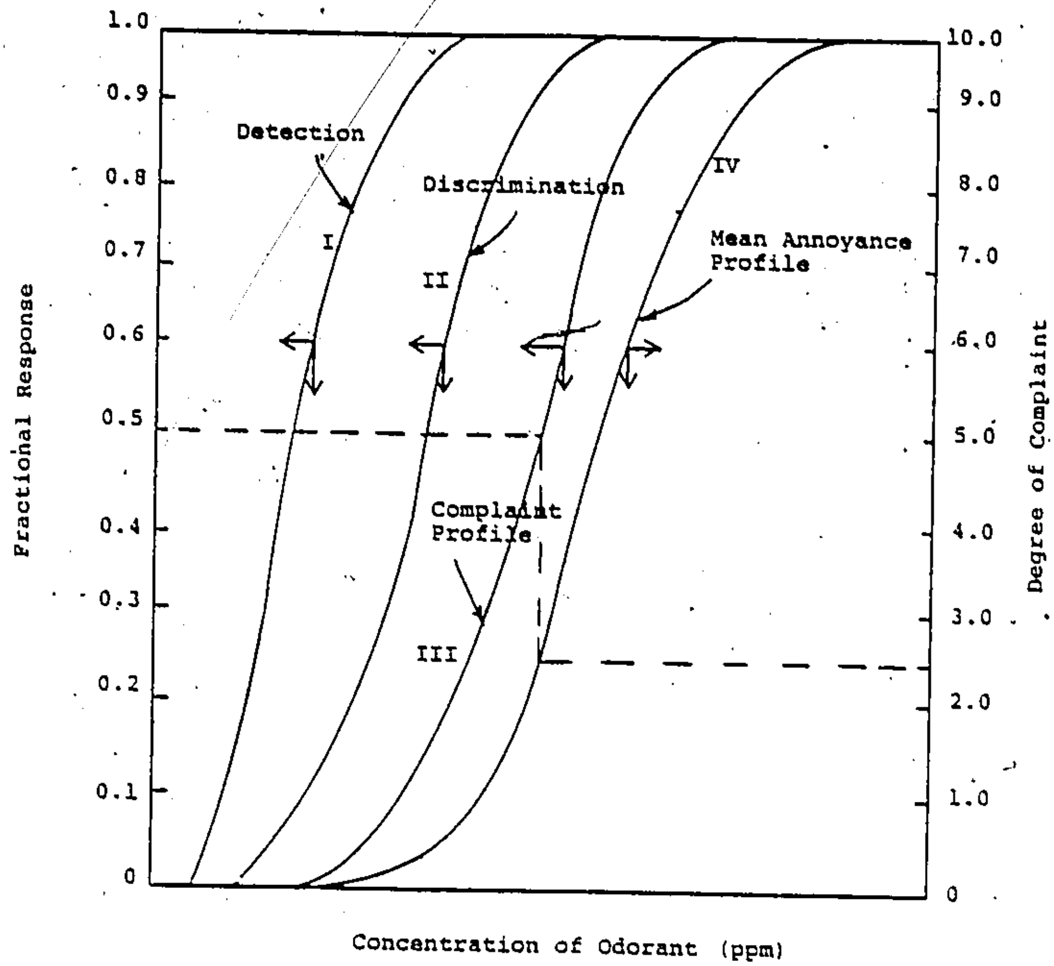


FIGURE 2: Illustration of Typical Odor Impact Model Profiles

panelists express a tendency to complain and their magnitudes of complaints provide data for the generation of complaint potential and mean annoyance profiles for the panel as shown by curves III and IV in Figure 2.

For illustrative purposes, consider a panel of 10 members evaluating an odor stimulus through a five level dynamic olfactometer using a ternary forced choice technique in an ascending series of concentration.

Now, for the sake of argument, suppose that at the first level, no panel member begins to consistently detect the presence of the odor under investigation. This means that the fractional response of the panel at this level is zero. At level No. 2, let us assume that two of the panelists begin to consistently detect the presence of the odorous stimulus. Accordingly, the fractional response of the panel at this level would be 2/10 = 0.2. At level No. 3, let us say that three more panelists begin to detect. At this level the fractional response of the panel on a cumulative basis would be $\frac{0 + 2 + 3}{10} = 0.5$. This process is repeated until all dilution levels have been examined.

A plot of the fractional responses versus the corresponding dilution levels in terms of odorant concentrations, on rectangular coordinates, provides the detection threshold profile of the panel under the specified conditions.

The discrimination and complaint potential threshold profiles of the panel are determined in a similar manner and results are plotted on the original coordinate system.

The magnitudes of complaints evaluated in terms of individual panel member ratings at each odor level are averaged over the entire panel for each odor concentration. The mean values define the mean annoyance profile of the panel which is plotted on the same graphical coordinate system.

The newly proposed model has been successfully applied to fish odors during this program. The results agree well with those obtained from the Hall-Ellis and Modified Dravnieks methods which were originally designed to provide only detection thresholds in terms of 50 percent responses from a panel.

V. EXPERIMENTAL PROGRAM

A. Odor Threshold Determination

1. Description of Equipment

A six level dynamic dilution olfactometer designed by Illinois Institute of Technology Research Institute, (IITRI), Chicago, Illinois (41) was used in this part of the program. This instrument provides six dilution levels each equipped with a set of three glass sniffing ports. Two of the ports emit deodorized room air (blanks) while the third discharges the odorous gas diluted with deodorized air.

The odorous samples were delivered to the olfactometer from Tedlar bags at a rate of 100 cm^3/min by means of a peristaltic pump. The deodorized dilution air was supplied at a total rate of 9000 cm^3/min. Two manifolds were provided for dividing the odor and air samples into specific ratios. Capillary tubes of different lengths regulated the amounts of samples required to make up the specified dilution levels. Each port delivered approximately 500 cm^3/min of air or odorous sample. The concentrations of odors at each dilution level increased from left to right according to the approximate dilution factors of 1440, 490, 162, 56, 20 and 7.

A signal box with six triple sets of lights provided panelists inside an odor free room with means of communicating their responses to the panel coordinator. A schematic diagram of the olfactometer is shown in Figure 3.

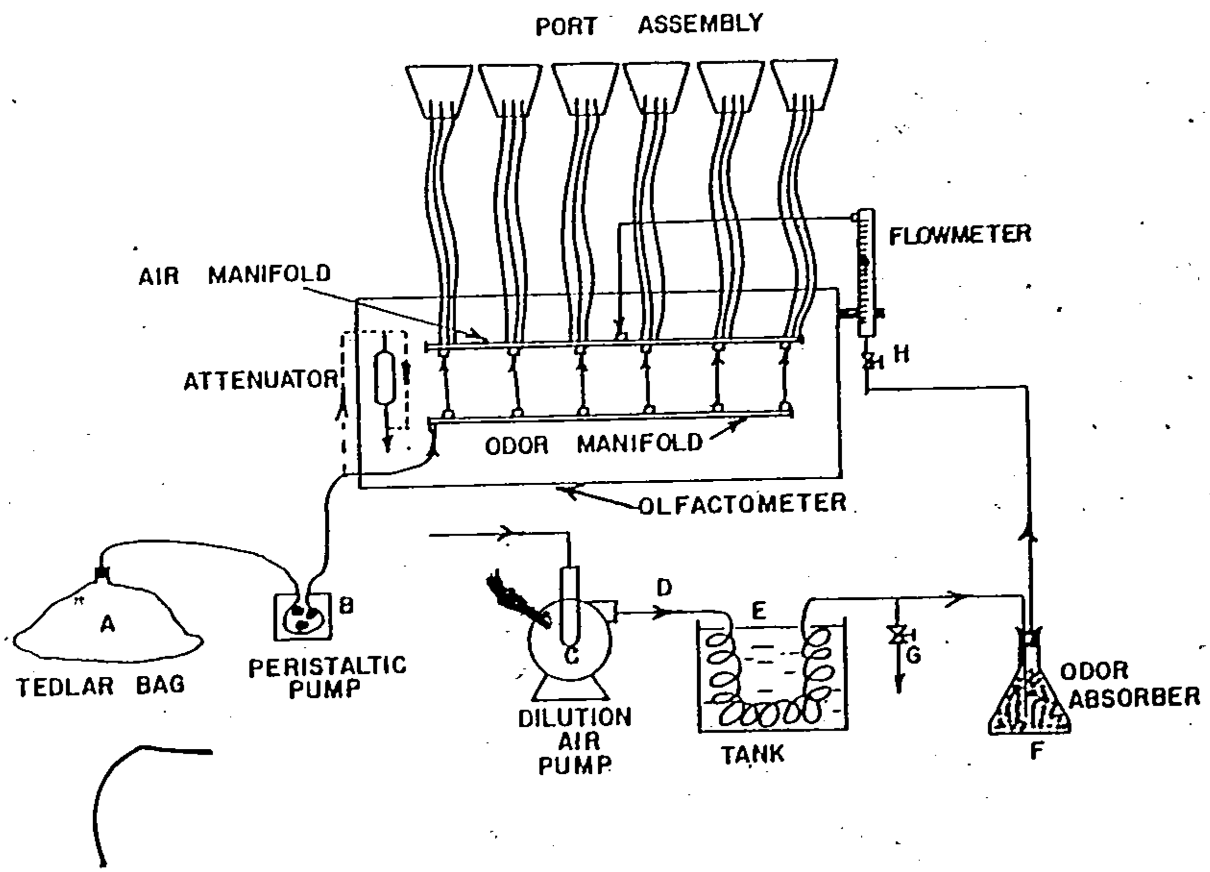


FIGURE 3: Flow Diagram for Odor Measurement System

2. Odor Test Room

All odor stimuli determinations were carried out in an odor-free environment maintained inside a previously designed odor test room (44). This 4 ft. long x 4 ft. wide x 8 ft. high facility was a double walled chamber equiped with a door, a glass window, an interior light, an electric air cleaner and an exhaust fan for ventilating odors. The inside walls and ceiling of the room were constructed of washable aroborite. A remote control signal box was mounted on one exterior wall for communication of panel responses to the panel coordinator.

The air cleaner was capable of delivering odor free background air into the test room at low and high flows of 100 ft^3/min and 150 ft^3/min respectively. It consisted of a two stage electrostatic precipitator for particulate removal down to 0.03 microns (47), a replaceable activated charcoal filter for smoke and odor elimination and an outside lint screen for trapping larger dust particles.

3. Selection of Panel Members

The objective of any odor evaluation program determines the rationale for panelist selection. For example, if the goal is to measure odor sensitivity distribution and the mean odor-detection threshold of the population at large, no selection of panelists is necessary and as many panelists as possible should be used (48).

For some odors, people can be found who are significantly less sensitive than the average population (48, 49). However, lower sensitivity of any individual to a specific odor does not automatically imply lower sensitivity to all odors (26).

Some researchers recommend using the more sensitive fraction of panelists in order to provide a safety factor in the results (50). Others would use a more homogeneous group whose sensitivity is average to produce a higher degree of reproducibility.

In the present program, panelists were selected from different age groups representing both sexes. Most had previous experiences with the odor evaluation procedures.

4. Procedures

The panel members were required to

i. function individually by starting from the most dilute level (left) and proceed towards higher concentrations of the sample.

ii. sniff fresh air from the air cleaner provided in the odor booth to sharpen their senses of smell between dilution levels and ports within a dilution level.

iii. press the switch corresponding to the port at which they could detect the odor.

iv. report to the panel coordinator, the ports at which they were sure about the presence of the odor.

The responses from the panelists conveyed through the signal box were recorded by the panel coordinator for subsequent evaluation.

5. Application of Models

The various models for odor threshold evaluations were applied to two samples of n-butanol vapours whose initial concentrations were 52.06 and 99.46 ppm measured as THC(total hydrocarbon content) based on butane as the calibrating gas. The standard IITRI six level, dynamic, ternary, forced choice olfactometer was used to present the odors to panel members.

To validate the models with actual field samples, odorous emissions were collected from the main grill of a fast food restaurant. These were evaluated using a five level dynamic dilution olfactometer with higher flow rates than provided by the IITRI instrument. The models were also applied to vegetable oil emissions created in a laboratory odor generator.

B. Major Component Approach

After an extensive infrared analysis of fish odors with a portable instrument providing potential field capabilities, it seemed that ammonia and triethylamine were two of the major components. Characteristic absorption bands were detected at 10.4 and 9.3 μm wavelengths as suggested by the literature (51). Comparison tests showed that triethylamine smells much like the typical odors associated with the fishing industry. Consequently, triethylamine (TEA) was taken as the basis for measurement of fish odor concentrations. The odorous properties of triethylamine reported by Hellman and Small (52) are listed in Appendix I.

1. General Description of Miran Gas Analyzer

The Miran-1A Portable Gas Analyzer (53) shown in Figure 4, is a single beam, variable filter spectrometer, capable of scanning the infrared spectral range between 2.5 and 14.5 μm. Essentially the instrument consists of two components, the gas cell and the analyzer. The variable path length gas

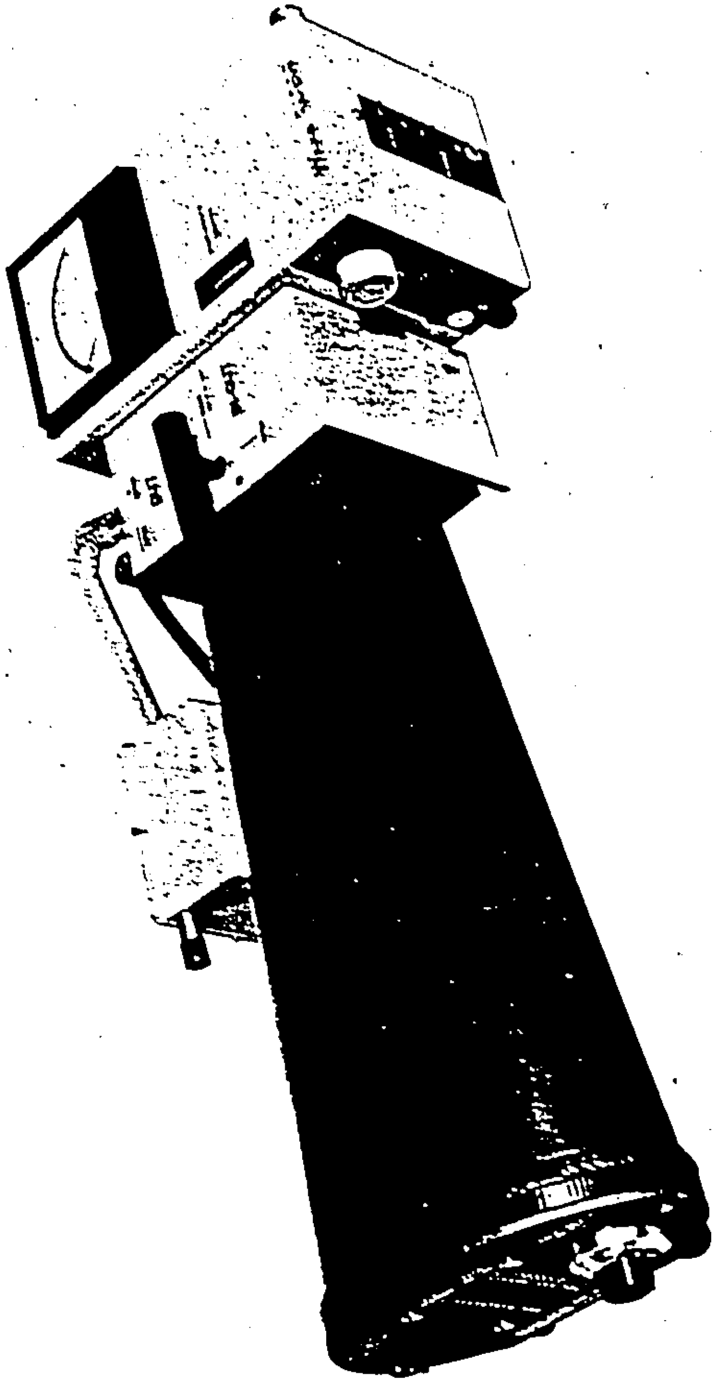


FIGURE 4: Miran IA General Purpose Gas Analyzer

cell has a 5.6 litre capacity body that is vacuum tight to 10^{-5} torr and pressurizable to 1000 K Pa (10 atmospheres). The gold plated internal optical system has an optical path which is variable in 1.5 meter increments between 0.75 and 20.25 meters. Interior lining of the cell with polytetrafluoroethylene minimizes sample absorption and corrosion.

The analyzer consists of a radiation source, mirror system, mechanical chopper, circular filter (variable in three segments between 2.5 and 14.5 μm), a scanning motor, polyelectric detector, a signal preamplifier, logarithmic range compensating circuitry, regulated power supplies, a meter providing absorbance and percent transmission scales and a 0-1 volt output for a strip chart recorder.

2. Calibration of Miran Gas Analyzer

The gas analyzer was calibrated with triethylamine (TEA) by setting a zero absorbance reading at a wavelength of 9.3 μm for a 20.25 Meter path length and a 1 mm slit width using "zero gas" passed through a carbon filter. The optimum sensitivity range providing stable readings was found to be 0-0.1A. The closed loop calibration arrangement is shown in Figure 5.

Liquid triethylamine was injected in incremental amounts. Subsequently, stable absorbance readings were recorded, after a steady state was obtained. Plots of absorbance versus concentration were prepared for two different ranges of concentration. The 0-28 ppm and 0-7 ppm ranges are illustrated in Appendix II.

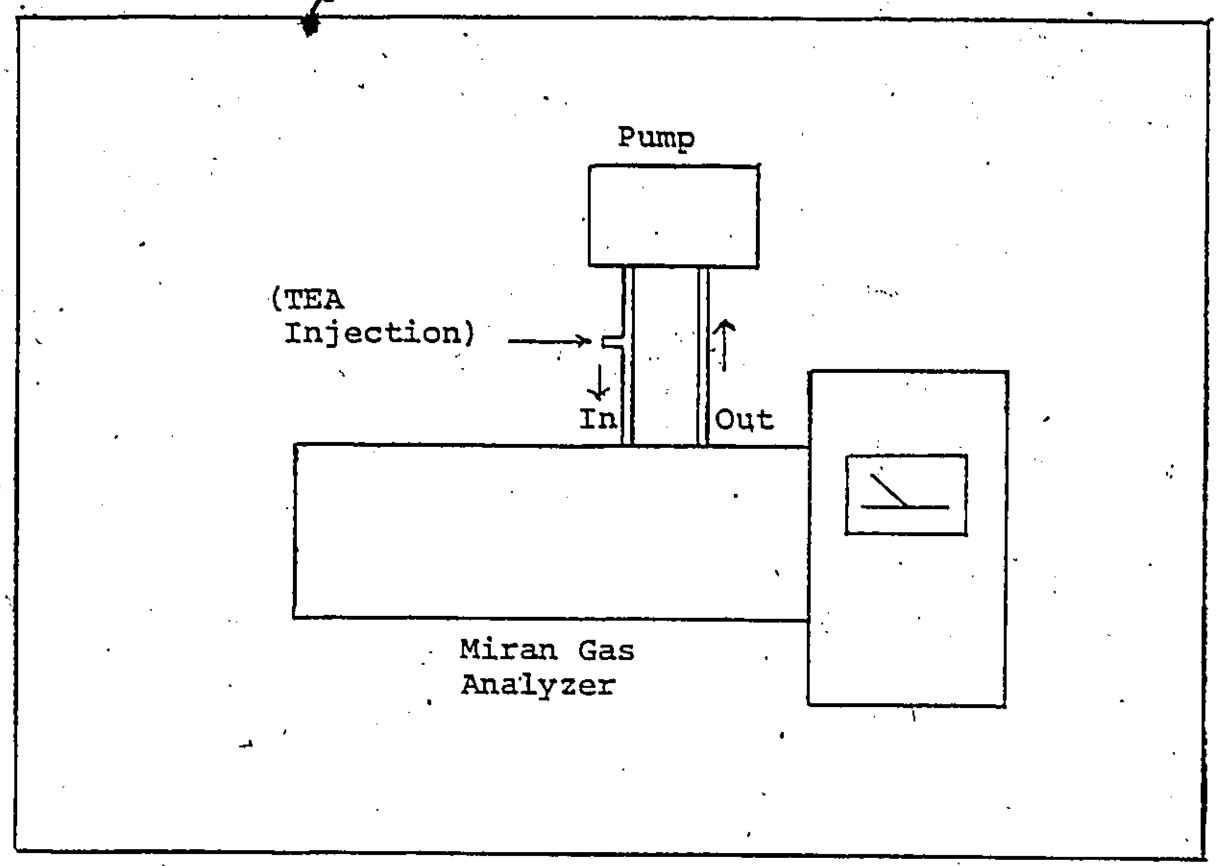


FIGURE 5 : Schematic Diagram of Closed Loop Calibration System

3. <u>Variation of TEA with Fish Ageing</u>

The aim of this particular experiment was to measure changes in TEA concentrations with time when fish or fish waste products created during commercial processing are not efficiently refrigerated.

Pieces of fresh smelt fish were placed in a one litre container connected to the Miran instrument and pump in a closed loop system as shown in Figure 6. The Miran gas analyzer was set at the 9.3 µm wavelength and other specifications mentioned in Appendix III. Before starting, the absorbance reading was zeroed using carbon filtered laboratory air. After the loop was reconnected, the pump was turned on and the absorbance readings were recorded with respect to time.

4. <u>Determination of Fish Odor Dimensions</u>

a. <u>Experimental Approach</u>

The olfactometer used in this program provided five dilution levels, each containing three sniffing ports. Two of the ports at each level delivered deodorized air. The third one provided an odorous sample.

The five levels, designed to provide dilution factors of 17, 8, 6, 3 and 1, were calibrated with a bubble flow meter. The level corresponding to a dilution factor of 1 represented the original fish odor sample without any dilution. In practice, the fish odors were drawn by a peristaltic pump from a vessel containing several pieces of fish, as shown in Figure 7. This arrangement was designed to simulate odor release from fish exposed to ambient air movements in a normal fish

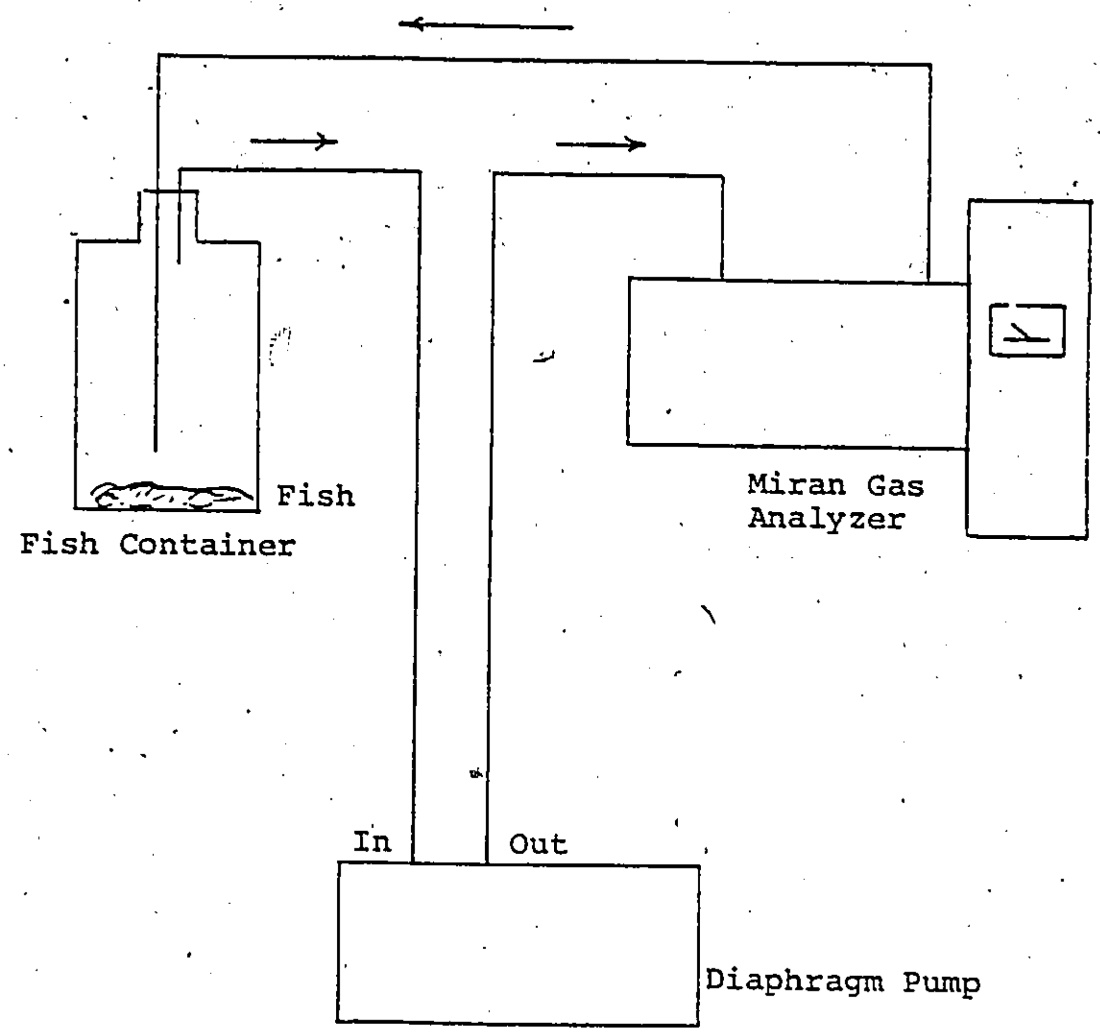


FIGURE 6 : Fish Container Incorporated into Miran Closed Loop System

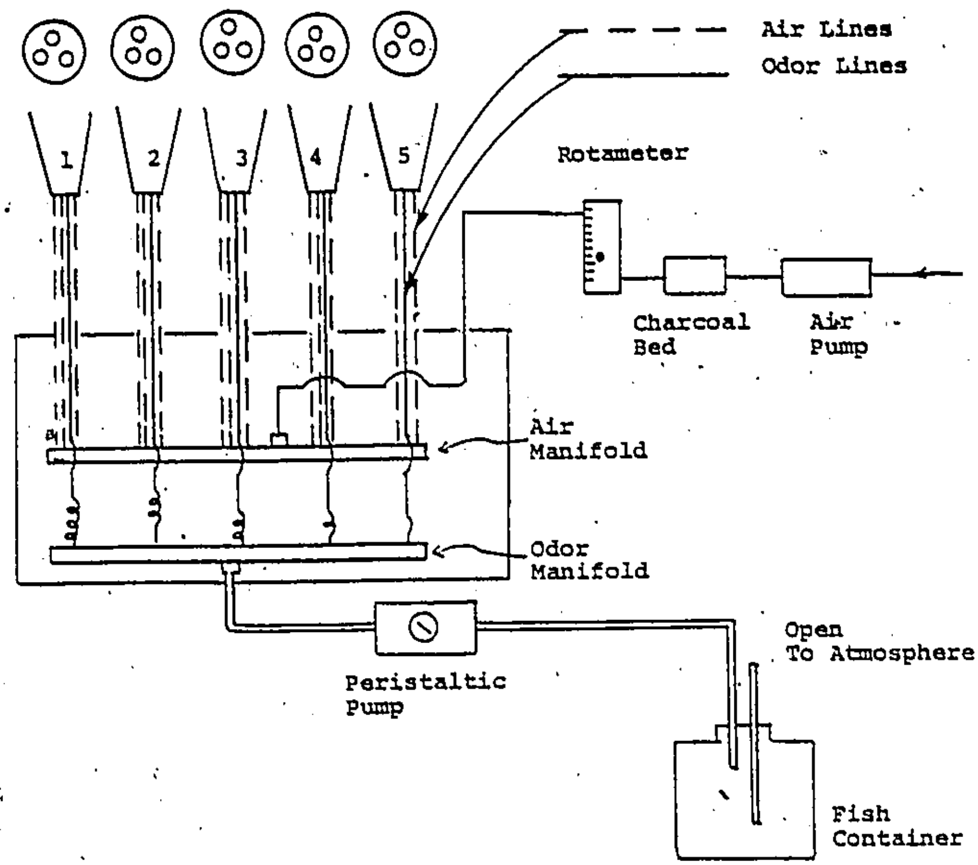


FIGURE 7 : Fish Container Incorporated into Olfactometer

packaging operation.

Each port supplied approximately 1000 cm^3/min of the odorous sample or pure air. Panelists were asked to identify at which dilution level they could detect the fish odor using a forced choice method.

Individuals participating in these tests were from different age groups, representing both sexes.

A signal box with five triple sets of lights provided a means of communication between the panel members and the panel coordinator who was located outside the odor booth. This arrangement minimized the potential for the panel leader to influence the judgement of panel members subjected to the odorous stimuli.

b. Experimental Procedure

Inside the odor booth each panelist was provided with a preprinted form for recording the individually perceived complaint level at each dilution level. Figure 8 illustrates the design of the complaint rating form. Participants were asked to

i. start from left to right in ascending order of concentration (from dilution factor 17 to 1)

ii. sniff all 3 ports at each level and using a forced choice technique to specify the port which was delivering the odor by pressing the corresponding signal button.

iii. identify the dilution level at which they were sure, beyond any doubt, about the presence of the odor.

At any port where you are certain, beyond a doubt, about the presence of the odor under investigation, circle a value which expresses your degree of annoyance or potential complaint level (if you were exposed to the odor for an average period of 8 hours) using a scale from 0-10.

Sampling Station	1	2	3	4	5
No Complaint Level	0	0	0	0	0
	1	1	1	1	1
	2	2	2	2	2
	3	3	3	3	3
	4	4	4	4	4
	5	5	5	5	5
	6	6	6	6	6
	7	7	7	7	7
	8	8	8	8	8
Maximum Complaint Level	9	9	9	9	9
	10	10	10	10	10

FIGURE 8: Typical Complaint Rating Form

iv. express, using the form providing a scale from 0 to 10, the degree of annoyance that would be created by exposure for average 8 hour periods to odors associated with each dilution level.

The panelists were advised to sniff fresh air, from the air cleaner provided in the odor booth, to sharpen their sense of smell between dilution levels and ports within a dilution level.

The panel responses through the signal box were also recorded by the panel leader located outside the odor test room for subsequent evaluation of detection, discrimination and complaint potential thresholds and the degrees of complaint for fish odors in terms of the newly developed odor impact modelling technique.

The TEA concentration of the original odor sample was measured using the Closed Loop Miran System.

VI. RESULTS

A. Odor Threshold Determinations

The results of the application of various methods of data analysis to odor detection and discrimination threshold determinations are presented in terms of:

i. Hall-Ellis Ranking

ii. Modified Dravnieks, and

iii. Maximum Likelihood Estimator Probability Model

techniques.

To compare the effect of the number of trials, initial concentrations and panel sizes on odor threshold values, experiments were conducted with

i. two samples of n-butanol whose initial concentrations were 99.46 and 52.06 ppm

ii. panels of 7 and 10 members

iii. each sample being presented three times to each panel.

Tables 2, 3 and 4 summarize the experimental data obtained from three trials with the IITRI dynamic olfactometer. The original concentration of the sample was 99.46 ppm of n-butanol. The panel consisted of seven individuals.

Tables 5, 6 and 7 provide the experimental data derived from three trials using a 52.06 ppm n-butanol initial concentration and a panel of 10 members.

The dilution levels at which the panelists made correct choices and continued to be correct were used for odor detection threshold evaluations. Odor discrimination thresholds have been based on the levels at which the panel judges were first certain about their choice of port emitting the odor under investigation.

Sample : 99.46 ppm n-Butanol
Temperature : 25°C
Date : July 8 , 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels					
	1	2	3	4	5	6
	Dilution Factors					
	1440	490	162	56	20	7
DAN	I	I	I	C	*C	C
KIM	C	C	C	*C	C	C
NAG	I	I	C	*C	C	C
RIK	C	C	C	I	*C	C
ANL	I	C	C	C	*C	C
MEH	C	I	C	*C	C	C
LI	I	C	C	C	*C	C

* indicates dilutions from which onwards panelists are certain about the presence of the odor under investigation.

TABLE 2: Odor Panel Responses During First Trial Using Dynamic Ternary Forced Choice Technique

Sample : 99.46 ppm n-Butanol
Temperature : 25°C
Date : July 8 , 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels					
	1	2	3	4	5	6
	Dilution Factors					
	1440	490	162	56	20	7
DAN	C	C	C	C	*C	C
KIM	I	C	I	C	*C	C
NAG	C	C	C	C	*C	C
RIK	I	I	I	*C	C	C
ANL	C	I	I	C	*C	C
MEH	C	I	*C	C	C	C
LI	I	I	C	I	*C	C

* indicates dilutions from which onwards panelists are certain about the presence of the odor under investigation.

TABLE 3: Odor Panel Responses During Second Trial Using Dynamic Ternary Forced Choice Technique

Sample : 99.46 ppm n-Butanol
Temperature : 25°C
Date : July 8 , 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels					
	1	2	3	4	5	6
	Dilution Factors					
	1440	490	162	56	20	7
DAN	C	I	I	C	*C	C
KIM	I	C	C	C	*C	C
NAG	C	C	*C	C	C	C
RIK	I	C	I	C	*C	C
ANL	C	C	C	*C	C	C
MEH	C	I	*C	C	C	C
LI	C	C	I	C	*C	C

* indicates dilutions from which onwards panelists are certain about the presence of the odor under investigation.

TABLE 4: Odor Panel Response During Third Trial Using Dynamic Ternary Forced Choice Technique

Sample : 52.06 ppm n-Butanol
Temperature : 26°C
Date : July 11,1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels					
	1	2	3	4	5	6
	Dilution Factors					
	1440	490	162	56	20	7
DAN	C	C	C	I	*C	C
KIM	I	C	I	C	*C	C
ROB	I	I	I	I	*C	C
LAG	C	C	I	*C	C	C
MAY	I	I	C	C	*C	C
MOH	I	C	C	C	*C	C
NAG	I	C	I	*C	C	C
MEH	I	C	C	*C	C	C
PRA	C	C	I	*C	C	C
PAL	I	I	C	*C	C	C

* indicates dilutions from which onwards panelists were certain about the presence of the odor under investigation.

TABLE 5: Odor Panel Responses During First Trial with Ten Member Panel Size Using Dynamic Ternary Forced Choice Technique

Sample : 52.06 ppm n-Butanol
Temperature : 26°C
Date : July 11,1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels					
	1	2	3	4	5	6
	Dilution Factors					
	1440	490	162	56	20	7
DAN	I	C	I	*C	C	C
KIM	I	C	I	*C	C	C
ROB	C	I	I	*C	C	C
LAG	I	C	I	*C	C	C
MAY	I	C	C	C	*C	C
MOH	C	C	C	*C	C	C
NAG	I	I	C	*C	C	C
MEH	I	C	I	*C	C	C
PRA	I	I	I	*C	C	C
PAL	I	C	*C	C	C	C

* indicates dilutions from which onwards panelists were certain about the presence of the odor under investigation.

TABLE 6: Odor Panel Responses During Second Trial With Ten Member Panel Size Using Dynamic Ternary Forced Choice Technique

Sample : 52.06 ppm n-Butanol
Temperature : 26°C
Date : July 11,1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels					
	1	2	3	4	5	6
	Dilution Factors					
	1440	490	162	56	20	7
DAN	I	I	I	I	*C	C
KIM	I	C	I	*C	C	C
ROB	I	C	I	*C	C	C
LAG	I	C	I	I	*C	C
MAY	I	I	I	I	*C	C
MOH	I	I	I	C	*C	C
NAG	I	I	C	*C	C	C
MEH	C	I	*C	C	C	C
PRA	I	I	C	*C	C	C
PAL	I	C	C	*C	C	C

* indicates dilutions from which onwards panelists were certain about the presence of the odor under investigation.

TABLE 7: Odor Panel Responses During Third Trial With Ten Member Panel Size Using Dynamic Ternary Forced Choice Technique

These levels have been designated by the symbol * on the data sheets.

1. Hall-Ellis Ranking Method

Evaluation of odor thresholds by the Hall-Ellis Ranking Method (41) involves plotting of average rank responses from the panelists (converted into plotting values) versus average log (dilution factors) also called log (tolerance level) for each separate trial. The method of analysis has been fully described in Chapter IV.

Figure 9 illustrates the evaluation of the detection thresholds of n-butanol odor for the presentation of a 99.46 ppm initial concentration to a panel of seven members during three trials. From these plots, the detection thresholds of n-butanol odor were found to be 0.28, 0.63 and 0.36 ppm.

Figure 10 illustrates the evaluation of n-butanol odor discrimination thresholds from three trials based on the dilution levels beyond which the panelists continued to be sure about the presence of the odor. From these plots the discrimination thresholds of n-butanol odor were determined to be 1.98, 2.23 and 1.57 ppm.

The evaluation of detection thresholds of n-butanol odor of original concentration 52.06 ppm is depicted in Figure 11. For the lower initial concentration, the detection threshold of n-butanol odor was determined to be 0.33, 0.28 and 0.42 ppm.

Figure 12 illustrates the evaluation of discrimination thresholds of n-butanol odor with a ten member panel. For the three trial presentations of 52.06 ppm n-butanol to 10 panelists,

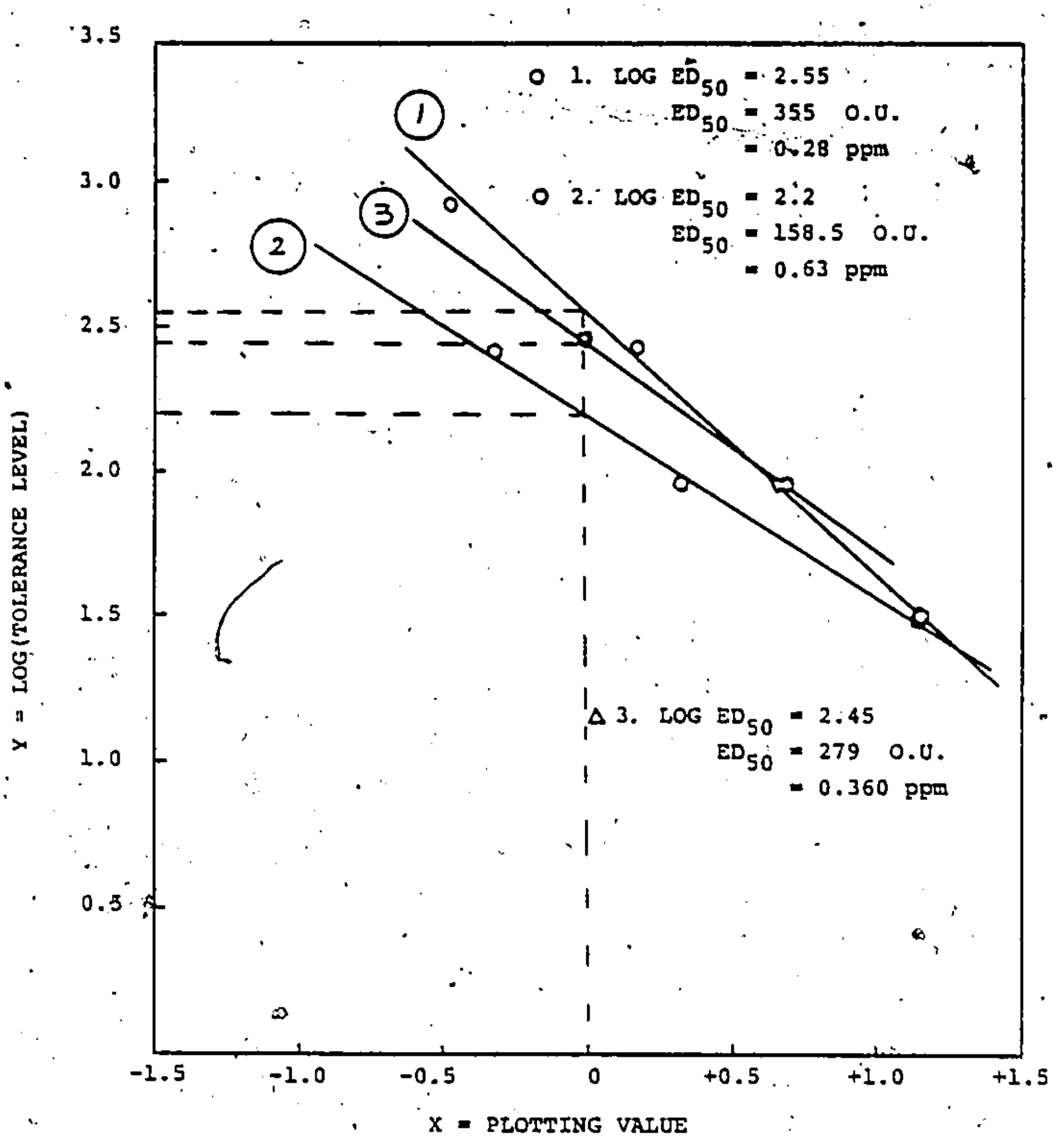


FIGURE 9: Evaluation of Detection Thresholds Using Hall Ellis Ranking Method With Seven Member Panel Size

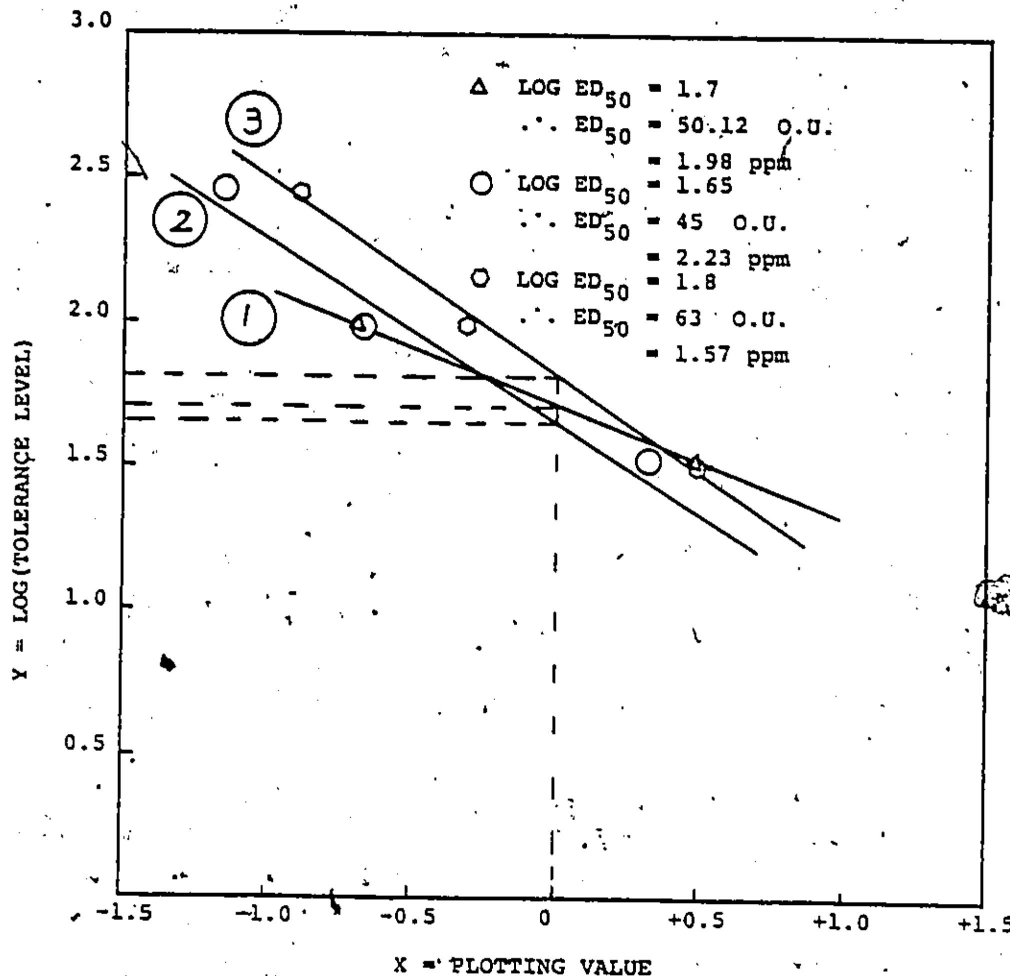


FIGURE 10: Evaluation of Discrimination Thresholds Using Hall Ellis Ranking Method With Seven Member Panel Size

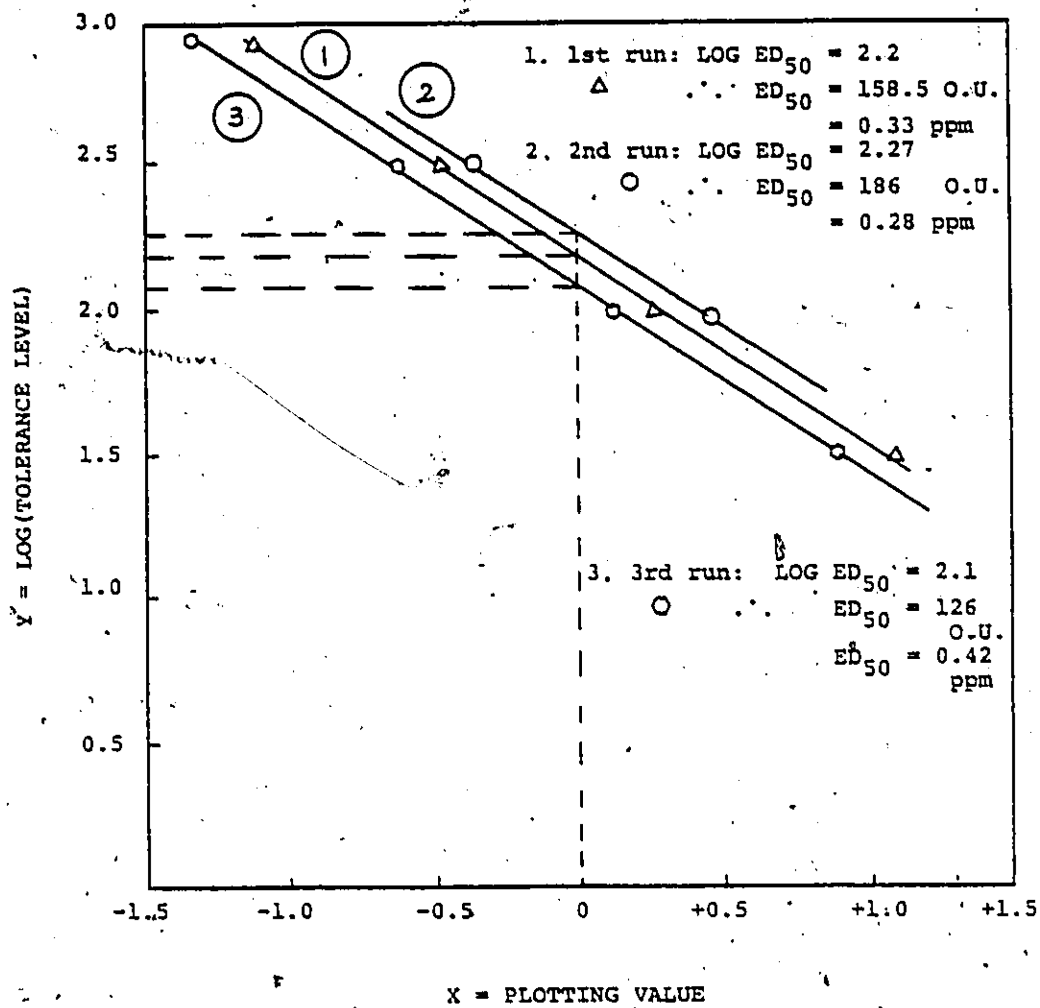


FIGURE 11: Evaluation of Detection Thresholds Using Hall Ellis Ranking Method With Ten Member Panel Size

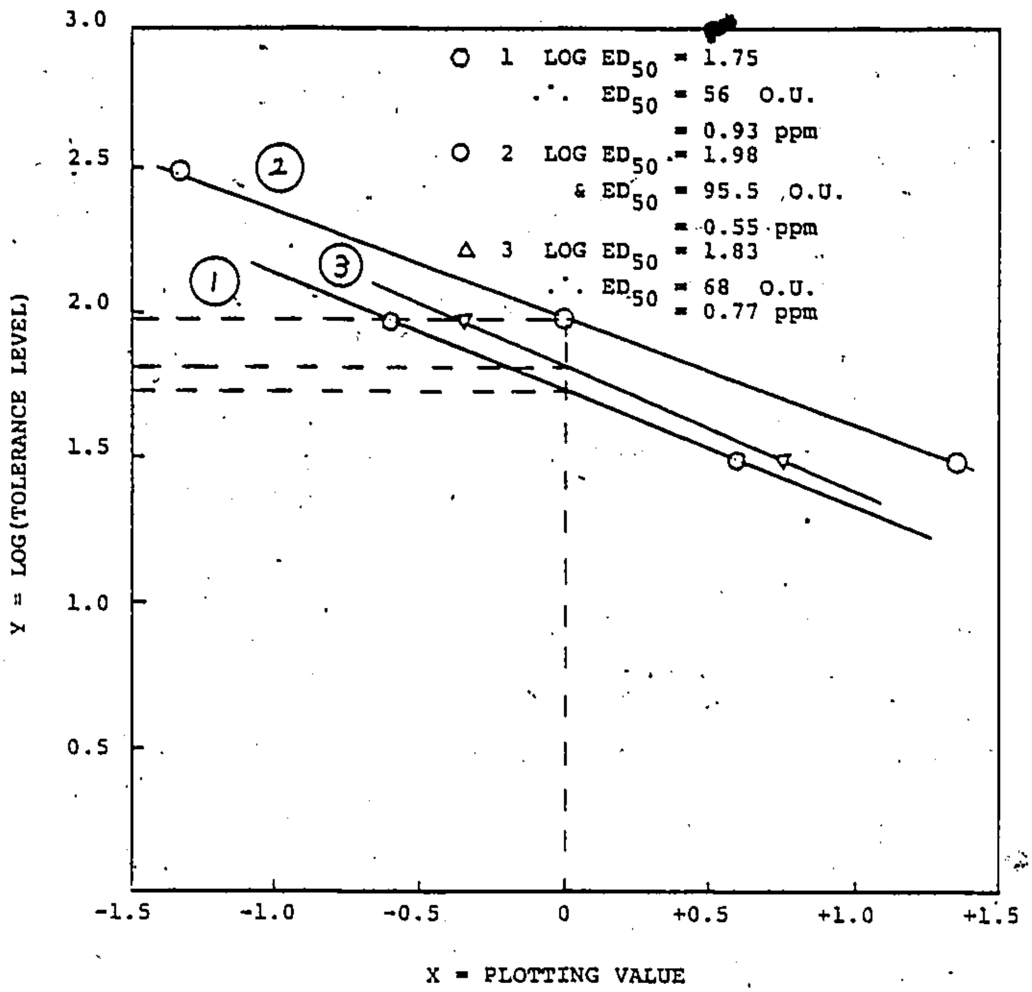


FIGURE 12: Evaluation of Discrimination Thresholds Using Hall Ellis Ranking Method With Ten Member Panel Size

the discrimination thresholds were calculated to be 0.93, 0.55 and 0.77 ppm.

Table 8 summarizes the results of both detection and discrimination threshold evaluations by the Hall-Ellis Ranking Method for the six trials involving two different initial concentrations of n-butanol and panel sizes of 7 and 10 members.

2. Modified Dravnieks Method

This method, developed by Dravnieks et al (42), eliminates the need for plotting the panel response data. Their procedure involves the estimation of a maximum likelihood threshold for each panel member and finally determining a geometric mean threshold for the entire panel. Tables 9, 10 and 11 illustrate the conversion of individual judgements to the maximum likelihood threshold for each panelist for three trials based on dilutions from which the panelists continued to correctly detect the odor. The mean threshold of the panel for any one trial is obtained by adding the logarithm of the individual maximum likelihood thresholds, dividing by the number of panelists and taking the antilogarithm of the result.

For an initial concentration of n-butanol corresponding to 99.46 ppm as butane equivalent and a panel size of 7, the detection thresholds were found to be 0.30, 0.40 and 0.26 ppm. Tables 12, 13 and 14, illustrating the evaluation of discrimination thresholds for the same conditions, provide values of 1.90, 1.90 and 1.40 ppm.

Tables 15 to 20 provide the results of the evaluation of detection and discrimination thresholds of n-butanol odor when an original concentration of 52.06 ppm was presented three

Initial Concentration ppm	Panel Size	Trial No.	Thresholds by Hall-Ellis Approach	
			Detection ppm	Discrimination ppm
99.46	7	1	0.28	1.98
		2	0.63	2.23
		3	0.36	1.57
52.06	10	1	0.33	0.93
		2	0.28	0.55
		3	0.42	0.77
Arithmatic Mean (AM)			0.40	1.34
Standard Deviation (SD)			0.15	0.63
AM ± SD			0.40 ± 0.15	1.34 ± 0.63

TABLE 8: Odor Thresholds of n-Butanol by Hall-Ellis Ranking Method

Sample : 99.46 ppm n-Butanol
Temperature : 25°C
Date : July 8, 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels						Log Individual ED_{50}
	1	2	3	4	5	6	
	Dilution Factors						
	1440	490	162	56	20	7	
DANA	I	I	I	C	C	C	1.98
KIM	C	C	C	C	C	C	3.40
NAG	I	I	C	C	C	C	2.45
RIK	C	C	C	I	C	C	1.52
ANL	I	C	C	C	C	C	2.92
MEH	C	I	C	C	C	C	2.45
LI	I	C	C	C	C	C	2.92

Sum Log Individual ED_{50} : 17.65 , Log ED_{50} : 2.52
Result : ED_{50} : 332 O.U., 0.30 ppm

TABLE 9: Evaluation of Detection Threshold By Modified Dravnieks Method for First Trial

Sample : 99.46 ppm n-Butanol
Temperature : 25°C
Date : July 8 , 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels						Log Individual ED_{50}
	1	2	3	4	5	6	
	Dilution Factors						
	1440	490	162	56	20	7	
DANA	C	C	C	C	C	C	3.40
KIM	I	C	I	C	C	C	1.98
NAG	C	C	C	C	C	C	3.40
RIK	I	I	I	C	C	C	1.98
ANL	C	I	I	C	C	C	1.98
MEH	C	I	C	C	C	C	2.45
LI	I	I	C	I	C	C	1.52

Sum Log Individual ED_{50} : 16.71 , Log ED_{50} : 2.39
Result : ED_{50} : 244 O.U., 0.40 ppm

TABLE 10: Evaluation of Detection Threshold By Modified Dravnieks Method for Second Trial

Sample : 99.46 ppm n-Butanol
Temperature : 25°C
Date : July 8 , 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels						Log Individual ED_{50}
	1	2	3	4	5	6	
	Dilution Factors						
	1440	490	162	56	20	7	
DANA	C	I	I	C	C	C	1.98
KIM	I	C	C	C	C	C	2.92
NAG	C	C	C	C	C	C	3.40
RIK	I	I	I	C	C	C	1.98
ANL	C	C	C	C	C	C	3.40
MEH	C	I	C	C	C	C	2.45
LI	C	C	I	C	C	C	1.98

Sum Log Individual ED_{50} : 18.11 , Log ED_{50} : 2.59
Result : ED_{50} : 386.50 O.U., 0.26 ppm

TABLE 11: Evaluation of Detection Threshold By Modified Dravnieks Method For Third Trial

Sample : 99.46 ppm n-Butanol
Temperature : 25°C
Date : July 8 , 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels						Log Individual ED_{50}
	1	2	3	4	5	6	
	Dilution Factors						
	1440	490	162	56	20	7	
DANA	I	I	I	C	*C	C	1.52
KIM	C	C	C	*C	C	C	1.98
NAG	I	I	C	*C	C	C	1.98
RIK	C	C	C	I	*C	C	1.52
ANL	I	C	C	C	*C	C	1.52
MEH	C	I	C	*C	C	C	1.98
LI	I	C	C	C	*C	C	1.52

Sum Log Individual ED_{50} : 12.00 , Log ED_{50} : 1.72
Result : ED_{50} : 52.40 O.U., 1.90 ppm .

TABLE 12: Evaluation of Discrimination Threshold By Modified Dravnieks Method For First Trial

Sample : 99.46 ppm n-Butanol
Temperature : 25°C
Date : July 8 , 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels						Log Individual ED_{50}
	1	2	3	4	5	6	
	Dilution Factors						
	1440	490	162	56	20	7	
DANA	C	C	C	C	*C	C	1.52
KIM	I	C	I	C	*C	C	1.52
NAG	C	C	C	*C	C	C	1.98
RIK	I	I	I	C	*C	C	1.52
ANL	C	I	I	C	*C	C	1.52
MEH	C	I	*C	C	C	C	2.45
LI	I	I	C	I	*C	C	1.52

Sum Log Individual ED_{50} : 12.00 , Log ED_{50} : 1.72
Result : ED_{50} : 52.40 O.U., 1.9 ppm

TABLE 13: Evaluation of Discrimination Threshold By Modified Dravnieks Method For Second Trial

Sample : 99.46 ppm n-Butanol
Temperature : 25°C
Date : July 8 , 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels						Log Individual ED_{50}
	1	2	3	4	5	6	
	Dilution Factors						
	1440	490	162	56	20	7	
DANA	C	I	I	C	*C	C	1.52
KIM	I	C	C	C	*C	C	1.52
NAG	C	C	*C	C	C	C	2.45
RIK	I	C	I	C	*C	C	1.52
ANL	C	C	C	*C	C	C	1.98
MEH	C	I	*C	C	C	C	2.45
LI	C	C	I	C	*C	C	1.52

Sum Log Individual ED_{50} : 12.96 , Log ED_{50} : 1.85
Result : ED_{50} : 71.00 O.U., 1.40 ppm

TABLE 14: Evaluation of Discrimination Threshold By Modified Dravnieks Method For Third Trial

Sample : 52.06 ppm n-Butanol
Temperature : 26°C
Date : July 11, 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels 1	2	3	4	5	6	Log Individual ED_{50}
	Dilution Factors 1440	490	162	56	20	7	
DANA	C	C	C	I	C	C	1.52
KIM	I	C	I	C	C	C	1.98
ROB	I	I	I	I	C	C	1.52
LAG	C	C	I	C	C	C	1.98
MAY	I	I	C	C	C	C	2.45
MOH	I	C	C	C	C	C	2.92
NAG	I	C	I	C	C	C	1.98
MEH	I	C	C	C	C	C	2.92
PRA	C	C	I	C	C	C	1.98
PAL	I	I	C	C	C	C	2.45

Sum Log Individual ED_{50} : 21.70 , Log ED_{50} : 2.17
Result : ED_{50} : 148 O.U., 0.35 ppm

TABLE 15: Evaluation of Detection Threshold By Modified Dravnieks Method With Ten Member Panel Size For First Trial

Sample : 52.06 ppm n-Butanol
Temperature : 26 °C
Date : July 11 , 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels						Log Individual ED_{50}
	1	2	3	4	5	6	
	Dilution Factors						
	1440	490	162	56	20	7	
DANA	I	C	I	C	C	C	1.98
KIM	I	C	I	C	C	C	1.98
ROB	C	I	I	C	C	C	1.98
LAG	I	C	I	C	C	C	1.98
MAY	I	C	C	C	C	C	2.92
MOH	C	C	C	C	C	C	3.40
NAG	I	I	C	C	C	C	2.45
MEH	I	C	I	C	C	C	1.98
PRA	I	I	I	C	C	C	1.98
PAL	I	C	C	C	C	C	2.92

Sum Log Individual ED_{50} : 23.57 , Log ED_{50} : 2.36
Result : ED_{50} : 227.50 O.U., 0.23 ppm

TABLE 16: Evaluation of Detection Threshold By Modified Dravnieks With Ten Member Panel Size For Second Trial

Sample : 52.06 ppm n-Butanol
Temperature : 26°C
Date : July 11 , 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels 1	2	3	4	5	6	Log Individual ED_{50}
	Dilution Factors 1440	490	162	56	20	7	
DANA	I	I	I	I	C	C	1.52
KIM	I	C	I	C	C	C	1.98
ROB	I	C	I	C	C	C	1.98
LAG	I	C	I	I	C	C	1.52
MAY	I	I	I	I	C	C	1.52
MOH	I	I	I	C	C	C	1.98
NAG	I	I	C	C	C	C	2.45
MEH	C	I	C	C	C	C	2.45
PRA	I	I	C	C	C	C	2.45
PAL	I	C	C	C	C	C	2.92

Sum Log Individual ED_{50} : 20.77 , Log ED_{50} : 2.10
Result : ED_{50} : 119.40 O.U., 0.44 ppm

TABLE 17: Evaluation of Detection Threshold By Modified Dravnieks Method With Ten Member Panel Size For Third Trial

Sample : 52.06 ppm n-Butanol
Temperature : 26°C
Date : July 11 , 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels						Log Individual ED_{50}
	1	2	3	4	5	6	
	Dilution Factors						
	1440	490	162	56	20	7	
DANA	C	C	C	I	*C	C	1.52
KIM	I	C	I	C	*C	C	1.52
ROB	I	I	I	I	*C	C	1.52
LAG	C	C	I	*C	C	C	1.98
MAY	I	I	C	C	*C	C	1.52
MOH	I	C	C	C	*C	C	1.52
NAG	I	C	I	*C	C	C	1.98
MEH	I	C	C	*C	C	C	1.98
PRA	C	C	I	*C	C	C	1.98
PAL	I	I	C	*C	C	C	1.98

Sum Log Individual ED_{50} : 17.50 , Log ED_{50} : 1.75
Result : ED_{50} : 56.23 O.U., 0.93 ppm

TABLE 18: Evaluation of Discrimination Threshold By Modified Dravnieks Method Using Ten Member Panel Size For First Trial

Sample : 52.06 ppm n-Butanol
Temperature : 26°C
Date : July 11, 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels 1	2	3	4	5	6	Log Individual ED_{50}
	Dilution Factors 1440	490	162	56	20	7	
DANA	I	C	I	*C	C	C	1.98
KIM	C	I	I	*C	C	C	1.98
ROB	I	C	I	*C	C	C	1.98
LAG	I	C	I	*C	C	C	1.98
MAY	I	C	C	C	*C	C	1.52
MOH	C	C	C	*C	C	C	1.98
NAG	I	I	C	*C	C	C	1.98
MEH	I	C	I	*C	C	C	1.98
PRA	I	I	I	*C	C	C	1.98
PAL	I	C	*C	C	C	C	2.45

Sum Log Individual ED_{50} : 19.81 , Log ED_{50} : 1.98
Result : ED_{50} : 95.70 O.U., 0.54 ppm

TABLE 19: Evaluation of Discrimination Threshold By Modified Dravnieks Method Using Ten Member Panel Size For Second Trial

Sample : 52.06 ppm n-Butanol
Temperature : 26°C
Date : July 11 , 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels						Log Individual ED_{50}
	1	2	3	4	5	6	
	Dilution Factors						
	1440	490	162	56	20	7	
DANA	I	I	I	I	*C	C	1.52
KIM	I	C	I	*C	C	C	1.98
ROB	I	C	I	*C	C	C	1.98
LAG	I	C	I	I	*C	C	1.52
MAY	I	I	I	I	*C	C	1.52
MOH	I	I	I	C	*C	C	1.52
NAG	I	I	C	*C	C	C	1.98
MEH	C	I	*C	C	C	C	2.45
PRA	I	I	C	*C	C	C	1.98
PAL	I	C	C	*C	C	C	1.98

Sum Log Individual ED_{50} : 18.43 , Log ED_{50} : 1.84
Result : ED_{50} : 69.66 O.U., 0.75 ppm

TABLE 20: Evaluation of Discrimination Threshold By Modified Dravnieks Method Using Ten Member Panel Size For Third Trial

times to a panel of 10 members. From this data, the detection thresholds of n-butanol odor were evaluated to be 0.35, 0.23 and 0.44 ppm, whereas the discrimination thresholds of the same odorous sample are 0.93, 0.54 and 0.75 ppm.

Table 21 summarizes the overall results of detection and discrimination threshold magnitude evaluations by the Modified Dravnieks approach for six trials involving two different initial concentrations of n-butanol and panel sizes of 7 and 10 members.

3. Maximum Likelihood Estimator Probability Model

The discrimination threshold of n-butanol odor has also been determined using a probability model based on a maximum likelihood estimator, for one, two and three trials when two initial concentrations of 99.46 ppm and 52.06 ppm were presented to panels consisting of 7 and 10 members respectively.

a. Higher Initial Concentration

i. One Trial

Table 22 provides the experimental data for one trial with the IITRI dynamic olfactometer for a 99.46 ppm initial concentration and a seven member panel.

The maximum likelihood estimates of the proportion of discriminators, $\hat{\alpha}$, for each dilution level were computed using Equation 3.

A plot of the logarithm of odor concentration versus $\hat{\alpha}$ provides the panel discrimination threshold in terms of the concentration corresponding to $\hat{\alpha} = 0.5$ as shown in Figure 13.

Initial Concentration ppm	Panel Size	Trial No.	Thresholds by Modified Dravnieks	
			Detection ppm	Discrimination ppm
99.46	7	1	0.30	1.90
		2	0.40	1.90
		3	0.26	1.40
52.06	10	1	0.35	0.93
		2	0.23	0.54
		3	0.44	0.75
Arithmatic Mean (AM)			0.33	1.24
Standard Deviation (SD)			0.073	0.53
AM ± SD			0.33 ± 0.073	1.24 ± 0.53

TABLE 21: Odor Thresholds of n-Butanol By Modified Dravnieks Approach

Sample: 99.46 ppm n-Butanol

Temperature: 25°C

Date: July 8, 1980

Sample Concentration ppm	Number of Subjects		$W_0/1$	$W_1/1$	$\hat{a}$ MLE
	Correct	Wrong			
0.07	3	4	0.43	0.57	0.145
0.20	4	3	0.57	0.43	0.355
0.61	6	1	0.86	0.14	0.79
1.77	6	1	0.86	0.14	0.79
5.00	7	0	1.00	0	1.00
14.20	7	0	1.00	0	1.00

TABLE 22: Application of Probability Model to the Estimation of n-Butanol Odor Discrimination Threshold for One Trial

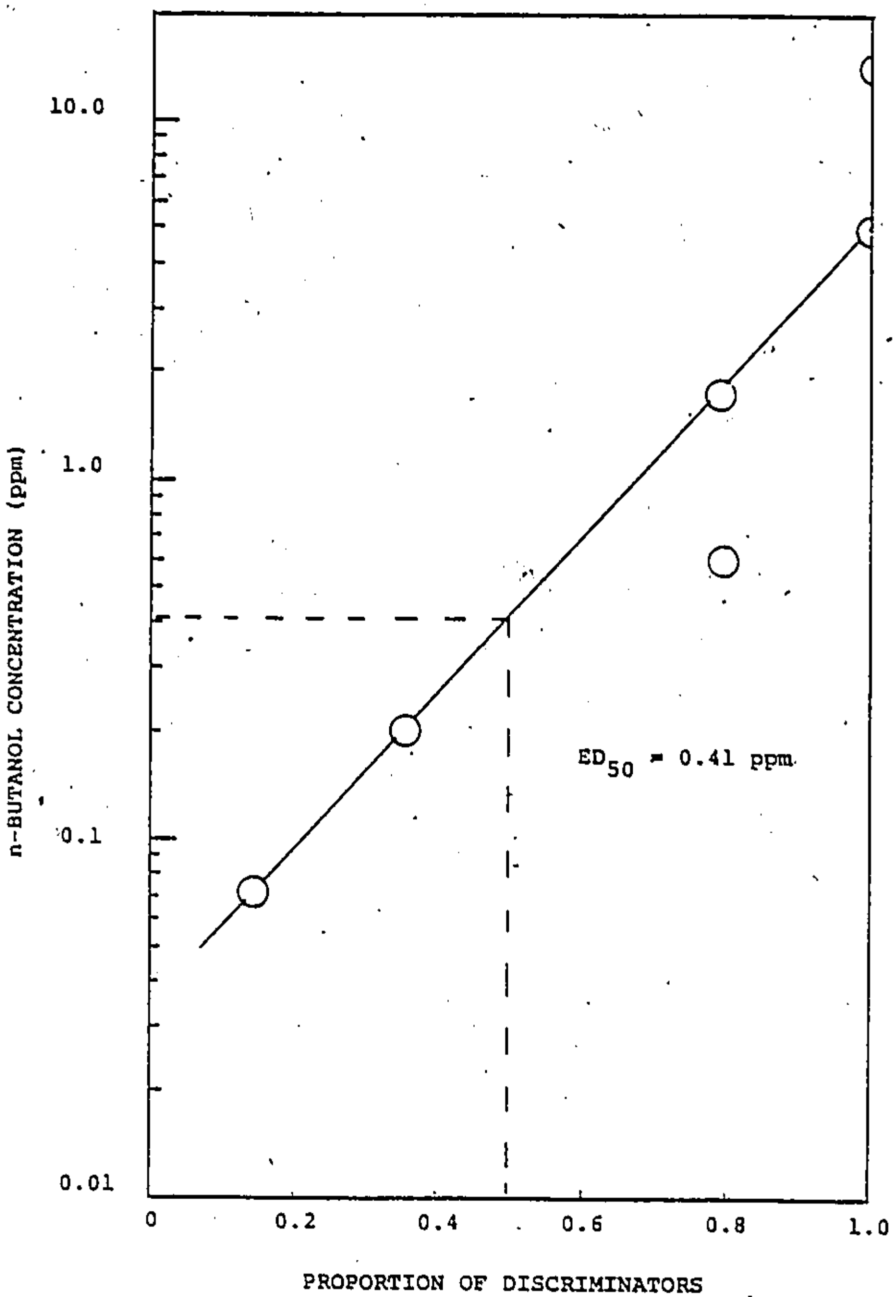


FIGURE 13: Evaluation of Discrimination Threshold Using Maximum Likelihood Estimator Probability Model For One Trial

ii. Two Trials

Table 23 summarizes the combined data obtained from two trials with the IITRI dynamic olfactometer for a 99.46 ppm initial concentration of n-butanol and a seven member panel. The maximum likelihood estimate of the proportion of discrimination, $\hat{\alpha}$, for each dilution level was computed using Equation 7. The results are listed in Table 24.

Figure 14 provides the plot of the logarithm of odor concentration versus $\hat{\alpha}$ from which the panel discrimination threshold, in terms of the concentration corresponding to $\hat{\alpha} = 0.5$, was found to be 0.96 ppm.

iii. Three Trials

Table 25 summarizes the experimental data obtained for three trials with the IITRI dynamic olfactometer for a 99.46 ppm initial concentration of n-butanol presented to a panel of 7 individuals.

The maximum likelihood estimate of the proportion of discriminators, $\hat{\alpha}$, for each dilution level was computed using Equation 12. The derived results are tabulated in Table 26.

The plot of the logarithm of odor concentration versus $\hat{\alpha}$, provides a value of 1.05 ppm for the estimated panel discrimination threshold in terms of the concentration corresponding to $\hat{\alpha} = 0.5$, as shown in Figure 15.

b. Lower Initial Concentration

Experimental data obtained with the original concentration of 52.06 ppm n-butanol and a 10 member panel using the IITRI dynamic olfactometer were also analyzed in terms of one, two

Sample: 99.46 ppm n-Butanol

Temperature: 25°C

Date: July 8, 1980

Sample Concentration as THC ppm	No. of Subjects Correct in Both Trials	No. of Subjects Wrong in Both Trials	No. of Once Wrong and Once Correct in Both Trials
0.07	1	1	5
0.20	1	1	5
0.61	3	1	3
1.77	5	0	2
5.00	7	0	0
14.20	7	0	0

TABLE 23: Combined Experimental Data From Two Trials for Evaluation of Odor Discrimination Threshold of n-Butanol

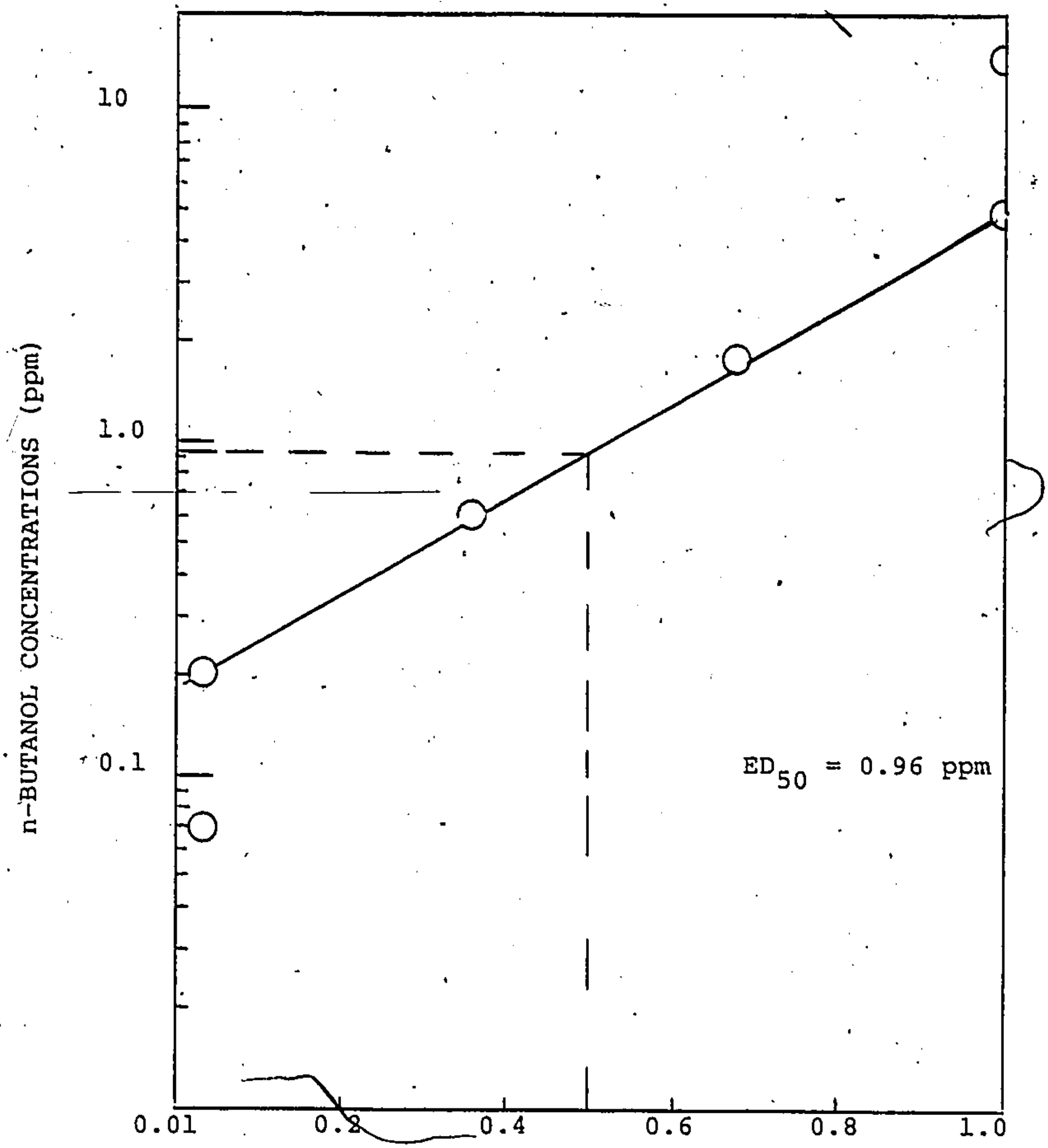
Sample: 99.46 ppm n-Butanol

Temperature: 25°C

Date: July 8, 1980

Sample Concentration as THC ppm	Proportion of Subjects Correct in Both Trials $W_0/2$	Proportion of Subjects Wrong in Both Trials $W_2/2$	Proportion of Subjects Correct Once and Wrong Once $W_1/2$	$\hat{\alpha}$
0.07	0.14	0.14	0.72	0.04
0.20	0.14	0.14	0.72	0.04
0.61	0.43	0.14	0.43	0.36
1.77	0.71	0	0.29	0.68
5.00	1.00	0	0	1.00
14.20	1.00	0	0	1.00

TABLE 24: Application of Maximum Likelihood Estimator Probability Model to Two Trials



$\hat{a}$ = PROPORTION OF DISCRIMINATORS

FIGURE 14: Evaluation of Discrimination Threshold Using Maximum Likelihood Estimator Probability Model For Two Trials

Sample: 99.46 ppm n-Butanol

Temperature: 25°C

Date: July 8, 1980

Sample Concentration as THC ppm	No. of Panelists Correct in All Three Trials	No. of Subjects Wrong in One Trial	No. of Subjects Wrong in Two Trials	No. of Subjects Wrong in All Three Trials
0.07	1	3	3	0
0.20	1	3	2	1
0.61	2	3	2	1
1.77	5	2	0	0
5.00	7	0	0	0
14.20	7	0	0	0

TABLE 25: Combined Experimental Data From Three Trials for Evaluation of Odor Discrimination Threshold of n-Butanol

Sample: 99.46 ppm n-Butanol

Temperature: 25°C

Date: July 8, 1980

Sample Concentration ppm as THC	Proportion of Subjects Correct in All Three Trials $W_0/3$	Proportion of Subjects Wrong Once $W_1/3$	Proportion of Subjects Wrong Twice $W_2/3$	Proportion of Subjects Wrong All Three Times $W_3/3$	$\hat{\alpha}$
0.07	0.14	0.43	0.43	0	0.11
0.20	0.14	0.43	0.29	0.14	0.11
0.61	0.29	0.43	0.29	0	0.26
1.77	0.71	0.29	0	0	0.70
5.00	1.00	0	0	0	1.00
14.20	1.00	0	0	0	1.00

TABLE 26: Application of Maximum Likelihood Estimator Approach for Evaluation of Odor Discrimination Threshold of n-Butanol for Three Trials

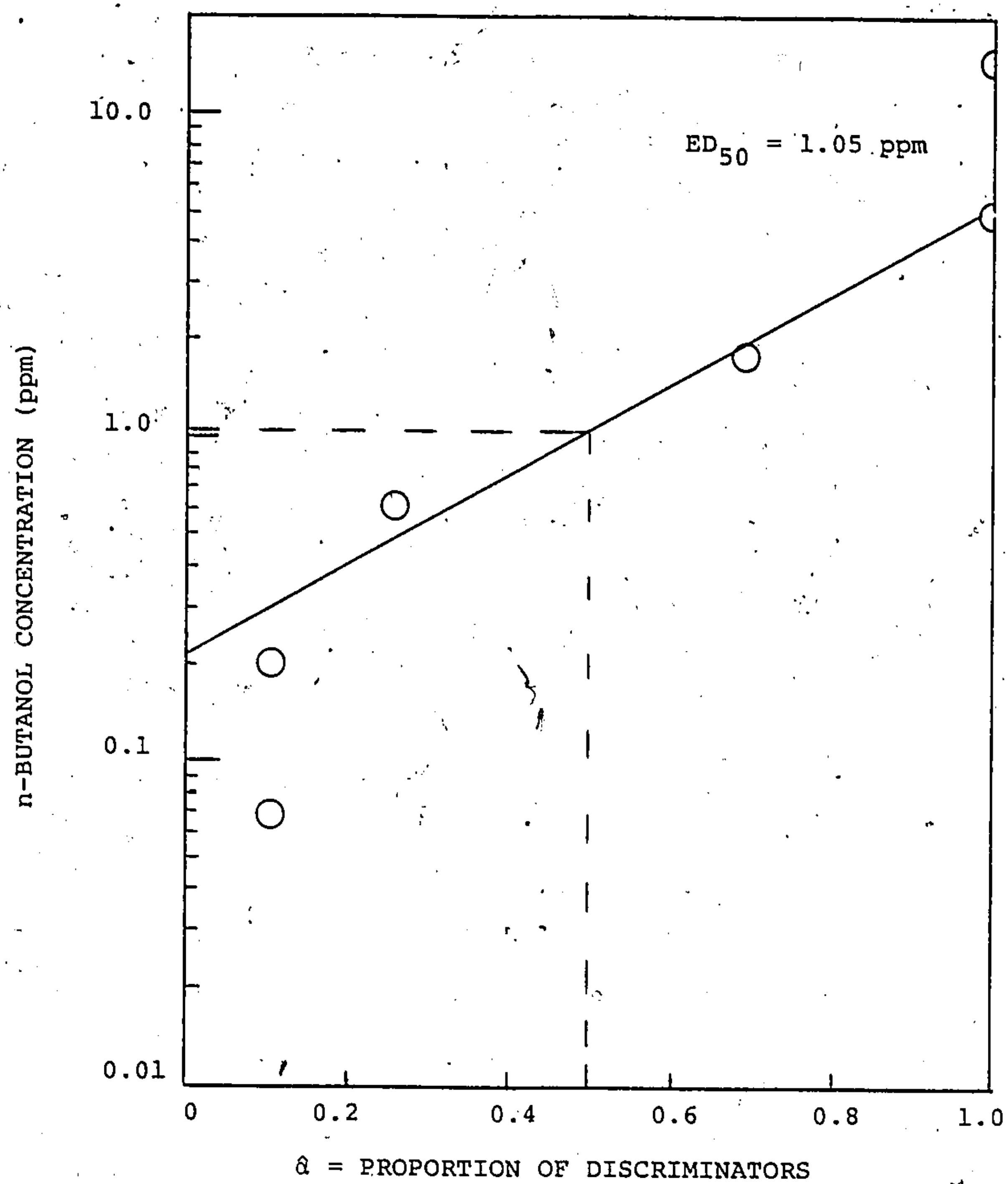


FIGURE 15: Evaluation of Discrimination Threshold Using Maximum Likelihood Estimator Probability Model for Three Trials

and three trials. Equations 3, 7 and 12 provided the maximum likelihood estimates of discrimination thresholds.

i. One Trial

From the plot of logarithm of odorant concentration versus the maximum likelihood estimate of the proportion of discriminators, $\hat{\alpha}$, determined for each level, the panel discrimination threshold corresponding to $\hat{\alpha} = 0.5$, was found to be 0.55 ppm.

ii. Two Trials

The evaluation of combined experimental data for two trials for the same sample and same number of panelists on the same day provides a discrimination threshold of 0.40 ppm.

iii. Three Trials

The panel discrimination threshold for the combined responses of three consecutive trials of the same sample and the same number of panelists was found to be 0.54 ppm. Table 27 summarizes the panel discrimination threshold values for a total of six trials involving 99.46 and 52.06 ppm initial concentrations of n-butanol vapors.

B. Major Component Approach

The results obtained during this part of the program are discussed in terms of

i. a basis of measurement of fish odors
ii. calibration of Miran Gas Analyzer for measurement of TEA
iii. variation of TEA with fish ageing
iv. determination of pertinent odor dimensions including detection, discrimination and complaint potential thresholds

Initial Concentration ppm	Panel Size	No. of Trials	Probability Model Discrimination Threshold ppm
99.46	7	1	0.41
		2	0.96
		3	1.05
52.06	10	1	0.55
		2	0.40
		3	0.54
Arithmatic Mean (AM)			0.65
Standard Deviation (SD)			0.25
AM ± SD			0.65 ± 0.25

TABLE 27: Evaluation of Odor Discrimination Thresholds of n-Butanol From Six Trials

and degrees of complaint of typical fish odors in terms of the Odor Impact Model.

1. Basis of Measurement of Fish Odors

There is still a genuine need for a capability of measuring odors objectively. Odor regulations and control technologies cannot be implemented successfully without reproducible odor level measuring techniques.

During this program, infrared absorbance bands, characteristics of fish odors, were detected in regions free from atmospheric interferences as shown in Figure 16. Triethylamine has been reported as one of the major components of fish odors (1). This compound [TEA] has a strong characteristic infrared absorbance band at the 9.3 μm wavelength (51).

Absorbance bands in this wavelength region were detected during repeated experiments with fish odors. However, they were absent during analysis of fish odor-free air as illustrated by Figure 16.

Comparison tests also showed that triethylamine is similar to the odors associated with fish processing industries. On this basis, triethylamine was taken as a reference standard for the determination of fish odor levels.

2. Calibration of Miran Gas Analyzer

The calibration of the Miran (Miniature Infrared Analyzer) provided capabilities for measuring the TEA content of fish odors at concentrations as low as 0.3 ppm as indicated by the data in Appendix II.

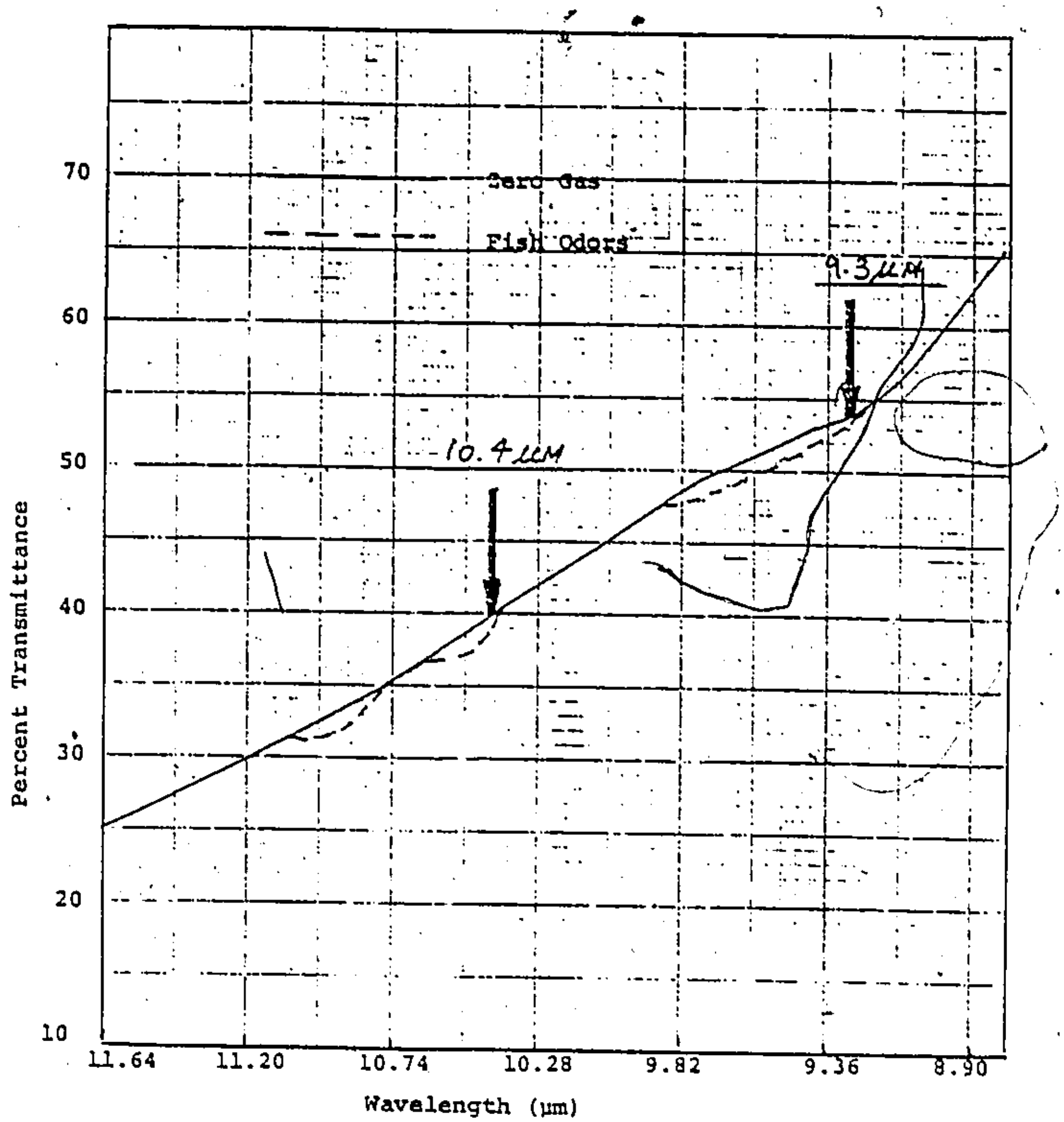


FIGURE 16: Comparison of Infrared Spectra of Fish Odors and Zero Gas Showing Absorption Bands Characteristic of Ammonia and Triethylamine.

3. Variation of TEA with Fish Ageing

To quantitatively assess the impact of a fish processing plant on a community it is necessary to have a reproducible analytical technique for evaluating magnitudes of odor levels of representative odor samples. Changes in absorbance due to variations in TEA content of odors released by ageing fish have been successfully recorded under laboratory conditions as illustrated by Table 28.

4. Application of Odor Impact Model

The responses from panelists provided a basis for the determination of detection, discrimination and complaint potential thresholds as well as degrees of complaint (on a scale of 0 to 10) for typical fish odors. All dilution levels were converted to corresponding TEA concentrations using the TEA concentration of the original odor sample as the basis.

The fractional responses as functions of TEA concentrations are shown in Figure 17. This approach provides a very convenient method for correlating the reactions from odor panel members. In principle, a 50% panel response can be taken as the representation of an average human nose.

Table 29 provides the threshold values and degree of complaint for the 50% panel response level to fish odor generated under laboratory conditions.

Absorbance	Time (minutes)
0	0
0.0110	7
0.0130	26
0.0148	45
0.0150	75
0.0165	100
0.0170	130
0.0180	185

TABLE 28: Absorbance vs Time Measurements at 9.3 μm Wavelength for TEA Generated by Ageing Fish

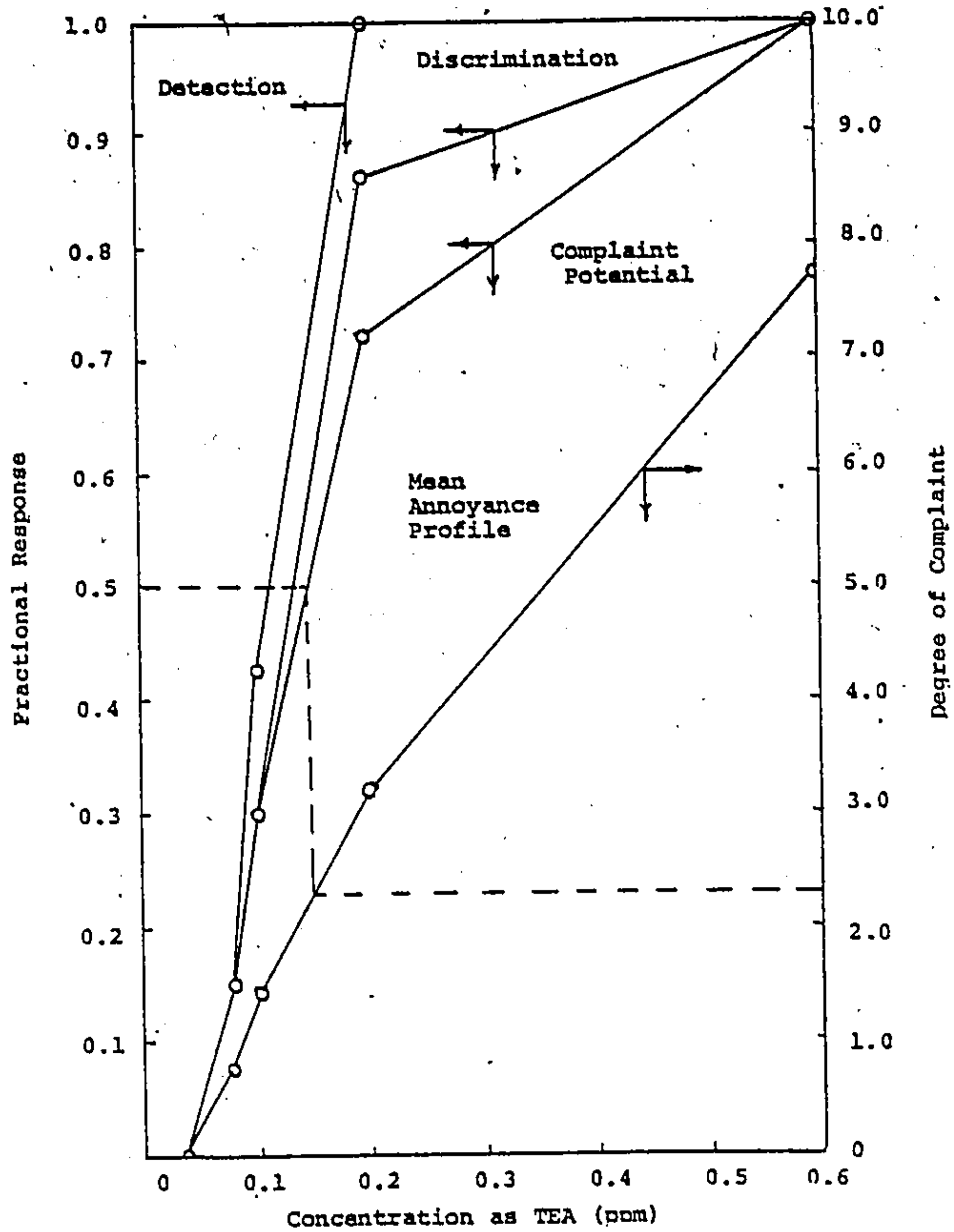


FIGURE 17: Evaluation of Fish Odor Dimensions

Detection Threshold	0.11 ppm
Discrimination Threshold	0.13 ppm
Complaint Potential Threshold	0.14 ppm
Degree of Complaint (Scale 0 - 10)	2.3

TABLE 29: Threshold Values and Degree of Complaint for an Average Human Nose Exposed to Fish Odors

VII. DISCUSSION OF RESULTS

Previous investigators (54, 55, 56) have indicated that many factors can affect the results of odor threshold determinations. Earlier studies show that:

i. sex and age of respondents
ii. smoking and eating habits of panelists
iii. sample humidity and temperature
iv. background odors and noises
v. mode of odor presentation
vi. sample flow rate
vii. measurement techniques
viii. anticipation effects and olfactory fatigue,

have influenced experimentally determined threshold values. It is, therefore, not surprising that during this investigation the same panels repeatedly judging the same odor sample with the same olfactometer under the same conditions did not provide the same detection and discrimination thresholds each time.

A. Hall Ellis and Modified Dravnieks Approaches

Since odor thresholds are based on subjective determinations, it is not possible to evaluate an absolute magnitude that defines a "true" threshold value. Consequently, the concept of accuracy is not applicable to sensory odor measurements. The scatter in repeated odor evaluations must be discussed in terms of an acceptable range. For example, the data in Tables 8 and 21 show that a single evaluation of a detection or discrimination threshold by the Hall-Ellis or Modified Dravnieks procedures will always be within ± 50% of the mean of six trials. This variability is consistent with evaluations reported by other investigators. Dravnieks and Jarke (57) have suggested that properties determined by sensory techniques can be discussed in terms of the ratio of the highest to lowest panel responses. They have shown that if R denotes the ratio between the highest and lowest odor thresholds measured for the same odorous air sample, the observed scatter in evaluated data can be correlated in terms of

i. R = 2.5, for the same panel of nine, on the same day, with the same high-state-of art system

ii. R = 4, for the same panel and same systems on the same day but the flow rate from sniffing ports changed from 0.5 to 9 L/min.

iii. R up to 200, for the same panel, same day, but different olfactometric systems

iv. R = 10, for static systems, different panels deliberately selected to consist of normally sensitive people, but one panel at the lower end, the other at the higher end of the sensitivity spectrum.

All the threshold values determined during this program fall within the range of data reported in the literature (58). The variability in the measured threshold values evaluated from current studies is summarized in Table 30. It is evident that the R values are consistent with published results.

Conditions	HALL-ELLIS THRESHOLDS		MODIFIED DRAVNIEKS THRESHOLDS		Researchers
	Detection	Discrim-ination	Detection	Discrim-ination	
Same day, same panel and same state of art of system. Initial conc. = 99.46 ppm Panel size = 7	2.25	1.40	1.54	1.35	Present Work
Same day, same panel and same state of art of system. Initial conc. = 52.06 ppm Panel size = 10	1.50	1.70	1.90	1.70	Present
Same day, same panel and same state of art of system. Panel size = 9	2.50	-	-	-	Dravnieks (57)
Different days, different initial concentrations. Panel sizes of 7 and 10. Same state of art of system	2.25	4.00	2.00	3.50	Present Work

TABLE 30: Comparison of Ratios of Highest to Lowest Threshold Values Evaluated by Hall-Ellis and Modifed Dravnieks Approaches

B. Maximum Likelihood Estimator Probability Model

In all cases, the discrimination threshold values evaluated by the Maximum Likelihood Estimator Probability Model, fall between the detection and discrimination thresholds evaluated by Hall-Ellis or Modified Dravnieks methods.

The discrimination thresholds evaluated by the Probability Model approach must be higher than any corresponding detection threshold because successful guess work is eliminated by this mode of data analysis. The discrimination thresholds evaluated by Hall-Ellis and Modified Dravnieks procedures are higher than the maximum likelihood estimator Probability Model values because they approximate recognition thresholds. In practice, panelists often admit to recognizing the character of an odor when denoting positive detection under forced choice decision conditions. The ratio of the highest to lowest odor discrimination threshold for the higher concentration of n-butanol is 2.5, while for the lower initial concentration it is 1.4. The overall R value for six trials is 2.6. The arithmatic mean for the six trials is 0.65 $\pm$ 0.25 ppm.

The current results agree very well with the earlier work of Viswanathan (59) who applied the maximum likelihood estimator Probability Model to two trials with n-butanol of 69 ppm initial concentration. A nine member panel provided a 0.64 ppm odor discrimination threshold.

C. Comparison of Three Approaches with Reported Values

Table 31 summarizes the odor threshold values of n-butanol as determined by various approaches and investigators, using a

Panel Size	Initial Concentration ppm	No. of Trials	HALL-ELLIS		MODIFIED DRAVNIEKS		Probability Model Discrim- ination Threshold ppm	Performed By
			Detection ppm	Discrim- ination ppm	Detection ppm	Discrim- ination ppm		
7 & 10	99.46 52.06	6	0.40 ± 0.15	1.34 ± 0.63	0.33 ± 0.07	1.24 ± 0.53	0.65 ± 0.25	Current
9	69	2	0.42 - 0.52	-	0.55 - 0.59	-	0.64	Viswanathan (59)
9	71	1	0.52 (0.42 - 0.82)	-		-	-	Varshney (47)

TABLE 31: Comparison of Odor Thresholds of n-Butanol Determined by Different Models and Investigators Using the IITRI Dynamic Olfactometer

a ternary forced choice IITRI dynamic olfactometer technique. The detection thresholds evaluated during this program agree well with those reported by other researchers (59, 47). The panel discrimination threshold evaluated by the Probability Model also agrees with the results obtained earlier by Viswanathan (59). The various odor thresholds of n-butanol determined by Hellman and Small are summarized in Table 32.

D. Application of Models to Practical Situations

1. Fast Food Restaurants

Fats and oils are used extensively for fast food restaurant cooking. They are the essential media for deep frying. Animals fats are solid at room temperature. Their hardness is directly proportional to the degree of saturation of the fatty acids which constitute part of the glycerides. In contrast, the fluidity of oils is proportional to the unsaturation of the glyceride fatty acids. Frequently a fat or oil will develop an unpleasant odor or taste on storage which renders it unsuitable for the originally intended purpose. A general indication of rancidity is evidenced by the production of free fatty acids through enzymic action on the glycerides.

Both animals fats and vegetable oils are composed of glycerides, which, in turn are made up of fatty acids, the most common to both is oleic acid (28). Fats play a major role in the generation of flavour and aroma compounds in meats while cooking.

Type	Odor Threshold ppm	Investigator
Detection	0.3	Hellman et al.
50% recognition	1.0	Hellman et al.
100% recognition	2.0	Hellman et al.

TABLE 32: Odor Thresholds of n-Butanol Evaluated by Hellman and Small (52)

In an analytical study of meat, Hornstein and Crowe (60) concluded that the flavour was associated with the fat. They examined the free fatty acid composition of beef and pork before and after heating in air at 100°C for 4 hours. Their findings revealed the predominance of oleic acid in both meats and also showed an increase in all acid concentrations following the heat treatment.

The volatiles in dry-cured country style ham were the subject of investigation by Ockerman, Blumer and Craig (61). They found carbonyls and fatty acids to be major volatile contributors.

The previously described odor threshold evaluation models were applied to odorous emissions from a fast food restaurant. Odorous samples were collected into Tedlar bags with the aid of a dynamic dilution device in order to minimize adsorption, absorption and condensation of condensible materials inside the bags. These sample bags (see Appendix IV for properties) are noted (59) not only for their capacity to retain odors without permeation through their walls, but also for negligible adsorption on the walls.

Analyses were carried out with panel sizes of 8 and 10 people using a five level dynamic ternary forced choice olfactometer.

Tables 33 and 34 summarize the results of the fast food restaurant odor studies. The threshold values are indicated in terms of both odor units and ppm as THC based on a butane gas

Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Date: July 17, 1980

Time	Initial Concentration as THC Based on Butane ppm	Hall Ellis Thresholds				Modified Dravnieks Thresholds				Probability Model Thresholds
		Detection		Discrimination		Detection		Discrimination		
		ppm	O.U.	ppm	O.U.	ppm	O.U.	ppm	O.U.	ppm
3:00 PM	8.4	0.80	10.5	1.90	4.5	0.86	9.7	2.20	3.9	1.10
3:30 PM	8.4	1.23	6.8	1.80	4.7	1.22	6.9	1.80	4.7	1.70

TABLE 33: Application of Different Models to Estimation of Odor Thresholds of Emissions from a Fast Food Restaurant

Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Date: July 22, 1980

Time	Initial Concentration as THC Based on Butane ppm	Hall Ellis Thresholds				Modified Dravnieks Thresholds				Probability Model Thresholds
		Detection		Discrimination		Detection		Discrimination		
		ppm	O.U.	ppm	O.U.	ppm	O.U.	ppm	O.U.	ppm
12:00 PM	5.4	0.40	13.3	0.70	8.5	0.41	13.0	0.58	9.3	0.44
12:30 PM	7.1	0.45	15.8	1.00	6.8	0.51	13.3	0.97	7.3	0.76
1:00 PM	10.8	0.75	14.5	1.00	10.0	0.75	14.5	1.03	10.5	0.97

TABLE 34: Replication of Odor Thresholds of Emissions From a Fast Food Restaurant

equivalent. The Hall-Ellis and Modified Dravnieks methods provide detection and discrimination thresholds which are in close agreement. The discrimination thresholds evaluated by the Probability Model fall between the detection and discrimination thresholds determined by the other models as expected. The experimental observations and analytical calculations are provided in Appendix V.

2. Vegetable Oil Emissions

The previously described models were also applied to vegetable oil emissions generated in the laboratory. The odorants were evolved from an electrically heated pan covered with a cone supporting an eight inch diameter stack. The oil odors were sampled with a dynamic dilution device into Tedlar bags from where they were pumped into the dynamic olfactometer for sensory evaluations by panels of eight and nine members. Table 35 summarizes the results derived from the three methods of data analysis.

From the studies performed during this program, it became evident that research should be directed towards the utilization of oleic acid as a major component reference for analytical measurement of odorous emissions from fast food restaurants. The sensory properties of these odors could then be related to and expressed in terms of this reference material.

The successful application of this procedure to fish odors emitted from fish processing plants during this project is described in the following section.

Sample: Vegetable Oil Emissions

Temperature: 27°C

Date	Initial Concentration (Butane Equivalent) ppm	Hall Ellis Thresholds				Modified Dravnieks Thresholds				Probability Model Thresholds
		Detection		Discrimination		Detection		Discrimination		
		ppm	O.U.	ppm	O.U.	ppm	O.U.	ppm	O.U.	ppm
August 6, 1980	3.8	0.20	19.0	0.38	10.0	0.2	18.4	0.35	10.6	0.26
August 6, 1980	4.6	0.24	19.0	0.67	6.8	0.25	18.4	0.66	7.0	0.31
August 14, 1980	5.5	0.26	21.0	0.30	18.8	0.29	18.9	0.31	17.9	0.31

TABLE 35: Application of Different Models to the Estimation of Odor Thresholds of Vegetable Oil Emissions in the Laboratory

3. <u>Application of Major Component Odor Impact Model</u>

The application of the Odor Impact Model has been demonstrated in terms of the sensory characteristics of fish odors. Triethylamine, which is a major component of fish odors, was selected as the basis of analytical measurement. The fractional responses of panel members at various dilution levels are shown in Figure 17. The value for the 50% panel response agrees very well with those calculated by the standard Hall Ellis and Modified Dravnieks methods.

Table 36 provides a comparison of fish odor threshold values evaluated by four approaches including the Probability Model. The Impact Model provides not only the detection and discrimination thresholds for 50% panel response, which agree well with values derived by other methods, but also complaint potential and degrees of complaint for various fractions of the panel representing a community.

Sample: Fish Odors - 0.6 ppm Based on TEA Content

Date: December 3, 1980

Hall-Ellis Thresholds		Modified Dravnieks Thresholds		Maximum Likelihood Estimator Probability Model Threshold ppm	Odor Impact Model Thresholds (for 50% panel response)			
Detection ppm	Discrim-ination ppm	Detection ppm	Discrim-ination ppm		Detection ppm	Discrim-ination ppm	Complaint Potential ppm	Degree of Complaint
0.11	0.13	0.11	0.13	0.12	0.11	0.13	0.14	2.30

TABLE 36: Comparison of Fish Odor Dimensions Determined By Different Approaches

VIII. CONCLUSIONS AND RECOMMENDATIONS

A. Odor Threshold Determinations

From the results obtained during this part of the program, several conclusions can be drawn with respect to the application of the various models to the determination of odor thresholds.

1. Hall-Ellis Ranking Method

This approach has been the traditional procedure for the evaluation of odor detection thresholds from ternary forced choice experimentation. It is usually based on one trial with seven to ten panelists. The effect of successful guessing on the part of the panelists cannot be eliminated from the evaluation of the detection threshold values since their magnitudes are based on the dilution levels from which panelists continue to make correct choices.

In order to obtain more objective threshold values from this procedure, in terms of the responses from the panelists, the dilution levels at which individuals were sure about the presence of the odor were used for calculation purposes. On this basis a new odor dimension called the discrimination threshold was defined. This sensory dimension tends to approximate the recognition threshold of the odor under investigation since panelists often recognize the character of the odor at the levels where they begin to be sure about its presence.

It can also be concluded that a single evaluation of a detection or discrimination threshold, by the Hall-Ellis Ranking Method, utilizing a ternary forced choice dynamic olfactometer, will be within ± 50% of the mean of six trials performed with different initial concentrations and panel sizes of 7 to 10 individuals.

2. Modified Dravnieks Method

This technique is based on the estimation of a maximum likelihood threshold for each panel member and ultimately determining a geometric mean threshold for the entire panel. The need for plotting is eliminated. Like the Hall-Ellis Ranking approach, this method is also usually dependent on one trial with seven to ten panelists. Traditionally, it has been used for the evaluation of odor detection thresholds. However, in this program, it was also applied to the evaluation of discrimination thresholds. Both the Hall-Ellis and Modified Dravnieks approaches were found to produce very closely related results.

A single evaluation of a detection or discrimination threshold by the Modified Dravnieks technique, utilizing a ternary forced choice dynamic olfactometer, will be within ± 50% of the mean of six trials performed with different initial concentrations and panel sizes of 7 to 10 individuals.

3. Maximum Likelihood Estimator Probability Model

To determine an odor discrimination threshold of a panel on the basis of all the responses from the members it is necessary to account for successful guesses. This can be accomplished by applying the currently developed probability model utilizing the principle of the maximum likelihood estimator. During this investigation, this model was applied to one, two and three trials of the same odorous samples. The R value, defining the ratio of maximum to minimum panel threshold magnitudes for six trials was 2.6. The mean discrimination threshold from six trials for n-butanol odor is 0.65 ± 0.25 ppm measured as butane equivalent. Since this magnitude falls between the detection and discrimination threshold evaluated by previously described approaches, it provides a more realistic measure of the true discrimination threshold. For routine work the success of one trial is particularly important from the economic and time requirement points of view. The magnitude of a threshold evaluated from a single trial can be expected to be within ± 40% of the mean of six tests.

4. Odor Impact Model

The Odor Impact Model was developed during this program in order to facilitate prediction of the reactions to olfactory stimuli by a community in terms of responses from a panel of judges working under controlled conditions. This approach provides a fast and reliable method of evaluating such important odor dimensions as detection, discrimination and complaint potential thresholds, as well as degrees of complaint profiles. The magnitudes of the detection and discrimination thresholds for 50% response from the panel, agree very well with those evaluated by the currently used approaches. The Odor Impact Model is based on one trial with at least seven panelists.

B. Major Component Approach

Odor control technology is still severely handicapped by the serious lack of representative sampling techniques and objective analytical procedures. Sample collection in plastic bags for ultimate presentation to a panel, in a laboratory prevents any real time analysis of source and related ambient odor levels. Due to the variability of the human nose as a measuring tool, the conventional approaches provide very controversial evaluations of performance characteristics of currently available odor control devices.

Fortunately, a portable infrared gas analyzer appears to provide the needed capability of measuring real time odor levels objectively. Its potential for general use can be inferred from the present application to the determination of fish odors associated with fish processing plants.

1. <u>Basis of Measurement of Fish Odors</u>

The need to measure odors objectively will increase as citizens continue to expect improvements in ambient air quality. The results of current investigations show that triethylamine can be used as a rational basis for the approximation of the concentrations of fish odors in and around fish processing plants.

2. <u>Calibration of Miran Gas Analyzer</u>

To date, the only analytical instrument that exhibits any potential for the objective measurement of fish odors under field conditions is a portable infrared gas analyzer. When calibrated for the triethylamine (TEA) content of fish odors, this device provides a reliable means of quantitatively assessing the magnitude of odorous assaults in the vicinity of fish processing plants.

3. <u>Variation of TEA with Fish Ageing</u>

Under laboratory conditions the Miran Closed Loop

System was capable of quantifying the increasing olfactory annoyance resulting from increases in concentrations of TEA when fresh fish was kept at temperatures ranging from 68-72°F for extended periods of time. These measurements provide basic information for the assessment of the impact of fish odors on the neighboring community with respect to time. If the fish and resulting by-products are not handled effectively, especially during warm weather conditions, the extent of the increasingly unfavorable environmental problems can now be determined quantitatively for regulatory purposes.

4. Determination of Fish Odor Dimensions

As a result of this investigation, the current methods used for the evaluation of sensory properties of odors have been improved. Reliable assessment of odor impact on the public can be obtained with the aid of the Odor Impact Model.

The detection, discrimination and complaint potential thresholds as well as degrees of complaint profiles of fish odors were evaluated in terms of triethylamine (TEA) concentrations. These profiles provide magnitudes on which regulatory standards could be based. The complaint potential or annoyance profile is particularly important because it establishes levels which can protect the public welfare as well as the people working in the plant. Knowledge of the severity of panel reactions over a wide range of odor levels provides flexibility with respect to establishment of emission and ambient standards consistent with the socioeconomic structure of the community and the importance of the odor emitting source in any locality.

On the basis of the fish odor experiences it would appear that detection, discrimination and complaint potential thresholds, as well as degrees of complaint profiles for fast food restaurant emissions can be related to a major component such as oleic acid. Successful correlations would provide meaningful data for maintaining odorous emissions at levels that would minimize citizen complaints.

C. Regulatory Agency Strategies

The regulation of odors presents many challenges. Technical uncertainties, varying perceptions of and social attitudes towards odors tend to undermine any uniform regulatory strategy. According to the recent US EPA publication on Regulatory Options for Control of Odors (2), "the most serious problem is the absence of meaningful data that could help to relate emission rates or ambient odor levels to community annoyance. In the final analysis, it is the elimination of community annoyance that ought to form the policy basis of odor regulation."

Based on the experiments performed during this program, the implementation of the newly developed and tested Major Component Odor Impact Model is highly recommended. This model provides all the necessary sensory properties (detection, discrimination and complaint potential thresholds as well as degrees of complaint profiles) that would describe the impact of any odor on a community. These sensory properties can be expressed in terms of a major component which could be monitored objectively, both at the source and at ambient locations, by an analytical instrument such as a portable infrared gas analyzer which is capable of responding over a wide spectrum of gas concentration ranging from sub-ppm to the percent levels. Although refinements of analytical instruments for measuring concentration of gases in terms of ppb levels should be continued, the Miran gas analyzer used in this program can serve the purpose for the immediate future in many situations.

The panel evaluating the sensory properties of any odor should consist of at least seven individuals representing the diverse spectrum of the community. The Impact Model needs only one trial of panel responses from a five or six level dynamic olfactometer using a ternary forced choice technique for computation purposes.

Based on the experiments performed during this program, the model is sufficiently reliable for regulatory implementation. It provides threshold values that agree well with the results obtained from current methods such as the Hall-Ellis and Modified Dravnieks techniques which can be used only for the evaluation of 50% panel detection and discrimination thresholds. With the aid of the Impact Model, sources of odorous emissions in a community can be assessed to determine if they create any problems. If they do, emission and ambient standards based on the model can be set by an appropriate local agency which can account for the population distribution, socioeconomic activity and land use zoning of the area.

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NOMENCLATURE

ED_{50}	Effective Dosage based on 50% response from the panel
L/min	Liters/minute
MIRAN	Miniature Infrared Analyzer
MLE	Maximum Likelihood Estimator
O.U.	Odor Units
ppm	Parts per million on volume basis
R	Ratio between the highest and lowest odor thresholds measured for the same odorous air sample
TEA	Triethylamine
THC	Total Hydrocarbon Content
μm	Micrometer
W_0/K	Proportion of Panelists who are Correct K times out of K trials
W_r/K	Proportion of Panelists who are Wrong r times out of K trials, where r = 1, 2, ... K.
$\hat{a}$	Estimate of the Proportion of People who are sure about their choice

APPENDIX I

REPORTED PROPERTIES

OF

TRIETHYLAMINE

The odorous properties of Triethylamine as reported by Hellman and Small (52) are:

Detection	=	<0.09 ppm
50% Recognition	=	0.28 ppm
100% Recognition	=	0.28 ppm
Quality	=	fishy/amine
Hedonic Tone	=	unpleasant to pleasant

APPENDIX II

MIRAN CALIBRATION DATA

Miran Calibration Data

Absorbance	Concentrations (ppm)
0	0
0.0005	0.31
0.0010	0.63
0.0020	1.25
0.0030	1.88
0.0040	3.13
0.0080	4.38
0.0120	6.26
0.0225	9.39
0.0300	12.52
0.0390	15.65
0.0470	18.78
0.0560	21.91
0.0660	25.04
0.0750	28.17

TABLE II.1: Data Calibration of Miran Instrument with Triethylamine

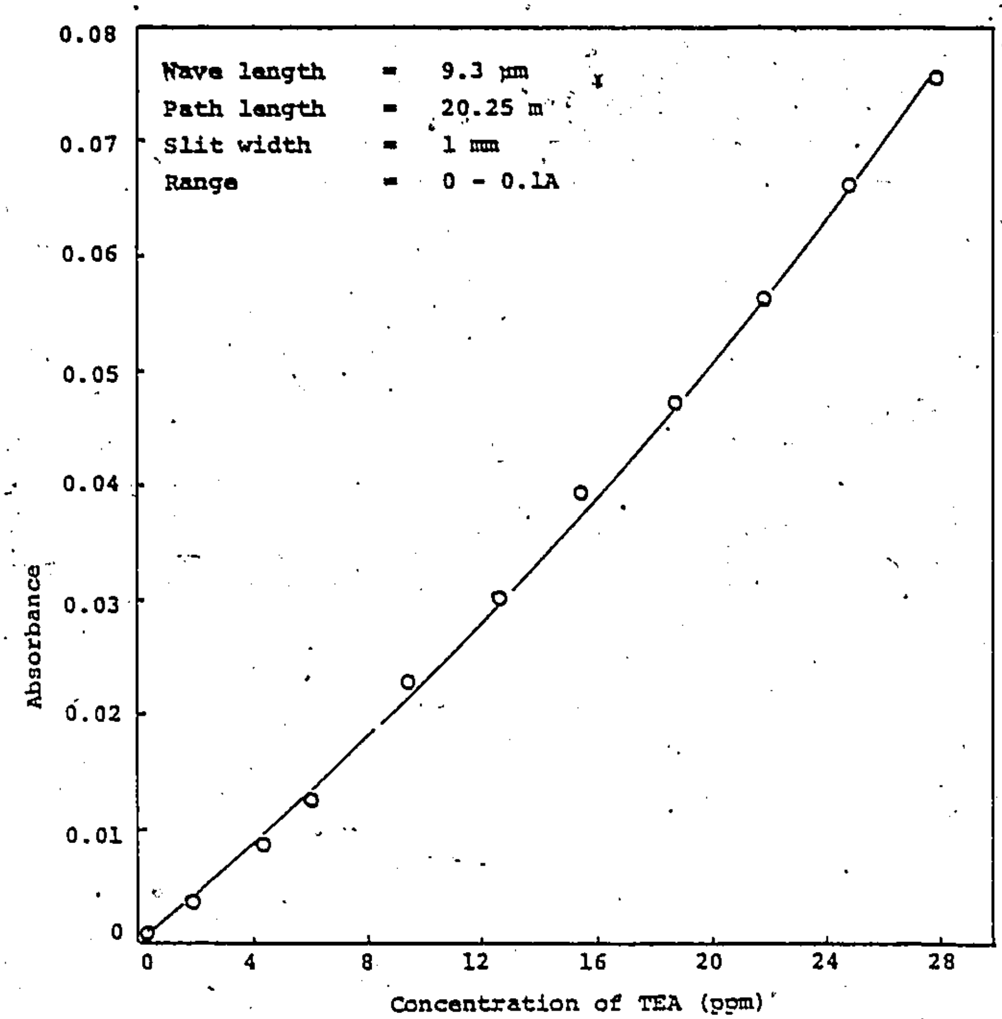


FIGURE II.1: Calibration Chart for Triethylamine

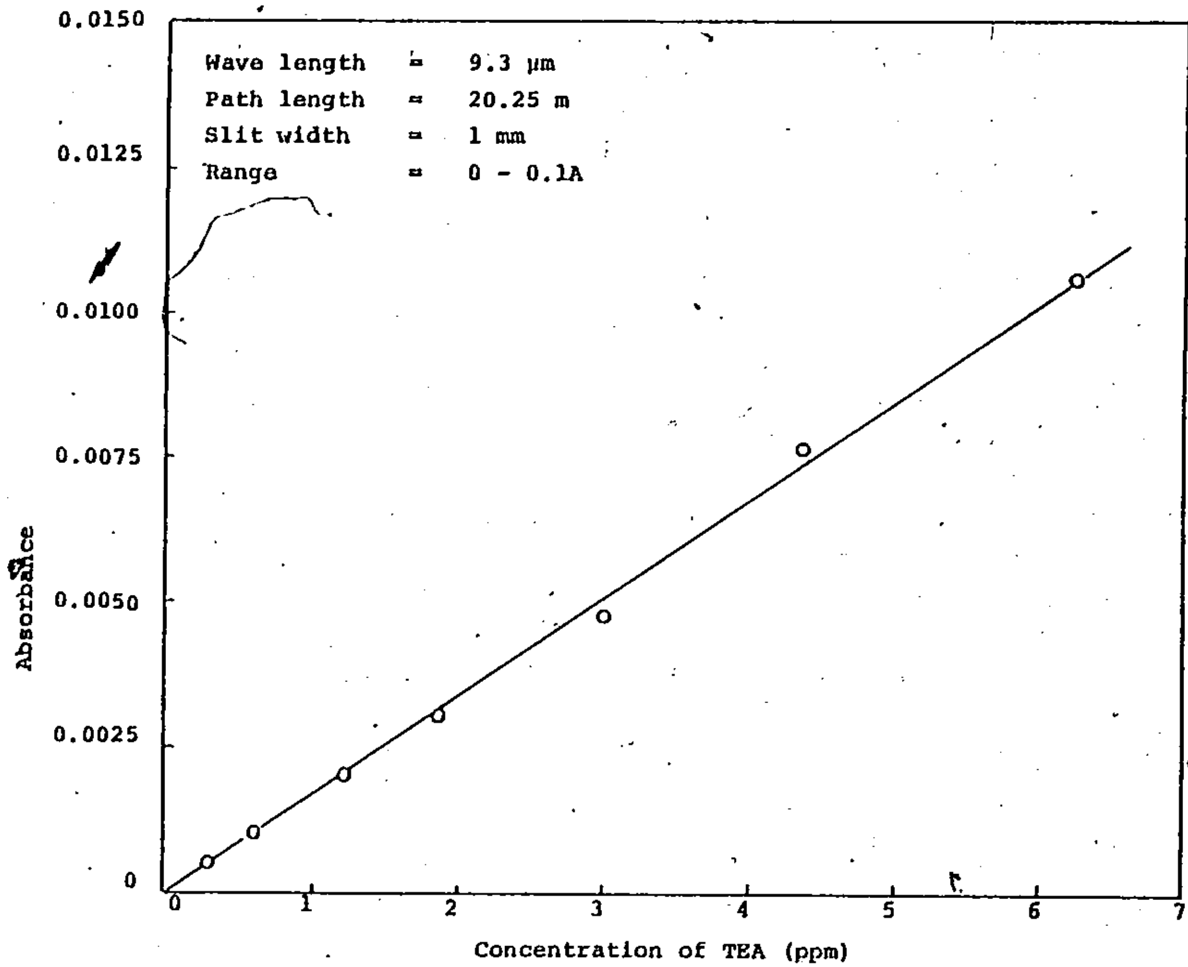


FIGURE II.2: Calibration Chart for Triethylamine
(Low Range)

APPENDIX III

MIRAN OPERATING SPECIFICATIONS

MIRAN OPERATING SPECIFICATIONS

Closed Loop Measurement of TEA

Operational Wavelength	9.3 μm
Path Length	20.25 m.
Slit Width	.1 mm
Operating Temperature	23°C.
Ambient Humidity	1.6%
Atmospheric Pressure	29.25 in-Hg

APPENDIX IV

Properties of Tedlar Bags

Properties of Tedlar Bags

The Tedlar bags used in this program were made from transparent Dupont polyvinyl fluoride synthetic polymer. The general properties of these bags include:

i. very high retention capacity for odors

ii. low adsorption of odors

iii. resistance to cracking or opening of seams even under 50 lb pressure

iv. minor wrinkling even after repeated use

v. high durability and ruggedness

APPENDIX V

Experimental Observations and Evaluations of Emissions from a Fast Food Restaurant

Sample : Fast Food Resturant Emissions
Temperature : 27°C
Time : 3:00 PM
Date : July 17 , 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels				
	1	2	3	4	5
	Dilution Factors				
	17	8	6	3	1
BOB	C	I	*C	C	C
DOUG	I	I	*C	C	C
RICK	C	C	C	*C	C
CARL	I	C	*C	C	C
ALEX	I	I	I	I	*C
MEH	C	C	*C	C	C
AKHR	C	I	C	C	*C
BTS	I	C	C	C	*C

* indicates dilutions from which onwards panelists are certain about the presence of the odor under investigation.

TABLE V.1: Panel Responses to 8.4 ppm as Butane Equivalent Emissions from a Fast Food Restaurant Using Dynamic Ternary Forced Choice Technique

Sample : Fast Food Resturant Emissions

Temperature : 27°C

Time : 3:30 PM

Date : July 17 , 1980.

C : Correct

I : Incorrect

Panelist	Dilution Levels				
	1	2	3	4	5
	Dilution Factors				
	17	8	6	3	1
BOB	C	I	I	*C	C
DOUG	C	I	*C	C	C
RICK	I	C	I	*C	C
CARL	I	*C	C	C	C
ALEX	C	I	C	*C	C
MEH	C	*C	C	C	C
AKHR	I	C	I	C	*C
BTS	I	C	I	C	*C

* indicates dilutions from which onwards panelists are certain about the presence of the odor under investigatio

TABLE V.2: Replication of Panel Responses to 8.4 ppm as Butane Equivalent Emissions from a Fast Food Restaurant Using Dynamic Ternary Forced Choice Technique

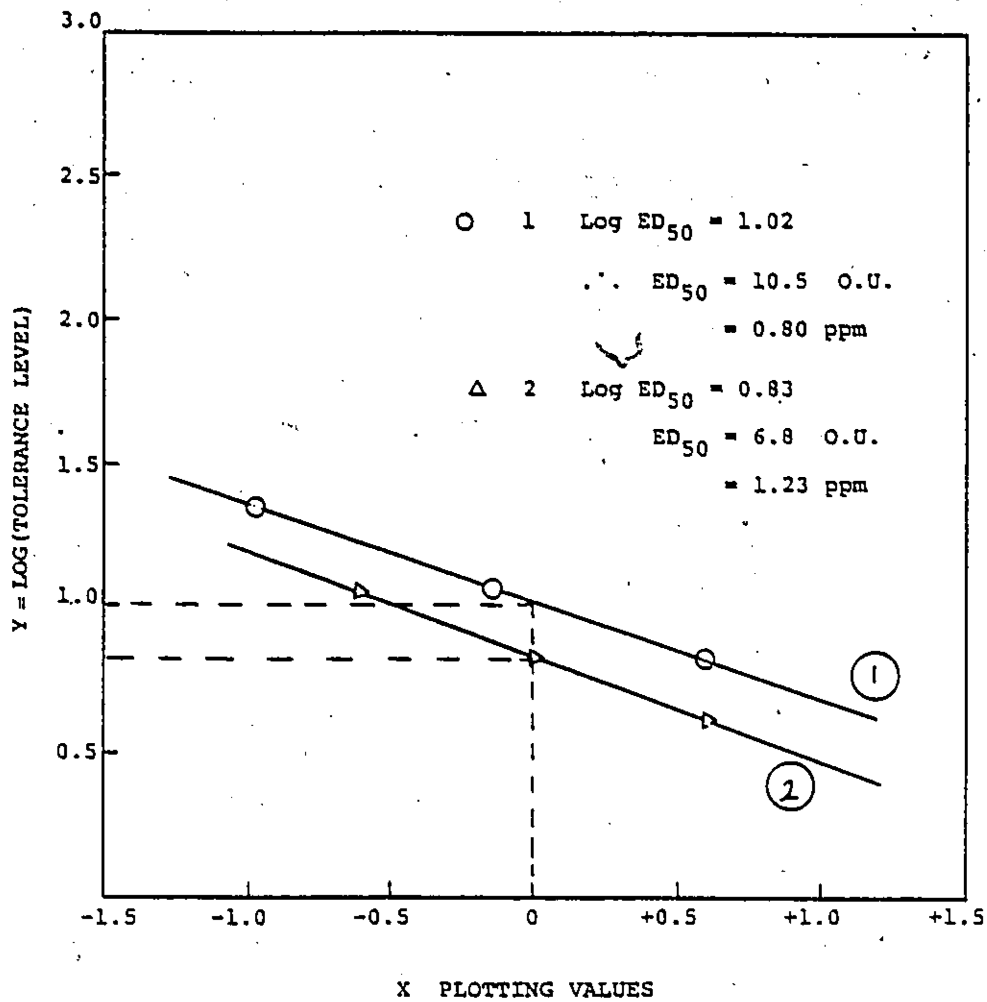


FIGURE V.1: Evaluation of Detection Thresholds of Odorous Emissions from a Fast Food Restaurant Using Hall-Ellis Ranking Method

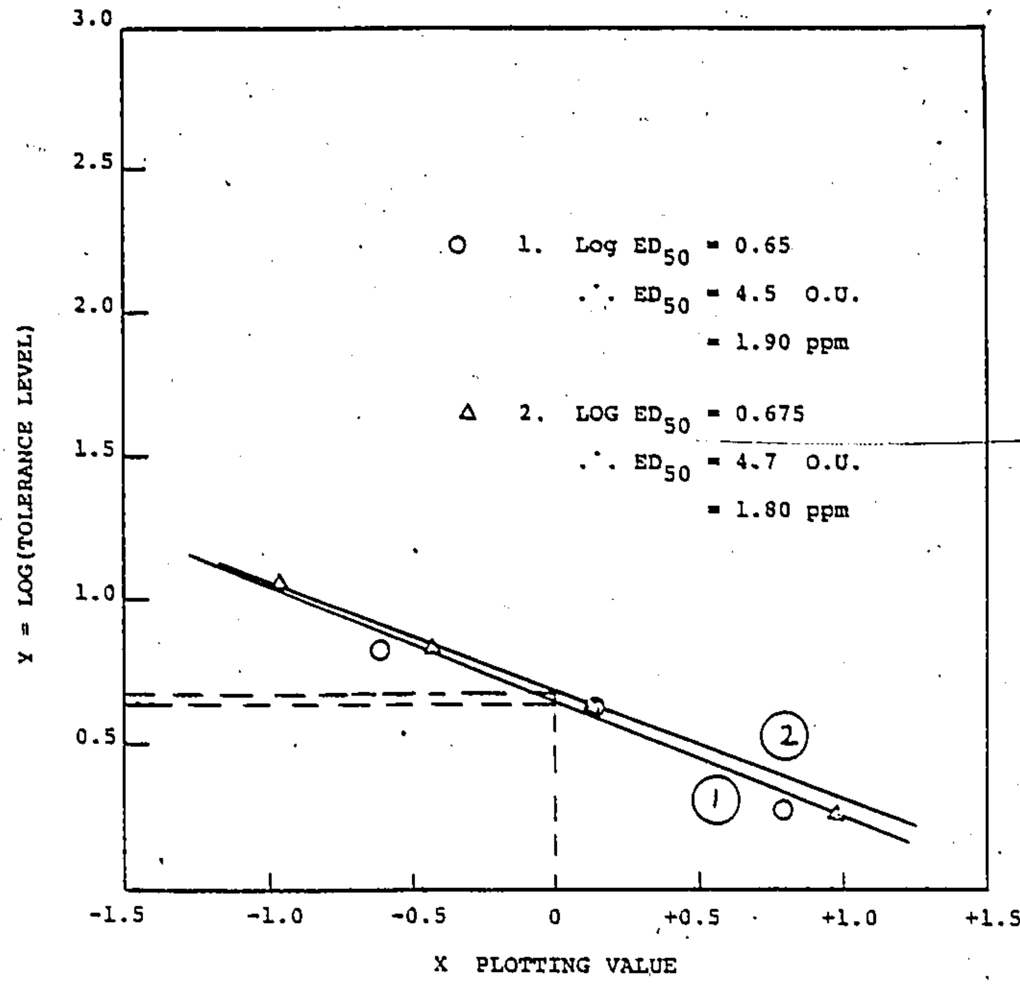


FIGURE V.2: Evaluation of Discrimination Thresholds of Odorous Emissions from a Fast Food Restaurant Using Hall-Ellis Ranking Method

Sample : Fast Food Resturant Emissions
Temperature : 27°C
Date : July 17 , 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels 1	2	3	4	5	Log Individual ED_{50}
	Dilution Factors 17	8	6	3	1	
BOB	I	I	C	C	C	0.84
DOUG	I	C	C	C	C	1.07
RICK	C	C	C	C	C	1.38
CARL	I	C	C	C	C	1.07
ALEX	I	I	I	I	C	0.24
MEH	C	C	C	C	C	1.38
AKHR	I	I	C	C	C	0.84
BTS	I	C	C	C	C	1.07

Sum Log Individual ED_{50} : 7.90 , Log ED_{50} : 0.99
Result : ED_{50} : 9.7 O.U., 0.86 ppm

TABLE V.3: Evaluation of Detection Threshold of Emissions from a Fast Food Restaurant by Modified Dravnieks Method

Sample : Fast Food Resturant Emissions

Temperature : 27°C

Date : July 17 , 1980.

C : Correct

I : Incorrect

Panelist	Dilution Levels					Log Individual ED_{50}
	1	2	3	4	5	
	Dilution Factors					
	17	8	6	3	1	
BOB	I	I	C	C	C	0.84
DOUG	I	I	C	C	C	0.84
RICK	I	I	I	C	C	0.63
CARL	I	I	C	C	C	0.84
ALEX	I	I	I	I	C	0.24
MEH	I	I	C	C	C	0.84
AKHR	I	I	I	I	C	0.24
BTS	I	I	I	I	C	0.24

Sum Log Individual ED_{50} : 4.71, , Log ED_{50} : 0.59

Result : ED_{50} : 3.90 O.U., 2.20 ppm

TABLE V.4: Evaluation of Discrimination Threshold of Emissions from a Fast Food Restaurant by Modified Dravnieks Method

Sample : Fast Food Resturant Emissions
Temperature : 27°C
Date : July 17 , 1980.

C : Correct
I : Incorrect

Panelist	Dilution Levels 1	2	3	4	5	Log Individual ED_{50}
	Dilution Factors 17	8	6	3	1	
BOB	I	I	I	C	C	0.63
DOUG	I	I	C	C	C	0.84
RICK	I	C	C	C	C	1.07
CARL	I	C	C	C	C	1.07
ALEX	I	I	C	C	C	0.84
MEH	C	C	C	C	C	1.38
AKHR	I	I	I	C	C	0.63
BTS	I	I	I	I	C	0.24

Sum Log Individual ED_{50} : 6.70 , Log ED_{50} : 0.84
Result : ED_{50} : 6.9 O.U., 1.22 ppm

TABLE V.5: Replication of Evaluation of Detection Threshold of Emissions from a Fast Food Restaurant by Modified Dravnieks Method

Sample : Fast Food Resturant Emissions

Temperature : 27°C

Date : July 17 , 1980.

C : Correct

I : Incorrect

Panelist	Dilution Levels 1	2	3	4	5	Log Individual ED_{50}
	Dilution Factors 17	8	6	3	1	
BOB	I	I	I	C	C	0.63
DOUG	I	I	C	C	C	0.84
RICK	I	I	I	C	C	0.63
CARL	I	C	C	C	C	1.07
ALEX	I	I	I	C	C	0.63
MEH	I	C	C	C	C	1.07
AKHR	I	I	I	I	C	0.24
BTS	I	I	I	I	C	0.24

Sum Log Individual ED_{50} : 5.35 , Log ED_{50} : 0.67

Result : ED_{50} : 4.7 O.U., 1.80 ppm

TABLE V.6: Replication of Evaluation of Discrimination Threshold of Emissions from a Fast Food Restaurant by Modified Dravnieks Method

Sample: Fast Food Restaurant Emission

Temperature: 27°C

Date: July 17, 1980

Sample Concentration ppm	Number of Panelists		$W_0/1$	$W_1/1$	$\hat{\alpha}$ MLE
	Correct	Wrong			
0.49	4	4	0.5	0.5	0.25
1.05	4	4	0.5	0.5	0.25
1.40	7	1	0.875	0.125	0.81
2.80	7	1	0.875	0.125	0.81
8.40	8	0	1.0	0.0	1.00

TABLE V.7: Application of Maximum Likelihood Estimator Probability Model to the Evaluation of Discrimination Threshold of Emissions from a Fast Food Restaurant

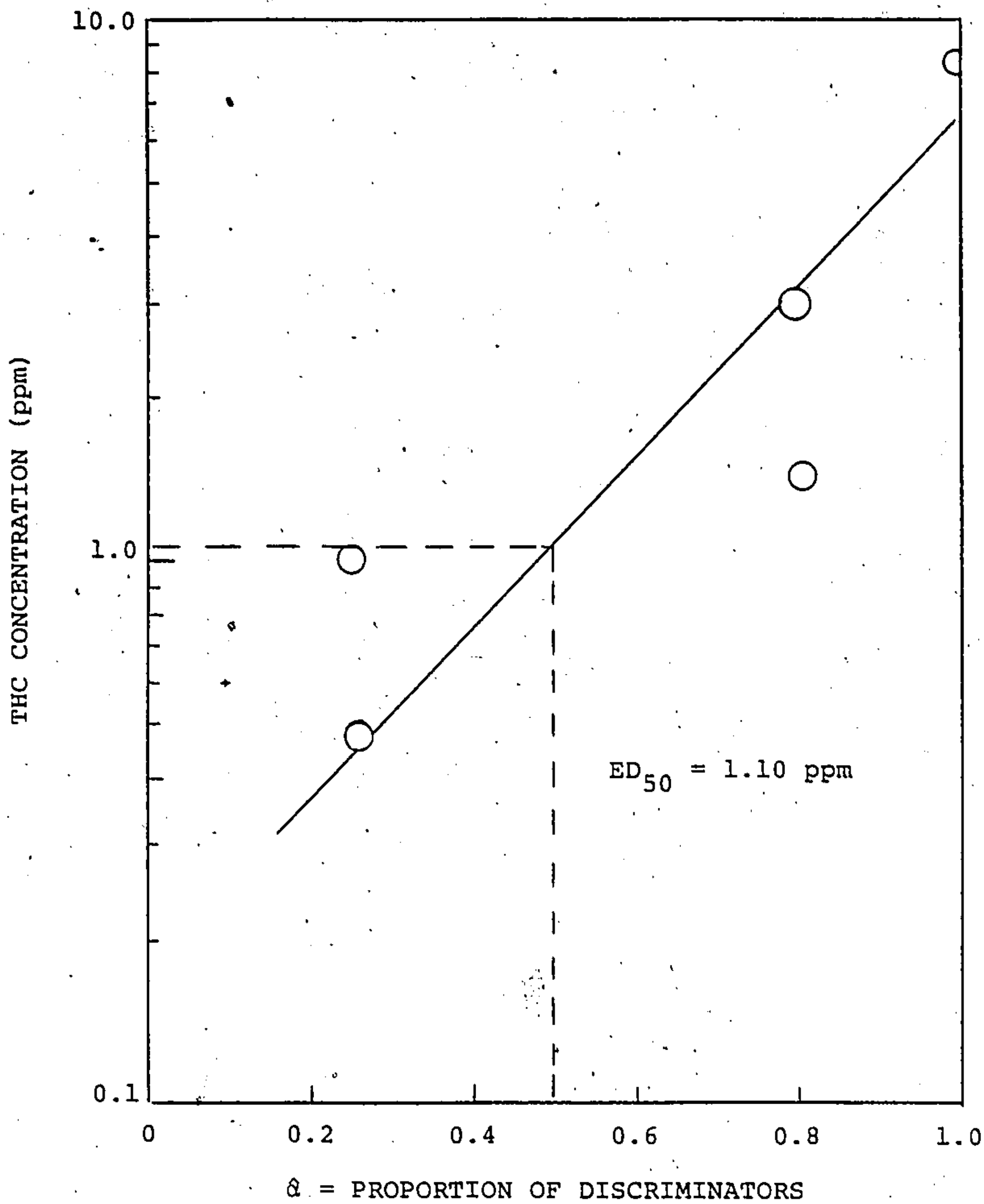


FIGURE V.3: Evaluation of Discrimination Threshold of Odorous Emissions from a Fast Food Restaurant Using Maximum Likelihood Estimator Probability Model

Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Date: July 17, 1980

Sample Concentration as THC ppm	No. of Subjects Correct in Both Trials	No. of Subjects Wrong in Both Trials	No. of Subjects Wrong Once and Correct Once in Both Trials
0.44	1	1	5
1.05	4	3	1
1.40	3	-	5
2.80	6	-	2
8.40	8	-	-

TABLE V.8: Combined Experimental Data From Two Trials for Evaluation of Odor Discrimination Threshold of the Restaurant Emissions

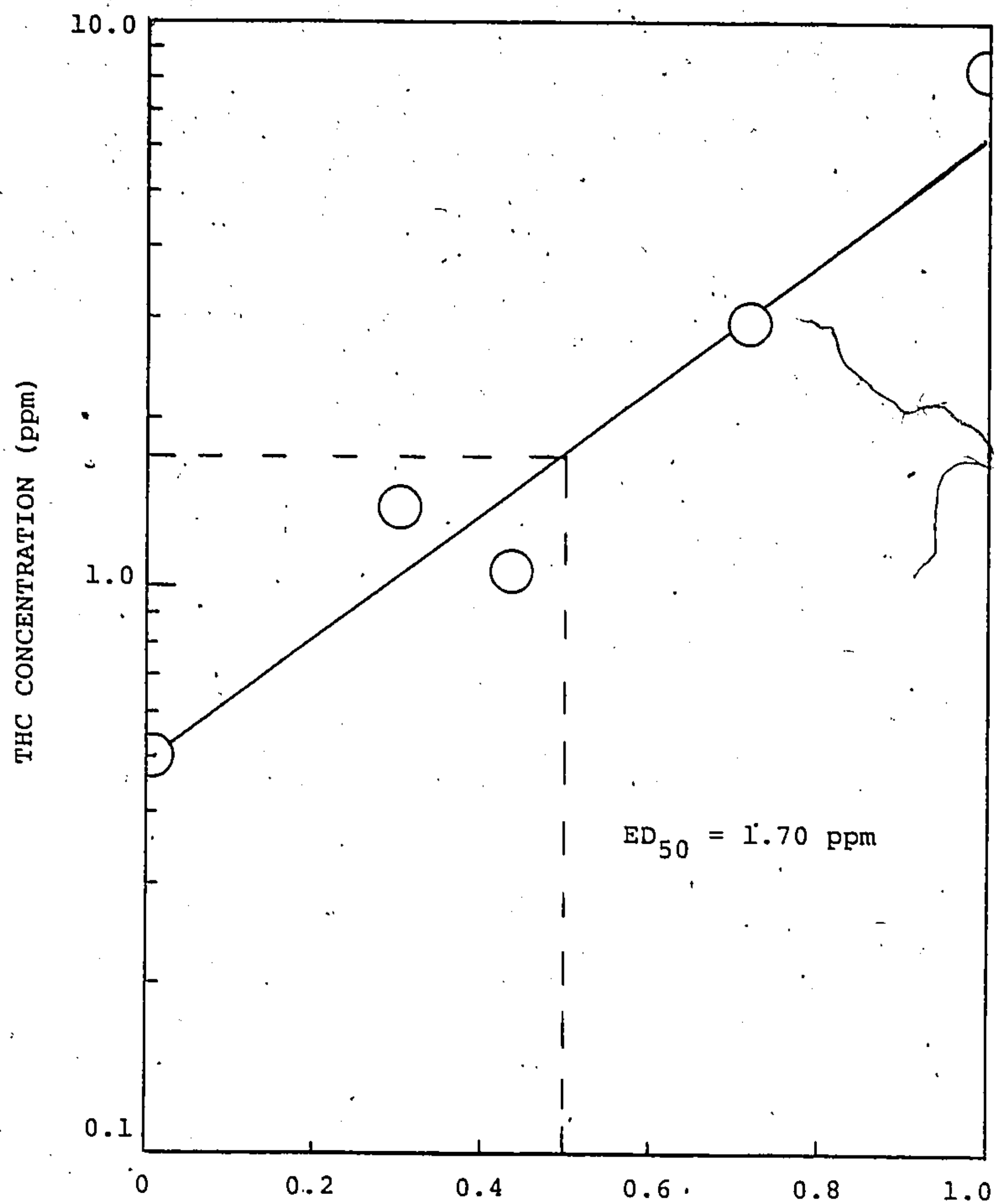
Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Date: July 17, 1980

Sample Concentration as THC ppm	Proportion of Subjects Correct in Both Trials $W_0/2$	Proportion of Subjects Wrong in Both Trials $W_2/2$	Proportion of Subjects Correct Once and Wrong Once in Both Trials $W_1/2$	α MLE
0.44	0.125	0.25	0.625	0.015
1.04	0.500	0.375	0.125	0.438
1.40	0.375	0	0.625	0.300
2.80	0.750	0	0.250	0.720
8.40	1.0	0	0.0	1.0

TABLE V.9: Application of Maximum Likelihood Estimator Probability Model to Restaurant Emissions for Two Trials



$\hat{a}$ = PROPORTION OF DISCRIMINATORS

FIGURE V.4: Evaluation of Discrimination Threshold of Odorous Emissions from a Fast Food Restaurant for Two Trials

Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Time: 12:00 PM

Date: July 22, 1980

C = Correct

I = Incorrect

Panelist	Dilution Levels				
	1	2	3	4	5
	Dilution Factors				
	17	8	6	3	1
LI	I	C	C	C	C
DOUG	*C	C	C	C	C
JVD	C	C	*C	C	C
RICK	I	C	I	*C	C
KIM	I	C	I	*C	C
DANA	C	*C	C	C	C
MUTU	C	*C	C	C	C
ALEX	C	I	*C	C	C
CARL	C	*C	C	C	C
MEH	I	*C	C	C	C

* indicates dilutions from which onwards panelists are certain about the presence of the odor under investigation.

TABLE V.10: Panel Responses to 5.4 ppm Butane Equivalent Emissions from a Fast Food Restaurant Using Dynamic Ternary Forced Choice Technique

Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Time: 12:30 PM

Date: July 22, 1980

C = Correct

I = Incorrect

Panelist	Dilution Levels				
	1	2	3	4	5
	Dilution Factors				
	17	8	6	3	1
LI	C	C	I	C	*C
DOUG	*C	C	C	C	C
JVD	I	*C	C	C	C
RICK	C	C	I	C	*C
KIM	*C	C	C	C	C
DANA	*C	C	C	C	C
MUTU	C	C	C	*C	C
ALEX	I	I	I	*C	C
CARL	C	C	*C	C	C
MEH	C	C	*C	C	C

* indicates dilutions from which onwards panelists are certain about the presence of the odor under investigation.

TABLE V.11: Panel Responses to 7.1 ppm Butane Equivalent Emissions from a Fast Food Restaurant Using Dynamic Ternary Forced Choice Technique

Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Time: 1:00 PM

Date: July 22, 1980

C = Correct

I = Incorrect

Panelist	Dilution Levels				
	1	2	3	4	5
	Dilution Factors				
	17	8	6	3	1
LI	I	I	*C	C	C
DOUG	*C	C	C	C	C
JVD	I	C	C	*C	C
RICK	C	*C	C	C	C
KIM	C	I	*C	C	C
DANA	C	*C	C	C	C
MUTU	I	*C	C	C	C
ALEX	I	I	*C	C	C
CARL	*C	C	C	C	C
MEH	C	*C	C	C	C

* indicates dilutions from which onwards panelists are certain about the presence of the odor under investigation.

TABLE V.12: Panel Responses to 10.8 ppm Butane Equivalent Emissions from a Fast Food Restaurant Using Dynamic Ternary Forced Choice Technique

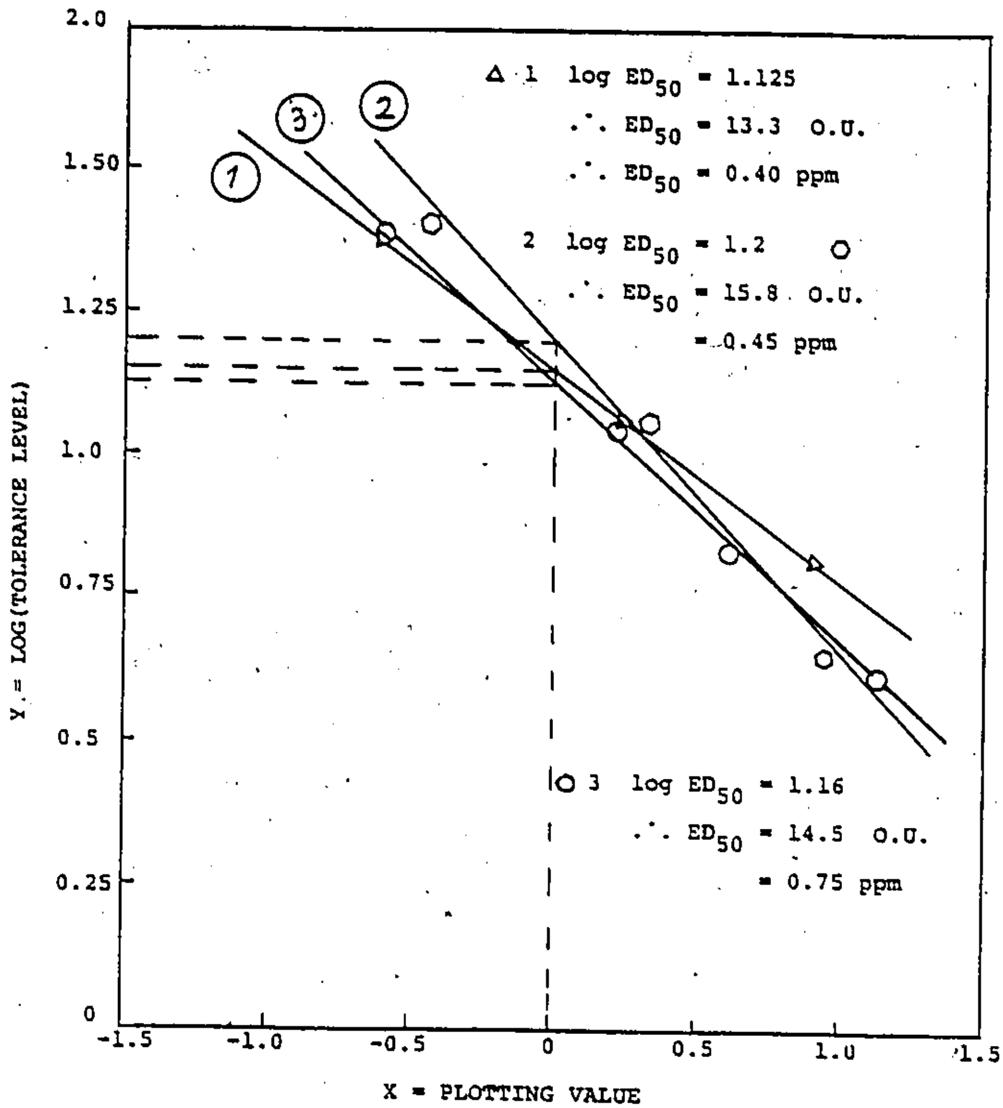


FIGURE V.5: Evaluation of Detection Thresholds of Odorous Emissions from a Fast Food Restaurant Using Hall-Ellis Ranking Method

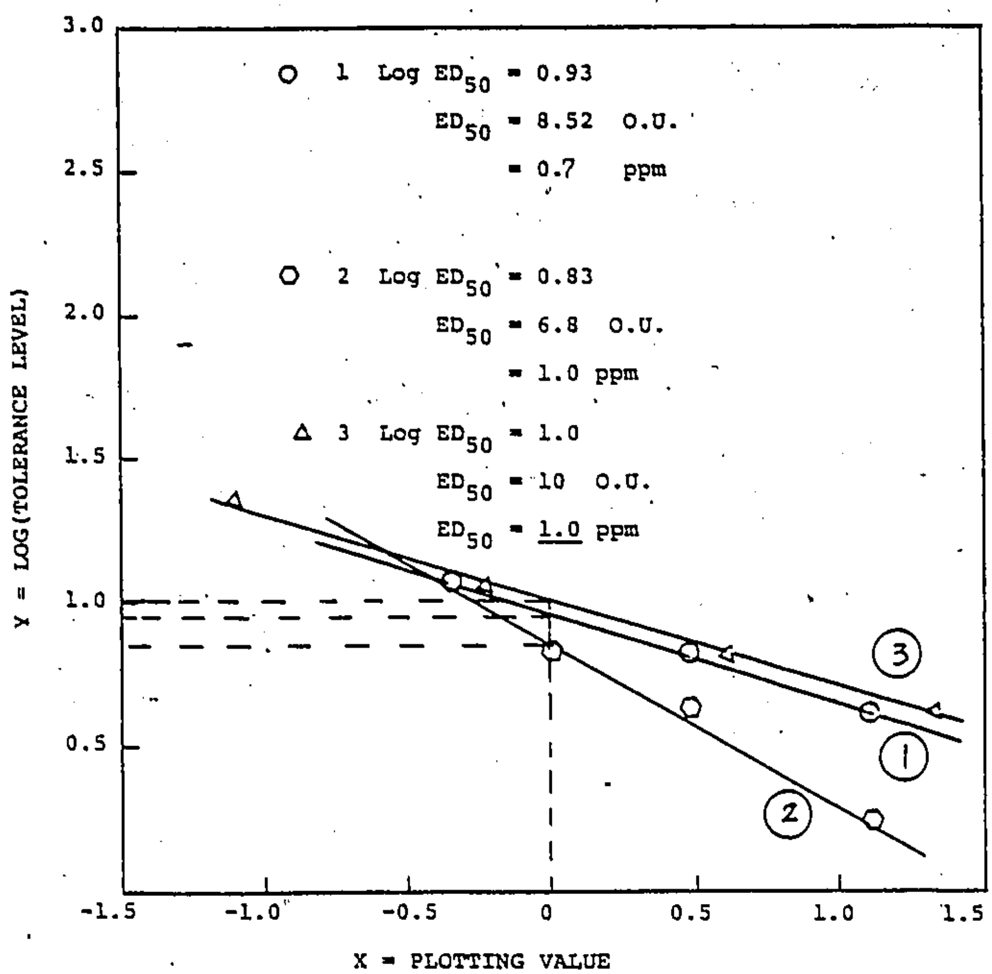


FIGURE V.6: Evaluation of Discrimination Thresholds of Odorous Emissions from a Fast Food Restaurant Using Hall-Ellis Ranking Method

Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Time: 12:00 PM

Date: July 22, 1980

C = Correct

I = Incorrect

Panelist	Dilution Levels					Log Individual ED_{50}
	1	2	3	4	5	
	Dilution Factors					
	17	8	6	3	1	
LI	I	C	C	C	C	1.07
DOUG	C	C	C	C	C	1.38
JVD	C	C	C	C	C	1.38
RICK	I	I	I	C	C	0.63
KIM	I	I	I	C	C	0.63
DANA	C	C	C	C	C	1.38
MUTU	C	C	C	C	C	1.38
ALEX	I	I	C	C	C	0.84
CARL	C	C	C	C	C	1.38
MEH	I	C	C	C	C	1.07

Sum Log Individual ED_{50} : 11.14 , Log ED_{50} : 1.11

Result : ED_{50} : 13.0 O.U., 0.41 ppm

TABLE V.13: Evaluation of Detection Threshold of 5.4 ppm as Butane Equivalent Emissions from a Fast Food Restaurant

Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Time: 12:00 PM

Date: July 22, 1980

C = Correct

I = Incorrect

Panelist	Dilution Levels					Log Individual ED_{50}
	1	2	3	4	5	
	Dilution Factors					
	17	8	6	3	1	
LI	I	C	C	C	C	1.07
DOUG	C	C	C	C	C	1.38
JVD	I	I	C	C	C	0.84
RICK	I	I	I	C	C	0.63
KIM	I	I	I	C	C	0.63
DANA	I	C	C	C	C	1.07
MUTU	I	C	C	C	C	1.07
ALEX	I	I	C	C	C	0.84
CARL	I	C	C	C	C	1.07
MEH	I	C	C	C	C	1.07

Sum Log Individual ED_{50} : 9.7 , Log ED_{50} : 0.97

Result : ED_{50} : 9.3 O.U., 0.58 ppm

TABLE V.14: Evaluation of Discrimination Threshold of 5.4 ppm as Butane Equivalent Emissions from a Fast Food Restaurant

Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Time: 12:30 PM

Date: July 22, 1980

C = Correct

I = Incorrect

Panelist	Dilution Levels					Log Individual ED_{50}
	1	2	3	4	5	
	Dilution Factors					
	17	8	6	3	1	
LI	I	I	I	C	C	0.63
DOUG	C	C	C	C	C	1.38
JVD	I	C	C	C	C	1.07
RICK	I	I	I	C	C	0.63
KIM	C	C	C	C	C	1.38
DANA	C	C	C	C	C	1.38
MUTU	C	C	C	C	C	1.38
ALEX	I	I	I	C	C	0.63
CARL	C	C	C	C	C	1.38
MEH	C	C	C	C	C	1.38

Sum Log Individual ED_{50} : 11.23 , Log ED_{50} : 1.12

Result : ED_{50} : 13.3 O.U., 0.51 ppm

TABLE V.15: Evaluation of Detection Threshold of 7.1 ppm as Butane Equivalent Emissions from a Fast Food Restaurant

Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Time: 12:30 PM

Date: July 22, 1980

C = Correct

I = Incorrect

Panelist	Dilution Levels					Log Individual ED_{50}
	1	2	3	4	5	
	Dilution Factors					
	17	8	6	3	1	
LI	I	I	I	I	C	0.24
DOUG	C	C	C	C	C	1.38
JVD	I	C	C	C	C	1.07
RICK	I	I	I	I	C	0.24
KIM	C	C	C	C	C	1.38
DANA	C	C	C	C	C	1.38
MUTU	I	I	I	C	C	0.63
ALEX	I	I	I	C	C	0.63
CARL	I	I	C	C	C	0.84
MEH	I	I	C	C	C	0.84

Sum Log Individual ED_{50} : 8.64, Log ED_{50} : 0.86.

Result : ED_{50} : 7.30 O.U., 0.97 ppm

TABLE V.16: Evaluation of Discrimination Threshold of 7.1 ppm as Butane Equivalent Emissions from a Fast Food Restaurant

Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Time: 1:00 PM

Date: July 22, 1980

C = Correct

I = Incorrect

Panelist	Dilution Levels					Log Individual ED_{50}
	1	2	3	4	5	
	Dilution Factors					
	17	8	6	3	1	
LI	I	I	C	C	C	0.84
DOUG	C	C	C	C	C	1.38
JVD	I	C	C	C	C	1.07
RICK	C	C	C	C	C	1.38
KIM	I	I	C	C	C	0.84
DANA	C	C	C	C	C	1.38
MUTU	I	C	C	C	C	1.07
ALEX	I	I	C	C	C	0.84
CARL	C	C	C	C	C	1.38
MEH	C	C	C	C	C	1.38

Sum Log Individual ED_{50} : 11.60 , Log ED_{50} : 1.16

Result : ED_{50} : 14.5 O.U., 0.75 ppm

TABLE V.17: Evaluation of Detection Threshold of 10.8 ppm as Butane Equivalent Emissions from a Fast Food Restaurant Using Modified Dravnieks Method

Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Time: 1:00 PM

Date: July 22, 1980

C = Correct

I = Incorrect

Panelist	Dilution Levels					Log Individual ED_{50}
	1	2	3	4	5	
	Dilution Factors					
	17	8	6	3	1	
LI	I	I	C	C	C	0.84
DOUG	C	C	C	C	C	1.38
JVD	I	I	I	C	C	0.63
RICK	I	C	C	C	C	1.07
KIM	I	I	C	C	C	0.84
DANA	I	C	C	C	C	1.07
MUTU	I	C	C	C	C	1.07
ALEX	I	I	C	C	C	0.84
CARL	C	C	C	C	C	1.38
MEH	I	C	C	C	C	1.07

Sum Log Individual ED_{50} : 10.2 , Log ED_{50} : 1.02

Result : ED_{50} : 10.5 O.U., 1.03 ppm

TABLE V.18: Evaluation of Discrimination Threshold of 10.8 ppm as Butane Equivalent Emissions from a Fast Food Restaurant Using Modified Dravnieks Method

Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Time: 12:00 PM

Date: July 22, 1980

Sample Concentration as THC ppm	Number of Subjects		$W_0/1$	$\dot{W}_1/1$	$\hat{\alpha}$ MLE
	Correct	Wrong			
0.32	6	4	0.6	0.4	0.40
0.67	9	1	0.9	0.1	0.85
0.90	8	2	0.8	0.2	0.70
1.80	10	0	1.0	0	1.00
5.38	10	0	1.0	0	1.00

TABLE V.19: Application of MLE Probability Model to the Estimation of Discrimination Threshold of 5.4 ppm Butane Equivalent Emissions from a Fast Food Restaurant

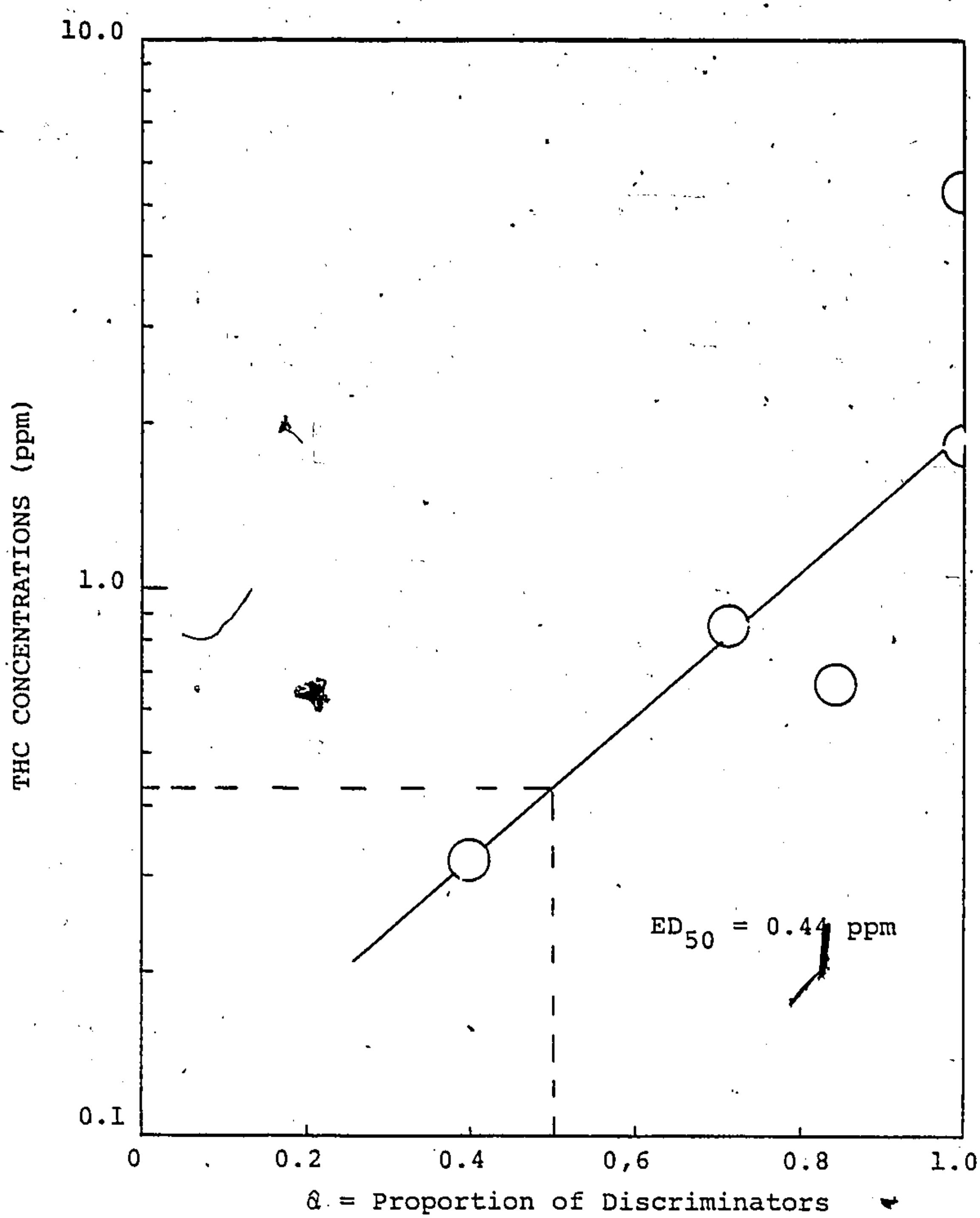


FIGURE V.7: Evaluation of Discrimination Threshold of Odorous Emissions from a Fast Food Restaurant Using MLE Probability Model for First Trial

Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Time: 12:30 PM

Date: July 22, 1980

Sample Concentration as THC ppm	Number of Subjects		$W_0/1$	$W_1/1$	$\hat{\alpha}$ MLE
	Correct	Wrong			
0.41	8	2	0.8	0.2	0.70
0.88	9	1	0.9	0.1	0.85
1.20	7	3	0.7	0.3	0.55
2.35	10	0	1.0	0	1.00
7.05	10	0	1.0	0	1.00

TABLE V.20: Application of MLE Probability Model to the Estimation of Discrimination Threshold of 7.1 ppm Butane Equivalent Emissions from a Fast Food Restaurant

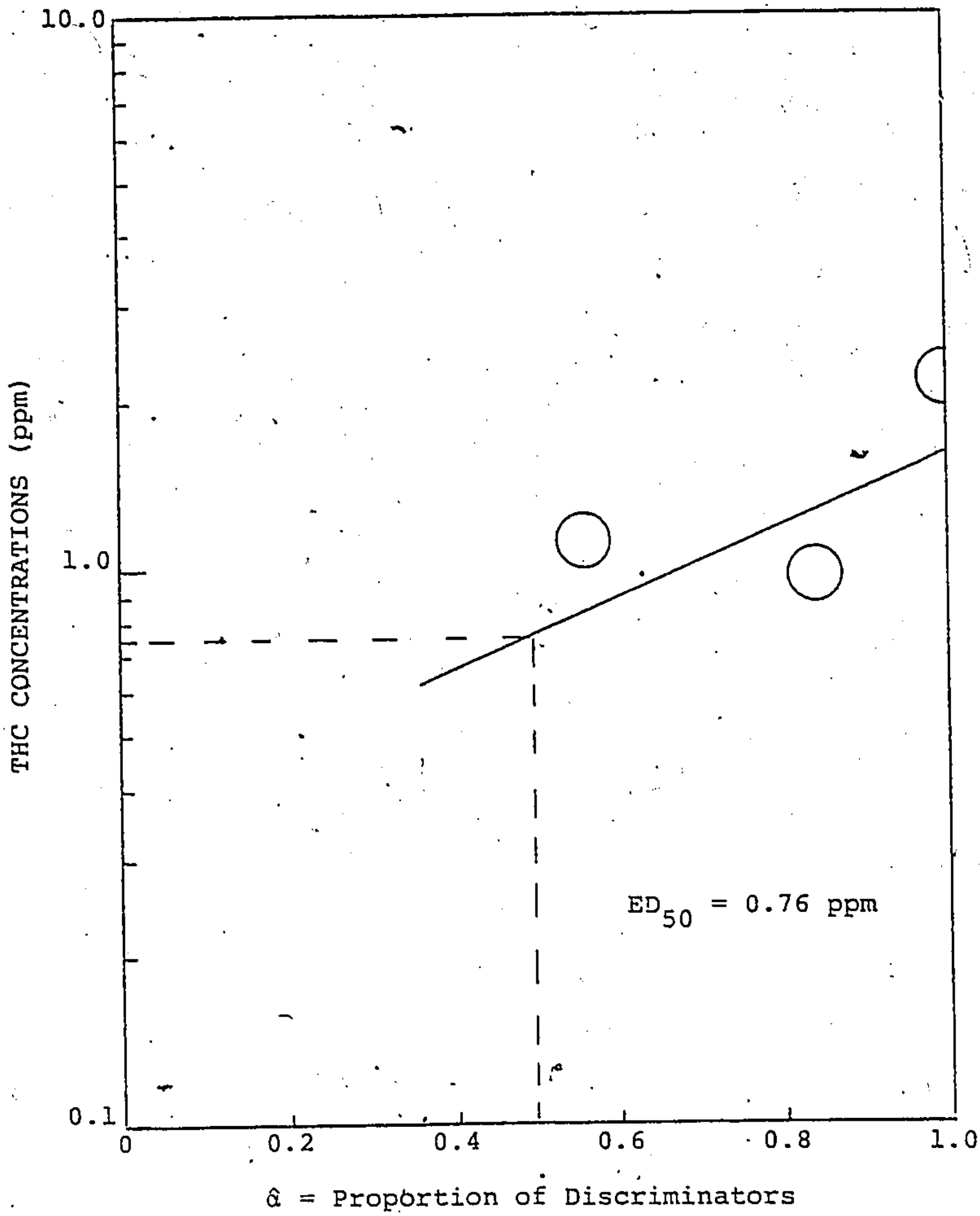


FIGURE V.8: Evaluation of Discrimination Threshold of Odorous Emissions from a Fast Food Restaurant Using MLE Probability Model for Second Trial

Sample: Fast Food Restaurant Emissions

Temperature: 27°C

Time: 1:00 PM

Date: July 22, 1980

Sample Concentration as THC ppm	Number of Subjects		$W_0/1$	$W_1/1$	$\hat{a}$ MLE
	Correct	Wrong			
0.63	6	4	0.6	0.4	0.40
1.34	7	3	0.7	0.3	0.55
1.80	10	0	1.0	0	1.00
3.60	10	0	1.0	0	1.00
10.76	10	0	1.0	0	1.00

TABLE V.21: Application of Maximum Likelihood Estimator Probability Model to 10.8 ppm Butane Equivalent Emissions from a Fast Food Restaurant

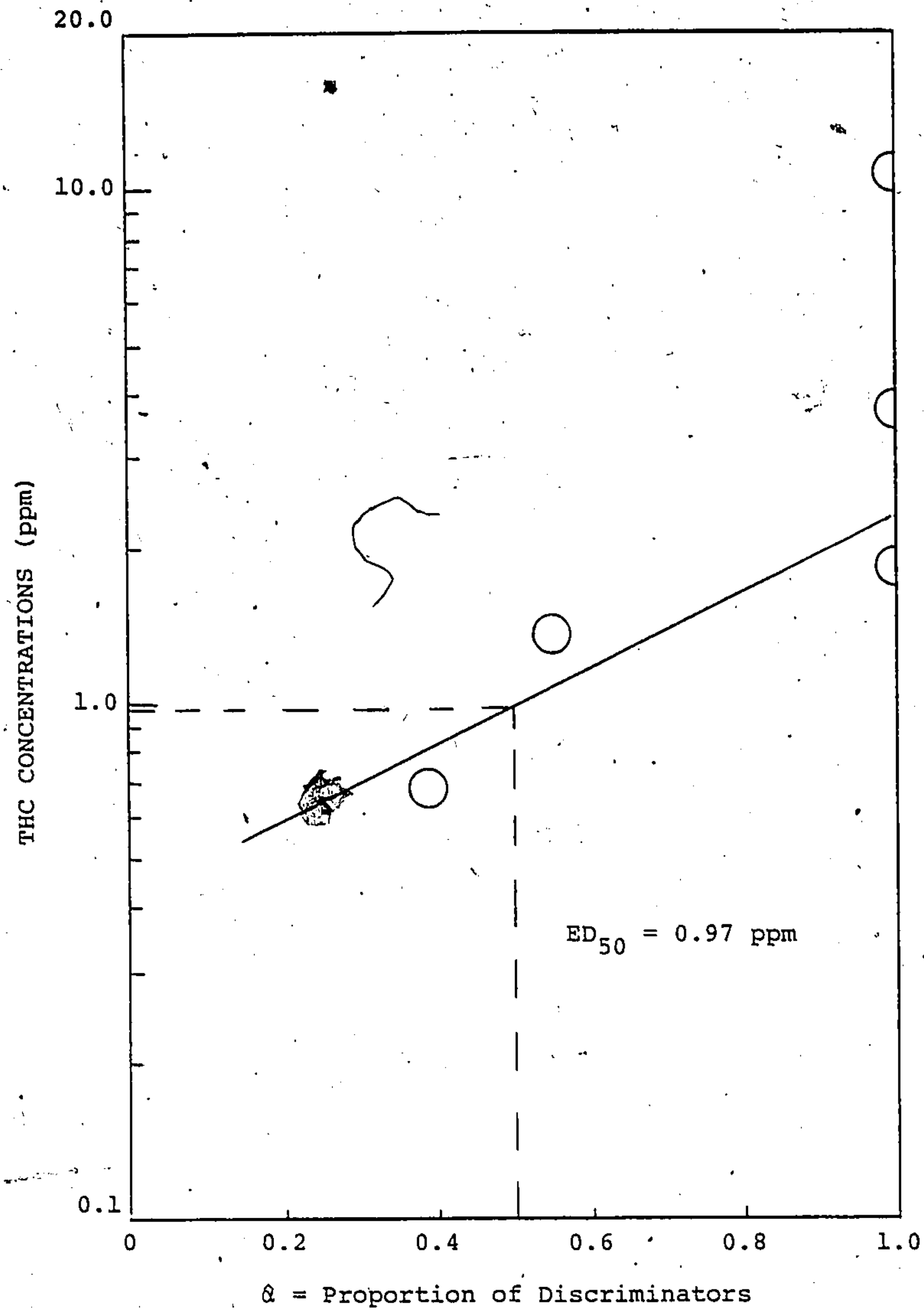


FIGURE V.9: Evaluation of Discrimination Threshold of Odorous Emissions from a Fast Food Restaurant Using MLE Probability Model for Third Trial

APPENDIX VI

Flow meter Calibration

Data

Flow Meter Setting	Time (secs)	Air Flow (ft^3)	Air Flow Rate at 24.6°C (liter/sec)
0.9	118.0	0.1	0.024
3.0	51.5	0.1	0.055
4.9	32.67	0.1	0.087
7.0	21.0	0.1	0.135
9.0	18.0	0.1	0.157
11.0	14.0	0.1	0.202
13.0	11.0	0.1	0.257
14.9	10.0	0.1	0.283
16.9	9.0	0.1	0.315

TABLE VI.1: Flow Meter Calibration Data

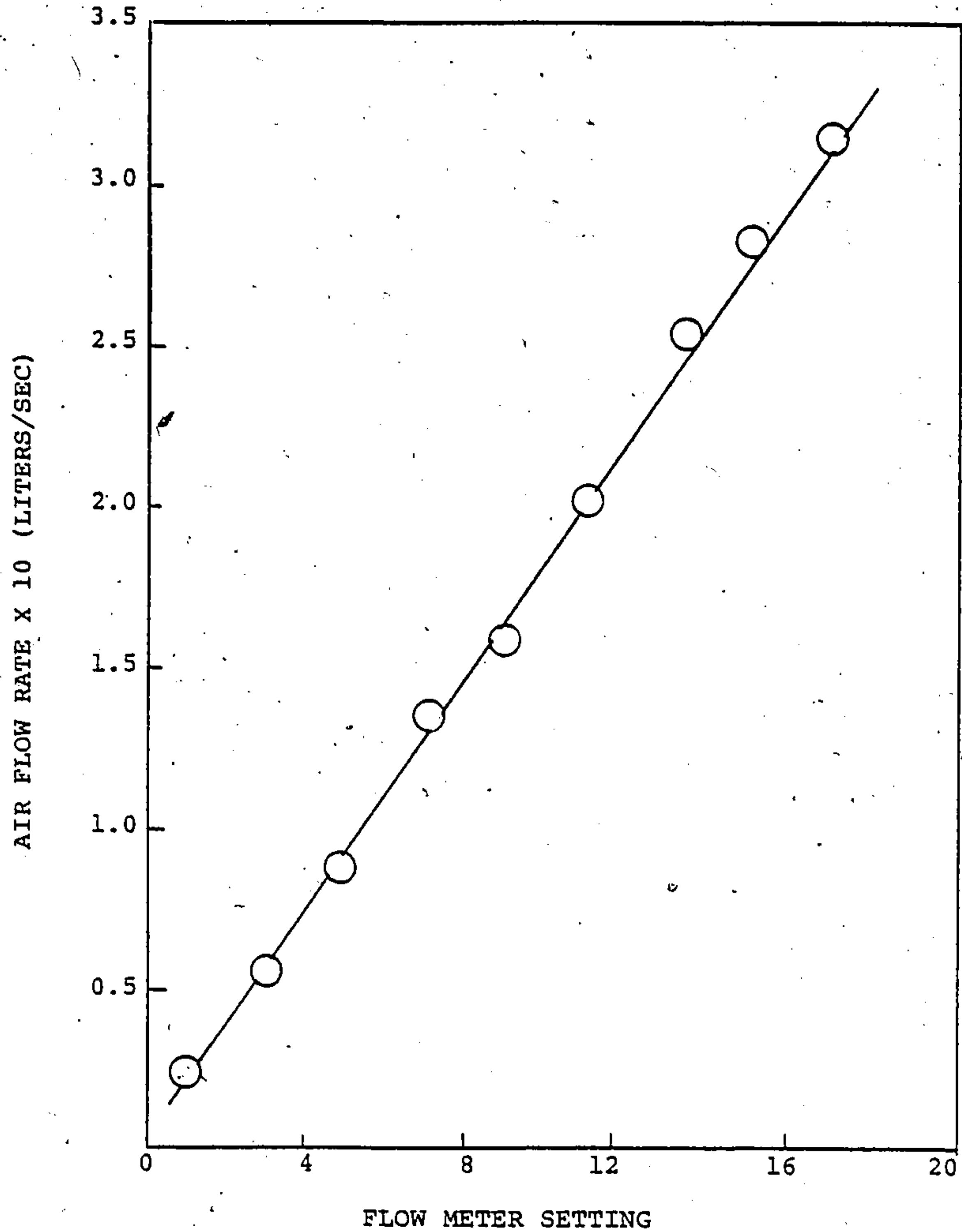


FIGURE VI.1: Flow Meter Calibration Curve

APPENDIX VII

Total Hydrocarbon (THC)

Measurements

Total Hydrocarbon Measurements

A Varian Aerograph series 1200-2 chromatograph, modified by the Air Quality Group of the University of Windsor, was used for the determination of Total Hydrocarbon Content (THC). This analyzer, equipped with a flame ionization detector, incorporated a six port gas sampling valve with a 1 ml sample loop and a recorder, Model No. 4272A, supplied by Varian Aerograph Corporation. This recorder provided a 0-1 millivolt scale for data acquisition. Odor samples were transferred into the analyzer sample loop through Teflon tubing and air tight fittings by applying pressure on the odor sample bag. The THC analyzer measured the hydrocarbon content as butane on the basis of calibration with standard 98 ppm and 980 ppm butane gas. The analyzer response was a linear function of butane concentration. All data were recorded on the basis of 3 constant peak heights.

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