INVESTIGATION OF ODOROUS EMISSIONS AND IMMISSIONS IN ANKARA WITH OLFACTOMETER

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ABSTRACT

INVESTIGATION OF ODOROUS EMISSIONS AND IMMISIONS IN ANKARA WITH OLFACTOMETER

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Turkish Air Quality Control Regulation (AQCR) is in force since 1986. However, AQCR does not contain any standards for odour control. In order to respond to various odour complaints and handle odour problems in Turkey, a regulation for odour control is necessary. Since Turkey is a candidate country for European Union, environmental legislation of Turkey has to be improved to the standards of the other member countries.

The purpose of this study is to investigate the "odour problem" in Turkey, specifically in Ankara, and to establish the odour measurement techniques. The techniques and information acquired throughout this study will form the basis of "Odour Regulation" in Turkey. For this purpose, odorous gas samples were collected from different industries in Ankara and these samples were analysed with the Olfactometer TO7. The results of the emission measurements have shown that there are numerous industries in Ankara which are discharging high concentrated odorous gases into the environment.

Also, field measurements (immission measurements) were performed around a sugar factory in order to determine immission levels. At the end of the immission measurements, a setback distance (buffer zone) of 1.5 km is determined that should be around a sugar factory. The implementation of an odour regulation and odour control technologies in Turkey is expected in near future.

Keywords: Odour, Odorous Emissions, Olfactometer, Odorous Immissions, Field Measurements

ÖZ

ANKARA'DAKİ KOKU EMİSYON VE İMİSYONLARININ OLFAKTOMETRE İLE İNCELENMESİ

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Türkiye'de 1986 yılından beri Hava Kalitesi Kontrol Yönetmeliği (HKKY) uygulanmaktadır. Ancak, HKKY koku kontrolü ile ilgili herhangi bir standart içermemektedir. Türkiye'de, farklı koku şikeyetlerine yanıt vermek ve koku problemlerinin üstesinden gelebilmek için bir koku kontrolü yönetmeliği gereklidir. Türkiye Avrupa Birliği'ne aday ülkelerden biri olduğu için ülkemizde çevre mevzuatının diğer üye ülkelerin standartlarına göre düzenlenmesi gerekmektedir.

Bu çalışmanın amacı, Türkiye'de özellikle Ankara'daki "koku problemlerini" araştırmak ve koku ölçüm tekniklerini yerleştirmektir. Bu çalışmadan elde edilecek teknikler ve bilgiler "koku yönetmeliği"nin temelini oluşturacaktır. Bu amaçla, Ankara'daki değişik endüstrilerden kokulu gaz örnekleri alınmış ve bu örnekler "Olfactometre TO7" ile incelenmiştir. Emisyon ölçüm sonuçları Ankara'daki birçok endüstrinin yüksek konsantrasyonlardaki kokulu gazları çevreye yaydığını göstermiştir.

İmisyon seviyelerini belirlemek için bir şeker fabrikası etrafında alan ölçümleri (imisyon ölçümleri) gerçekleştirilmiştir. İmisyon ölçümleri sonucunda, bir şeker fabrikası etrafında 1,5 km’lik bir koruma bandı olması gerektiği saptanmıştır. Türkiye’de koku yönetmeliğinin ve koku kontrol yöntemlerinin en yakın gelecekte uygulanması beklenmektedir.

Anahtar Kelimeler: Koku, Koku Emisyonları, Olfaktometre, Koku İmisyonları, Alan Ölçümleri

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LIST OF ABBREVIATIONS

A_+	Percent odour time (odour frequency)
A_m	Number of positive single measurements
AQCR	Air Quality Control Regulation
ASTM	American Society for Testing and Materials
ASAE	American Society of Agricultural Engineering
A&WMA	Air and Waste Management Association
BAT	Best Available Technology
BACT	Best Available Control Technology
BOD	Biological Oxygen Demand
C	Odour concentration (odour unit)
$\hat{C}_{od,cs}$	Odour concentration
$\hat{C}_{od}$	Odorant concentration at the threshold (equal to 1 OU/m^3)
C_{50}	Odorant immission concentration, which leads to an odour impression with 50% of the defined population, OU/m^3
CEN	European Committee for Standardization
COD	Chemical Oxygen Demand
d	Density
dB	Decibel
D/T	Dilution/ Threshold
ECOMA	Emission Measurement Technique and Consultation Mannebeck Ltd.
EN	European Standard
EPA	Environmental Protection Agency
EROM	European Reference Odour Mass
EU	European Union
GC	Gas chromatograph
GOAA	Guideline on Odour in Ambient Air
H_e	Effective outlet height, m
H_m	Percent odour hour (%)
I	Odour index

I_{limit}	Immission limit
$I_{initial}$	Initial odour impact
I_{add}	Additional odour impact
I_{total}	Total odour impact
IE	Industrial emissions
ISCST3	Industrial Source Complex – Short Term 3 Model
K_A	Ambient odour characteristic for a square (%)
K_P	Ambient odour characteristic for a measurement point
L	Radius of the abatement zone, m
L_+	Number of responses recorded as ‘1’
L_{od}	Odour level
m	Ordinal number of a measurement point
M	Geometric mean of the panellists’ responses
MFC	Mass flow controller
MS	Mass spectrometer
OU/s	Odour unit per second
OU/m^3	Odour unit per cubic meter
OU_E	European odour unit
PM	Particulate matter
PTFE	Polytetrafluorethylene (teflon)
R	Total number of measurements
V	Volume
VDI	Verein Deutscher Ingenieure
VOC	Volatile organic carbon
$\dot{V}_{cs}$	Volumetric flow rate of the odorous sample
$\dot{V}_{n}$	Volumetric flow rate of the added neutral air
W_m	Number of single measurements per measurement point
WHO	World Health Organization
Z_{50}	Dilution number (or odour number) at the odour threshold
µg	Microgram
µmol	Micromole

CHAPTER I

INTRODUCTION

1.1 BACKGROUND

Offensive odours affect the quality of air as much as the conventional air pollutants. Compared to other air pollutants, odour has different characteristics and it is the most complex of all the air pollutants to be dealt with. In Turkey, not much attention has been given to odour until today.

Offensive odour problems and the odour complaints to environmental regulatory agencies increase gradually. One reason for this increase is the improvement in the living standard of inhabitants. Inhabitants desire the qualitative improvement of the living environment although they endured the odours before. The second reason is the growing population and as a result the nationwide spreading of urban areas towards the industrial areas. Consequently, the offensive odour emitting companies have grown in scale and odour pollution has increased [1].

In many countries environmental odour control strategies have already been developed and the standardization of odour has progressed significantly. In the Netherlands, Denmark, Germany, Belgium, Austria, Switzerland, Ireland, United Kingdom, Japan, Korea, the U.S.A. and Australia the development of odour measurement, regulation and control technique has been greatly progressed [2].

Recently, as a result of the common market in the European Union, there is a movement to achieve a high degree of environmental protection. These developments have led to a gradual introduction of regulations and guidelines that increasingly depended on quantification of impacts and criteria for acceptable exposure to odours [3].

The European Committee for Standardization (CEN) has developed a standard method for odour laboratory measurement using olfactometry and this method has been accepted as an official method by a number of European countries [3].

Turkish Air Quality Control Regulation (AQCR) is in force since 1986. Despite the amendments in some fields, AQCR is still deprived of standards for odour control and management. As a candidate country for the membership of European Union, environmental legislation of Turkey has to be improved by including the odour criteria.

The most effective method of overcoming the odour problem is to have an odour regulation. In order to regulate odorous substances, sources of odour must be identified followed by the emission and immission measurements at these sources. A reliable method of quantifying odour concentration is required to evaluate the odour nuisance. Olfactometers have been developed for this purpose. Many types of olfactometers, in which the human sense of smell used as a detector, are currently available.

In Ankara, there are Organized Industrial Estates where different kinds of small and medium sized industry are located. There are many chicken farms, livestock, integrated meat plants, food industry, landfills, waste water treatment plants etc. which cause odour problems and need to control their emissions not to annoy the residents in that area. Whereas the local authorities and the experts do not have power and expertise to solve these problems since there is no regulation for odour control.

Therefore, there is a demand for such a study in order to form the basics for the solution of such problems.

1.1.1 DEFINITION OF ODOUR

Odour molecules spread from all existences that constitute the nature. It can be said that we live in a world of odours; some are considered as pleasant and some as unpleasant. “Whether an odour is offensive or not, it is subjectively based upon individual preferences, sensitivities, and experiences” [4].

Odour can be defined as the “perception of smell” or in scientific terms as “a sensation resulting from the reception of stimulus by the olfactory sensory system” [5]. According to ISO 5492, odour is defined as “organoleptic attribute perceptible by the olfactory organ on sniffing certain volatile substances” [6].

Unlike conventional air pollutants, odour has distinctly different characteristics, which, to an extent, can be comparable with noise pollution. Similar to noise, “nuisance” is the primary effect on people [2].

1.1.2 SOURCES OF ODOUR

Odours can arise from several sources and most of these sources are man-made. Unscientific landfill design, increased sewage load and improper sewage treatment can produce unpleasant odour. Large livestock operations, poultry farms, tanneries, slaughterhouses, food and meat processing industries, and bone mills are among major contributors to odour pollution. Agricultural activities like decaying of vegetation, production and application of compost etc. also contribute to odour pollution. Vehicular sector also has its share in odour pollution. Rapidly growing vehicular population as well as harmful pollutants emitted by them generate very harmful and pungent odour that have marked effects on pedestrians as well as near-by residents [2].

Most commonly reported odour-producing compounds are hydrogen sulphide (rotten egg odour) and ammonia (sharp pungent odour). Carbon disulfide, mercaptans, product of decomposition of proteins (especially of animal origin), phenols and some petroleum hydrocarbons are other common odorants. Most offensive odour is created by the anaerobic decay of wet organic matter such as flesh, manure, feed or silage. Warm temperatures enhance anaerobic decay and foul odour production [2, 7].

According to the emission types, sources of odour can be classified as follows:

- *Point sources* are sources which have either a stack or a ventilation channel exhausting the odorous gases with a known flow rate, such as a discharge stack from a slaughter house or a ventilation channel from a bone mill.

- *Area sources* are sources where the odorous gases are emitted from a wide surface. It can be a water or solid surface, such as the water surface of a slurry storage tank, solid waste landfill, composting or a cattle feedlot.

- *Building sources* are sources that have a number of openings where the odorous gases escape to the atmosphere, such as chicken and pig sheds.

- *Fugitive sources* are sources where odour emissions are given to the atmosphere unintentionally, such as emissions from soil bed or biofilter surface. The emission normally has an outgoing or upward gas flow [8].

Odours can result from a single source (a single event) or a combination of several sources and events. A brief inventory of some odours and their possible sources follows:

- Odours originating from animal housing (including open lots), manure storage structures, and land application of manure and other sources such as dead animal disposal sites, silage piles, feed centres, and any other areas where organic matter is present contribute to odour emissions.

- Coal-burning electric utilities produce sulphur oxide emissions in the form of sulphur dioxide (SO_2), a heavy, colourless gas with an odour similar to a struck match.

- Printing, rubber, and leather industries use “xylene” as a solvent. It is also used as a cleaning agent, a thinner for paint and varnishes. Xylene is a colourless, sweet smelling gas.

- Toluene is a major component of paint and is emitted from painting operations. It is used in the production of nylon, plastic soda bottles, other organic chemicals, and in some printing and leather tanning processes. Toluene is a colourless gas that has a sweet pungent odour.

- Phenol is used in the making of plywood, and in the construction, automotive, and appliance industries. It is also used in the production and manufacture of nylon and epoxy resins. Phenol is a colourless gas that has a strong sweet odour [4].

As a summary, the various odorous chemicals emitted from industrial operations are listed in Table 1.1.

Table 1.1 Industrial sources of odour and associated odorous chemicals [2, 9]

INDUSTRY	CHEMICAL GROUPS
Transportation (products of incomplete combustion)	Hydrocarbons, nitrogen compounds
Pulp and Paper	Mercaptans, hydrogen sulphide, alcohols, terpenes, camphor
Petroleum Refining	Sulphur compounds from crude oil, mercaptans, phenolic compounds, acids, aldehydes
Metallurgical (coke and core ovens, metal casting)	Aldehydes, aromatic and aliphatic hydrocarbons, acids
Chemical (paint manufacturing, rubber compounding, chemical manufacture)	Acids, alcohols, aldehydes, ketones, amines, phenols, mercaptans, chlorinated organic solvents, esters
Pharmaceuticals (biological extracts and wastes, spent fermentation liquors)	Amines, reduced sulfur compounds
Fertilizers	Ammonia, nitrogen compounds
Swine Operations	Hydrogen sulfide and ammonia
Waster Water Treatment Plant	Hydrogen sulphide
Municipal Solid Waste Landfill	Hydrogen sulphide

1.2 OBJECTIVES OF THE STUDY

The objectives of this study are:

- To study the examples of odorous emissions in Ankara,

- To establish the olfactometry method for measurement of odour concentration because “odour” concentration has not been measured in Turkey before,

- To make odour measurements at different emission sources and determine the odorant concentrations in odour units per volume (OU/m^3) for some industries in Ankara,

- To establish the immission measurement techniques for odour,

- To determine odour concentrations in ambient air (immission) by means of ‘odour hour’ through field inspections, and to obtain the odour map for the immission area selected for this study,

- To make some suggestions for “Odour Regulation” in Turkey based on the scientific findings of this study (the new “Odour Regulation” is expected to be issued in 2005 by the Ministry of Environment and Forestry).

CHAPTER II

ODOUR PERCEPTION

2.1 ANATOMICAL AND PHYSIOLOGICAL PRINCIPLES

The olfactory sense works with sensory cells in the upper nasal cavity. The neurons that sense odour molecules lie deep within the nasal cavity, in a patch of cells called the olfactory epithelium (Figure 2.1). Each of the two nasal passages in humans has a 2.5 cm^2 patch containing about 50 million sensory receptor cells. The reception of the odorant and the beginning of sensory signal transduction occurs with receptor proteins located on the olfactory cilia, which are hair-like extensions of the receptor neurons (10-20 cilia per neuron) [10, 11, 12, 13].

When we inhale, most of the chemical stimuli in the air are dissolved in the layer of mucus coating, the epithelium. This mucus contains water, mucopolysaccharides, antibodies, enzymes, salts, and odorant-binding proteins. When the chemical stimuli, or odorants, dissolve in the mucus on the epithelium, they bind specific receptor proteins on these cilia. This binding causes a change in permeability of the sensory neuron, which creates a slow electrical potential that travels to the olfactory bulb. From the olfactory bulb, the signal is transmitted to the limbic system in the brain, where memory is used to recognize the odour [10, 11, 12, 13].

The odorants must be sufficiently volatile and sufficiently water soluble to permeate the mucus layer on the olfactory cells. In addition, certain fat-solubility is required to allow the odorant to penetrate the surface of the lipid-containing membrane of the olfactory cells [14].

Due to the structure of the nasal cavity, inhaled air normally does not contact with the olfactory epithelium directly, but it is redirected inversely only after the formation of turbulence as a function of the air flow velocity (Figure 2.2). This turbulence may be intensified by “sniffing”; which is an accelerated inhalation in jerks. The velocity of the inhaled air flow increases by twice or four times of the normal value and increase the sensitivity of the olfactory sensation [14, 15].

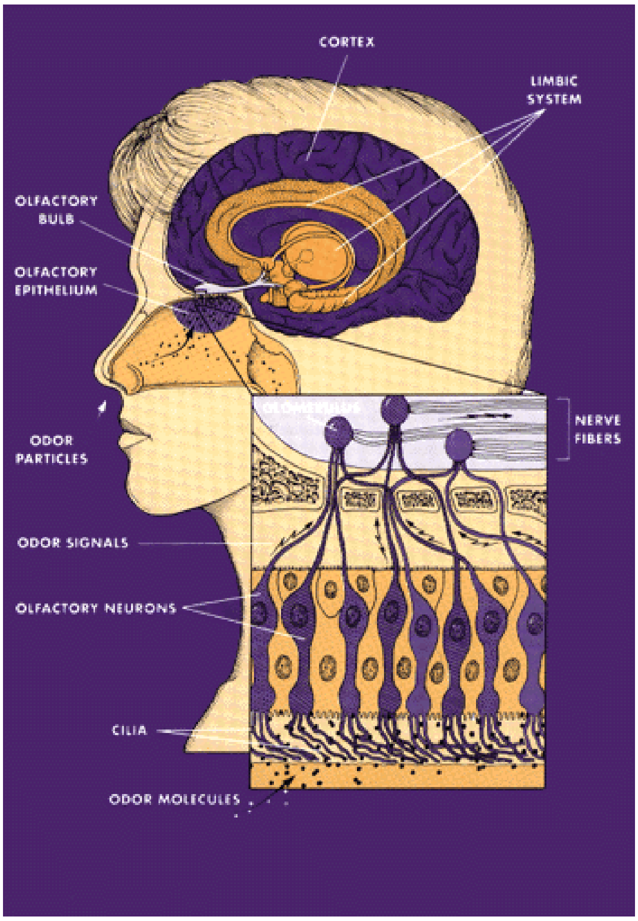
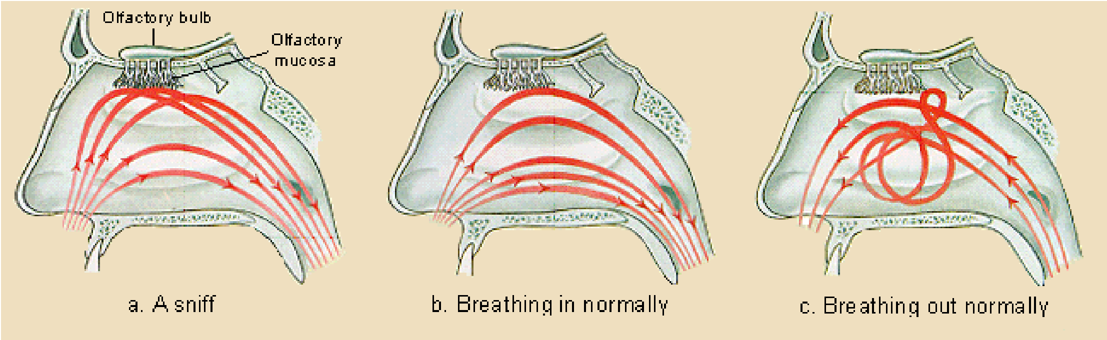


Figure 2.1 The anatomy of the human nose [12]



a. A sniff

b. Breathing in normally

c. Breathing out normally

Figure 2.2 The nasal cavity and breathing [13]

2.2 SPECIAL ASPECTS OF THE PERCEPTION OF SMELL

The human olfactory system can serve as an aid in the detection of potentially hazardous compounds. However, the sensitivity of each individual's olfactory system is widely varied. Some individuals possess a heightened sensitivity to odours (hyperosmic) while others are physically unable to detect odorous compounds (anosmics). This wide variance in an individual's ability to detect odours, as well as the variability and complex nature of odours themselves, makes the determination of odours very difficult to standardize and measure quantitatively [9].

In addition, an individual's judgement of the existence of an odorous agent is affected by the following variables: [9]

- age
- sex
- eating, drinking smoking habits
- natural sensitivity
- health problems
- medications
- pregnancy
- education
- personal experience
- prejudices against the source

The perception of odours by humans is not completely understood because of the complex series of chemical and neurological interactions that take place in the human olfactory system [9].

One of these complex interactions is odour fatigue. When a person is exposed to an odour for some time, his sensation of intensity changes. He/she adapts to the odour environment and the perceived odour intensity decreases typically within minutes. This situation occurs due to 'olfactory fatigue' since olfactory senses relies on mass, not energy to trigger action potential. In the nose, once a molecule has triggered a response, it must be disposed of and this takes time. If a molecule comes along too quickly, there is no place for it on the olfactory hairs, so it cannot be perceived. The change is greatest by low intensities, so that the sensory experience by high concentrations changes far less. When the impact stops the observer's sensitivity is back to normal within 5-10 minutes as shown in Figure 2.3. On the other hand to fully perceive a scent, humans smell in quick, short sniffs, often moving the source of smell in front of one nostril than the other. This behaviour also prevents odour fatigue [10,15].

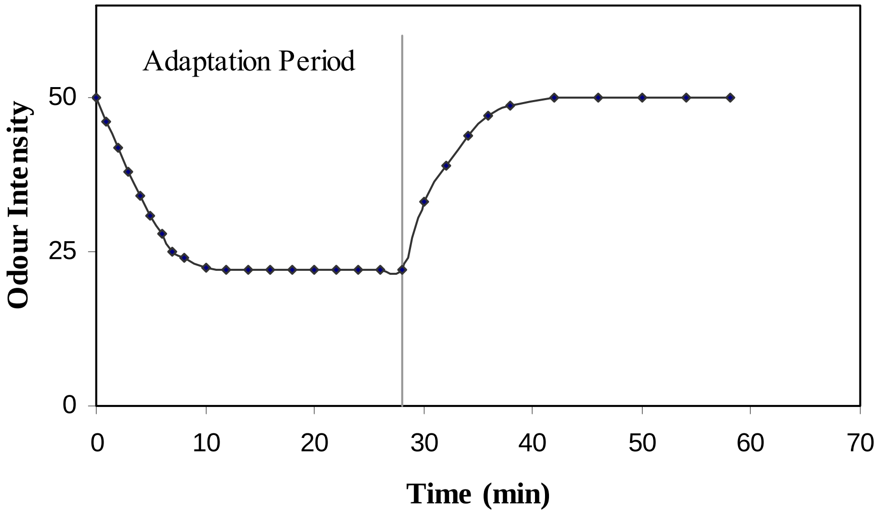


Figure 2.3 Example of adaptation due to odorant exposure [15, 16]

2.3 IMPACT OF ODOUR ON SOCIETY

Odour has many effects that result in strong annoyance or even severe health problems. However, the classical "odour" discussion deals with the 'annoyance aspect' of odorants in the ambient air rather than the 'health aspect' [17].

Strong, unpleasant or offensive smells can interfere with a person's enjoyment of life especially if they are frequent or persistent. Odour nuisance is generally defined by the following factors; [2, 18]

- Frequency; how often an odour occurs
- Intensity; the strength of an odour
- Duration; the length of time the odour is encountered
- Offensiveness; the unpleasantness or 'hedonic' character of the odour.

In Turkey, major sources of odour complaints are due to chicken farms, livestock operations, slaughters, integrated meat plants, wastewater treatment plants and landfill areas. According to the information obtained from the Ministry of

Environment and Forestry, mostly the complaints regarding the odorous emissions are due to the operations given in Table 2.1.

Table 2.1 Complaints regarding the odorous emissions in Central Anatolia

Complaints / Number of Operations			
Chicken Farms	360	Sugar Factory	6
Animal Houses	651	Oil Factory	5
Integrated Meat Plants	25	Rendering Plant	4
Slaughterhouse	52	Improper Wastewater Discharge	3
Dairy Farm	58	Mushroom Production	3
Leather Industry	32	Fodder Factory	3
Wastewater Treatment Plant	25	Pulp and Paper Factory	3
Solid Waste Disposal Area	18	Wine Factory	3
Chemical Plant	15	Beer Factory	2

2.3.1 ADVERSE HEALTH EFFECTS

People who are exposed to offensive odour for long periods and suffer from bad smells usually feel unwell. The WHO says: “Health is a state of complete physical, mental and social well-being and not merely the absence of disease and infirmity”. Unhealthiness caused by foul odour is not caused by the fact that the odour is poisonous. Foul odour damages health because of the irritation and the nuisance it causes.

On the contrary, it is possible for certain odorous emissions to have an impact on physical health. The most frequently reported symptoms attributed to odours include eye, nose, and throat irritation, headache, nausea, hoarseness, cough, nasal congestion, palpitations, shortness of breath, stress, drowsiness, and alterations in mood [2, 4, 9].

2.3.2 ECONOMIC EFFECTS

On the economic front, loss of property value near odour causing operations/ industries and odorous environment is partly a consequence of offensive odour.

In Turkey, there are odour problems not only in the residential and industrial areas, but also at the tourist sites. This problem is especially being very disturbing at the tourist sites and will affect the tourist incomes. The local authorities and the experts fail to solve these problems since there is no regulation for odour control at present.

CHAPTER III

LITERATURE SURVEY ON ODOUR DETERMINATION AND ODOUR REGULATION

3.1 LITERATURE SURVEY ON ODOUR DETERMINATION

3.1.1 MEASUREMENT TECHNIQUES USED FOR ODOUR DETERMINATION

Odour assessment is a critical component of odour control and regulation procedures. Odours are often a composite of many single odorous substances. Therefore, due to this complexity it is difficult to evaluate odours.

The primary methods used for odour evaluation includes; electronic nose technology, gas chromatography and olfactometry. These measurement techniques and detailed information related with their potential to represent human olfactory response is discussed below.

3.1.1.1 ELECTRONIC NOSES

The “electronic nose” is a developing technology. Scientists are studying the mechanism of the smell process that works in humans and trying to use electronics to mimic the process involved. For this purpose, an array of electronic chemical sensors with partial specificity is used [19]. One or more sensors of arrays emulate the different type of olfactory sensors found in the human nose. The sensor response results in specific patterns. The patterns are then compared to the responses of known sample standards to characterize the odour [18].

Each sensor is designed to sense different odour. As its selectivity capacity increases, the price of the sensor also increases and its production becomes more difficult. The signals which sensors collect from the environment is turned into dual-codes by electronic systems and sent to a computer. The computer defines the odour pattern by a model and classifies the type of odour (Figure 3.1). The electronic systems mimic the olfactory sensors and the computer mimics the human brain. The computer is programmed to evaluate the incoming information from the electronic system so that it can interpret signals consisting of dual-codes [20].

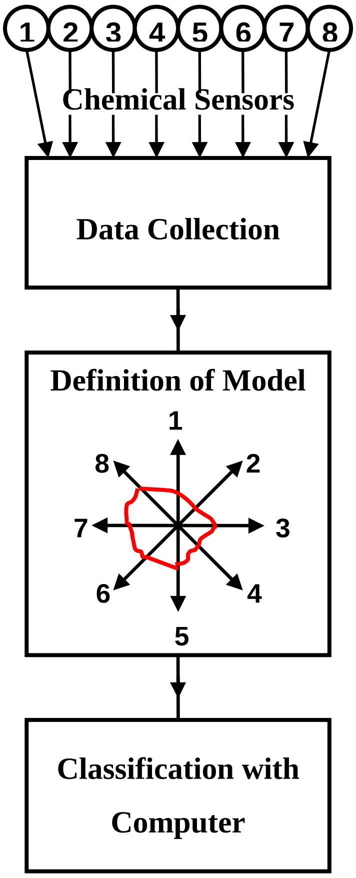


Figure 3.1 Illustration of odour evaluation by an electronic nose [20]

The application areas of electronic noses are for automated detection and also for classification of odours, vapours and gases. Electronic noses are generally used for quality control applications in the food, beverage and cosmetic industries. Other application fields are detection of odours specific to diseases for medical diagnosis, and the detection of pollutants and gas leaks for environmental protection [19, 21].

Due to its ease of use and rapid response rate, when used in routine operations, electronic noses have advantages over other odour determination techniques [21]. Electronic noses have high sensitivity for certain odours, high reproducibility and can be used for onsite evaluations. Despite these advantages, they are typically large and expensive (as seen in Figure 3.2) [21]. It is difficult to determine the correct odour concentration with electronic sensors since they designate intensity of odour depending on the chemical dose. No absolute calibration is currently available for electronic noses. In addition, the detection of different components of odours occurs sensitively but not selectively [19].

Figure 3.2 Appearance of an electronic nose [22]

3.1.1.2 GC/MS + SNIFFING PORT

Gas chromatograph is a method used to differentiate between very similar compounds in a mixture. The components present in a gas mixture can be found by using this method. When definite quantitative and qualitative results are needed, a mass spectrometer coupled to the gas chromatograph is used (Figure 3.3) [23].

A chromatography system is composed of a gas chromatograph and a recorder for plotting chromatograms or a data station for generation and evaluation of chromatograms.

Figure 3.3 Gas chromatograph coupled to a mass spectrometer [23]

A gas chromatograph consists of a sample injector, gas supplies, oven with temperature control for the chromatographic column and the detector (FID, FPD, MS). The schematic representation of a GC/MS system can be seen in Figure 3.4.

Once a sample solution is introduced into the GC inlet it is vaporized immediately because of the high temperature (250 ^{0}C) and swept into the column by the carrier gas (usually Helium). The vapour then is transferred into the column either completely or partially (split technique). The sample flows through the column experiencing the normal separation process. As the various sample components emerge from the column opening, they flow into the capillary column interface. This device is the connection between the GC column and the MS. Then the sample enters the ionisation chamber. The mass spectrometer acts as a filter, transmitting ions with a preselected mass/charge ratio. These transmitted ions are then detected with a channel electron multiplier [24, 25].

The detector sends information to the computer by generating a more or less intense electrical signal (response) that is specific to a substance. The electrical signals are then converted into visual displays (chromatogram) and hard copy displays (numerical report) through the analogue (recorder) or digital (computer) processing [24].

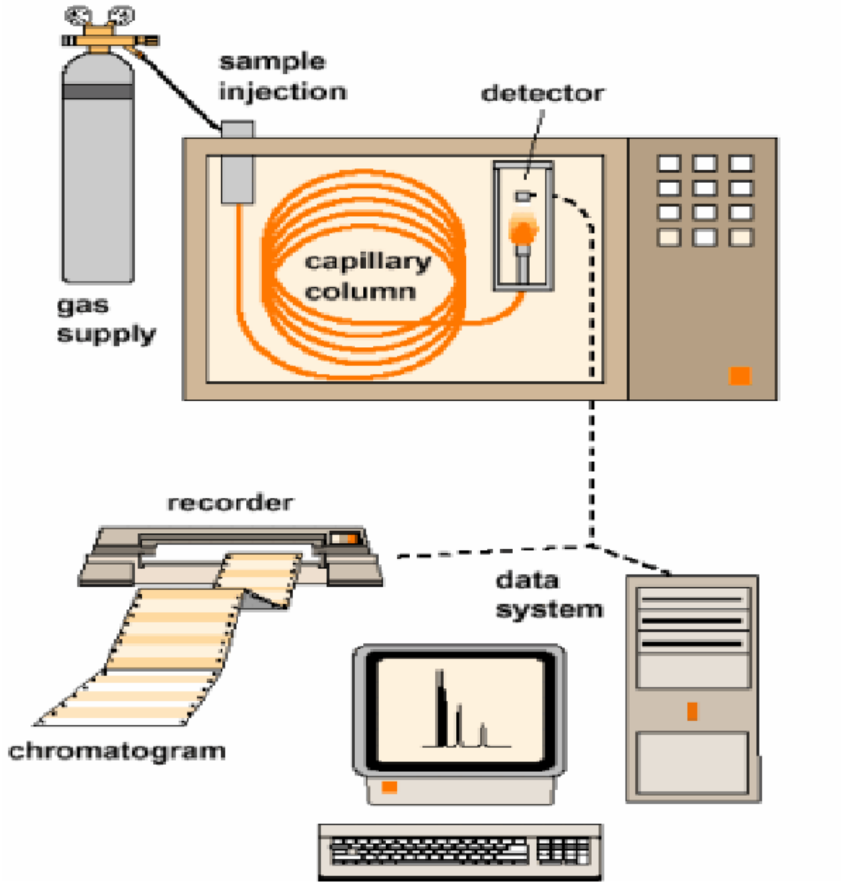


Figure 3.4 Schematic representation of a GC-MS [25]

Gas chromatograms are analytical sensors that can only identify single odours in a mix of compounds. In the gas chromatogram a correlation of certain signals to odours is almost impossible. The combination of human nose (by inserting a sniffing port in the system) with GC-MS will be successful to find the main odour components. On the other hand, this method is not practical, time consuming and expensive [26].

3.1.1.3 OLFACTOMETER

Olfactometry is the most practical method among the others to evaluate odours because it is an “effect related” measurement method. It uses the human nose as sensor and the effect on the human sense of smell is the unit of measurement. Olfactometry deals with the controlled presentation of odorous gas to a panel of selected and screened human assessors (called panellists) and the evaluation of their reactions to the odour sample. Of the gas to be investigated either a continuous partial flow is conducted into the olfactometer or gas samples in odourless vessels which were filled at the source of odour are connected to the olfactometer [26, 27].

The odour concentration of the gas is determined by presenting odorous gas to the panellists in gradually increasing concentrations. The odorous gas is diluted with neutral air. In this way, different concentrations, starting from the lowest concentration, reach the nose of the panellists via sniffing tubes (nose masks). In the beginning the most diluted odorous gas is given to the panellists, later on the concentration increases (dilution decreases) gradually. Each panellist is individually required to identify which gas presentation contains the odorous gas sample. If a panellist is unable to detect the odour in the gas sample presented to him/her, the panel leader increases the dilution by one increment. According to the panellists’ response to the gas presented, the odour concentration is determined [28, 29].

Many types of olfactometers are in use around the world and they can be categorised in three groups on the basis of dilution system used [30]:

- Static method (syringe method in U.S.A., triangle bags in Japan)
- Rotameter/fixed orifice based olfactometers (VIC. EPA B2 in Australia, TO7 in Germany, IITRI in U.S.A.)
- Mass flow controller (MFC) based olfactometers (Ac’scent olfactometer in U.S.A., Olfaktomat as used in the Netherlands).

All olfactometers use human panellists to detect odours and these olfactometers range from single panellist to multi-panellist units. Since “rotameter or fixed orifice” based olfactometers are able to dilute odorous sample dynamically, these types of olfactometers are called “dynamic dilution olfactometry”. Dynamic dilution olfactometry is used in the United States, Europe, and Australia and is accepted as standard practice by ASTM (American Society for Testing and Materials) and CEN (European Committee for Standardization) [31]. A picture of a dynamic dilution olfactometry model TO7 can be seen in Figure 3.5.

Figure 3.5 Picture of an olfactometer model TO7 [29]

The practical application of olfactometry is the investigation of gas samples with unknown composition with regard to their property to induce odour sensations. Also, olfactometry has been successfully used in the agrarian and food industry, also started to be used in the plastics industry [26].

3.1.1.4 COMPARISON OF THE METHODS

In order to respond odour complaints, development of onsite and objective evaluation methods are needed. Electronic noses and chemical measures may offer some potential towards this objective whereas these methods are not sufficient to determine an individual’s annoyance.

The effect of odour cannot be represented with the technical or physical sensors. The odour sensation cannot be described by the quantity of the odorants. Odour originates from a wealth of chemical substances. The effect to the sense of smell can vary enormously, depending on the different components and on their proportion. Due to the large numbers of different substances an analysis of these odorous substances is very difficult. By measuring guide components a correlation to the odour intensity and concentration can not be found in most cases and technical sensors are unsuitable for a qualitative evaluation of offensiveness [21, 29].

The human nose is more sensitive than any electronic equipment. The main disadvantage of olfactometry test is the variability of the test results and time necessary to perform the tests. To reduce this variability to a minimum, the panel has to be screened and trained. An increased number of panellists will improve the accuracy of the measurement. Usually the panel consists of 4-12 people. Therefore, the olfactometry is not a practical method for routine (every day or hour) measurements of special types of odours. On the other hand electronic noses can provide faster results and are particularly useful for routine operations [21].

3.1.2 MEASUREMENT WITH OLFACTOMETER

Olfactometric measurements are commonly used for;

a) Quantifying odours that can be used to assess the impact of the odour on human subjects (e.g. annoyance or nuisance assessments).
b) Assessing the efficiency of odour abatement systems in terms of total odour [29].

3.1.2.1 FUNDAMENTALS

Odour measurements are conducted by an operator called ‘leader’. In order to perform an odour measurement four panel members and a test leader is needed. The leader adjusts the dilution level according to the strength of the odorous gas sample. The odorous gas sample is diluted with neutral air (air with no odour). The panel members are supplied with diluted odorous sample. The concentration of the sample is started at very low levels and increased gradually. In this way, different low concentrations reach the nose of the panellists via sniffing tubes (nose masks). With the first odour impression, the response button has to be pushed by the panellists meaning “yes, it smells”. When two consecutive ‘yes’ answer is obtained from panellists the first round of the measurement ends. The result of 4 panel members who proved their odour impressions in 3 rounds, the odorant concentration measurement is finished and the odorant concentration is found in “odour units per m^3” (OU/ m^3).

The following definitions will be helpful at this point:

Odour unit (OU)

Based on the definition of the odour threshold, 1 OU is the very quantity (number of molecules) of odorants which just induces an odour sensation when dispersed in 1 m^3 of neutral air. 1 OU/m^3 is also the bench mark of the odorant concentration scale ($\hat{C}_{od}$) [14].

Odour threshold

The concentration of odorous substances at threshold level leads to an odour impression with 50 % of the defined population. The concentration at the threshold is 1OU/m^3 by definition [14].

In other words the panellists’ response determines the dilution factor at the 50 % detection threshold which means 50 % of the human subjects can detect the gas sample as odorous. According to the definition, the odour sample with threshold concentration has one odour unit. The odour concentration of the examined sample is the dilution factor at the detection threshold and is expressed as multiples of “one odour unit per cubic meter” (OU/m^3) [29].

3.1.2.2 OLFACTOMETERS WITH GAS JET DILUTION

There are two gas jet pumps operating in a rotameter/fixed orifice based olfactometer. One of them is for odorous sample and the other one is for the dilution air. The odorous gas sample is sucked from the sample bag via the pre-mixing unit and via the flow meters. The flow rate of odorous gas is controlled in steps by the needle valves. The other gas jet pump is for neutral air (odourless air). The dilution air is sucked and passed through a filter system containing silicagel, activated carbon and a microfilter that retains humidity, carbon compounds (smelling compounds) and dust withdrawn from the compressed dilution air respectively. The neutral air (odourless air) is mixed with the odorous gas sample in a mixing chamber. A schematic diagram of the preparation of gas mixture is shown in Figure 3.6 [29].

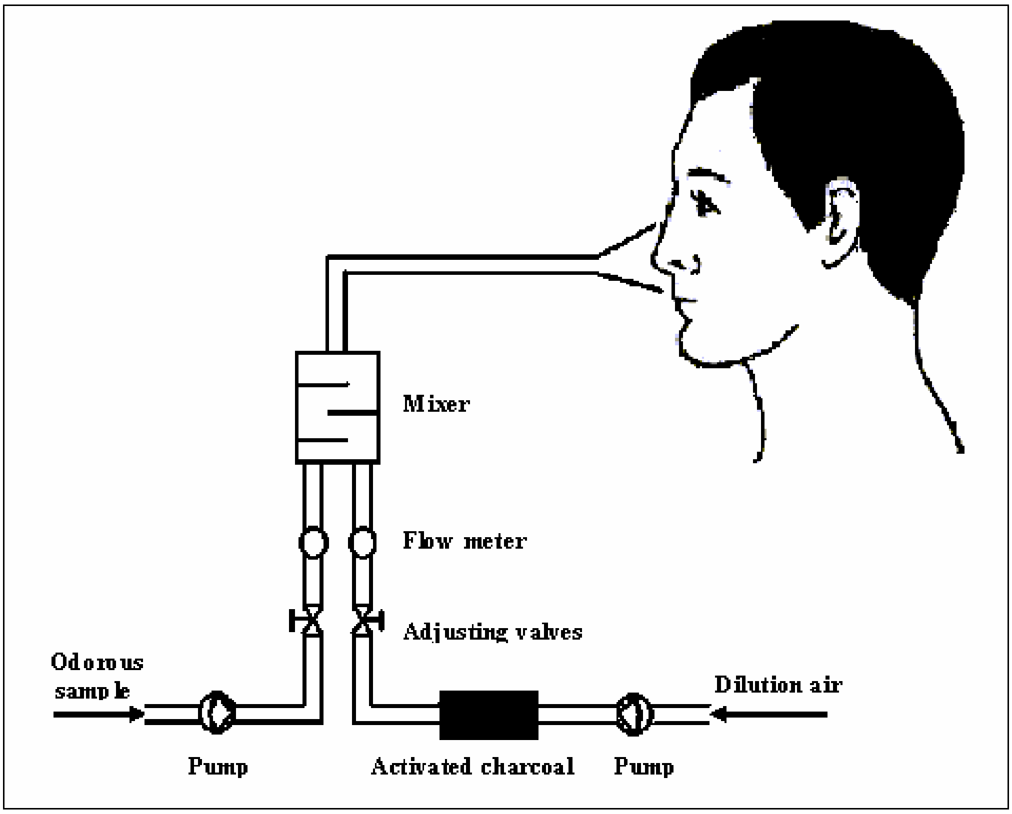


Figure 3.6 Principle of odour determination by olfactometry [27]

The mixture flows via the rotary slide valve to the sniffing ports. While one panel member is provided with the mixed air (diluted sample air) the opposite panel member receives neutral air (Figure 3.7). The panel members who are in the expiration phase (2 per time) are provided with a minimal flow of neutral air [29].

The central switch-over valve switches from neutral air to the mixture between two breathing phases. The breathing frequency is given by optical signals. The procedures are run simultaneously for the four panellists. The duration of a measurement sequence is thereby held to a minimum [29].

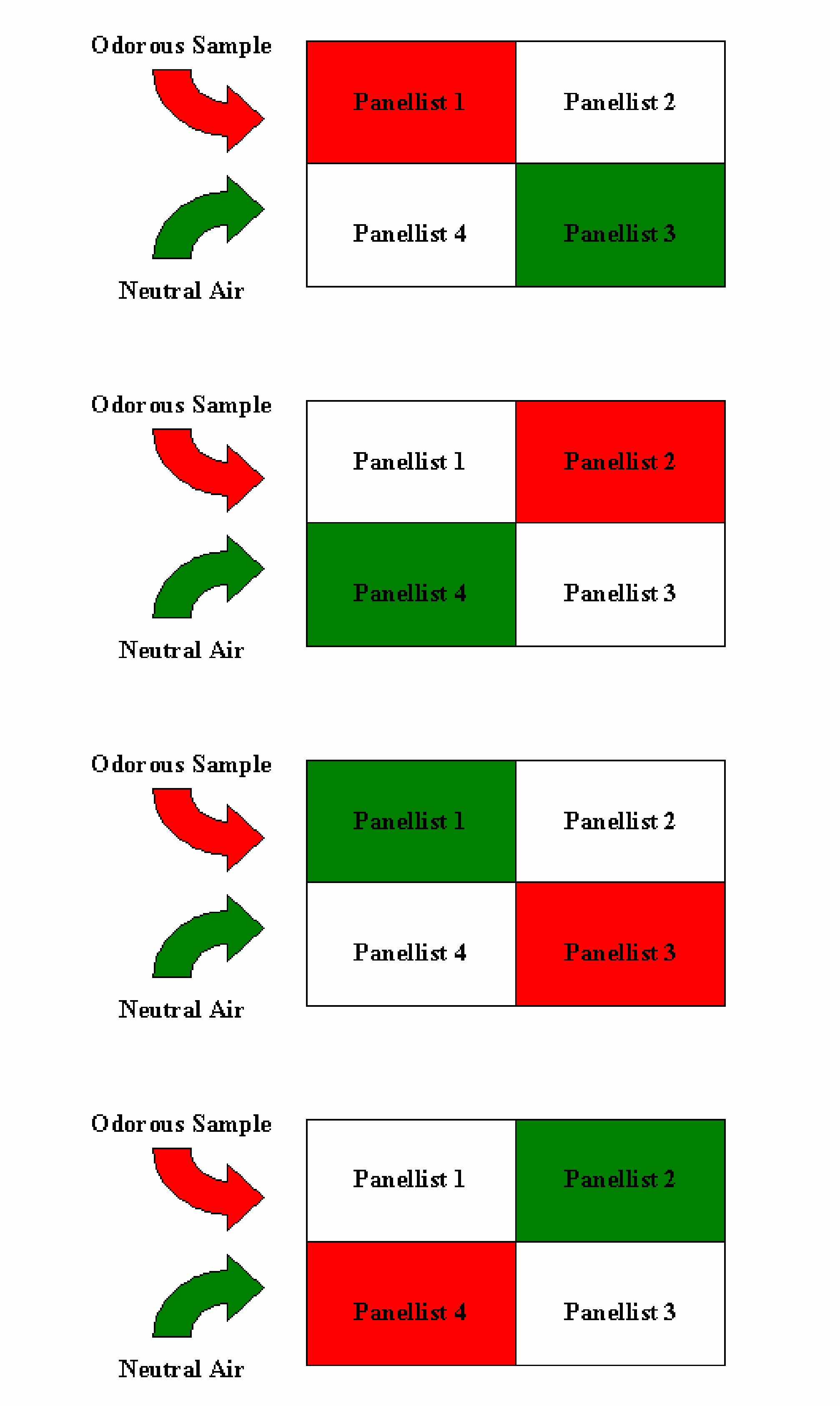


Figure 3.7 Presentation of odorous sample and neutral air to the panellists

Due to the fact that neutral air and mixture are offered within two consecutive breathing periods, the panel members have the possibility of direct comparison of gas samples. Therefore, with this technique, the reliability of the results is increased considerably [29].

The total measurement program is computer controlled and runs automatically with software installed in the computer. The software includes several measurement sequences; recovery breaks for the panel members and includes clean air flushing functions for the dilution unit [29].

3.1.2.3 PRESENTATION OF THE RESULTS

The "odour concentration" ($C_{od,cs}$) of the gas sample is determined by dilution with neutral air down to the odour threshold. In other words, the number of odour units of an odorous sample is identical with the "dilution number" (Z_{50}), which is defined as the point at which the odour threshold is reached and can be calculated as follows [14, 27]:

$$Z_{50} = \left(\frac{\dot{V}_{cs} + \dot{V}_n}{\dot{V}_{cs}} \right) = 1 + \left(\frac{\dot{V}_n}{\dot{V}_{cs}} \right) \qquad \text{(Equation 3.1)}$$

$$C_{od,cs} = Z_{50} \times \hat{C}_{od} \qquad \text{(Equation 3.2)}$$

where;

Z_{50} dilution number (or odour number) at the odour threshold

$\dot{V}_{cs}$ volumetric flow rate of the odorous sample

$\dot{V}_n$ volumetric flow rate of the added neutral air

$C_{od,cs}$ odour concentration

$\hat{C}_{od}$ odorant concentration at the threshold (equal to 1 OU/m^3)

('od' and 'cs' represents, odour and concentration respectively)

“Odour level” is another term that describes the intensity of a sensation as a function of the logarithm of the amount of the stimulating quantity. It is useful for practical purposes to describe the sensation of odour intensity analogous to the sound intensity level. The unit is dB (decibell) similar to the sound intensity unit. The odour level is defined as the logarithm of the ratio of two odorant concentrations [14].

$$L_{od} = 10\log\left(\frac{C_{od}}{\hat{C}_{od}}\right) \qquad \text{(Equation 3.3)}$$

where;

L_{od} odour level, dB

The denominator indicates the reference quantity which is the odour concentration at the threshold, 1 OU/m^3.

3.1.2.4 SELECTION OF PANELLISTS

Panellists must be screened and trained. They should be familiarized with the test procedures, and tested for their ability to detect standard reference odorant (n-butanol or in some cases H_2S). Panellists should neither be highly sensitive nor be insensitive to odours. Generally, those individuals representing "normal" sensitivity are selected to serve as panellists.

The screening procedure involves: familiarization of the candidates with the olfactometric procedures and determination of each candidate’s detection threshold for standardized concentration of n-butanol.

To be accepted as a panellist, the geometric mean of the individual detection threshold should be within 20-80 ppb for n-butanol. The same method is used for the calibration of the panellists which should be carried out at some intervals [14].

The rules for panellists are as follows [14]:

- Panel members should be at least 16 years of age.
- Panellists are not being allowed to eat or drink anything except water 30 minutes prior to and during an odour panel session.
- Panellists should not eat spicy foods, onion, etc on the day of measurement.
- Panellists should take care of their body cleaning and they are not allowed to use any perfumed body lotions, perfumes, etc. on the day of measurement.
- Panellists should concentrate on the measurements and follow the leader's instructions.
- Panellists should be present in the measurement room in order to be adapted to the room air at least 15 minutes before the measurement starts.
- Panellists whose sense of smell is impaired permanently or temporarily have to be excluded from the measurement.
- Panellists should not talk with each other or to make signs to each other during measurements.

3.1.2.5 SAMPLING TECHNIQUES

Sampling and sample preparation are important elements of the measurement procedure. They greatly affect the quality and the reliability of the measurement results.

The odorous sample should represent the chemical and physical properties of the emission source. During sampling the composition of the odorous sample should not change with regard to quality and quantity.

In order to avoid the main sources of error, the following has to be observed in the course of these procedures [32]:

a) The formation of condensate must be avoided by predilution with dry and odourless air.
b) No particles should enter the olfactometer.
c) One has to ensure the absence of odour in the sampling system.

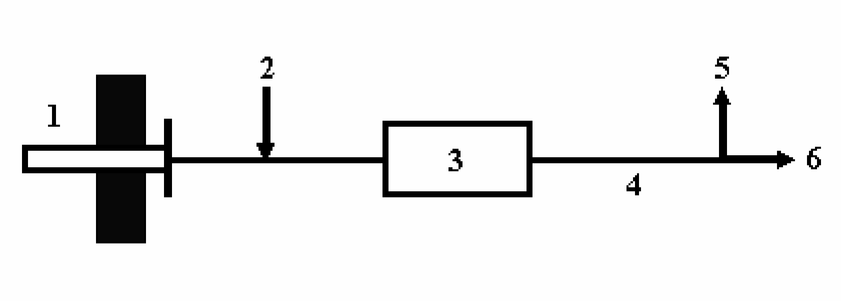
d) Chemical reactions between the components as well as sorption on the walls of the sampling system must be avoided during the transportation from the sampling place to the olfactometer.

If applicable, these important problems have to be solved in advance tests by varying the time interval between sample collection and investigation.

Basically, there are two different sampling techniques:

1. *Dynamic Sampling:*

The olfactometer can be installed near the odour source (e.g. in an on-site odour laboratory or in a laboratory truck). A partial flow of the odorous gas is conveyed directly and continuously from the source to the olfactometer. The measurements are carried out on the olfactometer. The sampling technique is illustrated in Figure 3.8.



1. Sampling probe, inserted	4. Sampling duct
2. Neutral air supply for predilution	5. Excess sample to atmosphere
3. Dust filter	6. To the olfactometer

Figure 3.8 Representation of dynamic sampling [32]

A probe is inserted in the stack and the sample is conveyed without pressure via a duct to the olfactometer. During the measurement period the sample flow to the olfactometer is constant. The excess gas is released without pressure. If the gas contains dust or particulate matter, the odorous sample should be filtered and/or prediluted. This has to be tested with preliminary tests. If the odour level of a sample exceeds the upper dilution range of the olfactometer, odourless air should be supplied to the duct. This is called “predilution” of the sample. Depending on the thermal sensitivity of the sample, the duct may be heated in order to minimize adsorption and condensation on the walls of the sampling duct [32].

2. *Static Sampling:*

The odorous gas sample is collected using an “odour sampling system” from a source as shown in Figure 3.9 and then examined with the olfactometer.

A vacuum pump and a rechargeable battery are built in the sampling device. The lid of the device is opened. A new empty odourless bag is placed into the vacuum sampling device. Then the lid of the sampling system is closed tightly. There is a small cork plug at the inlet tube of the sampling bag to protect the inflow of any gas into the bag. Then the air in the device is pumped out by a battery operated pump so that a vacuum inside the device is created. Against that vacuum, the odorous gas sample is drawn into the sampling bag due to the pressure difference between the inside and outside of the bag. When volume of the sample bag completely fills the inside volume of the sampling device, the cork plug is put back at the inlet of the sampling bag. Then the lid of the sampling device is opened and the sampling bag is removed.

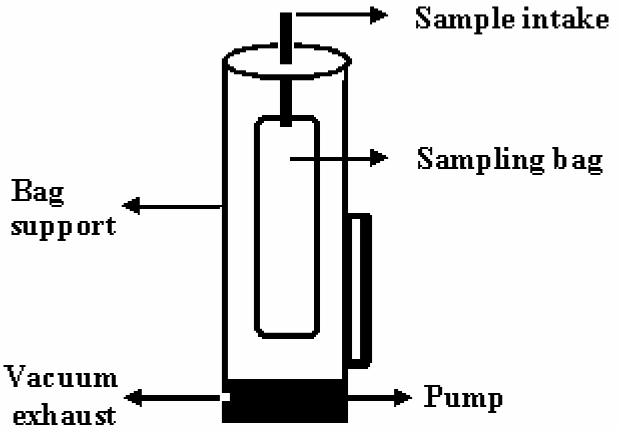


Figure 3.9 Schematic diagram of the sampling device

The total volume of the odorous gas sample is important fact to perform the measurement on olfactometer. The total gas volume required should be adjusted according to the following parameters:

- Odorant concentration in the crude gas,
- Number of measuring sequences.

In order to get reliable results from the olfactometric measurement, the sample should be rapidly transported to the odour measurement laboratory for testing. The residence time of the gas sample between the sampling time and the measurements should be minimized and must not exceed 24 hours [32].

Comparison of Dynamic and Static Sampling

The ideal sampling method for odour measurement would be to have the panellists directly at the emission source, where the odour sample could be continuously withdrawn without the need for storage. However, dynamic sampling technique is impractical because a mobile laboratory equipped for odour testing is required [9].

Assuming constant emission, the dynamic sampling method has the advantage of minimizing possible changes in the sample by chemical reaction or adsorption, because of the short time gap between sampling and analysis. On the other hand, dynamic sampling is not appropriate for emission sources with rapidly changing odorant concentrations, as the sampled material changes during the course of a single measurement.

By means of static sampling, a representative average of odorant concentrations can be determined during the sampling period at alternating emissions. The volume of the bag has to be large enough to provide for a sufficient quantity of homogeneous sample gas for single measurement. Additionally, to obtain reliable results the emission source should be investigated at various times and at different operation conditions.

3.2 LITERATURE SURVEY ON ODOUR REGULATION

3.2.1 ODOUR REGULATION IN EUROPE

In the past, the legislation of odour was on a local level in Europe. The smelly processes were located away from the residential areas. If the complaints related to these operations arise, the relevant authority was assessing the situation [3].

At the end of the 19th century, with industrialization and urbanization more residents were affected by the odorous emissions. As a result the Nuisance Law was established in many countries of Europe. “The principles of Nuisance Law are used until today, especially in countries with a legal system based on Common Law.” [3]. However, the citizens became less tolerant and a need for a uniform legislation occurred.

With the existing regulations in several countries of the EU, the European Committee for Standardization (CEN) decided to issue a European Standard on determination of odour concentration which was finally approved by CEN in December 2002 [17]. This standard follows ISO protocols and is entitled as “Air quality – Determination of odour concentration by dynamic olfactometry” which will unify the olfactometry standards in the EU countries [33].

The European Standard has been drawn up by the Technical Committee CEN/TC 264. CEN members, which are Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxemburg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and United Kingdom are bound to comply with the CEN/CENELEC International Regulations [6].

The national standards of EU countries will now be replaced by this European Standards (EN13725:2003) that has been introduced in April 2003, after close to 10 years of preparation [33].

The European Standard (EN) covers the information related with the principle of measurement of odour, performance and quality requirements, materials, gases and panel members, issues of odour sampling, presentation of the odorants to the assessors, data recording, calculation and reporting. However, the relation between emissions, dispersion, exposure and annoyance is not within the scope of the EN [6].

The EN is based on measurement of odour emissions using olfactometry method with three different choice modes. These choice modes are yes/no mode, forced choice mode and forced choice/probability mode. It is believed that these modes all produce the common result [6].

In the yes/no mode; the panellist is asked to evaluate gas presented from a specific port (sniffing port) and to indicate if an odour is perceived (yes/no). The panellist is aware that in some cases blanks (only neutral gas) are presented [6].

In the forced choice mode; the panellist is presented with two or more ports, of which one presents the stimulus and the others neutral gas. The panellist is asked to indicate which of the ports the one with stimulus is. To distinguish *false* from *true* responses, the panellist is asked whether his/her choice was a *guess*, *inkling* or *certain*. From the combination of the choice result and the indicated level of certainty the response is classified to be false or true [6].

In the forced choice/probability mode; the panellist is presented with diluted odour sample using an olfactometer with three or more ports, of which one presents the stimulus and the others neutral gas (three alternative forced choice). The panellist is asked to indicate which of the ports the one with stimulus is. When the panellist doubts, he/she is asked to indicate a port 'at random'. If the position indicated by the panellist is equal to the actual position of the stimulus, the result is recorded to be *true* and all other responses are recorded as *false* [6].

The European odour unit (OU_E) is expressed as the amount of odorants and it is equal to EROM (European Reference Odour Mass), or a mass that is just detectable when evaporated into 1 m^3 of neutral gas. For n-butanol one EROM is 123μg. When evaporated in 1 cubic meter of neutral gas, at standard conditions, this produces a concentration of 0.040 μmol/mol [6]. During panel selection procedures, n-butanol is used as a reference odour [33].

1 EROM ≡ 123 μg n-butanol ≡ 1 OU_E for the mixture of odorants.

3.2.2 ODOUR REGULATION IN GERMANY

In Germany, odorous substances were firstly named in the “Federal Law of Immissions Protection” in 1974. In 1986, the Federal Technical Regulation for Clean Air, which is the most important regulation connected with the immissions, is issued. The regulation was containing the limit emission concentrations and limit mass flows for a lot of organic substances but no limit for odour emissions [17].

Annoyance related work has been carried out to a remarkable extent in Germany in connection with the development of legal standards and governmental policy concerning offensive odours. These activities have led to a governmental guideline called the “Guideline on Odour in Ambient Air” (GOAA), discussed since the late 1980’s and issued as a regulation in the majority of states inside Germany in 1999 [17].

For assessing the odour impact, GOAA sets limit values for odours in ambient air (immission limit values) which indirectly implements the odour emission limit values. The immission values are assessed through “field measurements (grid measurements)” given in the guideline VDI 3940 and the initial odour impact from any installation is determined. The initial impact is the odour impact originating from existing installations without the additional impact caused by the object which is to be licensed [34].

The initial impact ($I_{initial}$) and the additional impact (I_{add}) add up to the total odour impact (I_{total}) which is compared with the immission limit value (I_{limit}) given in the Table 3.1. The odour impact is classified as significant nuisance if the total impact exceeds the I_{limit} where these limit values show relative frequencies of odour-hours. Odour-hour designates a percentage for which how much of the time the limit value is exceeded is obtained [34].

$$I_{initial} + I_{add} = I_{total} \qquad \text{(Equation 3.4)}$$

where;

$I_{initial}$ initial odour impact

I_{add} additional odour impact

I_{total} total odour impact

Table 3.1 Immission limit values, I_{limit}, for different land use [34]

Residential and mixed areas	Industrial and commercial areas
10 %	15 %

The *type* of the ambient air pollution is identified by the description of the smell; the *intensity level* is quantified by odour determination by means of the odour-hour concept and the *duration* is expressed by the frequency of occurrence. According to GOAA, these methods characterize the odour impact sufficiently well [34].

There are several methods to assess the significance of an ambient odour impact. These methods can be seen in Table 3.2.

Table 3.2 Methods to determine the ambient odour impact [34]

Method	Initial Odour Impact	Additional Odour Impact
Grid field measurements Olfactometric determination of the ambient odour impact by a panel and calculation of the frequency distribution	Preferred method	Not possible
Dispersion modelling Computation of the odour impact expressed in OU/m^3 from the odour emission rate (odour units per hour) and calculation of the frequency distribution	Possible, but the emission data have to be supplied, either by olfactometric emission measurements or plume measurements	Preferred method

In summary, grid measurements are carried out over an assessment area where equidistant grids are formed on the area. The corners of the grids are defined as the measurement points. According to the measurement schedule formed, each panellist goes to a measurement point on a measurement day and decides whether there exists odour or not. According to the data obtained odour-hour is determined. (In the following chapter this concept will be examined in detail).

GOAA basically deals with the odour immission limit values since it is difficult to set limits for odorous emissions. On the other hand, emission measurements are also carried out in Germany to determine the level of odour concentration emitting from a process and to decide whether this process will be an odour contributor or not.

In Germany “yes/no mode” is used as an olfactometric measurement method. According to guidelines, at least three samples should be taken per emission source and for each sample the odorant concentration is determined in three runs. Olfactometric analysis has to be done immediately after sampling.

In Germany, also separate guidelines for pigs (VDI 3471, 1986), cattle (VDI 3473, 1994) and poultry (VDI 3472, 1986) are used. These guidelines set separation distances by evaluation of the parameters such as the number of livestock units, the manure handling, the ventilation system, the type of feed and the topography of the site [35].

3.2.3 ODOUR REGULATION IN DENMARK

In Denmark, odour laws were established between 1950 and 1980. These laws included ventilation chimneys and setback distances from houses. By the end of 1980s, it was noticed that the good agricultural practice had not reduced odour to acceptable levels. Afterwards, the Ministry of Environment imposed restrictions on the construction and location of manure storage and swine buildings, as well as on the land application of manure [2].

Since 2002, the guideline prepared by the Danish Environmental Protection Agency is in force in Denmark. This guideline is based on industrial odour control and it aims formation of the basis for uniform consideration of complaint and approval cases relating to odour problems in the ambient air. The guideline deals with enterprises emitting large quantities of odorants. However, agricultural activities and animal farming in rural areas are not covered by the guideline [15].

In addition, the maximum allowable emission and/or required dilution of odorous compounds is calculated on the basis of the odour threshold value, according to the directions given in the Danish EPA guidelines No. 7/1974 (control of air pollution from enterprises), No. 3/1976 (control of air pollution from oil-fired plants), and No. 2/1978 (control of air pollution from plants emitting cellulose thinners and other thinners into the atmosphere) [15].

The opinion maintained in the guideline is that the extent of the smell impact can normally not be determined by physical or chemical measurement methods. Because of this reason, measurements based on human perception of smell are used. In Denmark two methods are used for determination of odour thresholds in particular. One is a high volume method developed in Sweden, the other is a method developed in the U.S.A. on the basis of the triangle olfactometer. And these panels consist of 6 –10 panellists. Both methods determine dilution factors for industrial exhaust air and the results are expressed as odour units per m^3 (OU/m^3) [15].

The odorous emissions are limited so that the maximum concentration (sampling time: 1 minute) of the odorant does not exceed the odour threshold concentration by a factor of 5 –10. The maximum concentration, which should not be exceeded at ground level outside the plant site in residential areas, is calculated as the average of anticipated peak values in specific atmospheric conditions. These atmospheric conditions represent neutral-moderately unstable conditions with 4.5 m/s wind speed which are for about 60 % of the time observed in Denmark [15]. In addition, for industrial areas and open rural areas this concentration may in some cases be increased by a factor of 2-3.

In case of an odour contribution problem; the contributions from a single plant are added up where different plants with different emission properties are dealt with separately. If several plants of the same type are expected in one area, the total emission should be limited so that the total immission concentration does not exceed the limits [15].

In the guideline, it is mentioned that satisfactory conditions can be achieved either by cleaning of exhaust air, by dispersion into the atmosphere by means of stacks, or by a combination of these methods.

Two phases of odour reducing measures are discussed in the guideline. The first phase is related with the production and technical design. Process modification and an operational review of odorous substances are suggested. Some of these suggestions include temperature, pressure, air exchange, supervision and maintenance, decay and containment modifications. And the other phase deals with the equipments used for removal of odorants. These methods are based on adsorption, absorption, incineration, catalytic oxidation and biological cleaning [15].

On the other hand, the guideline moves with the thought of “dilution is a solution to pollution” and to reduce odour nuisances by dilution through high outlets is proposed for odorous processes. If the odorant emission concentration exceeds 100,000 OU/m^3 before dilution and the emission takes place centrally through a well-defined outlet, then the emission height should be established with the calculations given in the guideline [15].

Furthermore, some decisions are taken in the guideline related with the emissions from low sources/open plants. Since the emission can generally not be controlled and/or reduced, emission of large quantities of odorous gases from open plants is prohibited. New plants, which may be potential odour sources, should therefore in certain circumstances be fitted with covers or hoods enabling treatment of exhaust gases or dilution by means of stacks. And considering the existing plants, if complaints are raised against odour from existing plants, the odour emission must be estimated roughly, and the decision then taken whether design or production improvements are required and whether hoods and/ or stacks to central outlets should be established [15].

Also, the following expressions are offered for the estimation of the abatement zone surrounding an odour source [15]:

$L = 1.6(RC_{50})^{0.6}$ for low sources (Equation 3.5)

$L = 5.62(H_e)^{1.16}$ for high sources (Equation 3.6)

where;

R Air volume from outlet (dry air), Nm^3/s

C_{50} Odorant immission concentration, OU/m^3

H_e Effective outlet height, m

L Radius of the abatement zone, m

It is claimed (by experience) that odour can be perceived within a circle with this radius (m).

3.2.4 ODOUR REGULATION IN THE U.S.A

Mahin, T. [36] states that odour complaints to environmental regulatory agencies have been increasing in the U.S.A. Because more homes are built near odorous facilities and many residents have become less tolerant to odours. In addition, in agricultural areas of the U.S.A there has been an increase in corporate large-scale confined animal feeding operations. Since most of these facilities do not have significant odour treatment systems, there has been an increase in complaints and regulations relative to animal feeding operations [36].

To deal with these odour problems different approaches have been used in the U.S.A such as [36];

1) Ambient air limits: These limits are set for individual compounds such as hydrogen sulphide (Table 3.3). For example; the Feedlot Hydrogen Sulphide Program administered by the Minnesota Pollution Control Agency is in effect since July 1997 [2].

Table 3.3 Examples of ambient air standards for odour causing compounds in the U.S.A [36]

Location	**Compound**	**Ambient Odour Standard**
California	Hydrogen sulphide	30 ppbv * (1-hour average)
Connecticut	Hydrogen sulphide Methyl mercaptan	6.3 μg/m^3 2.2 μg/m^3
Idaho	Hydrogen sulphide)	10 ppbv (24 hour average) 30 ppbv (30 min. average
Minnesota	Hydrogen sulphide	30 ppbv (30 minute average)** 50 ppbv (30 minute average)***
Nebraska	Total reduced sulphur	100 ppb (30 minute average)
New Mexico	Hydrogen sulphide	10 ppbv (1 hour avg.) or 30 – 100 ppbv (30minute avg.)
New York State	Hydrogen sulphide	10 ppbv (14 μg/m^3) 1-hour average
New York City	Hydrogen sulphide	1 ppbv (for wastewater plants)
North Dakota	Hydrogen sulphide	50 ppbv (instantaneous, two readings 15min. apart)
Pennsylvania	Hydrogen sulphide	100 ppbv (1 hour average) 5 ppbv (24 hour average)
Texas	Hydrogen sulphide	80 ppbv (30 minute avg.) - residential /commercial lands 120 ppbv -industrial, vacant lands

* parts per billion by volume
** not to be exceeded more than 2 days in a 5-day period
*** not to be exceeded more than 2 times per year

2) The field inspections: It is used to response the odour complaints from the public. The inspectors rate the intensity of the odour in the field, based on an intensity scale.

3) Off-site limits: These limits are based on the odour levels predicted by dispersion modelling and the dynamic olfactometry approach with the criteria as odour units (OU/m^3) or as dilutions/threshold (D/T) value.

4) Best available control technology: BACT or similar approaches are used to specify required levels of odour treatment controls for new or upgraded large facilities.

5) Setback distances: The American Society of Agricultural Engineering (ASAE) document Engineering Practice 379.1 "Control of Manure Odours" recommends

setbacks from livestock facilities of 0.4 to 0.8 km for neighbouring residences and 1.6 km to residential development.

In August 23, 2002 the A&WMA / EE-6 Subcommittee on the Standardization of Odour Measurement prepared a document titled “Guidelines for Odour Sampling and Measurement by Dynamic Dilution Olfactometry” [37].

The EE-6 Odour Committee has submitted the guidelines to the ASTM as a more detailed odour testing replacement method for the current ASTM method E679-91 (Standard Practice for Determination of Odour and Taste Thresholds by a Forced-Choice Ascending Concentration Series Methods of Limits). The purpose of this attempt was the standardization of odour sampling procedures and odour measurement techniques by dynamic dilution olfactometry all over the U.S.A. This standardization would allow the comparison of odour measurement results from one laboratory to another or one instrument to another with some degree of reliability and reproducibility [36, 37].

The method accepts the use of forced choice or non-forced choice sample presentation method in an ascending concentration triangular method (one diluted odour sample and two blanks per presentation) or a binary method (one diluted odour sample and one blank per presentation) [36, 37].

The A&WMA guidelines are similar to the European Standard. In the U.S.A several universities follow the European standard’s basic tenets including Duke University, Iowa State University, the University of Minnesota, Purdue University, the Los Angeles County Sanitation District and the Minnesota Metropolitan Council [36].

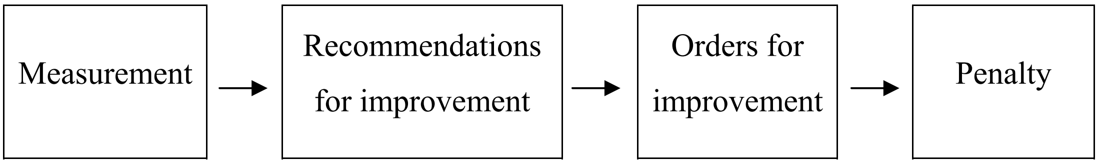
3.2.5 ODOUR REGULATION IN JAPAN

In Japan, the odour assessment and regulation studies started in 1960s with the increasing complaints against offensive odours. The total number of complaints was peaked when the Offensive Odour Control Law was enforced in 1972. The Law introduced an instrumental odour measurement method on each substance, mainly by utilizing gas chromatograph [38]. At present, twenty two substances are regulated, and it is stipulated that measured values at an enterprise's site boundary should not exceed these limits. Some of these substances are listed in Table 3.4 and the values show average concentration for five minutes [1, 7].

Table 3.4 Regulation levels at site boundary specified by Japan's Offensive Odour Control Law [7]

Odorant	Concentration in gas (ppm)
Ammonia	1 ~ 5
Methyl Mercaptan	0.002 ~ 0.01
Hydrogen Sulphide	0.02 ~ 0.2
Dimethyl Sulphide	0.01 ~ 0.2
Dimethyl Disulfide	0.009 ~ 0.1
Acetaldehyde	0.05 ~ 0.5
Styrene	0.4 ~ 2.0
Trimethylamine	0.005 ~ 0.07
Propionic acid	0.03 ~ 0.2
n-Butyric acid	0.001 ~ 0.006
n-Valeric acid	0.0009 ~ 0.004
isoValeric acid	0.001 ~ 0.01

The governments determine the regulation areas. Moreover, the typical areas to be regulated are built-up areas and suburban areas with schools and hospitals. The law regulates the generation of offensive odour by factories and enterprises that spread offensive odour pollution in their neighbourhood. As a first step, it gives recommendations for improvement of the situation. Then it gives orders to enterprises that do not fulfil the regulation criteria. If this is not done it imposes penalties on them [7]. The regulation procedure can be seen from the chart given below [38].



In 1992, the Environment Agency in Japan established the national method for olfactometry measurement using “triangular odour bag method” which the Tokyo Metropolitan Government had already verified the reliability of the method in 1972. In 1995 the Environment Agency made amendments and the full set of guidelines on regulatory standards for odour emission was completed in 2000 [38].

In order to accelerate the adoption of the regulation, the Ministry of Environment promotes the movement by carrying out seminars in many regions and by providing information materials [38].

The Japanese Offensive Odour Law prescribes olfactory and instrumental methods to measure odours. Table 3.5 shows the current status of these instruments [22].

For practical application of odour measurement odour sensors are also being used in Japan. In Japan odour sensors have been in practical use for about ten years and they offer the advantage of conducting odour measurements on-site [22].

Table 3.5 Odour evaluation method in Japan [7]

			Advantages	**Disadvantages**
Official methods	Olfactory method	Triangular odour bag method	Official method	Requires a panel of at least 6 members. Complex procedures.
	Instrumental method	GC GC-MS Absorptiometry	Official method	Instrument preparation required. May not reflect actual odour intensity.
Simplified methods	Instrumental method	Odour sensor	Permits on site measurements	Requires calibration for odour element.
		Electronic noses	Can evaluate odour category. Can identify odours and determine the intensity.	Expensive.
		Detector tube	Permits on-site measurements.	Low sensitivity for some odours.
		Monitoring specific components	Permits on-site measurements.	Cannot measure some odours.
	Olfactory method	Comparison using 2 odour bags 6-4 selection method	Simpler than official methods.	Reduced accuracy.

Triangular odour bag is a kind of olfactometric measurement method and being widely used in Japan. Using this method not only the concentration, but also the intensity and the quality can be determined.

To identify the quality of odour; the odorous sample is sniffed and its impression is expressed in words. Since it is difficult to express this impression in words, some representative expressions are shown and panellists select the suitable ones out of them. Some of these expressions are such as; rotten egg odour, fecal odour, irritant odour, garbage odour, onion odour, flower odour, sweaty odour, aromatic odour, sewer odour, oily odour, disinfectant odour, night-soil odour, fruity odour, rotten fishy odour, sour odour, bitter odour, coal-tar odour, fish-like odour, indescribable odour, odour from which people feel like escaping, etc [7].

To identify the odour intensity, the odour sample is sniffed by panellists and then the intensity of odour is graded according to the intensity scale as indicated in the Table 3.6 [7];

Table 3.6 Expression method of odour intensity using six gradations [7]

Gradation	Odour Intensity
0	No smell
1	Very slight *
2	Light **
3	Moderate
4	Strong
5	Very strong

* Detection threshold
** Recognition threshold

Finally, the odour concentration is defined. This is a method of establishing odour intensity by diluting sample gas with purified air to find the degree of dilution at which smell can no longer be perceived with the olfactory sense. In this method, three bags are prepared, only one of which is filled with a certain amount of sample gas. The panel has to determine the bag containing sample gas. As sample becomes more diluted, judgement becomes more difficult. In Figure 3.10 the equipment used in preparing odourless air for the test is shown [7].

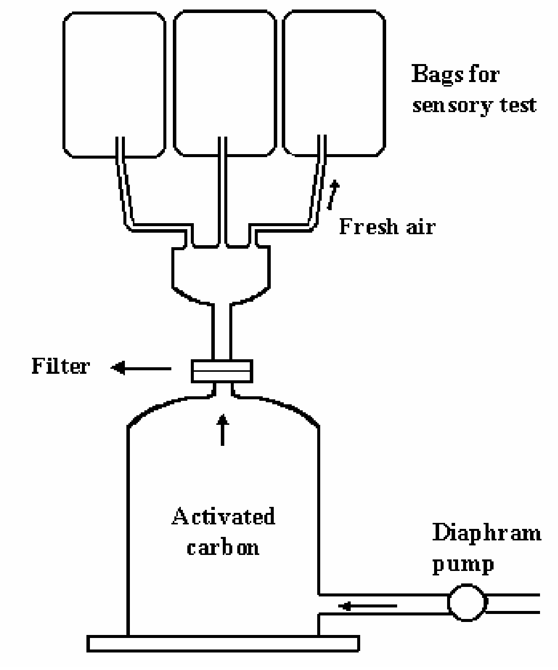


Figure 3.10 Equipment for making odourless air for a sensory test for odour [7]

The results of this triangular olfactometry test are expressed as “odour index” and given by the following equation;

$$I = 10 \ \log C \qquad \text{(Equation 3.7)}$$

where;

I Odour index
C Odour concentration (odour unit)

In fact, C represents the dilution multiple (times) at which smell can no longer be perceived with olfactory sense [7].

The Japanese Offensive Odour Law also includes both boundary lines and emission port standard levels which determine the height of the stack with respect to the emitted gas quantity. In the Law potential odour contributors are examined one by one and possible emissions from all operations are stated within charts.

Furthermore the Japanese Government take some measures for odour prevention. These odour preventing and deodorizing methods basically include: gas washing methods, combustion methods, chemical treatment methods, etc.

3.2.6 ODOUR REGULATION IN KOREA

Park, [39] states that in Korea the number of civil petition cases related to odour increases every year. And he explains the major cause of civil petition as the close distances between residential and manufacturing areas. Consequently, the complaints have caused large manufacturing plants to restructure their policies [39].

In Korea, the Environmental Protection Agency takes action and reduces odour through technical support for small and medium-sized companies and making a database of odour-emitting facilities, deodorization fuel, and odour-victimized areas [39].

There exist three major methods of odour analysis that is used in Korea. These methods are direct sensory test, air dilution method and analysis of chemical compounds causing odour. According to the regulation, the researcher can use analysis chemical compound by using GC or UV as well as the two former tests [39].

The measurement and regulation of odour in Korea has been conducted in two places: 1) at outlets including stack, and 2) at boundaries of companies including enclosures.

In the environmental protection law of Korea, eight odorous compounds given in Table 3.7 are classified according to the place of measurement.

Table 3.7 Analysis and permission level of odour in Korea [39]

Methods of Odour Analysis	**Criteria for Permission Level of Odour Release**		
Direct sensory test	Odour Intensity : less than 2 degree		
Air dilution Sensory test	A. Outlets including stack (a) Companies in industrial area: less than 1000 OC* (b) Companies in other area : less than 500 OC B. Boundaries of companies including enclosures (a) companies in industrial areas : less than 20 OC (b) companies in other areas : less than 15 OC		
Chemical compound analysis using GC or UV	Compounds	In Industrial Areas	In Other Areas
	Ammonia	< 2 ppm	< 1 ppm
	Methane ethiol	< 0.004 ppm	< 0.002 ppm
	Hydrogen sulfide	< 0.06 ppm	< 0.02 ppm
	Dimethyl sulfide	< 0.05 ppm	< 0.01 ppm
	Dimethyl disulfide	< 0.03 ppm	< 0.009 ppm
	Trimethyl amine	< 0.02 ppm	< 0.005 ppm
	Acetaldehyde	< 0.1 ppm	< 0.05 ppm
	Styrene	< 0.8 ppm	< 0.4 ppm

* OC: Odour concentration

In Korea, atmospheric and environmental protection laws are highly limited to control over regulation of odour emission. As a result, odour prevention was separated from atmospheric and environmental protection on July 1, 2002. Since then, legislation of odour prevention law is started. According to this law [39];

1. Local communities are in charge of odour management on behalf of the government.
2. Problematic areas are designated and managed.
3. Establishment and management of the permission level of odour release are determined according to the characteristics of areas.
4. Regulation standards are applied for odour emitting facilities.
5. Preliminary prevention measures are utilized for odour emitting facilities.
6. Odour inspection institutions for the reliability and objectivity of measurements are established.
7. Management of odour by the inspection of odour status is done on a regular basis.

3.2.7 COMPARISON OF THE ODOUR REGULATIONS

In many countries environmental odour control strategies have already been developed and the standardization of odour has progressed significantly. According to the dominant atmospheric conditions and the topographical properties that are specific to a country and to the living standard of the inhabitants, different odour control criteria have been set for these countries. Some of these countries have adopted *emission limits* whereas some adopted *immission limits* or both. In order to control odorous emissions and immissions, different odour quantification techniques are used in these countries. Table 3.8 summarises the odorous emission and immission measurement techniques used, the emission and immission limits adopted, the setback distances and the odour dispersion models used in some countries.

Table 3.8 Summary of the odour control regulations at different countries

	EUROPEAN STANDARDS	**GERMANY**	**DENMARK**	**U.S.A**	**JAPAN**	**KOREA**
Emission Measurements	Olfactometric Methods	Olfactometric Methods	Olfactometric Methods	- Olfactometric Methods - Instrumental Methods	- Olfactometric Methods - Instrumental Methods	- Direct sensory test - Air dilution method - Instrumental methods
Immission Measurements	-	Field Inspections	Olfactometric Methods	Field Inspections	- Odour sensors - Detector tubes - Monitoring specific compounds	Air dilution method
Emission Limits	-	Specific to some operations (e.g. Composting and Biological Treatment; 500OU/m^3)	If odorous emissions > 100,000 OU_E/m^3 before dilution, emission height should be established.	-	Odorous compounds are examined individually at the source	- At stack outlets; a) 1000 OC for industrial area b) 500 OC for other areas - Limits on the basis of compounds
Immission Limits	-	- 10% odour hours for residential areas - 15% odour hours for industrial areas	5-10 OU_E/m^3 at the nearest neighbour	- Based on odour levels predicted by dispersion modelling and olfactometry - Based on individual compounds	At the site boundary levels on the basis of odorous compounds	At the company boundaries; a) 20 OC for industrial area b) 15 OC for other areas
Setback Distances	-	Specific to livestock facilities	Specific to some industries (e.g. Composting and Biological treatment; 500 m to nearest neighbour)	For livestock facilities; - 0.4 to 0.8 km for neighbouring residences - 1.6 km to residential development	-	-
Dispersion Models	-	AUSTAL2000 (expected to be a standard model)	Abatement zones are defined by special equations	EPA recommends ISCST3	-	-

CHAPTER IV

EXPERIMENTAL METHODS

4.1 EMISSION MEASUREMENTS

Offensive odours are the kind of environmental pollution that directly stimulates the senses of people and impairs the health and the living environment. Therefore, odorous emissions have to be controlled.

In order to control odorous emissions and to improve legislations and regulations, the first step is the determination of potential odour sources and the second step is the evaluation of these sources.

In this study, for odour quantification “olfactometric measurement method” was used. With the olfactometric measurement odorant concentration, which is necessary for the characterization of an emission source, was determined for various emission sources.

Odorant concentration is the amount of odorant material or odour units (OU) dispersed in 1 m^3 of neutral air. It is used for quantitative evaluation of the “emission” source. The product of the measured odour concentration (OU/m^3) and the volumetric flow rate (m^3/s) of the odorous gas gives the *emission load* (OU/s) for that source. This information can also be used in odour dispersion modelling to calculate the spread of odorous substances in the atmosphere. By this way, the odorous “immissions” can be predicted [29].

4.1.1 INDUSTRIES STUDIED

Within the study, various kinds of industrial facilities and production processes were visited to have an overview of the emission levels from different industries. The process conditions, the indoor and the outdoor environment of these plants were examined and the appropriate sampling procedures were investigated. In addition, these odour emission sources were characterised in quantity with olfactometric measurements.

Gas samples from industrial facilities including; foundry and forging operations, paint manufacturing, mineral wool production (glass and stone wool productions), solid waste landfill, poultry farm-egg production, waste water treatment plant of an aerospace industry, meat storage area, beer factory, waste water collection well, solid waste separation plant, herbicide plant, different restaurants, battery factory, packaging industry, spice factory, food industry, printing , washing machine factory, sponge factory, asphalt machine industry, rubber industry, pipe and machine industry, dried fruit/nuts factory, cable element industry and animal houses (sheep and cattle) were taken and measured with olfactometer. Most of these industries are typical odour sources and they were chosen on the basis of odour complaints from the public.

Considering the fluctuations in the emissions and the changing work loads at the factory under investigation, at least three samples have to be taken per industry/ operation at different times. Some of these odour sources, where highly concentrated odorants emitted from the factory / operation, were examined in detail. These odour sources are foundry and forging operations, paint manufacturing, mineral wool production (glass and stone wool productions) and solid waste landfill area. Each of these industries/ operations was visited several times and odorous gas samples were collected on three different days (for solid waste landfill four different measurement days were arranged). In order to obtain reliable results with olfactometric measurements, 3 odorous gas samples were collected from each industry/ operation on each measurement day and each sample were measured for 3 times with olfactometer.

The measurement results of the first 3 months' were not taken into consideration because panellists had to be trained for a certain period in order to make them used to the measurement procedure. Also, in order to obtain reliable results, the standard deviations of the measurement results were examined. If the standard deviation for a measurement was greater than 1.5, that measurement result was discarded.

4.1.2 SAMPLING PROCEDURE

During two years of study, air samples were collected from the aeration channels, exhaust stacks and surface bodies of selected industries / operations. Throughout the study static sampling method was used. Odorous gas samples were collected in 10 L "nalophan" bags using the vacuum sampling device (the schematic diagram of the sampling device is shown in Figure 4.1). Samples were tested at Odour Laboratory of METU within 24 hours.

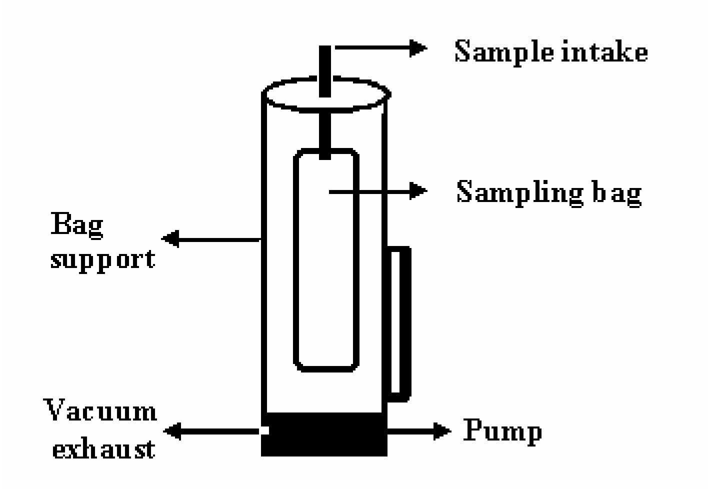


Figure 4.1 Schematic diagram of the sampling device

Sampling from the aeration channels and exhaust stacks were accomplished through stack sampling. An extension tube made of teflon, which was connected to the vacuum sampling device, was inserted into the stack and the gas sample was filled into the nalophan bag.

While sampling from the surface bodies (liquid and solid surfaces), a special device called "flux hood" (flux chamber) was used. The dimensions for this flux hood is given in Appendix A. Flux hood was inverted on the surface to be sampled and waited for at least 2 hours to obtain a continuous flow of the odorous gas through the hood. Then, as it is done in stack sampling, extension tube was inserted into the sampling port of the hood and the odorous gas sample was collected by using vacuum sampling device.

4.1.3 OLFACTOMETER TO7

In order to determine the odour concentration of the gas samples, TO7 yes/no olfactometer (shown in Figure 4.2), which was purchased from the company Emission Measurement Technique and Consultation Mannebeck Ltd. (ECOMA), was used throughout the experiments. This instrument is purchased from the project entitled “Odorous Emissions and Immissions Management Policy in Turkey” (LIFE00/TCY/TR/009) which is financed by LIFE, a program in EU supporting environmental policy and legislation.

Figure 4.2 Picture of an olfactometer model TO7 [29]

Olfactometer TO7 is a compact measurement system for odour measurement in the laboratory or in mobile operation. The Olfactometer TO7 is concurring with the

German Guidelines VDI 3881 and 3882 and with the new European Standard (CEN 13725). Since 1992 it is sold and applied reliably. Hard- and Software of the instrument have been constantly developed during the last years. The users are legislative authorities and universities as well as industrial and engineering companies [29].

The Olfactometer TO7 is in principle a dilution system in which a sample of odorous air is diluted with clean air. The principle of odour determination by olfactometry is given in Figure 4.3.

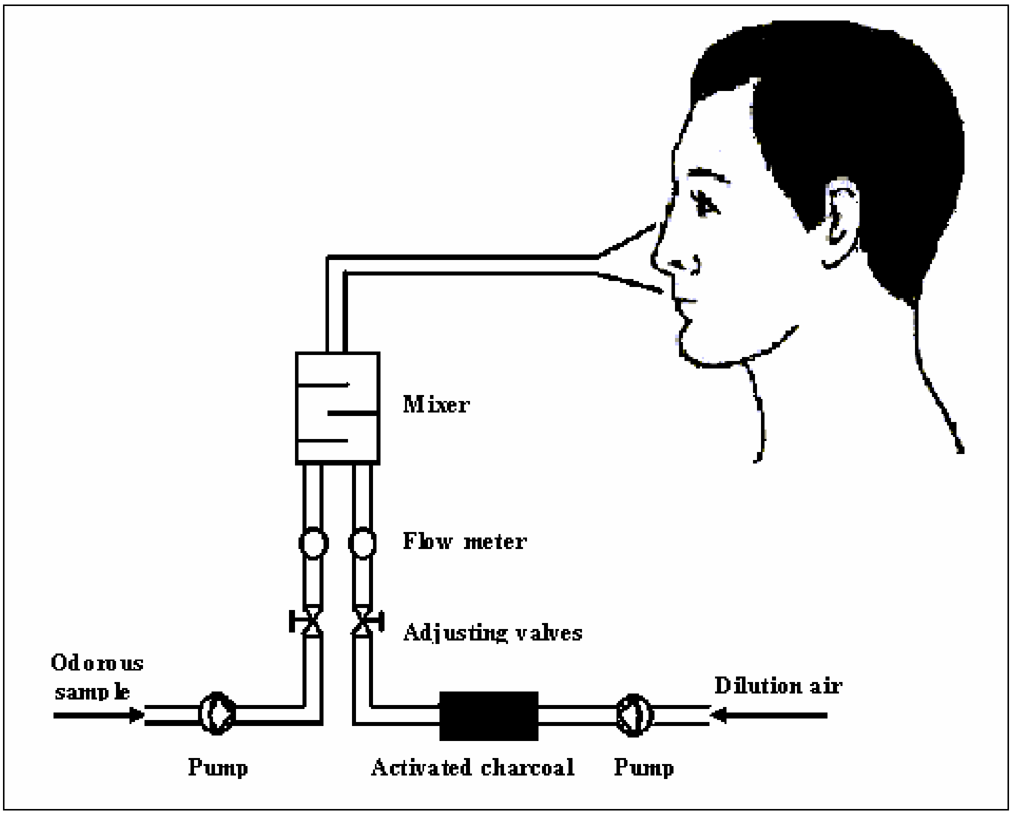


Figure 4.3 Principle of odour determination by olfactometry [27]

The diluted sample is offered to panel members who judge the sample for odour. The concentration of sample air is increased from step to step according to the method of limits. The step width is in factor of 2. The panel members usually start measurement with neutral air in which no odour is perceptible until they can just perceive it. The answers are collected according to yes/no-questioning [29]. With the Olfactometer TO7 the measurement is run with four panellists at the same time. A photograph of panellists during an olfactometric measurement is given in Appendix F. (Information on "Olfactometer TO7" is also given in Chapter 3.)

The air sample is sucked from the sample-bag via the predilution unit and via the flowmeters. The flow-rate of odorous air is controlled in steps by the needle valves which are adjusted by the leader of the panel. The following dilution ratios are adjustable: 1:2.5 to 1:640 without pre-dilution, 1:250 to 1:64,000 with a pre-dilution ratio of 1:100. The pre-dilution ratio can be adjusted to 1:25 and to 1:100.

The odour concentrations of the gas samples were calculated by the special software according to the response of the panel members. The software comes with the olfactometer. The resultant odour concentration is expressed by Z_{50} which is calculated by taking the geometric mean of the "panellists' odour thresholds" and Z_{50} is displayed in terms of OU/m^3. The standard deviations of measurements are also calculated by the software. The calculation procedure is given in Appendix B.

4.1.4 PANELLIST SELECTION AND CALIBRATION PROCEDURE

Sixteen panellists, who were selected among undergraduate and graduate level environmental engineering students, took part in odour measurements. Sensitivity of smell for all students was tested with n-butanol and those who pass the test were selected as panellists. The panellists were trained for odour tests with the olfactometer and for field inspections.

The panellist screening test, which is in fact called "calibration", was carried out with the following procedure:

1. A 20 L sampling bag made of aluminium and covered inside with PTFE was filled with neutral air.

2. 4 μL of n-butanol (with 0.81 kg/L of density) was injected into the sampling bag with a syringe.

3. The bag was set aside at room temperature for a day for uniform mixing of n-butanol and the air in the bag.

4. Olfactometric measurements were carried out by using this bag of sample gas.

5. Students' responses were evaluated and the odour detection threshold for each student was determined.

6. The students, whose detection threshold found in the range of 64.8 OU and 270 OU, were selected as panellists and included in the odour panel.

Table 4.1 describes the n-butanol sample preparation and the panellist response range in detail.

Table 4.1 Preparation of n-butanol sample for calibration of panellist noses

Volume of the sample bag	20 L
Volume of n-butanol injected	0.4μL
Density of n-butanol	0.81 kg/L
Mass of n-butanol injected (m = d*V)	$0.81 kg/L \times 0.4 \times 10^{-6} L = 3.24 \times 10^{-7} kg$
Concentration of the sample n-butanol	$\frac{3.24 \times 10^{-1} mg}{20 \times 10^{-3} m^3} = 16.2 mg/m^3$
Detection threshold range for a good panellist	0.06 mg/m^3 < threshold < 0.25 mg/m^3
$\frac{\text{Concentration of n-butanol found in the bag}}{0.06\text{mg/m}^3} = \frac{16.2\text{mg/m}^3}{0.06\text{mg/m}^3} = 270\,\text{OU}$ $\frac{\text{Concentration of n-butanol found in the bag}}{0.25\text{mg/m}^3} = \frac{16.2\text{mg/m}^3}{0.25\text{mg/m}^3} = 64.8\,\text{OU}$	
64.8 OU < odour detection threshold < 270 OU	

4.2 IMMISSION MEASUREMENTS

The olfactometric measurements of odorous “immissions” do not give relevant results, because the concentration of odorous compounds are very low and depends very strongly on the wind speed and wind direction. Therefore, the measurements of odorous immissions are accomplished through “**field inspections**” according to the method of TA Luft (German Technical Instructions for Clean Air) used in Germany [42].

Field inspections are accomplished by using panellists in the field where odour is present. The measured parameter is the “**percent odour time”**, which represents how often the odorants in the outdoor air exceeds a recognition threshold so that it is definitely identifiable by the observer (panellist). In principle, each panellist goes to the measurement point and tests the ambient air for odours regularly inhaling the air during a defined measurement period (single measurement). Therefore, the method is appropriate to describe an *existing status* [42].

In this study, field inspection method was used for odour immission measurements around a sugar factory in Ankara. The main reasons for this selection were the high odorous emissions released from the factory and the factory being located in a residential area.

In this factory approximately 4,000 tons of sugar beets are processed per day. About 12 % of this amount is converted to sugar. Therefore, 480 tons of sugar is produced per day. In the campaign period, from different parts of Turkey tons of sugar beets arrive and stored in the factory area. When sugar manufacturing starts, sugar beets are washed in a pond near the factory and the wastewater is sent to the wastewater treatment plant of the factory. In the treatment plant which lies within the factory boundaries, there are equalization basin, sedimentation pond and aeration chambers. The odour from the sugar factory, is a sweat, aromatic odour peculiar to processed beet. However, the wastewater treatment plant also contributed to the odour around the factory to a small extent.

Since the factory lies in the centre of the city and there exist residents all around the factory, the situation is very disturbing. The factory works in shifts and emits odour 24 hours per day during the campaign period. During the campaign period which lasts for 3-4 months, the intensity of odorous emissions increase and odour in the surroundings becomes more and more annoying. Although some of the residents are used to the situation, odour complaints still arise from that area.

In the German guideline, GOAA, it is stated that "field inspections are particularly helpful with sources whose emission is difficult to measure (e.g. fugitive emission) or whose ambient air effects are difficult to forecast". Considering this explanation and the above mentioned reasons, sugar factory was selected as the emission source with multiple emissions of the same kind and it was decided to perform *field inspections* in the surrounding area.

In order to locate the measurement points in the immission area, wind data was necessary. First of all the wind rose for Etimesgut area was plotted by using 10 years of meteorological data as given in Figure 4.4. The dominant wind directions were determined as North-East (NE), East-North-East (ENE) and West-South-West (WSW).

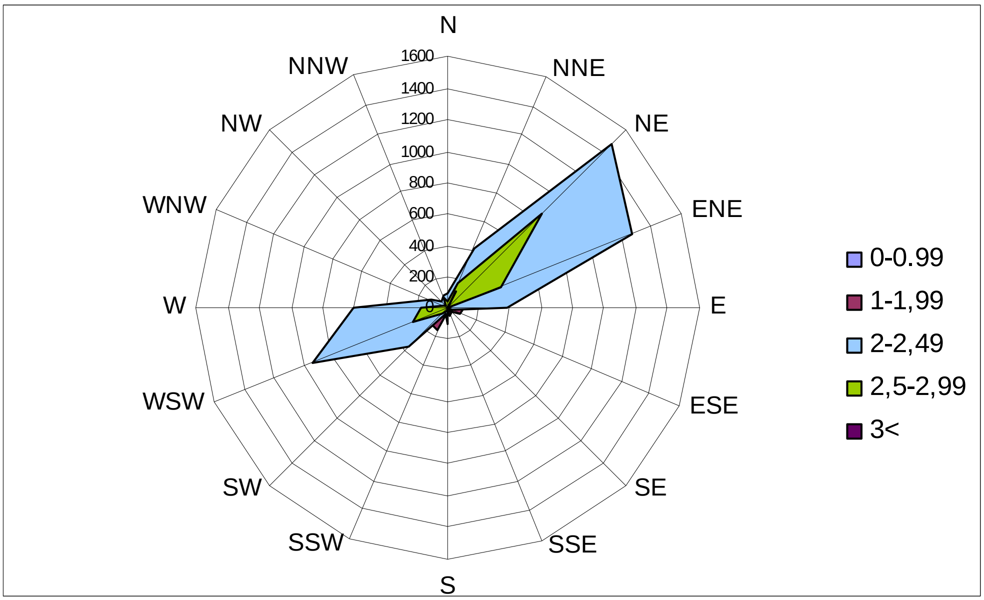


Figure 4.4 Wind rose plotted with 10 years of meteorological data (1992-2001)

The assessment area, which is the area defined for measuring and assessing the odorant immissions, was determined. The size and the shape of the assessment area were formed considering the following factors [42];

- *The type of the emitter;* the factory itself was taken as a point source and waste ponds as area sources,

- *Odorant character;* typical sugar beet odour; sweaty and aromatic, possible to reach far away areas,

- *Dominant wind direction;* wind blows from NE direction 24.2 % of the time, ENE direction 18.0 % of the time and WSW direction 15.2 % of the time,

- *Accession of the area;* some regions in the factory area were not accessible so these regions were not assigned measurement points,

- *Location of the residential area;* with respect to the sugar factory; West, South and South-West are the residential areas.

For measurement purposes, the assessment area was gridded according to the principles stated in VDI 3940 (given in Figure 4.5). The distance between measurement points is defined according to the desired resolution as 250 m. The grids were located especially in the NE – WSW direction covering an area of approximately 1.7 km^2.

The corners of the grids, which were in fact the measurement points, were named with letters (A, B, C, D) and numbers (1, 2, 3,…10) as shown in Figure 4.6. At the end 40 measurement points were obtained.

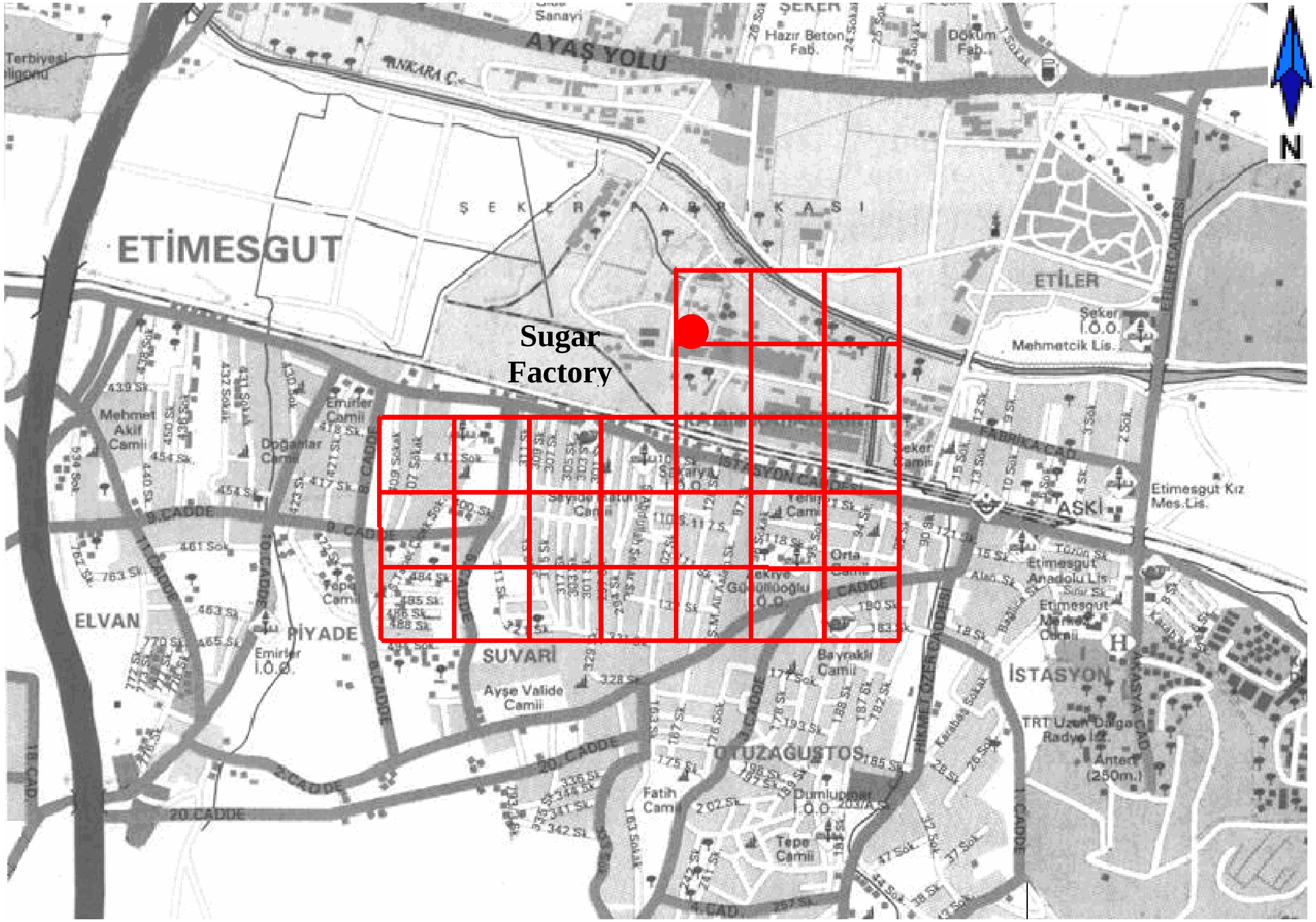


Figure 4.5 Assessment area for the field inspections around the sugar factory

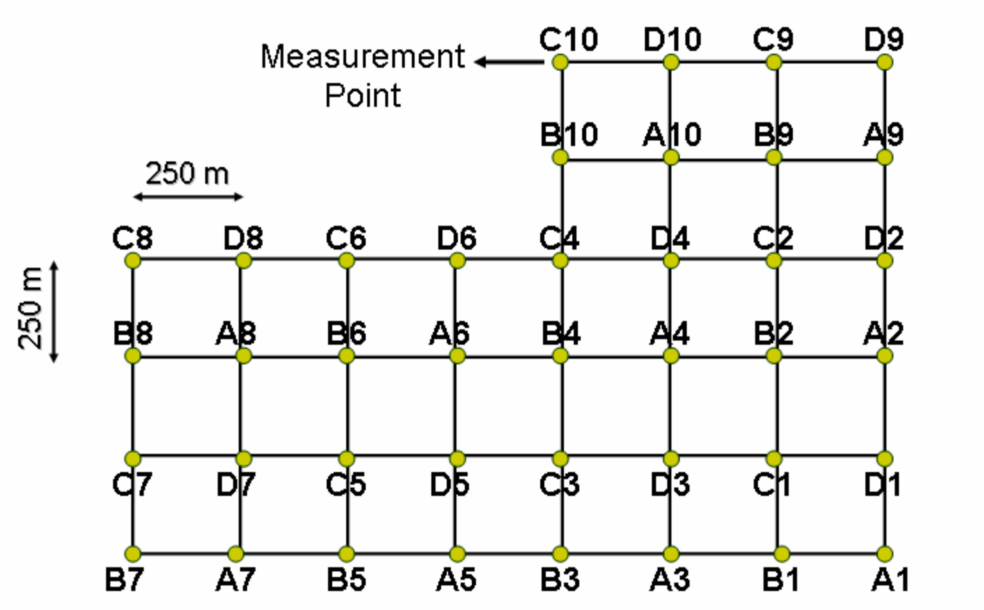


Figure 4.6 Measurement points around the sugar factory (B10 indicates the source)

The assessment period was decided as 1 year that covers 104 measurement days [42]. The period started on February 21, 2003 and ended on February 15, 2004. Then, the measurement schedule was formed. The measurement dates were planned to be representative of;

- time of the year,
- time of the week,
- time of the day (e.g. 0-4hrs, 8-12hrs, 20-24hrs).

By this way, a good distribution over time was obtained. A part of the measurement schedule can be seen in Table 4.2. The complete measurement schedule is given in Appendix C.

Table 4.2 Schedule for the field measurements around the sugar factory for 8 days

NO	DATE	DAY	TIME, hrs	POINTS
1	February 21, 2003	Friday	16:00 - 20:00	D
2	February 24, 2003	Monday	08:00 - 12:00	A
3	February 27, 2003	Thursday	12:00 - 16:00	B
4	March 2, 2003	Sunday	16:00 - 20:00	C
5	March 5, 2003	Wednesday	20:00 - 24:00	D
6	March 8, 2003	Saturday	12:00 - 16:00	A
7	March 11, 2003	Tuesday	16:00 - 20:00	B
8	March 14, 2003	Friday	20:00 - 24:00	C

In order to measure the ambient odour characteristic, single measurements were performed repeatedly at each grid point over a measurement period of one year (104 measurements). According to the guideline VDI-3940 single measurement is defined as “the measurement of odorant immission at a defined measurement point within a defined measurement duration”. For a representative assessment of odour situation at a particular hour, a duration of at least **10 minutes** is needed to give at least 80 % reliability [42].

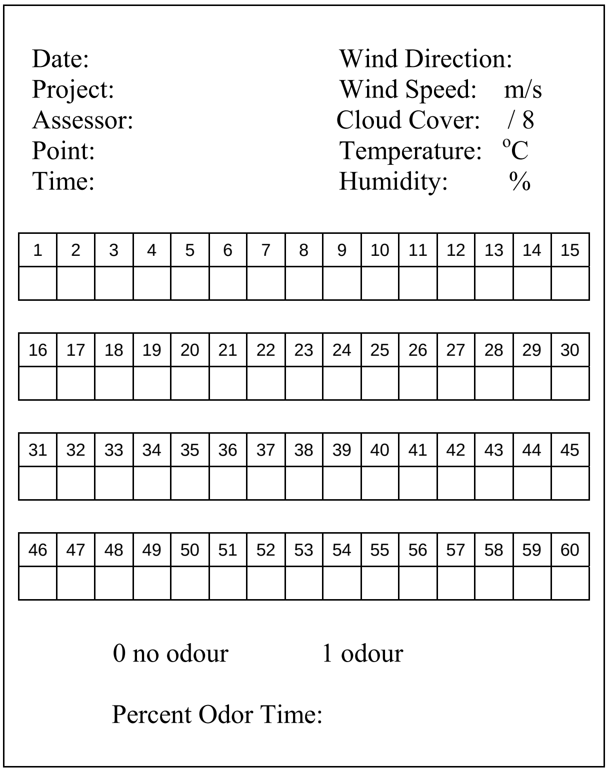
Single measurements were performed by a panel of 16 students who were familiarized with the odour emitted from the sugar factory. Since there were 40 measurement points, it would be difficult to do the measurement at all points on a measurement day. Therefore, only one type of measurement point e.g. only points A, were measured on a measurement day. There are 10 of the A-points in the grid system. 10 points were measured per measurement day. Totally, 26 measurements (104 / 4 = 26) were made for each measurement point in one year.

As it can be seen in the measurement schedule (Table 4.2), the measurements at these points were distributed over time. Also, as many different panellists as possible were involved in the measurements, so that panellists distribution was also ensured.

On a measurement day, two panellists went to the assessment area to perform single measurements within the defined time intervals given in the measurement schedule. Total measurement duration should not exceed 4 hours according to VDI 3940. However, all single measurements had to be performed within that time interval. 2 panellists worked for each measurement day. Therefore, each panellist performed 5 single measurements on a measurement day.

After the panellist arrived at the measurement point, he/she stood at that point for 10 minutes, breathed naturally and calmly, and tested the ambient air by inhaling at regular intervals (every 10 seconds).

During single measurements, the panellists only looked for the odour being investigated and recorded their perceptions as ‘1’ (represents yes) or ‘0’ (represents no) on a data sheet as shown in Figure 4.7.



Date:
Project:
Assessor:
Point:
Time:

Wind Direction:
Wind Speed: m/s
Cloud Cover: / 8
Temperature: °C
Humidity: %

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

31	32	33	34	35	36	37	38	39	40	41	42	43	44	45

46	47	48	49	50	51	52	53	54	55	56	57	58	59	60

0 no odour 1 odour

Percent Odor Time:

Figure 4.7 Data sheet used for field inspections

The following data was also recorded by the panellist in the data sheet: date of measurement, name of the panellist, name of the measurement point, time that measurement has started and ended, wind direction, wind speed, cloud cover, temperature and humidity. A portable anemometer (ALMEMO 2290-4 V5, patented by Ahlborn GmbH) was used to determine the wind speed, temperature and humidity of ambient air. The wind direction was determined with the help of a ribbon and a compass, and the cloud cover was determined by panellist observation as a fraction of 8. Additionally, stopwatches were used by the panellists in order to follow the breathing intervals. At each point, a total of 60 samples were obtained in ten minutes according to the following calculation;

$$(1 \text{ sample} / 10 \text{ sec}) \times (10 \text{ min}) \times (60 \text{ sec/min}) = 60 \text{ samples}$$

After the data sheets were filled out, the total number of responses regarded as ‘1’ were divided by the total number of measurements (60 measurements). Expressed as a percentage, this gives the “**percent odour time**” (odour frequency). The “percent odour time” for each measurement point was calculated as follows [42]:

$$A_+ = \frac{L_+}{R} \qquad \text{(Equation 4.1)}$$

where;

A_+ percent odour time (odour frequency)

L_+ number of responses recorded as ‘1’

R total number of measurements

In the German guidelines VDI 3940 [42] the immission limit values for different land uses in Germany are given as follows;

Immission limit = 10 % for residential and mixed areas
Immission limit = 15 % for industrial and commercial areas

The work related with odour annoyance has been carried out in Germany since 1980s. However, the odour measurements and odour standards are new for Turkey and considering that different societies have inherently different levels of acceptance for odours, the immission limits are not planned to be very strict in Turkey. In fact, these limits are set as a trial work in order to see the reach of impact of odorous immissions.

Starting out with this thought, the immission limit value for the sugar factory and its surrounding was suggested as **20%** for residential areas which is twice the value given for the residential and mixed areas in Germany and as 30% for industrial and commercial areas.

Immission limit = 20 % for residential and mixed areas
Immission limit = 30 % for industrial and commercial areas

After setting the limit values, the “percent odour times” for each point were checked whether it exceeded the predefined limit or not. If the immission limit was exceeded, the single measurement is regarded as *positive*. If the immission limit was not exceeded, the single measurement is regarded as *negative*. There are 26 days that single measurements are made at a specific point, and the measurements are evaluated as (+) or (-) for total 26 days [42].

Percent odour time > immission limit value → positive (+)

Percent odour time < immission limit value → negative (-)

For example; a single measurement is regarded as "positive" if 15 ones ('1') are recorded on a measurement day. Since 15/60 is 25% and this value is greater than 20%, this result is taken as (+).

For each measurement point, the percentage of positive single measurements was calculated during the whole measurement period as follows and this is called "percent odour hour" [42];

$$H_m = \left(\frac{A_m}{W_m} \right) \times 100 \qquad \text{(Equation 4.2)}$$

where;

H_m percent odour hour (%)

A_m number of single measurements recorded as (+)

W_m number of single measurements at a measurement point (104 / 4 = 26)

m ordinal number of measurement point (e.g. A1, A2…B1, B2…)

(Note: During a measurement period of 1 year, 104 measurements are done for each grid, and for each grid point, 104 / 4 = 26 measurements are done.)

As the last step, the "ambient odour characteristic", K_A, was calculated for each square [42]. For a square, there are 4 measurement points at the corners and the arithmetic average of K_P, which is equal to the H_m at that point, was taken.

$$K_A = \sum_{i=1}^{4} \left(\frac{K_{P,i}}{4} \right) \qquad \text{(Equation 4.3)}$$

where;

K_A ambient odour characteristic for a square (%)

K_P ambient odour characteristic for a measurement point ($H_m = K_p$)

In fact, K_A indicates whether the immission limit value (20%) is exceeded in that square or not. If the limit value is exceeded in any of the squares outside the factory area, it means that the factory has to take some measures to reduce its odorous emissions.

The method of calculations followed during evaluation of field inspection is given in detail in Appendix D.

In order to determine the reach of odour impact and to assign the iso-concentration curves, odour map was plotted with Surfer Graphics Software 7.0 by using "percent odour hours". Surfer is a contouring and 3D surface mapping program that runs under Microsoft Windows. By using this software, odour immission levels were displayed for the assessment area on a contour map.

CHAPTER V

RESULTS AND DISCUSSIONS

5.1 EMISSION MEASUREMENT RESULTS

Emission measurements were conducted in several operations/ industries. However, single measurements are never sufficient and considering the odorous emissions are profound concepts to be dealt with, several measurements have to be carried out at these odour sources in order to illustrate the real odorous emission rates. Because of this reason, a part of the emission measurement results are discussed in detail within this thesis.

The operations/ industries examined in detail are; foundry and forging operations, paint manufacturing, mineral wool production (glass and stone wool productions), solid waste landfill area and poultry farm-egg production. Process descriptions, possible odorous emissions and odour control technologies related to the operations are given in Appendix E.

5.1.1 FOUNDRY AND FORGING OPERATIONS

Odour emission measurements were performed at three different foundry and forging operations at different times. A detailed explanation of the process is given in Appendix E. Odorous gas samples were collected from the aeration channels of these operations by using the vacuum sampling device. These samples were analysed with olfactometer at METU Odour Laboratory.

The characteristic smell for these gas samples were similar; metallic, coal-tar, bitter odour. Different odour concentrations were observed at different times. According to these observations, the odour concentrations for these operations ranged from 28

OU/m^3 to 2000 OU/m^3 and the corresponding odour levels were found to be 14.5 dB and 33.0 dB, respectively. The results of measurements are given in Table 5.1.

Table 5.1 Results of odour measurements at foundry and forging operations

Emission source	Foundry and Forging Operations
Sampling Unit	Aeration Channel
Range of Odour Concentration (Z_{50})	28 – 2000 OU / m^3
Odour Level	14.5 – 33.0 dB
Characteristic Smell	metallic, coal-tar, bitter odour

During odour sampling, parameters such as temperature, humidity and velocity of the gas in the stack were also measured. The cross-sectional area of the gas exit system was determined and used in determination of odour emission rate with other parameters.

As mentioned before in Section 4.1.3, the results of the olfactometric measurements are calculated by taking the geometric mean of the "panellists' odour thresholds". In this regard, it is more logical to take the geometric means of the measurement results to give an overall odour concentration.

In Table 5.2, the geometric means of odour concentrations and related odour levels are given for each foundry operations with the above mentioned parameters. Odour emission rate was found by multiplication of odour concentration (OU/m^3) with olfactometric gas flow rate in the aeration channel (m^3/s).

Table 5.2 Emission measurement results of foundry and forging operations

	Foundry 1	**Foundry 2**	**Foundry 3**
Odour Concentration (OU/m^3)	184	1843	30
Odour Level (dB)	22.7	32.6	14.7
Temperature (^{o}C)	45	65	30
Humidity (%)	16.0	8.4	26.5
Velocity (m/s)	1.06	1.75	1.10
Outlet Cross-Sectional Area (m^2)	0.60×0.60	0.80×0.80	0.60×0.60
Gas Flow Rate (m^3/s)	0.38	1.12	0.40
Odour Emission Rate (OU/s)	70.2	2064	11.9

The geometric means of odour concentrations for these foundry operations were 184, 1843 and 30 OU/m^3 and the odour emission rates were 70.2, 2064.2 and 11.9 OU/s for foundries 1, 2 and 3, respectively. According to these results, foundry 2 seems to be a significant odour source. Not only the odour concentration, but also the gas flow rate for foundry 2 was very high. Therefore, odour emission rate for this foundry was found to be high.

During the sampling visits, information related with operational capacities of the foundries was also obtained. Foundries 2 and 3 were small scaled foundries and the work loads for these foundries were lower as compared to foundry 1. However, the odour emission rate for foundry 2 was found much higher than foundry 1 and 3.

In foundries, molten metals are cast into objects of desired shapes. Castings of iron, steel, light metals (such as aluminium), and heavy metals (such as copper and zinc) are made. Odorous substances are emitted during melting of the raw materials soiled with oil, paints and plastics. In fact, in small foundries in order to decrease the costs these kind of low quality materials are being used. Therefore, the odour emission from these foundries basically depends on the selection of the raw materials used for processing.

On the other hand, a relation between odour concentrations and temperature and humidity was observed. In regards to three foundries considered, as the temperature of the odorous gas increases, the concentration has been observed to increase. This is again because of the dirt on the materials used. When these materials are burnt, the dirt on the materials evaporates and odours are released to the environment.

Therefore, the quality of the raw material should be improved by using selected and clean scrap to reduce the release of pollutants and odours to the environment.

5.1.2 PAINT MANUFACTURING

Odour emission measurements were performed at two different paint factories. In one of these paint factories both paint and varnish were produced and solvent-based process was being used. In the other paint factory, water-based paint was produced.

Odorous gas samples were collected from paint and varnish aeration channels of the first factory by using the vacuum sampling device. These samples were analysed with olfactometer at METU Odour Laboratory.

The characteristic smell for the gas samples collected from the first plant was typical of paint and varnish manufacturing odour which includes solvents (esters, aromatics, ketons etc.). Odour was extremely strong inside and also outside the plant. The odour concentrations for paint manufacturing were found to vary between 1400 OU/m^3 and 13000 OU/m^3, and the corresponding odour levels were found to be 31.5 dB and 41.3 dB, respectively. The results of measurements are given in Table 5.3.

Table 5.3 Results of odour measurements at solvent-based paint manufacturing

Emission source	Paint Factory 1
Sampling Unit	Paint Aeration Channel
Range of Odour Concentration (Z_{50})	1400 – 11 000 OU / m^3
Odour Level	31.5 – 41.3 dB
Characteristic Smell	typical paint odour

The odour concentrations for varnish manufacturing were found to vary between 1300 OU/m^3 and 1900 OU/m^3 and the corresponding odour levels were found to be 31.3 dB and 32.8 dB, respectively. The results of measurements are given in Table 5.4.

Table 5.4 Results of odour measurements at solvent-based varnish manufacturing

Emission source	Paint Factory 1
Sampling Unit	Varnish Aeration Channel
Range of Odour Concentration (Z_{50})	1300 – 1900 OU / m^3
Odour Level	31.3 – 32.8 dB
Characteristic Smell	typical varnish odour

In the other paint factory water-based process is used in paint manufacturing. Odorous gas samples were collected from paint aeration channel of this factory by using the vacuum sampling device. These samples were analysed with olfactometer at METU Odour Laboratory.

The characteristic smells for the gas samples were typical of paint manufacturing odour but was not so strong as compared to the first paint factory. Additionally, outside the factory odour was not sensed very strongly. The odour concentrations for the second factory were found to be between 910 OU/m^3 and 1700 OU/m^3 and the corresponding odour levels were found to be 29.6 dB and 32.3 dB, respectively. The results of measurements are given in Table 5.5.

Table 5.5 Results of odour measurements at water-based paint manufacturing

Emission source	Paint Factory 2
Sampling Unit	Paint Aeration Channel
Range of Odour Concentration (Z_{50})	910 – 1700 OU / m^3
Odour Level	29.6 – 32.3 dB
Characteristic Smell	typical paint odour

In Table 5.6, the geometric means of odour concentrations and related odour levels are given for each paint manufacturing plant. The related information on gas temperature, humidity and velocity could not be obtained for this case because the plant did not have a defined channel for exit gases.

Table 5.6 Emission measurement results for paint manufacturing

	F-1 Paint	**F-1 Varnish**	**F-2 Paint**
Odour Concentration (OU/m^3)	4560	1581	1112
Odour Level (dB)	36.6	32.0	30.5

For the first factory, the geometric means of odour concentrations were 4560 and 1581 OU/m^3 for paint and varnish manufacturing, respectively. The geometric mean of odour concentrations for the second paint manufacturing was 1112 OU/m^3.

As can be seen from Table 5.6, there is a big difference in odour emissions between the first and the second paint manufacturing factories. According to the results of measurements, the odour concentrations for water-based paint manufacturing were found to be lower than that of solvent-based paint manufacturing. In the solvent-based paint production, the solvents used have a higher vapour pressure than water, therefore they evaporate more. These measurement results again designate the importance of the process selection for cleaner production.

In fact, all results show that paint manufacturing is a big odour contributor and related odour control measures should be taken, especially, by the solvent-based paint manufacturers.

5.1.3 MINERAL WOOL PRODUCTION

Mineral wool can be divided into two main categories: *glass wool* and *stone* or *slag wool*. The products are used in essentially the same applications and differ mainly in the raw materials and melting methods used. A detailed explanation of the process used is given in Appendix E.

Odour emission measurements were performed at a mineral wool producing factory on different days. Odorous gas samples were collected from glass and stone wool exhaust stacks by using the vacuum sampling device. These samples were analysed with olfactometer at METU Odour Laboratory.

The characteristic smells for these gas samples were extremely strong irritant and had a bitter odour. The exhaust stacks were high (about 25 m and 10 m) that odour was not sensed right outside the plant. The odour concentrations for glass wool manufacturing were varying between 2000 OU/m^3 and 6700 OU/m^3, and the corresponding odour levels were found to be 33.0 dB and 38.3 dB, respectively. The results of measurements are given in Table 5.7.

Table 5.7 Results of measurements at glass wool manufacturing

Emission source	Glass Wool
Sampling Unit	Exhaust Stack
Range of Odour Concentration (Z_{50})	2000 – 6700 OU / m^3
Odour Level	33.0 – 38.3 dB
Characteristic Smell	irritant and bitter odour

The odour concentrations for stone wool manufacturing were varying between 18 000 OU/m^3 and 27 000 OU/m^3, and the corresponding odour levels were found to be 42.5 dB and 44.3 dB, respectively. The results of measurements are given in Table 5.8.

Table 5.8 Results of measurements at stone wool manufacturing

Emission source	Stone Wool
Sampling Unit	Aeration channel
Range of Odour Concentration (Z_{50})	18 000 – 27 000 OU / m^3
Odour Level	42.5 – 44.3 dB
Characteristic Smell	irritant and bitter odour

During odour sampling, parameters, such as temperature, humidity and velocity were also measured in the aeration channel with an anemometer. The cross-sectional area of the gas exit system was determined and used in determination of odour emission rate with other parameters.

In Table 5.9, the geometric means of odour concentrations and related odour levels are given for glass wool and stone wool manufacturing. Odour emission rate is found by multiplication of odour concentration (OU/m^3), with the volumetric flow rate of the odorous gas (m^3/s).

Table 5.9 Emission measurement results for mineral wool manufacturing

	Glass Wool	**Stone Wool**
Odour Concentration (OU/m^3)	4049	22 045
Odour Level (dB)	36.1	43.4
Temperature (^{o}C)	30	100
Humidity (%)	30.2	12
Velocity (m/s)	4	2.5
Outlet Cross-Sectional Area (m^2)	1.13	1.13
Gas Flow Rate (m^3/s)	4.520	2.825
Odour Emission Rate (OU/s)	18 301	62 277

The geometric means of odour concentrations for glass wool and stone wool manufacturing were 4049 and 22 045 OU/m^3, and the odour emission rates were

18,301 and 62,277 OU/s, respectively. The temperature for stone wool manufacturing was very high that increased the strength of the odorant effect of the sample.

According to the results, it is obvious that glass wool and stone wool manufacturing are high-odour operations. Moreover, these manufacturing processes take place within the same factory in different buildings. These are both large scaled operations. Because of the property of the raw materials used, they are both odorous operations.

The odour emission rates for both of these processes were found to be very high. Considering the intensity and the hedonic quality, it can be said that these odours were very disturbing. However, outside this mineral wool factory, odour sensation was very low because a right approach has been used by the factory and high stacks were built. For glass wool manufacturing stack height was 25 m and for stone wool manufacturing the stack height was 10 m. In fact, these high stacks increase the dispersion of odorous gas and reduce the odour impact at ground level. In case of lower stacks, these types of odours may affect the community's well being. In addition to high stacks, appropriate odour control technologies should be used in these industries to reduce odorous emissions.

Additionally, these types of industries should not be constructed in the vicinity of the residential areas or a setback distance must be defined by using appropriate odour dispersion models.

5.1.4 SOLID WASTE LANDFILL

Odour emission measurements were performed at a *solid waste landfill area* in Ankara. Odorous gas samples were collected from different surfaces of the landfill area by using flux hood and vacuum sampling device on different days (related pictures are given in Appendix F). These samples were analysed with olfactometer at METU Odour Laboratory.

The characteristic smells for landfill gas samples were extremely strong garbage, sour, foul odour. The odour concentrations for solid waste landfill were varying between 630 OU/m^3 and 45 000 OU/m^3, and the corresponding odour levels were found to be 28.0 dB and 46.6 dB, respectively. The results of odour measurements are given in Table 5.10.

Table 5.10 Results of odour measurements at solid waste landfill

Emission source	Solid Waste Landfill
Sampling Unit	Flux Hood
Range of Odour Concentration (Z_{50})	630 – 45000 OU / m^3
Odour Level	28.0 – 46.6 dB
Characteristic Smell	garbage, sour, foul odour

During odour sampling, parameters such as temperature and humidity were also measured. However, velocity in the hood could not be measured, instead velocity was assumed as 0.1 m/s and the following calculations were performed in this regard. The bottom cross-sectional area of the flux hood is 1 m^2 and used in determination of odour emission rate with other parameters.

In Table 5.11, the geometric means of odour concentrations and related odour levels are given for the solid waste landfill area under consideration. Odour emission rate was found by multiplication of odour concentration (OU/m^3).

Table 5.11 Emission measurement results for a solid waste landfill

	02/04/03	**05/12/03**	**12/12/03**	**27/05/04**
Odour Concentration (OU/m^3)	721	1446	38284	7440
Odour Level (dB)	28.6	31.6	45.8	38.7
Temperature (^{o}C)	11.3	3.3	2.1	16.4
Humidity (%)	52	58	78	46
*Velocity (m/s)	0.1	0.1	0.1	0.1
Cross-Sectional Area of Sampling Section (m^2)	2.25×10^{-2}	2.25×10^{-2}	2.25×10^{-2}	2.25×10^{-2}
*Gas Flow Rate (m^3/s)	2.25×10^{-3}	2.25×10^{-3}	2.25×10^{-3}	2.25×10^{-3}
*Odour Emission Rate (OU/s)	1.62	3.25	86.14	16.74

* Assumption values

Odorous gas samples collected on different days were analysed with olfactometer and distinct odour concentrations were obtained. For the measurement performed on April 2, 2003, the geometric mean of the odour concentrations was found as 721 OU/m^3. On the day of measurement, the ambient temperature and humidity were 11.3 ^{o}C and 52%, respectively. On December 5, 2003, the geometric mean of the odour concentrations was found higher than before as 1446 OU/m^3, and for that day ambient temperature and humidity were 3.3 ^{o}C and 58%, respectively. One week later, on December 12, 2003, the geometric mean of the odour concentrations was much higher, like 38 284 OU/m^3. On that day, the temperature and humidity were 2.1 ^{o}C and 78% respectively. In fact, the weather was rainy in the morning and during sampling it stopped. The landfill area was all damped and the ambient odour was very annoying. In the last measurement, the geometric mean of the odour concentrations was found as 7440 OU/m^3, and the temperature and humidity were 16.4 ^{o}C and 46%, respectively.

The odorous gas velocity was assumed as 0.1 m/s and the odour emission rate calculations were made accordingly. The objective of this assumption was to show the possible odour emission rates and their significance from odorous emissions point of view. In first sight, the odour emission rates seem to be very low, especially for the 1st, 2nd and 4th measurement days. However, if 1m^2 of the base area of the flux hood (dimensions of the flux hood is given in Appendix A) is considered, the scale of the odour emission rates can be understood. By assuming a landfill area of 10 000 m^2 (dimensions with 100 m × 100 m), odour emission rates are found as 16 200, 32 500, 861 400 and 167 400 OU/m^3, respectively and the importance of the problem can be realized better.

According to the results given above, it is difficult to determine the specific odour concentration and the odour emission rate for solid waste landfill area. Since a solid waste landfill area is not uniform and it contains a number of surfaces which have different potentials to emit odorous gases. Additionally, local terrain and local meteorology are common constraints that limit the odour sampling and quantification practices.

On the other hand, important knowledge has been gained during the sampling and measurement practices. First of all, the effect of humidity was seen. On high-humidity days (e.g. above 60 – 65% relative humidity), the odour concentrations are expected to be higher. Because usually a low pressure system exists in the atmosphere during high-humidity conditions. Wind velocities are low; however, air parcels ascend from ground level to higher altitudes. Ascending air parcels carry the odorous gases with them. Secondly, the effect of temperature, which can be observed by comparing the 2nd and the 4th measurement results, can not be denied. As the ambient temperature increases, the rate of anaerobic reactions also increase which produce gases causing the odour. Finally, the composition of solid wastes affects the odour a great deal. According to the place where the flux hood is set up, distinct odour concentrations were obtained.

5.1.5 POULTRY FARM – PRODUCTION OF EGGS

Emission measurements were performed at a *poultry farm* on different days. Detailed information on poultry farm and a picture of the poultry housing are given in Appendix E and F, respectively. Odorous gas samples were collected from the indoor air of the cages of the farm by using vacuum sampling device. Therefore, these are samples representing the indoor air. The samples were analysed with olfactometer at METU Odour Laboratory.

The characteristic smells for the gas samples were typical poultry odour. The odour concentrations for the poultry cages were varying between 25 OU/m^3 and 210 OU/m^3, and the corresponding odour levels were found to be 14.0 dB and 23.3 dB, respectively. The results of odour measurements are given in Table 5.12.

Table 5.12 Results of odour measurements at a poultry farm

Emission source	Poultry Farm
Sampling Unit	Indoor Air
Range of Odour Concentration (Z_{50})	25 – 210 OU / m^3
Odour Level	14.0 – 23.3 dB
Characteristic Smell	Typical poultry odour

In Table 5.13, the geometric means of odour concentrations and related odour levels are given for the poultry farm. The related information on temperature, humidity and gas velocity could not be obtained for this case.

Table 5.13 Emission measurement results for a poultry farm

Measurement Days	1st day	2nd day	3rd day
Odour Concentration (OU/m^3)	171	39	102
Odour Level (dB)	22.3	15.9	20.1

The geometric means of odour concentrations for each measurement day were found as 171, 39 and 102 OU/m^3, respectively. On the second measurement day, the odour concentrations for the poultry farm were found to be lower as compared to other measurement results. In all measurement results similar odour concentrations were obtained. During the measurements the highest concentration measured was 210 OU/m^3. Although the poultry farm was a big one with 70,000 chickens, odour concentrations were found to be low, because a good housekeeping practice is applied in the farm and the droppings of the chickens are collected with a dry process.

In fact, the abovementioned results were obtained from the indoor air of the poultry housing systems because there was no ventilation channel. At both sides of the housing wired openings exist and they are covered with large curtains. During the day, the workers open the curtains and the inside odour is released to the atmosphere. When the samples were taken, the curtains were closed.

According to the information taken from the manager; when the poultry farm was built, the region was a rural area with many other animal houses. With the spread of the urban area into the rural area and with increasing number of buildings, the poultry farm has been left in the residential area. Resultantly, the poultry farm became the origin of many complaints related with odour. Against these complaints, large investments had been made on the housing system. Some of the equipment in the housing system had been automated. According to the system used, the bird droppings fall through the bottom of the cages at the back and are removed by belts every day. Therefore, inside the housings, strong odour annoyance is not present. However, the bird dropping are stored at the outside, near the housings. The main odour nuisance may arise from this process and the odour problems related with this process have to be solved by more frequent collection and removal of stored droppings.

Also, there exist a number of animal housings (cattle and sheep) which result in offensive odours in the environment. Therefore, a field inspection programme covering 6 months period has been started in March 2004 in that region in order to observe the odour immission rates. Both of these animal farms need to control their odours by taking better control measures.

5.2 IMMISSION MEASUREMENT RESULTS

5.2.1 SUGAR MANUFACTURING

Field inspections were accomplished within the assessment area (gridded area is given in Figure 5.1) around the sugar factory for 1 year (with 104 measurements). The schedule given in Appendix C was followed for measurements and the data sheets were filled out by the panellists for each measurement day.

The data sheets were evaluated at the end of the measurement period. "Percent odour times" were calculated for each point for each measurement day (single measurement) by using the Equation 4.1 given in Chapter 4. This value was compared with the immission limit value defined for the study (I_{limit} = 20%) and the single measurements exceeding the limit value were regarded as positive measurement. Then, percentage of positive single measurements was calculated for each measurement point (Equation 4.2). These percentages represent **annual** percent "odour hours" which indicates odour sensation frequency for that area. The annual percent odour hours for each measurement point are given in Table 5.14.

Annual "percent odour hours" describe how often the odour emitted from the sugar factory was sensed in a measurement point. According to this explanation, the most odorous points are A10, B10, C10 and D10 which are the closest measurement points to the sugar factory. A9, B9, C9 and D9 are the following most odorous measurement points.

Table 5.14 Annual percent odour hours for each measurement point around the sugar factory (February 2003 – February 2004)

Point	% Odour Hour	Point	% Odour Hour	Point	% Odour Hour	Point	% Odour Hour
A1	15.4	B1	15.4	C1	0.0	D1	15.4
A2	46.2	B2	46.2	C2	34.6	D2	46.2
A3	19.2	B3	19.2	C3	23.1	D3	19.2
A4	53.8	B4	57.7	C4	80.8	D4	50.0
A5	15.4	B5	11.5	C5	15.4	D5	15.4
A6	53.8	B6	50.0	C6	46.2	D6	57.7
A7	7.7	B7	3.8	C7	0.0	D7	11.5
A8	30.8	B8	23.1	C8	15.4	D8	23.1
A9	61.5	B9	57.7	C9	53.8	D9	61.5
A10	84.6	B10	88.5	C10	76.9	D10	84.6

In addition to the measurement points mentioned above, C4, D4, C2 and D2 also lie in the area that belongs to the sugar factory. Especially, the measurement point D2, which was located in front of the flats provided to the factory workers, odour was very annoying. About 46.2% of the time odour was sensed at that point. Severe complaints related to odour arise from that area. On the other hand, from the middle of the assessment area, there is a highway going across the area from right to left (can be seen in Figure 5.1). The odour is felt intensely by the passengers of cars travelling on this highway. Many odour complaints come from these passengers. As a matter of the fact, the measurement results show the same thing. With the movement of air, odorous air is dragged directly towards the highway and the results confirm the unpleasant situation in the area.

Additionally, it was observed from the measurement results that the odour dispersion follows a typical pattern, although the short term or long term changes in the wind direction and magnitude, briefly, the atmospheric conditions and the obstructions, such as buildings, affect the turbulence of the arising odorous air. Consequently, the movement of odour may change with time (even within an hour). In fact, all these changes are observed during the field inspections. From time to time it was observed that the odour was sensed in the residential area while it was not effective in the vicinity of the factory. The reason for such a case was thought as the changing dispersion behaviour due to the obstructions and the atmospheric stability.

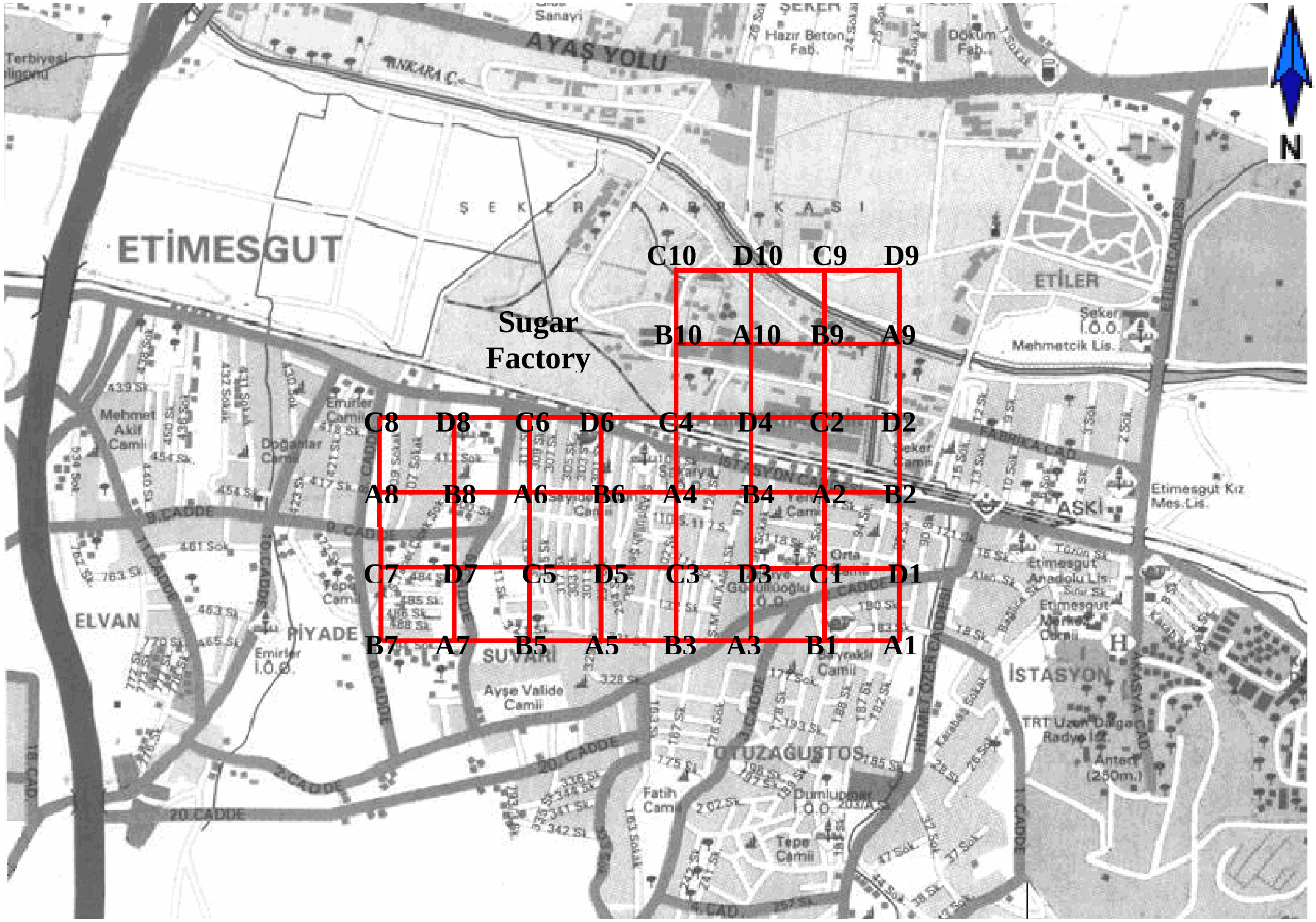


Figure **5.1** Assessment area with gridded squares

While performing the field inspections, some observations have drawn the attention of the panellists. In the early mornings, odour was sensed clearly whereas it was difficult to judge odour presence in the afternoons. The reason is that at nights the atmosphere is more stable because of less temperature gradients at night. Therefore, the odours released into the atmosphere are not dispersed and in the mornings more odour is sensed than during the day time. The mixing height is low in the mornings. When the earth is started to be warmed up by sunrays, the temperature gradients in the atmosphere start to increase, causing winds with increasing mixing height. Therefore, odour is dispersed better.

During single measurements, in case of a dilemma for the presence of odour exists, the measurement, was considered as a negative measurement. On hot summer days, the impact of odour has been increasing. Sometimes, strong winds resulted in odour sensation and sometimes resulted in no sensation, although it was blowing through the odour source. The effect of obstructions was sensed considerably.

Following the percent odour hour calculations, ambient odour characteristic, K_A, for each measurement square was calculated by using Equation 4.3. The annual percent odour hours for each square are shown in Figure 5.2.

According to Figure 5.2, it is obvious that the immission limit (20%) has been exceeded in most of the measurement squares. The impact of odour was observed not only in the factory area but also in the residential area with percent odour hours ranging from 5.8 to 62.5. It means that odour was sensed ranging from 5.8 to 62.5 percent of the time in the squares lying in the residential area. The ambient odour characteristic implies that the factory should develop an odour control strategy.

The percent odour hours for each measurement point were also entered to Surfer Graphics Software 7.0. During this process, coordinate numbers were given to each measurement point and the % odour hour for that point was entered (e.g. B7 is determined as “0,0” and the % odour hour 3.8 was entered for this coordinate). After entering all the coordinates and the percentages for these coordinates, the contoured odour map was plotted. Contours were coloured from red indicating high percentage to yellow indicating low percentage. The outcome of the annual odour map can be seen in Figure 5.3.

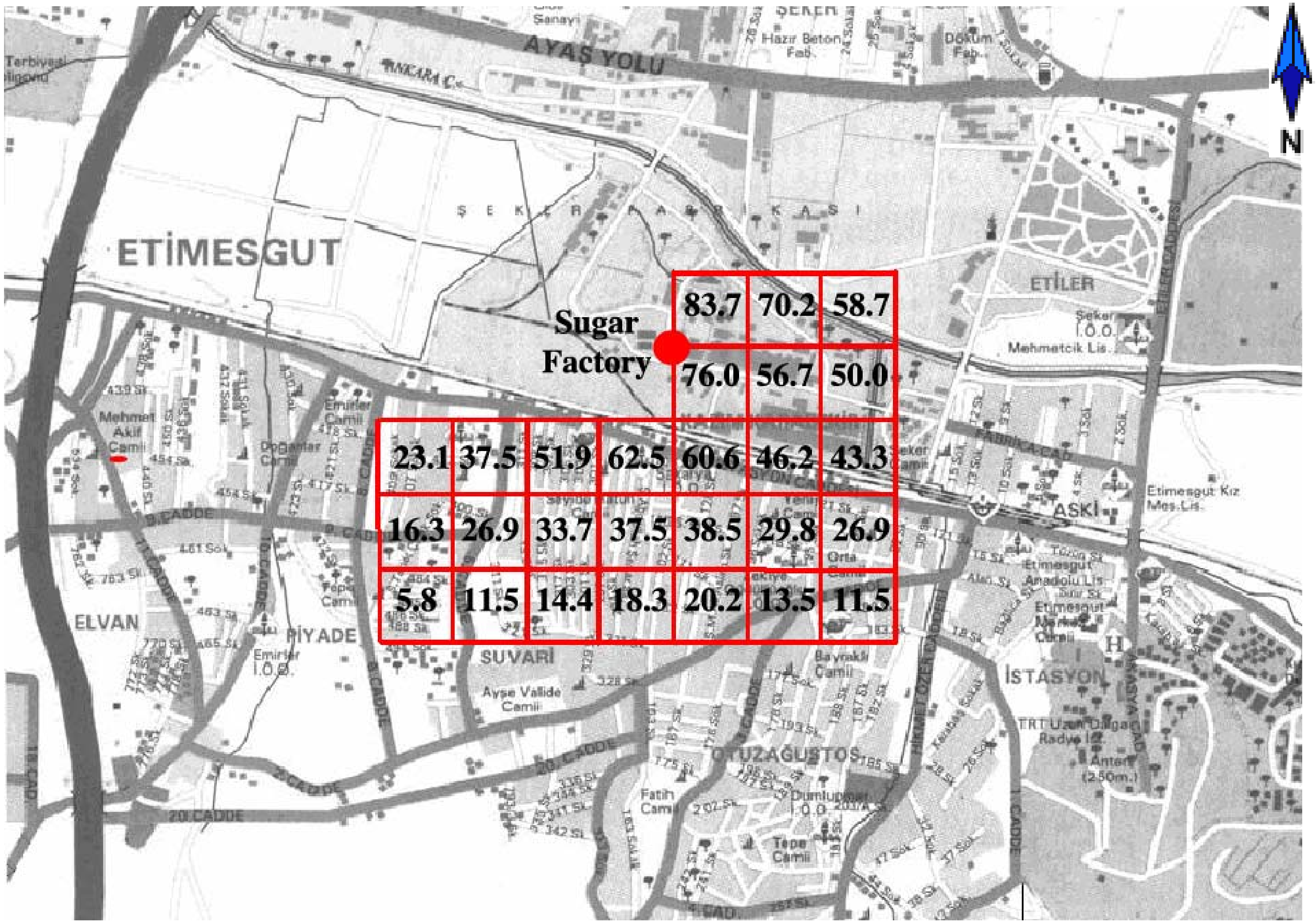


Figure **5.2** Annual percent odour hours for each measurement square (February 2003 – February 2004)

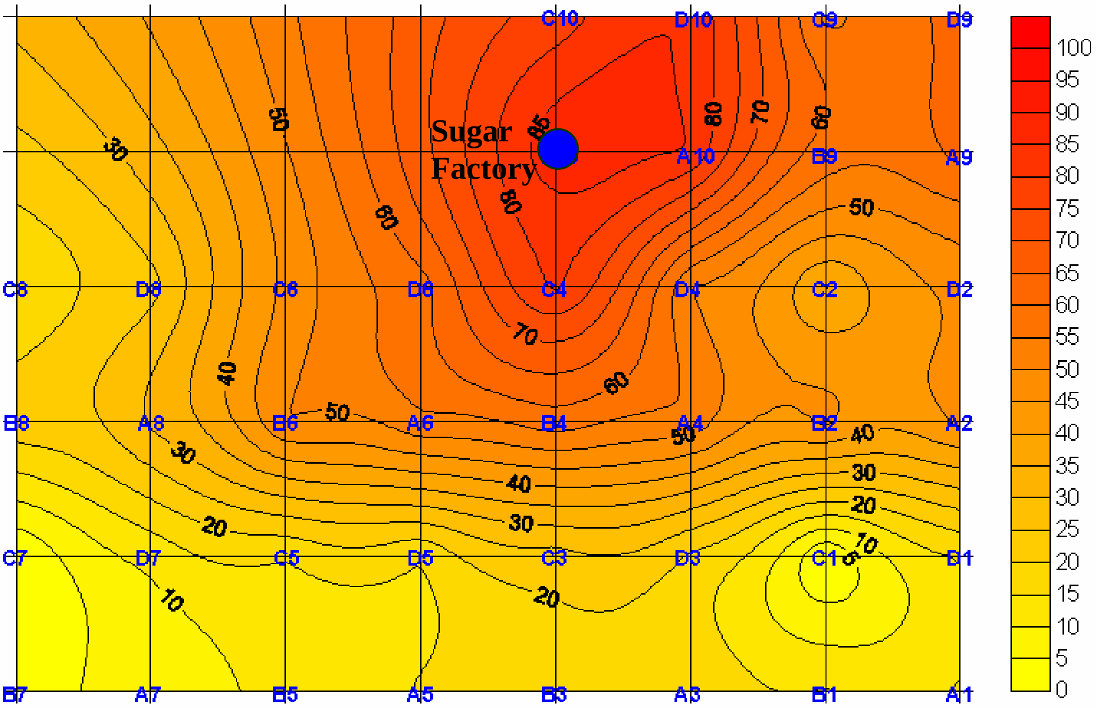


Figure 5.3 Annual odour map for the assessment area for the period of February 2003 – February 2004

Measurement points, colour scale and iso-concentration curves are shown on Figure 5.3. As can be seen from the figure, near the factory odour was sensed 85 % of the time. In the boundary of the factory area, the concentration decreases to 60 – 70 percent odour hours. Considering the distance between the grids as 250 m, approximately 750 m far away from the source in south direction, odour concentration decreases to 20%. Moving in other directions (W, SW, SE), % odour hour is decreasing approximately within 750 m down to 20% which was accepted as immission limit value for residential areas. The residents living within that distance are highly affected from odour. In order to overcome this problem, a setback distance, in which no residential area located, is suggested in this study. If a setback distance is used for the sugar industry, this can be a circle with a radius of at least 750 m. The centre of the circle is the emission source. Radius of this circle can be enlarged based on the capacity of the factory and this circle can be moved towards the opposite side of the dominant wind directions not to annoy the residents.

The dispersion of odour from factory to the surrounding area can easily be seen from the figure. Looking at the odour map, the dominant wind direction can be predicted as North and North-North-East. On the other hand, there exists more than one parameter that affects the dispersion of odour. Wind velocity, odour intensity, temperature and humidity are other parameters that affect odour percentages other than wind direction. This is the reason why odour is not dispersing in one direction with respect to emission source.

On the other hand, the wastewater treatment plant located at the northern part of the factory stack is another contributor to odour pollution. The odour released from the wastewater treatment plant had not too different odour characteristics with the sugar factory stack emissions. Therefore, the odour map obtained is not only for a point source but also for an area source.

As mentioned before, odour problem around a sugar factory is mostly effective between the months of July and December since harvesting and storage of sugar beets in the factory area starts in July and sugar beet processing ends in early December. In the following months the sugar manufacturing continues without processing of sugar beets. However, the odour problem related with the wastewater system continues throughout the year with a similar kind of odour character. Therefore, the evaluation of odour hours was also done by considering these two periods; January – June and July – December.

The percent odour hours for each measurement point covering the months between January and June were calculated and the results are given in Table 5.15.

In this period odour was sensed less as compared to the following period of July and December. Although for most of the measurement points lying in the factory area % odour hours were found to be high, odour was not effective at 14 measurement points. Especially the measurement points located at the farthest squares, odour was not sensed during January – June time period. On the other hand, at the measurement points numbered 2, 4, 6 and 9 odour was sensed about 20 – 30 % of the time. However, these percentages were exceeded at C4 with the points numbered 10 which are the closest points to the factory stack. The % odour hours at these points reached to 70 – 78.6%.

Table 5.15 Percent odour hours for each measurement point covering the months between January and June, around the sugar factory

Point	% Odour Hour	Point	% Odour Hour	Point	% Odour Hour	Point	% Odour Hour
A1	0.0	B1	0.0	C1	0.0	D1	0.0
A2	28.6	B2	21.4	C2	14.3	D2	21.4
A3	0.0	B3	0.0	C3	7.1	D3	0.0
A4	21.4	B4	35.7	C4	71.4	D4	21.4
A5	0.0	B5	0.0	C5	7.1	D5	0.0
A6	28.6	B6	21.4	C6	14.3	D6	42.9
A7	0.0	B7	0.0	C7	0.0	D7	7.1
A8	7.1	B8	0.0	C8	7.1	D8	7.1
A9	35.7	B9	28.6	C9	35.7	D9	35.7
A10	71.4	B10	78.6	C10	71.4	D10	78.6

According to the percentages given in Table 5.15, ambient odour characteristic for each measurement square was formed and given in Figure 5.4. As can be seen from the figure, immission limit was exceeded in the factory area and in three squares out of the factory area. The impact of odour was observed in the factory area and in a part of the residential area (3 squares). In three squares lying in the residential area, immission limit was exceeded and % odour hours range from 26.8 to 44.6. However, the residential area was not affected so much. The ambient odour characteristic implies that the factory was not a severe odour source for this time period.

Next, the percent odour hours for each measurement point covering the months between January and June were entered to Surfer Graphics Software 7.0 by following the same procedure described before. The contoured odour map was plotted for the period and shown in Figure 5.5. Measurement points, colour scale and iso-concentration curves are again shown on the plot.

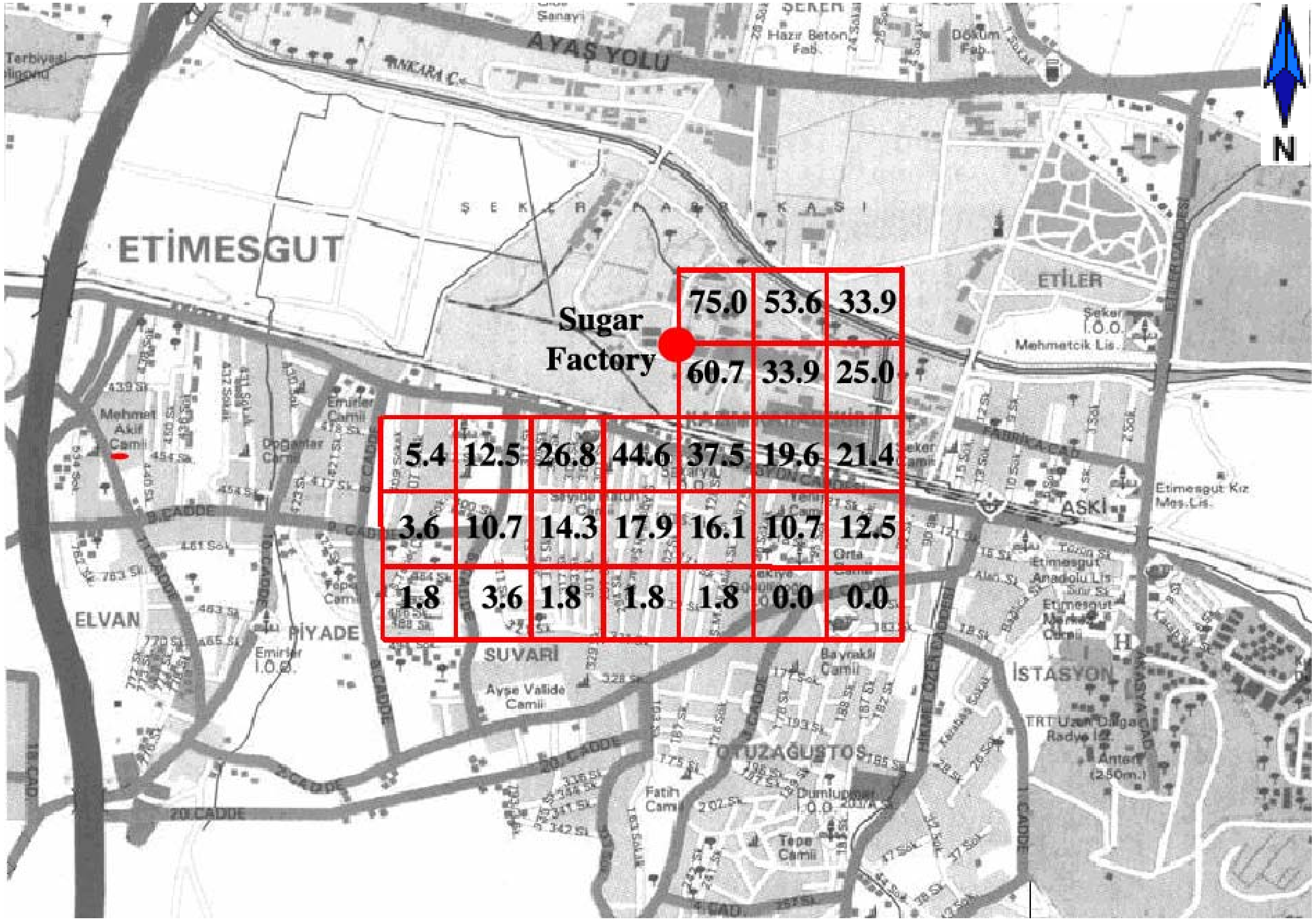


Figure 5.4 Percent odour hours for each measurement square covering the months between January and June

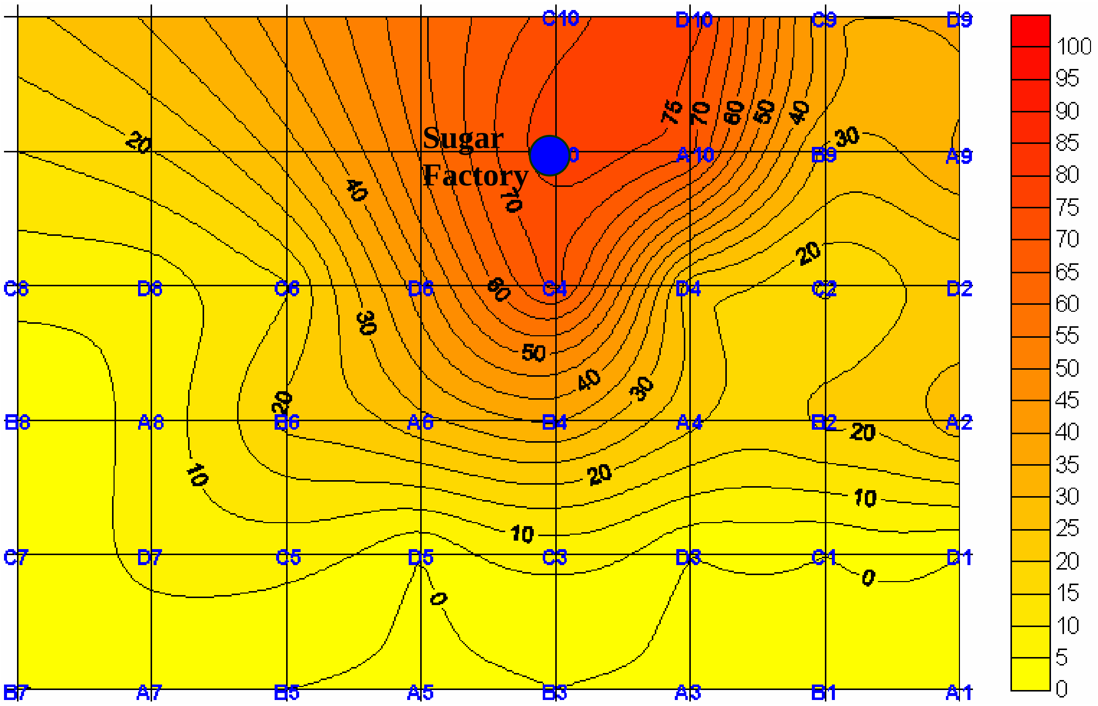


Figure 5.5 Odour map for the assessment area covering the months between January and June

Figure 5.5 shows that near the factory odour was sensed 75 % of the time. In the boundary of the factory area, the concentration decreases to 30 – 45 percent odour hours. Considering the distance between the grids as 250 m, approximately within 600 m far away from the source, odour concentration decreases to 20% which was accepted as immission limit value. Looking at the dispersion pattern of odour and the frequency of the contours, the dominant wind direction can be predicted as North and North-East.

The percent odour hours for each measurement point covering the months between July and December were calculated and given in Table 5.16. In this period odour was sensed much more as compared to the previous months.

Except 5 points, percent odour hours were above 20 % at all measurement points. As can be seen from the chart below, odour was very disturbing at all around the assessment area during the period considered. Especially, during the months between July and October with the increasing temperature and heating of the lower atmosphere by the ground, odour problem increases. Even at some of the measurement points lying at the far ends of the gridded area, odour was sensed with a frequency of 25 – 40 %.

Table 5.16 Percent odour hours for each measurement point covering the months between July and December, around the sugar factory

Point	**% Odour Hour**	**Point**	**% Odour Hour**	**Point**	**% Odour Hour**	**Point**	**% Odour Hour**
A1	33.3	B1	33.3	C1	0.0	D1	33.3
A2	66.7	B2	75.0	C2	58.3	D2	75.0
A3	41.7	B3	41.7	C3	41.7	D3	41.7
A4	91.7	B4	83.3	C4	91.7	D4	83.3
A5	33.3	B5	25.0	C5	25.0	D5	33.3
A6	83.3	B6	83.3	C6	83.3	D6	75.0
A7	16.7	B7	8.3	C7	0.0	D7	16.7
A8	58.3	B8	50.0	C8	25.0	D8	41.7
A9	91.7	B9	91.7	C9	75.0	D9	91.7
A10	100.0	B10	100.0	C10	83.3	D10	91.7

According to Table 5.16, ambient odour characteristic for each measurement square was formed and given in Figure 5.6. As can be seen from the figure, immission limit was exceeded in all of the squares except one. The odour release from the factory during the campaign period greatly affects the residents in health aspect. The area is also affected in both aesthetic and economic point of view.

In order to observe the dispersion of odour during this period and to be able to calculate the suitable setback distance, odour map was plotted. By using Surfer Graphics Software 7.0, the contoured map covering the period between July and December was formed and given in Figure 5.7.

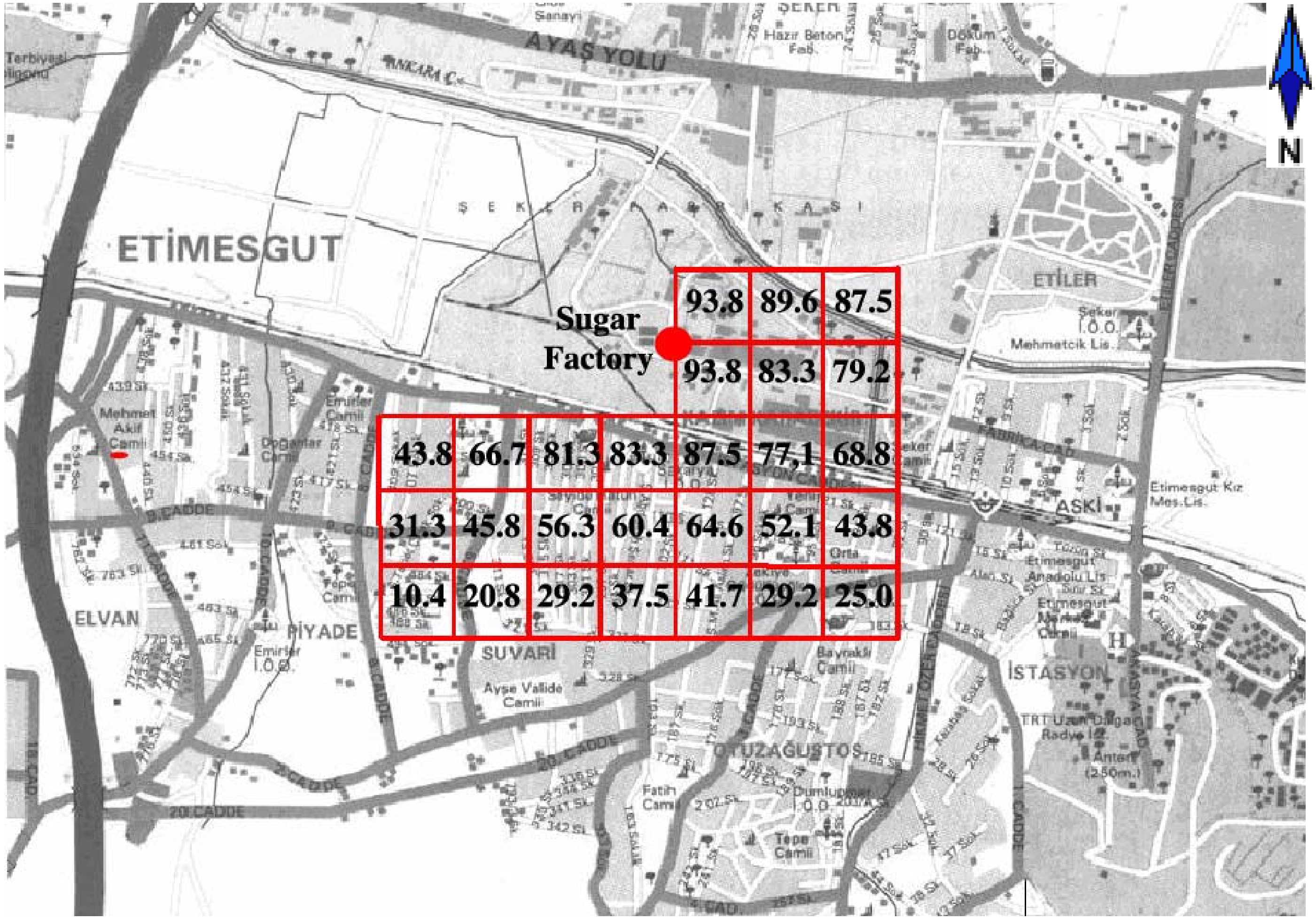


Figure 5.6 Percent odour hours for each measurement square covering the months between July and December, around the sugar factory

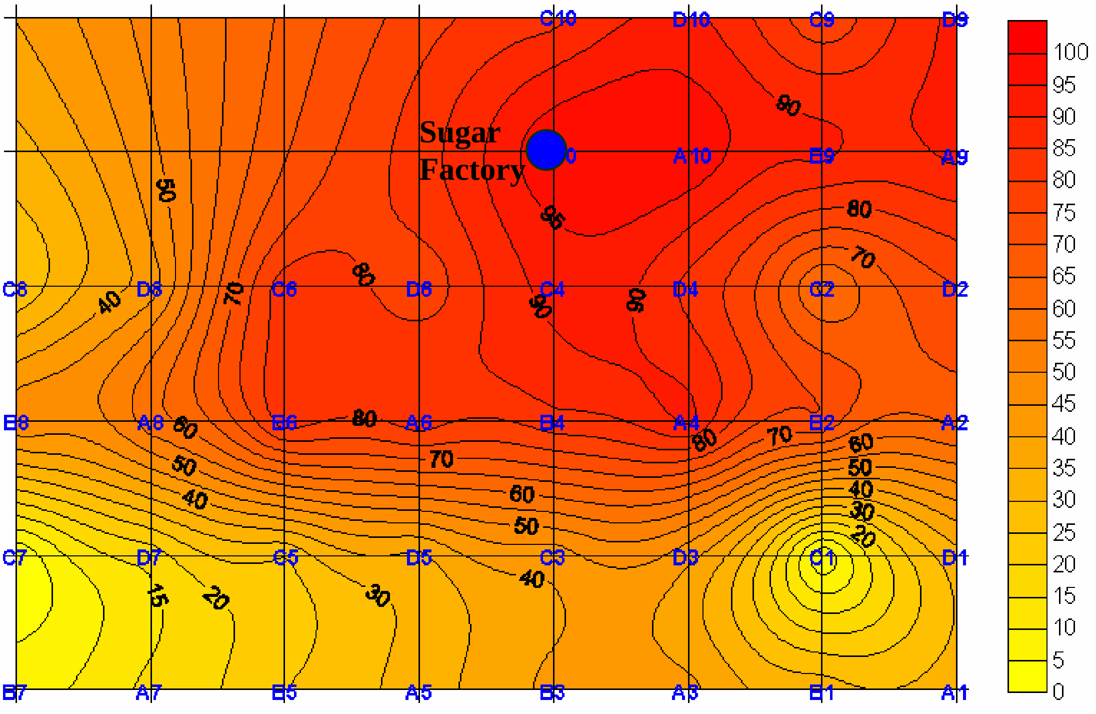


Figure 5.7 Odour map for the assessment area covering the months between July and December

Figure 5.7 shows that near the factory odour was sensed 95 % of the time. In the boundary of the factory area, the concentration decreases to 80 – 85 % odour hours. However, the odour emitted from the factory affects all the assessment area. Approximately 1 km away from the factory odour concentration decreases to 20%.

In order to determine a setback distance, maximum odour emission rate and the period of maximum odour emission should be considered. Besides, the dominant wind direction, location of the residential area, odorant character, and type of the emitters should also be taken into consideration while locating the setback distance.

In the case of the sugar factory considered in this study, the maximum odour emission rate was determined as the period between July and December. The maximum odour emission through the assessment area was determined in terms of “percent odour hours” which shows the frequency of odour sensation. The dominant wind direction was NE, ENE and WSW with 10 years of data (1992-2001). The residential area is located in the S and SE direction. Assessing all these parameters, the suitable setback distance for this area is determined to be 1.5 km. It means that, if a setback distance is used for the sugar industry, this can be a circle with a radius of 1.5 km having the source at the centre of the circle. Radius of the circle can be enlarged based on the capacity of the factory and it can be moved towards the opposite side of the dominant wind directions not to annoy the residents.

5.3 PREPARATION OF AN ODOUR REGULATION IN TURKEY

The results of the emission and immission measurements performed within this study will form the basis of a new “Odour Regulation” in Turkey. Since this regulation is going to be a new one in Turkey, the limits should not be set very strict. Therefore, the following suggestions for the industrial emissions and immisions have been developed and the Ministry of Environment and Forestry have found this approach favourable. The basic idea is “sustainable development” of the industry without causing an odour problem in the environment.

5.3.1 ODOUR EMISSION MEASUREMENTS

In most of the countries, olfactometric measurement methods are being used. Therefore, olfactometry method is also recommended to be used as an odour measurement method.

5.3.2 ODOUR IMMISSION MEASUREMENTS

There is no consistency between several countries for the measurement of odorous immissions. Different approaches are being used in different countries. In Germany and the U.S.A field inspections are carried out to investigate odorous immissions, however, in Japan a different method, like odour sensors and detection tubes are used. In Denmark, olfactometry method is also being used for immission measurements.

Field inspections will be a reliable method of investigating odorous immissions. However, it needs at least 3-6 months and very well trained panellists for immission measurements. In this case, field inspection method is suggested to determine the odour presence and odour annoyance (not the quantity of odorants).

Also with the development of more skilled odour sensors or electronic noses, the panellists may be replaced by these instruments in quantification of odour in the ambient air.

5.3.3 ODOUR EMISSION LIMITS

In European countries, mostly the “immission limits” are being used rather than “emission limits” in odour regulation. However, there exists some emission limits specific to some operations. For example; in Germany and Austria the odour emission limit for composting and biological treatment facilities is 500 OU/m^3. In Sweden, some odour ranges are implemented and within these ranges some action plans are foreseen. In Korea, odour emission limits are designated for industrial areas and residential areas, and the limits for emissions are defined as 1000 OU/m^3 and 500 OU/m^3, respectively. In Japan, there exist some odour immission limits on the basis of some specific compounds like H_2S and NH_3.

Although, the immission criterion (reach of odour impact to people) is more important, for Turkey it will be more realistic to set odour emission limits as a first step. By this way, it will be easier to manage and control odorous emissions. In this regard, a range of emission limits may be implemented as given in Table 5.17. The concentration ranges given in the table are suited as a result of the odour measurements performed around Ankara. It is found out that around the facilities with odorous emissions below 1000 OU/m^3, odour is not so annoying. Between the ranges of 1000 OU/m^3 and 10 000 OU/m^3, odour may be disturbing depending on the frequency, intensity, duration and hedonic quality of odour. Therefore, in this case the odour problem needs more assessment and odour reducing measures may be necessary. If odour concentration is greater than 10 000 OU/m^3, it means that odour problem is a serious one and definite application of odour control technologies is required.

Table 5.17 Emission limit values for industrial emissions (IE)

Emissions Limits	Odour Control Action
IE < 1000 OU/m^3	No action
1000 OU/m^3 < IE < 10 000 OU/m^3	Odour problem needs more assessment and odour reducing measures need to be taken
IE > 10 000 OU/m^3	Definite implementation of odour control technologies

5.3.4 ODOUR IMMISSION LIMITS

Since different societies have inherently different levels of acceptance for odours in their communities, different approaches are in question. In Germany, immission limits are set in terms of '% odour hours' on the basis of the type of the area. In Denmark, the limits are focusing on the concentrations at the nearest neighbour. In the U.S.A., there exist limits based on the odour emission levels and odour dispersion modelling criteria. Also, in some states of the U.S.A. there exist limits based on the individual compounds as it is in Japan. However, in Korea, the company boundary limits are used and they are different depending on the type of the area.

If field inspection method is adopted for measurement of odorous immissions, it is logical to adopt an approach like in Germany. However, the immission limits can be adjusted according to the odour acceptance level of the community. For this study, the immission limits are taken as 20% for residential and mixed areas, and 30% for industrial and commercial areas, as a first trial as given in Table 5.18. Because odour regulation is new for Turkey and time is necessary to get accustomed to these regulations. Also, Turkey is a developing country and in this development period the industries should be supported by making some regulations easier.

Alternatively, company boundary limits may be used as immission limits. This approach will be favourable in assessing the presence of odorous immissions.

Table 5.18 Immission limit values for different land use

Immission Limits	Odour Control Action
20%	For residential and mixed areas
30%	For industrial and commercial areas
For large scaled industries	A setback distance of 500m–1500m may be implemented

5.3.5 SETBACK DISTANCES (BUFFER ZONE)

Setback distances are being used in Germany, Denmark, Austria, and the U.S.A. in case of livestock facilities, agricultural applications, composting and treatment facilities. The range of these setback distances is 0.4 km to 1.6 km.

In this study, in order to overcome the odour problem, a setback distance in which no residential area present, is suggested around a sugar factory. However, such protection distances are highly dependent on the industrial processes and the character of the source as well as the dominant atmospheric conditions. As a result, it can be said that setback distances are profound concepts and should be assessed for each sector separately.

5.3.6 ODOUR DISPERSION MODELLING

Air dispersion modelling can be used to evaluate the movement of odour from a source and determine the extent and frequency of odour impacts on a surrounding community. Using modelling, many scenarios can be considered at low cost, and the modelling effort may save a facility time and money.

The odour dispersion model recommended by EPA is ISCST3 model [43, 44]. This model takes local topographical and meteorological data into account and combines this information with emissions concentrations, site layout, operational parameters, and source dimensions to determine the movement of odours from the site. Modelling results are expressed as a series of isopleths, or concentric circles, which show the maximum concentration of odour that is projected to occur at any given point over the modelled time period. Also, it is known that CALPUFF Model used in Austria gives reasonable results [45].

5.3.7 MEASURES TO REDUCE ODOROUS EMISSIONS

Odour control depends on the type of the source, the character of the odorants emitted, the operational processes, the raw materials used and emission rates. In this regard, for each odour source these parameters should be examined and the most suitable odour removal strategies should be established. With this opinion "best available technologies" (BAT) were introduced in many countries. BATs are developed for different sectors and they give information about cleaner technologies from air, water and soil point of view.

It is not possible to give a complete description of all odour control techniques but the following sections are presented to give an overview of odour reducing measures.

5.3.7.1 MEASURES RELATING TO PRODUCTION AND TECHNICAL DESIGN

Below are listed a number of factors, which should be considered in connection with the establishment of new plants and control of odour from existing plants [15].

a) Odour emissions and temperature

Temperature can considerably influence odour emissions in three different ways. The generation of odorous compounds depends on the temperature. Odorous compounds are produced more quickly at high temperatures (summer/winter). Heating of heat-sensitive substances may lead to generation of odorants. Also the release of odorants to the ambient air is influenced by temperature (e.g. processes with hot liquids result in greater release than if cold liquids are used). Very high temperatures may decompose odorants during incineration with sufficient oxygen and appropriate incineration throughput rates [15].

b) Pressure

If pressure in a process plant is changed from a small positive pressure to a small negative pressure by relocating valves or ventilators, the number of possible uncontrolled leakages is reduced [15].

c) Air exchange

If the exchange of air surrounding an odorous process is large the emitted odorants will be diluted. But if the odour comes from evaporated material, the emission may increase. In normal circumstances it is best to reduce the amount of air which gets in contact with odorous materials. In this way odour control equipment will be required for smaller volumes of air; the equipment may be simpler and costs be reduced. Due regard must of course be had to the risk of explosion and health hazards in the plant when the air volume is reduced [15].

d) Supervision and maintenance

If equipment is supervised and maintained frequently, leakages in joints, pump gaskets, boilers etc. can be avoided and odour nuisances be prevented. Ordinary operational practice should include maintenance of equipment to prevent uncontrolled escape of odour. Odour emissions are often a result of plant overloading or chemicals spill. It is therefore essential that processes operate correctly and chemicals are handled carefully. Odour emitted in connection with tank filling operations can be minimised by means of floating covers or smell charcoal filters at ventilation outlets [15].

e) Decay

Evaporation of odorants from stored decaying material may often lead to odour emission (e.g. food, waste products). Good housekeeping may eliminate the problems. It is recommended to process animal products quickly, and not to store them in the open air [15].

f) Containment

If preventive measures or changed process parameters are not enough to avoid annoying emissions of odorous compounds from a plant, it must be placed in a building equipped with ventilation and, where required, air cleaning equipment. It may be necessary to have non-opening windows and automatic gate and door closing devices, and to provide a negative pressure in the building. Odour nuisances can be prevented either by cleaning of exhaust air or by dilution in outlets [15].

5.3.7.2 ODOUR REMOVAL TECHNOLOGIES

ODOUR CONTROL FROM AREA SOURCES

For large area sources the following methods can be used to reduce odorous emissions [2];

a) Excluding development close to the site

Development close to the site is to be excluded. A reasonable “buffer zone” around the area sources has to be determined. The actual size of this zone will depend upon a number of factors, including the size of the area from which odours emanate, the intensity of the odours being emitted, the duration and frequency of the odour emissions, the actual process being undertaken, the topography of the site, the weather conditions that prevails at the site. Green belt development in the buffer zone may help at least partially to obfuscate the odour [2].

b) Ensuring that the operation is carried out under the best management practice

Best available technologies (BAT) will vary according to the industry producing the odour. However, for all new developments, BATs will start with the site selection and the building of the facilities [2].

c) Nozzles, sprayers and atomizers that spray ultra-fine particles of water or chemicals can be used along the boundary lines of area sources to suppress odours

Rotary atomizer is one such technique widely recommended for adoption for effective control of odour in case of area sources. The Atomizer uses centrifugal action by a spinning inner mesh to force droplets on to an outer mesh which "cuts" the water into atoms. The rotary atomizer produces millions of microscopic droplets of water up to 238 billion from a single litre droplets that are thinner than a human hair and a fine spray which covers up to 30 linear metres. This creates a fine mist, which is more effective with minimal use of water and electricity. There are a large number of chemicals and proprietary products that claim to reduce odour when they are applied to area sources. Atmospheric odours that are contained in a restricted area can be oxidized by atomization of the chlorine dioxide. Odour from sources such as holding ponds, lagoons, and sewage pre or post treatment effluent can be controlled by atomized spray of chlorine dioxide [2].

To reduce odour, chemicals have to be applied over very large area, the cost of materials and labours would be very high. The large quantity of these compounds required could themselves cause pollution. The spray/ atomizer techniques are used to conceal odours also from building and fugitive sources [2].

ODOUR CONTROL FROM POINT SOURCES

In case of point sources such as that of industries, the odour-causing gas stream can be collected through piping and ventilation system and made available for treatment. Dispersion method is the simplest of the methods that can be adopted for odour abatement. This is nothing but to release odorous gases from tall stack. It results in normal dispersion in the atmosphere and consequent decrease in ground-level concentration below the threshold value. Dispersal by stacks requires careful consideration of the location and meteorological parameters, etc. In general, dispersion of odour emissions via chimneys is not a recommended method [2].

An array of treatment technologies is available for control of odour from gas streams collected through process ventilation systems. These include are [2]:

a) Mist filtration

Sometimes odour problems may result from aerosols in the fumes. Mist filters can be used in this case. Mist filters can remove solids and liquids from the gas stream and it will result in odour reduction [2].

b) Thermal oxidation/ Incineration

Thermal oxidation/ incineration is the oxidation of the odour into carbon dioxide and water by the combustion of the odour with fuel and air [2]. By thermal incineration odorous chemicals are oxidised into less odorous or non-smelling substances [15]. The reaction takes place at temperatures ranging from 750^{o}C to 850 ^{o}C [2].

c) Catalytic oxidation

Operating temperatures in catalytic oxidation are lower (250–500 ^{o}C) than incineration temperatures [15]. In catalytic oxidation, a number of transition and precious metal catalysts can be used in catalytic oxidizer to destroy various VOCs over a wide range of process conditions [2].

d) Biofiltration

Biofiltration is a successful way of reducing odours from biological process. It is a natural process that occurs in the soil that has been adopted for commercial use. Biofilters contain microorganisms that break down VOCs and oxidize inorganic gases and vapours into non–malodorous compounds such as water and CO_2 [2].

e) Adsorption

The process of adsorption is occurs when gas molecules are “captured and retained“ on a solid surface (the adsorbent). Some adsorbents preferentially adsorb specific chemical species, hence odorous components can be removed from gaseous streams by passing through a bed or filter of the appropriate adsorbent material. Activated carbon, zeolite and alumina can be used as adsobents [46].

f) Wet scrubbing/Absorption

Wet scrubbing of gases to remove odour involve either absorption in a suitable solvent or chemical treatment with a suitable reagent. Absorption is applicable when the odorous gases are soluble or emulsifiable in a liquid or react chemically in solution. Wet scrubbing is a useful process to handle acid gas streams, ammonia or streams with solids that might foul other equipment [2].

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

In this study odour concentration was measured first time in Turkey and the olfactometric technique was established. Various kinds of industrial facilities in Ankara were visited to measure the odour emission levels from different industries. The process conditions, the indoor and the outdoor environment of the plants were examined and the samples were taken from emission sources. Odorous gas samples were analysed with Olfactometer TO7.

The results of the emission measurements have shown that there are numerous industries in Ankara which are discharging odorous gases into the environment. Depending on the odour concentration, the impact of these gases can be quite annoying.

Among the industries studied, the odorous emissions of;

- glass wool and stone wool manufacturing,
- paint and varnish manufacturing (especially solvent-based),
- foundry and forging operations,

processes are found to be quite high. Additionally, solid waste landfill area can give very concentrated odours and can be very annoying depending on the temperature, composition of the solid waste and weather conditions.

The odour impact in the ambient environment was determined by immission measurements. However, it can not be claimed that the odour is dispersed following a typical pattern. Because of wind fluctuations at times, the short term or long term changes in the wind direction and magnitude, briefly, the atmospheric conditions and the obstructions, such as buildings, affect the turbulence of the odorous air. Consequently, the movement of odour may change within time (even within an hour).

The results of immission measurements around a sugar factory have shown that the percent odour hours covering the months between January and June, were much lower than the period between July and December. The percentage of grids exceeding the 20% “odour hour” limit during the January – June period was 37. However, this percentage was 92.6 during the July – December period.

In order to overcome odour problem around industrial plants, a setback distance (buffer zone) is suggested. Assessing all the parameters, the suitable buffer zone for a sugar factory was determined to be 1.5 km based on immission measurements.

6.2 RECOMMENDATIONS

The data obtained in this study can be used for future studies of odour dispersion modelling. Odour dispersion modelling can be used to evaluate the movement of odour from a source and determine the extent and frequency of odour impacts on a surrounding community.

By modelling, many scenarios can be considered at a low cost, and the modelling effort may save a facility the expense of constructing an inappropriately located or designed facility and the hardship associated with public opposition.

APPENDIX A

Dimensions of the flux hood which was used for surface sampling.

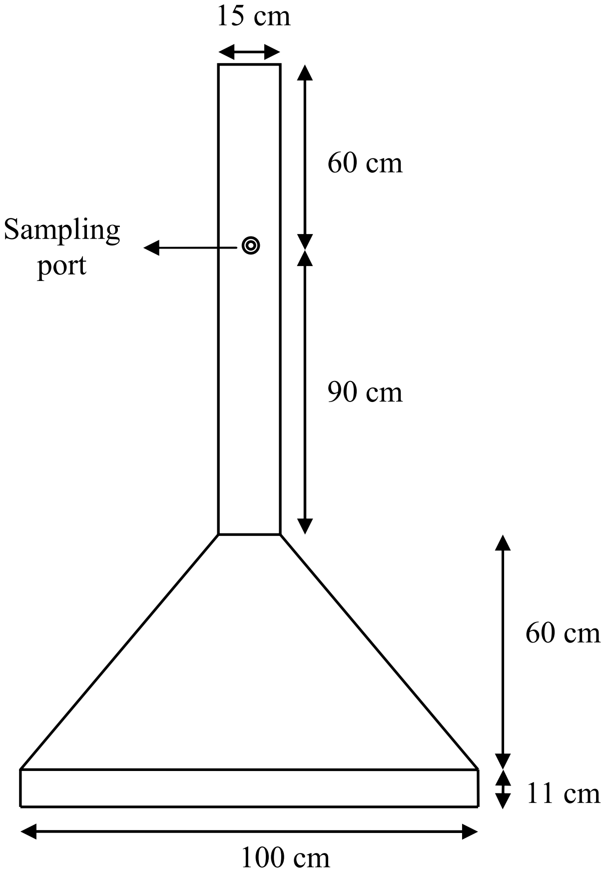


Figure A.1 Front view of the flux hood (cross-sectional area is 1 m^2)

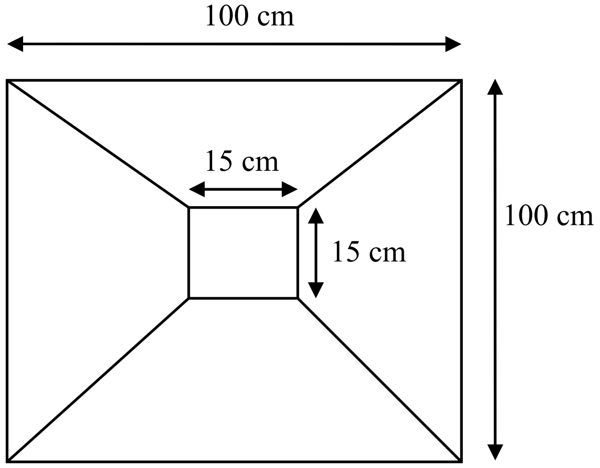


Figure A.2 Top view of the flux hood (cross-sectional area of the sampling section is 0.0225 m^2)

APPENDIX B

B.1 Evaluation of Olfactometric Measurement Results

With olfactometer TO7 several dilution steps can be applied to an odorous sample. The applicable main dilution steps are as follows; 1:2.5, 1:5, 1:10, 1:20, 1:40, 1:80, 1:160, 1:320 and 1:640. Meaning that an odorous gas sample can be diluted ranging from 640 times to 2.5 times with the neutral air according to the strength of the sample. These main dilution steps are adjusted manually with needle valves by the test leader.

In case the odour concentration is too high to measure with the dilution steps given above, the internal predilution of the olfactometer must be set before starting the measurement. The predilution can be selected as follows; no predilution, 1:25, 1:50 and 1:100. After adjusting the predilution, the main dilution must also be selected. Consequently, the total dilution is equal to the multiplication of main dilution with predilution and total dilution is adjusted automatically with the gas jet pumps. In addition, dilution factor is defined as “1 / total dilution”

Example 1:

Predilution × Main Dilution = Total Dilution
1:25 × 1:160 = 1: 4000

1 / Total Dilution = Dilution Factor
1 / 1: 4000 = 4000

Total dilution and the dilution factor show that the odorous gas sample is diluted 4000 times with neutral air (odourless air).

In this case, the maximum dilution level that can be achieved with olfactometer is 64000. In other words, an odorous gas sample can be diluted 64000 times with neutral air.

Where odour concentration is high above that can not be measured with 64000 dilution level, dynamic predilution should be applied. Dynamic predilution is accomplished through a second bag filled with neutral air and sample is prediluted with this odourless gas.

In order to do measurement with olfactometer TO7, four panellists and a test leader is required. Test leader adjusts the dilution level required and odour measurement starts. Odorous gas sample is given to the panellists starting from the defined dilution level and the dilution level decreases step by step. Between two odour presentations at least one odourless air is given to the panellists. 20 % of accidental blanks is the minimum necessary blank according to European Standards (EN13725). 20 % accidental blanks means, 20 % of the time odourless air is given to the panellists.

The task of panellists is to push the button with the first odour impression. If panellists do not give response, which means they can not sense odour, the dilution level decreases (odour concentration increases). When a panellists gives a positive answer, a second one is expected to confirm his/her sense. The measurement sequence is finished when each panellist is given two positive answers in a row.

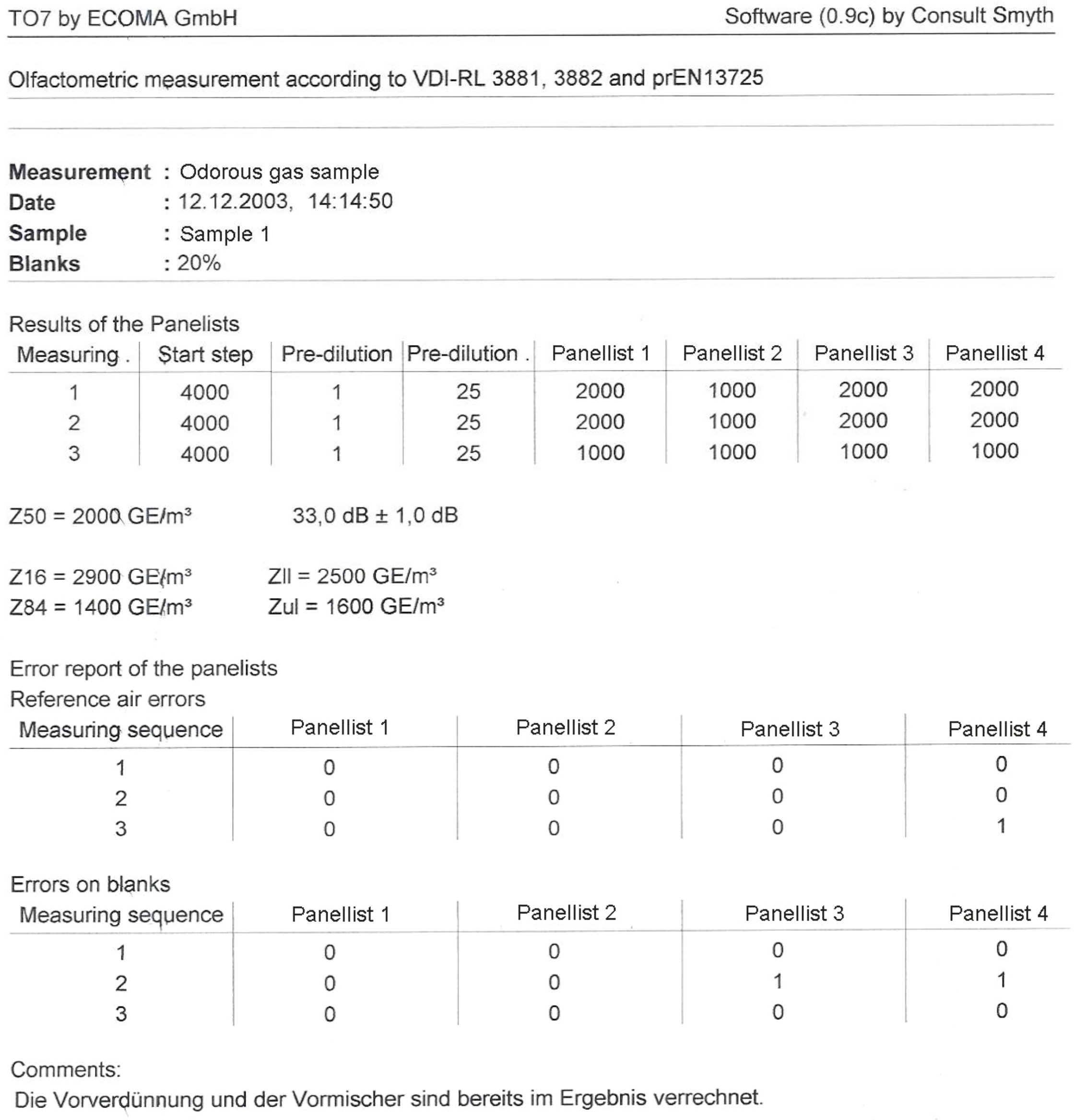
Example 2:

If dilution factor is set as 4000 with 20 % accidental blanks, dilution level starts and decreases as follows;

4000 → Blank → 2000 → Blank → Blank → 1000 → Blank → 500 → Blank → 250 → Blank → Blank → 125 ...... → Blank→ 2.5

Until all panellists give two positive responses in a measurement sequence.

According to the panellists’ response, the concentration of odorous gas sample is determined automatically with the software special to olfactometer TO7. The measurement results can be saved and printed out. In Figure B.1 a measurement output is given.



TO7 by ECOMA GmbH Software (0.9c) by Consult Smyth

Olfactometric measurement according to VDI-RL 3881, 3882 and prEN13725

Measurement : Odorous gas sample
Date : 12.12.2003, 14:14:50
Sample : Sample 1
Blanks : 20%

Results of the Panelists

Measuring .	Start step	Pre-dilution	Pre-dilution .	Panellist 1	Panellist 2	Panellist 3	Panellist 4
1	4000	1	25	2000	1000	2000	2000
2	4000	1	25	2000	1000	2000	2000
3	4000	1	25	1000	1000	1000	1000

Z50 = 2000 GE/m³ 33,0 dB ± 1,0 dB

Z16 = 2900 GE/m³ Zll = 2500 GE/m³
Z84 = 1400 GE/m³ Zul = 1600 GE/m³

Error report of the panelists
Reference air errors

Measuring sequence	Panellist 1	Panellist 2	Panellist 3	Panellist 4
1	0	0	0	0
2	0	0	0	0
3	0	0	0	1

Errors on blanks

Measuring sequence	Panellist 1	Panellist 2	Panellist 3	Panellist 4
1	0	0	0	0
2	0	0	1	1
3	0	0	0	0

Comments:
Die Vorverdünnung und der Vormischer sind bereits im Ergebnis verrechnet.

Figure B.1 An output of olfactometric measurement

A measurement is consists of 3 measurement sequences as given in Table B.1.

Table B.1 Panellists' answers to dilution levels

Measurement Sequence	Panellist 1	Panellist 2	Panellist 3	Panellist 4
1	2000	1000	2000	2000
2	2000	1000	2000	2000
3	1000	1000	1000	1000

According to the table above, in the first measurement sequence, panellist 1 has given the following answers at related dilution factors;

Dilution Factor		Answer
4000	→	"no"
2000	→	"yes"
1000	→	"yes"

When panellist 1 gave two consecutive 'yes' answers, the measurement sequence for him ends. The same procedure is applied to all panellists. When two consecutive 'yes' answers are obtained from all panellists a measurement sequence ends. The following measurement sequences are performed by the same procedure.

At the end of the measurement, odour concentration of the sample is given as Z_{50}, which is the concentration at threshold level leads to an odour impression with 50 % of the defined population. The concentration at the threshold is 1 OU/m^3 by definition [14].

In order to calculate Z_{50}, a Table B.2 is formed by taking the logarithm of the dilution factors according to the last 'no' and the first 'yes' answers given by the panellists.

Table B.2 Panellists' answers to dilution levels

M. Sequence / Answer	Panellist 1	Panellist 2	Panellist 3	Panellist 4
1 / No	log 4000	log 2000	log 4000	log 4000
2 / No	log 4000	log 2000	log 4000	log 4000
3 / No	log 2000	log 2000	log 2000	log 2000
1 / Yes	log 2000	log 1000	log 2000	log 2000
2 / Yes	log 2000	log 1000	log 2000	log 2000
3 / Yes	log 1000	log 1000	log 1000	log 1000

The arithmetic mean of these logarithmic values is taken. In fact, this value gives the geometric mean of the panellists' responses, "M". Antilogarithm of M gives odour concentration Z_{50}. By this way, odour threshold for each panellist can also be found. The calculation procedure is given in the following tables.

Table B.3 Logarithms of the panellists' answers to dilution levels

M. Sequence / Answer	Panellist 1	Panellist 2	Panellist 3	Panellist 4
1 / No	3.602	3.301	3.602	3.602
2 / No	3.602	3.301	3.602	3.602
3 / No	3.301	3.301	3.301	3.301
1 / Yes	3.301	3.000	3.301	3.301
2 / Yes	3.301	3.000	3.301	3.301
3 / Yes	3.000	3.000	3.000	3.000

Table B.4 Odour threshold calculation for each panellists

	Panellist 1	Panellist 2	Panellist 3	Panellist 4
Total (T)	20.107	18.903	20.107	20.107
Average (T/6)	3.351	3.150	3.351	3.351
Threshold (10^{Average})	2244	1414	2244	2244

Table B.5 Calculation of the odour threshold for the gas sample

Total	20.107 + 18.903 + 20.107 + 20.107 = 79.225
Average	79.225 / 24 = 3.301
Z_{50} (OU/m^3)	$10^{3.301}$ = 2000

Z_{50} designates the odour concentration of the gas sample. It means that the gas sample stimulates an odour sense even though it is diluted 2000 times with odourless air. Therefore, the higher the value of Z_{50}, the higher the concentration of the gas sample is.

Another important parameter obtained from olfactometric measurements is the "odour level". Odour level describes the intensity of a sensation as a function of the logarithm of the amount of the stimulating quantity. It is useful for practical purposes to describe the sensation of odour intensity analogous to the sound intensity level. The unit is dB (decibel) similar to the sound intensity unit. The odour level is defined as the logarithm of the ratio of two odorant concentrations [14].

$$L_{od} = 10\log\left(\frac{C_{od}}{\hat{C}_{od}}\right) \qquad \text{(Equation B.1)}$$

where;

L_{od} odour level, dB

$\hat{C}_{od}$ odorant concentration at the threshold (equal to 1 OU/m^3)

Example 3:

Odour level for the example given above:

L_{od} = 10 log (2000 / 1)

= 33.0 dB

The standard deviation in dB designates the reliability of the measurement performed. It should be around 1.0 to obtain an accurate odour concentration for the sample examined.

APPENDIX C

Table C.1 Measurement schedule for the field inspections around the sugar factory

NO	DATE	DAY	TIME, hrs	POINTS
1	February 21, 2003	Friday	16:00 – 20:00	D
2	February 24, 2003	Monday	08:00 – 12:00	A
3	February 27, 2003	Thursday	12:00 – 16:00	B
4	March 2, 2003	Sunday	16:00 – 20:00	C
5	March 5, 2003	Wednesday	20:00 – 24:00	D
6	March 8, 2003	Saturday	12:00 – 16:00	A
7	March 11, 2003	Tuesday	16:00 – 20:00	B
8	March 14, 2003	Friday	20:00 – 24:00	C
9	March 17, 2003	Monday	00:00 – 04:00	D
10	March 20, 2003	Thursday	16:00 – 20:00	A
11	March 23, 2003	Sunday	20:00 – 24:00	B
12	March 26, 2003	Wednesday	00:00 – 04:00	C
13	March 29, 2003	Saturday	04:00 – 08:00	D
14	April 1, 2003	Tuesday	20:00 – 24:00	A
15	April 4, 2003	Friday	00:00 – 04:00	B
16	April 7, 2003	Monday	04:00 – 08:00	C
17	April 10, 2003	Thursday	08:00 – 12:00	D
18	April 13, 2003	Sunday	00:00 – 04:00	A
19	April 16, 2003	Wednesday	04:00 – 08:00	B
20	April 19, 2003	Saturday	08:00 – 12:00	C
21	April 22, 2003	Tuesday	12:00 – 16:00	D
22	April 25, 2003	Friday	04:00 – 08:00	A
23	April 28, 2003	Monday	08:00 – 12:00	B
24	May 1, 2003	Thursday	12:00 – 16:00	C
25	May 4, 2003	Sunday	16:00 – 20:00	D
26	May 7, 2003	Wednesday	08:00 – 12:00	A
27	May 10, 2003	Saturday	12:00 – 16:00	B
28	May 13, 2003	Tuesday	16:00 – 20:00	C
29	May 16, 2003	Friday	20:00 – 24:00	D
30	May 19, 2003	Monday	12:00 – 16:00	A
31	May 22, 2003	Thursday	16:00 – 20:00	B
32	May 25, 2003	Sunday	20:00 – 24:00	C
33	May 28, 2003	Wednesday	00:00 – 04:00	D
34	May 31, 2003	Saturday	16:00 – 20:00	A
35	June 3, 2003	Tuesday	20:00 – 24:00	B
36	June 6, 2003	Friday	00:00 – 04:00	C
37	June 9, 2003	Monday	04:00 – 08:00	D
38	June 12, 2003	Thursday	20:00 – 24:00	A
39	June 15, 2003	Sunday	00:00 – 04:00	B
40	June 18, 2003	Wednesday	04:00 – 08:00	C
41	June 21, 2003	Saturday	20:00 – 24:00	D
42	June 24, 2003	Tuesday	00:00 – 04:00	A
43	June 27, 2003	Friday	04:00 – 08:00	B
44	June 30, 2003	Monday	08:00 – 12:00	C
45	July 3, 2003	Thursday	00:00 – 04:00	D
46	July 6, 2003	Sunday	04:00 – 08:00	A
47	July 9, 2003	Wednesday	08:00 – 12:00	B
48	July 12, 2003	Saturday	12:00 – 16:00	C
49	July 15, 2003	Tuesday	04:00 – 08:00	D
50	July 18, 2003	Friday	08:00 – 12:00	A
51	July 21, 2003	Monday	12:00 – 16:00	B
52	July 24, 2003	Thursday	16:00 – 20:00	C

Table C.1 Measurement schedule for the field inspections around the sugar factory (cont.)

NO	DATE	DAY	TIME, hrs	POINTS
53	July 27, 2003	Sunday	08:00 – 12:00	D
54	July 30, 2003	Wednesday	12:00 – 16:00	A
55	August 3, 2003	Sunday	16:00 – 20:00	B
56	August 7, 2003	Thursday	20:00 – 24:00	C
57	August 11, 2003	Monday	12:00 – 16:00	D
58	August 15, 2003	Friday	16:00 – 20:00	A
59	August 19, 2003	Tuesday	20:00 – 24:00	B
60	August 23, 2003	Saturday	00:00 – 04:00	C
61	August 27, 2003	Wednesday	16:00 – 20:00	D
62	August 31, 2003	Sunday	20:00 – 24:00	A
63	September 4, 2003	Thursday	00:00 – 04:00	B
64	September 8, 2003	Monday	04:00 – 08:00	C
65	September 12, 2003	Friday	20:00 – 24:00	D
66	September 16, 2003	Tuesday	00:00 – 04:00	A
67	September 20, 2003	Saturday	04:00 – 08:00	B
68	September 24, 2003	Wednesday	08:00 – 12:00	C
69	September 28, 2003	Sunday	00:00 – 04:00	D
70	October 2, 2003	Thursday	04:00 – 08:00	A
71	October 6, 2003	Monday	08:00 – 12:00	B
72	October 10, 2003	Friday	12:00 – 16:00	C
73	October 14, 2003	Tuesday	04:00 – 08:00	D
74	October 18, 2003	Saturday	08:00 – 12:00	A
75	October 22, 2003	Wednesday	12:00 – 16:00	B
76	October 26, 2003	Sunday	16:00 – 20:00	C
77	October 30, 2003	Thursday	08:00 – 12:00	D
78	November 3, 2003	Monday	12:00 – 16:00	A
79	November 7, 2003	Friday	16:00 – 20:00	B
80	November 11, 2003	Tuesday	20:00 – 24:00	C
81	November 15, 2003	Saturday	12:00 – 16:00	D
82	November 19, 2003	Wednesday	16:00 – 20:00	A
83	November 23, 2003	Sunday	20:00 – 24:00	B
84	November 27, 2003	Thursday	00:00 – 04:00	C
85	December 1, 2003	Monday	16:00 – 20:00	D
86	December 5, 2003	Friday	20:00 – 24:00	A
87	December 9, 2003	Tuesday	00:00 – 04:00	B
88	December 13, 2003	Saturday	04:00 – 08:00	C
89	December 17, 2003	Wednesday	20:00 – 24:00	D
90	December 21, 2003	Sunday	00:00 – 04:00	A
91	December 25, 2003	Thursday	04:00 – 08:00	B
92	December 29, 2003	Monday	08:00 – 12:00	C
93	January 2, 2004	Friday	00:00 – 04:00	D
94	January 6, 2004	Tuesday	04:00 – 08:00	A
95	January 10, 2004	Saturday	08:00 – 12:00	B
96	January 14, 2004	Wednesday	12:00 – 16:00	C
97	January 18, 2004	Sunday	04:00 – 08:00	D
98	January 22, 2004	Thursday	08:00 – 12:00	A
99	January 26, 2004	Monday	12:00 – 16:00	B
100	January 30, 2004	Friday	16:00 – 20:00	C
101	February 3, 2004	Tuesday	08:00 – 12:00	D
102	February 7, 2004	Saturday	12:00 – 16:00	A
103	February 11, 2004	Wednesday	16:00 – 20:00	B
104	February 15, 2004	Sunday	20:00 – 24:00	C

APPENDIX D

D.1 Evaluation of Immission Measurement Results

During the measurement period of 1 year totally 104 measurements have been performed. Considering that only one type of measurement point (e.g. points named with letter A) can be tested on a measurement day, 26 single measurements (104 / 4 = 26) have performed for each type of measurement point. Data sheets were filled out by panellists during single measurements for each measurement point. Panellists record their perceptions as ‘1’ (represents yes) or ‘0’ (represents no) on the data sheet.

On a data sheet there exists 60 odour test records consisting of 0 and 1. The percentage of positive responses (1, meaning yes odour exists) was divided by the total number of samples (60 samples) and expressed as a percentage. This percentage designates the “**percent odour time**” (odour frequency). For each measurement point, the percentage of positive single measurements is calculated as follows [42]:

$$A_+ = \frac{L_+}{R} \qquad \text{(Equation C.1)}$$

where;

A_+ percent odour time (odour frequency)

L_+ number of positive samples (responses)

R total number of samples

By comparing the calculated percent odour time with the immission limit value, single measurements are regarded as positive or negative.

Example 1:

$I_{limit} = 20\%$ (for residential and mixed areas for this study)

$I_{limit} <$ % odour time → positive

$I_{limit} >$ % odour time → negative

A1 : 15/60 = 25 % → 1 (1 odour hour)
B1 : 20/60 = 33 % → 1 (1 odour hour)
C1 : 3/60 = 5 % → 0
D1 : 12/60 = 20 % → 1 (1 odour hour)

A2 : 0/60 = 0 % → 0
B2 : .... → ...
C2 : .... → ...
D2 : .... → ...

Next, the percentage of positive single measurements (percentage of odour hours) for each measurement point is calculated as follows [42];

$$H_m = \left(\frac{A_m}{W_m} \right) \times 100 \qquad \text{(Equation C.2)}$$

where;

H_m percent odour hour (%)
A_m number of positive single measurements
W_m number of single measurements per measurement point (104 / 4 = 26)
m ordinal number of measurement point (e.g. A1, A2…B1, B2…)

Example 2:

For A1: $A_{A1} = 4$ and $W_{A1} = 26$

$$H_{A1} = \left(\frac{4}{26} \right) \times 100 = 15.4\,\% \text{ odour hour}$$

For A2: $A_{A2} = 4$ and $W_{A2} = 26$

$$H_{A2} = \left(\frac{12}{26} \right) \times 100 = 46.2\,\% \text{ odour hour}$$

As the last step, the ambient odour characteristic, K_A, is calculated for each square [42]. For a square, the 4 measurement points at the corners were considered and the arithmetic mean of K_P, which is equal to the H_m at that point, was taken.

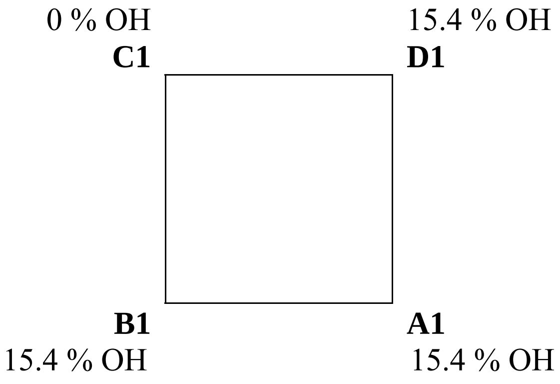
$$K_A = \sum_{i=1}^{4} \left(\frac{K_{P,i}}{4} \right) \qquad \text{(Equation C.3)}$$

where;

K_A	ambient odour characteristic for a square (%)
K_P	ambient odour characteristic for a measurement point ($H_m = K_p$)

Example 3:

For square 1: A1 = 15.4 % odour hour
B1 = 15.4 % odour hour
C1 = 0.0 % odour hour
D1 = 15.4 % odour hour



$$K_1 = \left(\frac{15.4 + 15.4 + 0 + 15.4}{4} \right) = 11.6\ \%$$

APPENDIX E

E.1 FOUNDRY AND FORGING OPERATIONS

PROCESS DESCRIPTION

In foundries, molten metals are cast into objects of desired shapes. Castings of iron, steel, light metals (such as aluminium), and heavy metals (such as copper and zinc) are made. The main production steps are shown in the following figure [47];

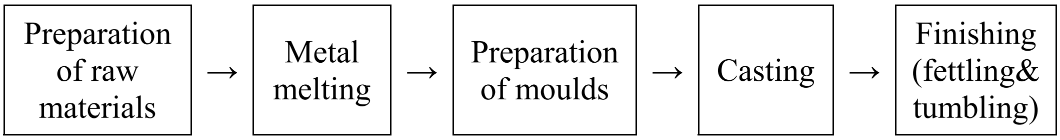


Figure E.1 Production steps of casting

Electric induction furnaces are used to melt iron and other metals. However, large foundries and some small foundries melt iron in gas or coke-fired cupola furnaces and use induction furnaces for aluminium components of engine blocks [47].

The casting process usually employs non-reusable moulds of green sand, which consists of sand, soot, and clay (or water glass). The sand in each half of the mould is packed around a model, which is then removed. The two halves of the mould are joined, and the complete mould is filled with molten metal, using ladles or other pouring devices [43].

For hollow casting, the mould is fitted with a core. Cores must be extremely durable, because of this reason strong bonding agents are used for the core and also for the moulds. These bonding agents are usually organic resins, but inorganic ones are also used. Plastic binders are being used for the manufacture of high-quality products. Sand cores and chemically bonded sand moulds are often treated with water-based or spirit-based blacking to improve surface characteristics [47].

Aluminium and magnesium, as well as copper and zinc alloys, are frequently die-cast or gravity-cast in reusable steel moulds. Die casting involves the injection of metal under high pressure by a plunger into a steel die. Centrifugal casting methods are used for pipes [47].

Finishing processes such as fettling involves the removal from the casting of the gating system, fins (burrs), and sometimes feeders. This is accomplished by cutting, blasting, grinding, and chiselling. Small items are usually ground by tumbling, carried out in a rotating or vibrating drum, usually with the addition of water, which may have surfactants added to it [47].

EMISSIONS TO AIR

Gaseous emissions from smelting are: carbon monoxide, sulphur dioxide, fluorine compounds and nitrous oxides; those from casting are: phenol (briefly), ammonia, amines, cyanide compounds and aromatic hydrocarbons (traces) [48].

Additional emissions of hydrochloric acids, soot and traces of organic compounds (possibly dioxins) occur when smelting large amounts of scrap mixed with oil, paints and plastics [48].

Highly odorous substances such as formaldehyde, phenols and ammonia occur in foundries for small castings for which moulds are produced according to the cold-box, hot-box or croning process. In addition to the odour nuisance, these substances are also health hazards. As formaldehyde and high ammonia concentrations are suspected carcinogens, steps must be taken to reduce these [48, 49].

ODOUR CONTROL TECHNOLOGIES

For foundry and forging operations; to control odorous emissions, it is essential to intercept emissions in all operating phases, including blowing and melting-down. For this reason induction furnaces should be preferred to cupola furnaces. With the use of induction crucible furnaces, emissions from the crucible opening are intercepted by an extraction system [48, 49].

The moulds made of moulding sands with approx. 4 to 10 % binder (clays, cement, organic materials, hardenable plastics, soda, water glass etc.) are usually used once and then broken up. The used sands can be treated and reused as components in clay-bonded mould production so that odorous emissions can be reduced [48].

The formation of odorous substances can be eliminated by replacing the cold-box method for core manufacturing.

Odorous substances such as formaldehyde, phenols and ammonia can be reduced by a counter-current scrubber with a phosphoric acid solution. In this case the scrubbing fluid should be recirculated and continuously treated [47, 48].

The feed quality should be improved by using selected and clean scrap to reduce the release of pollutants and odours to the environment. Otherwise a high-performance wet scrubber must be used under these operating conditions [47, 48].

E.2 PAINT MANUFACTURING

PROCESS DESCRIPTION

Paint manufacturing includes the production of two main products: solvent-based paint and water-based paint. At a typical plant, both types of paint are produced. A block flow diagram of the steps involved in manufacturing paint is presented in Figure E.2 [50].

The production of solvent-based paint begins by mixing: resins, dry pigment, and pigment extenders, in a high speed mixer. During this operation, solvents and plasticizers are also added. Following the mixing operation, the batch frequently is transferred to a mill for additional grinding and mixing. The type of mill is dependent on the types of pigments being handled. Next, the paint base or concentrate is transferred to an agitated tank where tints and thinner (usually a volatile naphtha or blend of solvents) and the balance of the resin are added. Upon reaching the proper consistency, the paint is filtered to remove any non-dispersed pigment and transferred to a loading hopper. From the hopper, the paint is poured into cans, labelled, packed, and moved to storage [50].

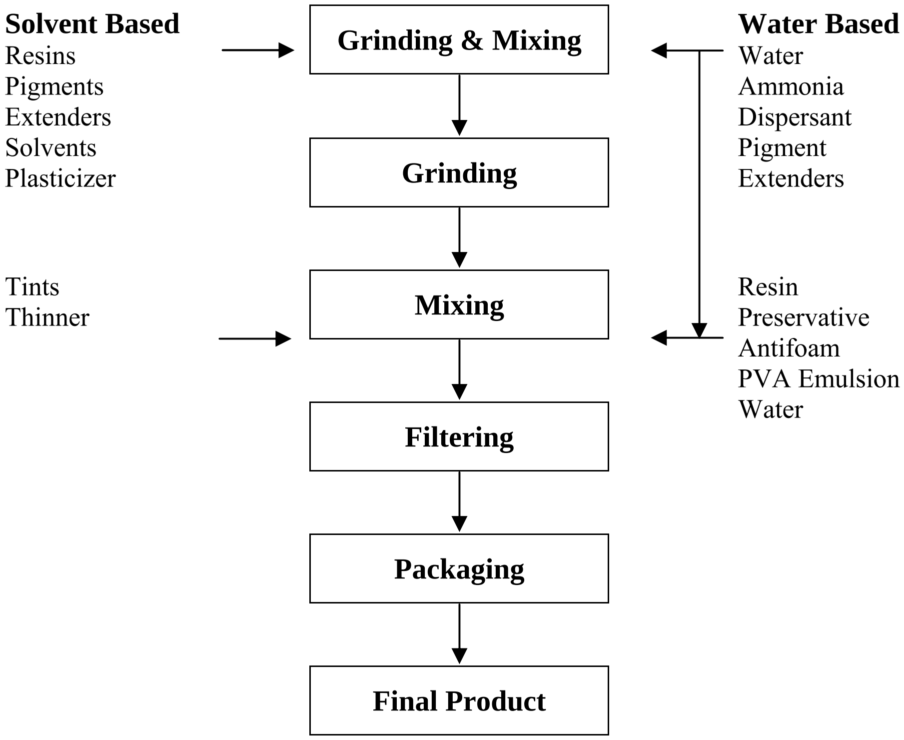


Figure E.2 Flow diagram for paint manufacture [50]

The water-based paint process is very similar to the solvent-based process. The major difference is the substitution of water for solvent and the sequencing of material additions. Preparation of water-based paint begins by mixing together water, ammonia, and a dispersant in a mixer. To this mixture, dry pigment and pigment extenders are added. After mixing, the material is ground in a mill and then transferred to an agitated mix tank. Four additions of materials occur in this tank. First, resin and plasticizers are added to the mixture; second, a preservative and an antifoaming agent are added; third, a polyvinyl acetate emulsion is added; and fourth, water is added as a thinner. Following this mixing operation, the handling of the paint is similar to that for solvent-based paints. At many facilities the grinding and the mixing and grinding operation may be bypassed with all the dispersion operations occurring in a single high-speed mixer [50].

EMISSIONS TO AIR

The two major types of air emissions that occur in the paint manufacturing process are volatile organic compounds and pigment dusts. Volatile organics may be emitted from the bulk storage of resins and solvents and from their use in open processing equipment such as mix tanks. Since most existing equipment is of open design, reducing or controlling organic emissions from process equipment could require substantial expenditures [50].

Solvent based paints are the source of most plant VOCs, but water based paint formulations do not include VOCs. Mixing in open top drums and portable tanks causes fugitive emissions. Lids are usually used, but fugitive evaporative emissions still occur when lids are open, through mixer openings or cracks, and when filling or emptying. Product packaging and equipment cleaning create emissions. Solvent storage tanks vent emissions when being filled, from day/night heating/cooling, or from simple diffusion [51].

Toxic emissions from paint manufacturing may include xylene, toluene, methyl ethyl ketone, methyl isobutyl ketone, methanol, isopropyl alcohol, acetone, n-butyl acetate, ethyl acetate, iso-butane, methyl chloroform, and methylene chloride [51].

ODOUR CONTROL TECHNOLOGIES

Many methods are available for reducing the amount of emissions resulting from fixed roof storage tanks. Some of these methods include use of conservation vents, conversion to floating roof, use of nitrogen blanketing to suppress emissions and reduce material oxidation, use of refrigerated condensers, use of lean-oil or carbon absorbers, or use of vapour compressors [50].

Stack gas scrubbing and/or carbon adsorption (for toxic organics) are applicable and effective technologies for minimizing the release of significant pollutants to air. Combustion is used to destroy toxic organics. Combustion devices should be operated at temperatures above 1100 °C (when required for the effective destruction of toxic organics), with a residence time of at least 2 second [52].

In addition, water-based processes should be preferred rather than solvent-based processes.

E.3 MINERAL WOOL PRODUCTION

Mineral wool manufacture consists of the following stages: raw material preparation; melting; fiberisation of the melt; binder application; product mat formation; curing; cooling; and product finishing. Mineral wool can be divided into two main categories: glass wool and stone or slag wool. The products are used in the essentially same applications and differ mainly in the raw materials and melting methods. Following the melting stage the processes and environmental issues are essentially identical. The materials utilised in the mineral wool sector are given in Table E.1 below [53].

Table E.1 Materials utilised in the mineral wool sector [53]

Glass Wool	Silica sand, process cullet, external cullet, process wastes, nepheline syenite, sodium carbonate, potassium carbonate, limestone, dolomite, sodium sulphate, borax, colemanite.
Stone Wool	Basalt, limestone, dolomite, blast furnace slag, silica sands, sodium sulphate, process waste, occasionally wastes from other processes e.g. foundry sand.
Binder Materials	Phenol formaldehyde resin (in solution), phenol, formaldehyde and resin catalyst if resin produced on site), ammonia, urea, mineral oil, silicone, silane, water
Fuels	Natural gas, electricity, coke (stone/slag wool only), back up fuels (light fuel oil, propane, butane).

E.3.1 GLASS WOOL

PROCESS DESCRIPTION

The basic materials for glass wool manufacture are sand, soda ash, dolomite, limestone, sodium sulphate, sodium nitrate, and minerals containing boron and alumina. The various raw materials are automatically weighed out and blended to produce a precisely formulated batch [53]. Then these materials are conveyed from storage piles to the glass melting furnace by belts. In the glass melting furnace, the raw materials are heated and transformed through a series of chemical reactions into molten glass [54]. (A typical glass wool plant is given in Figure E.3.)

Glass fibres are made from the molten glass using the rotary spin process. In the rotary spinners, centrifugal force causes molten glass to flow through small holes in the wall of a rapidly rotating cylinder to create fibres that are broken into pieces by an air stream [54].

After the glass fibres are produced, they are sprayed with a solution of phenolic resin based binder and mineral oil onto the fibres to provide integrity, resilience, durability and handling quality to the finished product. The resin coated fibre is drawn under suction onto a moving conveyor to form a mat of fibres. This mat passes through a gas fired oven at approximately 250 ^{0}C, which dries the product and cures the binder. The product is then air cooled, cut to size and packaged [53, 54].

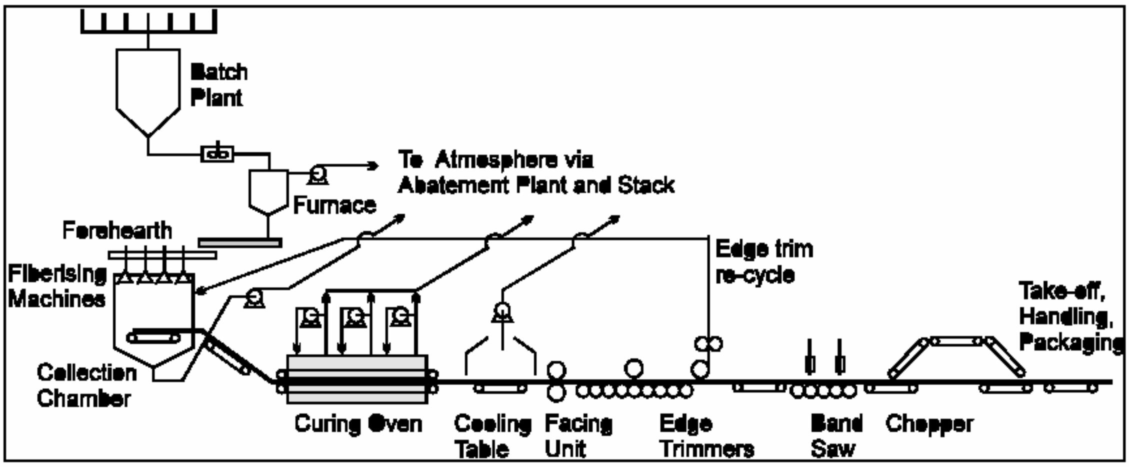


Figure E.3 A typical glass wool plant [53]

E.3.2 STONE WOOL

PROCESS DESCRIPTION

Stone wool is made by melting a combination of alumina-silicate rock (usually basalt), blast furnace slag, and limestone or dolomite. The batch may also contain recycled process or product waste. The most common melting technique is the coke fired hot blast cupola. The cupola consists of a cylindrical steel mantle which may be refractory lined and closed in at the bottom [53]. (A typical stone wool plant can be seen in Figure E.4.)

The raw materials and coke are charged to the top of the cupola in alternate layers, or are sometimes mixed. The molten material gathers in the bottom of the furnace and flows onto the rapidly rotating wheels of the spinning machine, and is thrown off in a fine spray producing fibres. Air is blasted from behind the rotating wheels to attenuate the fibres and to direct them onto the collection belt to form a mat [53].

An aqueous phenolic resin solution is applied to the fibres by a series of spray nozzles on the spinning machine. The phenolic resin provides strength and shape to the product as in glass fibre insulation [53].

The mat passes through a fossil fuel-fired oven at approximately 250 ^{0}C, which sets the product thickness, dries the product and cures the binder. The product is then air cooled and cut to size before packaging [53].

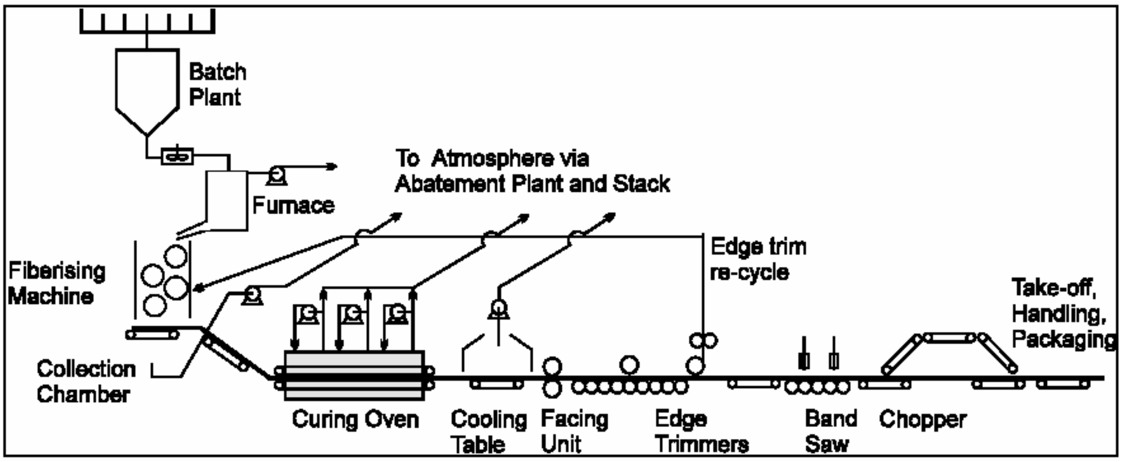


Figure E.4 A typical stone wool plant [53]

EMISSIONS TO AIR

In the mineral wool sector the emissions to air can be divided into two parts; emissions from melting activities and emissions from downstream processes or line operations (i.e. fiberising and forming, product curing, product cooling, and product finishing) [54].

As in other glass manufacturing processes, the major air emissions associated with mineral wool sector include PM_{10}, calcium carbonate, sodium fluoride, sodium fluorosilicate, silica, calcium fluoride, aluminium silicate, sodium sulphate, and boron oxides. Gases emitted include fluorides, sulphur dioxide, oxides of nitrogen, boric acid, carbon monoxide, and water vapour. Figure E.5 shows these emissions [50].

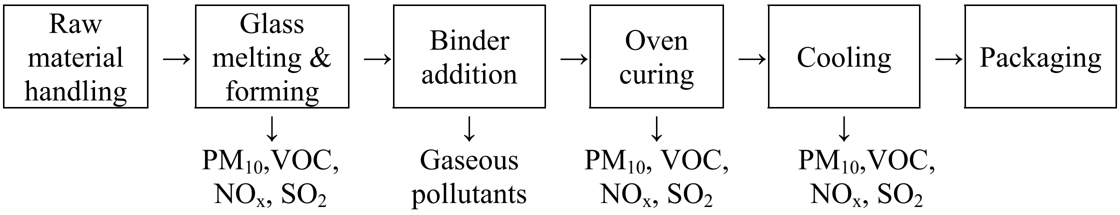


Figure E.5 Emissions from mineral wool processes [54]

Mineral wool installations can be the source of odour complaints from local residents. An emission from the downstream processes that is difficult to quantify is odour. Odours arise mainly from the curing operation and are thought to be caused by binder breakdown products. Also the use of high external cullet levels or other recycled materials can sometimes cause odour problems [54].

Most odours are thought to arise from the curing oven, where the main chemical reactions and thermal processes take place. The drying process will also give rise to a certain amount of steam distillation of binder compounds and intermediates. The inside of most curing ovens shows a build up of fibrous and resinous material which may also give rise to odorous compounds under the influence of the oven temperature. Small fires and localised instances of smouldering are also not uncommon in curing ovens and the smoke and fume emitted can be very odorous [53].

ODOUR CONTROL TECHNOLOGIES

Conventional air-gas fired, and oxy-gas fired furnaces do not usually give rise to odour problems, even when recycled material is melted, due to the high temperatures. Cold top electric melters rarely cause odour problems, but can if mineral wool waste is being recycled. Binder materials can undergo partial thermal breakdown during the melting process, and some odorous substances may be emitted. This problem can be minimised by the addition of oxidising agents or pre-treatment of the fibre [53].

Cupola melting gives rise to significant emissions of odorous hydrogen sulphide. The accepted solution to this is combustion in an after burner system, which also deals with any other odorous emissions from recycled material or raw materials [53].

The main sources of odour are from the downstream operations, particularly forming and curing. Odours can also arise from the product cooling, particularly from dense or high binder products, or if a degree of over-curing has taken place. Odour from the individual chemicals used in the process is not considered to be very significant. Odour results predominantly from the chemical and thermal reactions of the organic binder used in the process. The characteristic smell is of ‘burned Bakelite’. Complaints of formaldehyde or ammonia odours are very rare outside of the plant [53].

Instances of odour can be greatly reduced by good oven maintenance and cleaning, wet scrubbing systems, adequate dispersion and provision for the rapid extinguishing of any fires. Incineration of curing oven waste gases is a very effective solution to the problem. The forming area activities can also result in the formation of odorous compounds particularly when the binder is sprayed onto the hot fibres. However, the atmosphere is cooler and therefore moister than the curing oven, and the gas volumes are very much higher and concentrations of any odorous compounds are diluted. Although, a significant mass of odorous compounds can be emitted from the forming area an odour only “exists” if the compound is in a concentration above the odour threshold, and so forming area emissions are generally less odorous than curing oven emissions. If forming area emissions do give rise to odours they can be minimised by wet scrubbing and adequate dispersion. Problematic odours can be addressed by wet scrubbing using an oxidising agent, but this would have to be separate from the process water system [53].

E.4 SOLID WASTE LANDFILL

PROCESS DESCRIPTION

Waste disposal comprises of the collection, transport, treatment, storage (intermediate storage), dumping and recycling of waste [55]. However, two of these disposal stages are regularly applied in Ankara; waste collection and waste dumping. Also at the landfill site, solid waste separation is performed manually by workers.

Waste transport involves the collection of wastes from different sides of the city by hauling trucks and emptying of vehicles at landfill site.

Waste dumping is a method of controlled final disposal at landfill sites which should be done after the following conditions are supplied; base sealing, treatment of percolation water, landfill gas disposal/utilisation etc. [55]. Whereas, for Ankara municipal solid waste landfill area none of them exists.

Waste separation includes separation of valuable materials, such as used glass, used oil, waste paper, plastics, metals etc., and transfer of these materials to a waste recycling centre.

EMISSIONS TO AIR

Emission sources, that include hauling trucks, specific odorous materials, landfill gas, cell cover breaches and other on-site activities, are difficult to identify and to compare on a relative basis. In addition, the greatest challenge for odour control is the open working face of the municipal solid waste landfill.

Assessing odour emissions from large landfill sites is a significant problem. The odour comes from operations and processes on site exposing mixtures of volatile organic compounds present in the landfill gas, leachate, as well as waste odours from sludges and solids [57].

Even at the collection and transport stages, waste decomposition starts and typical waste gas is emitted to the atmosphere. This odorous gas mainly consists of carbon dioxide, methane and trace amounts of other constituents [57]. The odour character differs according to the composition of the waste. Substances formed by decomposition, decay and anaerobic processes emit odours.

In landfills, as a result of anaerobic decomposition; inorganic substances; ammonium, hydrogen sulphur, and organic substances; amine aldehydes, alcohol, carbonyl mercaptan and amino acids emitting foul odours are generated. These odorous gases can be poisonous at high concentrations. For example, H_2S; when it is low in concentration, it is not known whether it has harmful effect on human health or not. On the other hand, when H_2S concentration exceeds $320 mg/m^3$, limit value, its existence in the environment is not sensed and at a concentration of $1120 mg/m^3$, it results in fast, sudden deaths [58].

ODOUR CONTROL TECHNOLOGIES

Every landfill produces leachate and landfill gases (including methane), which must be properly treated or disposed of, or utilised in the case of landfill gas.

The separation of valuable materials from waste greatly facilitates its proper disposal. If relevant waste items are already collected at source (i.e. pre-sorted), this can greatly facilitate the collection and transport of the remaining waste.

Against odours and other emissions; enclosure of relevant areas, containment and filtration of waste air and daily covering of the operating areas may be useful for reduction of odour emissions, as well as for paper drift, insect infestation, avoidance of fire danger and unaesthetic appearance.

Besides, in order to reduce odour problems, regular dumping sites should be used. Solid waste separation plants, compost plants and solid waste incineration plants may be alternatives to landfills. Consequently, not only the waste load of landfills but also with the odorous emissions from landfills will be reduced [58].

E.5 POULTRY FARM – PRODUCTION OF EGGS

PROCESS DESCRIPTION

For commercial egg production, laying breeds are used that result from selection and breeding programmes that optimise their genetic potential for high egg production. Laying birds kept in the commonly used laying cages have one laying period of about 12 – 15 months measured from the end of the growing period (around 16 – 20 weeks) [59].

The number of birds per surface area varies between housing systems. The commonly used cage systems allow a stocking density, depending on tier arrangement, of up to 30 – 40 birds/m^2 [59].

Intensive egg production usually takes place in closed building made of various materials (stone, wood, steel with sheet cladding). The equipment in the housing varies from hand operated systems to fully automated systems for indoor air quality control, manure removal and egg collection. Close to the housing or immediately attached are the feed storage facilities [59].

In cage systems, four major battery designs are; flatdeck, stair-step, compact and belt-battery. In addition to these, fully stepped designs are also available. Rows of cages can be more than 50 m long and with several corridors. Some of the modern large enterprises have buildings with 20000 to 30000 birds or more. The cages are mostly made of steel wire and equipped with installations for automatic watering and automatic feeding of the birds [59]. Figure E.6 shows a schematic picture of an enriched cage.

Cage floor inclination makes the eggs roll to the front side of the cages, where they are collected by hand or on a transport belt and removed for further selection and packaging. The bird droppings fall through the bottom of the cages at the back and are stored underneath or are removed by scrapers or belts [59].

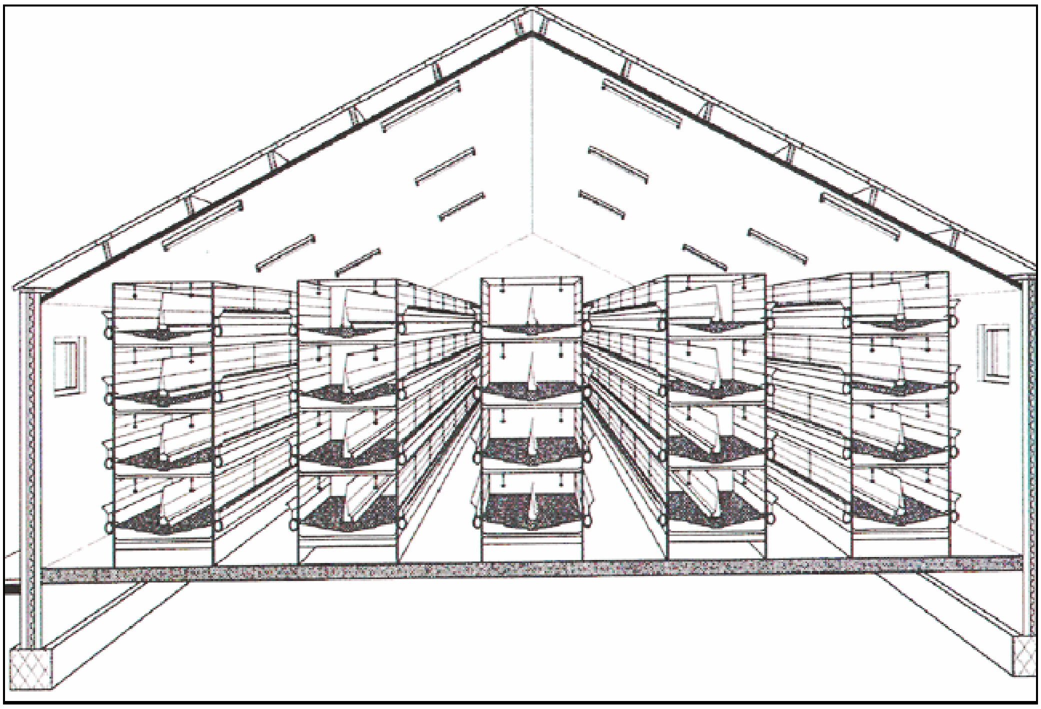


Figure E.6 Schematic picture of a possible design of an enriched cage [59]

In general, flatdeck and stair-step cages need more space and require a larger investment per bird. Due to the way they are applied, these systems produce wetter manure and also account for a higher NH_3 emission than the other systems (concentrations 40 ppm in the cage area at low ventilation rates) [59].

EMISSIONS TO AIR

The majority of emissions from the main activities on any poultry can be attributed to the amount, structure and composition of manure. From an environmental point of view, manure is the most important residue to be managed on-farm.

Depending on the housing system and the way of collecting manure different types of poultry manure (wet manure, dry manure, deep litter manure with different dry matter contents) are produced. The dry matter content is important, as with increasing dry matter content, emission of NH_3 will decrease.

Feed type housing system (application of manure drying and the use of litter) and poultry breeds are factors that account for dry matter content variation. With respect to feeding, it is clear that the higher the protein level in feed the higher the N-levels in manure.

After manure, the major emissions arise from the animal housing. Key emissions to air are ammonia, odour and dust. Dust development is important as it can be a direct nuisance to animals and humans, and as it also plays an important role as a carrier of odorous compounds. Major factors that influence air emissions from housing are:

a. Design of the animal housing and manure collection system,
b. Ventilation system and ventilation rate,
c. Applied heating and indoor temperature,
d. The amount and quality of manure, which also depends on:
    - feeding strategy,
    - feed formulation (protein level),
    - application of litter,
    - watering and watering system,
    - number of animals.

Emissions from poultry housing are reported mostly in terms of ammonia but other green house gases such as methane (CH_4) and nitrous oxide (N_2O) are emitted as well and are expected to attract more attention. NH_3 and CH_4 primary result from metabolic reactions in the animal and the slurry and are produced from compounds in the feed. N_2O is a secondary reaction product of the ammoniafication of urea and is readily available or can be converted from uric acid in urine.

The development of nitrous oxide (N_2O), methane (CH_4) and non methane volatile organic compounds (nmVOC) is associated with the internal storage of manure, and their levels in housing can be considered very low when the manure is frequently removed. Hydrogen sulphide (H_2S) is generally present at very low quantities.

ODOUR CONTROL TECHNOLOGIES

To prevent odorous emissions, some measures should be taken in two areas; nutrition techniques and the housing systems.

Feeding measures include phase-feeding, formulating diets based on digestible/available nutrients, using low protein amino acid-supplemented diets and using low phosphorus phytase-supplemented diets and/or highly digestible inorganic feed phosphates. Furthermore the use of feed additives may increase feed efficiency, thereby improving nutrient retention and diminishing the amount of nutrients left over in the manure. As a result the odorous emissions from manure will be reduced [59].

Housing measures include advisable alternative systems such as enriched cage or non-cage systems. These systems of housing reduce the ammonia emissions and thereby odorous emissions. On the other hand, best available techniques for housings are such;

- A cage system with manure removal, at least twice a week, by way of manure belts to a closed storage, or
- Vertical tiered cages with manure belt with forced air drying, where the manure is removed at least once a week to a covered storage, or
- Vertical tiered cages with manure belt with whisk-forced air drying, where the manure is removed at least once a week to a covered storage, or
- Vertical tiered cages with manure belt with improved forced air drying, where the manure is removed at least once a week to a covered storage, or
- Vertical tiered cages with manure belt with drying tunnel over the cages; after 24–36 hours the manure is removed to a covered storage [59].

E.6 SUGAR MANUFACTURING

PROCESS DESCRIPTION

The sugar industry processes sugar beet to manufacture edible sugar. It is a seasonal industry, with season length of about 3 – 4 months. In Turkey, sugar beets are harvested starting from the end of July up to early winter. They are transported to the sugar factory by large trucks from different parts of the country and they are stored at the factory. Sugar beet storage is necessary since harvest periods are short and continuous beet flow to the factory is required to operate the factory at full capacity.

In the factory, sugar production activities start at the end of September and ends in January-February. This period is called as the 'campaign period'. In the campaign period, sugar factory works continuously for 24 hours a day during 120 days in a year.

Sugar beet is composed of 75 % water and 17 % sugar; however, 12 % of a sugar beet is converted to sugar [60].

Following the harvesting and storage, sugar manufacturing (Figure E.7) begins with washing the sugar beets and chopping into long thin strips known as 'cossettes'. Then, sugar is extracted from the slices in the counter-current with water at 60 - 70°C in an extraction plant. After the raw juice has been extracted, it is purified mechanically and chemically. First fibre and cell particles are removed mechanically, then the juice is purified chemically by precipitation of some of the nonsucrose substances dissolved or dispersed in the juice, and the precipitate is then filtered off. The clear juice is continuously concentrated by multiple stage evaporation until it has a dry matter content of 60 to 70%, each stage of this process being heated with the steam (steam-saturated air released when the clear juice is concentrated) from the previous stage. When a certain ratio of sugar to water (supersaturation) is reached, crystals form. This process continues under controlled conditions until the required crystal size and quantity are obtained. Refining of sugar involves removal of impurities and decolourisation. Decolourisation methods use granular activated carbon, powdered activated carbon, ion exchange resins, and other materials. At the end, sugar extracted is cooled and dried before storage or packaging [61].

EMISSIONS TO AIR

The major air emissions from sugar manufacturing result mainly from the combustion unit, beet processing units and from the process waste wasters.

In beet plants coal or fuel oil is employed as fuel, thereby NO_x and SO_x are the potential pollutants [61]. In this case, odorous emissions related with combustion processes are observed. However, the other emissions mentioned above surpass the combustion odours.

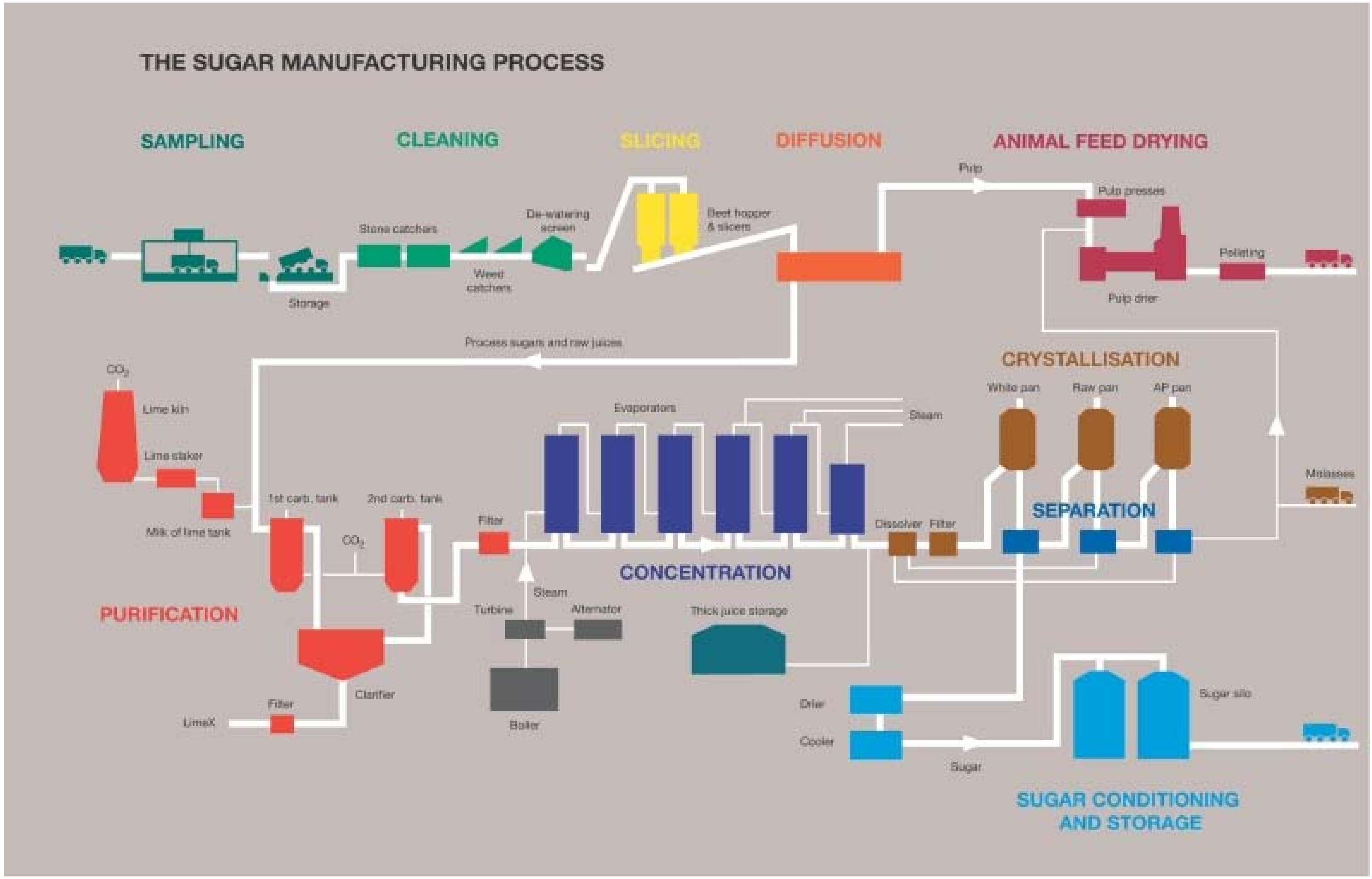


Figure E.7 The sugar manufacturing process flow diagram [61]

Juice fermentation units, evaporators, and sulfitation units often generate odours and odour discharged through the stacks which need to be controlled [60].

On the other hand, wastewaters from beet manufacturing processes contain extremely high dissolved organic matter. Therefore unpleasant odours mainly occur in the settlement and treatment lagoons. Unfortunately the processing season occurs during the dry seasons which enhance the intensity of odour [62].

ODOUR CONTROL TECHNOLOGIES

Odor controls should be implemented where necessary to achieve acceptable odour quality for nearby residents.

Monitoring of air emissions should be on an annual basis with continuous monitoring of the fuel used. Odour control by ventilation and sanitation may be required for fermentation and juice processing areas. Biofilters may be used for controlling odour [60].

Fermentation processes and juice handling are the main sources of leakages. Odor problems can usually be prevented with good hygiene and storage practices [60].

To decrease the odours releasing from the waste water treatment units, first of all the BOD/COD loading of water discharges should be reduced. Once this is done the odour aspect can be dealt with, usually by enhanced anaerobic treatment where the odours can be contained and ultimately burned with the biogas which is generated [60].

APPENDIX F

Figure F.1 A picture of the flux hood over the solid wastes

Figure F.2 A picture of the solid waste landfill

Figure F.3 A picture of the poultry farm housing

Figure F.4 A picture of panellists during an olfactometric measurement

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