ODOUR POLLUTION PROBLEMS WITHIN THE DISTRICT OF THE WREKIN COUNCIL

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SUMMARY

This thesis is concerned with various aspects of Air Pollution due to smell, the impact it has on communities exposed to it, the means by which it may be controlled and the manner in which a local authorithy may investigate the problems it causes. The approach is a practical one drawing on examples occurring within a Local Authority's experience and for that reason the research is anecdotal and is not a comprehensive treatise on the full range of options available.

Odour Pollution is not yet a well organised discipline and might be considered esoteric as it is necessary to incorporate elements of science and the humanities. It has been necessary to range widely across a number of aspects of the subject so that discussion is often restricted but many references have been included to enable a reader to pursue a particular point in greater depth.

In a "fuzzy" subject there is often a yawning gap separating theory and practise, thus case studies have been used to illustrate the interplay of various disciplines in resolution of a problem.

The essence of any science is observation and measurement. Observation has been made of the spread of odour pollution through a community and also of relevant meteorological data so that a mathematical model could be constructed and its predictions checked. It has been used to explore the results of some options for odour control.

Measurements of odour perception and human behaviour seldom have the precision and accuracy of the physical sciences. However methods of social research enabled individual perception of odour pollution to be quantified and an insight gained into reaction of a community exposed to it.

Odours have four attributes that can be measured and together provide a complete description of its perception. No objective techniques of measurement have yet been developed but in this thesis simple, structured procedures of subjective assessment have been improvised and their use enabled the functioning of the components of an odour control system to be assessed. Such data enabled the action of the system to be communicated using terms that are understood by a non specialist audience.

Keywords:-

Air Pollution Control, Odour, Stench, Local Authority, Environmental Health

To Tot, Wendy and Ian

"So many things I would have done,
But clouds got in my way.
I've looked at clouds from both sides now,
From up and down,
And still somehow,
It's clouds illusion I recall,
I really don't know clouds at all"

"And if you care don't let them know,
Don't give yourself away.
I've looked at love from both sides now,
From give and take,
And still somehow,
It's love's illusion I recall,
I really don't know love at all"

"But something's lost, and something's gained,
in living everyday.
I've looked at life from both sides now,
From win and loose,
And still somehow,
It's life illusions I recall,
I really don't know life at all"

"Both Sides Now" Roger Whittaker

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CHAPTER 1

1. INTRODUCTION

1.1 The first question to be addressed within this thesis is the fundamental one of "Why Write it?" What are the reasons for making a personal commitment of time, money and effort to researching a subject that might not be considered to be one of major importance to human existence. Therefore some statements, possibly axioms, are presented to justify this choice of subject.

a. Odour is a form of pollution. It can seriously interfere with the quality of life experienced by a substantial minority of the population of the U.K. Thus, the pursuit of knowledge about the nature of this pollution, its production, propagation and control is humanitarian in that any insight gained will benefit human welfare.

b. Odour pollution is not a well organised discipline. It is largely unrecognised by academic institutions, statutory laws and the publishers of scientific journals. Thus, any attempt to collect and organise existing knowledge in this field, is an exercise in scholarship.

c. Knowledge of odour pollution is growing rapidly. Recent advances in analytical chemistry, chemical engineering, physiology and psychometrics have enabled new insight to be gained into problems of odour pollution and the means by which it can be controlled. Application of this knowledge to real problems is a considerable intellectual challenge.

1.2 What is Odour Pollution?

Odour, a word of latin origin, is defined in a dictionary (1) as "the property of a substance that has pleasant or unpleasantness or any effect on the nasal sense of smell". This definition and indeed common usage conveys a neutral detached attitude unlike the anglo-saxon word, "smell", which by itself implies unpleasantness so that the term "smell pollution" would appear to be more explicit but is not used in the literature of the subject.

Pollution is defined in a dictionary (1) as the "contamination or defilement of (man's) environment". What it is that contaminates or pollutes depends on human values and particular environments. For example, nitrate nitrogen is an essential nutrient for vigorous growth of plants and is deliberately added to irrigation water as a fertiliser. However, its inadvert addition to some aquatic eco-systems can cause unwanted growth of some plants that are considered undesirable and thus nitrate is then considered to be a pollutant. A further form of nitrate pollution occurs if excessive amounts of fertilizer nitrates leak into drinking water supplies in such concentrations that are considered to be hazardous to health. Thus a substance, that is beneficial in one circumstance can also be a pollutant if it interferes with man's intended use of his environment. Pollution depends not so much on the pollutant but on the context in which the potential pollutant is found. This is particularly so when odours are concerned.

An odour that is acceptable in one circumstance may not be so in another as is often the case for the aromas of cooking, particularly if the cuisine is exotic. Thus the smells of a Tandoori restaurant may be mouthwatering to a hungry passerby and an appropriate accompaniment to a diner within the same establishment, but they are frequently the cause of vexation to neighbouring residents who are over exposed to them.

The consequences of exposure to many chemical pollutants can be established by clinical trials that enables a dose response relationship to be estimated. Limits can then be assigned to regulate exposure to those substances so that ill effects due to them can be avoided. Thus pollution control becomes a matter of ensuring that numerical limits are not exceeded and the success or failure of abatement measures can be easily assessed, in principle at least. For odour such an approach is not possible for the following reasons:-

a. Odours have not yet been proved to directly cause clinical symptons of ill health.
b. Odours are not often due to single chemical substances but are often mixtures of many compounds.
c. Odours cannot be satisfactorily measured in terms of a single unit but have several dimensions that contribute to the perception of odour.
d. Odours are sensory pollutants that are subject to psychological interpretation by an observer. Feelings of annoyance depend as much on the personality and experience of

an observer as on the character and dosage of the observer. The dose response relationship is replaced by that of stimulus-response.

A cardinal fact of odour pollution is that it is subjective. Odour problems involve people and the sentiments they express so that its assessment is not precise but is subject to the ambiguities and paradoxes that are a result of human values and environments that people inhabit. The annoyance that a smell causes is more often related to the information it conveys or the associations or emotions is excites rather than to its intensity, frequency or character. Odour pollution is thus a form of information pollution.

Osmics, that is the science of smell, just as acoustics is the science of sound, has not developed sufficiently to coin a term that defines a smell undesired by the recipient. It is suggested that the word "stench" would be appropriate to this definition and is analogous to the word "noise" used to describe acoustic pollution. Stench is defined in a dictionary (1) as being a foul or offensive smell. This is in accordance with standard usage of the word but if used as the technical term suggested the meaning would be expanded and somewhat weakened to be an expression of annoyance caused by a smell. This suggestion is not entirely novel as Clarenburg (2) used the word "stench" to describe odour pollution giving rise to complaint but he defined it in chemical terms as being the composite description of all odorous pollutants whose concentration may vary strongly from place to place and from time to time.

1.3 Annoyance due to Stench; Psychological Aspects

The annoyance caused by stench can be thought of as the resentment people feel at an intrusion imposed on the enjoyment of private environment, or into the thoughts or emotions that people wish to experience in these places. The amounts of substance causing a stench may be extremely small but they can convey astonishingly powerful suggestions of alarm, disease, death, uncleanliness as well as stimulating recall of memories otherwise long forgotten by a recipient; and so in some people stench has an emotional effect out of all proportion to its physiological intensity.

The most readily available indicator of annoyance within a community is public complaint made to Local Authorities (LAs) who are in close contact and easily accessible to their residents. However, complaint is an unreliable indicator of the number of people who are annoyed by odour pollution but it can at least indicate the degree of their annoyance. Many people who are annoyed are tolerant enough not to make an official complaint although they may be disturbed as much as those who do complain. Any complaint that is recorded is the final result of a long chain of decision and responses that includes administrative procedures, soci-economic circumstances, psychological and physiological factors, cultural values and accessibility to a telephone. It is therefore very likely that an official public complaint represents a small fraction of the total number of people annoyed.

1.4 The Extent of the Odour Problem; National Statistics

National statistics of public complaint about odour pollution are not readily available as there has been few attempts to collate annual statistics on this problem. There was a survey on odour pollution for the decade 1960 to 1970 in which 248 Local Authorities (LA's) reported 2334 complaints for the first year rising by almost steady annual increments to 5218 in the last year. In 1978 a further questionnaire (3) on odour pollution was circulated to LAs in the North West of the UK and 67 replied reporting 3114 complaints. Thus, odour pollution is widespread matter of public concern which seems to be a growing problem either because the extent of odour pollution is becoming more widespread or there is increasing public awareness of environmental pollution in all its forms. The Governmental Warren Springs Laboratories have attempted to monitor changes in odour pollution over a period 1974 - 1980 (4) and concluded that there had been a reduction in complaint due to a reduction in the number of sources of odour emission and an improvement in odour control technology. However the major problem areas remained unchanged.

1.5 Is Odour a Cause of Ill Health?

Odour is a form of pollution directly detectable by a normal human sense, unlike many other forms of pollution, for instance lead or radiation, which are hazardous to human health but are not perceptable.

Bad or unfamiliar smells are source of worry to the many people who associate them with ill health. Such a belief is not surprising since the view held for millenia was that pleasant smells tended to be beneficial while malodours were injurious. The history of such ideas is well recorded.

Aristotle held that the fragrance of flowers preserved health while also noting that content is important by remarking that "smells (of food or drink) are pleasant when we are happy, but when we are sated and not required to eat, they are not pleasant " (5). If pleasant smells tended to be beneficial then bad smells were injurious. Thus the feotid atmosphere of swamps was thought to be the cause of the disease Malaria (Italian bad air).

Such teachings powerfully influenced the practise of medicine. Doctors protected themselves with masks of sweet smelling herbs when treating patients affected by bubonic plague, magistrates wore long snouts of dried herbs to ward off the diseases of the gaol house, hence earning the nickname of "The Beak". Fragrant posies of flowers were introduced into the sick room to aid recovery and bandages were sprinkled with perfumed water such as Eau de Cologne to inhibit infection.

These beliefs continued into the late 19th Century when the researches of Pasteur established the microbiological causes of disease and demonstrated that bad smells were often evolved by pathogens living within an environment of putrification and decay that such organisms created. However doubts had been expressed much earlier when the industrial revolution caused numerous factories to be built that emitted clouds of noxious fumes within giant conurbations of houses, schools and hospitals. In 1806 the Editors of the Edinburgh Medical and Surgical Journal posed the question "Are those manufacturers which emit a disagreeable smell prejudical to Health?" (5). The conclusion was "A disagreeable smell is by no means a certain criterion of an unwholesome atmosphere, and on the other hand, the air is often pestilentical, when, to our senses, it appears uncontaminated". This opinion cannot be faulted in the light of present day knowledge.

Modern opinion tends to dismiss any relationship between smell and illness and the most authoritive work on pollution control published in the UK (6) states that "odours are a nuisances, not a toxic danger". This opinion is justified by relating a measure of toxicity, the Threshold Limit Value (TLV) to the Odour Threshold Concentration (OTC) which is the least concentration at which an odorant is perceived. For a selected list of 40 substances,reproduced in Appendix 1, only 3 had OTC's greater than their TLV's so that the smell of them may have injurious consequences. However TLV's are assigned assuming a 8 hour working day for a healthy work force while it is customary to take a fractional 1/40 TLV to assess the 24 hour exposure of a community which may contain sensitive individuals such as the old, the young, and the ill. Taking fractional TLV's and repeating the comparison produces a result in which 23 compounds in the list have OTC's greater than fractional TLV's. Thus the quoted statement would seem to be complacent.

The approach to the relationship between odour and health that is based on chemical toxicity is flawed on two counts. Firstly, many common odours are not composed of single odorants but are, as in the case of diesel exhaust or manure, an overall perception of very many components. TLV's are assigned to a single component on the basis of an established dose-response function but if several substances contribute to an exposure then the combined dose-response function becomes impractical to estimate. Toxicity may not be additive when several components are involved as then potentiation and synergistic effects may cause increased injury. Smells constituted of many odorants may thus have injurious effects at concentrations much less than the sum of the individual TLV's may imply.

Secondly, it has already been argued that smell is a form of communication and if there are ill effects due to odour, then the message may be prejudicial to health irrespective of the intensity with which it is perceived. Faint smells may thus be as annoying as strong ones or indeed may be quite as prejudicial to health. Foul smells might warn of danger but pleasant smells may pose a greater danger since they may be breathed for longer without hazard being appreciated. For example the war gas, lewisite, is said to smell of new mown hay, and hydrogen cyanide of almonds.

1.6 Somatic Effects of Odour

Odour is widely recognised to trigger unpleasant sensation and reflexes akin to symptons of illness such as nausea, vomiting, headache, loss of appetite and irritation of nose and throat. (7) but far more subtle effects have been observed. Pheromones are volatile substances found widely in the insect and animal kingdoms that signal social class, sexual receptiveness and emotional status of a individual. Recently tests have emerged that such substances are active in the human species. Menstrual cycles of women living in close communities become synchromised and women's sensitivity to musk fragrances are much keener than those of men and vary regularly throughout their menstrual cycle. Musk based perfumes are considered to be aphrodisiacs while women are sensitive to "boar taint" in bacon caused by a male steroid present in the bacon. Hormonal compounds are excreted in urine consequently it is tempting to speculate that the odours of manure, which are spread in enormous quantities on farm land, are not only more annoying to women than to men but could effect their health by exerting subtle though powerful effects on their body rhythms.

Recent research has indicated that odour messages may be passed to the brain not only by means of electrical responses resulting from an odour stimulating a receptor in the nose, but also by transport of substances along the olfactory connection between the nasal surface and the brain. Both colloidal gold and ammino acids placed in the nasal cavity can be carried toward the brain at a surprisingly rapid velocity of 400mm/day so that only hours intervene between a large molecule entering the nose and it appearing deep within the nervous system of the brain (5). The consequences of the introduction of large molecules directly into the central nervous system has yet to be evaluated but it raises the possibility that the olfactory sense can produce physiological responses by mechanisms not available to the other human senses. Indeed drugs intended to alter the health of an individual are now being administered via the nasal cavity (83) a technique known as osmotherapy.

Malodours produce powerful feelings of anger, annoyance and resentment in people experiencing them (7) though such emotional responses are not usually considered to be symptons of chronic ill health. However, the World Health Organisations (WHO) defines health not in narrow terms of clinical illness but in the wider context of being "a state of complete physical, mental and social well being, and not merely the absence of disease or infirmity." Thus many of the unpleasant sensations associated with exposure to odorants appear to pose a threat to well being, including even the belief itself that malodours are unhealthy. The purpose of this discussion of the health aspects of odour pollution is not so much to demonstrate that there is an unrecognised epidemic of illness resulting from community exposure to odorants but rather to question the validity of the legal barriers that separate the concepts of "prejudice to health" from that of nuisance. If the WHO definition of health is accepted the distinction no longer applies that separates the amenity problems from the pathological problems of pollution.

1.7 Odour and Human Welfare

There is a tendency to trivialise complaints of malodour that is encapsulated in the often used phrase "it's only a smell", although there is sufficient evidence to demonstrate that odours can have serious effects on human welfare, and it is likely that further research will confirm some of the speculative effects referred to in previous paragraphs. Whatever stance expert opinion adopts in this matter the average citizen believes firmly and justifiably that his senses serve in part to provide a good warning of hazard. In the absence of trusted information to the contrary the citizen exposed to foul odour will draw the reasonable conclusion that if something smells nasty, then it is likely to do nasty things to him or her. In the case of ambient stenches today's citizen has no more reason to reject this conclusion than his ancestors. Indeed he is encouraged in this belief by the practise of adding stenching agents to inodorous hazardous substances such as natural gas and industrial oxygen and the deliberate adulteration of methylalcohol by pyridine and purple dye to produce an undrinkable methylated spirit.

1.8 The Sensory Pollutants :Stench and Noise

Stench and Noise are both sensory pollutants that are the cause of numerous public complaints and some insight may be gained into the problems of controlling stench by considering some aspects of noise pollution.

First those points that are shared in common. Stench and noise are both perceived by human senses, both carry unwanted information imposed on an observer, both are pollutants of the air, and both are the cause of complaint to local authorities and within those authorities the same officers are likely to investigate and take the necessary action of abatement if the circumstances justify such action.

Neither noise nor stench can be objectively measured since the annoyance they cause depend on the circumstances of the person they effect. However unlike odour, sound in all its forms can be accurately measured by a sound level meter, for sound is a simple stimulus induced by pressure fluctuations in the air acting on the aural cavities of the ear. Instruments called noise analyzers are manufactured that are simply data loggers of varying sophistication that can be programmed to display their data in a variety of statistical measures. In addition to the basic unit, the decibel, there are a variety of noise criteria including Loudness Equivalent (Leq), Statistical Levels (Ln), Noise and Number Index (NNI), Day-Night Sound Level (LDN), Noise Exposure Forecast and Perceived Noise Decibel. This is not a pollution control. However case law has established that odour is a form of "effluvia" and therefore is a statutory nuisance defined by the Public Health Act 1936.

4. Exposure to excessive industrial noise is recognised to be a health hazard by causing deafness and can be the basis of a claim for Industrial Injury. This has increased the awareness of industrial managers to the problems of noise, even though levels of environmental noise are generally much less than factory levels. Odour has not yet been demonstrated to cause industrial injury consequently industry often fails to recognise the problems of stench that it is responsible for. However considerable damages have been awarded in damages when an accident causes a loss of the sense of smell.

The capability of using physical means to measure sound has been an essential factor in establishing acoustics as a proper scientific discipline and endowing it with an authority to command legal recognition. It is a subject taught widely in universities and polytechnics, consequently text books are published that explain the subject and advances in knowledge are reported in specialised journals. Training in elementary noise control is good so there can be few local authorities in the UK that do not posses a basic noise level meter and employ at least one person able to use it effectively to investigate complaint and advise on the means of abatement of noise nuisance.

1.9 The Science of Osmics

The development of osmics as a science is undoubtedly inhibited by the absence of instrumental means of measurement. Objective measurement is practical but requires the use of observers organised in panels. In some ways this human element is no great disadvantage for in investigations of complaint it is the subjective human reaction that is important and not objective physical measurements. However panels are impractical in the routine investigation of complaint as they simply cannot be organised at a moment's notice and the local authority officer is not trained in the management of panels of people and the protocols that should be followed if reliable results are to be obtained. Further as this complicated and costly exercise is undertaken there is no certainty that the results would have any legal standing in the absence of any definitive advice from a respected source on acceptable levels of smell in a community. It is also questionable that the responses obtained from a panel under the artificial environment of a structured test reflect the responses of a larger community whose individuals are going about their normal business.

In this thesis the problems of the measurement of odour will be addressed. It is hoped that it will be demonstrated that a lone investigator using methods of social survey and small panels can achieve a useful insight into the annoyance caused by stench and the means by which it might be controlled.

CHAPTER 2

2. Odour as a Public Nuisance

2.1 Introduction

Any member of the public who suffers from stench is entitled to complain to the person responsible for its emission, or to a local authority, or to a Court of Law within whose jurisdiction the smell occurs. The only important exceptions are:-

a. Crown premises which are owned or operated by government ministeries, for the crown is immune from prosecution for statutory offences.

b. Those industrial premises subject to the Health & Safety at Work Act whose emissions are overseen by the Governmental Air Pollution Inspectorate.

Many individuals and businesses prefer to be good neighbours and will listen to a complaint reasonably made and take action to prevent it recurring. However if the informal approach is ineffective then an aggrieved complainant may consider a legalistic solution to his or her problem.

The law will only intervene in a dispute concerning odour pollution if one of two effects of smell can be proved in court. These are:-

1. The smell may be "prejudicial to health" that is to cause

some clinical sympton of illness.

2. The smell may be a "nuisance" that is an interference with property and the rights of a person with an interest in it to use the property as he or she wishes.

2.2 The Role of a Pollution Control Officer

A Pollution Control Officer called in to investigate a complaint will have to chose which of these alternatives should be invoked if formal legal proceedings are contemplated.

The attitude of the law towards odour pollution is not immediately apparent but it does take a stance based on precedents established in cases taken under Common Law whose origin goes back almost into antiquity. Some aspects of case law have been consolidated into the framework of Statute Law which is created by Act of Parliament. In the field of Public Health the most important Act is the Public Health Act (PHA) 1936 which is the legislation that local authorities are required to implement. Unfortunately no word directly associated with smell appears in this Act and a quite influential body of legal opinion believes that a Local Authority may not act to abate odour nuisance (8). This is incorrect for a subsection of the Act use the words "any dust or effluvia". Effluvia, according to the dictionary, is a flow of particles and thus the molecules of particles causing a smell that are carried to the nostrils of an observer by diffusion or movement of the air must therefore be described as efluvia. This argument was indeed accepted in a case (No. 11) heard in a High Court during 1972 and all doubt about the correctness of local authority powers to control odour pollutions thus removed.

It is not the purpose of this thesis to undertake an in depth examination of the role of the Law in the control of Odour Pollution as this is a subject that could only authoritively be undertaken by a person with legal training and such work has been published (9). However a Pollution Control Officer needs to know something of the framework of Law that he must use to enforce the abatement of nuisance. He or she meets both the public and industrialists who will naturally ask about the role of the law. He will have to understand how his observations of stench can be incorporated in evidence and take statements from witnesses which will be used in prosecution arguments in Court. He or she may also have to appear as an expert witness, open to cross examination by the defence and prosecution, who has special knowledge to impart to the Court and the ability to expand the evidence given by technically naive witnesses. It is to the acquisition of this special knowledge of odour pollution that most of this thesis is directed but its relevance to the legal process cannot be ignored.

2.3 Prejudice to Health

Exposure to some obnoxious smells can certainly induce symptons of nausea and vomiting which is good evidence that a smell is "prejudicial to health". However such extreme responses are rarely encountered and it is accepted that in general odours do not cause risk of infection. It is also doubtful that mental strain, irritability or resentment often reported by people exposed by odour (7) would be regarded as evidence of ill health as the effect is upon a person's well being only. The World Health Organisation definition of Health is broad enough to encompass well being but this concept has not been tested in a British Court who must be presumed to take a more robust view of health. That is to say that "prejudice to health" requires proof of potential for infectious disease.

The effects of odour on people already ill may be greater than on healthy people and certainly people with breathing difficulties such as bronchitis and asthma seem to be particularly distressed by foul odours. In such instances the law will intervene to protect the patients of a Hospital as in the precedent of "Local Board of Health for the District of Malton V. Malton Farmers Manure and Trading Co. Ltd." [1879] IV Ex. D. 302.306 when it was stated "The kind of smell which makes sick people worse must interfere with the vigour and vitality of those who are well, but at all events it is sufficient to show that sick people are injured thereby"

The law does not necessarily demand a "body count" of sick people but will intervene if there is a reasonable likelihood of injury to health. For instance a smelly manure heap might well provide a breeding ground for vermin or flies that can carry disease. Thus in the case of "Coventry City Council V. Cartwright",

[1975] I.W.L.R. 845 it was held that an accumulation or deposit of matter was prejudicial to health if it was likely to cause a threat of clinical disease or attract vermin.

The same point also made in a further case Bone V. Seale, [1975], I.W.L.R., 797CA when it was accepted that the test of a public health nuisance was "whether it caused risk of infection" while a claim was rejected that "nothing in the way of smells was a nuisance to public health unless it so nauseated the smeller that he vomitted."

The health arm of the law offers a simple method of dealing with a restricted range of odour problems usually associated with smelly dung heaps or the decomposing contents of a badly managed waste bin. If a nuisance abatement notice of a Council is ignored, and prosecution follows, then a case can be based solely on the evidence of a council officer, who should be both an expert witness and a reasonable person. But if health is not threatened then the complex problems of nuisance must be tackled.

The concept of nuisance is a notoriously obscure branch of law that in 1867 was said to be "immersed in undefined uncertainty" and still in 1983 it remained "far from susceptible to exact definition". It has become a catchall for a multitude of ill assorted sins, linking offensive smells, street queues, lotteries, houses of ill repute, and a host of other rag ends of the law (10). However, the issue is not with the multitude of sins but with the multitude of smells and whether they are more than a temporary and brief annoyance but are sufficiently disagreeable to become legal nuisances. A Local Council Officer must therefore have a clear idea of the evidence that must be collated in order to convince a Court that a public nuisance is being caused by a smell.

2.4 Public, Private and Statutory Nuisance

There are three types of nuisance:-

a) Public Nuisance - A criminal offence consisting of an act or omission which materially effects the comfort or convenience of the public. Where such an offence is concerned it would be unreasonable to expect one person to incur the inconvenience of taking action, and so the community, as represented by the local authority, does so.

b) Private Nuisance - An act or omission connected with the lawful use of land and which causes unlawful interference to another person's use or enjoyment of land. Because this act is not criminal the plaintiff does not prosecute and the nature of the evidence is less than the standard of "proof beyond reasonable doubt" required in a criminal case.

c) Statutory Nuisance - An act or omission which has been designated a nuisance by Act of Parliament.

It is of considerable importance for a Pollution Control Officer investigating a complaint of nuisance to decide if the issue is one of Public Nuisance, which is actionable by a Local Authority, or a Private one in which a local authority should not intervene. The distinction concerns the number of people effected within a community and whether they constitute a class of Her Majesty's subjects. Local Authority solicitors commonly apply a "rule of thumb" that the minimum number of witnesses necesary to prove public nuisance is three separate householders but there is no legal basis for this opinion. An important legal case on this matter is:

Attorney General V. P. Y. P. Quarries Ltd [1957] ALL E.R. 894: 2 Q.B. 1969 Lord Denning stated "I decline to consider the question how many people are necessary to make up H.M.'s subjects generally. I prefer to look to the reason of the thing and to say that a public nuisance is one so widespread in its range or so indiscriminate in its effect that it would not be reasonable to expect one person to take proceedings on his only responsibility to put a stop to it, but that it should be taken on the response of the community at large."

This judgement clarifies the legal issue but does not define it. It still leaves open the question of how many people effected by nuisance comprise a class of Her Majesty's subjects. Defendants sometimes claim that all H.M. subjects within the range of the alleged nuisance must be proved to be effected but this is absurd for it would be almost impossible to prove public nuisance.

A public and a private nuisance are different types of legal wrongs but the tests necessary to establish the existence of a private nuisance also apply to a public nuisance. Also there is an important difference that a defendant cannot claim a prescriptive right to create public nuisance, that is a right to commit nuisance having caused it continuously over 20 years as he can claim for a private nuisance. The reason is that public nuisance is a crime and nobody has a legal right to commit a crime. Nor is it a defence to a charge of nuisance to show that the complainants came to a nuisance. Thus, the residents of new housing estate built alongside an old established smelly factory can certainly expect their complaints to be answered.

2.5 Legal Tests of Nuisance

The following principles of evidence have been established in the Courts to assist in proving of nuisance.

1. There must be material interference with property or personal comfort as with the Case of Walter V. Selfe (1851) 4 De & G & Sm 315 where nuisance is defined as an "inconvenience materially interferring with the ordinary comfort, physically of human existence, not merely according to elegant or dainty modes of living, but according to plain and sober and simple notions amongst English People". In practice a Pollution Control Officer requires to gather evidence that windows have been shut against ingress of smell into a home, that outdoor activities have been curtailed, washing hung out to dry has been tainted, and has been rewashed or any other similar tangible affects of smell.

The law of nuisance affords little protection to people who are unduly sensitive and an interesting example being when the taste of biscuits was tainted by odorous fumes from a pesticide factory several miles distant (11).

Some examples of smells that have been the cause of successful abatement actions have been odours from a fried fish shop, stables, effluvia from a factory chimney, from a gas works, sewage works, spraying of cars, from brickworks, pig swill boiling and a feather hydrolysis plant.

2. It is no defence for the defendant to show that he has taken all reasonable steps and care to prevent nuisance as demonstrated in the case of Rushmoor V. Polsue and Alferi Ltd 1907;
"It does not follow that because I live, say, in the manufacturing part of Sheffield, I cannot complain if a steam hammer is introduced next door and so worked as to render sleep impossible, although previous to its introduction my house was a reasonably comfortable abode, having regard to the local standard; and it would be no answer to say that the hammer is of the most modern approved pattern and is reasonably worked"

The law accepts that in populated country a certain amount of give and take is necessary but there are limits and even in an industrial zone a factory is required to have a regard for the comfort of its neighbours and take steps to curb excessive emissions of smell. However if measures have been taken to curb emissions of smell then the defendant may use the defence of best practical means (BPM). A complex term that will be discussed later.

3. Injury to health need not be proved as in the Case of Local Board of Health for District of Malton Vs. Malton Farmers Manure and Trading Company [1879] IV Ex D 302, 306 when it was said:
"... it was sufficient to prove that, the manufacture being one causing effluvium, such effluvium was a nuisance, injury or not"
The law accepts that any act that materially interferes with the ordinary physical comfort of a neighbour constitutes an actionable nuisance.

2.6 Intermittancy and Standards of Comfort

Temporary odours will not generally be accepted as a nuisance, as in the Case of Bamford V. Turnley [1862] 3B & S62 concerned with odours from brick burning.
"...that which may be a nuisance at midday would not be so at midnight, that may be a nuisance which is permanent and continual would be no nuisance if temporary or occasional only."
However if the temporary odour may recurr then action under a 1968 Act (p 42) is possible.

The Courts recognise that smells are carried on the wind which is subject to frequent changes of direction so very frequent, albeit intermittent smells, will cause nuisance and this argument has been accepted in several significant cases. Bone V. Seale (pigs) [1975] 1.All E.R. Att. Gen. V. Costonia Coaches [1977] RTR 219 (diesel fumes)

The Courts do not seek to apply a fixed standard of comfort and numerous cases may be cited to illustrate this point of which the following two are the most significant. In the Case of Sturges Vs. Bridgeman [1879] II Ch. D. 852 it was stated that "What would be a nuisance in Belgrave Square would not be so in Bermondsey" while in the case Case of Halsey V. Esso Petroleum Co. Ltd "Everyone must put up with a certain amount of discomfort from neighbours" The problem of nuisance is summarised in the Case of Sedleigh-Denfield Vs. O'Callaghan [1940] 3 All E.R. 349 H.L. when it was said that "A balance has to be maintained between the right of an occupier to do as he likes on his property and the right of his neighbour not to be interferred with. Consideration has to be given to matters such as locality, time, severity and duration."

2.7 The Question of Best Practical Means (BPM)

In some circumstances a defendant may very well claim that he is using the best practical means of controlling the emission of smell from his activities and if this is accepted then the prosecution case fails. BPM is a peculiar British concept in Pollution Control and the PHA 1936, interprets this expression as being means reasonably practical for preventing nuisance having regard to cost, local conditions and circumstances. There is an alternative definition given in the Control of Pollution Act which breaks down the term into its constituent parts. "Practical" implies having regard to local conditions and circumstances, to the current state of technical knowledge and to

financial considerations.
"Means" is to include the design, installation, maintenance, manner and periods of operation of plant, and the design of buildings and structures.
This defence raises a number of problems for the prosecution who may well have the ability to prove nuisance and the expertise to suggest an effective means of abatement but cannot always question matters of business finance which a Company is not anxious to devulge. A local authority can compare costs of pollution abatement with which essential costs of industry such as rates, and details of company accounts filed under Company Acts. However a bench of Magistrates is more experienced with dealing with simple matters of crime than with rare cases of public nuisance and any complications of an attempt to present straight forward prosecution evidence is likely to favour the defence. A local authority should endeavour to avoid the possibility of this form of defence which it can do by careful choice of the powers available under sub-sections of the Public Health Act.

2.8 Wording of an Abatement Notice: Choice of Sub-Section

The PHA 1936 has 5 sub-sections under which action can be taken to control matters of nuisance or prejudice to health. These are:-

S. 92(1)(a) Any premises [SPHON]
S. 92(1)(b) Any animal kept in such a place or manner [SPHON]
S. 92(1)(c) Any accumulation or deposit [SPHON]
S. 92(1)(d) Any dust or effluvia caused by trade, business, or

manufacture or process [SPHON]

S. 92(1)(f) Any other matter

[SPHON = such as to be prejudicial to health or a nuisance]

The defence of BPM applies to Sections (c) and (d) and thus it is to a plaintiffs advantage to avoid these sections if at all possible although obviously the notice must be relevant to the circumstance.

Alternatively if a local authority is of an opinion that summary proceedings in a magistrates court will not succeed, or has failed, or is unacceptable due to a defence of BPM the proceedings can be taken in a High Court under S. 100 of the PHA. However these proceedings are expensive, objective evidence of statutory nuisance must be of a very high standard and a final resolution of the problem is longwinded. Such a case was Shoreham by Sea Urban District Council V. Dolphin Canadium Proteins Ltd in which 5 years elapsed between the original writ being issued and the Company being compulsorily closed down. Such are the economic consequences and practical problems of High Court Proceedings that a Local Authority is normally very reluctant to take such action unless the Aggravation caused was considerable.

2.9 Public Health (Recurring Nuisances) Act 1969

Odours, by their nature are transient, being blown wherever the wind will take them so that a complainant may only experience them as a transient aggravation. The recognition of this type of nuisance caused the above Act to be made by Parliament that permits a Prohibition Notice to be served where an Order has occurred and is likely to recur but unlike an abatement notice there is no need for a nuisance to exist at the time of a notice. Further whereas an abatement notice runs for only 6 months after expiration of its conditional time, a prohibition notice has no time limit. The application of this Act has been nicely indicated in the following judgement. Case of Peaty V. Field [1971] 2 ALL ER 895, 898

"A man may deposit on his land excrement which is foul smelling and a nuisance, but it may be that the evil effects wear off in 24 to 48 hours so it is difficult for a local authority to serve an abatement notice and prove that the nuisance was still in existence when service was made, whereas now, once the deposit is made and is indeed a statutory nuisance, then the statutory nuisance has occurred, and if the local authority are satisfied it will occur again they may serve a prohibition notice".

The powers of this Act overlap those conferred by the Public Health Act to an extent there is an ambiguity as to which notice should be served in a particular circumstance. Council Solicitors therefore advise that both notices should be served simultaneously so that if one is challenged the other remains intact.

2.10 The Nuisance Order

Neither an abatement notice or a prohibition order is enforceable by a local authority. If the work required by an abatement notice is not done or a nuisance recurs after service of a prohibition order then it is the duty of the Local Authority to institute proceedings in a magistrates court with a view to obtaining a nuisance order. If the Court is satisfied that nuisance is proved then nuisance order is granted so that

a) The defendant is required to comply with the notice of the local authority
b) Recurrence of the nuisance is prohibited and works ordered by the Court should be executed within a specified time

A fine of up to £1,000 may be imposed and the defendant ordered to pay the local authority the costs of proceedings.

Failure of a defendant to comply with a nuisance order may mean fines of up to £2,000 plus £50 for each day the offence continues while the local authority may do whatever is necessary to execute the nuisance order and recover costs.

A defendant may offer a reasonable excuse for non-compliance. Lack of finance is not such an excuse (Saddleworth UDC V. Aggregate and Sand Ltd [1970], 114 Sol. J. 931) while special difficulty such as illness or failure to obtain planning consent where this is necessary would apparently be acceptable.

preventing the emission of noxious or offensive substances into the atmosphere and for rendering them harmless or inoffensive. This can be achieved by replacing existing legislation by health and safety regulations or Codes of Practice with the particular measures being agreed between industry and the enforcing authority. If a new Act incorporate such provisions then it may simplify nuisance proceedings since justifiable complaint could be attributed to non-compliance with a Code of Practice of BPM and the adoption of such measures would become the content of a nuisance order. Such procedures are already employed in nuisance proceedings for noise brought under the Control of Pollution Act where the Department of Environment have published COP's for ice cream van chimes, model boat and model plane sporting events, water sking and audible intruder alarms. These have been successfully applied nationally to regulate activities that have a great potential for nuisance. Some agricultural practices that cause odour nuisance are already subject to COP's and these provide useful guides to good practise when investigating complaint under the current state of the law.

The overall effect of the new Act will be to bring uniformity in Pollution Control Standards across the UK so that British Practise meets requirements of the EEC. A great gain will be the ability to anticipate problems and control them before they happen. A disadvantage will be a loss of local iniative to control pollution by imposition of planning conditions. Odour will be specifically defined as an air pollutant. (86)

2.11 Summary of Nuisance Law

This review of the law is necessarily brief and the quotes of judicial judgement are often parts of a considerable statement so there is a possibility that they are taken out of context. No two cases of nuisance are identical and it is important to carefully consider which precedents are applicable to any new situation.

A Pollution Control Officer must recognise at the beginning of the investigation of any complaint that he or she may be starting on a path that can have serious consequences for the person, or business complained about. But a complaint cannot be ignored for there are powers in the PHA for an aggrieved individual to initiate his own action to abate a nuisance and call to account the Local Authority for their failure to do so and Ratepayers may also complain of maladministration to the Local Authority Ombudsman.

In the years since 1936 public services and local government has been reorganised and many sections of the PHA have been repealed so that the emasculated act is now under review and a new Clean Air Act is imminent. It is likely, should this happen, the nuisance provisions will be brought into line with modern procedures of pollution control such as are employed by the Control of Pollution Act 1974 and the Health and Safety Act 1974. These impose a duty on the person having control of any premises prescribed under the Act to use the Best Practical Means for controlling the escape of noxious or offensive emissions.

2.12 Prevention of Pollution: The Role of Planning

The nuisance provisions of the Public Health Acts can only be used to control odour nuisance after the emission has occurred. Enforcement of the law in this situation brings local authorities into confrontation with local industry which is not often desired by either side. When new developments are concerned then Planning Authorities can prevent pollution by use of their powers at a time when a developer wishes for something, planning consent, which the Local Authority can give. Then difficulties can be tackled by negotiation, and with normal good will satisfactory solutions to problems found.

Planning legislation requires that the amenities of an area be protected implying a greater degree of control than would be sufficient for the prevention of nuisance. Amenity being defined as the pleasantness of an area.

2.13 Planning Powers to Control Stench

The Royal Commission on Environmental Pollution distinguished two aspects of planning : that which a planning authority initiates and that to which it responds.

The first aspect includes strategic planning exercised by County Councils including the location of industrial land and residential zones which are designated in structure plans. Under these powers it may be possible to create a "cordon sanitaire" about smelly processes such as sewage works or oil refineries. These are areas of open space in which odorous emissions can be dispersed with minimal effects on the amenities of a neighbouring community.

The second aspect includes development control in which planning permission is granted to a developer by a District Council. A DOE Circular 1/85 advises that "permission should be granted unless there are convincing objections such as intrusion into open countryside of noise, smell, safety, health or excessive traffic generation." Permission can be granted subject to conditions to prevent or reduce any such disadvantage.

Inspite of this advice a recent survey (3) suggested that some planning authorities do not believe that odour pollution is best dealt with by planning but that such problems can be dealt with under the nuisance provisions of the Public Health Act. The unfortunate consequence of this opinion is that residential development is permitted next to existing odour emitters with the results that when complaint is received and the person responsible for the emission is approached then he or she vigorously argues that the Council is at fault for permitting the development. Legally it is no defence to argue that the complainant came to the nuisance but even so the Pollution Control Officer and even judges (Ref 9) can often feel some sympathy with this point of view.

Conditions attached to planning permissions are required to be

1) necessary; 2) relevant to planning 3) relevant to the development; 4) enforceable; 5) reasonable (12).

Many local authorities endeavour to control odorous developments by attaching a condition to the effect that "No fumes or odours shall be emitted from the development, which in the opinion of the Local Planning Authority create a nuisance in the locality". Such wording is unfortunate for in the event of enforcement action it will be necessary to prove nuisance in the same way as required under the Public Health Act and thus there is a difficulty of enforcement. It is preferable to specify the works required to achieve abatement e.g. "Fumes and odours shall be collected and discharged from a chimney of height N metres above ground level"

Planning Permission may be refused to prevent odour problems when a development is:-

(i) a potential odour emitter is near to residential property,
(ii) itself affected by a existing emission of odour.

A developer who considers that planning permission has been unreasonably refused or unreasonable conditions imposed when permission has been granted may appeal and then the Local Planning Authority must be able to give rational grounds for their decision.

2.14 Stopping an Existing Use

A Local Authority has the power under Section 51 of the Town and Country Planning Act 1971 where an existing use gives rise to serious problems to issue a Discontinuance Order when this appears to be expedient to the proper planning of their area. However such an order requires confirmation by the Secretary of State and probably a public inquiry. If successful the Local Authority is required to pay compensation.

2.15 Summary of Statutory Controls of Stench

A local authority has considerable power to control odour emissions from new developments by the use of its planning powers. However the planning responsibilities and public health responsibilities of a Council are separate functions often exercised by different departments of the Council and by Council Officers with different professional disciplines.
Environmental Health Officers or Pollution Control Officers are not expected to understand the legalities of the planning process although they are expected to give their specialist advice to planning officers and close cooperation is certainly necessary if each profession is not to interfere with each others role in improving the environment.

2.16 Local Government Organisation

Local Government Officers such as Planning Officers, Environmental Health Officers or Pollution Control Officers are employed to discharge the day to day duties of a Council and they may have delegated powers to serve legal notices such as abatement or nuisance notices. They have no powers to institute legal proceedings, such as prosecutions or the granting of planning consents. These can only be authorised by Councillors sitting on the appropriate Committees or Sub-Committees of a Council. Council officers may advise the Members verbally or by written report and recommendations but the decision for action can only be taken by elected Members. They are the employers and give instructions to their employees, the Council Officers.

2.17 Other Legal Controls on Odour: "Offensive" Trades

Certain occupations have traditionally been associated with foul smells and since time immemorial have been subject to legal controls. Thus in Roman times trades such as abattoirs, launderers, tanners and soap makers were restricted to certain areas of towns where their emissions caused the least offence. In the UK the Public Health Act of 1875 and 1936 tidied up a number of ancient statutes and enabled Local Authorities to exert considerable control of certain named businesses that might operate in their District. These are the so called "offensive trades" and a list of them is almost a poem of noisome activities.

Offensive trades fall into two categories: those that are declared offensive by statute and those that may be declared offensive by a local authority after confirmation of an order by the Department of Environment.

A Local Authority can control odour emissions from such trades by

1) requiring consent before such a trade can be carried on
2) the making of byelaws to regulate the manner in which such a trade is carried on

The Bye Laws can specify the type of "good housekeeping" required to minimise the generation and emission of bad smells as well as indicating the means by which noxious emissions can be arrested. Any such Bye-Laws have a limited life and lapse after 10 years unless renewed.

The Public Health Legislation for offensive trades has to some extent been superceded by planning legislation which can also specify similar measures as a condition for granting planning permission. However there is a dislike in planning circles to use planning powers where alternative legislation is available although planning can control the siting of offensive trades which Public Health Legislation cannot.

2.18 Cable Burning

Scrap electrical cable is often burnt with the intention of removing insulation and recovering metal, aluminium, copper and lead. If this is done without proper pollution control then this activity becomes the source of obnoxious odours. Section 78(i) of the Control of Pollution Act 1974 makes it an offence to carry out cable burning unless it is done in a place registered under the 1906 Alkali Etc. Works Regulation Act. Since 1984 prosecution of persons committing this offence has become the responsibility of Local Authorities.

2.19 Clean Air Acts of 1956 and 1968

Local Authorities have considerable powers under these Acts to control emissions from combustion processes by:

1) Witholding approval from industrial furnaces which in the opinion of a Local Authority cannot operate continuously without emitting smoke.
2) Prosecuting the occupier of a building who allows dark smoke to be emitted from a chimney.
3) Approving the height of chimneys that are of sufficient height to prevent their emissions becoming prejudicial to health or a nuisance and prosecuting the occupier of a building who uses a chimney not approved by a local authority.
4) Prosecuting occupiers of industrial or trade premises that emit dark smoke.
5) Abating smoke nuisances by a procedure derived from the nuisance provisions of the PHA 1936 but domestic chimneys are exempt.
6) Creating Smoke Control Areas in which smoke from domestic

premises is closely controlled, while that of industrial premises is rigorously controlled although exemption for certain industrial premises may be obtained.

Noxious odours are often associated with combustion processes when these are inefficient or if fuels containing substantial amounts of sulphur are burnt. These can be eliminated by efficient combustion and emitting flue gases from tall chimneys so allowing effective atmospheric dispersion to take place.

The Clean Air Acts also permit Local Authorities to control the height of chimneys not serving furnaces but which emit gases that are capable of causing nuisance. These can include exhaust stacks from ventilation systems serving garages, paint spray booths and restaurants.

2.20 Chimney Height Calculations: The role of Mathematical Modelling

Dispersal of chimney gases in the atmosphere is a well researched subject and there is a considerable theoretical understanding that enables simple mathematical models to be used to calculate effective chimney heights. The most common of these used by local authorities are contained in the chimney height memorandum, 3rd Edition, 1981 (13) published by the Department of the Environment, which is based on the sulphur content of the fuel burnt in a furnace. Alternatively if the substance emitted is not sulphur dioxide then a simple expression that is a approximation of equations derived by Sutton (14) can be used so that

$$H^2 = \frac{9M}{20P}$$

where H is the effective chimney height, P is the max. 3 in ground level concentration in mg/m^3 taken to be 1/30th of an occupational exposure limit, and M is the mass rate of emission of pollutant in kg/day.

If the odour of the flue gases is not caused by a single odorant but is the overall perception of an undefined chemical mixture, and is thus a stench, then a chimney height can be calculated by a formula deduced by workers at the Warren Spring Laboratory (6) so that

$$H_e=(0.1DF)^{0.5}$$

where D is the number of dilutions to detection threshold of the flue gases F is the volume flow of gaes, and H_e is the effective chimney height. The effective chimney height is composed of both the structure of the chimney plus any additional rise in a plume brought about by momentum in the ejected gases and any thermal bouyancy that a heat emission may possess.

2.21 Summary. Clean Air Legislation

There is little doubt that this legislation is a very effective means by which local authorities can control air pollution including that caused by stench. Its success can be largely attributed to the rational basis of the Clean Air legislation which defines those variables that must be considered in giving approval to the Chimney. These are (15):-

a) The purpose of the chimney.

b) Position and description of any nearby buildings.

c) Levels of neighbouring ground.

d) Any other relevant matters.

All these factors with the exception of the catchall (d) are quantified in the chimney height memorandum. For odour however, although the means for effective control is provided, the quantitative element is absent and there seems little possibility that the detectabililty of a stench can be predicted in advance of approval being given. The Warren Spring Laboratory formula certainly attempts to do this but has not the predictability that a sulphur dioxide emission has when the sulphur content of fuel and rate of its burning is known.

CHAPTER 3

3. Case Studies in the control of odour nuisance within the District of the Wrekin

3.1 Introduction

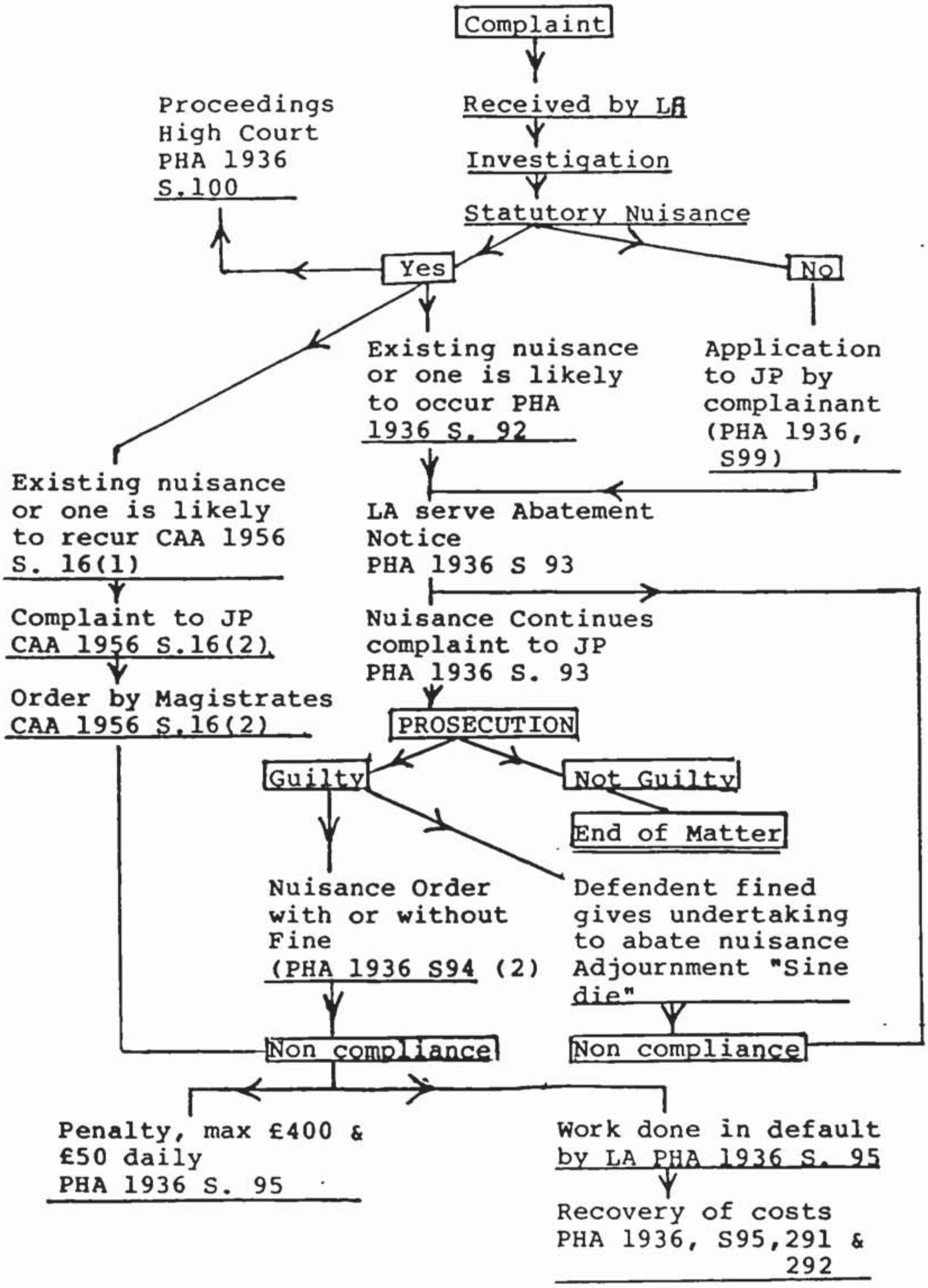
The flow chart (3.1) summarises the procedure required to abate the statutory nuisance due to odour but in practise the application is more complex. Some case studies of odour nuisance will illustrate some practical approaches to the investigation and the abatement of odour nuisances.

3.2 The Informal Approach - The Water Treatment Plant

A factory concerned with the carpet trade opened on an industrial estate in 1974. Part of the process required that rough baled wool from the UK and overseas is washed to free it of dung, dust and grease. Large quantities of warm, detergent laden water are needed and an effluent is generated with a very high BOD which the water authority will only accept into the public sewer at a high cost for treatment. The Company therefore invested in a costly compact water treatment plant enabling them to conserve energy and save water and sewage charges by recirculating cleaned water back into the washing process at the same time recovering wool grease lanolin, which has a commercial value. To do this a compact water treatment plant of 10,000 gallon/hour was installed within the factory building using a plant based on the principle of ultra filtration.

Fig 3.1 Procedures for the Formal Abatement of Odour Nuisance

Note CAA = Clean Air Act
PHA = Public Health Act



The water treatment plant did not function completely satisfactorily and in particular did not achieve its designed throughput so that warm water of a high BOD was retained for longer than anticipated in holding tanks. The operation of wool washing often continued for 24 hours throughout a 5 day working week and at week ends the plant was drained and re-started on Monday with clean water. By Wednesday the water in the holding tanks became septic and headspace gases leaking from tanks, channels and discharge sumps developed a foul smell with a manurial character that caused complaint to the Council from both neighbouring factories and passersby.

This type of complaint, in which a factory complains about another factory, caused the Council some difficulty in taking formal action as before 1982 the most appropriate section of the PHA S.92 (1)(d) required that nuisance be to inhabitants of a neighbourhood and there was considerable doubt that factory employees were such inhabitants. Therefore the problem was tackled by an informal approach to the Company in an effort to obtain their cooperation in eliminating complaint. However in 1982 the legal ambiguity was clarified by the passage of the Local Government Act, 1982 which eliminated the phrase "inhabitants of the neighbourhood" thus allowing factory workers to be complainants".

An early approach by the Council to the Company resulted in a series of meetings over a period of 3 years. These resulted in:-

1. the character of the smell being defined in chemical terms. Thus it was determined that the odorants included

i) Indole and Skatole derived from dung on the fleece

ii) Fatty acids washed from the fleece

iii) Hydrogen sulphide, organic sulphides and mercaptans derived from bacteriological action within septic sewage

2. the use of a centrifuge being discontinued. This apparatus was intended to remove solids from the effluent so reducing the load on the ultra filters but it disturbed the surface of the effluent and encouraged the release of gases. Apparently the increased holding times in the balancing tanks resulting from reduced capacity of the malfunctioning ultrafilter cells, enabled the solids to settle in the tanks so making the centrifuge redundant.

3. the Council's own investigation that found the seals on several inspection pits on the public sewer to be corroded due to the high hydrogen sulphide content in the sewer gas so allowing the release of this in sensitive areas close to several factories. These were replaced and seals renewed.

4. high levels of hydrogen sulphide being detected within the factory, that exceeded the TLV and caused frequent failures in the electrical switch gear controlling the water treatment plant.

5. a decision being taken that at the end of a week's operation the plant would be drained, and disinfected with hypochlorite solutions.

6. the lanolin recovered in the plant had no value and was thus a waste.

Complaints continued to be received by the Council but were sporadic. The late 70's saw a severe recession in the carpet industry at the same time as synthetic fibres were replacing wool in carpet. Thus the wool washing plant seldom operated for more than 2 or 3 days per week so that the circulating water seldom became septic.

In 1981 a further episode of complaints were received by the Council. These were apparently due to experimental oxygen injection into the effluent undertaken by the Company in a further attempt to keep hydrogen sulphide levels under control. However, an inspection by the Council showed the effluent to be black with precipitated iron sulphide and levels of hydrogen sulphide in the headspace of certain tanks and weirs in the washing plant were measured to be several hundreds of parts per million. The Company agreed that the use of oxygen injection was not effective and merely stripped sulphide from the effluent and tended to make the odour problem worse.

The use of hydrogen peroxide addition to the recirculated water had been considered before and the Council took the opportunity to press the Company to experiment with the use of this chemical. The Council had information from a manufacturer that indicated that peroxide would oxidise hydrogen sulphide and organic sulphides to innocuous sulphates when the reagent was added in amounts only slightly in excess of the stoichiometric ratio. The Company agreed to a trial that would demonstrate the effectiveness of peroxide in the control of sulphide without this causing ill effects on the quality of the washed wood. This experiment was successful and consequently chemical dosing was adopted as a permanent feature of the operation of the wool washing plant.

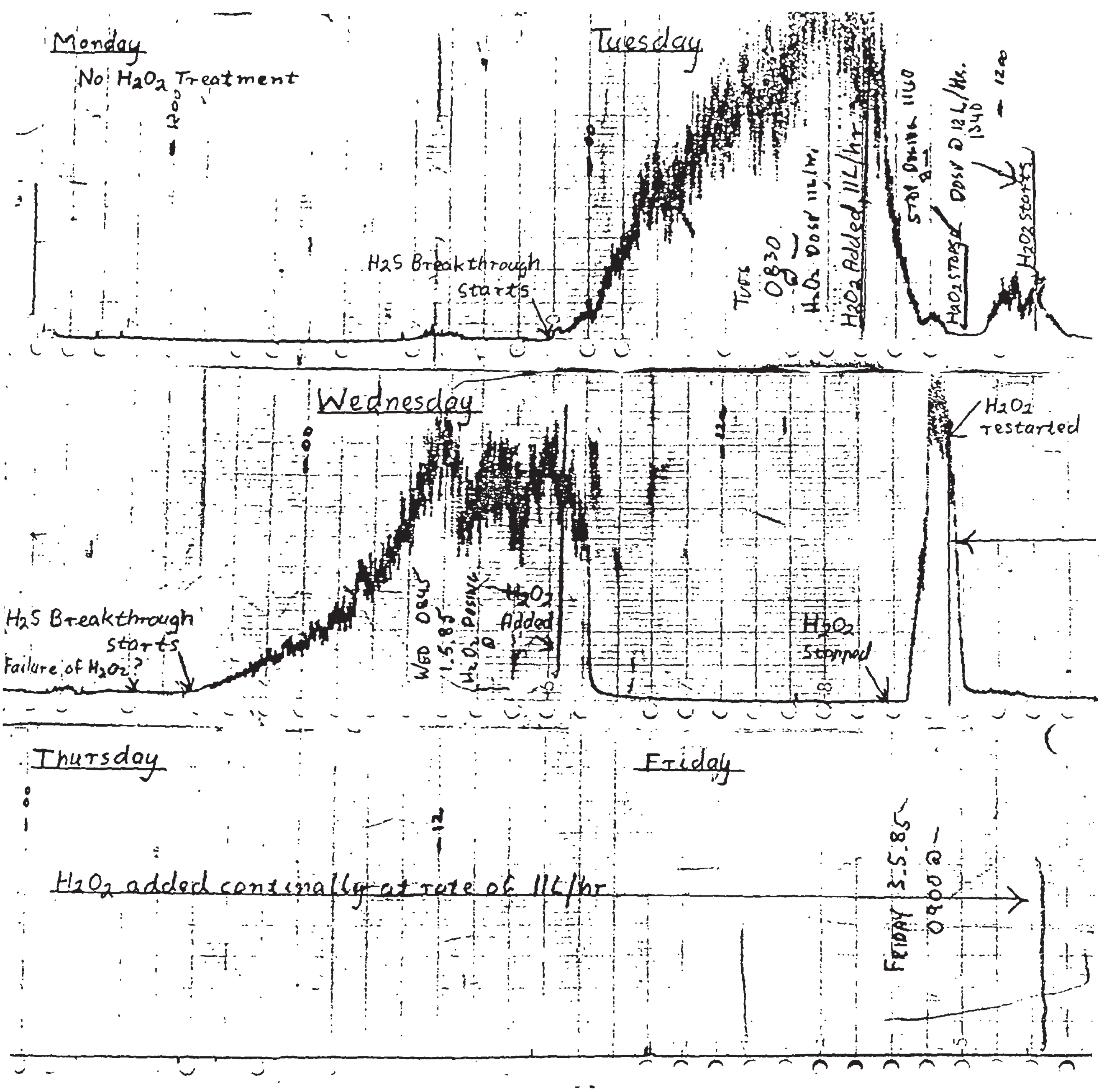
In 1983 there was a further episode of complaint which seems to have been caused by a failure of a plant operative to maintain the dosing of hydrogen peroxide. The Company agreed to improve management of the plant and also indicated their intention to add a sediment tank before the effluent tank so that floccating agent could be added, and precipitated sludge allowed to settle. The ultrafilters could then operate on an effluent reduced in its dissolved solid content. A screen was also incorporated in these improvements so that wool fibres could be removed from the effluent again reducing the load on the ultra-filtration cells.

In the summer of 1985 further complaint was received and the Council took the opportunity of negotiations concerning planning permission for an expansion of the factory to press for the installation of an automated sulphide meter with chart recorder to provide a continuous record of sulphide content in the effluent. Thus peroxide addition should be better controlled with cost savings brought about by more effective use of a costly chemical and reduced effluent treatment costs often charged at punitive rates by the water authority for infringement of discharge consents into a public sewer. A meter was borrowed from the Water Authority and this used to prove the principle of monitoring the onset of septicity in the plant and its control by peroxide addition. Fig 3.2 shows a trace of the chart obtained over 3 days with this instrument and the onset of septicity can be clearly seen to start about 12 hours after the start of the washing plant on a Monday Morning with clean mains water. Within 30 minutes of the start of peroxide addition the sulphide level in the effluent has been reduced to the base line of the instrument and maintained there. However within 3 hours of chemical dosing being stopped the sulphide level is again increasing rapidly until peroxide is again added and again sulphide quickly returns to zero.

No further complaint has been received since installation of this meter so hopefully the odour nuisance is under control. Smells are still apparent about the plant but of lesser intensity and offensiveness. The factory management has also gained sufficient confidence in the system to operate the treatment plant with the external doors of the plant room closed. In the past these have had to be kept open to provide sufficient ventilation to disperse toxic levels of hydrogen sulphide. The next step the Council would like the factory to adopt is to ventilate the plant room with a fan discharging to a chimney so improving dispersal of the

Fig 3.2 Effect of Hydrogen Peroxide in the control of sulphide in Wool Wash Effluent

Note. Meter is measuring H_2S in the Headspace of a sealed inspection chamber
Pulsation in the trace is caused foaming on the water surface



residual odour.

No doubt complaint will be received whenever there is a failure to add peroxide and if this occurs the Council will press the Company to adopt automatic addition of peroxide to the effluent via a pump triggered directly by a signal from the sulphide meter whenever a set level of sulphide is exceeded. At present the peroxide dosing is manually controlled by the works chemist by frequent observation of the meter.

This case study demonstrates the strengths and weaknesses of informal proceedings. Without resort to legal proceeding there is no need to organise reluctant witnesses or serve a notice detailing work of sometimes dubious efficency. Good relationships can be maintained between the Council and Local industry and the cooperation may assist with experimentation and the adoption of new methods of control when these become apparent. However the length of time is often considerable, in this case 10 years, and complainants may become impatient with an apparent lack of progress. Council officers may also have to spend much more time over a period of years in negotiation, inspection and research of the problem than in the short intense period of work required to prove nuisance in formal proceedings.

3.3 The Formal Approach - The Village Silage Clamp

During September a complaint was received from the Clerk of a Parish Council of a village in a rural area of the Council

District that concerned foul smells affecting residents that were emitted from a silage clamp in the village centre.

Silage is winter feed for cattle consisting of fermented grass. The grass should be cut in swathes during the morning of a fine summer day and allowed to wither for a few hours before being loaded into carts. The opportunity is taken at this stage to dose the crop with formic acid to control the subsequent fermentation. The cuttings are arranged in a pile 2 or 3 metres deep, gently compacted and closely covered with heavy polythene sheeting. It is very important to the final quality of the crop that air is excluded during fermentation so the sheeting is well weighted down to eliminate the access of air. During fermentation a very large quantity of dark coloured leachate is formed rich in sugars, proteins and organic acids. This is highly odorous and with a very high BOD has a great potential of water pollution. The Agriculture Advisory Service (ADAS) has a recommended method of silage making and silage clamp construction in which a drainage system and cess pit is constructed to intercept and collect the leachate. This can be disposed of by feeding the nutrious liquor to livestock or spreading on to farmland at places distant from water courses and habitation.

Investigation of the complaint revealed that the offending silage clamp had been constructed within an old dutch barn with a leaky roof and partially walled with railway sleepers. The polythene cover had been weighed down with a generous covering of farmyard manure. No drains had been constructed so that the silage leachate and rainwater run off polluted with manure had seeped through the retaining walls of the clamp, to saturate the surrounding ground and form deep puddles in the rut of tractor tyres. Swarms of cluster flies and midges were feeding on the liquor and breeding in the mud which evolved a powerful putrid odour particularly when warmed in the hot late summer sun. Surplus leachate was also overflowing into an adjacent public road and was draining into a road gulley.

Within a 100 yard radius of the clamp where the smell was apparent there was at least 5 households prepared to give evidence of nuisance. An ADAS publication was available that gave guidelines for satisfactory silage clamp construction and these had not been adopted in the offending clamp. Even well constructed clamps with a proper fermentation can release foul "cheesy" odours when they are broken open in the winter and should the fermentation go wrong then foul stenches accompany both the fermentation and opening of the clamp, thus the site so close to the village centre was inapproprite.

It was decided to serve notice on the farmer to abate the nuisance and the Council Solicitor advised the service of 2 notices. One under the Public Health Act 1936, S. 92 (2) for premises kept in such a state as to be a nuisance and requiring that a drain be constructed about three sides of the clamp connected to a sump. The sump to be pumped out as often as necessary to prevent nuisance and also all depressions about the clamp to be filled in. A period of 28 days was permitted for compliance. This notice was intended to eliminate the immediate problem.

A second notice was served under the Public Health Recurring Nuisances Act 1969 and was intended to provide a permanent solution by securing removal of the clamp as part of the normal course of events and prohibit the building of a new clamp on the same site during the next summer. Thus the notice required that the building shown on a map should cease to be used for the production and storage of silage and a period of 9 months was permitted for compliance.

This formal approach to the odour problem appears to have been entirely successful. There was no appeal; the PHA Notice was fully complied with, and the complainants were satisfied. There has been no recurrence of the problem in the four years since the notice was served. The recurring nuisances notice has not been complied with but it remains valid and can be invoked should any further complaint be forthcoming. The trouble free application of law in this instance probably lies in the vigour of the community response within a small village which undoubtedly embarrassed the farmer, and the obvious practicality of the required work based upon ADAS Advice.

3.4 The Unsuccessful Prosecution - The Foundry

In 1979 the Wrekin Council received complaints from residents of a big new housing estate on the south of the Council District that they were being annoyed by smoke and fume from a neighbouring Iron Foundry that lay within a newly created Smoke Control Area.

The foundry occupied a site of about 21 acres along the floor of a shallow valley with steep well wooded sides. The valley is orientated along a North-South axis, with the south opening to level ground occupied by a New Town Corporation Industrial Estate and beyond that an old established residential area. To the North the valley is closed by the embankment of a new road and beyond that a New Town Corporation housing estate where the complainants lived.

The foundry was the present day successor of an iron industry that had existed on the site for 200 years. At the time of the complaints it had just been purchased by an American based international company and was used solely to manufacture castings for electrical power lines. The new owners had invested heaviliy in new semi automatic plant to prepare sand moulds bound into a solid mass by a resin cured by amine injection. Iron was melted in one of a pair of 8 tonne an hour capacity cupolas which had been exempted from the full rigour of Smoke Control Legislation subject to certain conditions. Each cupola was fitted with a wet arrestor. The castings were finally galvanised in a plant close to the northern boundary in a process using hand dipping and hand fluxing with sawdust and ammonium chloride.

Consultation between the Council and the Company started immediately with the initial object of ensuring that the cupolas complied with the conditions of the Smoke Control exemption order. Complaints however continued and in 1981 systematic observations revealed that the complainants were most troubled by smell although annoyance was also expressed about a visible emission of occasionally evil smelling fog that blanketed the area and caused police to express concern about poor visibility creating a traffic hazard.

Three distinct smells were apparent:-

i. A fishy smell of amine escaping from the sand moulding plant.
ii. A smoky smell due to cupola emission.
iii. A sharp acrid smell due to the galvanising emission often accompanied by the taste of salt on the lips.

After many consultations during 1981 and 1982 the amine smell no longer caused complaint. Control was achieved by careful housekeeping, care in disposal of empty drums and more effective use of gas fired afterburners already attached to the sand moulding plant. However in a period of one year between September 1981 and September 1982, over 100 complaints of smell and a petition signed by 71 residents had been received by the Council. Research by the Council had also revealed that there was a practical method of arrestment for galvanising emission, consequently a decision was made to serve an abatement notice under the PHA 1936 S92(c) for nuisance caused by effluvia, a procedure which permits the defence of best practical means.

The Notice specified 4 sources of odour being

i. The Moulding Plant.

ii. The Cold Blast Cupolas.

iii. The Galvanising Plant.

iv. Other sources.

The works required to eliminate the smell from each process given in the same order were:-

a. To use after burners fitted to the moulding plant is an effective manner.
b. To use after burners in the cupola which were also required for exemption from the Smoke Control Order.
c. To scrub or filter the air extracted from the galvanising plant.
d. Abate the nuisance by any other suitable and effective means. (A catch all phrase giving the Company the opportunity to comply by any means they may wish provided it is effective).

A period of 6 months was specified for compliance.

The Council hoped that the Foundry would use irrigated candle filters, a process developed by I.C.I. and Monsanto to treat troublesome acid mists. This had the advantage of high efficiency for submicron particles, continuous operation and compact size. The Council eventually persuaded the Foundry to operate a pilot plant lent by a manufacturer and on site testing suggested efficiencies of greater than 95% could be expected for the galvanising fume, although the cost would be £35,000. This should be compared to the £2 million spent on capital improvements in the production methods in the foundry.

Shortly after service of the notice the New Town Development Corporation intervened with a suggestion that the foundry was in financial difficulties and that Corporation attempts to preserve the Company were being jeopardised if the Council continued to press nuisance proceedings. This development caused the Council to review the evidence available and strengthen some points that seemed weak to ensure that if legal proceeding were undertaken then the Council statutory duties to abate nuisance could be clearly demonstrated.

If nuisance continues after expiration of the period specified in the Notice the Council must lay a complaint before the local magistrates within 6 months. However before this happens the Elected Members sitting on the appropriate Council Sub-Committee must instruct their officers to take the necessary proceedings. Such instructions were received to prosecute for nuisance due to odorous emissions from the galvanising plant.

A date was set aside at the local magistrates court to hear the case and there followed a series of six adjournments requested by the Foundry so that they could experiment with a low fuming flux that could abate the galvanising fume emissions. These were successful in reducing the emission but were unacceptable to the

Foundry because of the increased reject rate of poorly galvanised components. The case was finally arranged for a 2 day hearing in June 1983 which was an awkward date for a Local Council as it included the day of a General Election.

The Council presented 9 witnesses to support its case. Of these 6 were local residents who gave evidence of how the smell effected their normal way of life. Of the remaining three, one was a technical officer of the Company who manufactured the candle filter who could report on the experiments he conducted with such a filter on the Foundry premises. The remaining 2 were Council Officers, one to give evidence that the proper proceedings had been followed in bringing the case, and the other to inform the Court of the properties of the emission, the frequency with which it occurred and the effects it had on the area it covered.

The Company presented 3 witnesses in its defence. The works engineer outlined the galvanising process. He suggested that the use of low fuming flux during starting up of the galvanising plant when the week's work began on a Sunday night had ameliorated the worst fogs formed when excess flux was used to condition the surface of the metal in the galvanising plant. The Foundry's accountant gave details of the Company's poor financial position and that it was currently trading at a loss. The Company Director stated the difficulties he had of operating the foundry when the Company was under stringent financial control by its American masters so that even the purchase of wheelbarrows had to be sanctioned by telex to the parent Company. He gave his view that although he was sorry for any inconvenience caused to neighbours by his Company's activities nevertheless the foundry provided work in an area of high unemployment and thus, on balance, the local community benefited greatly. If forced to incur any extra cost of pollution control the Company might have to close down, dismiss its employees and thus disadvantage the local economy.

The Magistrates took the opportunity offered by the Foundry Management to inspect the offending plant and observe the emissions for themselves. At the time of this visit the plant was apparently operating normally and although the weather was warm and dry so that the emission was not at its worse, the Magistrates agreed they could detect a faint to moderate smell within the neighbouring housing estate.

The verdict of the Magistrates was that a nuisance had been established but dismissed the summons as in their view the Company had taken steps to reduce and abate the nuisance. Nominal costs of £150 were awarded against the Company.

The Council's Solicitor considered that this decision was flawed as the Company's own proposal to use low burning flux on the first shift of a week should have been made the subject of a nuisance order. Without this order the Foundry could discontinue this practise whenever it wished without penalty. Consequently an appeal was lodged with the High Court but no proceedings followed as within 6 weeks of the Magistrates decision, the foundry closed down. No accusation was levelled at the Council for accelerating this closure by the proceedings that had been taken but rather that the strength of the pound against the dollar had been responsible by making the Company's product non-competitive in export markets.

This case is an example of the difficulties a local authority can experience when it takes formal action to abate a nuisance. The technical problem of specifying suitable works of abatement and the practical problems of establishing evidence of nuisance required a very considerable amount of work and not a little expense to solve. Effective and convincing observations of odour had been presented as evidence and accepted by the Court, and a plant capable of arresting the odorous emission had been located and tested successfully. The major difficulties that defeated the Council were political and legal.

The Councillors agreed to the serving of a Notice under the Public Health Act, S.92(c) to which the defence of BPM is available. The Company invoked this successfully by raising the issue of the socio-economic circumstances of the surrounding district. Curiously the set back was unimportant as the forebodings of closure given by the foundry management in evidence proved correct.

With the benefit of hindsight it became apparent that the Company had drawn up a 5 year trading plan shortly after the American take-over in 1978 and apparently traded according to this until closure in 1983. It took the Council 20 months from service of notice in October 1981 to bring the case to Court due to the Company successfully employing a number of delaying tactics. In particular it appreciated that a local authority must be seen to be reasonable in its negotiations and diligent in the advice it gives so that the Company had everything to gain from being cooperative with the Council, especially as research and development takes time. And when this was complete the law seemed to permit endless adjournments if the defending solicitor asks for extra time to prepare his case. Extension of the period for negotiation and complexity of argument tend to favour the defence, conversely shortness of proceedings and brevity of presentation of evidence favour the prosecution, for the reason that magistrates are lay people trained in summary justice and unused to the technical complexities of technical and economic aguments.

It is interesting to compare the proceedings outlined above taken under the Public Health Act with those taken for noise nuisance under the Control of Pollution Act. The legal principles of nuisance are the same but when an abatement notice is served under the Control of Pollution Act there follows a 28 day period in which a recipient of a notice may appeal and the Local Authority must then defend its notice. This procedure assists in speeding procedures and reducing the time that a nuisance is inflicted upon people, since an appeal causes Council Committee procedures to be by-passed and offers an early opportunity for the case to be presented before a Court.

3.5 The Waste Disposal Site - A successful prosecution

In the south west of the Wrekin District is a large disused quarry which has resulted from open cast coal extraction. It is sited on high ground overlooked by a small community of about 40 households. For about 5 years from 1980 to 1985, this quarry, essentially a hole in the ground, has been used as a privately operated land fill site licensed by the County Council to accept both household refuse and industrial wastes. The method of tipping used was to construct "coffins" that had rolled clay bottoms enclosed by 3 metre high clay walls and tip wastes into these. Bulky wastes were compacted by driving heavy dumpers across it and this was then used as a sponge to soak up offensive or toxic liquid effluents. Finally the coffin is sealed by covering with a thick rolled layer of clay. In the site being considered the depth of the quarry enabled three or four tiers of these "coffins" to be stacked on top of each other.

In May of 1984 complaints were received from residents living along the boundary of the site that they were experiencing foul smells apparently emanating from the waste disposal site. An inspection showed that the walls of the tiers of "coffins" had become unstable and cracked open releasing large quantities of foul smelling leachate that had percolated downwards into a small pool occupying the bottom of the quarry. This had become septic and black with precipitated iron sulphide and was the source of a foul odour akin to decaying cabbage, probably caused by a mixture of mercaptans and organic sulphides.

The Company was advised by the Council to add hydrogen peroxide to the pool. A literature report (15) indicated that tip leachate odours could be controlled by simply drip feeding peroxide to the upward edge of a polluted lagoon so that the diluted peroxide could be carried by the action of wind across the surface of the water. Oxidation of sulphur compounds to inoffensive sulphate was said to be rapid and visibly effective as the black sulphides changed to brown oxides. Some laboratory tests performed by the Council on polluted pool water confirmed the effectiveness of the treatment. Liaison with the County Council Waste Disposal Officer was necessary since the County Council is the waste disposal authority and issued the licence for the site and it was necessary to ensure the proposed treatment would not contravene any condition imposed by the County Council.

The Company bought 1 tonne of liquid hydrogen peroxide in 50 Kilo drums and arranged them about the pool. Taps were fitted and these opened to allow the reagent to drip into the water. Observation from the top of the quarry face showed the peroxide to spread across the pool over a period of about 30 minutes with its progress marked by the ebony appearance of the water turning a muddy brown. The smell diminished and vanished completely when the whole of the pool had been treated.

As the summer continued further complaints were received and it became apparent that the treatment was only temporarily effective. Whenever the Company failed to maintain peroxide dosing, particularly at weekends, the septicity returned and with it the smell.

Confident in the effectiveness of the treatment the Council served a prohibition notice on the Company using provisions of the Recurring Nuisances Act and specifying peroxide treatment as the work required for compliance. This did not stem complaint or prevent lapses in peroxide dosing, consequently a report was made to the appropriate Council Committee who instructed a complaint to be laid before the local magistrates court.

Evidence in the form of written statements was taken from three households who lived adjacent to the landfill site. The Company indicated that they would plead guilty and in due course the case came before the Magistrates.

The defence pleaded guilty but used their right to make a plea of mitigation and produced an expert witness, a consultant chemist. He criticised the Council's preferred method of water treatment suggesting that peroxide treatment was only a palliative measure that although it chemically destroyed the odorants did not prevent the microbiological processes that generated them. The Consultant then outlined a comprehensive range of works that the Company intended to implement. Ditches dug across the collapsed face of coffin tiers would intercept leachates and take them to a sump. The sump and polluted pool would be treated with lime that would increase the pH of the water to a point where the iron salts in the water would be precipitated, the hydrogen sulphide equilibrium shifted towards non-volatile sulphide and the water rendered sterile so preventing the generation of further odorants. The method of water treatment is similar in principle to a well established practice for treatment of sink wastes in emergency circumstances (16). The Council raised no objection and indeed welcomed the employment of a Consultant by the Company.

The verdict of the Magistrates was that a nuisance had occurred and the Company was fined £200 with costs. However instead of giving a nuisance order they decided to adjourn the case "sine die", a procedure in which should a nuisance recur or the work promised not be done then the Council could require the trial to be resumed. This circumstance did not arise as the work was done and no further complaint of nuisance due to odour has been received.

Again this case study indicates how the practise of nuisance control is different to the theory, and how long the legal process takes. Inspite of a swift intervention by the Council and an early successful experiment with a method of odour control, it still took nearly 6 months of fine summer weather with a persistent odour nuisance before the use came to Court and a successful solution implemented. Even with the benefit of hindsight it is difficult to see how the procedure could be made to operate faster. Also it is apparent that magistrates do not seem willing to issue a nuisance notice having accepted that a public nuisance exists while the level of fines also seems relatively low compared with other infringements of the law enforced by a Council. Food, Health and Safety and water pollution incidents often incur much more penalties than does Public Nuisance.

3.6 The Use of Clean Air Acts : The Straw Burning Furnace

During the past few years the cereal harvest of the UK has increased enormously from 7.7 million tonnes in 1961 to 19.5 million in 1981 (17) as a result of increases in both yield and area under crop. At the same time the traditional uses for straw has decreased as livestock number have declined thus there is a great surplus of straw. Much of this waste has been burnt as it lay in the field after harvest, some 6 million tonnes in 1981. The smoke, smell, and ash that results from this practise has been the cause for considerable public complaint and there has been great effort to find alternative uses for this straw. One obvious use is to burn the straw in boilers to provide hot water for domestic and agriculture purposes. However although highly combustible straw is difficult to burn efficiently.

In the early summer of 1985 the Council received complaint from a resident living in a rural area of smoke and smell coming from a straw burning appliance newly installed at a nearby farmhouse. The farmer was approached and asked to submit an application for approval of the furnace and chimney height as required by the Clean Air Acts of 1956 and 1968. The farmer put the matter into the hands of the local branch of the NFU so that subsequent negotiations were conducted between the Council, the NFU, the farmer, and the boiler manufacturer.

When the application was received it was apparent that an offence had been committed as a developer is required to inform the local authority of the intent to install a furnace, except if it is an appliance intended only for domestic purposes and rated at less than 55,000 BTU. The straw burner was certainly rated in excess of this and although it met a domestic load, it was intended to be used eventually to heat a potato cutting building. However this is a technical offence and it is normal for the Council not to prosecute but to invite a retrospective application and take action only if this is not received.

The next issue to be resolved was that of chimney height approval under the Clean Air Act, 1968. This is required for chimneys attached to appliances burning more than 100lbs of solid fuel an hour. The rate of fuel burning was not given in the application but can be calculated from the heat output of the boiler and the calorific value of the fuel it burnt. The particular appliance being considered was dual fired, burning both straw and wood, and taking appropriate values for wood then it seemed that chimney height approval was required.

The manufacturer and farmer were informed and an inspection of the appliance was arranged. This revealed the following facts.

1. The straw, required in baled form, would burn satisfactorily if the moisture content was in a range 16 - 20%, attained by

being left to dry in the fields for 2 - 3 summer days after harvest.

2. The furnace was manually stocked by occasional loading with up to 6 bales of straw.

3. Straw is a bulky fuel and the more straw that was loaded in the less was the combustion space.

4. The only air required for combustion was supplied by a forced draught fan.

5. The fan operated at 2 speeds, a timer permitting full blast for up to 20 minutes after loading, and then at low draught until a thermostat on the water side of the boiler sensed high temperature and cut out the fan.

6. At cut out the chemical processes of combustion ceased and those of pyrolysis commenced. These produced large amounts of tars and creosote which were apparent, dripping from seals of the appliance, from the base of the chimney and clogging the air tubes of the boiler.

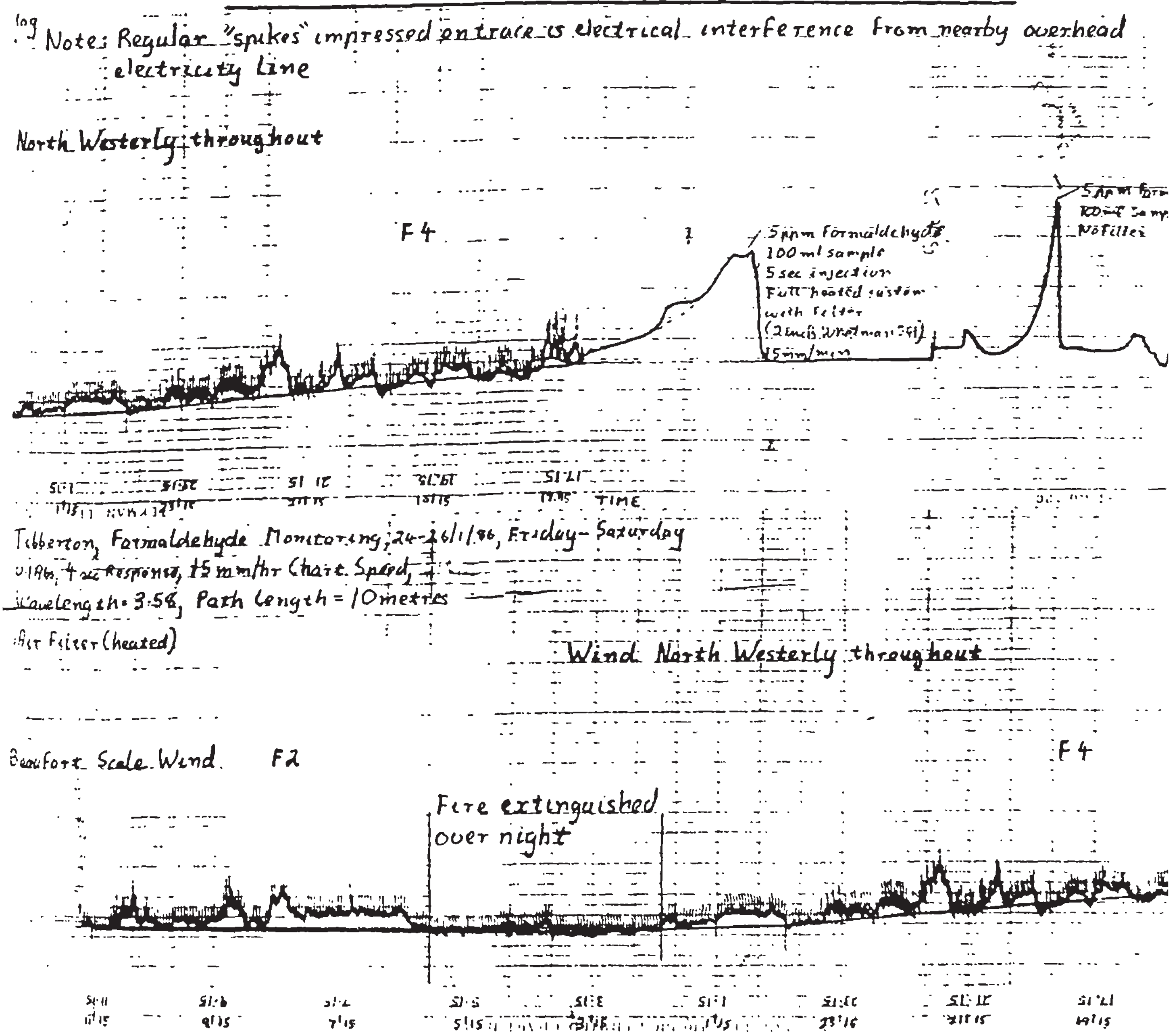
The conclusion of the inspection was that combustion was inefficient, the boiler was overated for the limited domestic load it was connected to, the fuel was out of specification, the appliance poorly maintained and the incorporation of periods of pyrolysis within a fuel cycle permitted episodes of extreme pollution and possibly also hazard. The manufacturer recommends great care in opening the combustion chamber in case of explosion of pyrolysis gases when air is introduced.

A program of maintenance and improvement in design was arranged with the manufacturer before a further inspection was made. On this occasion a higher powered fan had been attached, and an air spreader incorporated within the combustion chamber. These modifications were intended to achieve firstly a better balance between the primary air supply required to keep the fuel burning and the secondary air necessary to burn the volatile substances released as the straw burns. Secondly the secondary air was directed as a jet across the roof of the chamber to increase the turbulence in the combustion space so permitting better mixing between the air and volatile matter to be burnt. The fuel load was also restricted to 3 bales so increasing the combustion space and allowing more time for combustion to occur. These measures were all directed towards improvement in the factors affecting combustion efficiency that are known as the three "T's": Time, Temperature and Turbulence. The manufacturer also cleaned and maintained the appliance, fitted improved thermostatic controls to the water side of the boiler, removed an airlock in the domestic heating circuit and checked straw bales for excess moisture, rejecting those that were out of specification. Observation of chimney emissions over 1 hour of start up from cold and a complete fuel cycle to include a period of pyrolysis showed an improvement in the emission. No dark or coloured smoke was observed and indeed only a minimal smoke emission occurred. Efficient combustion was therefore possible when the appliance had been properly maintained and operated under close supervision.

After this brief testing the Council had to take a decision on approval of the appliance and chimney height. A compromise was reached. The appliance was not approved because of the possibility of pyrolysis and non approval would enable the Council to take nuisance proceedings if complaint warranted abatement action. The chimney, of height 11 metres, was already tall and well constructed and there was no rational argument available to justify an increased height. Therefore the chimney was approved subject to the condition that emissions of formaldehyde and pitch volatiles would not exceed quantities estimated by application of the simple Sutton equation. Measurement, by flue gas analysis was to be made within 3 months of approval.

In January 1986, further complaint of odour nuisance was received due to emissions from this appliance. The critical condition for nuisance appeared to be a strong breeze from the north west therefore when such conditions were forecast an infra red gas analyser was installed on the complainants property. It was tuned to the formaldehyde absorption peak at 3.58 micrometres and calibrated by a injection of a known formaldehyde atmosphere into the sampling part of the instrument. The instrument operated over three days, on two of which the wind blew strongly from the north west. Manual observation at this time confirmed that a strong odour as of a garden bonfire pervaded the complainant's property and over a period of about 9 hours in 24 the average formaldehyde concentrations were in a range 0.5 to 1 ppm. with occasional peaks to 2ppm. The odour threshold is 1 ppm and the industrial TLV level is 2 ppm, therefore it was demonstrated that formaldehyde contributed to the smell apparent on the complainants property and exceeded the commonly accepted criteria for community exposure which is usually set at 1/30 or 1/40 of the industrial TLV value. A copy of the chart recording is shown below and provides an objective support to the complaints allegations.

Fig 3.3 Chart Record of Air Pollution due to Formaldehyde in the Plume of a Straw Burning Furnace



A further episode of complaint occurred after chimney height was given and the following inspection of the appliance showed that its grate had distorted in the heat of the furnace. This resulted in the balance between the secondary and primary combustion air being disturbed consequently combustion efficiency was reduced and noxious substances appeared in the flu gas. A new grate was fitted with an immediate improvement in the quality of emission.

This case illustrates how a local authority may use its powers under the Clean Air Acts to put pressure on manufacturers and owners of appliances to improve the design and operation of furnaces so reducing emissions of the offensive products of incomplete combustion such as smoke and odorants.

Such pressure is necessary for a fuel such as straw that is an agricultural waste readily available to farmers for only the cost of collection. As a waste is being burnt there is no financial incentive to achieve efficient combustion consequently pollution control legislation has to be employed to resolve complaints of nuisance.

The use of straw as a fuel is so novel that no standard text book of fuel technology gives details of its characteristics as a fuel. However it can be said to have a low sulphur, hydrocarbon composition that has a low calorific value although easily combustible. In theory it should burn completely to give only inoffensive compounds of carbon dioxide and water. In practise the heat degrades the chemical structure to give large amounts of a mixture of numerous chemicals. Some idea of the substances present in the emission from a straw burner can be guaged from work done on the chemical composition of the extremely offensive smoke from the burning of straw in fields after harvest. (17)

3.7 Conclusion

These case studies have been included in this thesis to give examples of the type of odour nuisance encountered within a local authority. They are intended to indicate the amount of work required to investigate a complaint and indicates the effort that is necessary to add flesh to the skeleton of the flow diagram that depicts the legal procedures. Successful resolution of odour nuisance is a team effort in which complainants and Local Government Officers work together in order to press home upon the person responsible for an odour a need to tackle the problem, either by cooperation or coercion through resort to legal procedures.

CHAPTER 4

4. Public Complaint

4.1 Introduction

Odour pollution is sensory pollution that effects the human perception of the surrounding environment. Unwanted, intrusive smells imposed upon people cause first annoyance and eventually anger and at some point in this progression the individual's threshold of tolerance is passed so that there is motivation to do something about removing the offending smell. This may take the form of a complaint to the person responsible for the smell and then if nothing is done, to the local authority.

There are a number of steps in this sequence of events that are uncertain so that public complaint is an unreliable indicator of the amount of annoyance caused by any incident of odour nuisance. A casual analysis of the factors that lead to public complaint demonstrate

1. What is an unpleasant smell?
2. What amount of it becomes unacceptable?
3. What level of individual tolerance has to be reached before a complaint is needed?
4. To whom is the complaint made?
5. How is the complaint made?
6. What is the probability that the authorised council officer receives the complaint?
7. What criteria are used to register a complaint?

These will be discussed in turn.

4.2 Unpleasantness of Smell

This matter will be discussed in more detail later in this thesis but there is a common concensus amongst local government officers that the following common activities have a great potential for causing complaint.

Fish frying, exotic food restaurants, intensive livestock and poultry rearing, pig breeding, sewage effluent disposal, paint spraying, foundry emissions, maggot breeding, animal by-product processing, abbattoirs, refuse tips, animal feed manufacture, chemical plants, coach or bus depots, garden bonfires, and silage clamps.

The range of smells produced by these activities is very wide and at first sight it may seem surprising to compare the aroma of an Indian curry restaurant with the stink of putrification from a maggot breeding establishment, but each can generate vigorous complaint.

A recent and comprehensive list of odour sources and the number of complaints they have caused has been compiled by Denise Artis (3) from a questionnaire sent to 65 local authorities. Even in an exercise directly concerned with odour some indication of the unreliability of public complaint is evident. Many complaints are quantified as greater than a given number and some are subjectively reported merely as "few" or "some". Only 2 authorities reported complaint of smell from drains although all must have received dozens of these per year. However these are more likely to be classified as a drainage complaint rather than an odour complaint. Thus, complaints are likely to be under reported and misclassified.

4.3 Acceptable Dose

It is reasonable to assume that people will accept a more frequent exposure to a normally pleasant smell, perhaps cooking aromas, than to a foul smell, from manure spreading. Similarly strong smells are likely to be less acceptable than weak smells. Even so, the acceptability of many smells are difficult to assess especially for simple, olfactory neutral chemical odorants such as styrene from glass fibre resin moulding while a weak smell can be just as offensive as a strong odour if it draws attention to a socially unacceptable smell such as sewage treatment. At present there is no statutory dose limit for smell nor are there any guidelines or Codes of Practice that can give guidance. Each complaint of odour nuisance must therefore be considered on its merits. One day of foul smell in a year would be unlikely to justify legal action, and the case would still be weak if the frequency of stench was once a month, but 12 times a year with several outbreaks each lasting several days might well justify the service of an abatement notice.

4.4 Individual Tolerance

Anybody receiving and investigating public complaint soon becomes aware of the unpredictability of the stimulus response relationship in this field.

In general most people are tolerant and are reluctant "to make a fuss" even in circumstances where such action is justifiable. While some people will never, under any circumstances, involve themselves in public action, yet others need little prompting to make their views known. Every local authority must have a few residents who are considered to be professional complainants who seem to sieze upon any issue to draw attention to themselves.

Research into noise nuisance (18) has indicated that about 20% of the population are sensitive to noise, about 30% are not bothered at all with the remaining fraction presumably lying in the middle ground between these extremes. This work suggested that a population exposed to a sensory pollutant cannot be treated as a homogenous group since several distinct behaviour patterns are apparent. There is a wide range of susceptibility to noise nuisance and individual annoyance correlates poorly with objectively measured noise levels. (19) Noise, like odour, a is sensory pollutant and thus the behaviour of a population is likely to be similar in for both senses.

Socio-economic factors can have a great effect on the level of public complaint. Thus private householders with a financial stake in their community tend to be more vocal than public housing tenants who may be able to remove themselves from a problem without great financial inconvenience. Highly educated complainants tend to press their complaint more effectively, while communities economically strongly dependent on a polluting industry have a remarkable tolerance to a poor environment. However many exceptions to these rules can occur and circumstances such as the presence of a well organised Residents Association can effectively mobilise a high level of complaint for low levels of exposure to odour. Indeed one problem of public complaint is that complainants tend to raise a spectrum of complaint with odour as only one facet of a larger problem.

Some research has been published into the influence of socio-economic factors such as age, education and economic dependence on the pollution on a community tolerance of sensory air pollution in particular a paper by Creer, Gray and Treshow (20) They demonstrated the validity of the very reasonable hypothesis that "individuals who are highly dependent economically on a source of air pollution do tend to perceive a pollution problem as being relatively less serious with a greater amount of effort being made to control it than do their counterparts."

4.5 Public knowledge of Pollution Enforcement

Effective pollution enforcement by a local authority is dependent upon public complaint being received. A Pollution Control

Officer may be aware of a nuisance in his or her locality but without receipt of a complaint enforcement action is unlikely to be effective. A door to door survey could be done to elicit complaint but this is rarely attempted due to the opinion that such action would be destructive to the relationship between a Council and its local industry as soliciting complaint would likely to be regarded as harassment by the factory being targeted.

A member of the public wishing to make a complaint about pollution to an enforcing authority could face a formidable problem. The motivation to complain is probably strongest when pollution is present and then may fade rapidly with the passing of time. As Local Authorities are only open to receive complaint during normal office hours, Monday to Fridays, then pollution occurring at night and during week-ends is probably under recorded. A complainant must also have a means of passing his complaint to the Council, thus access to a convenient telephone will assist in making effective complaint as verbal communication with an enforcement officer is quickly achieved and there is a good possibility of an investigation starting within minutes. Letters, visits in person to council offices and passing complaint via a Councillor will achieve a response but obviously after a period of delay when memory of the annoyance suffered and details of facts have faded.

Having been motivated and having chosen the means of communication, a complainant must then find the correct person to investigate the complaint. This is a formidable bureaucratic hurdle as pollution control in the UK is not centralised or has a unified structure. Local Government, at County or District Council level, and Central Government have distinct and separate roles defined by statute. Public Health and Clean Air Legislation, of major importance to control of odour, is enforced at District or Metropolitan Council level which is the tier of government in closest contact with local populace. It lacks any common structure so that Departmental Organisation varies to suit local circumstances. Public Health is usually the responsibility of an Environmental Health Department and legislation is enforced by Environmental Health Officers who have responsibilities in the fields of food hygiene, health and safety, housing, waste collection and licensing. The term "pollution control officer" is not a common Local Government term but has been used in this thesis for its convenience.

Without specific knowledge then a complainant may contact the police, the Citizens Advice Bureau, the rent collector, the local councillor, a Council Information Centre, The Council receptionist or switchboard operator, all of whom have no specific duty to investigate the complaint. Alternatively the Government Air Pollution Inspectorate may be contacted who, if they do not have jurisdiction, will certainly forward the complaint to the Environmental Health Department of the appropriate Council who normally exercise the statutory duty of pollution control but again delay is inevitable.

The Wrekin District Council is unusual in not having a specific Environmental Health Department and the public health function normally concentrated in this Department is shared among 5 other departments. Air Pollution Control is assigned to a specialist section in the Environmental Service Arm of the Planning and Environmental Services Department, which may not be immediately identifiable to the general public as the Department with responsibilities in Pollution Control.

4.6 Probability of Receipt of Complaint

Each link in this chain of events has to be completed before a complainant contacts a Pollution Control Officer and a certain degree of persistance is necessary before a formal complaint is registered. The difficulties have probably been overrated but clearly the dose/response or annoyance/complaint function is certainly not going to be a simple one with so many steps in the procedure. The probability of a Pollution Control Officer becoming aware of a nuisance in his area is likely to be high but the severity of a nuisance may not be easily gauged by the number of complaints received.

4.7 Criteria for Registering a Complaint

A Council officer is often asked how many complaints of nuisance he has received. A precise answer is not as easy to give as it may seem. For instance if a smell occurs on a Thursday and a Friday then a complainant may phone in each day and so two complaints are received. If the smell occurs on a Saturday or Sunday then the complaint may be made on a Monday and thus only one complaint is registered. Similarly many days of a persistant smell may be reported in a letter and again only one complaint is apparent.

Council organisation can also effect the numbers of complaints. Sometimes a receptionist may take all incoming calls and redirect them to the appropriate officer making a note of the complaint in the process. Thus a single criterion is used to classify complaint. More often the Council officer directly takes the call and as several officers may share the responsibility of pollution control, each may use a different criterion in making a decision to note the complaint.

For instance a complainant may complain about a neighbour's garden bonfire. This would be classified as a smoke nuisance, or a smell nuisance or, if it is a once a year problem, not a nuisance at all and the complaint not recorded. In a crowded environment some degree of give and take is necesary and many problems are best sorted out between neighbours without involving officialdom, so that Council Officers will often try to resolve complaints informally by giving advice and not recording the complaint. The complainant is advised to attempt to resolve the problem for themselves and return if the approach is rebuffed with a completed diary recording the periods of annoyance. Thus recorded complaints are likely to have substance.

4.8 Summary and Conclusion

The following statement appears in a report by two Swedish workers who have researched the subject of public complaint and their views are:-

"In general very few people will register a formal complaint with the authorities about environmental problems. In Swedish, British and American annoyance surveys, less than 10% of the population reported any formal complaint by writing letters, telephoning or making personal visits to officials. In British and American surveys only 20 - 23% of those who felt they had a serious local problem ever felt like calling or writing to an official. In contrast reports of annoyance in these surveys showed that only a small fraction of those who actually report annoyance take action in any spontaneous way. A study of annoyance to aircraft noise showed that the main characteristics of individuals discriminating complainants from non-complainants were those of education; value of property; and membership in organisations. Thus the volume of complaint received by officials may reflect not so much the amount of discomfort experienced by the exposed population as its social class composition and level of community organisation." (21)

CHAPTER 5

5. Clarenburg's Model of Odour Nuisance. Penalisation of the Environment due to Stench

5.1 Introduction

The argument so far presented is that the dose-response function for odour nuisance is indeterminate because of the uncertainties in the processes that lead to a complaint being received by a local authority. However, this may be a result of a haphazard system of complaint and a simple, easily used and convenient method of communicating with an authority may yield better defined pattern of complaint. The work of Clarenburg suggests that such is the case and his paper (21) is worthwhile studying in some detail.

Clarenburg's approach to odour pollution is rooted in the concept of public health with health being defined according to the World Health Organisation as being a condition of physical, mental and social well being. "Stench" was held to be a "mental irritant" that violates mental well being. Such problems might be best controlled by regional planning once reliable methods had been developed to set a control limit for odour emission. Clarenburg did not base his approach to quantification of odour nuisance upon laboratory based studies but on the pattern of complaint downwind of an emitter.

5.2 The Mathematical Model

The mathematical model that is developed uses several novel concepts that Clarenburg defines in considerable detail thus:

"Penalisation of the environment due to stench in an area is equal to the proportion of the population, living in that area, capable of perceiving it."

"Penalisation" refers to a group of individuals within a population who are "bothered by" a smell.

"The environment" is a limited area considered over a long period of time, arbitarily considered to be a year so that short term fluctuations in penalisation caused by meterological conditions can be averaged.

The "area" mentioned is one of limited dimensions.

The mathematical model of this concept combines two other models. One of atmosphere dispersion enabling the concentration of a pollutant to be calculated at a distance downwind of an emitter. The other is a statistical distribution of the range of sensitivity towards a smell that can be expected within the general population. The result of this combination is a mathematical statement of the dose-response relationship for odour nuisance in which a fraction of a population perceiving an odour can be calculated provided that the appropriate variables can be quantified. A graph can then be constructed for any specific situation so that penalisation is plotted along one axis and downwind distance from source along the other.

Clarenburg was not content to merely propose a theory of odour nuisance but he continued with work directed towards verifying his model by demonstrating its application in several practical situations. He drew on data provided by a central complaint office organised by his employing Authority, Rijmond which is a Authority with a large petro-chemical industry. A telephone complaint system operated which recorded 31,000 calls in 1971. However door to door surveys were done where necessary so that 5 further cities were used as suitable subjects for investigation. These included a point source as well as area sources, multiple sources as well as single sources and a range of odorous industries including refineries, bitumen coating plants, rendering plants, and fertilizer works, open areas and complex terrain, and communities of different socio-economic status. However Rijmond and its chemical industry provided the data for the experimental work which was extended and confidence in the method gained by its application elsewhere. Correlation between predicted complaint and observed complaint was always good if not excellent with the minimum correlation co-efficient being 0.6 and the maximum 0.996 inspite of socio-economic correction factors being introduced to account for accessibility to telephones and the tolerance level of the population. This last factor, Clarenburg observed, seemed significantly higher in communities that had strong economic ties with industry than in those without such a relationship, which is the conclusion to be expected by sociological research done in the USA (20).

In discussion of his work Clarenburg drew attention to a useful property of two parameters used in his model. One of these is called "the odour characteristic" and is defined as the geometric standard deviation of the distribution of odour sensitivity within a population. It is determined by laboratory studies using a panel of observers. The second is called "the odour nuisance parameter" which is a unitless value of a mathematical relationship between the odour characteristic and the threshold distance. This is the distance downwind of a source where odour has been dispersed to such an extent that it can no longer be perceived. Perception has a strongly individualistic quality therefore Clarenburg defines it in statistical terms as being the value selected to cut off a given fraction of the population into the tail of the statistical distribution of odour sensitivities of a population. Neither parameter is thus simple to define. Their advantage is that if two of the three parameters, being nuisance parameter, odour nuisance parameter, odour character and threshold distance, are known then the third can be calculated.

An unexpected generality Clarenburg found was in the somewhat arbitary values he assigned to odour/parameter and odour characteristic that were adequate to describe five very different situations so demonstrating that the specific model developed for Rjmond seemed to have general application. Thus it may be possible to predict the effect of any new industrial complex on the surrounding community without researching the chemistry and olfactory properties of its emissions.

Clarenburg's work is a remarkable application of atmosphere pollution modelling applied to socio-economic problems. The atmosphere dispersal part of the model is a well established method that has an accuracy normally considered to be within a factor of 2 of observed values although recent research suggests that this might be much improved over long averaging periods. The statistical part of the model uses a distribution, the log-normal, that is only tentatively suggested by a few workers on the basis of limited research. Add to these uncertainties the normally crude indices of socio-economic behaviour such as telephone ownership and the output of the model might be expected to be present only a poor guide to the effects of odour pollution. Instead a comparitively simple model predicts human behaviour with remarkable accuracy.

In his paper Clarenburg discusses some possible application of his successful model. Firstly, he suggests that by drawing graphs of penalisation versus distance and setting a standard of penalisation it is possible to define the width of a "cordon sanitaire" about an odorous industrial complex within which residential development should not be permitted. Secondly, the results of abatement action can be monitored independently of changes in tolerance of a population, since the model is able to accurately predict the expected level of penalisation. Thirdly, the model can be developed to set targets for odour reduction for different industries in an industrial zone so that a general penalisation standard can be set for the whole area.

Clarenburg was successful in persuading Rijmond City Council to incorporate his penalisation concept within statute at a value of 30%. Set first in 1972 and again in 1974 it seemed to have a local validity but no other Dutch Authority seems to have adopted a similar approach.

It is surprising, given the stated success of the model, that Clarenburg's work does not receive further reference in any English Language Journal. Neither is there any mention of it in the considerable research into Odour Problems in the UK that commenced with a Working Party Report in 1974, continued with a programme of laboratory investigation done by the Department of Environment and finished with the Publication of a handbook summarising the work in 1982. Possibly the title of the paper "Penalisation of the environment due to Stench" lacks the keywords to attract attention in a literature search. May be a better title would be "Bother caused by Odour Pollution".

5.3 Social Survey

For reasons already discussed spontaneous public complaint cannot be relied upon to indicate a severity of odour nuisance. So instead of waiting for the existence of a nuisance to be brought to its attention, a local authority could consider the alternative technique of going to its residents and asking them for their opinion about the environment they live in. Care must be taken both in the formulation of the questions asked of a householder and in the selection of the particular householders to be interviewed. It is in these matters that the well researched methods of social survey can be of assistance.

Social survey (also called public opinion surveys, attitude surveys, or socioepidemiological survey) have been used to evaluate the views of a community towards morality, easthetics, politics, and commercial products. The results of such investigations influence many aspects of modern democratic society to an extent that few political decisions on the administration of the nation are made without research into the effect on public opinion. However social surveys have not been widely applied to the problems of pollution control by the responsible enforcement authorities. Indeed there is considerable prejudice against this approach which is often equated to soliciting for complaint and a local authority who does this lays itself open to an accusation of harassment of local industry. However there seems not to be any illegality and indeed it is even encouraged by the wording of the Public Health Act which imposes a statutory duty in a local authority to "inspect its district with a view to detecting nuisance".

5.4 Reactions to Social Survey

The reaction of industry towards a specific attitude survey is revealed in a short debate in "Chemistry in Britain" (22) The Managing Director of a Company that was the source of a pollution problem was aware that the Company was the subject of public conern so that "the vast majority of local residents would much prefer that we went elsewhere". However, he went on to state that the Company was "deliberately chosen as a target for the purpose of further sensation of a subject that should only be treated by authoritative bodies in a carefully considered and responsible manner." He was referring to an "attitude survey" carried out in the neighbourhood of his factory by an University Team researching problems of perceived risks in a community. Replying, the superviser of the survey stated (23) ".... the methodical elicitation of views in such a survey might be expected to provide a source of information of possible interest to industry and authority, apart from serving its initial role as an element in a research thesis"

The objectives of an attitude survey must be formulated as on these depends the key element that are population sampling, questionnaire design, (23a) and final analysis. It is not the intention to discuss the methods of social survey in any detail but only to outline the basic considerations.

5.5 Choosing a Survey Area

Obviously there are practical matters to be considered at the outset such as what area is to be covered, how many people are available as interviewers, how much time can be taken for the survey, and how many people in a sample population are to be questioned. Answers to these questions will depend upon the resources available as intensive in depth surveys are extremely costly in terms of manpower.

The area to be investigated can be delineated either by studying the pattern of any complaint received or by strolling through the general area and noting the boundaries within which the odour is perceived although then several visits should be undertaken under different meteorological conditions. The test area should also be large enough to contain the minimal number of people needed to permit adequate analysis of the data, say 20 to 30 households while Topographical features such as embankments, hills, valleys and edges of built up areas may themselves provide tangible boundaries.

With the test area delineated the gross socio-economic characteristics of sub-divisions should be examined. For instance whether there are large estates of private housing, or public housing, newly built estates or more mature areas of housing. These elements are indicators of social homogenity.

The next step is to estimate the number of households in the area which is relatively easily founded by reference to either large scale street maps showing property boundaries or to electoral registers as the magnitude of the task facing the investigator will then become apparent.

5.6 Designing a Survey Questionnaire

A questionnaire can then be designed to obtain the information needed to secure the objective of the survey. An effective questionnaire is not easy to design as there are a number of established formats available, each with recognised strengths and weaknesses and many pitfalls for a novice social surveyor to fall into. Bias can readily be introduced by asking questions that are misunderstood or by posing "leading questions." An unambiguous presentation is important and it is considered good practise to mask the true purpose of the questionnaire so that a more spontaneous reply, considered more reliable, is obtained from a respondant. Many drawbacks can be avoided by employing a professional organisation but this is obviously costly, the objectives may be misinterpreted by the outside organisation, and incidental information gained in a doorstep interview lost to the Council. Obviously the use of a standard format designed by expert, practitioners and administered by a pollution control officer appears to offer a satisfactory procedure in which expertise in different disciplines is shared and knowledge of local circumstances is not lost.

Decisions must be made as to how the questionnaire is to be administered and the protocols to be followed during interviews. Each question has to be considered with respect to its ability to communicate and elicit accurate response. To assist in this, selection may be made from a number of well researched techniques of social survey which are presented in text books of Marketing, Social Science or Psychophysics (23). However a researcher must remember that a door to door survey is an imposition, if a minor one, on the daily business of a householder so that a short explanation of the purpose of the exercise together with a polite invitation to take part is required as in matter of courtesy and will certainly assist in securing cooperation. Brief and simple questions that can be quickly administered on a doorstep in a few minutes will greatly assist in retaining a respondents attention and maintaining accuracy in response.

Once the format of a questionnaire has been finalised it should be checked to ensure its effectiveness by administering it to a small community similar to the one to be tested. This should ensure that there are no unforseen difficulties but if these are detected then these should be eliminated by changes in the design and a further test carried out.

If several interviews are required to administer the survey then it will be necessary to check the overall validity of the response for any sign of bias. This is always possible as a result of inevitable variations in the ability of interviewers to establish a rapport with their respondents. Such difficulties can be detected by reinterviewing a sample of the respondents using a different interviewer. Alternatively a single interviewer could conduct all interviews if this is not too great a task.

5.7 Summary

Public complaint is often a necessary part of pollution control procedures as it demonstrates that abatement of nuisance does benefit the community exposed to it. However it is an unreliable indicator of the effects of pollution as it is the result of a complex response to a dose of pollution which, in the case of stench, is poorly quantified. A more rational approach would use a carefully designed attitude survey of residents living within an area exposed to a pollutant and relating the measured response to a quantified dose of pollutant. This technique has been applied to the setting of environmental noise indices but not yet to similar measures for stench.

Clarenburg, working in Holland, has deduced a very accurate mathematical model of the dose response function for the exposure of a population to an odorous plume of pollution emitted by industrial sources. The output of the model was checked by measurement of public reactions in the forms of both public complaint and attitude surveys. This technique permitted a statutory standard for odour pollution to be set termed a "penalisation function". No such standard appears to have been contemplated in the U.K.

Public complaint will continue to be an essential ingredient of pollution control procedures in any future legislation because the concept of nuisance which it demonstrates is a fundamental principle of British Law. The setting of indices for stench is possible but until convenient methods of quantifying odour exposure become available such measures are unlikely to be created. Very recent advances in the chemical analysis of traces of gaseous pollutants suggest that the invention of an "electronic nose" is feasible and if so it may take its place alongside "noise level" meters as a means of controlling odorous pollution.

CHAPTER 6

6. Qualitative and Quantitative aspects of the Physiology and Psychology of Odour

6.1 The Perception of Odour

So far this thesis has discussed the legal and social dimensions of odour pollution, for these are the human consequences of a problem to which scientific and technical knowledge may provide the means of a pragmatic solution.

6.2 Physiology of Odour

The organ of the body associated with the sense of smell is obviously the nose but this appendage of the face also serves to cleanse, warm and humidify inspired air, thus it functions as an air conditioner protecting the delicate tissues of the lung from damage due to hostile environments, and a dust arrester preventing the ingestion of harmful particles.

Many functional features of olfaction are not yet understood but at least the obvious features of its physiology have been mapped. The nose has two nares or nostrils each opening into separate, symetrically arranged, airways through which inspired air must travel on its way to the lungs, typically at a rate of 0.5 litre per second. However in normal breathing only a small fraction, about 2.5 mls, passes by the olfactory surfaces of the nose, but this increases to 0.1 litre during the act of sniffing in which muscular constriction brings about redirection of air flow through nasal air channels.

Only a small area of the internal surface of the nose is sensitive to odour. This is a yellow patch in each nave about 2.5cm^2 in an area called the olfactory epithelium situated at the top of each nasal cavity immediately under the cerebral cortex. The epithelium comprises of some 10 to 15 million specialised receptors in the form of rods bearing cilia or hairs that project into a specialised mucous secreted by unique glands, called Bowmans. Other cells have muscular hairs that continuously beat to propel the mucous over the ephileum.

6.3 The Mechanism of Olfaction

The mechanism of the olfaction is not yet understood but there are two contending theories that each have merit. Amoore argues (86) that the nature of olfaction is stereochemical with molecules of similar shape fitting into an appropriately shaped site on the surface of receptor cells much as a key fits a lock. As a result of his studies on anosmia, "smell blindness" Amore believes that there are seven primary groups of odourants where one molecule interlocks with one receptor; and an unspecified number of secondary odorants in which a single odorant locks onto and stimulates more than one type of receptor. Wright does not accept this explanation but proposes a "vibrational" theory in which olfaction is induced by certain characteristic low frequency vibrations of an odorant molecules forming a resonant system with a molecule of a receptor cell so triggering response.

Both theories are supported by observations and have been used to predict the olfactory properties of newly synthesised odorants however neither has been unequivocally accepted to give a full explanation of the mechanism of olfaction. For instance both theories propose that, in common with the other senses of taste and sight, there are primary receptor sites responsive to primary odours and yet no such structures have been identified in the olfactory epithelium.

Any theory of olfaction has to explain three features of the sense which are:-

a. High sensitivity to a number of odorants that can be detailed at concentrations of parts per billion or less.
b. Excellent discrimination so that professional perfume chemists can distinguish upwards of 10,000 different smells.
c. Olfactory Adaption or fatigue in which the sensations of a smell rapidly fades after an initial exposure although recovery of sensitivity occurs rapidly and completely on removal of the odour.

The third feature is most easily explained by an assumption that odour molecules only stimulate a receptor on first contact. Subsequently the receptor site undergoes either a recovery period or a period when it is physically shielded from further stimulation by the presence of the odorant molecule.

A solution to the problems of sensitivity and discrimination is suggested by Persuad and Dodd (24). They describe the organisation of the olfactory system in terms of a convergent hierarchical structure in which many primary transducers, the olfactory cells, are linked to relatively few secondary tranducers located in the olfactory bulb of the brain from whence a small number of nerves conduct signals to specialised centres of olfaction but the exact pathways have not yet been fully mapped. These authors emphasise that the combination of high surface area in the primary sensors, a convergence of about 10,000 to one between the primary and secondary levels, a short pathway to the brain and a constant renewal of primary cells are all features conducive to maximum capture of an olfactory signal and minimum loss of data during transmission along a nervous channel. Sensitivity is thus ensured. As for discrimination Persuad and Dodd postulate that this may be achieved by means of a number of similar types of sensing elements different only in their responsiveness to odorants; a feature described by Persuad and Dodd as being a "broadly tuned, poorly selective receptor organised in a convergent neurone pathway"

The features of this system were simulated by the construction of an electronic nose based on only three different types of tin oxide semiconductor flammable gas detectors. The signals generated by these were electronically amplified; the ratios of the response compared and the output produced displayed by an illuminated pattern of light emitting diodes. This quite simple device was apparently able to discriminate between "a wide variety of odours" and may be capable of being developed into a commercial instrument for routine quality control in the perfume and flavour industries. Recent reports indicate that Dodd has developed a semiconductor chip bearing 20 primary odour receptors whose output is analysed by computer using a sophisticated pattern recognition program. The advent of an "electronic nose" seems imminent and the implications of this concept of the olfactory system could be very significant in the development of olfaction as a science for two reasons.

Firstly the electronic model could provide the basis of an objective instrumental measurement of smell that may find the same uses in odour control as the sound level meter has been used in noise control. Secondly the development of the model may be of considerable assistance in advancing understanding of the olfactory system which has been deadlocked in the controversy surrounding the actual mechanism by which smell is sensed. Emphasis is placed on the importance of the organisation of the olfactory system which seems easier to understand and once unravelled may give clues to the functioning of the receptor mechanism.

Olfaction that has been so far discussed is the specialised human sense located in the nose and capable of immense subtlety in the perception of smell. However, the complete olfactory perception is bimodal and includes a contribution from another sense, also chemoreceptive, that is called variously the sense of irritance, common chemical sense, or the trigeminal sense. The latter name is derived from the nerve whose free receptive endings are commercial instrument for routine quality control in the perfume and flavour industries. Recent reports indicate that Dodd has developed a semiconductor chip bearing 20 primary odour receptors whose output is analysed by computer using a sophisticated pattern recognition program. The advent of an "electronic nose" seems imminent and the implications of this concept of the olfactory system could be very significant in the development of olfaction as a science for two reasons.

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As with every other human attribute the sense of smell varies from individual to individual according to age, sex, state of health, and personal habits. The contribution of each factor to observed individual variation will now be discussed.

6.4 Odour Acuity

The idiosyncrasies of human acuity to odour have been extensively studied by the gas industry, because of its statutory duty to provide an odorous warning of the presence of gas below its flammable limit (26) by the oil industry concerned about the odour pollution from oil refining (27) and by researchers interested in the mechanism of odour perception. (28)

The work of Wilby (29) was specifically directed to a statistical study of odour acuity in a small panel selected to reflect the approximate age and sex distribution in the American population, with this work being conducted in the open air. Amoore (28) conducted fundamental research into odour mechanism using large panels of between 100 and 400 observers. The statistical data in these two reports suggested to Clarenburg (2) that the variation in a population could be described by a log-normal distribution although this was bi-modal with a distinct group of subjects apparently lacking odour sensitivity. These people are said to be anosmic to a specific odorant, that is they have in general a good sense of smell but are unable to detect the odour of a specific substance. Specific anosmics, sometimes called "odour blindness" can vary in its incidence from 10% for hydrogen cyanide to 1.0% from hydrogen sulphide, to 0.1% for butyl mercaptan. Amoore concluded that specific anosmia is caused by the absence of a primary receptor site in the nose, just as colour blindness is due to the absence of a primary colour receptor in the eye.

The sex of an observer may also effect the individual sensitivity and, as already discussed, women show a much greater sensitivity, nearly 10,000 times, than do men to some odours of sexual significance such as musks, that form the base of quality perfumes and androgenous compounds such as "boar taint". Moreover the magnitude of this sensitivity varies throughout a woman's monthly sexual cycle, being greatest just before ovulation and ceases altogether with sensitivity reduced to normal male values after menopause. However it should be noted that, in a general response to the majority of odorants, the odour acuity of women is similar to that of men.

Age causes a systematic deterioration in the sense of smell although Venstom (29) suggest that this accounts for only about 20% of the total variance in olfactory sensitivity. The "half life" of the sense of smell is about 22 years showing that this sense is somewhat more durable than either sound (15 years) or sight (13 years).

6.5 Odour Acuity in the Outdoor Environment

Reference has been made elsewhere to the dual function of the nose as being an air conditioner for inhaled air and the principal organ of the body for the sense of smell. Schneider and Wolf (78) studied interaction between these functions particularly as this effects odour acuity.

Odour acuity appears to increase considerably with increased swelling and increased temperature of the internal soft membrane of the nostril. These symptons along with increased nasal secretions, are typical of nasal irritation caused by the common cold, hay fever, dust or irritant vapours. Eventually a loss of the sense of smell brought about by physical blocking of the airways by viscous mucous.

A highly dilated nasal membrane is accompanied by poor odour acuity and this condition is brought about by inhalation of very cold, dry air. The normal temperate climate of the UK, usually lacking in the extreme dryness or cold of continental weather, would appear conducive to good outdoor odour acuity throughout all seasons of the year.

The outdoor environment is the favourable location for sport and hard physical activities and the "healthy" image of such positives demand a pleasant, pollutant free atmosphere. Quite extreme measures were taken during the 1984 Olympic Games to prevent exposure of athletes to the notorious photochemical smog of Los Angeles. No research appears to be reported on the effects of exercise on odour acuity but in the light of the preceding discussion it seems likely that nasal membranes experience swelling, higher temperatures and increased air flows brought about by vigorous activity. Thus odour acuity should be greatly improved and indeed personal but somewhat anecdotal evidence suggests that the normally tolerable but unpleasant smells of silage effluent if breathed during a fast run can cause considerable discomfort similar to the extreme somatic effects of malodours. Indeed it is now becoming common practise for leading vehicles in road marathons to be electrically powered to avoid causing distress to leading runners (79).

If athletic activity is associated with good odour acuity then it calls into question the common practise of creating a "cordon sanitaire" or buffer zone of restricted residential development about sewage works and using the land for sports fields.

6.6 Loss of Odour Acuity

Personal habits such as work in an odorous industry may cause a loss of sensitivity to odours of the work place; this phenomenum being called "habituation." Smoking is also widely held to cause a drastic deterioration in the sense of smell so that most standardised methods of odour assessment require that panelists practice a form of abstinence from tobacco taking. However research has failed to demonstrate any conclusive evidence of any deleterious affect of smoking on odour acuity.

Minor day to day variations in the comfort of an individual are reflected in changes in olfactory sensitivity, especially if the interior membrances of the nose and the mucous covering them are effected (30). Moderate swelling of the membrance assists olfaction and this condition is brought about by warm humid weather. Shrinking of the membrance inhibits olfaction and this occurs in cold, dry weather. Irritating vapours and dust cause swelling and hence heightened perception of smell as also does nasal illness, such as cold, until the great increase in mucous accumulation almost destroys the sense. Courses of drug treatment may also effect the condition of the nasal membrances and hence influence the sense of olfaction.

All these influences effect the pure sense of olfaction but, as already mentioned there is an olfactory contribution from the common chemical sense. Variations in this have not been well researched but the available indications are that pungency is relatively stable and persists even when the sense of smell has been virtually lost (31).

6.7 Measurement of Odour

The enormous variation in human response to odour causes considerable problems in the assessment of odour by sensory procedures using panels of odours. There are four characteristics that can be measured which are detectability, intensity, character and description, each of which will now be discussed.

6.8 Detectability

The Detectability of an odour is measured by its threshold dilution which is the number of dilations using clean air that must be made to a sample of odorant so that it can no longer be perceived by an observer. Because of individual variations it is necessary to use a panel of observers, usually of eight members and to estimate the median value of the distribution of responses to represent the Threshold value.

This assessment, although simple in concept, is notoriously difficult to apply consistently and compilation of thresholds for various substances often reveal a hundredfold difference in threshold between one study and another (32). Indeed for one much studied odorant, hydrogen sulphide, the range is greater than 2000 to one. In part this variation is due to unspecified minor impurities in odorants (27) that effect its odour but the greatest proportion is probably due to procedural differences. Obviously odour threshold is not a fundamental property of a substance as are boiling or freezing points, but is a secondary characteristic dependent not so much on the substance as upon the observer. Literature values of odour thresholds seldom quote the procedures used in their determination, the size of panel and the spread of observed results so that such compilations should be treated as guides to relative odoricity rather than absolute values.

Pyschophysics, which is the science of perception, has long recognised the great difficulty experienced by people in making decisions about their perception of stimuli when these are presented at levels close to the threshold of response. Then non-sensory factors may have as much effect as direct sensory clues upon the decision of a panelist to say "Yes I do detect an odour." To prevent such influence acting, the equipment and procedures used to assess odour threshold should be as neutral as possible and impose minimal demands on a panelist. Extraneous clues such as the noise of valves operating should be avoided and the environment of the test be as relaxed as possible to put a panelist at ease.

6.9 Odour Threshold - The Detectability of Smell

Many pieces of equipment have been devised and used to assess odour threshold but only two types have become accepted as standard methods. All equipment falls into one of three categories as follows:-

a. Odour rooms that are walk in cubicles filled with odour at a known dilution into which an observer steps, takes a breath and reports upon his or her immediate perception of smell. It is possibly the most reliable of olfactory tests as an observer encounters an experimental rig that closely resembles a normal experience of everyday living. However it is also the least used, probably because of the size, complexity, number of people needed and the time required. Neither does the methodology required lend itself to sophisticated psychophysical procedures.

b. Dynamic methods in which a continuously flowing stream of odour is diluted with "clean air" and the ratios adjusted to find the threshold dilution. The necessary equipment is usually small enough to be portable and very high quality components can be used without incurring excessive costs. Such equipment is usually accompanied with electronic apparatus to signal response of panellists and so highly structured psychophysical tests may be applied. The major disadvantage is that there has been insufficient investigation of the factors that permit optimal performance of the equipment consequently there are considerable differences in results obtained using different designs (33). One such that has been standardised is used within the gas industry for investigation of the potency of stenching agents. It is called the Watson House odorimeter, after the research station when it was developed (34).

c. Static Methods. These are based on the preparation of a series of diluted odours within simple containers, the contents of which are then presented to the nostrils of panelists. Possibly the simplest equipment available for this purpose are 100ml glass syringes and these are specified for use by the standard batch dilution test, ASTM D1391 - 57. This method is unusual as no claim is made for its precision and accuracy while it is also stated that the glass surface of a syringe is unsuitable for containing many odorants which may be lost from the entrained atmosphere by absorbtion onto the walls of the enclosure. Moreover the statistics of the procedure has been attached by Itzhowitz (35) in a provocative paper. He argues that the variability of odour sensitivity between individuals is so large, and panel size so small that any result obtained is statistically meaningless. Consequently any attempt to use this unreliable test in enforcement proceedings would be irrational and unjust. Although the ASTM method was attacked this same criticism could be directed at almost any method of sensory assessment that could be conveniently used by an enforcement authority.

Of the four characteristics of odour, threshold dilution is the most objective and consequently there has been a tendency to use it exclusively in the assessment of odour nuisance. Source strengths can be measured quantitatively and by substitution in equations, where threshold may replace the mass term, it becomes possible to estimate the dispersal of odour by atmospheric processes (36). However threshold dilution gives no information about the acceptability of an odour as it is possible for two odours, one causing complaint, the other not, to have the same strength when assessed only by this characteristic.

6.10 Intensity

This characteristic describes "how strong" an odour appears to an observer and relates the concentration of the odourous substance to the corresponding human perception of its smell. A simple empirical relationship between a physical stimulus and human respnse has been suggested by Stevens (37) so that:-

$$S = K\ C^N$$

where S is the magnitude of the perception, C is the concentration of odorant, N is a number which for smell varies between 0.3 and 0.7 dependent on the particular odour, and K is a constant.

This equation is generally valid for a wide range of human sensations but controversy over its correctness rages in psychophysical circles as to the merits of "Steven's Law" over the previously universally accepted "Weber-Fechner Law" of psycho physics which proposed a logarithmic relationship between the variables of Steven's Equation. It is not intended to argue the various points of view in this thesis as neither is inconsistent in its appropriate context and each appears valid if suitable definitions and methods are used. Prophetically, if not provocatively, Fechner wrote that his "psychological edifice will stand because other workers will never agree on how to tear it down". Stevens may be accomplishing the demolition.

All methods of intensity measurement require that a series of odour dilutions are presented to panelists who are then required to rank their perceptions to this stimuli. There are three methods available for this form of assessment.

The first is category sealing which normally uses a 5 point scale which are: just noticeable, faint, moderate, strong, very strong. A series of dilutions of the test odour are presented to an observer who is asked to signify the most suitable category. The results are plotted on a graph of category versus concentration of odour and the slope of the line is the power of Steven's law. This method is easily applicable in a door to door community survey but suffers from the disadvantages that it is prone to "compression at the extremes" due to a reluctance of people to display extreme attitudes and the limited scale gives poor resolution.

The alternatives to category scaling is magnitude estimation in which a panelist is presented with a standard stimulus and asked to assign a number to his or her perception with a magnitude of at least 10. The diluted odours are then presented and the panelist asked to assign numbers to his or her perception of them so ranking them relative to the first stimulus. The individual responses are then normalised so that the responses of the entire panel can be generalised in a single scale, plotted on a graph of response against log odorant concentration. The slope of line is the power function of Steven's Law. This method is not easy to apply if niave panelists have to be used as the task has to be carefully explained and cross-matching is necessary in which the reference odour is different chemically and perceptically from the odour whose intensity is being assessed. However the method is capable of fine resolution and so can be used effectively to monitor the effect of changing operating parameter in an odour control system.

The third alternative is the use of reference scales which requires a series of standard odours whose concentrations are accurately known. Special equipment has been devised which continuously generates a number of standards each successively twice the concentration of the previous one. The test odours are each compared against the standards to find one of closest match and so the odour intensity of the tested odour can be related through Steven's Law to that of the standard odorant. Full details of the test are given in the ASTM E-544 which uses n-Butanol as a reference odour. A comparable procedure has been developed for the Gas Industry by CERG (Groupe European des Researches Gaziers)(34) uses pyridine as a reference who link a magnitude scaling to reference scaling in a table designed to assist gas fitters to detect gas leaks, as shown in Table 6.1

Table 6.1 G.E.R.C. Scale of odour intensity

Olfactory Degrees	Defintion of Odour	Pyridene equivalent (mg/m^3)
0	None	0
1/2	Very Feeble-detection limit	0.42
1	Feeble	0.65
2	Medium (alert)	1.5
3	Strong	3.5
4	Very strong	8.5
5	Maximum upper limit	20.0

The significance of intensity to odour pollution lies in the value of the power term in Steven's Law that indicates that perception of odour changes according to the square or cube root of variations in odourant concentration so that quantitively large changes in an odorant emission may not achieve the benefits that might be expected.

6.11 Quality

Also called hedonic tone, this attribute of odour is highly subjective as it attempts to assess the pleasantness or otherwise of a smell. Obviously there are some smells that a concensus of public opinion would agree to be disgusting such as those of death, decay, uncleanliness and defecation. Even slight exposures to these smells will generate public complaint.

However many other smells, in particular those of cooking, would not normally be considered unpleasant but to which overexposure will cause a change in opinion expressed as complaint. No method yet devised will account for this effect.

A crude initial assessment of character can be made by presenting an panelist with an odour and asking for initial reaction to be recorded on a bipolar magnitude scale. This is a scale labelled at one end with the word, pleasant and at the opposite end the word, unpleasant. By inference a distinct mark at the midpoint is neutral. The distance of the panelist mark from the midpoint is measured using positive values along the pleasant arm and negative values along the unpleasant arm. The individual responses of all the panelists are averaged to obtain a indication of the character of the smell.

Odour character is of significance in pollution abatement since many methods of odour control may completely destroy the smell intended to be controlled but replace it with an entirely different one. In these instances threshold measurements may suggest a poor efficiency but the overall result could be satisfactory if a stench is replaced by a smell of more neutral character. Care is required in the interpretation of such results since even "pleasant" smells can cause complaint. It is part of the mythology of odour control that complaint will cease ifa malodour is overpowered "masked" by a pleasant smell but even these will cause annoyance if they are inappropriate and inflicted on unwilling recipients.

6.12 Character

Smell cannot yet be objectively analysed in the same way as sound and light can be described in terms of their spectra. Thus descriptions of smells can only be communicated by drawing parallels with whatever a common experience of odour may be. Hydrogen sulphide is thus said to smell like "rotten eggs" and hydrogen cyanide to smell like "almonds". Therefore ~~if~~ it is assumed that most people share an experience of a number of common odours that can be clearly identified. If those descriptions are presented to odour panel in the form of list then any novel odour would be described in terms of the descriptions on that list. The list is not essential but only acts as a prompt to avoid the "tip of the tongue" dither (38) that people commonly experience when searching their memory for recall of an odour. The relevance of this assessment to odour pollution control lies not so much in any quantitative measurement of odour abatement but rather in the assistance it gives to the communcation of the problem and any success that may be achieved. Thus to describe a smell as being of valeric acid would mean little to many people, but describe the same smell as "sweat like" and the understanding of an audience is greatly assisted.

6.13 Odour Profiling

American Researchers (39) have made a determined effort to limit the subjectiveness of the assessment of both odour character and odour quality by combining both these attributes in an odour profile. This is based on a standardised list of odour descriptions in which each is assigned a hedonic factor within a numerical range from -5 the most unpleasant, to +5 the most pleasant.

A profile is assessed by presenting a test odour to a panel and asking panelists to select words from the standard list that seemed to give the most appropriate description of the odour character. A single overall figure for the rest odour is then calculated by multiplying the percentage response of each description by the individual hedonic value.

The work reported in the literature is American research and therefore uncritical adoption of the stated hedonic value in any British investigation may be faulted because of variations caused by different cultural contexts and different usage of language. Thus words such as kerosene and gasoline would be unfamiliar to a British panel, while household gas in the UK may not have the same smell as gas in the USA due to differences in the stenching agents added. Other words in the list should be omitted in a UK study simply because they are beyond the common experience of the British populace. These are words such as cedarwood, eucalyptus and incense. Other words in the list seem imprecise thus "chemical like" seems poorly defined as to be meaningless although a panel of 450 were apparently able to give a value of 1.67 to their perception. However these problems are a minority in a list of 150 words and a cull of this should provide a subset of descriptions suitable for use in the UK without need of reassessment.

6.14 Application of Sensory Methods

These methods of sensory assessment of odour are inconvenient as the use of panels composed of a number of individuals requires a certain amount of organisation and management. People are not always prepared to serve on panels and may not be available at the time they are required to take part in tests. Colleagues in a Council Department are most likely to constitute panels but they have their specific duties to perform and too frequent participation is likely to tax their patience although it is essential that panelists give their whole hearted cooperation to the tasks they are to perform. Itzkowitz (35) has indicated the problems of consistency that result if membership of panels change from test to test. However the organisation of a panel does not incur great capital cost, particularly if simple laboratory equipment is used for odour assessment and the results achieved are human responses directly relevant to the particular problem of odour pollution being investigated. Sensory methods of the types outlined probably represent the best approach to the quantitative, objective measurement of odour.

Sensory methods are usually applied to source odours taken from the odour emitter and so not diluted by atmosphere dispersion. There seems no reason that similar tests should not be done in the environment at the home of the complainants or by driving an odour panel through the plume of an odorous emission and asking panelists to make assessments of the odour at known locations so that an odour map may be plotted.

Odour thresholds in the environment can be measured by using simple equipment such as the "Scentometer" that is a small hand held dilution apparatus but the results are of dubious validity. Cain (40) summarises the problems, the main one of which is that by definition odour threshold is the concentration of an odour about which people disagree with half reporting the rest and half not. In such situations any slight bias will alter the measurement of detectability very considerably. Thus Semp (41) found that training alone can reduce the reported threshold of an odour about tenfold, while Engen (42) drew attention both to similar effects that expectation can have on the measured response and to a similar effect of irrelevant clues such as colour. Such factors can be easily controlled in a laboratory but not so in the field. Thus quantitative assessment of threshold in the field is best avoided except for the crudest binary response of "Yes, I can smell" or "No, I can't" Engen suggested that intensity matching, that is comparing an environmental odour against a standard test odour, should present far fewer difficulties. Character and quality present few problems possibly because they are the most subjective items of assessment and indeed their environmental assessment may be more valid than a laboratory based one since the "appropriateness" of an odour in a particular environment is better judged in such circumstances.

The large perception of an odour in the environment is obviously very different from the controlled conditions in a laboratory and very little work appears to have been published that attempts to relate the two experiences. Barynin and Wilson have researched this problem (43) as they had developed a sensitive and highly responsive meter able to continuously monitor sulphur containing substances in the atmosphere. Instrumental measurements were compared against magnitude estimates of odour intensity made by panelists with each sited in the open air downwind of an odorous source. Experimental results indicated that panelists were able to very accurately follow the fluctuations occurring in a plume but that responses were supressed by adaption whose speed of onset varied very idiosyncritically between individuals. Atmospheric conditions when puffs of odour were separated by periods of clean air enabled panelists to retain their sensitivity over prolonged exposure, while conditions in which puffs merged without clean air seperated allowed adaption to suppress the panelist response for category 3 to 0 on a 5 point scale of intensity and found good correlations. The chemical parameters were assessed by chromatographic techniques so providing a useful link with practical methods for chemical analysis of odorants.

6.15 Odour Characteristics and Structural Chemistry

Dravnieks (39) has tried a different approach in which the odour characteristics of a compound are predicted from the structural formula of its molecule as drawn on to the two dimensional surface of paper, the so called "paper form" structure. Each structure is then examined for the presence of 14 features or "building blocks" believed to contribute to the odoricity of the compound of which the following list is a shortened version sufficient to indicate the principles:-

a. Size, length and "bulkiness" of the molecule.
b. The number of double bonds.
c. The number of sulphur atoms excluding any S - 0 bond.
d. The number of nitrogen atoms excluding any N - 0 bond.
e. The number of halogen atoms.
f. The presence of OH, COOH, ester groups or "ether oxygen" sites.
g. Polarisation of the molecule.

The statistical method of correlation analysis was then used to obtain a polynomial equation in which each structural feature was a variable that reflected its contribution to a particular odour property of a compound. Predictions made by this procedure were good and demonstrated that olfactory characteristics could be extracted from a simple chemical formula. However the approach was empirical and was dependent on the relevance of the data base used in the statistical analysis.

6.16 Overall Odour - The Interaction of Odorants in a Mixture

All the work so far discussed has been concerned with the smell of pure single substance where as many smells encountered in everyday life are complex mixtures of many substances. Over 2000 active odorants have been identified in diesel exhaust fumes (44) 35 in maggot odour and in the exhaust of animal by-product plants. The possible interactions in such mixtures are highly complex as substances may react chemically with each other so destroying themselves and creating new substances. Alternatively the sensory characteristics of the odorants may interact by adding to or subtracting from the overall perception and even odourless substances may contribute a synergistic effect on the perception of odour. However in general an complex odour mixture will smell less intense than might be expected by summation of its single components; a phenomenum known as *hypoadditivity*.

Two extreme examples of odour interactions that are exploited with limited success in odour control, are "masking", in which one powerful odour overwhelms the perception of another, and "counteraction" in which one odour neutralises another so that the overall perception is virtually zero. Masking is the effect exploited by innumerable domestic air freshners based on pine, lemon, or floral essence. If used sparingly within an internal environment masking can be effective against weak malodours but if overdone or the chracter of the essence is inappropriate this technique can be as annoying as the odour it is intended to mask.

Counteraction is a much more subtle technique in which the counteractant must be carefully compounded to be specifically antagonistic to the malodour it is supposed to be neutralising. This effect is often advocated, especially by manufacturers, as being as effective method of environmental odour abatement but such claims, normally based on laboratory studies, are likely to be unsound. It seems very doubtful that the intensity and threshold characteristics of a masking agent can remain in balance with the same characteristics of the malodour during the process of atmospheric dispersal. If the balance cannot be maintained then either the smell of malodour or masking agent will become apparent and the potential for nuisance remains. A good critic of these phenomena has been written by Cain and Drexler (45).

Inspite of the difficulties described in accounting for the interaction of odorants in a complex mixture some progress has been made by Berglund (46) who used vectorial addition of the perceived intensity of single odorants to estimate the overall perception of the mixture. By this means the variations in concentration of a five component mixture of odorants could be linked to the variations in overall odour perception. The particular odorants were hydrogen sulphide, dimethyl sulphide, dimethyl disulphide and pyridine which were all known odorants in the efflux gases of paper mills. This research concluded that less than 50% of the measured odour strength of the effluent could be accounted for by the known odorants and thus other unrecognised odorants or synergistic substances were likely to have been present. Thus Berglund warned that elimination of all known odorants might not reduce the final odour strength of the effluent and might even cause an increase. Lidwal (47) attempted to find the synergistic substances involved and concluded that possibly these were subliminal amounts of nitric oxide and sulphurdioxide that act on the pH of the mucous membrance of the nose causing variation in the disassociation of odorants such as hydrogen sulphide, $H_2S \rightleftharpoons HS + S$. Thus acid synergens favour high concentrations of the odorant, H_2S, in the nasal mucous and hence increase the odoricity of hydrogen sulphide.

6.17 Summary

Odour is a complex perception with several modalities that each can only be measured satisfactorily by sensory procedures. These require careful structuring and equally careful management of panels of observers if consistent results are to be obtained. Even then elements of subjectiveness remain so that National Standardisation Bodies are reluctant to assign measures of precision and accuracy to the sensory methods that they recommend. However simple methods of practical application are available that enable the modalities of detectability, intensity, quality and character to be described in terms that are comprehensible to non-specialists and assist in communicating those aspects of odour that are of concern in odour abatement. The major problem of achieving an objective measure of stench continues unresolved because of the wide range of odorants, and the very low concentrations of these that are perceptible. Some progress has been made both in clarifying links between the chemistry of odorants and the perception of odour, and in understanding the interaction of odorants in a complex mixture. However for the present objective odour measurements are not possible and thus chemical analysis of odorants is of little assistance to Local Authorities wishing to establish an odour nuisance. The future offers some promise of progress as analytical instrumentation is a field of rapid innovation and physical models of the human olfactory system have been developed that have the features of an "electronic nose". Such an instrument might be used in the investigation of stench in much the same way as a sound level meter is used to investigate noise.

CHAPTER 7

7. Chemical Analyses of Odorants

7.1 Introduction

The lack of any clear link between odoricity and chemistry of odorants obviously discourages any attempt to develop a special methodology for the chemical analysis of odour. Instead the chemical analysis of odorants is no different to the chemical analysis of single substances *in complex mixtures*.

7.2 The Methods of Analysis

Specific odorants may be determined by appropriate analytical methods and a number of these has been standardised (48) Thus hydrogen sulphide may be determined at odour threshold levels by a standard procedure of the American Public Health Association and the same organisation also publish other procedures for mercaptans, sulphur dioxide, acrolein and formaldehyde, all of which are powerful and common odorants. Japanese workers (49) have developed simple impregnated glass fibre filters that are effective traps for amino and sulphur compounds that are powerful odorants.

Specific procedures for individual odorants are of limited use in monitoring stenches which are commonly mixtures of many substances. However single species monitoring can be of use for indicating exposure to an odour, particularly if one odorant dominates perception of an odour or a simple convenient procedure is the only alternative to others that are more costly or use inconvenient specialised equipment.

Procedures are available that can monitor a number of substances simultaneously, in real time and at high sensitivity. These depend on intrinisic properties of odorant molecules that can be measured by such techniques as mass spectrometry and infra-red spectrometry. Such instruments are the "PETRA" transportable mass spectrometer manufactured by V. G. Instruments and the "MIRAN" portable infra-red analyzer manufactured by Quantitech. Each are computer or microprocessor controlled and can be programmed with data enabling up to 10 substances to be determined at concentrations down to parts per billion. A lower cost alternative is to use a broadly tuned non specific detector such as the OVA portable chromatograph with a flame ionisation detector responsive to hydrocarbons at levels less than 1 part per million.

The literature contains few reports of odorants monitoring in the community exposed them. Japanese workers (49) applied their impregnated filters to capture sulphur and amines in various sites about an oil refinery and fish meal factory. Roe (49b), an employee of the Severn Trent Water Authority who were the recipients of an odour abatement notice, undertook trapping of odourous organic sulphur compounds in the vicinity of sewage treatment works. Also Barynin (50) whose work has been discussed elsewhere, has monitored organic-sulphur compounds at sites downwind of odorous sources.

7.3 Trapping Techniques

A possible reason for this paucity of research lies in the difficulty of odorant analysis which usually employ traps to concentrate the minute traces of odorant that are often the cause of nuisance. However a trap exposed over a period of minutes or hours, will only determine the average value of an odorant over the period of exposure and this may have little relevance to odour nuisance which is caused by short lived intermittent peaks that exceed the threshold of smell. Traps are thus a poor substitute for real time monitoring of fluctuations in an odorant plume.

Most investigations of the chemical constitution of stenches is most reliably conducted at the source where concentrations of odorants will obviously be greatest so that the task of identifying traces of odorants is assisted. Many methods of trapping organic vapours have been developed based on Cryogenic or absorptive techniques. None is obviously superior to others and application to any specific circumstance is very much a case of "horses for courses". Whatever method is selected should have high efficiencies of collection and subsequent release of trapped odorants, minimum decomposition of trapped species during storage, absence of release of background substances (artifacts) contributed solely by the method itself, and a small affinity for water. A good review of the merits of various procedures has been published by Pelizzari et al (51) while interesting practical applications for odorants has been reported by Brookes and Young (52) for landfill gas, Leonardos et al (53) for paint oven emissions and Pope et al (54) for rendering plant odours.

Between 1975 and 1980 the Warren Springs Laboratory undertook some fundamental research into odour pollution and means of its control. As part of this research a standard method of odorant analyses was developed based on the use of Tenax (2-5 Diphenyl -phenylene oxide) traps followed by gas chromatography. In this procedure two Tenax traps connected in series were used; one operated at ambient temperatures collected high molecular weight compounds, while the other operated at sub-ambient temperatures, collected low molecular weight compounds. The trapped species are subsequently released by heating in the oven of a chromatograph and the odorants separated. In the basic procedure the chromatographic effluent is divided between a general purpose flame detector and a "sniffing port" to which the operator's nose is placed. The result is an "odourgram" of un-identified peaks annotated by odour descriptions. Identification is usually achieved by interfacing the chromatograph with a variety of sophisticated detectors including a mass spectrometer.

7.4 Financial Considerations

The standard WSL technique has been applied to a number of practical problems and does not appear to be difficult for a local authority to use the traps in an investigation then forward the exposed tubes to a laboratory for analysis. However few laboratories are prepared to undertake the necessary work and fees, 1986 prices, for the basic method appear to start at £100 per tube rising to £500 for identification using a GC/MS instrument. An indication of the costs of equiping a laboratory with basic instrumentation for odour analysis is given in Table 7.1

<u>Table 7.1 Methods for the Measurement of Odours and their costs</u>

1) Sensory Measurements

Cost of portable dynamic dilution apparatus		£5,000
Cost of ancilliary sampling apparatus	say	£2,000
Effort required for 8 samples (panel of 8)		*7 man days*

2) Instrumental Measurements

Gas chromatograph+	£8,000
Flame Conisation detector	£1,500
Flame photometric detector	£1,500
Microwave plasma detector	£20,000
Mass spectrometer + data bank	£250,000 (approx)

Effort required to analyse 8 samples : 1 - 4 man weeks

Such costs are difficult to justify particularly as the strength of a stench cannot be related to its chemical constitution although such knowledge may be of assistance in the choice of a method of abatement. A paper by Pope (54) demonstrates how odorant analysis may be of assistance in odour control but equally the number of tests undertaken indicate the type of costs that can be incurred which are appropriate to a major research effort but not to routine investigation of odour nuisance.

Fortunately for local authorities in view of the costs of odorant analysis, there are available a number of reports, notably those of the Warren Spring Laboratory that detail the expected chemical constituents of a number of common stenches. However these are often lists of several dozen chemicals that are not easy to assess and these are difficult to relate to the magnitude of an odour problem.

7.5 Presentation of Data

Japanese workers (55) have tackled this problem of presentation of data. They proposed a new unit (Pou) based on the ratio of detected concentration to odour recognition threshold value. This recognition value is normally considered to be approximately five times the concentration of the more commonly quoted threshold value at which an odour is just perceptible. These workers then reduced the chemical complexity of stenches by classifying odorants into 8 classes. Thus Group I consisted of sulphur compounds, Group II contained lower aliphatic amines; Group III was carbonyl compounds; Group IV was hydrocarbons, Group V was lower alphatic alcohols; Group VI was phenols; Group VII was indoles.

Having classified the odorants the next step is to calculate the overall pOU of a stench such that

$$pOU\ (tot) = \log C_1/RT_1 + \log (_2/RT_2 \ldots \log Cn/RTn$$

where "pOU" is the composite odour unit C_1, C_2 ....Cn are the concentrations of the respective odorants and RT_1, RT_2, RTn are the respective odour recognition levels.

7.6 Odour Charts

The results of this exercise are then plotted on a circular odour chart containing, in the Japanese work, seven radial axes, each corresponding to one odorant category. The pou value is plotted along each arm and the figure is enclosed by a circle of radius equal to the overall Pou value. The result is a graphic representation of the magnitude of the odour emission with large circles indicating strong emissions and smaller circles indicating weaker ones. The star shapes on the completed chart indicate the relative contributions of chemical constituents of the stench which could indicate appropriate methods of odour control. Two examples have been selected to illustrate this approach and are displayed in Tables 7.1, 7.2 and 7.3

The Japanese approach can be criticised in that their use of logarithmic addition of odour units greatly distorts the graphic display of data for it suggests that the overall detectability of a mixture of odorants is a multiple of all their thresholds which is highly unlikely. It is suggested that the combined effect is more likely to be related to the arithmetic addition of the detectability of all odorants although many other types of interaction are possible that may increase or decrease the overall effect. Thus in the examples of circular odour charts the magnitude of no correction along each arm is calculated by adding the individual odour unit of each odorant and taking the logarithme of the sum. Some examples taken from the Japenese work follow and are intended to illustrate the strengths of the Graphic technique compared to conventionable tables.

Fig 7.1 Examples of Odour Charts after Hoshika

TABLE 7.2 CALCULATION OF POU FOR SEWAGE TREATMENT PLANT BASED ON MAJOR ODORANTS

Group	Compound	Conc (pp6)	RTV (pp6)	OU	Log Ou	pOU
RSR	Hydrogen sulphide	4.6	6			
	Methyl mercaptan	6.0	0.7	8.6	0.93)	1.23
	Dimethyl sulphide	4.0	2.0	2.0	0.30)	
	Dimethyl disulphide	2.0	2.8			
RCOR	Acetal-dehyde	8.6	15			
CH	Toluene	6.5	4800			
ROH	Methanol	330	$1x10^6$			
PhOH	Phenol	1.0	10,000			
RCOOH	Acetic Acid	1.6	1,000			

RTV = Recognition Threshold Value OU = Odour Units

TABLE 7.3 CALCULATION OF p OU FOR STENCH OF A PIG PEN BASED ON MAJOR ODORANTS

Group	Compound	Conc	RTV	OU	Log OU	pOU
RSR	Hydrogen Sulphide	38	6	6.3	0.8	
	Methyl Mercaptan	1	0.7	1.4	0.15	0.95
	Dimethyl Sulphite	2	2	1.0	0	
	Dimethyl Disulphide					
RCOOR	Acetic Acid	1540	1000	1.5	0.18	
	Propionic Acid	990	8	118	2.07	
	Iso-Butyric Acid	164	1.3	126	2.10	8.02
	n-Butyric Acid	247	0.8	305	2.48	
	Iso-Valeric Acid	40	2.6	15.6	1.19	
	n-Valeric Acid	20				

Table 7.4 Calculation of pOU from the stench from a Shell Moulding Plant

Group	Odorant	Conc (pp6)	RTV	OU	Log OU	pOU
(i) RSR	Hydrogen	14	6	2.3	0.36	0.36
(iii) RCOR	Acetaldehyde	1129	15	75	1.88	1.88
iv) HC	Benzene	1111	4680			
	Tolnene	596	4800			
	Ethylbenzene	33				
	p-Xylene	41	470			
	m-Xylene	55				
	o-Xylene	--				
	Propylbenzene	231				
v) ROH	Methanol	44100	100,000			
	Ethanol	37900	10,000	3.8	0.58	0.58
vi) PhOH	Phenol	2048	59	34.7	1.54	1.14

In a further example a slightly modified form of the circular odour chart has been used to depict in graphic form the data reproduced in the following table 7.4 from a paper by Young and Parker (52) that summarises research into odourous gases produced in landfill sites. In Table 7.5 the odorants are classified by chemical type, and their odour units calculated to enable odour charts to be compiled.

TABLE 7.4

HIGHLY ODOROUS COMPONENTS IN LANDFILL GAS

Compound	Odour Threshold (mgm^{-3})	Site					
		A	B	C	D	E	F
Limone	$5.7x10^{-2}$	0.4	4.0	1.9	3.3	4.2	<0.1
Xylene	$4x10^{-1}$	<0.1	0.2	0.1	0.3	<0.1	<0.1
Ethyl benzene	$2x10^{-1}$	<0.1	0.1	<0.1	0.2	<0.1	0.4
Propyle benzene	$4x10^{-2}$	1.7	2.4	3.0	2.1	0.9	2.0
Butyl benzene	$1x10^{-1}$	1.4	0.6	0.3	0.9	<0.1	0.2
Methanethiol	$4x10^{-5}$	<0.5	1	2000	<50	1500	<2.5
Dimethyl sulphide	$1x10^{-1}$	<0.1	0.4	0.4	<0.1	6	<0.1
Butan-2-ol	$1x10^{-1}$	<0.1	<0.2	2.1	<0.1	1.1	<0.1
Methyl butanoate	$5x10^{-3}$	<0.1	<0.1	0.8	<0.1	3.0	<0.1
Ethyl propionoate	$1x10^{-1}$	<0.1	<0.1	<0.1	<0.1	1.4	<0.1
Ethyl butanoate	$3x10^{-3}$	<0.1	1.3	5.0	<0.2	120	<0.1
Propyl propionoate	$1x10^{-1}$	<0.1	<0.1	<0.1	<0.1	2.1	<0.1
Butyl acetate	$3x10^{-3}$	<0.1	<0.1	<0.1	<0.1	2.1	<0.1
Propyl butanoate	$1x10^{-1}$	<0.1	<0.1	<0.1	<0.1	1.0	<0.1

TABLE 7.5 THE COMPOSITION OF LANDFILL GAS STENCH IN TERMS OF ODOUR UNITS (OU) AND LOG OU AND POU

Group	Compound	A		B		C		D		E		F	
		OU	Log OU	OU	Log Ou	OU	Log Ou	OU	Log Ou	OU	Log Ou	OU	Log Ou
RSR	Methan-ethiol	5	)	1.0	)	2000		50	1.70	1500		2.5	
	Demethyl-sulphide	0.1	)	0.4	)	0.4		0.1		6		0.1	
		5.1	3.71	1.4	3.14	2000.4	6.30	50.1	4.69	1506	6.18	2.6	3.41
HC	Limonene	0.4		4.0		1.9		3.3		4.2		0.1	
	Xylene	0.1		0.2		0.1		0.3		0.1		0.1	
	Ethyl benzene	0.1		0.1		0.1		0.2		0.1		0.4	
	Propyl benzene	1.7		2.4		3.0		2.1		0.9		2.0	
	Butyl benzene	1.4		0.6		0.3		0.9		0.1		0.2	
		3.7	3.56	7.3	3.86	5.4	3.73	6.8	3.83	5.4	3.73	2.8	3.45
ROH	Butan-2-ol	0.1		0.2		2.1		0.1		1.1		0.1	
		0.1	2.0	0.2	2.3	2.1	3.32	0.1	2.0	1.1	3.04	0.1	2.0

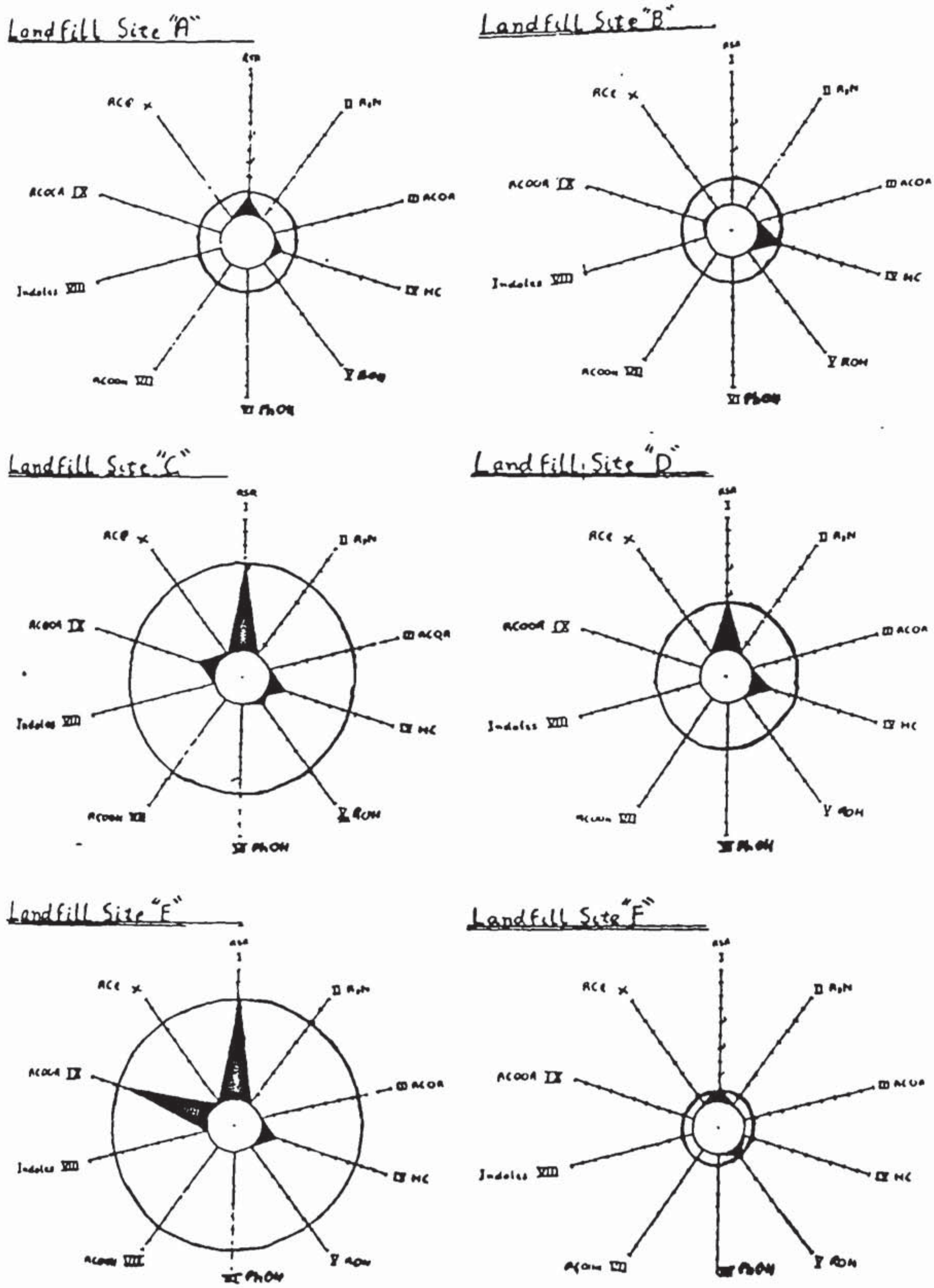
...cont'd....

Table 7.5 Continued

Group	Compound	A		B		C		D		E		F	
		OU	Log Ou	OU	Log Ou	OU	Log Ou	OU	Log Ou	OU	Log Ou	OU	Log Ou
RCOR	Methyl butanoate	0.1		0.1		0.8		0.1		3.0		0.1	
	Ethyl propionate	0.1		0.1		0.1		0.1		1.4		0.1	
	Propyl propionate	0.1		0.1		0.1		0.1		2.1		0.1	
	Butyl acetate	0.1		0.1		0.1		0.1		2.1		0.1	
	Propyl butanoate	0.1		0.1		0.1		0.1		1.0		0.1	
	Ethyl butanoate	0.1		1.3		5.0		0.2		120		0.1	
		0.6	2.78	1.8	3.25	6.2	3.79	0.7	2.84	129.6	5.11	0.6	2.78
Total OU and pOU		9.5	3.98	10.7	4.03	2014	6.3	57.7	4.76	1642	6.2	6.1	3.78

OU are given in units of 1000's

Fig 7.2 Odour Charts showing the emission of stench from Landfill Sites



The circular odour charts have ten radial arms each of a different organic chemical class instead of the eight used by the Japanese Workers. Thus two additional chemical species have been added, esters which are included in the Table, and chlorocarbons which are not. However they are common constituents of landfill gas and were found in the reported work at concentrations below their olfactory threshold, and they can be frequent cause of odour nuisance in other circumstances.

The odour charts have an immediate visual impact giving a readily assimilated impression of the strength of odour in landfill gas and an indication of the chemical constitution of the odourants. Crude differences in chemical composition are easily spotted although reference to the detailed table is necessary to discover which specific compounds are present. Thus sites C and E and particularly the latter are powerful sources of stench as indicated by the obviously larger radius of their odour charts. These two sources have organic sulphides as major odorants, dominant in the case of site C, while esters make an equal contribution to the overall stench of site E. Some idea of the character of the stenches can be gauged by considering the generic descriptions of the smell of the chemical species that are the major odorants. Organic sulphides have odours similar to garlic or rotting cabbage, while esters are commonly associated with fruity smells. Hence site E might have a stench of fruity, decaying cabbage requiring over one million dilutions before it is rendered undetectable and thus it has a considerable potential for nuisance.

Circular odour charts appear to have a useful role in communicating the often considerable amount of indigestable information that is necessary to describe the complex chemical constitution of many common stenches. Thus the chemical species involved often employ tongue twisting chemical nomenclature while the quantitative data uses awkward numbers. If instead simple chemical categories and logarithmic units are used to scale numbers a simplified and more comprehensible presentation will result. The logarithmic scale also reflects the psycophysical link between odourant concentration and perception so that the relative dimensions of the odour chart are related, however crudely, to the perceptions of the stenches they depict. The major shortcoming of these charts is the assumption of additivity of odour perceptions of odorants in a complex mixture which, as already discussed is a gross oversimplification.

7.7 Summary

This chapter has been about the link between chemical constitution and perception of an odour. The sense of smell is certainly chemically based but smell is a perception that cannot be closely related to chemical constitution. Many common stenches are complex mixtures of many odorants that interact in uncertain ways on the overall perception of the stench. Such complex mixtures of substances require specialised and costly methods of analysis to resolve but such work has enabled the constitution of many common stenches to be described and when such results have been published they provide a useful guide to the type of substances that might be a cause of public complaint. The presentation of this information, which is often highly technical and in considerably quantity, presents problems of comprehension. A possible solution is to construct circular odour charts with radial axes on which the odorant concentration can be plotted. Odorants are classified according to the basic functional groupings of organic chemistry and by connecting plots along each arm a stellated pattern is obtained which has an immediate visual impact. Total odour strength and the chemical nature of odorants is easily assimilated without details of chemical nomeclature and awkward numerical units of concentration interfacing with the information that needs to be communicated.

CHAPTER 8

8. The Atmospheric Dispersal Modelling of a Stench

8.1 Introduction

A plume of smoke emitted by a chimney can be seen to fan out, thin and eventually disappear as it is diluted by unpolluted air. The action of wind in this process is obvious but less apparent is that of the sun which influences the structure of the atmosphere within which the smoke is dispersed. The dynamics of atmosphere mixing is complicated but over the past 60 years intensive efforts have been made to develop mathematical models that can calculate the magnitude of atmosphere dispersal under varying meteorological, topographical and architecture conditions. Odours are dispersed in the same fashion as are smoke or gases and so are capable of being modelled by the same procedures but with some relatively minor modification to account for the peculiarities of the perception of smell. This approach is well described in the Warren Spring Guidebook, Chapter 3. (6).

8.2 Development of a Model

The advantages of developing a reliable mathematical model can be listed as follows:-

(a) The development of a model demonstrates a high degree of understanding of the working of a system so enabling decisions to be made with confidence.

(b) Predictions can be made, unusual circumstances or options can be investigated and their impact evaluated before decisions are made

(c) Information can be obtained quickly, cheaply and conveniently without undertaking difficult or expensive fieldwork.

(d) A discipline is imposed on the method of gathering the relevant data in an economic and effective manner.

Air pollution models share with other mathematical models a number of difficulties and in particular the feature of results that have a high mathematical precision but a poor accuracy as measured by agreement between the values predicted and those found. Errors can be caused by:-

i. Over simplification of the model due to inadequate description of poorly understood processes

ii. An unsuitable choice of model and in particular the uncritical application of a model developed to describe one situation to a different set of circumstances.

iii. Incorrect input data sometimes referred to as "nonsense in; nonsense out."

iv. Uncertainties in the procedures used to test the model

v. Construction of an over complex model whose workings are not comprehended by the user so that calibration of the model is impossible.

These points emphasise that great care has to be exercised both in the initial selection of a modelling method and in acceptance of the results of the final product.

A paper by Young (56) analyses the problems in the modelling of poorly defined dynamic systems of the natural environment. He argues that the size and complexity of a model is dependent on the information content of the input data and not on the model builders perception of the complexity of the system being modelled. The objective of a system analysis of a "badly defined" system should be to find the simplest description of the data that is available. If the result is a model that is not acceptable in that it does not achieve the objectives of the study then the investigator should return to his data and seek for more information that can be incorporated in the model so increasing its complexity. The alternative is to reach decisions on the basis of an unvalidated model which are not necessarily wrong but must not be supported by invoking spurious scientific arguments. Young advocates that model building methodology should proceed in the direction

DATA ----> MODEL

without too much reliance of prior conceptions of model subsystems. The main laboratory of the scientist who studies environmental pollution must be the environment.

8.3 Types of Pollution Model

A survey of mathematical air pollution model published in the literature of the subject suggests that there are four types of models that are:-

a. Comparative Models in which observations of dispersion about one example of a process is used to estimate the impact of a similar process in another neighbourhood. No attempt is made to understand the mechanism of dispersal and clearly this procedure accepts the "status quo" in that the effects of reducing emission cannot be estimated.

b. Box Models which are the simplest mathematical models based only on two variables that are the ventilation of a neighbourhood and the rate of emission of a Pollutant. Accuracy is poor and this method seems most useful as a first tentative "order of magnitude" calculation before commencing alternative procedures.

c. Gaussian Plume Models in which the plume of pollution is held to have the shape of Gaussian curve of statistics and hence the equation of this curve incorporating suitable variables can be used to provide a numerical solution to the problems of pollution dispersal.

d. Numerical Models which use advanced mathematical iterative procedures to calculate pollutant concentration. These can give results of high accuracy but require large amounts of meteorological data. The use of computers is essential and the costs of both computation and data collection can be considerable.

Only the Comparative and Emissions Plume models have been reported in the literature to be used to predict the impact of odorous plumes, and in the case of *Gaussian* plumes, modifications are usually made to account for the special needs of this application.

8.4 Prediction of Pollutant Concentration

Most predictions of pollutant concentrations are averaged over periods of 3 minutes or an hour, or even longer but very few experiments have been reported for the very short exposures, 5 seconds or so, that are significant for the perception of odour. Some relevant work has been reported by Barynin and Wilson (50) who used a fast response apparatus to relate a breath by breath record of odorant concentration to the corresponding human response to smell at points downwind of an odorous emission. Their work highlighted the role of olfactory adaption on the ability of an individual to detect an odorous plume in the "great outdoors"

8.5 Perception of Odour within an Odorous Plume

A subject's response at any instance depends on the product of two factors, concentrations of odorant and odour sensitivity. Sensitivity can be reduced by olfactory adaptation. These two workers found that along an axis downwind of the odorous source the peak to mean concentration ratio of odorant in a fluctuating plume was low, perhaps only of the order of 2:1 and thus adaptation was likely to reduce the perception of odour. However, on the cross wind axis and as the edge of the plume is approached most of the time is spent in clean air as shown by fluctuations as much as 100:1 in the peak/means ratio and there is little opportunity of adaptation to reduce the sensitivity of the sense of smell. Thus as a cross wind traverse of an odorous plume is made the sensitivity to odour is good at the fringes where episodes of odour are intermittent but is reduced although probably never completely removed at the centre of the plume where odour exposure is almost continous. The consequences of this for odour nuisance are unclear but perhaps the simplest view is that the potential for nuisance is constant across the width of an odorous plume.

Barynin and Wilson also considered the perception of smell as distance increases along the downwind axis from a source. Obviously dilutions will reduce the perception of smell but equally puffs of smell will expand and their edges will become diffuse. Now experience of olfactory measurement shows that sudden changes of concentrations are smelt more obviously than slow ones. The authors calculated the spreading of a puff and demonstrated that the rate of change of concentrations for a doubling in concentration, increased from 2 seconds at 100 metres to 100 seconds at 5000 metres. Consequently at the shortest distance the abrupt change in concentration inhibits the onset of adaptations but at greater distances the gradual change taking place of several inhalations allows adaptation to occur and the smell may not be noticed at all. Thus with increasing distance from source the perception of smell is reduced by two effects. One is the decrease in concentration, the other is the onset of adaptation so that the range of odour perception calculated by a suitable model may be greater than actually observed.

8.6 A Comparative Model due to Harden and Wood

This approach (57) forsakes any deep insight into the physical processes of odour dispersal and relies instead on comparison with problems experienced by other similar plant or processes. A paper by the above workers illustrate this approach.

These workers were required to make a submission to a public inquiry concerned with the consequences of the development of a fifth terminal at London Airport. This required that sewage sludge treatment works be relocated to a site closer to residential districts and there were objections on ground of odour nuisance.

The two authors decided that odour modelling was not reliable enough to give an accurate prediction of nuisance so instead they investigated the pattern of complaint about other sludge treatment works although only two somewhat similar ones were identified. A survey was also conducted into various national standards for acceptable separation distances between sewage works and a residential district.

The results of both surveys were consistent in that complaint for sludge treatment of the type being considered would be unlikely beyond a range of 300 metres from the works boundary. However the authors considered that beyond this zone lay another within which the stench would be so weak that it would not stimulate complaint once residents exposed to it had become accustomed to it, although a lower level of annoyance would still result. Harden and Hood attempted to estimate the width of this zone of annoyance on the theoretical basis of research done in America and Britain (58). This suggested that stench has three sensory factors that in order of decreasing dilution or increasing concentration, are detection, recognition and annoyance. After considering the character of sewage sludge smell the authors estimated that recognition would occur at half the concentration that gives rise to complaint. By use of the relationship derived by the Warren Spring Laboratory

$$d\ max = 2.2\ E^{0.6}$$

Harden and Hogg calculated that sludge stench would not be recognised beyond a distance of 450 metre from the works. These two zones were then superimposed on a map of an area showing the proposed works so enabling a count to be made of residents who would be exposed to the stench.

This model of odour dispersion is entirely empirical and makes no attempt to estimate the strength and character of the stench being considered. It is based solely on a body of experience embodied within industrial codes of practise and verified by a survey of the pattern of complaint. Its major advantage is that the approach is easily explained to a Planning Inquiry, with an authority that stems from reference to a body of past experience codified in industry guidelines. Its disadvantage is that it accepts, without comment, the status quo and cannot tackle unusual situations where there is no experience to draw on nor can it predict the consequences. Such a model is quite simply, rubbish.

8.7 A Conventional Gaussian Dispersal Model

Balling and Reynolds (59) have developed an odour dispersal model to calculate the frequency of "odour days" in a community surrounding a sewage treatment works. Their approach uses a conventional gaussian distribution method that is very well explained with many worked examples in a Work Book edited by D. B. Turner and published by the U.S. Government (60). This warns that the equations do not produce exact predictions but they provide best estimates when precise measurements used in more sophisticated models are unavailable.

Meteorological data used in the model was obtained from a nearby airport and this included the height of the inversion layer which is impenetrable to the odour plume and is a special case requiring special treatment within the model. Daily meteorological data was fed in the model and the detectability of odour was calculated at various points in a grid downwind of the source. Any point where the calculated threshold exceeded 1.0 was assigned a value of "1 odour day" and thus over a period, a pattern of odour frequencies was generated enabling a contour map to be drawn. Some testing of the model was done using observers driving around the city to check the validity of the threshold criteria used.

This odour model lies in the mainstream of atmospheric disperson modelling in that it uses conventional calculation that is thoroughly explained in a number of textbooks and thus, so far as the computation is concerned, can be used with confidence by a non-specialist. The authors suggest the advantages of using the model include the ability to determine the effectiveness of changes in odour emission rate, escape velocities and water inputs on the spread of odour and enable costs and benefits of odour abatement schemes to be evaluated.

8.8 Odour Frequency Model due to Hogstrom

This paper (61) develops an intermittent plume model in considerable detail and presents results of exhaustive testing that appear to validate the approach.

Plume intermittency is caused by:-

a. The plume "looping" in the vertical dimension.

b. The plume "meandering" in the horizontal dimension.

Thus meandering plumes sweep pockets of highly polluted air across an observer and these are separated by periods of untainted or relatively unpolluted air. This is indeed what was observed by Barynin and Wilson in their observations of an odour plume, however there has been a growing interest in meandering plume models for reasons other than odour dispersal such as:-

i. The toxicity of a cloud of gas from chemical spills is determined by short time variations in chemical concentrations.

ii. The flammability of a combustible gas cloud is determined by small local pockets of gas with concentrations within limits of flammability.

iii. The obscuration of a military smoke screen is highly intermittent due to pockets of clean air entrained within it.

Hanna (62) has reviewed seven different meandering plume models and concludes that no concensus has yet emerged to establish a preferred technique for the reason that little reliable field work has been done to verify the theories. A major difficulty "being well known by persons frustrated by attempts to conduct field experiments with fixed receptors located in finite time slots." Hogstrom has used human observers to overcome this difficulty, people being usually more easily available than fast response sensitive analytical instruments.

Hogstrom tested his model of odour dispersal by a static or "sector experiment" and a mobile or "car experiment". In the first, 7 observers were positioned downwind of a paper factory at distances up to 20 kilometres and over a 8 hour day had to record the presence or otherwise of a smell. This experiment continued over a 5 day week for 1 month. In the mobile experiment observers were passengers in a car that was driven through the plume at a constant speed and each person recorded the presence or otherwise of smell at every sixth second. The results were plotted as a frequency distribution with cross wind distance along one axis.

The predicted results were in reasonable agreement with observations of the odour plume so demonstrating the soundness of the model. However the model underestimated the observed odour frequencies by an amount that was small at short ranges but systematically increased with increasing downwind distances.

Hogstrom discusses the reason for this discrepancy without coming to any firm conclusion but he appears to favour two errors as being major contributors to the discrepancy. The first error is wind direction frequency which in the case studied was provided by a meteorological station 50 kilometres distant and thus it was probable that the data used in the model was in error by an appreciable factor. The second major error lies with psychology of odour perception which causes a subject to overestimate the presence of odour when odours are faint as they will be at greater distances.

A possible third error is a statistical one resulting from a tendency of an observer to occasionally give false responses and answer "Yes, there is an odour" during periods of untainted air, and "No, none present" when there is an odour. Assuming the error rate is consistant under both conditions, which seems very reasonable, then as true odour frequency falls with distance so overestimation of "Yes" responses increases; exactly the effect observed. To illustrate this point data taken from a Table in Hogstrom's Paper will be corrected for statistical error. At 10km Hogstrom believes the error rate to be 5%, the total number of observations to be 5528 of which 470 are "Yes" responses. The observed odour frequency was 8.5% while the predicted frequency was 3.2, an overestimate in a ratio of 2.6 Now there are 5058 "No" responses which would have generated 5058 x 5/100 = 253 false "Yes" response. Take these away from the reported 470 "Yes" responses yields the number of true "Yes" responses to be 217. Presumably this figure itself is false by the same 5% error ratio so that 11 "Yes" observations should be transferred to "No" total. Thus the corrected figures are 206 "Yes" and 5322 "No" responses, giving an odour frequency of 3.9 that more closely approaches the predicted frequency of 3.2

Other errors Hogstrom considered included chemical changes in the plume that form more odorous substances, variations in the odour emission rate at sources, incorrect values of variables used in the mathematical model, a weakness in the model that over simplifies complex atmospheric processes and a difference in the perception of odour between laboratory studies and field observations. However, as previously stated Hogstrom does not conclusively favour any particular explanation.

The researches of Hogstrom and his co-worker Lidval, provide a very comprehensive account of odour dispersion and effects of odour perception in the environment. However the odour model was developed on data applicable to only one Scandinavian source and thus the use of the model in other circumstances is suspect unless the model is recalibrated which is a difficult process beyond the means of a local authority.

8.9 A simple Gaussian Model applied to a Complex Site

This paper (63) is an explicit account of the straight forward application of a Gaussian Plume model to the dispersal of odour from a large sewage works containing a number of odorous sources. The paper is also significant in that it tackles a specific problem of large sprawling sites with a number of uncontained emissions.

Keddie discusses the application of the standard Gaussian equation to odour problems and illustrates how the equation is modified to account for various geometries of an emitter other than a point source. Also discussed are modifications to the standard equations that are needed to account for the peculiarities of human perception of odour. Thus an extra variable R is added as a multiplier to the Gaussian plume equation which represents the empirically observed ratio of peak to mean fluctuations in the odour plume and thus estimates the magnitude of short peaks lasting about 5 seconds. These peaks may be detected by the sense of smell when the standard of Gaussian plume model, calibrated to calculate 3 minute average concentrations would suggest levels of odour to be below threshold levels. The magnitude of R may be in a range 5 to 10. Keddie also suggests the addition of a further factor to the equation intended to suggest the potential for nuisance in a plume and is based on the experimental observations that complaint is likely when the detectability of an odour is about 5 times the threshold level. Although Keddie does not state so, if the two variables are combined, then public complaint can be presumed whenever the dilution to threshold of an odour exceeds the value predicted by a standard Gaussian Plume by 25 times. e.g. x 5 for short period peaks multiplied x 5 for recognition level above threshold.

Keddie mentions in his paper a very simple relationship between the maximum distance of complaint and the amount of odour emitted based on data obtained by Warren Spring Laboratories by analysis of questionnaires sent to Local Authorities. The relationship is:-

$$d\ max = (2.2E)^{0.6}$$

where d max is the distance of complaint, E is the odour emission in m^3/s

$$E = DxF$$

where D is the dilution to threshold of an odour and F is the flow rate

The relationship is a tentative one subject to error in a range $(0.7E)^{0.6}$ - $(7E)^{0.6}$ and should not be used for weak odours below a value of D below 500. The source should be from a point or small area and be isolated from other odours emitted in its vicinity.

This paper is a summary of the opinion of leading British proponents of air pollution modelling but no attempt has been reported to test its conclusions by a survey in the vicinity of an operating sewage works. Indeed Keddie argues that such fieldwork is impossible as sufficient resources are unlikely to be available to quantify the emission of odours from a large number of sources that are each likely to vary with time. Furthermore within a complex site such as a sewage works, even the isolation of a single source for measurement without interference from neighbouring sources is extremely difficult. Under such circumstances the input data into the model is suspect and fieldwork is likely to be inconclusive. However in the particular case studied it was possible to use knowledge of atmospheric dispersal to overcome some of the difficulties and use an odour model that gave results broadly consistent with the pattern of complaint about an operating plant.

This paper is certainly a useful contribution to the literature of odour modelling as it suggests that relatively simple, well established methods of atmospheric dispersal model can be adopted to give useful predictions on the impact of odourous emissions on the surrounding environment. Further this work has been done at a Government establishment whose expertise is readily accessible to Local Authorities.

8.10 Penalisation of the Environment due to Stench

This work (2) has been referred to previously in this thesis in the context of public complaint which is the output of the model and is a remarkable example of the successful application of such techniques.

Clarenburg starts his paper with a pain staking definition of the concepts he introduces. Thus stench is the chemically undefined smell that is the cause of complaint; penalisation is the "bother" experienced by people exposed to stench; and "penalisation of the environment applies to the situation in the area being considered when averaged over a year and encompassing a number of meteorological conditions with their associated "penalisations"

Clarenburg's model is based on a standard Gaussian plume method and indeed in calculation the values of some variables are taken from standard works describing such procedures. Such equations enable the concentration of a pollutant to be calculated at ranges downwind of a source. However Clarenburg does not do this but in place of concentrations he introduces a further relationship that estimates the number of people in an exposed population that perceive a stench. This has the form of a log normal distribution and includes a variable, 6g that is the geometric standard deviation of the distribution which Clarenburg suggests in an odour characteristic that assumes different values for different odourous compounds.

Clarenburg introduces a parameter that he calls a "nuisance parameter" that has a complex form but has the effect of quantifying the amount of stench emitted from a source. Using this parameter it is possible to relate the threshold distance downwind of a source where complaint ceases to the geometric standard deviation.

Clarenburg's model is obviously a complex model employing 32 defined variables and several concepts unique to the modelling of odour complaint. Inspite of these difficulties this model is a considerable simplification of a complicated situation in which odour emission atmospheric diffusion and socio-economic behaviour are all brought together in a mathematical form. Clarenburg was not content with an intellectual exercise but tested his conclusions by fieldwork in five towns which was so successful that the model became part of a statutory legal standard for odour emission in the Netherlands. Correlations between calculated and predicted complaints exceeded 0.90 in 4 of 5 cities studies inspite of different industries, different source geometrics and complex terrain, and in three cases coefficients exceeded 0.97

The effectiveness of this model is remarkable, particularly as atmospheric diffusion modelling is often quoted as having an accuracy no better than a factor of 2 (60). It is thus surprising that Clarenburg's work does not appear to have been quoted in any subsequent publication on atmospheric diffusion modelling, for instance Pasquill's text book (60), or in odour pollution for instance the Warren Springs Guidebook. Possibly odour is not a common topic in pollution modelling but other relevant applications would be those where the response to a pollutant is in the form of a statistical relationship such as LD_{50} for toxic substances or "puffs" of a toxic gas cloud.

Penalisation modelling is a useful model for local authorities to use in tackling problems of Pollution Control although the concepts and operations of a model are not easy to master. At the time of writing the paper Clarenburg was employed by the City of Rijmond Authority and thus was a local government officer who seemed familiar with the problem of public complaint and used telephoned complaints or door-to-door surveys as a tool to measure odour pollution. This tool, as Clarenburg argues in his paper, has a number of applications relevant to strategic planning about an industrial area.

8.11 Summary

The mathematical modelling of the atmospheric dispersal of odorous plumes presents a challenge to conventional plume dispersal theory because the character of odour perception requires the peak concentrations of odour to be calculated and these may persist for only a few seconds. Conventional treatments are geared to estimating average concentrations over a period of minutes or hours. Four approaches have been successfully used that are:-

a) An empirical approach in which odour dispersal about a particular type of source is estimated by comparison with other examples of a similar character.

b) Straight forward application of a conventional dispersal model with an odour emission rate based on detectability substituted for the mass emission rate of conventional treatments.

c) A modified conventional treatment with extra parameters added to account for the peculiar characteristics of odour perception.

d) Special case variants of dispersal models, sometimes known as "meandering plume" models that enables peak concentrations of odorants to be directly estimated.

Examples of all treatments have been discussed and its is apparent that not only is odour modelling feasible, but that it is very successful. The approach of Clarenburg in particular is remarkable in the exactitude of the prediction that uses a dose-response function on the basis of theoretical relationships of odour dispersal, odour perception and socio-ecomic factors in an exposed population.

CHAPTER 9

9. Application of Odour Modelling in the Wrekin District

9.1 Introduction

The most visible feature of iron foundries are the tall, top heavy stacks that are often grouped in pairs and from which are emitted plumes of "smoke" with colours ranging from white, through brown to black. These emissions disperse with reluctance leaving a long tail of blue fume which rolls along the ground and is associated with an unpleasant acrid odour.

These stacks are cupolas that are vertical shaft furnaces in which batches of scrap iron are melted with limestone as a flux and coke as a fuel. The exhaust gases are carried up the shaft into a wet arrestor that sits on its top and gives the cupola its top heavy appearance. The hot gases are deflected by a conical baffle, pass through a water curtain and then an expansion chamber, so that much of the grit burden and most of the sulphur content of the exhaust gases are removed. However the efficiency for removal of fine particles and many gaseous pollutants is low and, after water scrubbing, the plume is cool and saturated so that it tends to sink towards the ground.

The distinctive odour of a cupola plume does not appear to have been analysed for its chemical constituents but it is possible to speculate on the organoleptic species present. These will be

Fig 9.1 Map of the Foundry and its Neighbourhood

Aston University

Illustration removed for copyright restrictions derived from the combustion process and its by-products and from oily contaminants present on the surface of the charge of scrap iron.

Carbon dioxide is the major pollutant and although odourless it is a nasal irritant that is active in olfaction (64). Nitric oxides are present as a by-product of combustion and these have a pungent odour as also do the aldehydes such as acrolein or formaldehyde that result from incomplete combustion or hydrocarbons released from the coke or oily residues in the scrap charge. Traces of organic sulphides are also present in the coke and, although these would be largely burnt in the cupola shaft, traces of these extremely potent odourants may still emerge in the cupola plume and contributes to its characteristic stench. In character this is similar to diesel engine exhaust being pungent-smoky although lacking the oily tone. If this analogy is correct then cupola fume may be a complex chemical mixture for 2000 components have been identified as contributing to the smokey character of diesel fume (65).

9.2 The Site

The foundry being investigated occupies a large square site of about 17 hectares on a level terrace cut into the northern slopes of the Central Telford Plateau. To the south the site is overlooked by an embankment carrying a motorway; to the west is a steep sided dingle and a further road embankment with a spur of high ground rising above it; to the east there is a further spur of high ground and to the north the ground falls away gently. The site is thus open to the north but enclosed on all other sides by rising ground.

No residential neighbourhood immediately adjoins the Foundry but 5 distinct communities surround it on 3 sides and only to the South is there open land, mostly in agricultural use. The closest neighbour is an industrial estate east of the foundry occupied by a large modern news printing works and a large Civil Engineering Depot with an attached factory estate. A map of the locality is shown in Figure 9.1

9.3 Foundry Operations

Within the foundry are 11 cupolas, 10 of which are grouped in pairs of which 9 were operational at the time of the investigation. Observation suggested that only 4 would be melting iron on any single day with the other in the pair being under maintainance as is normal practise in the Foundry industry. The height of the operating cupolas varied between 60 and 80 feet, and their melting rate was about 4 tonnes of iron an hour. The odd cupola was a small 1 tonne an hour unit, 12 metres used only to produce metal for specialised ornamental castings using a clean charge of pig iron or foundry return. Operating cupolas melt iron on 5 days a week from 7.00 a.m. to 3.00 or 4.00 p.m. thus there is no evening, weekend or bank holiday working. The foundry shuts down for a fortnight in early August and for a week at Easter and again in late autumn.

The foundry also operates a bitumen plant to dip coat the products of the foundry and the creosote like odour of this can occasionally be smelt outside the boundary of the site, particularly on a calm evening when the cupolas are not operating.

The Foundry is a well recognised source of local pollution (66) but surprisingly has not generated very many complaints, only 2 or 3 are received annually. This apparently low level of annoyance may reflect the tolerance of the local population for traditional industry which is a major employer of residents in the surrounding communities. However the Foundry is employing fewer people than it has done in the past, new businesses are opening in its neighbourhood, new housing estates have been built close to it and more are intended. Thus the socio-economic circumstances of the district are changing and the pattern of complaint may change at any time. Hence an investigation of the factors that spread cupola fumes through surrounding neighbourhoods and the potential for complaint that exist there are the worthwhile objects of an extensive investigation.

9.4 Details of the Dispersal Model

Atmospheric Dispersal Modelling can be a complicated exercise requiring a considerable amount of mathematical and meteorological expertise to achieve satisfactory results. Fortunately there is an excellent introductory Workbook written by D. B. Turner and published by the US Department of Health, Education and Welfare. (60) This text formed the base of Balling and Reynolds approach to odour modelling (59) which in turn is the base of the model to be discussed.

a) <u>The Basic Equation</u>

For sampling times of 10 to 30 minutes the average ground level concentration, C at any distance downwind from a chimney is given by an equation.

$$C = \frac{Q}{\pi \sigma_y \sigma_z U} \exp\left[-\frac{1}{2}\left(\frac{Y}{\sigma_y}\right)\right] \left(\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma}\right)\right] \right)$$

Where Q is the mass emission rate, σ_y and σ_z are the standard deviation of plume dispersal in the vertical and horizontal axis, Y is the distance cross wind from the downwind axis, Z is the height above ground, H is the height of chimney and U is the wind speed. The magnitude of the variables σ_y and σ_z vary with distance and their magnitude is obtained from graphs reproduced in the workbook.

Examples of the application are given by Turner and also by Nonhebel (67) whose textbook discusses its relevance to difficult topographies often encountered in practical circumstances.

In the case of ground level sources and points immediately downwind the standard equation is simplified to:

$$C = \frac{Q}{\pi \sigma_y \sigma_z U}$$

9.5 Variables used in the Model

The Height H

This is the effective stack height at which an emitted plume becomes level. It is normally higher than the physical height of a chimney due to the bouyancy and momentum of the gases emitted. Considerable controversy surrounds the choice of an appropriate formula for its calculation and the one recommended by Turner is that due to Holland which is

$$\Delta H = \frac{V_s d}{U}\left(1{\cdot}5 + 2{\cdot}68 \times 10^{-3} P \, \frac{T_s - T_a}{T_s} d\right)$$

where H is the plume rise, Vs is the exit gas velocity, d is inside stack diameter, U is Wind speed, Ts is stack gas temperature, Ta is ambient temperature and P is atmospheric pressure (mb) and 2.68×10^{-3} is a constant. This formula was incorporated in the model as an option although observation of cupola emissions, that are cool and damp, indicated that plume rise was negligible in all but the calmest of conditions and that any taking place was best estimated and entered into the model.

C, The Ground Level Concentration

In the standard calculation this is the ground level concentration of pollutant but in the odour model represents the detectability of odour in terms of dilution to threshold. Curiously the use of a dilution factor is recommended by Nonhebel as part of the standard procedure since "the concept is better understood by laymen"

Q, The Emission Factor

Instead of Q being measured in g sec $^{-1}$, it is expressed as the emission rate, $E(m^3s^{-1})$ which is the product of detectability (thresholds to dilution (D)) and emission rate. Thus:-

$$E = DF$$

There is a difficulty in quantifying D since this is not an intrinsic property of an odour but is a subjective characteristic strongly influenced by the methodology of its assessment, as has already been discussed. Few local authorities have the equipment or expertise necessary to make an assessment in the laboratory. Furthermore there are problems in relating the laboratory assessment to actual perceptions of odour in the field, and in selecting suitable weighting factors to be included in the Gaussian equation to reflect the peak to mean ratio of a ground level dilution, and in making a decision as to whether a threshold level is to be the criteria of detection or the recognition level that may be a better indicator of nuisance.

A simple resolution of this problem is suggested by the use of the equation that relates the maximum distance (d max) of complaint to the odour emission rate (E) Thus:

$$d\ max = (2.2E)^{0.6} = (2.2DF)^{0.6}$$

This relationship is a tentative one developed by the Warren Springs Laboratory on the basis of a survey they conducted of the complaint pattern surrounding strong sources of odour emissions.

Rearranging

$$\text{Log } E = 0.6 \, [\text{Log } d - \log (2.2)]$$

It is suggested that E is a good quantification of stench, that is an odour of undefined chemical constitution, that is a cause of public complaint. Thus E can be substituted in the Gaussian Equation without the need to consider weighting factors or subjective factors indicating the potential of an odour to cause complaint. It is a composite parameter incorporating elements of detectability, intensity, quality and character.

The Wind Speed

Wind speed increases with increasing height above ground level because of the effect of drag caused by obstruction on the ground, decreases with height. The wind speed should be assessed at the point of emission of the odour which in the case being considered is the cupola top, according to the relationship

$$U(Z) = U10 \, (Z/10)^n$$

where $U(Z)$ is the wind speed at height Z and U10 is the wind speed at a height of 10 metres; n is dependent on surface roughness although a value of 0.25 is widely used.

Classification of Atmospheric Turbulence

Atmospheric Turbulence is caused by two major mechanisms:-

1. Roughness due to obstacles on the surface of the ground such as hedges, trees, buildings and hills cause ripples in the air passing over them.

2. Incoming solar radiation generates bouyancy in air close to the ground by warming the ground surfaces and bubbles of warm air float upwards in the atmosphere. At night thermal effects are supressed and if the sky is clear, ground level cooling may be considerable and thermal turbulance is quenched completely.

A typing scheme has been developed by Pasquill (68) that is simple to use yet based on sound theoretical principles, thus:-

TABLE 9.1 CLASSIFICATION OF STABILITY CATEGORIES DUE TO PASQUILL

10 metre wind speed (U_{10})	Insolation			Night	
	Strong	Medium	Slight	Overcast or thin cloud	Heavy Cloud
<2	A	A - B	B	---	---
2 - 3	A - B	B	C	E	F
3 - 5	B	B - C	C	D	E
5 - 6	C	C - D	D	D	D
>6	C	D	D	D	D

Strong insolation corresponds to a sunny summer mid-day in the UK, and slight insolation to corresponding conditions in winter. Night is the period between 1 hour before sunset and 1 hour after dawn. A is the most unstable category, G the most stable, and D is neutral and is used whenever the sky is overcast. For this reason D category is the most common condition with an annual frequency of occurrence of 60%.

In consequence of the stability categories the graphs of vertical and horizontal dispersion coefficients consist of 6 lines representing each stability category. The coefficients themselves are derived from observations of the dispersal of smoke "puffs" over level moderately rough country and they might underestimate dispersal in terrain of greater roughness such as urban areas.

In the odour model the product of the coefficients 6Y, 6Z is calculated by the use of a relationship of form

$$Y = M \log X + C$$

where M and C are coefficients that vary with stability category. The linear form is an approximation that is good for short distances below 1Km and for intermediate stabilities of classes B to E. For categories A and F significant departures from the approximation occur at distance over 1 kilometre.

9.6 Building Effects

When a chimney has a height less than 2½ times the height of an attached building, any plume emitted is trapped in the aerodynamic disturbance caused by the building. Downwash causes the plume to drop swiftly to the ground where it is trapped in the turbulence existing in the lee of building. This increased turbulence dies away as the distance downwind increases until it merges into the ambient turbulence that would have existed in the absence of the building. Fackrell (69) has discussed the manner by which the horizontal and vertical dispersion coefficients of the Gaussian equation can be modified to account for the effect of a building.

A method suggested by Huber was incorporated into the model and has the form

$$\sigma_y' = (\sigma_y{}^2 + CA/\pi)^{2}$$
$$\sigma_z' = (\sigma^2 + CA/\pi)^{2},$$

where σ_y', σ_z' are the enhanced coefficients, C is a constant between 0.5 and 2.0, and A is the cross sectional dimension of the building normal to the wind. The value of C reflects the degree of entrainment of the plume in the turbulent wake of the building and a value of 1.0 was used in the model to reflect the fact that the cupola emission is from a source elevated above the attached building.

The mathematical characteristic of the relationship is to achieve maximum enhancement of dispersal coefficients when the σ^2 term is small compared with the term CA/π , but as distance increases the magnitude of σ^2 then the second term makes an ever diminishing contribution.

9.7 Inhibition of Dispersal by a Mixing Layer

The dispersal of pollutants released close to the ground takes place in a layer of the atmosphere that is mixed by aerodynamic and convective forces that are influenced by meteorological factors. This layer is called variously the boundary layer, mixing layer or Ekman layer. The air in the mixing layer is turbulent, that above it is stable and a distinct boundary exists between the two that is virtually impenetrable to pollutants. A plume of pollution is thus trapped between the "lid" created by the boundary layer and the surface of the ground and spreading of the plume in a vertical axis is thus limited and is assumed to be reflected from the two impenetrable boundaries. Under these conditions a special case of the Gaussian Equation applies that should be used at distances greater than 0.94L with L the height of the mixing layer in metres.

The relationship is:

$$C = \frac{Q}{\pi \sigma_y \sigma_{zL} U} \left[\exp - \frac{1}{2} \left(\frac{Y}{\sigma_y} \right)^2 \right]$$

where $_zL = 0.81$

The height of the mixing layer varies with meteorological factors and although it can be estimated by acoustic methods there is a nomogram available that has been developed by Pasquill (68) and this was used.

9.8 Input Data

The foundry does not generate much complaint although it is locally recognised as a significant source of pollution (66). However there has been persistent complaint of cupola fume from a school situated 0.8 kilometers east of the site and this distance was substituted into equation so that the emission of stench could be calculated and was found to be 40,000 $m^3 s^{-1}$

The 4 pairs of cupolas are approximately situated at the corners of square of size 100 metres and it was thought that this configuration could be approximately modelled by the assumption of a point source, particularly as plume spreading is enhanced by increased turbulence of the buildings and the observation of the plume was conducted outside the boundaries of the foundry site at a distance of at least 200 metres from the pseudo source.

Meteorological observations relevant to the model were as follows:-

Wind; Speed and Direction

Speed was assessed according to the Beaufort Scale (70) which assigns a number to a number of wind characteristics related to speed and relates these to corresponding observations of the effect of wind. It is a scale well known and widely used in meteorological circles.

Wind direction was estimated by observation of the extension of a flag flying from a 10 metre flag staff in the grounds of the printing works on the north eastern boundary of the foundry site.

Humidity

This was simply noted as wet, which included falling rain or recent rain with wet surfaces still present, or dry

Temperature

This was measured by thermometer.

Atmospheric Pressure

This was taken by reference to the local newspaper and was the reading observed in Shrewsbury.

Cloud Cover

This was assessed by observation of the sky.

Stability Category

This was assessed by reference to Table 6V (68).

Boundary Layer

This was estimated by reference to the nomogram published on page 139 (68)

Cupola Operation and Plume Rise

The number of cupolas operating at the time of observation was noted, and also whether the plume was rising, falling or level.

Photography

At the time of observation a photograph was taken from a disused pit mound overlooking the foundry and about 1 kilomtre east of the site. It provided a permanent record of the daily observation.

Daily Observation

A special sheet Appendix 1 was prepared on which the daily observations were recorded. This included a reproduction of a 1:25,000 map of the foundry and surrounding neighbourhood. Each day the odour plume was located and its boundaries plotted on the map by walking through the area and noting where the odour could be smelt.

Daily observations were made throughout the autumn of 1984 commencing on 6th August and finishing on 20th December, a total of 79 records.

9.9 Outline of the Stench Dispersal Model

A complete description of the program used to compute the mathematical model of odour pollution is given in Appendix 2 but an outline of its functioning is necessary.

The full Guassian dispersion equation is broken down into three elements that are then combined to give the required result. One element calculates the dilution of stench at a receptor point located on the plume centralised directly downwind of a ground level source. The second element introduces a correction required for an elevated source, and the third element modifies the result when the receptor lies at a distance away from the plume centre line. Sub-routines within the program calculate the magnitude of the vertical and horizontal mixing coefficients that continually vary with distance from the source and with atmospheric stability. There is an option to modify these coefficients to allow for the increased turbulence caused by building. A special case calculation is introduced for receptors that are influenced by reflection of the plume from an inversion layer.

Graphic routines are incorporated within the program that enables the output of the model to be displayed on a screen or printer. Account is taken of wind direction to indicate the spread of colour plume downwind across a grid with a point source depicted in its centre. The data generated by daily inputs is stored so that a map of odour day frequencies is compiled and is the final output of the model. An "odour day" is simply a day on which a stench is calculated or observed to exist at a given location.

Not too much confidence should be placed in the predictions of this model unless these are verified by observations made "in the field". Discrepancies then revealed may be minimised by adjustments to the inputs of the model; a process sometimes called "calibration".

9.10 Testing and Calibration of the Model

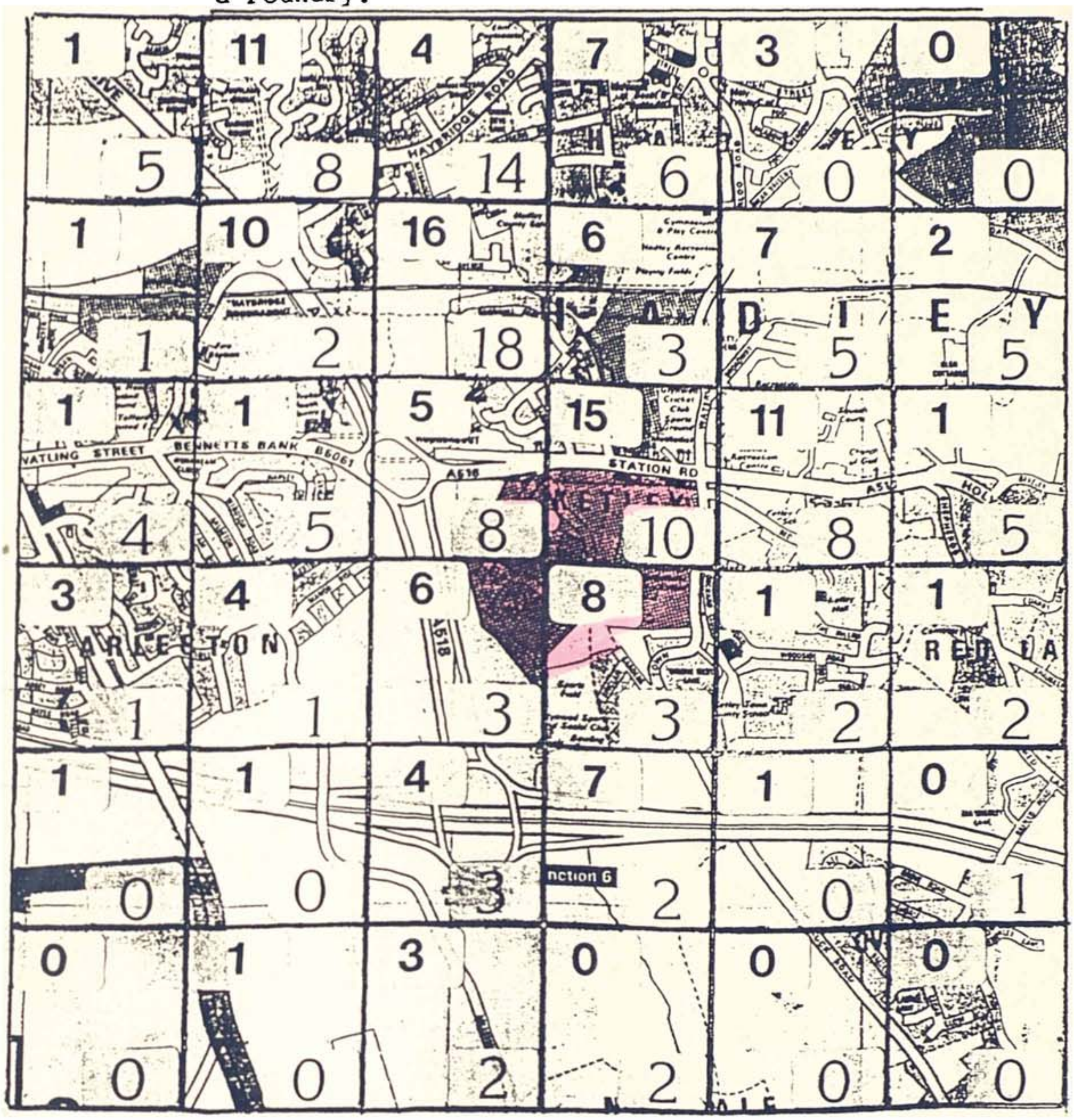
The spread of cupola stench through the neighbouring communities had been observed daily on week days over a period of 4 months from August through to Christmas giving 77 days of observations. These maps were transposed on to a transparent overlay marked as a grid so that the daily observations assumed a form similar to that generated by the model.

A problem of fieldwork is that the odour plume could only be observed in places where there was public access, because of the constraint imposed by the law of trespass. Thus matching of predicted against observed data is not possible in every cell of the grid.

Calibration of the model produced a good match between prediction and observation for model inputs of 80,000 units of stench and an effective chimney height of 25 metres. The results are shown in Figure 9.2

The matching of the data was good with exception of the quadrant to the South East that covers the Orchard Close Estate. This neighbourhood was also found to be anomalous during the Social Survey to be reported later in this thesis. It became obvious that residents in this estate perceived a different character of the Stench than those interviewed elsewhere. It is likely that a nearby pipe dipping plant is emitting tarry odours and these are perceived in Orchard Close and nowhere else and that a similar confusion occurred during daily observations. At levels close to the threshold the acrid odour of tar or creosote is similar to that of cupola fume.

Fig 9.2 Grid matching predicted Odour Frequencies and observed Odour Frequencies in the neighbourhood of a Foundry.



Roman Script = Predicted Odour Day Frequencies

Itallic Script = Observed Odour Day Frequencies

1) To accept the present strength of odour emission but achieve improved dispersion of it by the erection of taller chimneys.

2) To reduce the strength of odour emissions although the means of achieving this are not yet apparent.

9.11 <u>Reduction of Odour Days by Increases in Chimney Height</u>

The use of tall chimneys allows a greater dilution of emissions to be achieved when they eventually touch the ground because of improved dispersion. Tall chimneys can also penetrate low level inversion layers that trap ground level emissions below the inversion and lead to episodes of gross pollutions. However emission released from chimneys above the inversion cannot penetrate the inversion and so are stopped from contributing to ground level pollution.

Chimneys are a favoured method of pollution control since once built they do not incur running costs of power or chemical consumption and require little maintainance. However their effectiveness is variable being determined by meteological factors and they can be substantial structures requiring deep foundations for their support. Thus they are costly to construct and often being structures over 45 feet in height require planning consent which might be given reluctantly as chimneys are not considered to be desirable architectural forms. Thus any proposal to construct a chimney should be backed by evidence to indicate its effectiveness.

The model was used to predict the odour day frequencies in neighbouring communities for effective chimney heights varying from a nominal ground level emision of one metre to the almost excessive height of 100 metres. The necessary meteorological data was provided by the 77 daily observations, and building effects were incorporated in the model for heights less than 50 metres. The results of the model's predictions are shown in the following table and are based on 100 intersections in a grid of 4 kilometres square.

TABLE 9.1 THE EFFECT OF DIFFERENT CHIMNEY HEIGHTS ON ODOUR DAY FREQUENCY

Chimney Height (metres)	Total Odour Day Frequency
1	416
25	361
35	295
50	216
100	108

Two particularly significant heights are those of 25 and 35 metres. The lower one corresponds to the existing cupola heights, where the higher one is recommended in the Cupola

Memorandum (80) for instances where cupola fume is a problem.

The results in the table suggest that an inverse square relationship exists between chimney height and odour day frequency and this is predicted by the simple Sutton Formula (14). There are benefits to be obtained from increasing the height from 25 to 35 metres in the form of a decrease in odour days from 361 to 295 and with a further increase to 50 metres a reduction to 216 odour days is achieved. However the benefits are small with considerable potential for nuisance remaining while the cost incurrred would be considerable as 4 chimneys are necessary to serve the 4 pairs of cupolas. If the existing structures have foundations insufficient to support the required extension then new chimnies will have to be constructed at a total cost in a range £100,000 - £250,000.

The term "effective chimney height" is widely used in the discussion of chimney performance and refers to the additional height achieved by emissions leaving a chimney as a consequence of their momentum and thermal bouyancy. This bonus height varies with meteorlogical conditions and can be calculated by various expressions. In the case of cupolas the extra height gained is minimal as the emissions emerge from the wet arrestors as a heavy water saturated plume with a low exit velocity. However in exceptionally calm anticylonic conditions it is possible to see the cupola rising to a great height but such occurrences are rare.

9.12 The Reduction of Odour Days caused by Decreased in Source Strength

The model was used to predict the total odours days in the surrounding community resulting from vibrations in the value of stench. These ranged from 10,000 to 100,000 and the necessary meteorological data was that observed on the 72 days of observation. The results are shown in Table 9.2 and are based on 100 intersections in a grid of 4 square kilometres.

TABLE 9.2 THE EFFECT OF VARIATION IN EMISSION OF STENCH ON ODOUR DAY FREQUENCIES

Units of Stench (m^3/sec)	Total Odour Day Frequencies
10,000	34
20,000	106
40,000	190
80,000	361
100,000	445

The results suggest that the areas experiencing odour is directly proportional to the strength of odour emission so that halving the emission rate will halve the odour frequency in the community surrounding the source. However, the means by which such predictions can be achieved is not apparent at present.

Procedures such as maintaining a flame in the cupola shaft, or failing that, the use of after burners in the shaft, are recognised techniques for reducing visible emissions but their effectiveness for odour control is now known, although they are likely to be beneficial.

9.13 Errors typical of Stench Dispersal Model

Errors in the variables of model will obviously lead to error in the output and equally obvious it is necessary to quantify these and assess which variable is the most critical. Freeman et al (77) have investigated error propogation in the Gaussian Dispersion Model by deriving a propagation formula and testing its results against several thousand trials of the model in which variables were randomly varied.

The magnitude of errors investigated reflected the uncertainties of practical circumstances being 20% for mixing coefficients, boundary layer height and chimney height; 10% for source strength, and wind speed, 3% for wind direction.

The conclusions of this work is relevant to the odour model developed in this thesis and were as follows:-

a) Along the downwind axis:-

1) Uncertainties in the region close to the chimney, less than 10 chimney heights, are of a magnitude different to those in the region beyond. This is due to the dominant influence of the

chimney, itself accounting for over half the total uncertainty, and the very minor influence of wind direction so close to the source. At distances beyond 20 chimney heights the influence of the chimney becomes vanishingly small but wind direction uncertainty increases in magnitude.

2) Total uncertainty as a percentage of calculated pollutant concentrations decline rapidly to a minimum at about 20 chimney heights but thereafter tend to increase.

3) At distances 20 chimney heights and greater the dominant uncertainty is wind direction and this increases with distance.

4) Beyond 20 chimney heights the second most significant uncertainties were introduced by the combined effects of the vertical and horizontal mixing coefficients.

5) Uncertainties associated with the source strength, wind speed and mixing height are small

b) <u>Across the width of a plume</u>

1) Total uncertainties increased with distance from the centre line so that at a point where the concentration became 20% of the centreline concentration the total uncertainty becomes equal or greater than the predicted concentration. By convention the width of the plume is taken to be the point at which the pollution concentration declines to 10% of that at the downwind centreline, but it would be more appropriate

improving the quality of decision making. If errors are made then as Young recommends (56) the model is corrected and, may be the next time it it used, success is achieved.

9.14 Discussion

The mathematical modelling of odour dispersion about the foundry has proved to be possible to a degreee of accuracy that gives confidence in its use as a tool to explore options of control. The predictions of the model yielded no surprises and are those that generally would be expected by use of commonsense. Thus the raising of cupola chimneys to the maximum recommended height improves dispersal of the emitted fumes and benefits most the industrial areas close to the foundry by reducing odour days they experience, but there is little such reduction in the more distant residential areas. Decreasing the strength of the stench emitted produces a directly proportional reduction in the areas effected by stench and this measures benefits both industrial and residential areas. The desirable reduction would be to 1/4 of the present emission, equivalent to the retention of one pair of the present 4 pair of coke fired cupolas. Alternative methods of metal melting use electric or oil fired furnaces but a move to these is unlikely if the only reason for doing so was to reduce pollution. The alternative of operating cupolas to reduce odour cannot at present be considered due to a lack of knowledge about the chemical mixture of odorants emitted from the cupola top.

9.15 The Social Survey on the Perception of Pollution about a Foundry

The Foundry is the same one that was the subject of the Odour Modelling Exercise. It is surrounded by a community, that in terms of complaint, seems oblivious to the the pollution emitted even though the fumes and smell associated with the foundry's activities are recognised by visitors to its neighbourhood. The traveller John Hillaby (71) refers to its smoke "drifting about the Wrekin". The Wrekin Council in a report upon the Quality of Life in its District (66) remarks that:

"The environmental nuisances, such as factory (foundry) smoke and smell, noise or eyesore are often generated by a single source but effect a large area"

A number of explanations can be advanced for the apparent tolerance of the neighbouring community and the following are some of them:

1. Residents may not perceive the pollution they are exposed to because:-

i) They are not at home when the foundry is operating which are Monday to Friday 8.00 a.m. to 4.00 p.m.

ii) If at home they have become habituated to the presence of fume and smell.

2. Residents perceive the pollution but are inhibited from complaining because:-

i) They or their family are economically dependent on the foundry.

ii) They do not know who they should complain to.

iii) By nature they are imperturbable.

3. Residents do complain but complaints are not received by the relevant Council Officers.

These issues can only be resolved by interviewing residents and asking for their opinions and attitude to the air pollution they experience in their neighbourhood. Such an exercise requires care in its presentation and structure if statistically valid conclusions are to be reached. The pit falls that lay in wait for an unwary social researcher are described in text books on the subject and these often warn that questionnaire design is as much an art as it is a science. It is hoped that the worst errors have been avoided in the questionnaire designed in this survey by basing it on similar successful work that has been reported by other researchers (20) who have been active in the field of environmental annoyance.

The major constraint on the design of questionnaires were dictated by the resources in manpower available to execute the investigation. The sample of households to be interviewed was to be 100% of the communities that were immediate neighbours to the foundry and so received the full affect of its emissions. These numbered approximately 500. By using an interview methodology that would be completed on a doorstep within 5 minutes allowing for a 25% response rate after 2 call backs it appeared that 1 person could accomplish the survey within 4 weeks, working a 4 hour day. This enabled this work to be done within a reasonable period during normal office hours and still leave time for other duties to be done.

The questionnaire was structured in a form that would appear to the respondent to be clear in its intentions and simple to answer. Thus it was hoped that a rapport would be easily established between interviewer and respondent which would benefit the reliability of the responses. Confused questionnaires and harassed or disinterested respondents would be unlikely to give truthful or considered replies.

The final questionnaire took the form of three A4 sheets each using a different technique to tackle a different aspect of the research.

9.16 Questionnaire, Sheet 1

This first sheet reproduced in Appendix 3 was designed as recommended by Creer at Al (20) to test their hypothesis on the role of cognitive dissonance in explaining the differential behaviour of people exposed to air pollution.

Cognitive dissonance is a theory developed by social scientists who observed that in many facets of human behaviour people cannot tolerate prolonged inconsistency betweeen their actions and beliefs without experiencing a strain that brings about a distortion in their perception of a problem that acts to reduce the inconsistency. It provides the theoretical base to statutory attempts to modify peoples behaviour in fields such as racial prejudice and equalities of opportunity. Applied to industrial air pollution problems this theory suggests that an employee of a company causing pollution has to justify his position when faced with consequences of his employment. In extreme cases he or she might resign their employment, but since this would involve hardship then the alternative is to perceive a less serious pollution problem and a greater effort to control it than might actually be the case.

Question 1 The Cognitive aspects of Air Pollution

"What do you think the words "Air Pollution" mean to most people in your neighbourhood"

The first question was designed to instantly indicate the purpose of the interview to a respondent by asking people to indicate their experience of air pollution. The indirect format with a reference to other people is good practise when asking a

Question 2. Awareness of Pollution.

"Do you think that air pollution is often present in your street?"

Awareness is the simple recognition of a Pollution Problem and was estimated by a simple Yes/No response to the Question asked. This resulted in 54 respondents agreeing that pollution was a frequent occurrence and 45 disagreeing. Thus there appears to be a high degree of awareness of pollution.

Question 3. Degreee of Concern

"How bothered are you by air pollution?"

Concern was equated with more familiar word "bother" and people were asked how bothered they were by pollution with the following results.

TABLE 9.5.2 DEGREE OF CONCERN EXPRESSED BY POPULATION

Degree of Bother	No. of responses
Very Much	25
Little	48
None	25

There is an obvious symmetry to this response raising the possibility of the well known phenomenum that people tend to dislike the expression of extreme views and favour moderate responses. However the straightforward interpretation of this Table is that the community about the foundry is considerably bothered by pollution, 73 respondants of 98 expressing some degress of concern.

Question 4. Recognition of Sources of Pollution

Outsiders recognise the foundry to be the major source of pollutant but residents might take a different view. The question concentrated on Industrial Pollution which is the responsibility of the Council to control and asked people to select those industrial activities they believed to cause pollution and 93 respondants of 98 identified the foundry. Thus whatever the level of awareness or concern expressed by respondents the overwhelming opinion expressed by residents was that the foundry was the major polluter of the area.

Question 5. Economic Dependence

"Do you or any member of your family work in "local industry"

This question sought to identify the number of households with a member employed in local industry and is relevant to testing the hypothesis of cognitive dissonance. Of the 19 households with such an economic dependence 11 had a member employed in the foundry, the rest being ex employees, mainly retired. Of course many households who failed to respond were not present when called upon and were likely to be all at work at the time the visit was made. No attempt was made to call during leisure hours to sample this population since these people would not experience the pollution of the foundry to the same degree as those present during the day since the foundry operates on a 8 hour day, 5 day week regime, from 8.00 a.m. to 4.00 p.m. Thus the response will underestimate the economic dependence of the total community upon local business.

Question 6. Control Potential

"Do you believe an effort is being made to reduce air pollution caused by local factories"

Again this question is required for testing of cognitive dissonance and it asked people to indicate their expectation for abatement of the pollution they experience with the following results.

TABLE 9.5.3 EXPECTATION OF POLLUTION CONTROL

Degree of Control Possible	Response
A lot	25
A little	41
None	32

The obvious deduction gained from these results is that the community has a high expectation, 66 of 98 responses, of the potential of pollution control and conversely that the present degree of control falls short of what is believed to be possible.

Question 7.

"Do you believe that the amount of air pollution can be reduced?"

This question tackled directly the issue of the perceived effort of industry to tackle pollution and a simple yes/no response was invited. The replies were Yes 54; No 44; again indicating that a large proportion of the residents considered that a greater effort could be made to control pollution.

Question 8. Understanding of UK Pollution Control Organisation

"If you wished to make a complaint then who do you contact?"

It is important that, once motivated to complain, a complainant should have the complaint registered directly by the specific authority or preferably the particular person who will be investigating it. In a large and complex organisation, such as a District Council, the complaint may go astray unless the complainant has sufficient knowledge to know which part of the organisation is likely to deal with the complaint. In most Councils a pollution complaint would be handled by the

Environmental Health Department, but the Departmental organisation of Council can vary and such is the case in the Wrekin Council where the Pollution Control function operates within the Planning and Enviromental Services Department.

It is also possible that many people are ignorant of the Pollution Control function of the Council and thus complaints may be directed to other organisations. Hence the purpose of this question is to explore people's knowledge of the organisational aspects of statutory pollution control.

TABLE 9.5.4 AUTHORITIES LIKELY TO RECEIVE COMPLAINTS OF AIR POLLUTION

Authority	No. of Respondents
Factory Inspectorate	6
H.M. Air Pollution Inspectorate	16
The Police	3
Council (Environmental Health)	53
Local Councillor	27
Citizens Advice Bureau	4
Health and Safety Executive	9
Council (Planning & ES)	3

A casual inspection of the figures suggest that the Wrekin Council Organisation is not effective for the receipt of complaint about air pollution, only 2% of respondents identifying the Department that operates the pollution control function of the Council. However 44% would have asked for the Environmental Health Department and should have been correctly redirected by the post room or switchboard to the correct Department. A further 22% of respondents would have directed their complaints to a Councillor who should have initiated an investigation. Thus overall about 68% of respondents identified the Council's responsibility for pollution control so that ignorance of this function cannot explain the observed lack of complaint.

This view is reinforced by fact that although the Pollution Control Section has been featured in the Council's Newspaper delivered free to householders and officers have been named in accounts of prosecution for air pollution offences reported in the local press, no episodes of complaint follow as might be expected if people were searching for an authority to complain to.

Questions 9. and 10. Stability and Educational Status of Community

"How long have you lived in the District?
After leaving school have you been in further education?"

These are characteristics of respondents that have been found in some studies to influence the tendency of respondents to complain and though included in the questionnaire were not used in analysis.

9.17 Comment on Responses reported in Sheet 1.

It seems that there is no lack of awareness of air pollution in the community surrounding the foundry and residents almost unanimously identify this as being a major source of directly perceived pollution such as dust, smell and smoke. A considerable degress of concern about local pollution was expressed by respondants who also showed high expectations about the degress of improvement that could be obtained. In such circumstances a considerable amount of public complaint might be expected but this is not received for reasons that answers to sheet 2 will reveal. If individuals were motivated to complain then there is a high likelihood that contact would have been made with the section of the Council whose duty is to investigate them.

Cognitive dissonance

The following tables summarises the response to the 4 questions relevant to testing the hypothesis of cognitive dissonance; that is that people with an economic dependence on the foundry will tend to be less aware of the pollution it causes; will tend not to be bothered by it; will emphasise the degree of control undertaken; and exaggerate the amount of effort being made to reduce the pollution.

TABLE 9.7.1 AWARENESS OF POLLUTION BEING RESPONSE TO QUESTION 2.

Degree of Dependance	Awareness	
	Yes	No
Total Sample	57	43
High economic dependence	14	2
Low economic dependence	43	41

If the theory of cognitive dissonance applies then respondents with an economic dependance should give a reply indicating a lower awareness of pollution than others without an economic dependence. As will be seen this is not the case and the converse seems to apply.

TABLE 9.7.2 CONCERN WITH POLLUTION AS MEASURED BY THE "BOTHER" RESPONSES TO QUESTION 3

	Reported Bother	
	Some	None
Total Sample	33	67
High Economic Dependence	13	3
Low Economic Dependence	20	64

Question 3 gave a respondent 3 choices of reply being:- a) much bother; b) a little; and c) no bother. The Table indicates a median split with a) and b) indicating some bother, and c) indicating none.

If cognitive dissonance operates, respondants with an economic dependance on the foundry should report a lesser degress of bother than those without this dependence. As will be seen the opposite is the case.

TABLE 9.2.3 CONTROL POTENTIAL FOR POLLUTION CONTROL AS MEASURED BY QUESTION 6

	Reported Expectation of improvement	
	Some	None
Total Sample	36	64
High Economic Dependence	10	6
Low Economic Dependence	26	58

Question 6 as in Question 3 gave a respondent 3 choices and again the Table indicates a median split. "Some" corresponding to a "Lot" or "Little" response and "None" corresponding to a "No Way" response.

The theory of cognitive dissonance suggests that a high economic dependence should cause few of such respondents to report a potential for improvement when these are compared with a similar group of respondents without economic dependence on the foundry. In this survey the reverse response was found.

TABLE 9.7.4 EFFORT TO POLLUTION CONTROL AS MEASURED BY RESPONSE TO QUESTION 7

	Perceived Effort to Control Pollution	
	Yes	No
Total Sample	47	43
High Economic Dependence	10	6
Low Economic Dependence	37	37

Theory suggests that those with economic dependence should perceive a greater effort in pollution control than those without such dependence. This style of response was observed.

It is clear from these responses, with the exception of those in Table 9.7.4 that they do not follow the pattern predicted by the theory of Cognitive Dissonance and are indeed a reversal of those suggested by this theory. Those respondants considered to have economic dependence were more aware, more bothered and had a higher expectation of control potential that those respondents considered to have a low economic dependence. Only in control effort did the economically dependant emphasise the degree of control achieved and since the Foundry does make effort to control its pollution then these respondents might be considered better informed than their independent neighbours.

The results are so strikingly different from the predictions that it is tempting to suggest that "cognitive resonance" may be operating. That is to say that people may resent their dependence on a source of pollution and therefore be sensitive to the disadvantages of living in close proximity to that industry. The recent history of the foundry has been turbulent with its workforce being reduced by early retirement and redundancy so that new manufacturing processes using less labour could be introduced. Thus the insecurity felt by those with an economic dependence on the foundry might be expressed as an antipathy towards the Company.

9.18 Questionnaire Sheet 2

This sheet also reproduced in Appendix 3 visibly employs different techniques for the measurement of human attitudes and is designed to assess the perception and attitude of a respondant towards various pollutants perceived in the vicinity of the foundry; these being smoke, smell and noise. The methodolgy is borrowed from the work of H. Hodgins (82).

The inclusion of smoke and noise in a thesis concerned with odour pollution may seen unwarranted but these are also pollutants that stimulate the human senses and will interact to effect a person's overall perception of the quality of his or her environment. Both smoke and smell are carried on the wind and are dispersed by identical meteorological mechanisms and these are so closely associated that it is of interest to attempt to isolate the role of each in a respondants assessment of the environment.

The first exercise on the sheet employs the technique of magnitude scaling to obtain a subjective assessment of a respondent's concern or bother with a particular pollutant. The respondent is requested to indicate the extent of "bother" by placing a mark anywhere along a line that was divided into 10 equal intervals by faint graduations. One end was labelled "not bothered" and the other "extremely bothered". In the case of the first line used only for training purposes the graduations were more firmly indicated, than in the following response scales.

This technique is subjective as there is no absolute scale of annoyance and no way of knowing what interval scale exists in the mind of a respondent when an assessment is being made. Thus if two respondents place a mark at the same place on the line it does not necessarily mean that they are equally bothered by that pollutant. However, greater consistency is achieved when the scales are compared one against another so that a mark placed at double the distance along one line than a mark placed on another line should indicate double the degree of bother.

The second exercise used the technique of semantic difference to obtain a respondants opinion of air pollution. A ten point scale was used to separate two adjectives at the extremes that are opposed to each other. The location of the positive "pole" was randomised to counteract the tendency for a respondent to adopt an unthinking response set at an invarying position along the scale. Varying the position of the positive poles challenges a respondent to take care in his or her judgement.

It is important to give a respondant an opportunity to indicate the positive as well as the negative attributes of air pollution. Human behaviour is complex and any attempt to quantify human opinion should be open minded. Thus it is not inconceivable that some individuals might be happy with a certain degree of smell, smoke and noise as these indicate that local industry is functioning creating wealth and employment. Such benefits to the local community might well outweigh minor inconveniences of pollution. People sometimes become nostalgic for unpleasant pollutants, such as smoke and smell hence the enthusiasm for steam engines and there is even a half hearted regret for the demise of the London Smog.

The final three exercises continue to use the technique of semantic differential to probe the personality of the respondant and in particular the predisposition to make a complaint. Thus a person is a likely complainant who:-

1) Disagrees strongly to the proposition that air pollution from factories should be accepted and

2) Agrees that pollution is a feature of life in their community and

3) Disagrees that they "suffer in silence".

9.21 Responses to the Questionnaire: Sheet 2

Comparison of "bother" due to smoke with "bother" due to smell.

As previously discussed the plume of pollution spreading downwind from the foundry is an intimate mixture of smoke and smell. In order to determine which component caused most bother the scattergram reproduced in Fig 9.8.1 was prepared in which the magnitude rating of bother due to smell was plotted against bother due to odour for each respondant.

Of the 99 respondants reporting their opinions, 38 considered smoke to cause them more bother than smell, 25 considered smell to cause them more bother than smoke, while 36 rated the two components to be equal in their perception of bother. Smoke, the visible pollutant apparent at a distance thus appears to cause more bother than smell.

The scattergram indicates a full range of response with some interesting clusters of responses at equivalence points at the low and high assessments of "bother". In particular 9 respondants indicate the maximum score of 10 for "bother" with both smell and smoke.

Semantic Differential - The "Image" of Pollution

Figure 9.8.2 depicts the response to the bipolar adjectives used to guage the acceptibility of the features of pollution offered

Fig 9.8.1 Scattergram of "Bother" due to smell Vs. "Bother" due to Smoke Pollution

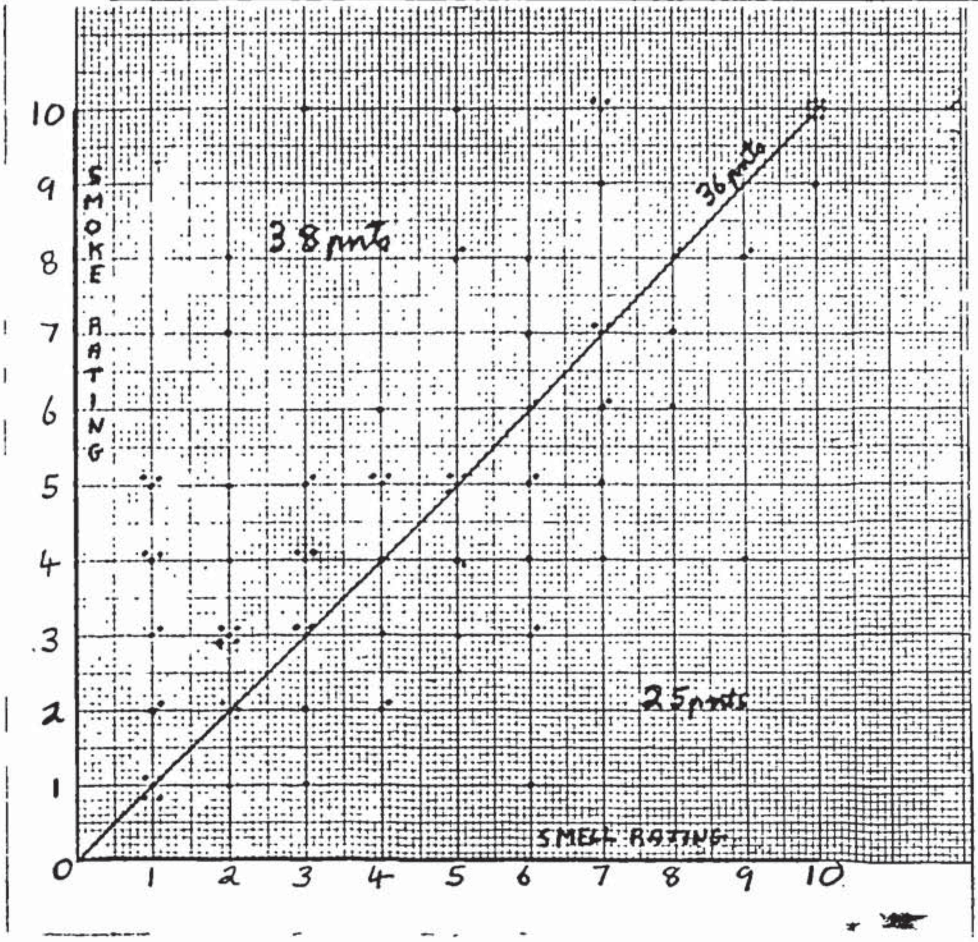
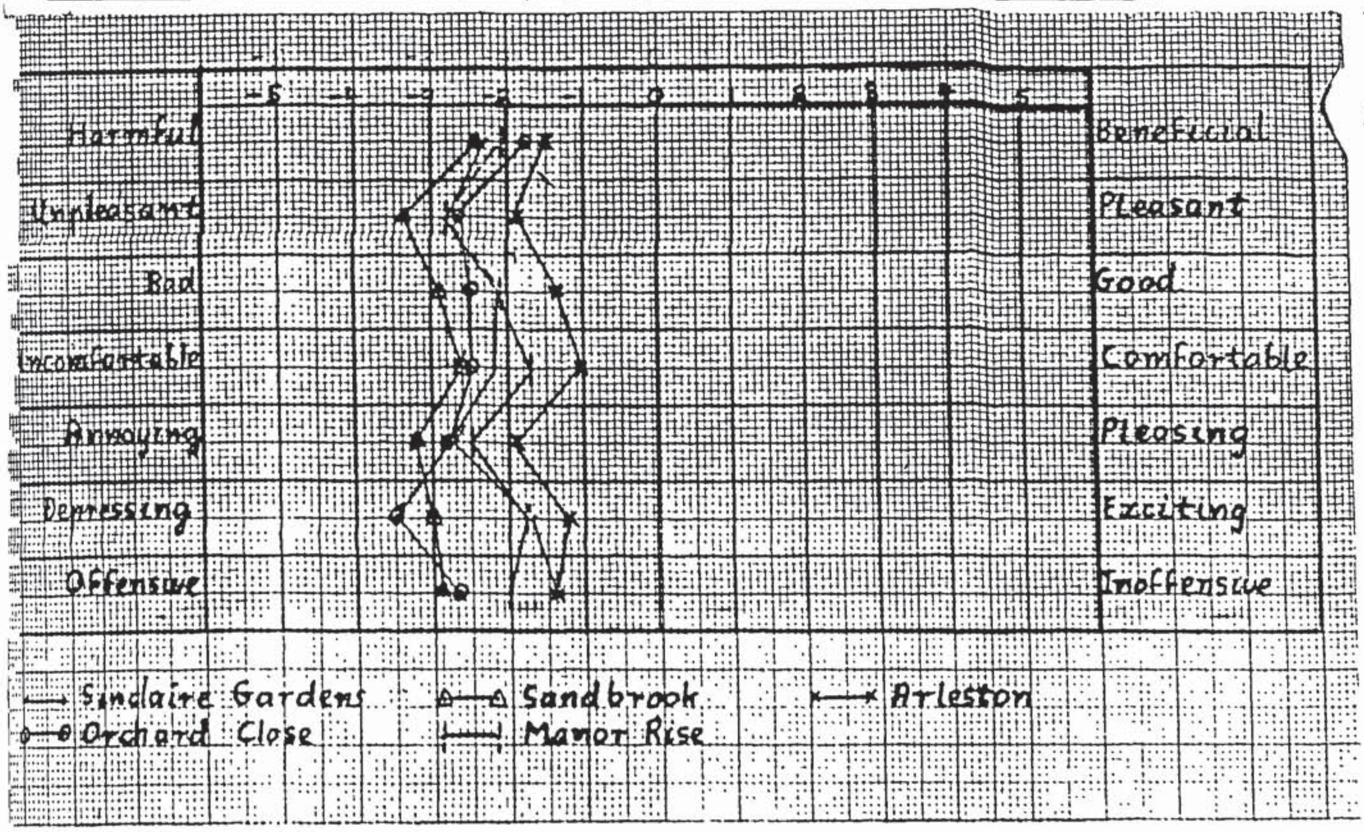


Fig 9.8.2 Profile of Adjectives used to describe Pollution

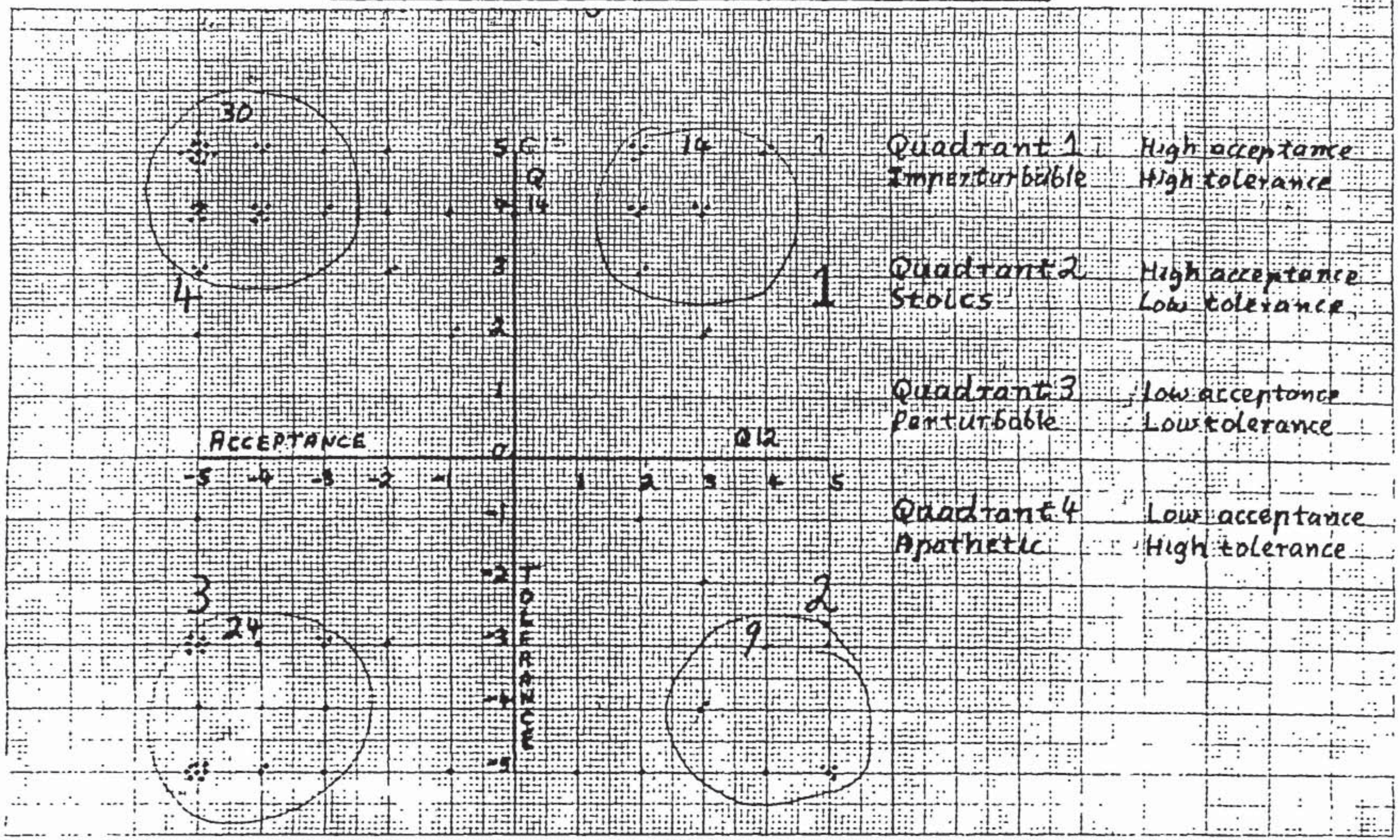


to respondants. Moderately negative scores were obtained for all features with unpleasantness and annoyance obtaining the strongest responses. The Sandbrook Road Estate to the North of the foundry expressed a marginally and uniformally stronger response that the communities to the East and West excepting the Arleston Estate which gave the weakest response in all scales. The Sandbrook Estate is on lower ground and consequently its southern skyline is dominated by the foundry thus its emissions are very perceptable at all times. The Arleston Estate has an aspect facing away from the foundry and is to some extent shielded from the emissions so that it is not surprising that its residents perception of pollution are less than those of other areas investigated. Only two individuals interviewed expressed any positive opinion of pollution and in one case this may have been due to a misunderstanding of the exercise.

Personality Assessment: Identification of a complaint group

This aspect of the investigation linked questions 13 and 15 with the intention of determining if there was a group of the community who were predisposed, by reason of their personality, to complain about the inconveniences of life. The assumption was made that people expressing a high recognition of pollution and assessing themselves as intolerant characters would constitute potential complaints. The results of this exercise are shown in scattergram Figuie 9.8.2 from which Table 9.8.1 was compiled. Respondants who expressed strong sentiments were crudely classified into 4 groups as shown being the "imperturbables"

Fig 9.8.3 Scattergram comparing Q12. "acceptance of air pollution" with Q4, personality



"stoics", "perturbables" and "apathetics"

TABLE 9.8.1 Classification of Personality of Respondants

Quadrant	Scores		Classification	Respondents by category
	Acceptance	Tolerance		
1	+ VE (high)	+ VE (high)	Imperturbables	14
2	+ VE (high)	- VE (low)	Stoics	9
3	- VE (low)	- VE (low)	Perturbables	24
4	- VE (low)	+ VE (high)	Apathetics	30

This Table indicates that there is a small group, about 14% of respondents who are very unlikely to complain about air pollution no matter how bad this may be. These have been called "imperturbable".

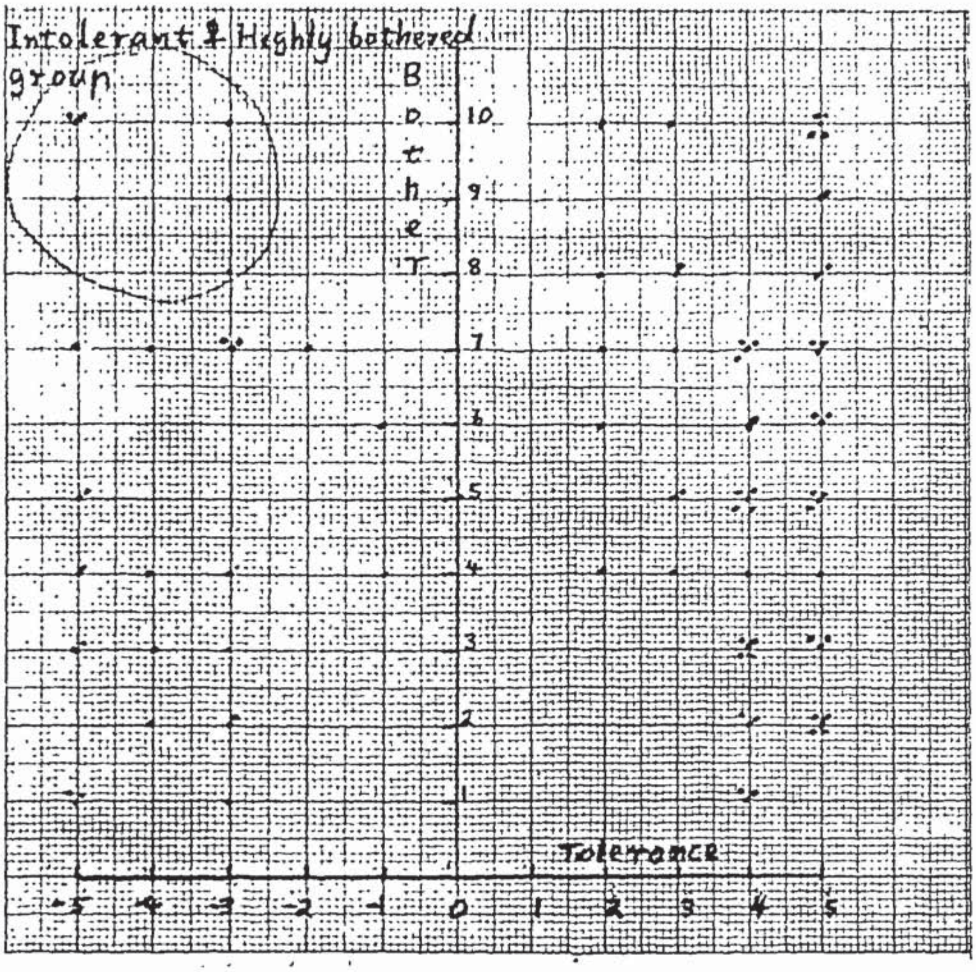
By contrast there is a larger group of 24% who indicate a low degree of acceptance and a low tolerance and are thus a group that should generate complaint. These are called "perturbable" in direct contrast to the group of "imperturbable"

The largest group of respondants, 30% have been called "apathetic" as they have a low acceptance of pollution but are prepared to tolerate it. Thus they may grumble about the local environment but are not likely to take any action to abate it.

A small group, 9% appear stoical by having a low tolerance to pollution but will accept the aggravation caused and are therefore unlikely to complain.

The results of this analysis are comparable with conclusions reached in a number of other well researched surveys into annoyance caused by exposure to noise. Thus Bryan and Tempest (72) emphasise that a community cannot be treated as an homogeneous population but that "a mere moment's reflection based upon observation of one's fellow men, should be enough to raise doubts about the assumption of homogenity as far as (noise) annoyance is concerned." They concluded that a fifth of the population (20%) were sensitive to noise (perturbables) and a third (33%) were not bothered at all (imperturbables). This compares with 32% classified in Table 9.8.1 as perturbable and 20 as imperturable.

Fig 9.8.4 Scattergram of "Tolerance" Vs. "Bother"



The Likely Complainants: Tolerance Vs Bother

A further scattergram was prepared that plotted tolerance scores ("sufferance in silence" against concern with air pollution ("overall bother with air pollution"). The result is shown in Figure 9.8.3

This identified a small group of people, 6 in number, who assessed themselves as having an intolerant character and who expressed the highest degree of concern about air pollution. It is suggested that it is this group, only 6% of the community sampled, that will generate complaint about air pollution, smoke and smell, from the foundry and indeed 3 complaints have originated from these addresses in the year 1985 - 1986.

9.22 Comment on Responses Reported in Sheet 2

This Study supports the opinion, expressed by Bryan and Tempest (72) that a population cannot be treated as a homogeneous group when it comes to expressions of annoyance with an environmental pollutant such as noise or odour. Evidence has been obtained that:-

1) There is a wide range of susceptibility to annoyance by stench.

2) Individual annoyance is poorly related to exposure to stench.

3) Several groups, each with distinct behaviour patterns, can be identified within a population.

Laboratory studies are unlikely to establish criteria for annoyance because the panellists likely to be employed in such tests are volunteers, the smell they are exposed to will finish at the end of the experiment and their opinion of annoyance is being sought. By contrast an annoyed member of the public is an involuntary recipient of a stench which is present, whether it is wanted or not, and he or she reacts to the imposition being inflicted. This attitude surveys are the only reliable procedures of setting environmental criteria for exposure to pollutants. Clarenburg's successful prediction of public complaint was based on such surveys or by soliciting complaint from a widely publicised and easily contacted central register.

9.23 Questionnaire : Sheet 3

This last sheet also reproduced in Appendix 3 is directed entirely towards a respondants perception of smell from the foundry and attempts to quantify the character of the smell, the frequency it is believed to be present, and any somatic effects that may be experienced.

The method of characterising a smell was based on the odour profile data compiled by Dravnieks and Young (73) but a subset of only 12 descriptions was selected from the 146 standard descriptions studies by these authors. This abbreviated list was thought necessary to simplify the formidable listing of the complete list which might otherwise deter a respondant from taking part as well as enabling the interview to be completed within the allocated time of 10 minutes. In making the selection some prejudgement of the character of the foundry smell was required but the respondant had a choice within the sample of descriptors provided.

Respondants were asked to assess the frequency of odour in their street by simply putting a mark in the box opposite the frequency table itself expressed in familar terms such as daily, weekly, or monthly.

The final exercise gave a respondent the opportunity to indicate somatic reactions to the smell of the foundry, that is those emotions and physical responses in an individual brought about by exposure to the smell. Again a multiple choice menu of responses was provided and the respondant was invited to indicate in the box provided any response he or she experienced.

9.24 Comment on Responses to Sheet 3

Table 9.9.1 reports the frequency of responses to the descriptors of smell provided

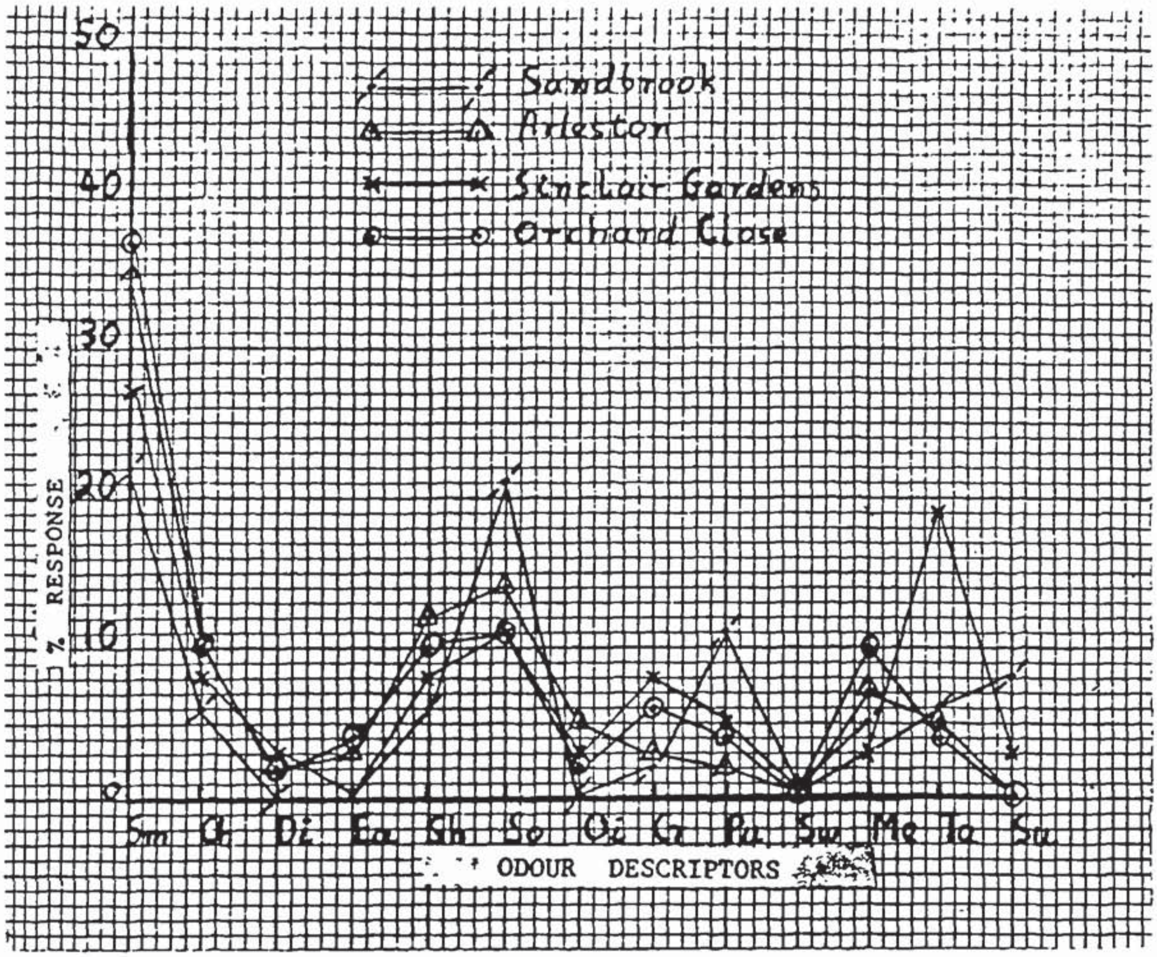
TABLE 9.9.1 DESCRIPTION OF THE CUPOLA ODOUR

Description	Sm	Ch	Di	Ea	Sh	So	Oi	Cr	Pu	Sw	Me	Ta	Su
No of responses	62	24	3	4	19	30	7	9	12	0	13	16	9
% of responses	30	11	1	2	9	14	3	4	6	0	6	8	4

Descriptors are indicated by their first 2 letters. Thus Smoky, Chemical, Disinfectant, Earthly, Sharp, Sooty, Oily, Creosote, Putrid, Sweaty, Metallic, Tarry, Sulphurous

Taking arbitarily any response amassing over 10% of the total it can be seen that the smell is described as being smoky, chemical and sour. Dravnieks (73) has assigned a hedonic value to each descriptor and in this scale smoke is assigned a value of -1.53, Chemical -1.64;, Sharp -2.34 These are moderately negative attributes compared with the very negative descriptor "sickening" having a value of -3.68 and the weakly negative alcohol -0.47 Interestingly some respondents spontaneously advanced their own

FIG. 9.9.1 Profile of Odour Descriptors by District



descriptor of "sulphurous" which corresponds to "sulphidic" -2.45, on the Dravniek hedonic scale.

Responses to each description were plotted in the form of profiles for 4 distinct neighbourhoods bordering the Foundry and the results are shown as Figure 9.9.1

The profiles can be seen to be broadly similar but some interesting small differences are apparent. Thus the residents of Sandbrook Estate to the North tend to emphasise the smoky and sulphurous components of the odour they experience. This may be because they live closest to the cupolas and experience more undispersed smoke than do the other neighbourhoods studied.

The residents of Sinclair Gardens mention a tarry or creosote component more than do other neighbourhoods. This is probably because they live closest to a bitumen pipe watering plant and therefore experience fumes of tar oils that are used in this plant.

Residents of Orchard Close and Arleston, who are equidistant to the east and west of the foundry respectively; give response profiles that are very similar and thus their perceptions of the stench of the foundry seem likewise to be similar.

To summarise the results of this exercise, the stench of the foundry appears to be similarly experienced by the residents of all neighbourhoods surrounding the foundry and the small differences in perception can be related to proximity to certain odorous activities carried on within the foundry.

Perception of the Odour Dose: Frequency of Exposure

Observations of the odour plume about the foundry enabled the frequency of odour exposure of each neighbourhood about the foundry to be estimated. Results are shown in Table 9.9.2

TABLE 9.9.2 REPORTED FREQUENCY OF ODOUR EXPOSURE BY NEIGHBOURHOOD

Neighbourhood	Frequency of Exposure %						Observed+
	100	40	20	10	5	2	Frequency %
Sinclair Garden	1	1	4	4	2	2	9
Orchard Close	4	4	6	3	1	0	15
Sandbrook	3	15	8	8	2	0	13
Arleston	6	8	6	7	2	0	5

\+ Note:-

Daily	= 100%	Twice monthly	= 10%
Twice weekly	= 40%	Once per month	= 5%
Once per week	= 20%	Once per 2 months	= 2%

Respondants obviously find the task of estimating the frequency of odour exposure to be a difficult one and there is a wide range of response with a tendency to overestimate the frequency. This might be because although the question specifically mentioned a respondants' street, respondants are likely to be mobile and walk through areas effected by smell so that the frequency of exposure is increased.

9.25 Somatic Effects: The response to odour

The final exercise on the questionnaire asked respondents to indicate from the multiple choice of effects which of these they experienced when exposed to foundry odour. The results are shown in Table 9.10.1

TABLE 9.10.1 RESPONDENTS SELECTION OF SOMATIC EFFECTS OF FOUNDRY ODOUR

Neighbourhood	Un	Te	Re	An	Fe	St	Di	Si	He
Sandbrook	3	5	5	7	1	4	0	6	4
Sinclair Gardens	2	0	3	3	0	7	1	0	3
Orchard Close	2	0	1	3	0	3	1	1	1
Arleston	0	1	4	3	0	2	0	1	1
Total	7	6	13	16	1	16	2	8	9

Symptoms are referred to by their first 2 letters except for St = sore throat. Thus UNease, TEnsion, ANger, FEar, DIzziness, SIckness and HEadache.

Thus tension and anger were the most common emotions experienced by respondents exposed to smell and sore throats the most common physical sympton. A high proportion of the sickness and headache responses reported came from respondents on the Sandbrook Estate indicating possibly that these residents who live closest to the foundry were most oppressed by the effects of air pollution.

9.26 Summary

The method of attitude survey is both a useful and enlightening exercise for a Council Officer as it allows the option to be taken of seeking the effects of air pollution upon an exposed population instead of taking the passive role of waiting to receive complaints that can be biased by emphasising one of several problems that may be simultaneously effecting a community. Thus the priorities in pollution control can be set based on the results of a social survey which is a rational method of consultation with a community.

One benefit of the technique of social survey is that residents who are bothered by air pollution can register their concern without being labelled as a complainant. The problems such people experience can be elucidated in a structured, objective manner without a complainant, possibly already upset, having to make the first contact with the Council.

The form of attitude survey used in this exercise was free of any undesirable consequences of soliciting opinions on a sensitive subject. There were no unpleasant doorstep confrontations, no complaint about the survey was made by residents to the Council, although a subsequent professional MORI opinion survey into housing matters attracted unfavourable comment, and there was no complaint of harassment from the industry that was being investigated. Neither did the experiment appear to alter the phenomenum being investigated in that the pattern of complaint was not disturbed by the survey.

Results of the survey clearly demonstrated that residents in the vicinity of the foundry unanimously recognise the pollution it causes and a significant number experience a range of ill effects that are associated with the perception of smell and smoke. A reason for the lack of public complaint that such conditions should engender may be lie in the small number of people, classified as perturbable, who both recognise the smell and have an intolerant personality. They are identified by the survey as probable complainants and indeed the few complaints that do arise from time to time do come from this group.

The pattern of complaint is considered to be unstable as a large number of people are effected and a slight but perceptible change for the worse in the foundry emission may well stimulate an increase in the level of complaint and vocal demand for improved control procedures to be adopted by the Foundry.

CHAPTER 10

The Maggot Farm: An investigation of an odour control plant

10.1 Introduction

The trade of a maggot breeder is a curious one sometimes described as a commercialised entomology. It requires flyblown offal to be carefully tended so that a good crop of maggots are reared that can be sold to anglers for use as fish bait. As a business it can generate a considerable amount of income, from a small capital outlay and low operating costs.

As in any trade considerable expertise is required to maintain a consistent and plentiful production. Raw material is meat in a form unacceptable for either human consumption or processing into pet food. Joints of this are exposed to specially bred flies, often imported species, and their eggs are laid on the surface of the meat. The fly blown meat is removed from the fly house and laid in breeding pens where the eggs hatch and the young maggots start to feed by liquification of the meat protein. Large amounts of ammonia are released whose pungent odour is overwhelming in the breeding room but other powerful odorants such as trimethylamine and mercaptans are present and these contribute to the peculiarly disgusting smell apparent downwind of the establishment. Although apparently simple, the breeding cycle is open to a number of problems and in particular the effects of temperature. Cold weather drives the developing maggots deep into the meat while hot weather causes them to come to the surface where odorants are more easily volatilised into the surrounding air. Maggots grow to marketable size in a week of feeding then they are separated from remnants of meat by riddling through a screen before cleaning by immersion in sawdust. Some control of odour can be achieved by the practise of good hygiene in the handling and storage of meat and wastes but the breeding process is intrinsically an odorous one.

10.2 The Telford Maggot Farm

In Telford a maggot breeder's and knacker's yard facility has been established for several decades at a site that is now close to prestigious development at the centre of Telford New Town. This site is surrounded by a motorway interchange, railway and private enterprise zone on which retail development is planned. Close by are a residential estate, a new railway station, a business park and a high technology campus site. Not surprisingly there has been considerable pressure on the owner of the business to improve the operation of the business or relocate to other less sensitive sites.

Council files demonstrate that complaints about the business started nearly thirty years ago when employees of the neighbouring steel works went on strike because of the intolerable nature of the smell. The Council explored several odour abatement techniques and eventually persuaded the maggot breeder to add a masking scent to the odorous emissions to disguise the character of the smell. This technique is still in use and although thousands of pounds must have been spent in purchasing scent it had done little to prevent complaint.

After local government re-organisation in 1974 when the Wrekin District Council came into being there commenced a period of concerted effort by the new Council and the New Town Development Corporation to eliminate this "blot on the landscape" on the plans for a prestigious town centre.

10.3 Attempts at Abatement

First an attempt was made to declare the business of maggot breeding to be an offensive trade subject to a high degree of local government control. This attempt faded out because it became apparent that the practises of good hygiene would be insufficient to control the odour nuisance.

The Warren Spring Laboratory were employed as consultants but failed to give any decisive advice on odour abatement. Nevertheless an Abatement Notice was served under provisions of the 1936 Public Health Act but in order to comply work had to be done that required planning consent. The Planning Committee differed in its opinions from those of the Environmental Health Committee and preferred relocation of the business to improvements on the same site. Thus no planning consent was given and consequently the abatement notice was invalidated as it is a defence to show that non-compliance with the notice was due to withholding of planning consent. By 1976 all these fruitless moves had been completed.

During the following years, complaints continued to be received from both local residents and neighbouring businesses. Realisation of developments in the Town Centre made the expensive option of relocation to be pursued and a site on an abandoned colliery site on the extreme eastern edge of the New Town was identified as being suitable. However ambitious plans were being drawn up for reclamation of the old workings and the National Coal Board were reluctant to release the site, also there was vocal opposition from the local Parish Council. To enable progress to be made Council officers gave assurances to elected members that the proposed maggot breeding establishment would have to adopt procedures that would prevent the escape of odour beyonds its boundaries. Planning consent for this development was then given, the breeder entered into a "Section 52" agreement to relocate his business by the spring of 1987 and the sale of the site was completed.

10.4 Options for Odour Control

For many years the Council has taken a keen interest in methods used elsewhere in England to control the smell from maggot breeders. These have included virtually all the major technologies that are used to control malodours and were as follows:-

a. Dispersal from tall chimneys

b. Absorption in beds of active carbon

c. Chemical oxidation in scrubbing towers

d. Thermal destruction by a) direct flame incineration
b) catalytic incineration

e. Masking or neutralisation by addition of powerful scents

Success has been elusive. Tall chimnies and carbon absorption are inappropriate techniques because of the power and quantity of odorants in the emission makes these approaches impracticable at a reasonable cost.

Chemical oxidation uses a two stage chemical scrubbing with sulphuric acid to remove amines, and sodium hypochlorite solution to wetoxidise organic compounds. It has been successfully used to control maggot odours elsewhere but the capital cost of equipment is considerable and running costs are high due to the need for replacement chemicals and the disposal of toxic liquors. Moreover the operator needs to acquire a practical understanding of the chemical engineering employed and this is hardly appropriate to the different skills of maggot breeding. Failure to operate the plant properly could lead to toxic hazard as well as an intensification in the odours emitted as incomplete oxidation cause the formation of chloramines that are odorants and lachrymators of considerable power.

Thermal oxidation is an excellent method for the destruction of organic odorants that at worst are converted to noxious compounds such as nitric oxides and sulphur dioxide each of which can be dispersed into the atmosphere from chimneys whose height can be calculated using approved procedures. However fuel costs can be considerable if large amounts of ventilation air must be treated and there is a temptation for an operator to turn off the flame if there is a possibility that untreated odour will not cause offence. Errors of judgement then results in complaint. Fuel savings can be achieved by the use of catalysts that enable destruction of odorants to be achieved at lower temperatures. However efficiencies of destruction are less than 100%. There is a high capital cost; catalyst poisoning can result in failure and there still remains a temptation to save fuel by turning off the incinerator.

The use of masking or neutralising scents to control stench is a controversial subject (74B) in which few people claim success, other than manufacturers or users of their product. Indeed complainants sometimes complain more about the added scent than about the stench being masked. In the case being considered such scents have been used and complaints prove them to be ineffective.

10.5 Peat Bed Bio Filtration

Many of the disadvantages associated with the odour control procedures described are absent in a novel technology developed at Munich University (74) for use in the German animal by-products industry. This is peat bed bio filtration of odorous generate toxic waste.

f. Wrekin Council had inspected an effective bio-filter at a rendering plant in Herefordshire and had purchased the design specification of the plant together with modifications necessary to overcome some teething problems.

All options investigated have disadvantages and for bio-filters these are the large size of a bed that require a considerable area of ground adjacent to the building and the obvious feature that the emission from the bed is at ground level without the opportunity of using a chimney to increase atmosphere dispersal. A further disadvantage was that at the time the Wrekin Council were considering the planning applications for the new site, no other maggot breeder in the UK was using the method therefore before making a recommendation it appeared prudent to construct an experimental pilot plant to demonstrate the effectiveness of a peat bio-filter to deodorise ventilation air from maggot breeding.

10.6 Optimum Conditions for Peat Bed Operation

The control of odours by biological oxidation (81) is an age old concept and has been exploited in the practise of burial and is the principal of the earth closet. However during the last 20 years this technique has been investigated as a potentially versatile and cost effective means of controlling industrial odours. Biological scrubbers, compost, soil and peat beds have all been investigted. At present it is peat that is showing most promise although the first practical unit to control pig smell in Germany was not constructed until 1975.

Biological oxidation is achieved in a wet, microbiologically active film covering the surface of an inert support. This should have as its most important feature, an open, mechanically strong structure, that allows the bed to support its own weight while allowing an uniform unobstructed passage of air through it without channelling or by passing as this would cause air to avoid biological oxidation so reducing the effectiveness of the bed. The necessary properties for good bed construction are possessed by peat although it is necessary to add sprigs of heather to avoid dimensional changes in peat brought about by small changes in its water content. The result is a spongy consistency that will support the weight of a man without any visible effects.

Biological activity depends on maintainance of adequate dampness in the bed which is assisted by the microporous structure of peat fibres. This can absorb up to five times its own weight of water so that the peat dries slowly and is resistant to waterlogging. However large volumes of air are handled by the beds and it is often necessary to humidify inlet air to about 90% Relative Humidity. Simple spray chambers will achieve this with an additional advantage that dust, which may block the bed, is removed by the scrubbing action of the water spray.

Temperature also effects biological activity and should be kept within a range of 10 - 40^{o}c and although the lower limit is not critical it may be necessary in some applications where hot emissions are to be treated, to cool inlet air to avoid breaking the higher limit.

The peat bed is a complex community of micro-organism with a balance of species that can adapt to changes in the condition of their environment. Hence its versatility for the satisfactory treatment of a wide variety of odorants but a period of time is necessary for this adjustment so that it is reported that a new bed may take several weeks to achieve its full effectiveness. In these respects the peat bed is a biological purification system closely ressembling a sewage treatment plant.

10.7 A Pilot Plant For Odour Abatement System

Introduction

A small scale maggot breeding plant and peat bed odour removal unit was constructed and operated for a period of 10 weeks. Structured sensory methods were used to measure odour in terms of strength, intensity, character and quality so that the change in maggot odour could be measured as it passed through the various components of the plant and thus assess the effectiveness of the odour removal system. Experience was gained in the breeding of maggots and the operation of the pilot plant that should be relevant to the design of the full scale unit to be constructed at the

Granville Colliery Bait Farm.

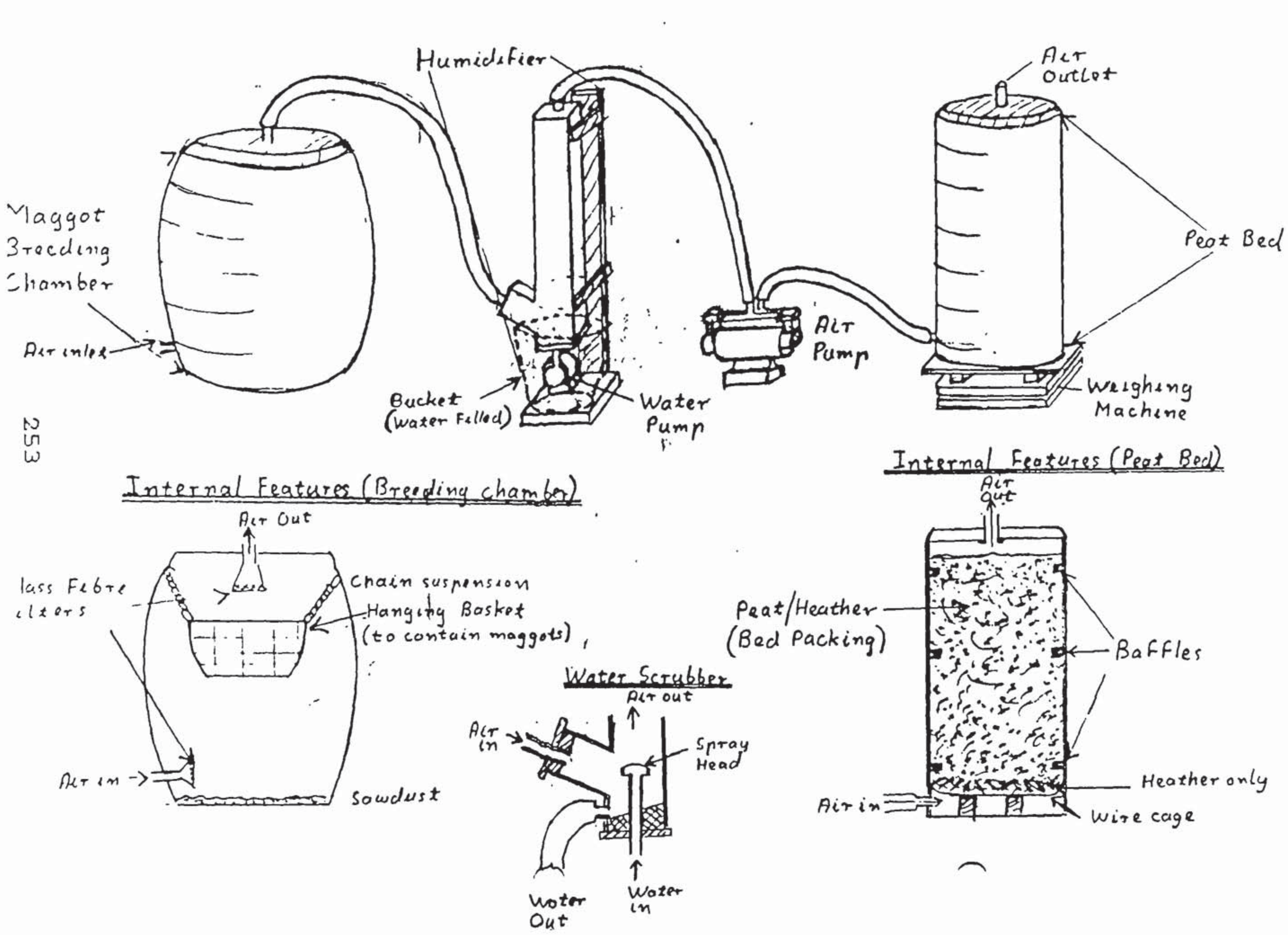
The Plant

This had four units as shown in Figure 10.1 being the breeding chamber, humidifier/water scrubber, air pump and peat bed. The overall scale was of the order of 1/1000 of the full scale plant being considered.

Breeding Unit

This was based on a 120 litre plastic water butt and well fitting rubber lid. The lip between the top of the butt and the rubber lid was sealed with a triple ring of silicone rubber bath caulk and a total seal was finally achieved by taping the external joint between the lid and the butt with adhesive plastic tape. The air inlet and outlet required for ventilation of the chamber were fitted with 10cm filters constructed of the glass fibre gauze supported by aluminium gauze covering the mouth of the plastic funnel. These were necessary to arrest the escape of maggots from the chamber. The maggots were bred in batches from about 4 kilogrammes of fly brown offal, normally lung or liver, provided by the maggot breeder. This meat was surrounded by a thick layer of fine wood dust retained within a nylon mesh bag placed in a hanging wire basket suspended close to the top of the breeding chamber.

Fig 10.1 Peat Bed Biological Filter (Pilot Plant)



Water Scrubber/Humidifier

This was made from square plastic drain pipe clamped vertically with a single 3 way branch connector fitted at the bottom (see Fig 10.1). Air entered from the side branch of the connector and passed up the pipe leaving the scrubber by a pipe connector. A garden fountain pump delivered recirculated water into the scrubber through a 9 nozzle rose that sprayed water to a height of 0.5 metres. Contact time of air stream with the water was about 6 and 12 seconds for the 60 l/min and 30 l/min air flow respectively.

Pump

Two Dymax pumps were used as air movers. These are each twin diaphragm pumps with a power rating of 100 watts and a volume flow of 30 litres per minute. These pumps are capable of sucking and blowing against a high pressure or high vacuum without considerable loss of performance.

Peat Bed

This was constructed within a 1 metre length of Glass Reinforced Concrete water pipe of 0.8 metre internal diameter. Three baffles of expanded polystyrene ceiling coving were glued to the internal walls of the pipe to prevent channelling of air through any gap that might open between the peat bed and the wall of the pipe. The peat bed was supported by a plastic coated wire mesh cradle resting on 10 cm wood supports. Thus the peat bed rested on a chamber or wind box in which air to be treated entered from the side and passed upwards through the bed.

The fibrous peat was of German origin obtained from a batch supplied to Bowketts of Tenbury Wells from a German Source. The peat/heather mixture of the bed was prepared by mixing equal volumes of peat and 4 year old heather whose sprigs were cut in half to enable void free packing of the small experimental bed. Intimate mixing of the peat and heather was achieved by tumbling these materials in a cement mixer.

The bed was built up by first spreading a 10 cm layer of pure heather on the wire cradle. This was intended both to prevent peat falling through the wide mesh of the cradle and to supply an even distribution of air to the bottom of the peat. The mixed heather and peat was then placed in position, handful by handful with gentle compression of such placement until a depth of 0.85 metres was obtained. Careful and even packing of the bed is particularly important in small scale plant where channelling of air through voids can seriously effect its performance than would be the case in a full scale plant.

The bed was capped with a rubber lid fitted with an exit pipe so that the exit gases of the bed could be channelled and conveniently sampled.

During 10 weeks of operation the peat bed required only the minimum of maintenance. Each week 1 litre of water was sprinkled over the surface and about 1 litre at least was drained from a sump at the bottom of the bed. In the first month slow compaction reduced the depth of the bed to 0.75m Residence time of gases in the bed at a flow rate of 60 litres/min was measured to be 35 seconds when using propane as a tracer gas.

0.8 Sensory Testing of Odour

Odour assessment employs structured tests in which an observer reports on his perception of a smell. The results of a number of observers that constitute a panel are grouped to enable a statistical measure to be calculated. However there is not at present any universally recognised method of odour assessment with the exception of ASTM Procedure which makes no claim for its precision and accuracy. The equipment for such tests is either expensive and convenient to use, or inexpensive and cumbersome in use. In such circumstances an investigator has great freedom in the choice of methods and procedures that may be used, consequently practical considerations will determine the final methodology.

Sensory testing was conducted over a period of 4 weeks with one observer conducting one assessment per day. Thus it is likely that the characteristics of the odour presented to the observer would have been different on each occasion.

Although this is not a satisfactory procedure because of the lack of standardisation it ensured that the overall assessment encompasses a wide range of odour characteristics generated at different stages of the maggot breeding cycle.

A panel of 9 observers was used comprising of colleagues, family and friends being equally divided between the sexes. The age ranged from 12 to 48 and thus can be claimed to be a reasonable cross section of the population although clearly no attempt to match the socio-economic status of the sample to that of the population likely to be exposed to odour from the bait breeding plant.

In this investigation the method was a static one based on the collection of a sample of odour within a 100 ml glass syringe and then diluting aliquots of this within a series of 100 ml syringes. The odour sample ws then injected by the panellist into a nostril through a PTFE tube with a ceramic bead attached to seal the nostril and prevent the unintentional introduction of dilution air should the panellist sniff during the test. Such equipment was similar to that specified in the ASTMS procedure.

The protocol used in sensory testing is vital if satisfactory results are to be obtained. In this investigation all panellists were volunteers. Individuals were invited to inspect the pilot plant and the purpose of the equipment and testing procedures were explained. The panellist was then seated at a kitchen table in a kitchen and introduced to the experimental equipment. The panellist was then invited to have his or her sense of smell tested using a standard atmosphere of 1000 ppm butanol in air and if this was satisfactory the remaining tests were applied. Afterwards the panellist was requested to comment on his or her experience of the test.

In each case the panellist reported that he or she was at ease, interested and had little or no difficulty in handling the equipment throughout the tests. These responses suggest that the attitude of these panellists was appropriate to their making a reliable sensory assessment of odour.

The following attributes of odour taken from various parts of the maggot plant system was assessed by the procedures described. Response sheets used in this exercise are reproduced in Appendix 4

a. Odour Threshold or Detectability

This is the number of times an odour has to be diluted by clean air until it is no longer perceived by a panellist. Thus a series of diluted odours was prepared in 100 ml syringes. The order of presentation was randomised and each dilution was presented to a panellist in a pair of syringes, one containing the diluted odour and the other the "clean" dilution air. The panellist's task was to indicate which tube contained an odour, and unlike the "forced choice" procedures usually recommended, the panellist was allowed to report his sensations so that two negative responses in a pair was permitted as indeed was two positives, although this never happened. Values given in Table 10.1 of Appendix 3 are the geometric means between the dilution of the correct choice and the next dilution of either a wrong choice or double negative result. Odour dilution threshold is a means of putting a numerical value on smell which can be used to define the quantity of smell emitted by a source and the efficiency of removal systems. It is not a measure that is in common use for description of an odour and indeed it cannot be estimated by observation.

b. Odour Intensity

This is the rate at which the sensation of an odour changes with change in odorant concentration. Although there is a rigorous psychometric definition of odour intensity this was not used in this investigation. Panellists were presented with a syringe of odorous air taken from the maggot plant, asked to inject the smell into one nostril and then indicate their sensation on a 5 point scale ranging from faint to sickening. These ratings are often used spontaneously by people describing their experiences of odour and those of the panel are given in Table 10.2 of Appendix 3.

c. Quality

The quality, sometimes termed the hedonic of an odour is an expression of the pleasantness/unpleasantness of a smell. Panellists were asked to assess this attribute immediately after their assessment of intensity and used the same sample of odour. A 10 point bipolar scale was used in the form of boxes with the adjectives 'unpleasant' and 'pleasant' written at opposite ends of the scale. The panellist was invited to place a tick in that box that approximated to his or her opinion of the smell. The results were simply assessed by assigned interger values to the boxes ranging from 1 to 5 for increasing degress of pleasantness and -1 to -5 for the increasing degrees of unpleasantness. Such description of an odour without ranking is, of course, commonplace. The panellists responses are reported in Table 10.3 of Appendix 3.

d. Character

The character of a smell is the answer to the question "what does it smell like?". American workers (77) have compiled a list of 146 standard adjectives used to describe odour and these have been ranked in terms of hedonic. The complete list was culled and the panellists were presented with a list of only 16 adjectives that seem most to the types of smells they were presented with. The panel's opinion so expressed is presented in Table 10.4 in terms of frequency of use of an adjective with the corresponding rating on a hedonic scale.

Thus of the 4 attributes, being intensity, quality and character, 3 are no more than commonplace descriptions of odour that are quantified to enable numerical assessment to be made.

10.9 Operational Experiences

a. Successful maggot rearing

Maggots are remarkable escapologists, being capable of breaking down chemically many substances that are common sealants and of penetrating filters by squirming, changing shape and forcibly prising open filters intended to incarcerate them within the breeding chamber. Thus the first batch of maggots were not restrained by gauze filters then in use and penetrated the odour control system as far as the pumps which became blocked by macerated bodies. Ventilation then ceased and other maggots attacked the plasticine seals on the breeding chamber and spilled through the gap so opened to the exterior of the chamber.

The secret of successful breeding was soon found to be the provision of a satisfactory environment that kept the maggots within the meat. This was achieved by surrounding the meat with a deep layer of fine sawdust, lowering a funnel over the meat to ensure that ventilation air swept past the meat, and by improvement in the construction of the filters to restrain the escapist tendencies of the maggots.

The maggots were collected from the bait breeder at an age of about 1 day and were reared until they formed chrysalids about 4 or 5 days later. The metabolic rate of the maggots appeared to be highest after 2 days when internal temperatures were often 7°C above ambient with carbon dioxide levels exceeding 0.3%.

b. Water Scrubber/Humidifier

After 3 weeks the water pump failed due to the filter and pump rose becoming blocked with a hard scale. The scrubber was stripped down and it was found that the internal surfaces of the scrubber were coated with a hard film of white scale. The scale was mechanically stripped from the equipment and the jets cleaned chemically with dilute acetic acid when the scale effervesed vigorously. The scale was thus believed to be calcium carbonate precipitated from the hard tap water by the high pH caused by the ammonia scrubbed from the odorous air. This problem was prevented from recurring by removing the pump filter and the addition of Calgon water softener to the water in the reservoir. A similar problem has been encountered in a full scale plant.

c. Air Pumps

These were diaphragm pumps capable of maintaining their rated capacity against a considerable back pressure which was excerted by the peat bed, and was measured to be 25mm of water. The only problem experienced recurred two days into the first batch of maggots when failure to contain them in the breeding chamber caused some to find their way into the pump inlet valves, so jamming them and stoping them moving air.

d. Peat Bed

No difficulty was experienced with the operation of this throughout the 10 weeks of the experiment and indeed the only likely one would be the drying out of the peat. This was monitored by weighing the entire bed daily and over 1 week a loss of about 700g was noted. This was replaced by the addition of 1 litre of water to the top of the bed and the excess was drained from a sump out into the plyboard base. This excess water was stained a deep brown by the humous acids extracted from the peat.

Efficiency of Operation - The Reduction in Detectability of Odour

The necessary dilutions were prepared from samples of odour taken from various points in the abatement system using a 100 ml glass syringe. Aliquots in 2 ml decrements, were taken from this using a 2 ml glass syringe and transferred via a 3 way valve into another 100 ml glass syringe containing about 50 ml of "pure" outdoor air. Full dilution to a final volume of 100 ml was then completed and the full syringe then paired with another identical one containing clean "outdoor" air. In all four pairs of syringes were prepared to form a regular series of diluted odours. Each syringe and each pair was colour coded for subsequent identification before being presented to the panellist.

10.10 Results of Sensory Testing

The overall efficiency of the peat bed, when measured in terms of dilution to threshold, was consistently found to be better than 95%. This efficiency may well indicate the minimum performance of such a system since there is a good reason to believe that small scale plant used in batch breeding of maggots may be considerably less effective than a full scale plant attached to a commercial bait breeding establishment. This is because channelling of untreated gases at the edge of the bed and very variable odour loadings that will detract more from the performance of a small pilot plant than a full scale unit.

The overall performance of the bed cannot be satisfactorily assessed by a simple statement of efficiency for not only is odour removed by the bed but it is also added. The effluent gas from the bed smells not of maggots but of peat, thus it is necessary to consider the changes in the odour characteristics of intensity, hedonics, and quality.

The intensity of the maggot odour is reduced by the peat bed system from strong to weak, and the quality from very unpleasant to neutral or slightly pleasant. Common adjectives used to describe the maggot odour were heavy, sickening, putrid, fishy, pungent and ammoniacal but, after the beds these became light, ammoniacal *and household gas.* Thus the pilot plant was highly effective in reducing the intensive foul smell of maggots to a weak scent of peat.

The tests allowed the performance of the water scrubber to be assessed separately from the overall performance of the system. However, the water scrubber's intended function is that of a humidifier and any odour removal achieved is unintentional. As an odour remover, the scrubber is approximately 50% efficient, the intensity reduction was from strong to moderate, and hedonics from very unpleasant to moderately unpleasant. Odour quality, assessed by adjectives used, also changed with the ammoniacal character becoming more apparent in the scrubber outlet even though about 90% of the ammonia content of the inlet gas was removed by passage through the water scrubber. This result was not unexpected as odour character often tends to become stronger for many odorants when very high concentrations are reduced to more moderate levels (84). Thus the water scrubber does bring about appreciable change in the odour presented to it, but when compared to the peat bed its role as an odour remover is a minor one. Its main purpose, and it is an essential one, is as a humidifier ensuring that moist air is passed forward to the peat bed so preventing this from drying out and losing performance.

10.11 Summary

The pilot plant appears to have been a worthwhile demonstration of the successful use of peat bed in removing the intense stench of breeding maggots and replacing it by a mild inoffensive aroma of peat. Furthermore simple sensory tests were established which could be used to assess the performance of a full scale plant.

In simple terms the maggot smell changed after passage through the abatement system from strong to weak, from very unpleasant to neutral in character, and from many strongly expressed adjectives to a few weak ones. An incidental but significant observation of panellist response to the smells was that while people took only a very small sample of maggot odour into their nostrils before making an immediate decision, they took virtually the whole sample of peat bed odour before making a rather indecisive assessment. This suggested a much less emotive response to peat bed odour than to maggot odour.

One important practical problem encountered was blockage of the pump and nozzles of the humidifier/scrubber by scale precipitated from the hard water being recirculated. This was caused by an increase of pH resulting from the dissolution of ammonia removed from the gases being scrubbed. In a full scale plant the water chemistry will be the same and the precipitate would result in unreliable operation unless water treatment is used to soften the water or the filters or nozzels are designed to be self cleaning.

CHAPTER 11

Summary and Conclusion

The sense of smell has been presented as being a remarkable and under-rated channel of communication between the human mind and world external to it. This sensory information is chemical in nature and seems capable of producing profound psychological responses in a recipient that effects the health and well being of an individual. Such responses are but a vestige of the powerful signals that control the social behaviour in the animal kingdom including primates, but present research is making progress in revealing the residual effects still acting upon human beings.

While this thesis was being written a report appeared that indicated how the same receptors in the brain are stimulated by both tranquillizers and some odours so that both types of stimuli bring about relaxation of a patient. The advantage for inhalation of an odour is that the process is non invasive of the body consequently no undesirable drug induced side effects are likely. Thus, there is little doubt that exposure to odour can exert a direct effect on the mood and health of individuals. Strong emotions can be roused and disturbing memories recalled. In the case of air pollution by stenches such reactions provide the motivation for people to direct vigorous complaints to pollution control authorities.

The British Legal System recognises that odours can cause distress and it provides a plaintiff with a remedy under the tort of nuisance if substantial interference with property rights can be demonstrated. Statutory Law enacted by parliament allows local authorities to secure abatement of nuisance if "a class of Her Majesties' subjects "is effected by a stench provided such action is in the public interest as demonstrated by evidence of public complaint." Unfortunately an act of public nuisance is a crime but unlike say theft its nature is intangible and objective evidence is often lacking. The legal process is intrinsically rational and thus if the acceptability of a smell could be measured and then matched against established criteria for environmental stench. This can be done for noise, "unwanted sound", because sound level meters have been available, for many years but not for stench, "unwanted smell", because an electronic nose has yet to be invented.

Recent reports have appeared about work done at Warwick University Olfaction Research Unit. An instrument is being developed based on a gas sensitive semiconductor carrying 20 individually tuned receptors so that 20 "primary" odours are detected. The output is interfaced with a computer and interpreted by a pattern recognition program. The final instrument is intended for use in the flavour and perfume industry where there are considerable commercial benefits to be gained from improved quality control, but the experience gained in such fields may assist in applications to pollution control such as the setting of environmental standards.

Developments discussed so far have been speculative but current problems of odour control can only be tackled in the light of existing knowledge and using existing methods of measurement. The most useful of these depend on sensory measurements of the 4 characteristics of smell which are detectability, intensity, character and quality. These require that panels of observers be organised and the smell presented in a structured manner that should yield consistent results. However such techniques are cumbersome and need care in their application as observers are people, not machines, whose responses depend on their motivation, attitude and individual acuity and even then the environment of the test can influence the result. However work reported in this thesis does indicate that useful results can be achieved using simple equipment and convenient methodology. These results can be communicated using a non specialised terminology that is easily understood by a non technical audience such as a Council Committee who may have to make decisions based upon a report of the investigation.

The sensory techniques mentioned in the thesis enable a local authority to undertake research and development of odour control procedures and it is important that local authorities take this initiative as expert advice is not readily available from commercial sources. The example reported in the thesis concerned the use of a peat bed to biologically oxidise odorants generated by maggot breeding. The technology involved in the construction of a peat bed is simple, and the cost of a pilot plant is very little but the experience gained in its operation is an extremely useful guide to the construction of a full scale plant. A successful demonstration of a pilot plant gives confidence to any recommendation to use this system and goes someway to removing the doubts of sceptics who doubt the claims made for what at first sight appears to be a curious process.

This thesis has addressed some fundamental causes that stimulate public complaint which is an important element in demonstrating that statutory control of pollution is in the public interest. But complaint is an unreliable indicator of public concern as it is the end result of a complex chain of events that do not result in a simple dose - response or pollution - complaint function Thus one community may complain vigorously about a mild exposure to stench while another endures stoically a most noxious atmosphere. A door to door attitude survey about a foundry revealed some reasons for this variation although the results of this were unexpected. It has been suggested that people with an economic dependence on a local cause of pollution, might be expected to underate the scale of pollution and overate the degree of control achieved but the survey indicated otherwise. Such people seem to have become sensitised to the ill effects of an industry that they believed had treated them badly.

The same survey also attempted to identify those individuals in a neighbourhood who might be expected to complain by classifying respondants into four groups labelled as imperturbable, perturbable, stoics, and apathetics. The basis for this was a self assessment of their acceptance of air pollution and tolerance to life's difficulties. Perturbable people who both recognise a high degree of pollution and have an intolerant personality are most likely to make a complaint. However only a very small minority of the community, about 6% comprise this group and indeed, these individuals have been the originators of most recent complaint. The conclusion reached as a result of this exercise was that the paucity of public complaint was due to the few numbers of people tempermentally disposed to complain but in view of the widespread recognition of the foundry as a source of pollution the current stage of affairs was unstable and any change of circumstances in the district, such as minor demographic changes or small changes in the foundry emission might trigger a storm of complaint. This in fact occurred during the late summer of 1986 after a new foundry plant was commissioned in 1986.

The unrealiability of public complaint as an indicator of pollution may be due to bureaucratic obstacles that make complaint difficult, or to a public ignorance of the procedures of pollution control and to a lack of encouragement for people to make complaint. If these difficulties are removed then it appears that the dose-response function is so precise that it can be accurately predicted by a relatively simple mathematical model This has been done by Clarenburg for industrial sources in the Netherlands with such success that the model has been incorporated into the statutory planning procedures. In Britain a very simple semi-empirical relationship has been established linking odour emission to maximum distance for complaint but this does not have the versality or the precision of the Dutch approach.

In this thesis an attempt was made to construct a mathematical model of odour dispersion based upon a complaint derived estimate of odour emission and a simple Gaussian model of atmospheric dispersion of a type that is frequently illustrated in standard text books of pollution control. Thus it was hoped to combine a complaint orientated criteria of stench with a simple mathematical technique to give a model of stench dispersal without requiring the modifications to the standard procedures that are necessary to calculate the peak concentrations lasting a few seconds that are significant to the perception of colour. Predictions of the model when matched against corresponding observations appeared to have sufficient accuracy to enable pollution control options to be explored with some confidence that a reliable decision can be made.

These four exercises have been undertaken to further the understanding of the effects and control of odour, pollution and each have been to some extent innovative in that an existing methodology was taken, developed and applied in circumstances which had not been investigated hitherto. Thus the ASTMS method of syringe dilution was modified to assess the four characteristics of odour, then this technique was applied to studies of the functioning of a peat bed method of odour control in a novel application for the treatment of emissions from maggot breeding. The method of attitude survey was used to investigate factors that generate public complaint and as well as suggesting socio-economic causes of motivation to complain it also identified individuals who are predisposed to become complainants. Finally a standard textbook procedure of atmospheric dispersal modelling was modified in one of its input parameters so that it could be used to predict the dispersal of stench in a community surrounding the industrial source.

All these techniques are sufficiently simple and practical in their application to be used by local authorities in tackling the problems of odour pollution and control. This statement can be made with confidence since they were developed and applied within a District Council without using unusual resources such as extensive laboratory facilities or specialised equipment.

Appendix 1. Does smell of a substance have health effects? A comparison of toxicity and odoricity for certain substances

Substance	CEL (ppm)	Odour Threshold (ppm)	OT> CEL
Acetaldehyde	2.5	0.21	
Acetic Acid	0.25	1.0	#
Acetone	25	100	
Acrolien	0.0025	0.21	##
Ammonia	0.62	47	##
Benzene	0.25	4.7	#
Bromine	0.0025	0.047	#
Butyric Acid	0.5	0.001	
Carbon Tetrachloride	0.25	100	##
Chlorine	0.025	0.31	#
Demethylamine	0.25	0.05	
Ethyl Mercaptan	0.0125	0.001	
Formaldehyde	0.05	1.0	#
Hydrogen Chloride	0.125	10	##
Hydrogen Sulphide	0.25	0.0005	
Methyl Mercaptan	0.012	0.0002	
Monomethylamine	0.25	0.02	
Nitrobenzene	0.025	0.005	
Paracresol	0.125	0.001	
Perchloroethylene	2.5	0.47	
Phenol	0.125	0.05	
Pyriline	0.125	0.021	
Styrene	2.5	0.05	
Sulphur Dioxide	0.125	0.5	#
Toluene	2.5	2.1	
Trechloroethylene	2.5	21.4	#

Note: 1) Abbreviated table based on that published in Ref 6 and the selection of substances is arbitary

2) The acronim CEL stands for Community Exposure Level and is such that CEL = TLV - 1/40

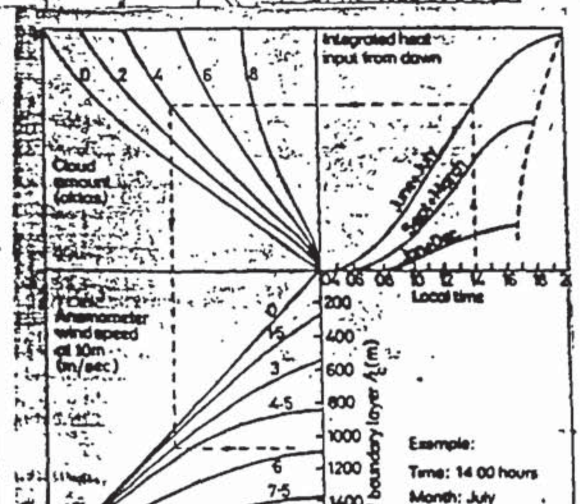
3) A single Hach # indicates those substances that if smelt might cause ill health in sensitive individuals of a general population. A double Hach ## indicates those substances that if smelt may be a health hazard in an industrial workforce.

This Table is obviously only a small selection taken arbitarily from the list of common industrial chemicals that are also odorants and whose toxicity has been established. In a large proporation of this list the smell of a substance signals a warning of possible health hazard due to its presence.

Surface wind speed (m/sec)	Insolation: Strong	Insolation: Moderate	Insolation: Slight	Night: Thinly overcast or > 4/8 low cloud	Night: < 3/8 cloud
<2	A	A–B	B	–	–
2–3	A–B	B	C	E	F
3–5	B	B–C	C	D	E
5–6	C	C–D	D	D	D
>6	C	D	D	D	D

(for A–B take average of values for A and B etc.)

Beaufort Scale no	Beaufort Scale and windspeed: character of wind	effects of wind inland
0	calm	calm, smoke rises vertically
1	light air	wind direction shown by smoke but not by flags
2	slight breeze	wind felt on face, leaves whisper, flags move
3	gentle breeze	leaves and thin twigs move, pennants extended fully
4	moderate breeze	paper and dust lifted, twigs and thin branches move
5	fresh breeze	small trees in leaf begin to sway, white horses on lakes
6	strong breeze	thicker branches move, whistling in telephone lines, umbrellas difficult to use
7	moderate gale	whole trees moving, resistance to movement against wind perceptible
8	gale	twigs broken from trees, movement in open difficult
9	strong gale	minor damage to houses (chimney pots and tiles)
10	whole gale	trees uprooted, major damage to houses
11	storm	widespread damage, state 1
12	hurricane	severe destruction



Date Time	Wind Speed	Wind Dirn.	Visibility	Humidity	Cloud	Temp	Bndy-Layer	Stab. cat	Cupolas No	Cupolas Plume rise
Mon 26/11/84 11 30	F3	SW	Good	Dry	0/8	10°C	800	C	4	Falling

Comment Bright, sunny, cool morning. Strong smell about Wren's Nest Pub.

Barometer 1024

Photo No 6 – 8.

Photograph overpage

APPENDIX 3 THE COMPUTER PROGRAM FOR COMPUTATION OF THE ODOUR DISPERSAL MODEL

These programs use the Guassian Plume procedures outlined in the Turner Work Book to calculate the spread of stench downwind from a point source. The presence of stench is calculated at receptors arranged in the form of a grid, of 22 x 22 cells, with the source at the centre. The calculated spread of plume takes into account wind direction and the results of each day's observations are displayed on a VDU. Daily data is printed and includes day number, wind speed, wind direction, stability category, effective chimney height, boundary layer height, count of cells influenced by an inversion. The only output printed daily is the total cell count of the area of the plume. The results of each daily calculations are stored so that towards the end of a run, a table is printed showing the cumulative daily data in the form of a map of odour frequencies. Inputs are read from tape so that a data entry program is also required.

The microcomputer used was a Commodore VIC 20 with 16K memory expansion, cassette tape data recorder, and Commodore 1515 dot matrix printer. Running time is a function of the number of daily observations, each one taking 3 minutes to compute.

Summary of Work Book Formula

$$C = \frac{Q}{\pi \sigma_y \sigma_z U} \exp\left[-\frac{1}{2}\left(\frac{Y}{\sigma_y}\right)\right] \left\{ \exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma}\right)\right] \right\}$$

In the model being developed concentration is replaced by dilution.

In the Work Book the variables and are estimated by reference to graphs giving their value as a function of distance. In this program the value was calculated as follows:-

$$\text{Log}\, \sigma_y = \left[(K_y \times LD) + YD\right] \quad \& \quad \sigma_z = \left[(K_z \times LD) + ZD\right]$$

$K_{y,z}$ & Y, Z D are constants

LD is the downwind distance

Special Case for Low Level Inversion

Turner suggests that when a plume which is reflected off an inversion layer becomes an influence on ground level concentration then the following calculation should replace the full Guassion treatment.

If $6_Z \geq 0.47L$ where L = Boundary layer height (eg inversion)

Concentration =

$$C = \frac{Q}{\pi \sigma_y \sigma_{zL} U} \left[\exp -\frac{1}{2}\left(\frac{Y}{\sigma_y}\right)^2\right]$$

Building Correction

To account for entrainment of the plume in the wake of buildings when the chimney height is lower than 2½ times the height of the building then 6_Y and 6_Z are modified.

Main Program Variable List

a) "Constant" information

Variable	
PN$	Output to printer (P) or Screen (S)
PN	Derived from PN$ (3 = Screen, 4 = Printer)
TN$	File Name of cassette file for input
TX$	Text information at head of file; limit of 255 characters
ND	Number of days
MD	Maximum distance (Kilometres)
DD	Step size of grid (DD = MD/10)
KP$	Dummy input to continue program after pause
HO$	Constant Height (of chimney) (Y/N)
SH	Effective Height (M)
BF$	Building Effect? (Y/N)
BW	Crosswind area of building (m^3)(0 if BF$ is N)
SQ	Odour emission rate (0/sec)

b) Daily Information

WS	Wind speed (m/sec)
BT	Wind direction (compass)
ST$	Stability category (A-E)
BH	Height of boundary layer (M)
EH	Effective Height of Chimney (M) Overridden and set to SH if HO$ is Y
AL	Wind direction (0-2
IS	Stability Category (1-5 for A-E)

c) Housekeeping and Utility Variables

I	Loop counter for daily loop
SP$	String of spaces
IY(5)	Intercepts for sigma Y for conditions A-E
IZ(5)	Intercepts for sigma Z for conditions A-E
BF(5)	Building effects
H1$	Top line of heading (Daily Information)
H2$	2nd line of heading (Daily Information)
H3$	3rd line of heading (Daily Information)
K	0.91/Log e(10) providing factor for daily information

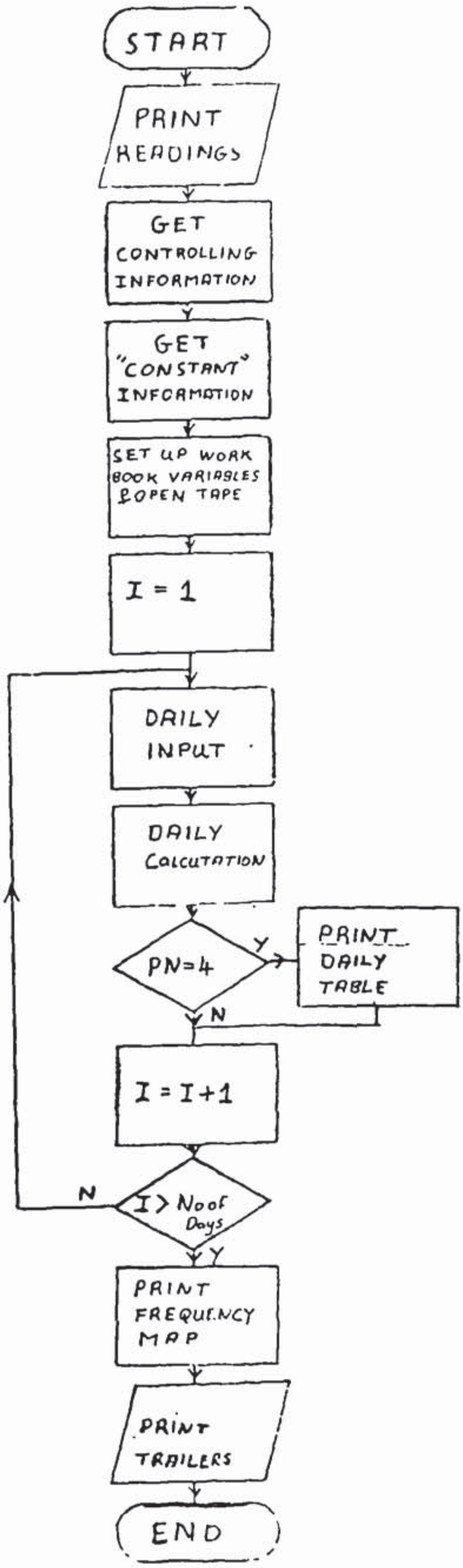
c) Housekeeping and Utility Variables (Cont'd)

I8	Loop counter for initialising IY, IZ and B. Farroys
YD	Daily sigma, y intercept (element of I. Yarray)
ZD	Daily sigma, z intercept (element of IZ)
DF	Building Effect (BF(IS)x BW/)
Y	Y distance from chimney (KM)
X	X distance from chimney (KM)
JY	Loop counter for cells in Y direction
JX	Loop counter for cells in X direction
R	Distance from chimney (KM)
PL$	Symbol to print * - chimney . - no effect, x - effect
TH	Angle from point to chimney
GA	Angle from wind direction to print
DW	Downwind distance [R Cos (GA)] units are kilometres
AW	A crosswind distance [R Sin (GA)] units are kilometres
LD	Log of downwind distance
SY	Antilog [(K x LD) + YD] = sigma Y This is corrected for building effect 6g SY =
SZ	Sigma Z exactly as for Sigma Y
F1	SQ/(SQR(2*π)*SY*BH*WS)
F2	EXP(-AW*1000*AW*1000/SY/SY/2)
F3	EXP (-EH*EH/SZ/SZ/2)
*	If
PL$	Print line for daily data
PT$	Each item in print line taken in turn
LW	Length of PT$ for each field in turn
TD$	Title line
F$	Symbol for frequency table for screen

3. Output

F(21,21)	Frequency matrix)
DC	Daily count of cells set becomes area later
BC	Daily count of cells under inversion
C	Concentration or dilution F1 * F2 * F3)

FLOWCHART FOR COMPUTER PROGRAM



PROGRAM LISTING

```
READY.

10 REM ODOUR MODELLING
20 REM SUN,19/10/86
30 REM B.J.D FOR C.A.D.
40 REM USES THE TURNER WORKBOOK PROCEDURES
50 REM THE CHIMNEY IS IN THE MIDDLE OF THE SCREEN
60 REM VERSION 2 - DAILY INPUT FROM TAPE
100 PRINT"⊐***ODOUR MODELLING***"
110 PRINT"XTHIS PROGRAM USES THE METHODS OF THE TURNER WORKBOOK"
120 PRINT
130 PRINT
135 GOSUB 10000:REM PAUSE
140 GOSUB 1500:REM THE CONTROLLING INFORMATION
150 GOSUB 1000:REM THE "CONSTANT" INFORMATION
180 GOSUB 1800:REM PREPARE FOR MAIN LOOP
190 REM* THE MAIN LOOP STARTS HERE
200 FOR I=1 TO ND
210 GOSUB 2000:REM THE DAILY INPUT
220 GOSUB 3000:REM THE CALCULATIONS
225 IF PN=4 THEN GOSUB 3500:REM PRINT DAILY DATA AND RESULTS
230 NEXT I
240 REM* ALL DATA PROCESSED -SUMMARISE
250 GOSUB 6000:REM THE OUTPUT
260 PRINT"⊐"
270 PRINT#4,:PRINT#4,:PRINT#4,"END OF OUTPUT"
280 PRINT#4,
290 CLOSE 4
900 END
910 REM****END OF MAIN LINE
1000 REM***OBTAIN THE "CONSTANT" INFORMATION
1010 PRINT"⊐**SETTING THE SCENE**"
1020 PRINT"XSTACK INFORMATION"
1030 PRINT"================="
1035 PRINT"XDO YOU WISH TO USE A CONSTANT EFFECTIVE":PRINT"HEIGHT(Y/N)";
1036 INPUT HO$
1037 IF HO$<>"Y" AND HO$<>"N" THEN PRINT" ERROR! PLEASE ANSWER Y/N ONLY":GOTO 10
35
1040 IF HO$="Y" THEN PRINT" EFF.HEIGHT M"TAB(14)":";:INPUT SH
1045 PRINT" DO YOU WISH TO USE A BUILDING EFFECT":PRINT"Y/N)";
1046 INPUT BF$
1047 IF BF$<>"Y" AND BF$<>"N" THEN PRINT" ERROR! PLEASE ANSWER Y/N ONLY":GOTO 10
45
1049 BW=0:REM DEFAULT TO ZERO
1050 IF BF$="Y"THEN PRINT" CROSS WIND AREA OF BLDG.M↑2"TAB(16)".":INPUT BW
1080 PRINT"XEMM. RATE ,O/S"TAB(14)":";:INPUT SQ
1090 PRINT :GOSUB 10000
1095 IF PN=3 THEN PRINT"⊐";
1100 PRINT#4,"ODOUR MODELLING "
1110 PRINT#4,"=============== "
1112 PRINT#4:PRINT#4:PRINT#4,"FILE NAME-"TN$
1114 PRINT#4:PRINT#4:PRINT#4,TX$
1120 PRINT#4,"X"      "STACK INFORMATION"
1130 PRINT#4,"----- -----------"
1135 PRINT#4,
1140 IF HO$="Y" THEN PRINT#4,"EFFECTIVE HEIGHT,M:"SH
1150 IFBF$="Y" THEN PRINT#4,"CROSS WIND AREA,M↑2:"BW
1180 PRINT#4,"EMM. RATE ,O/S :"SQ
1190 IF PN=3 THEN PRINT:GOSUB 10000
1400 RETURN
1500 REM***GET THE PROGRAM CONTROLLING INFORMATION
```

```
1520 PRINT"[illegible] INFORMATION
1530 PRINT"==================="
1540 PRINT"IS OUTPUT TO BE TO:"
1550 PRINT"    SCREEN OR ...."
1560 PRINT"    PRINTER"
1570 INPUT"    ";PN$
1580 IF PN$="S" THEN PN=3:GOTO 1595
1585 IF PN$="P" THEN PN=4:GOTO 1595
1590 PRINT "** ANSWER S OR P ONLY" GOTO 1540
1595 OPEN4,PN  REM FROM NOW ON PRINT #4 WILL PRINT TO THE SCREEN OF PRINTER.
1600 PRINT"FILE NAME":INPUT TN$
1605 PRINT"***PLEASE CHECK THAT  THE TAPE IS AT THE    CORRECT PLACE" PRINT GOS
UB10000:PRINT
1610 OPEN1,1,0,TN$
1620 INPUT#1,TX$
1625 INPUT#1,ND
1628 INPUT#1,ND
1630 PRINT"**SETTING THE SCENE**"
1640 PRINT"GRID INFORMATION"
1650 PRINT"================"
1660 PRINT"THE GRID WILL BE 21   POINTS WIDE IN EACH   DIRECTION"
1670 PRINT"'ROUND' SPACING WILL  BE OBTAINED WITH MAX  VALUES OF 2.5KM, 5KM  ET
C."
1680 PRINT"WHAT IS YOUR MAXIMUM":INPUT"DISTANCE ,KM ";MD
1690 LET DD=MD/10:REM STEP SIZE
1780 PRINT:GOSUB10000
1790 RETURN
1800 REM***INITIALISATION
1810 DIM F(21,21):REM FREQUENCIES
1820 DIM IY(5):REM INTERCEPTS  FOR SIGMA Y
1830 DIM IZ(5):REM INTERCEPTS  FOR SIGMA Z
1835 DIM BF(5):REM BUILDING EFFECT
1840 FOR I8=1 TO 5
1850 READ IZ(I8),IY(I8),BF(I8)
1860 NEXT I8
1861 DATA 2.48,2.31,0,2.00,2.18,0.5,1.78,2.00,1,1.51,1.82,2,1,32,1.70,.5
1862 H1$=" DAY WIND  WIND     STAB.      EFF.     BNDRY.   BNDRY.   PLUME"
1864 H2$="      SPEED DIRN.    CATY.      HEIGHT   HEIGHT   LAYER    AREA"
1866 H3$="      (M/S) COMPASS  PASQUILL   (M)      (M)      COUNT    (KM↑2)"
1870 DATA 2.48,2.31,2.00,2.18,1.78,2.00,1.51,1.82,1.32,1.70
1875 K=0.91/LOG(10):REM FOR SIGMAZ AND SIGMAY
1950 IF PN=4 THEN PRINT#4,:PRINT#4,:PRINT#4,LEFT$(SP$,32)"DAILY INFORMATION"
1960 IF PN=4 THEN PRINT#4,LEFT$(SP$,32)"=================":PRINT#4,:PRINT#4,H1$:
PRINT#4,H2$:PRINT#4,H3$
1980 RETURN
2000 REM***THE DAILY INPUT
2010 PRINT"DAY "I
2020 INPUT#1,WS,PT,ST$,BH,EH
2030 IF HO$="Y" THEN EH=SH:REM OVERRIDE WITH VALUE INPUT
2036 AL=270-BT
2037 IF BT>270 THEN AL=630-BT
2038 LET AL=AL*π/180:REM NOW CONVENTIONAL 0-2π
2050 LET IS=ASC(ST$)-64:REM INDEX OF STABILITY CATEGORY
2140 RETURN
3000 REM*** DAILY CALCULATION ROUTINE
3002 DC=0:REM COUNT OF CELLS SET
3003 BC=0:REM COUNT OF CELLS UNDER INVERSION
3005 IF EH>BH THEN PRINT "EFFECTIVE HEIGHT ABOVE BOUNDARY LAYER":GOTO3250
3010 PRINT"PICTURE FOR DAY "I
3012 YD=IY(IS):REM DAILY SIGMAY INTERCEPT
3013 ZD=IZ(IS):REM DAILY SIGMAZ INTERCEPT
3014 DF=BF(IS)*BW/π:REM DAILY BUILDING CORRECTION
3015 Y=MD
3020 FOR JY=1 TO 21
3025 X=-MD
3030 FOR JX=1 TO 21
3040 R=SQR(X*X+Y*Y)
3042 IF R<1E-5  THEN C=0:PL$="◆":GOTO [illegible]
```

```
3042 IF R<1E-5 THEN C=0:PL$="*":GOTO 3180
3045 IF X=0 AND Y<0 THEN TH=1.5*π:GOTO 3075
3048 IF X=0 AND Y>0 THEN TH=0.5*π:GOTO 3075
3050 TH=ATN(Y/X)
3060 IF X<0 THEN TH=π+TH
3070 IF TH<0 THEN TH=2*π+TH
3075 REM*TH NOW CONVENTIONAL ANGLE 0-2π
3080 LET GA=ABS(TH-AL)
3085 IF GA>1.5*π THEN GA=2*π-GA :REM CHANGE 270+ TO 0-90
3090 IF GA>=π/2 THEN C=0:PL$=".":GOTO 3180
3100 DW=R*COS(GA):REM DOWN WIND DISTANCE
3110 AW=R*SIN(GA):REM ACROSS WIND DISTANCE
3115 LD=LOG(DW)
3120 SY=K*LD+YD
3125 SY=10↑SY  :REM SIGMA Y
3126 SY=SQR(SY*SY+DF):REM BUILDING EFFECT
3130 SZ=K*LD+ZD
3135 SZ=10↑SZ  :REM SIGMA Z
3136 SZ=SQR(SZ*SZ+DF):REM BUILDIG EFFECT
3140 IF SZ<0.47*BH THEN GOSUB 4000
3150 IF SZ>=0.47*BH THEN GOSUB 4100
3155 PL$="."
3160 IF C>=1 THEN F(JX,JY)=F(JX,JY)+1:PL$="X":DC=DC+1
3180 PRINT PL$;
3190 X=X+DD
3200 NEXT JX
3210 PRINT
3220 Y=Y-DD
3230 NEXT JY
3240 PRINT"";
3250 RETURN
3500 REM***PRINT THE DAILY DATA AND AREA
3505 PL$="":REM EMPTY PRINT LINE
3510 PT$=STR$(I):LF=3:GOSUB 3800
3520 WS=INT(WS*10+.5)/10
3530 PT$=STR$(WS):LF=5:GOSUB 3800
3540 PT$=STR$(BT):LF=6:GOSUB 3800
3550 PT$=LEFT$(ST$,1):LF=10:GOSUB 3800
3590 EH=INT(EH+.5)
3600 PT$=STR$(EH):LF=12:GOSUB 3800
3610 PT$=STR$(BH):LF=9:GOSUB 3800
3620 PT$=STR$(BC):LF=7:GOSUB 3800
3630 DC=INT(DC*DD*DD*100+.5)/100:REM CHANGE COUNT TO AREA TO 2 D.P.
3640 PT$=STR$(DC):LF=9:GOSUB 3800
3650 PRINT#4,PL$:REM FINALLY PRINT
3660 RETURN
3800 REM***ADD PT$ TO THE PRINT LINE,LEFT JUSTIFY TO LF CHARS
3810 LW=LEN(PT$)
3820 IF LW>LF THEN PT$=" *"+MID$(PT$,2,LF-2):REM SIGNAL OVERFLOW
3830 IF LW<LF THEN PT$=LEFT$(SP$,LF-LW)+PT$
3850 PL$=PL$+PT$
3860 RETURN
4000 REM***USUAL DISPERSION CALCULATION
4010 F1=SQ/(π*SY*SZ*WS)
4020 F2=EXP(-AW*1000*AW*1000/SY/SY/2):REM METRES
4030 F3=EXP(-EH*EH/SZ/SZ/2)
4040 C=F1*F2*F3
4050 RETURN
4100 REM***EXCEPTIONAL DISPERSION CALCULATION
4105 BC=BC+1:REM COUNT OCCURENCES
4110 F1=SQ/(SQR(2*π)*SY*BH*WS)
4120 F2=EXP(-AW*1000*AW*1000/SY/SY/2):REM METRES
4140 C=F1*F2
4150 RETURN
6000 REM***OUTPUT THE FREQUENCIES
6010 PRINT"TOTAL  PICTURE"
6015 IF PN=4 THEN GOSUB 6200
6020 FOR JY=1 TO 21
```

```
6015 IF PN=4 THEN GOSUB 6200
6020 FOR JY=1 TO 21
6025 IF PN=4 THEN GOSUB 6300:REM PRINT ON PRINTER
6030 FOR JX=1 TO 21
6035 F$="*"
6040 F=F(JX,JY)
6050 IF F<10 THEN F$=STR$(F):F$=RIGHT$(F$,1)
6054 IF PN=4 THEN GOSUB 6400:GOTO 6060:REM PREPARE TO PRINT ON PRINTER
6055 PRINT F$,
6060 NEXT JX
6064 IF PN=4 THEN PRINT#4,PL$:GOTO 6070:REM PRINT ON PRINTER
6065 PRINT
6070 NEXT JY
6090 PRINT"⌧";:GOSUB 10000
6100 RETURN
6200 REM***PRINT TITLES FOR FREQUENCY OUTPUT
6205 PRINT#4,:PRINT#4,:PRINT#4,
6210 PRINT#4,CHR$(14)"FREQUENCY TABLE"
6215 PRINT#4,:PRINT#4,CHR$(15)"EACH UNIT IS "DD" KM":PRINT#4,
6220 TD$="       POSITION          "
6230 PRINT#4,"                    "TD$
6235 PL$="     "
6240 FOR JY=-10 TO 10
6250 PT$=STR$(JY)+"   "
6260 PT$=LEFT$(PT$,3)
6270 PL$=PL$+PT$
6280 NEXT JY
6290 PRINT#4,PL$
6299 RETURN
6300 REM***SET UP FREQUENCY TABLE LINE  FOR PRINTER
6310 PL$=MID$(TD$,JY,1)+" "
6320 PT$=STR$(JY-11)+"   "
6330 PT$=LEFT$(PT$,3)
6340 PL$=PL$+PT$
6350 RETURN
6400 REM***ADD ONE FREQUENCY TO PL$
6410 PT$=STR$(F(JX,JY))+"    "
6420 PL$=PL$+LEFT$(PT$,3)
6430 RETURN
10000 REM***WAIT FOR A KEY PRESS
10010 PRINT"PRESS ANY KEY ....."
10020 GET KP$
10030 IF KP$="" THEN 10020
10040 RETURN
10050 REM***END OF LIST

READY.
```

UNIVERSITY OF ASTON, FACULTY OF SCIENCE
AIR POLLUTION SURVEY.

Street No. Date Time Interview No.

1) What do you think the words "AIR POLLUTION" mean to most People in your nieghbourhood. Please Put an "X" in the suitable box.
   - [ ] Too much dirt and dust in the air.
   - [ ] Frequent bad smells in the air.
   - [ ] Too much smoke or haze in the air.
   - [ ] Too much noise.

2) Do you think that air Pollution is often Present in your street. YES/NO

3) How bothered are you by air Pollution
   - [ ] Very much bothered.
   - [ ] A little bothered.
   - [ ] Not at all bothered.

4) Factories are often the cause of air Pollution. Below is a list of factories to be found in Ketley . Please Put an "x" by those you believe to cause air Pollution in your street.
   - [ ] Contractors dePot
   - [ ] Road Hauliers
   - [ ] Scrap yard
   - [ ] MEB DePot
   - [ ] Printing Works
   - [ ] Foundry
   - [ ] Engineering Works.
   - [ ] Garage

5) Do you or any member of your family work in any of the above Places. YES/NO

6) Do you believe that the amount of air Pollution in your street can be reduced
   - [ ] By A lot.
   - [ ] By a little.
   - [ ] In no way.

7) Do you believe an effort is being made to reduce air Pollution caused by local factories? YES/NO

8) If you wished to make a complaint about air Pollution which of the following would you contact
   - [ ] The Factory Inspector.
   - [ ] HM Air Pollution Inspector.
   - [ ] The Police
   - [ ] The Council (Environmental Health DePt.)
   - [ ] Your local Councillor.
   - [ ] The Citizens Advice Bureau
   - [ ] The Health & Safety Executive
   - [ ] The Council (Planning & Environmental Services DePt.)

9) For how many years have you lived in Ketley? ________

10) After leaving school have you been to:
   - [ ] Technical College.
   - [ ] Polytechnic.
   - [ ] University.

AIR POLLUTION SURVEY, PART 2

Please put an "X" on these lines which to show the amount of your bother with each type of air pollution named above the line. For example if you are slightly bothered place an "X" somewhere in the left hand part of the line.

EXAMPLE

Not bothered ____________________ Extremely Bothered

Bother with smoke or fume

Not Bothered ____________________ Extremely Bothered

Bother with smell

Not bothered ____________________ Extremely Bothered

Bother with Noise

Not Bothered ____________________ Extremely Bothered

Overall Bother with air pollution

Not Bothered ____________________ Extremely Bothered

Please describe your opinion of air pollution in your street as you have known it in the past month or two.

Harmful											Beneficial
Pleasant											Unpleasant
Good											Bad
Comfortable											Uncomfortable
Annoying											Pleasing
Exciting											Depressing
Offensive											Inoffensive

Please indicate how much you agree or disagree with the following statements

People should have to put up with air pollution from factories

Disagree											Agree

Air pollution is a feature of life in Ketley

Agree											Disagree

I am a person that "suffers in silence"

Disagree											Agree

Appendix 4 ODOUR POLLUTION

This page is about the smells coming from Glynweds Foundry.

1) Which one or more of the following words do you believe to best describe the smell from Glynwed's Foundry:-

- [ ] Smoky
- [ ] Chemical
- [ ] Disinfectant
- [ ] Earthy of Mouldy
- [ ] Sharp or Acid
- [ ] Soot
- [ ] Oily
- [ ] Creosote
- [ ] Putrid or Foul
- [ ] Sweaty
- [ ] Metallic
- [ ] Tar

2) About how often do you believe they happen in your street.

- [ ] Nearly Every Day
- [ ] Twice per week
- [ ] Once per week
- [ ] Twice per month
- [ ] Once per month
- [ ] Once in two months

3) People often say that the smell causes them to feel one or more of the following:-

- [ ] Unease
- [ ] Tension
- [ ] Resentment
- [ ] Anger
- [ ] Fear
- [ ] Sore throat
- [ ] Dizziness
- [ ] Sick
- [ ] Headache

APPENDIX 5

ODOUR STRENGTH

Introduction

You will be given several pairs of syringes. In each pair, one syringe will contain a smell, the other will not. Please note that in some pairs the smell will be so weak that you will not be able to detect it, nevertheless the smell will be there. Your task is to sniff each syringe of every pair and indicate on the attached form which syringe contains a smell and which does not.

Method

Hold the syringe offered to you in one hand, insert the coloured bead in one nostril and inject some air pushing on the piston of the syringe. When you have decided whether there is a smell or not look at the colour code of the syringe and place a tick in the appropriate box if you detect a smell; leave a blank if you do not.

Test 1			Test 2			Test 3		
Tube No	Colour Code Green	Red	Tube No	Colour Code Green	Red	Tube No	Colour Code Green	Red
1								
2								
3								
4								

Appendix 5

RESPONSE SHEETS USED IN SENSORY ASSESSMENT OF BIOLOGICAL ODOUR FILTRR

Please Note: Maggot Odour is extremely unpleasant and is often said to be sickening but it does not cause illness. However do not take part in the following tests if you do not feel in the best of health.

Part 1

Take a syringe in one hand; place the bead in one nostril; hold your breath and gently inject a small amount of air into your nose bu pushing on the piston. Record your impression of the smell as follows in Parts 2, 3, and 4. If you wish to repeat the test transfer the bead to your other nostril.

Part 2 Intensity of Smell Please tick the appropriate box.

Tube Intensity	1	2	3	4	5
None					
Weak					
Moderate					
Strong					
Sickening					

Part 3 Hedonics Please place tick in box.

Tube									
1	Pleasant								Unpleasant
2	Unpleasant								Pleasant
3	Unpleasant								Pleasant
4	Pleasant								Unpleasant
5	Pleasant								Unpleasant

APPENDIX 5

Part 4 Descriptors

Below are some descriptions commonly used to describe smells. Please tick those that seem appropriate. You may tick as many as you wish.

Sickening					
Musty, Earthy					
Light					
Heavy					
Sweet					
Sour					
Ammonia Like					
Fishy					
Sulphurous					
Putrid					
Manurial					
Pungent					
Household Gas					
Ether Like					
Cadauerous (Death Like)					
Bad Eggs					

APPENDIX 6 RESULTS AND DISCUSSION OF SENSORY ASSESSMENT OF PEAT BED PERFORMANCE

Table 10.1 Assessment of Changes in Detectability of Odour Through the System

Observer	Dilutions to threshold		
	After Chamber	After Scrubber	After Peat
JS	395	195	6.3
BD	195	49	1.6
LM	98.7	98.7	6.3
RI	195	98.7	6.3
JBL	98.7	98.7	6.3
JL	195	49	6.3
Average	196	117	5

Discussion

Clearly this test is a relatively crude estimate of the quantity of odour passing through the system and no claim is made for the accuracy and precision of the procedure. However, panellists experienced little difficulty in operating the equipment and gave consistent responses. The results show that the overall effectiveness of the system was better than 95%, with the reduction occurring in 2 stages of 40% removal after scruffing and 97.5% after bilfiltration.

This method of the odour emerging from the system may be totally different from that entering and benefits of the plant can be underestimated. Thus a powerful unpleasant smell may during treatment become a weak pleasant smell. Measurement of odour detectability ignore such changes that the following tests attempt to quantify.

Estimates of Intensity Changes

This was assessed by an observer at the same time and on the sample taken for rating of hedonics. He or she was asked to tick an appropriate box in a 5 point magnitude scale with the results shown below.

Table 10.2 Assessment of Changes in Odour Intensity through the Systems

Odoour Sample / Observer	1	2	3	4	5
KM	1	3	2	0	1
S	1	3	3	0	2
RM	1	3	3	0	0
JS	0	2	1	0	0
JBL	1	3	1	0	0
BD	1	4	2	0	1
LM	1	3	3	0	1
JL	0	2	1	0	0
LM	1	3	3	0	0
WD	2	5	3	1	2
ID	1	3	2	1	2
Mean Response	0.9	3.1	2.2	0.2	0.8

Key

1 1000 ppm Butanol

2 After Breeding Chamber

3 After scrubber/humidifier

4 "Clean" outdoor air

5 After peat bed

Magnitude Scale

0 None

1 Weak

2 Moderate

3 Strong

4 Sickening

Conclusion

The concentration of 1000 ppm on the butanol scale was chosen to correspond to a moderate intensity rating although most observers rated its odour to be weak. This is probably due to the method of presentation of the sample. Most observers agreed that the odour from the breeding chamber was strong in intensity "3.1 units", weakened to moderate "2.2 units" after the water scrubber and finally emerged from the peat bed as weak "0.8 units" Thus the peat bed brings about a considerable weakening in the odour but a weak smell can still cause annoyance if its character is offensive.

Estimates of Quality Change

Observers were asked to assess their reaction to a smell presented to them in a 100 ml glass syringe and record their perceptions within a 10 point bipolar scale labelled at one end, Pleasant and at the other Unpleasant. The observers indicated their decision by placing a tick in an appropriate box.

In the table below the reactions of each observers to each smell are recorded, negative values indicate an unpleasant response and an increasing integer indicates an increasingly vigorous response. Conversely positive values indicate pleasantness.

Table 10.3 Changes in Odour Quality Through the System

Odour Sample / Observer	1	2	3	4	5
KM	-1	-4	-3	-1	-1
S	0	-4	-5	-1	-1
RM	3	-4	-4	0	0
JS	3	-4	-1	0	0
JBL	-1	-4	-1	0	0
BD	0	-5	-5	0	-1
LM	1	-3	-4	5	4
JL	0	-3	-3	0	0
LM	-2	-5	-5	0	0
WD	-1	-4	-4	2	2
ID	-2	-3	-1	1	1
Mean Response	-0.2	-3.8	-3.2	0.5	0.4

Key to odour sample

1 1000 ppm Butanol

2 After Breeding Chamber

3 After scrubber/humidifier

4 "Clean" outdoor air

5 After peat bed

Discussion

Maggot odours were consistently rated by observers to be most unpleasant but the consistency became less after the action of the water scrubber. The assessments were -3.8 units for untreated maggot odours, -3.2 after scrubbing and 0.4 after full treatment. Weaker unfamiliar odours, such as Butanol and the exit gas from the peat bed tended to be rated slightly unpleasant. Only in one instance was an "odd" response noted and this was for observer LM's reaction to pure outdoor air. This might be interpreted as an over reaction brought about by the relief at not being presented by a further foul odour, having experienced two samples of an undoubted stench.

These measurements demonstrate a useful function of this sytem which turns a intense, foul odour rated very negatively into a weak, neutral or even slightly pleasant odour. However no information is given concerning the type of smell being emitted.

Assessment of Odour Character

Again this parameter was assessed by an observer at the same time and on the same sample of odour used to rate hedonics and intensity. He or she were asked to describe the odour in terms of adjectives called from a list compiled by the Amercian Society for testing and Materials Sensory Evaluation Committee E 18 and described by Dravnieks, Masavat and Lamns (Ref 2). Each descriptor has been assessed for its hedonic value resulting from an extensive evaluation thus an additional estimate of the hedonic parameter of the odour can be made in addition to that already attempted. The following table lists the adjectives selected by panellists to describe the odour presented to them. Each has been selected more than once from the sample presented to them. The hedonic value on the ASTMS scale is presented, as is also the frequency with which the adjective was used. A mean hedonic value was calculated from the frequency of use of an adjective and its rating on the hedonic scale so that a hedonic value for the complex maggot odour could be assessed that occurred as it passed through the odour control system could be quantified.

Table 10.4 Changes in Odour Character through the system

Descriptor	Hedonic Value	Odour Sample 1	2	3	4	5
				0.08		0.27
Light	0.91	0.23				
Ether Like	-1.54	0.38				
Fishy	-1.98	0.23	0.12	0.20		
Heavy	-0.79		0.12			
Sickening	-3.34		0.12	0.12		
Ammonia Like	-2.47		0.12			0.18
Putrid	-3.74		0.12	0.08		
Pungent	-2.34		0.12	0.08		
Sour				0.12		
Household Gas						0.18
Total Frequency		0.84	0.72	0.68		0.63
Weighted Hedonic Mean		-0.51	-1.70	-1.37		-0.6

Key to Odour Sample

Odour 1 Butanol

Odour 2 After Breeding Chamber

Odour 3 After Scrubber

Odour 4 "Clean Air"

Odour 5 After Peat Bed

Conclusion

Using this standard test the panellists were prompted to be more informative about their impressions of the smells they experienced than they would have been if their response was spontaneous. Untreated maggot smell is so repulsive that people exposed to it normally recoil with only an exclamation to describe its character. With a standard list of objectives to choose from the usual adjective choosen were fishy, heavy, sickening, ammonical, putrid and pungent. The ??? of the smell seems adequately conveyed. After scrubbing this adjective became light, fishy, sickening, putrid, pungent and sour. Interestingly water scrubbing which does remove ammonia also caused this adjective to be no longer chosen. The final odour emerging from the bed caused some difficulty to the panelists in their selection of adjectives but it was generally agreed to be light, sour and ammonical.

A second opportunity was offered to assess quality using ratings applied to the standard adjectives with results similar to those obtained in the previous test although more compressed. Thus untreated maggot odour was rated highly negatively at -1.70 units, becoming -1.37 after scrubbing and -0.6 after full treatment. The 0.6 value is similar to the value for butanal that has been chosen as a reference odour because of its neutral character. It may be that people tend to have a slightly negative opinion of unfamilar smells.

Appendix 7

Observation of Some Single Parameters; Ammonia, Temperature

It was not possible to do a complete analysis for all the significant odorants contributing to the general maggot stench and then to follow the fate of these components as they travel through the abatement plant. However, a comprehensive analysis of maggot odour has been done by workers at WSL (2) and it is known that two major compounds present are ammonia and trimethylamine. These were likely to be present in concentrations sufficient to be easily and conveniently measured by Dreager gas detector tubes. Consequently, ammonia monitoring was undertaken using ammonia detector tubes which are also responsive to amines at a lesser sensitivity. Table 10.6 shows the results of this analysis with ammonia levels reaching a maximum of 320 ppm on days of a breeding cycle of about one week. Spot checks in the breeding room of the maggot breeder gave levels of 200 ppm in the air over the pens, thus the pilot plant has a comparable internal atmosphere.

The activity of the maggots in the breeding chamber could be assessed by measuring the carbon dioxide evolved by respiration of the maggots and the internal temperature increase of the chamber brought about by biological activity. Table 10.7 shows the increase in temperature of the chamber for successive batches but no systematic monitoring of carbon dioxide was undertaken since the detector tubes were not sufficiently sensitive to permit worthwhile measurements to be made. Spot checks did show that a maximum concentration of 0.15% was associated with intense maggot activity. Again the evidence suggest maximum activity in the growing maggots on day 3 of a 7 day cycle.

Comparison of the tables showing variation of ammonia and temperature shows that the level of each tended to peak on the third day after hatching of the maggots. However, there are considerable batchwise variations in the parameters monitored probably due to the lack of any attempt to control the variables associated with maggot breeding, such as condition of the meat and ambient temperature.

Maggots feed on dead tissue which in the case of these experiments were usually liver or lung. After death the intricate systems of a living body run away with first the cellular structure of tissue breaking down by a process of self digestion or autolysis that results in protein becoming liquified. Tissues are next invaded by bacteria which travel easily through the liquifying mass and cause putrification.

Maggots hatch from eggs laid in the dead tissues and feed on it by exuding powerful digestive enzymes that releases large amounts of ammonia from the dead protein. Ammonia is an effective sterilant and inhibits putrification but putrification generates heat which forces maggots to the surface of the meat where food is scarce and the rate of development is slowed. Thus successful maggot breeding is a balance between putrification and the feeding rate of maggots and which factor dominates depends on the freshness of the meat when it is first exposed to flies. In the case of the Telford Bait breeders, there is an associated knackers yard which provides the meat. Knackers meat is not slaughtered on the premises but it is provided by animals who have died at unknown times in the field from accidents or disease. Hence the freshness of the meat varies considerably from batch to batch and it is believed to account for the considerable batchwise variation in the parameters monitored.

Table 10.5 Ammonia (ppm) in outlet from Breeding Chamber

Day/Batch	1	2	3	4	5	6
3	30	200	300	140	60	60
4	40	130	400	180	100	60
5	30	100	500	150	100	50
6	60	200	450	200	50	30
7	40	250	200	100	40	
Mean	40	176	370	154	70	50

Table 10.6 Ammonia (ppm) in outlet from Water Scrubber

Day/ Batch	1	2	3	4	5	6
3	5	30	20	35	10	10
4	10	10	60	30	15	5
5	5	10	40	20	20	5
6	10	20	30	25	10	5
7	10	30	30	15	5	
Mean	8	20	36	25	12	6.25

Table 10.7 Excess Temperature within Breeding Chamber during a Breeding Cycle

Day/ Batch	1 (°C)	2 (°C)	3 (°C)	4 (°C)	5 (°C)	6 (°C)
3	0.5	2.5	5.5	4.0	2.0	1.0
4	0.5	1.5	7.0	2.5	1.0	0.5
5	0.5	7.0	2.0	1.0	0.5	0.0
6	2.5	5.0	6.5	2.5	1.0	0.0
7	1.0	4.0	3.5	2.0	0.5	0.0
Mean	1.0	4.0	4.9	2.4	1.0	0.5

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