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APPROACH TO ODOR NUISANCE EVALUATION IN SWITZERLAND

Markus Hangartner

University of Applied Sciences, Institute for Environmental Engineering, Rapperswil
markus.hangartner@hsr.ch

ABSTRACT

Since the promulgation of the Swiss Environmental Protection Act, the annoyance approach has been established for odor regulation. The direct scaling of the extent of annoyance in the neighborhood of odor emitting plants has led to an evaluation scheme for public odor annoyance.

The problem-solving procedure starts with checking compliance with emission standards for specific substances. Olfactometry plays an important role in defining the state of the art for odor abatement systems. An evaluation scheme for odor emissions is applied.

The link between emission and public annoyance gives the assessment of odor frequencies as a measure of the ambient odor burden.

Key Words: olfactometry, odor annoyance, odor frequencies, public nuisance, frequency/annoyance relationship
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1. INTRODUCTION

In the Ordinance of Air pollution control (OAPC) of 1986 [1], annoying odors are regarded as excessive emissions. The following definition is to be found in Article 2, Section 5b:

"Emissions are deemed to be excessive if a survey determines that they significantly disturb the wellbeing of a major part of the population".

The Ordinance is based on the perceived extent of annoyance. In other words, a plant may emit such quantities as will not result in annoyance. This is why the Ordinance does not state any specific limit values for odors. Nonetheless, methods and assessment standards are needed to implement the Ordinance.

Before the possible extent of odor emissions can be clarified in a so-called "odor situation", the first step is to check whether the precautionary emission limits stipulated in the OAPC have been met. The decisive factor concerns especially those emission limits which help to avoid or reduce odor emissions. In this context, one important precautionary measure is to identify and remove the emissions as described in Article 6 of the OAPC (e.g. the flue height).

A whole series of odor problems can be resolved by ensuring compliance with the existing precautionary emission limits. However, there are a number of emission sources which are not covered by these limits on account of their low concentrations, yet still result in odor pollution of the local environment. In such cases olfactometry can be used. With the aid of the human nose, odor samples are diluted right down to their detection thresholds. The dilution ratio or odor substance concentration is a measure of the strength of the source. Guideline values are available to allow the effects on the environment to be assessed. At the planning stage, requirements or guarantees can be defined regarding the limitation of the odor substance concentration. These guideline values enable the operator to check remediation efforts immediately, thereby documenting the state of the art.

The Swiss approach to evaluating excessive odors is based on the extent of the annoyance in the residential areas exposed to the odor pollution. Local residents must be consulted for the purposes of the evaluation. The extent or excessiveness of the odor burden can be determined by conducting a survey of the local residents affected. However, this approach is bound by certain conditions, e.g. a sufficient number of inhabitants living in the vicinity of the plant; what is more, this method cannot be applied at the planning stage.

At the present time, the best way to describe the emission burden involves documenting the frequency of specific plant odors. Based on random samples, the perception by test subjects of odors in the vicinity of plants is determined. Calibration takes place by questioning those concerned. In the event of any conflict, it is advisable to apply both methods – exposure of test subjects to the odors and questioning of the test subjects – to increase the reliability of the statements.

The emission burden caused by odors can be determined by means of the odor frequency. This method is also suitable in the case of very localized problems where questioning of local residents is not possible. Forecasts can be made even in the planning phase by using the distribution calculation. This method offers certain advantages from an administrative point of view, though it should be noted that frequencies cannot provide a complete description of the pollution situation.

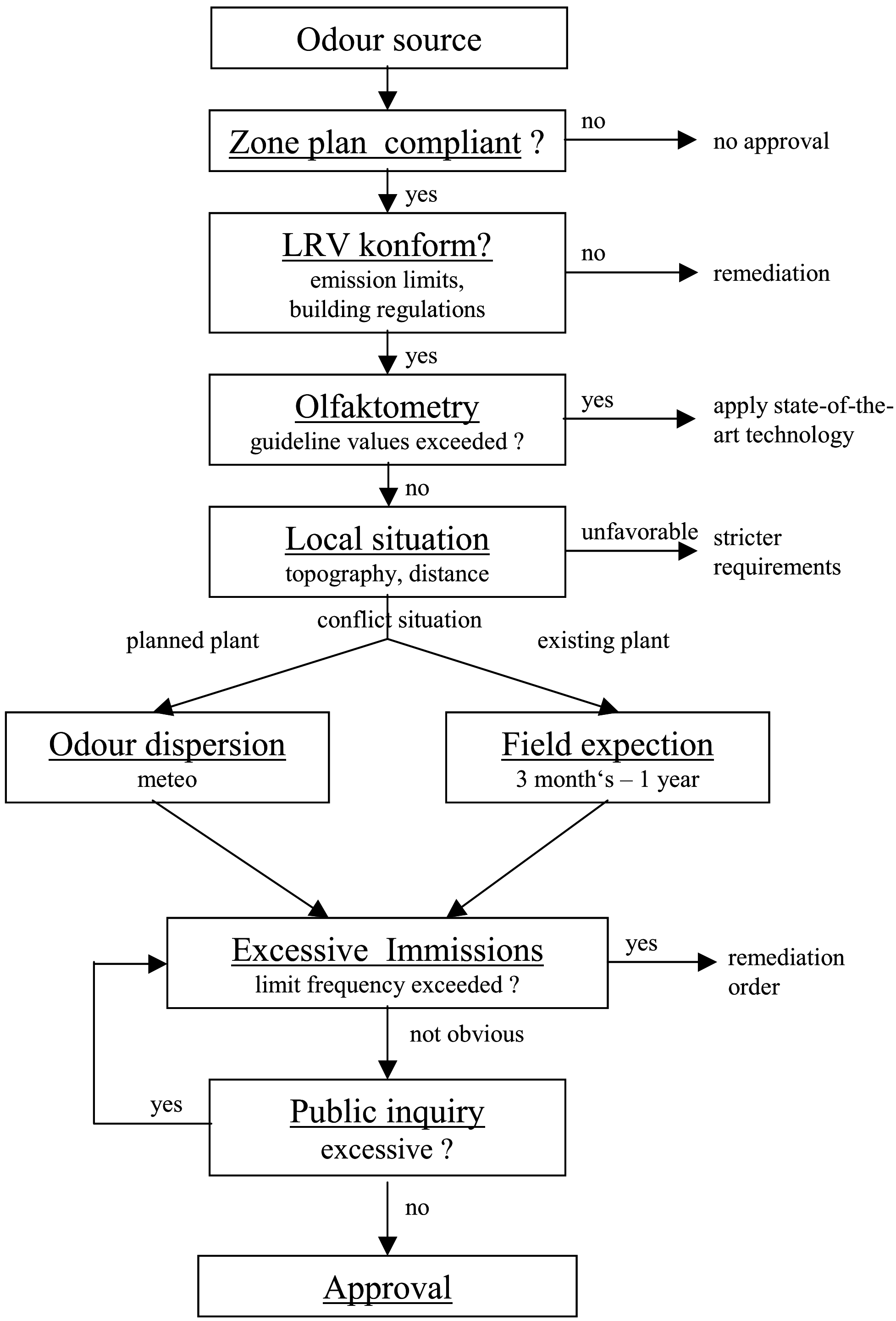

Figure 1: Flow chart showing procedure for dealing with an odor pollution complaint.

2. OLFACTOMETRY

Odors are generally made up of a large number of chemical substances which can affect the olfactory organ in different ways, depending on the type of substances and the concentrations in which they are present. On account of the number of different components, which is almost always very large, it is not possible to conduct a chemical analysis of the individual odor substances. What is more, even if all the contents of a particular sample are quantitatively determined, the odor that the sample causes cannot be described.

Olfactometry is a suitable method of conducting an "engineer's" evaluation of measures taken to reduce odor pollution, as it allows a measure and the odor reduction to be expressed in terms of mass and figures.

The olfactometry process uses the human nose as a detector. Compliance with certain principles which are laid down in standards [2,3] is important. Both the participating "smellers" and the dilution apparatus are subject to specific requirements. Although the scatter of the measured values is fairly large, the measurement process is also a biological one. Reliable statements can be made, especially when it comes to making a relative assessment of a particular measure.

A variety of measurements for different odor sources has resulted in a pragmatic system for evaluating odor emissions [4].

Class	Range	Likely effects
I	< 100	High probability of no odor emissions
II	100 - 300	High probability of no odor emissions if: • the waste air is routed through a flue • residential areas are more than 300 m away • the potential burden is low
III	300 - 1000	Odor emissions are possible but can be avoided by: • using a high/higher flue • ensuring that residential areas are more than 600 m away
IV	1000 - 3000	Odor emissions are probable: • a very high flue is necessary • action must be taken within the plant
V	over 10,000	purification of waste air is necessary

Table 1: Guideline values for odor emissions in odour concentrations [OU/m^3]

Depending on its topographical situation, a plant can be assigned to one of the above classes. If the values measured in a plant are below a stated range, emissions can be ruled out; above this range there is a high probability of annoying emissions. This applies to a mean range of volume flow rates from 5,000 to 50,000 OU/m^3. The type of buildings in the local area is taken into account for the purposes of this classification. It often happens that industrial and commercial plants were built a long time ago in the open countryside, with residential housing coming closer and closer to the factory boundaries. The Swiss Air Purity Ordinance stipulates that this must not result in significant odor pollution. It is not necessary to apply the same standards to plants in undeveloped areas as are applied to those right in the middle of residential areas, allowing some flexibility in the application of the guideline values.

3. ODOR ANNOYANCE

Subjective odor annoyance is no simple indicator of effect, and is largely impossible to define medically. A number of different factors determine the extent of the annoyance, such as the degree of perception, pleasant or unpleasant impression, attitude to source and, above all, a person's feeling of being at the mercy of the odor. Nonetheless, a person is able to make an integrative evaluation and to express their feeling of annoyance using a simple scale:

Odor annoyance is determined by surveying the local residents affected [5]. The zone chosen for the survey should be exposed to as homogeneous an odor pollution as possible, and must contain at least 40 residential units. If these conditions are met, the average self-evaluation score on the annoyance thermometer can be regarded as a measure of overall annoyance. The percentage of "extremely annoyed" people, i.e. those who classify their level of annoyance on the scale as being above ≥ 8, is likewise determined

It was found in a number of studies conducted in the vicinity of odor-emitting industrial plants that the 10 percent proportion of extremely annoyed people is reached at an average value of 3 and the 25 percent proportion is reached at an average value of 5 [6].

The evaluation takes place on the basis of the Swiss Noise Abatement Ordinance. The Noise Abatement Ordinance specifies an emission limit value of 60 dB(A) and an alarm limit value of 70 dB(A) for residential zones during the daytime. If these noise limit values are viewed in the context of the number of extremely annoyed persons, approximately 10 percent of those affected feel extremely annoyed when the emission limit value is reached, and approximately 35 percent when the alarm limit value is reached.

The following figure plots the level of tolerance to noise and odor emissions from the point of view of those affected against their perceived level of annoyance. The noise curve shows a shift towards "greater tolerance", which means that odors are accepted to a lesser extent than noise emissions at the same perceived level of annoyance.

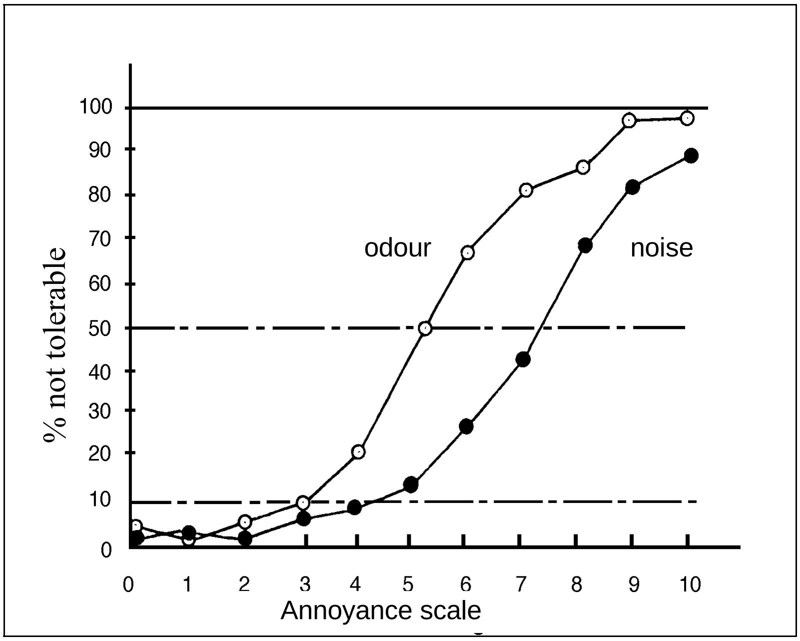

Figure 2 : Tolerance from the point of view of those affected, against perceived level of annoyance

Taking the reduced level of acceptance of odor emissions into account, the following evaluation system can be applied:

Odor level	Degree of annoyance	Percentage of highly annoyed persons	Measures
High	> 5	> 25 %	Immediate measures
Medium	3 - 5	10 - 25 %	Long-term measures
Tolerable	< 3	< 10 %	No particular measures

This type of survey has its limitations, however, especially during the planning of a plant or when the residential houses first have to be designed. In this case one is reliant on estimates which are based on model and distribution calculations and whose outcome is to show the frequency of odor threshold violations in a particular area.

4. FREQUENCY OF ODORS

This method of determination takes direct advantage of the effect of odorous substances on the human sense of smell. The measured variable is the odor time proportion, i.e. how often the detection threshold in the outdoor air is violated. To determine the emission burden, therefore, the human nose is used once again: neutral test subjects, chosen according to a previously defined random sample concept, enter a polluted area, where their odor perceptions are recorded at various control points [7].

Frequency/annoyance relationships were determined in a series of studies [8]. The frequencies relate exclusively to odors from industrial plants.
Food, grass drying and paint factories were classified in the questionnaires as "less unpleasant", while the remaining plants – chemicals, asphalt production, creosote, rubber latex, gelatin production and animal feed – were classified as "very unpleasant".

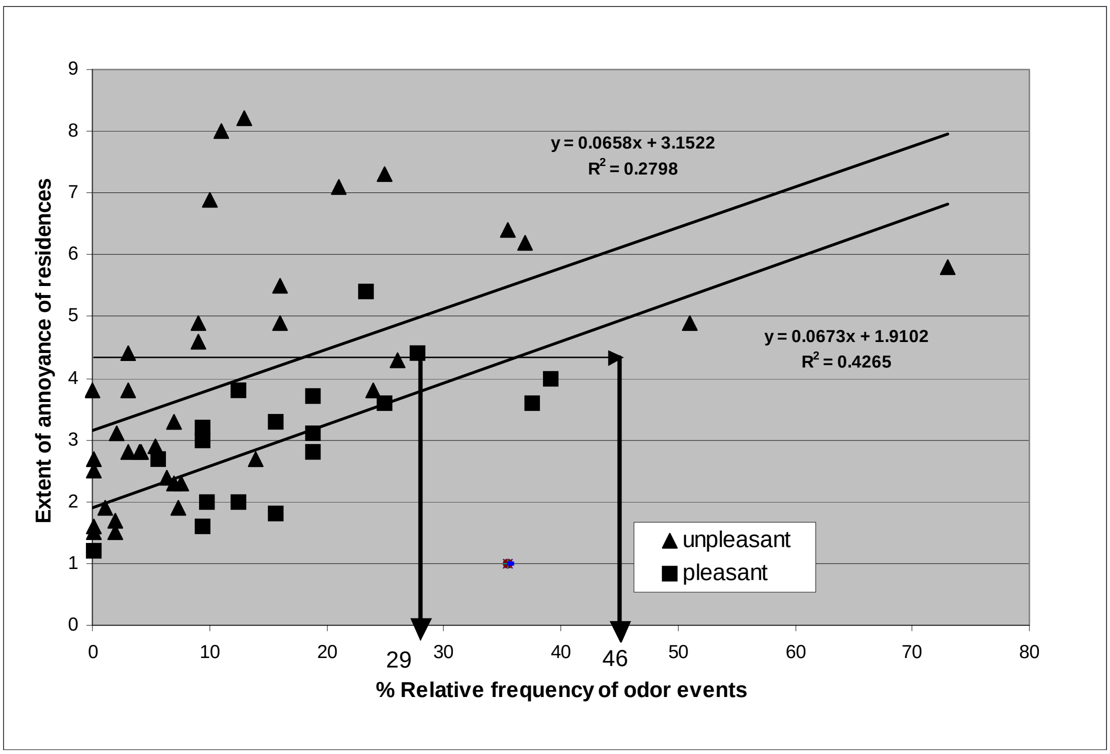

Figure 2: Frequency – annoyance relationship with respect to hedonic tne

It can be seen from Figure 2 that no simple linear relationship exists. The smoothing function shows roughly a shift by 1 scale unit on the annoyance scale if the hedonic tone is taken into account.

5. CONCLUSION

The extent of annoyance can only be determined by means of socio-psychological methods if the affected population is taken into account. At the same time, locally aesthetic values must be considered.

From an administrative point of view, the criterion of odor frequencies is easier to handle than the survey method. This method can also be used in the planning phase and in the case of smaller affected residential areas.

They are only suitable for describing the degree of annoyance to a limited extent. The same frequencies can produce different annoyance reactions, and here it is the hedonic impression on the "pleasant – unpleasant" dimension which plays a decisive role.

In important cases it may prove beneficial to apply the survey and exposure methods at the same time. This allows the odor frequencies to be calculated on the basis of current reactions of the population. In this case, odor frequencies will be individually defined for each particular plant.

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ODOUR MANAGEMENT DECISION SUPPORT SYSTEM FOR LICENSING AUTHORITIES

Lohmeyer A.[1], Czarnecki, S.[2], Homans, W.[3] and Müller, W.J.[4]

[1] Lohmeyer Consulting GmbH & Co. KG, Karlsruhe, Germany,
Achim.Lohmeyer@Lohmeyer.de
[2] State of Baden-Wuerttemberg Ministry of the Environment, Stuttgart, Germany,
stephan.czarnecki@um.bwl.de
[3] Institute for Sanitary Engineering, Stuttgart University, Stuttgart, Germany
[4] Industrial Inspectorate, Hildesheim, Germany, wjmueller@web.de

ABSTRACT

It is reported about a pilot project, aimed to speed up and to simplify the licensing processes by providing a tool to the licensing authorities for a first quick assessment of the importance of odour emitting plants. The tool, called GERDA, presently covers a choice of 5 different kinds of plants. The user feeds in the relevant data of the plant and the coordinates of its location within the State of Baden-Wuerttemberg. As output the system provides a kind of traffic light assessment on a map of the area around the plant with 3 colours according to the impact of the plant.

Key Words: Air quality, odour management, decision support, emission modelling, dispersion modelling

1. INTRODUCTION

Licencing processes have to be handled without delay. To speed them up, the German State of Baden-Wuerttemberg financed a pilot project which aims to bring together and to combine in a PC program the available knowledge of typical emissions of plants and the available (for Baden-Wuerttemberg area covering) information about dispersion conditions and land use as well as the German limit values for the frequency of odour concentrations in the vicinity of plants (GIRL 2004). The user should only have to input the relevant data of the plant and its location. As output he should get the assessment on a map of the area around the plant with the 3 colours red, yellow and green as a kind of traffic light assessment. The tool should allow to differentiate between plants with unimportant emissions, where the license in respect to odours may be granted without further delay and cases, where the authorities should insist on detailed studies. The tool will not replace detailed studies, it will only indicate their necessity. The first step of the project was to provide such a tool for a choice of 5 types of plants, considered by the licensing agencies to be important for the execution of their tasks.

To find out the most important plants, a poll was executed, asking the agencies which types of plants they wanted to be covered. On this basis it was decided to cover biological solid waste composting plants, repair paint shops, smokehouses, sewage treatment plants and foundries.
The Ministry of the Environment wanted to have the tool as a PC program with a user friendly surface and a calculation time of less than 12 minutes. For quality assurance purposes the output should contain a protocol of the input data and the emissions should be displayed for the different modules of the plant in a way, that a simple control of the calculation is possible. Additionally the durations of the emissions should be provided separately as continuous emissions, emissions only arising during working hours, emissions arising during certain actions as turning over of compost piles etc. as they are needed for a subsequent dispersion calculation. The meteorological parameters of the location should be assigned automatically as they are available area covering for Baden-Wuerttemberg in a high areal density. For the dispersion calculation, the system AUSTAL2000 (TA Luft, 2002) and GIRL (2004) had to be used, the official model for licensing procedures and odour assessments in Germany.

2. GERDA, WASTE TREATMENT PLANT AS EXAMPLE

2.1 Emission calculation

a) Input
The following illustrations concentrates on the biological waste composting plants as this type of plants is presently elaborated most in GERDA. Fig. 1 shows as an example the part of the input screen for the delivery section of a plant.

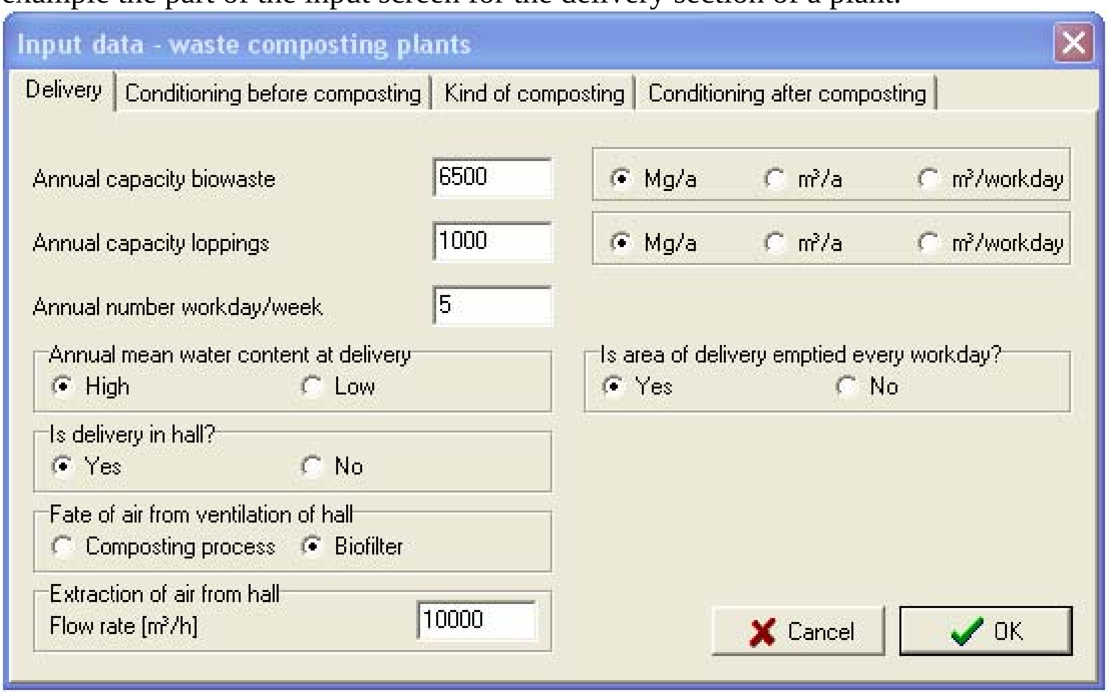

Figure 1: Input screen for waste composting plants, section delivery

It allows the input in the commonly used units Mg/a, m^3/a and m^3/workday. The questions about the number of workdays / week and whether the area of delivery is emptied every workday is needed for the calculation of the duration of the emission. The question concerning the water content of the material at delivery provides input to the selection of the emission factor. High water content might cause a higher emission factor. In case the question “Is delivery in hall” is answered “no”, all emissions of the delivery section are released into the atmosphere and no further questions are asked. But if the answer is “yes”, the last 2 questions appear on the screen asking first for the fate of the air from the hall. This air might be used for the forced aeration during the composting process or it might be conducted to the deodorizing bio filter. In both cases the flow rate of the air, out of the hall, needs to be known.
As can be seen from the top line in Fig. 1, input screens exist for the delivery, the section for conditioning before composting, the kind of (main) composting and the conditioning after composting. So it is helped to the user, to a) have a tool for an input of the data and b) to additionally have a kind of check list which shows the parameters needed for the input. Both points are important to support the quality of the estimation.

b) Output: Protocol of input
Fig. 2 shows part (rest is cut off) of the protocol of the input data, provided by the program together with the calculated emissions. All input data are contained in the protocol.

```
PROTOCOL INPUT DATA
Delivery:
 Annual mean of capacity of bio waste ........... 6500 Mg/a
 Annual mean of capacity of lopping ............ 1000 Mg/a
 Annual mean of number of workdays/week ......... 5
 Annual mean of water content at delivery ...... high
 Is area of delivery emptied every workday? .... yes
 Is delivery in hall? .......................... yes
 Fate of air of ventilation of hall ............ Bio filter
 Flow rate extraction of air from hall [m³/h] .. 10000
Conditioning before composting
 Is area for conditioning in hall? ............. yes
 Is it a separate hall or together with other .. separate
 Fate of air from hall ......................... Bio filter
 Flow rate extraction of air from hall [m³/h] .. 10000
Kind of compositing process .................... Box / Container
Main composting process:
 Is area for composting in hall? ............... yes
 Is it a separate hall or together with other? . separate
 Fate of air from hall ......................... Bio filter
 Flow rate extraction of air from hall [m³/h] .. 10000
 Feed air to composting box / container ........ 5 m³/(m³h)
Conditioning after main composting:
 Is area for conditioning in hall? ............... yes
 Is it a separate hall or together with other? ... separate
 Fate of air from hall ........................... Bio filter
 Flow rate extraction of air from hall [m³/h] .... 10000
 Number of days it takes to once turn over the ...
 ... the conditioning after main composting piles .. 1
 Number of turn overs of the piles per month ..... 1
 Cover of piles by semi permeable membrane? ...... No
Conditioning after composting:
 etc.
```

Figure 2: Part of input data documentation protocol for project with input screen as Fig.1

In Figure 2, the input data from Fig. 1 can be seen plus the additional data provided to the program via the other screens. It is structured in a way to allow a simple overview, in order to simplify the detection of inputs which might not be plausible.

c) Output: protocol emissions calculated

Fig. 3 shows the output protocol of the emission calculation for every part of the plant together with the emission factors selected by the program, the odours developed and where they go: Into the bio filter, into the main composting process or into the atmosphere. It can be seen that the duration of the emissions by single parts of the plant or single actions are quite different. The 260 day emissions are those arising during working days, the 365 day emissions are continuous emissions and the emissions arising 12 days arise by the once a month turning over of the piles taking 1 day per turnover in the example displayed. Differences between emissions in summer and winter are not considered in the program. The emissions of the bio filter are kept separate as they are treated differently by the different authorities in Germany.

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Calculated results:

 Capacity of plant [Mg/a]                          7500
                   [m^3/a]                        13333
             [m^3/workday]                        51.28
             [Mg/workday]                         28.85

 After Composting:
 Material    [m^3/workday]                        22.19

 Part of the plant                 Emis-   Odour  Flow   Odour     Odour     Dura- 
                                   -sion   devel-  to    flow to   flow to   tion  
                                   fakt.   oped  Biofil.  Biofil.  Atmosph.  Emiss.
                                 GE/(m^3s)  MGE/h   m^3/s   MGE/h    MGE/h     d/a 
                                                                 (except Bio f.)   
 Delivery                           8.2     1.5     2.8    1.5      0.0        260
 Conditioning before composting     9.7     1.8     2.8    1.8      0.0        260
 Piling or transfer to composter   10.5     1.9     2.8    1.9      0.0        260
 Main composting process           41.0    37.8     0.4   37.8      0.0        365
 Discharge and piling              27.0     5.0     2.8    5.0      0.0        260
 Subsequent composting              3.30   30.5     0.0   30.5      0.0        365
 Turnover of piles                 17.0   156.9     0.0  156.9      0.0         12
 Conditioning after composting      1.0     0.1     2.8    0.1      0.0        260
 Storage                            0.16    1.1     0.0    0.0      1.1        365
 Diffuse sources                    --      0.3     0.0    0.0      0.3        260
 ---------------------------------------------------------------------------------
 Sum                                --    236.9    14.2  235.5      1.3           
 ---------------------------------------------------------------------------------
 Bio filter                       150 GE/m^3       14.2             7.7           
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Figure 3: Typical output protocol of emission calculation for waste composting plant

2.2 Dispersion calculation

The dispersion calculation is done on the basis of the system AUSTAL2000, the official model for licensing procedures and odour assessments in Germany. Depending on the complexity of the input parameters, the regular calculation time on a regular PC is several hours, say 6 hours for a regular waste composting plant for an assessment area of 2 km by 2 km. In order to meet the demanded calculation time of 12 minutes, some time consuming parameters were excluded: Influence of topography is not respected by a three dimensional flow field but via the meteorological input data (three dimensional dispersion class statistics), dispersion categories statistics only contain three stability classes (stable, neutral unstable) instead of the regular 6 classes, no influence of buildings is possible, maximum stack height is 30 m (thus only small areas of assessment are necessary), minimum grid size of area of assessment is 50m by 50m and only a minimum of particles is released for the Lagrangian dispersion calculation. Therefore quite some advantages of the new German AUSTAL2000 procedure in comparison to Gaussian dispersion calculation were lost, but it was important for the project to basically build upon the new regulatory model.

2.3 Display of final results

Figure 4 shows the display of the final result for a plant emitting 200 MGE/h on the basis of the odour perception limit values for residential areas. For the red area (dark grey in this paper), the limit values for the frequency of odour perceptions in industrial areas might be exceeded. Within the yellow area (light grey), exceedances of the limit values for residential areas are estimated to be as likely as they are not, i.e. in case living quarters exist in this area, the licensing authority will demand more detailed studies. In case living quarters only exist within the green areas (white in this paper), the odour part of the project can be waved through.

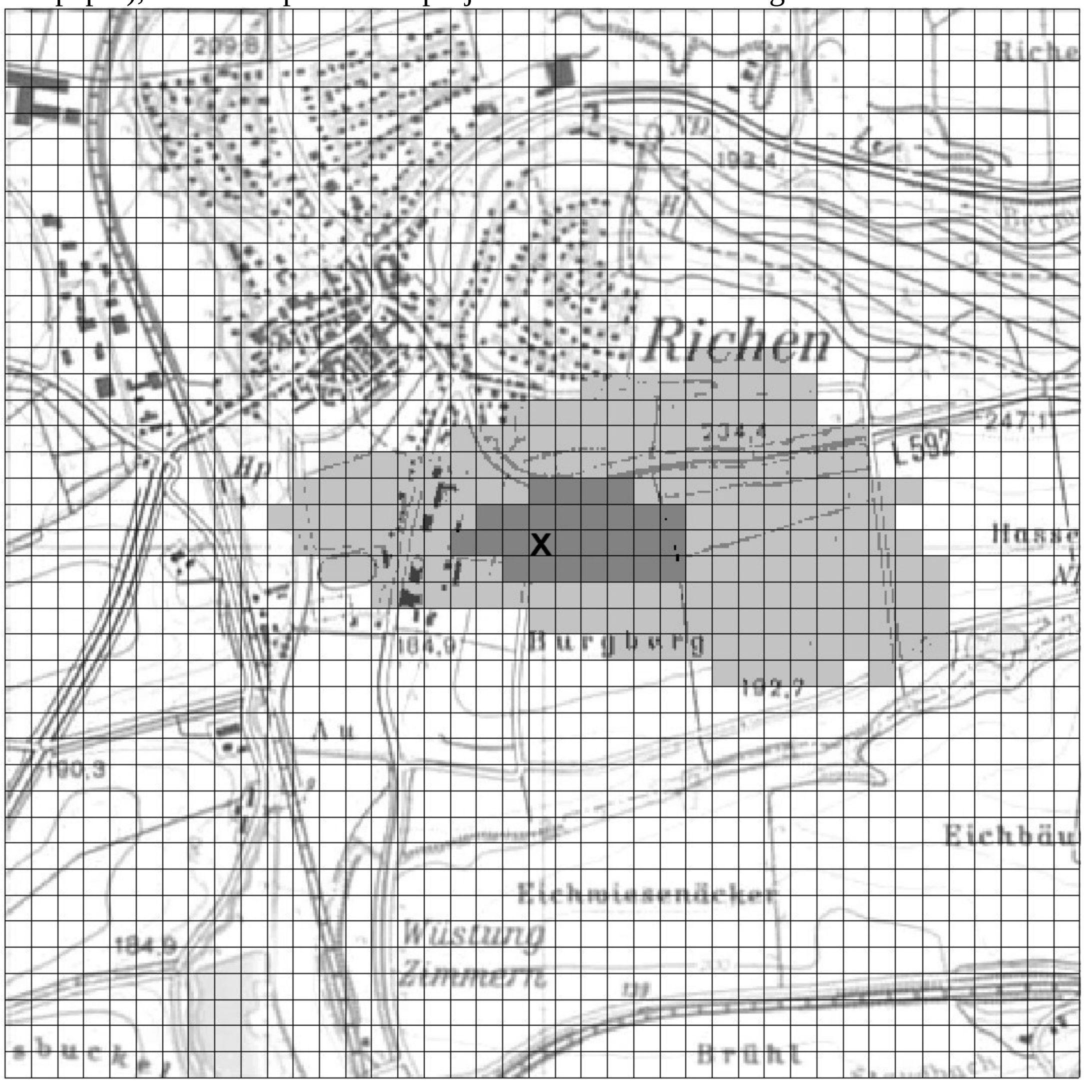

Figure 4: Display of result for residential areas. Dark grey: limit values are very likely to be exceeded. Light grey: exceedances are estimated to be as likely as they are not, i.e. more detailed studies are needed.

3. DATA USED AND VALIDATION

Presently, the dispersion part of GERDA is under development and not yet validated, but the emission part was finished some time ago and got some first validation. The data used for the determination of the emissions of the biological waste composting plants mostly come from the work of Bidlingmaier et al., 1997, which systematically collected this kind of data for different plants and created a sort of calculation sheet to determine the emissions in a concerted way. These data were enriched for GERDA by material in Homans and Bardtke, 1993 and VDI 3475, Part 1, 2003.
It is very important to note, that Bidlingmaier addresses in Bildingsmaier et al., 1997 the necessity to

- collect and include more data,
- annually update the data base,
- keep a data base with concerted data, i.e. data which are agreed in the community.

As GERDA has the character of a pilot study, it is its main aim the show that it is possible to create such a tool, that the expectations of the users basically can be met, that they can identify their plant in the program. Questions as a sophisticated validation of the calculated emissions and the securing of a continuous updating only were in the background. Deviations of the calculated emissions from the real emissions are therefore of minor damage. Seven first comparisons show in this respect

- for 2 of the comparisons an underestimation by the calculation and for 5 comparisons an overestimation
- for 2 of the comparisons, that are approx. 30 % of the comparisons, a deviation between calculation and measurement < ± 50 %, for 6 of the 7 comparisons, that are approx. 85 % of the comparisons, a deviation < ± a factor of 4.

GERDA is presently only validated by the above mentioned 7 comparisons, i.e. for quality assurance no systematic comparison has been executed between results of field measurements and results of the program for data sets which were not used for the development of the program. Such a validation therefore is recommended to each user.

4. AVAILABILITY AND MAINTENANCE

Presently the emission part of GERDA is used by the relevant authorities in Baden-Württemberg and it was made accessible by the Baden-Württemberg Ministry of the Environment to the authorities in the other German states. All costs for the development of this part were provided by the ministry, but the ministry is not able to distribute the GERDA CD and handbook to all interested parties and to provide advise, delivery, hotline etc. For that Lohmeyer Consulting GmbH & Co. KG was contracted and the ministry agreed that only a nominal fee of EUR 75.- (incl. VAT) is charged per order. See http://www.lohmeyer.de/eng/Software/Gerda/gerda.htm for further information.

5. FUTURE ACTIVITIES AND VISION

As already addressed by Bidlingmaier et al., 1997 it is important just not to have GERDA developed and let it be as it is. In this case it will get more and more outdated and it will slowly disappear. All the effort invested would be wasted. What needs to be done instead is (together with the already existing service) to secure continuity , to ensure validation, upgrades and updates and a web page for frequently asked questions, to enrich GERDA by additional types of plants and meteorological information outside Baden-Württemberg, to make it available for use all over Europe and to have it accompanied by a group of experts. The idea and vision for this accompanying expert group is as follows: A group of experts accompanying GERDA should be formed, consisting of persons from authorities, science and consulting. They should meet unsalaried 1 to 2 times per year, should observe new developments and the state of the art, should ensure a procedure within GERDA which is in concert with the community and should decide about upgrades, updates, enrichments, validations etc. This would give continuity, quality, reputation and acceptance to GERDA and would ease the raising of funds necessary to execute the upcoming tasks.

In case of interest to take part in such an expert group or the availability of a "full" high quality validation data set for the type of plants covered by GERDA, please mail to the corresponding author Achim.Lohmeyer@Lohmeyer.de.

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CORRELATION BETWEEN THE PUBLIC ODOR COMPLAINTS AND TOXIC AIR POLLUTANTS

Aysen Muezzinoglu and Faruk Dincer

Dokuz Eylul University, Environmental Engineering Department, Kaynaklar Campus, 35160 Buca, Izmir, Turkey, aysen.muezzin@deu.edu.tr, faruk.dincer@deu.edu.tr

ABSTRACT

Air Toxics program of the US EPA foresees the measurement of a long list of trace chemicals, mostly organics in the ambient air. This program covers 188 pollutants to be monitored in the ambient air according to protocols elaborated by the states.

In Kentucky Air Toxics Monitoring Protocol, 77 chemicals are measured every 12th day at a number of stations in the western part of the city of Louisville since July 1999. Presently, the number of stations is six. A large number of industries working with petroleum, petrochemicals and synthetic polymers, and chemicals exist in the industrial region of Louisville next to the Ohio River known as Rubbertown. In the city of Louisville, public complaints were stored in a detailed data file covering a period of more than 10 years.

Screening out the available air toxics data set for unimportant (mostly zero or below detection limit) concentrations ended in only 20 air toxics that were found worth for further studies. Between these concentrations and the complaint data, statistical analyses were performed. Pearson coefficients between concentrations of these gases and the public complaints on the measurement day showed only a few of these chemicals have some dependencies at the ambient levels. The air pollutants that were found of special interest for odor complaints in this study were the acrylonitrile, hexane, methyl acetate, MTBE, benzene, toluene and styrene. Of these, the last three might have been affected by traffic flow around the sites. However, only styrene is one of the sites has a notable correlation coefficient with public complaints.

Key Words: odor complaints, odor threshold, toxic air pollutants

1. INTRODUCTION

Odor annoyance is in connection with chemical stimulation of chemoreceptor cells in the olfactory epithelium of the nose (van Ruth, 2001) by the gas molecules. Evaporation from free surfaces, leaks and regulated emissions of odorous gases create problems in urban and industrial areas. In fact most of the pollution problems in air, soil or water bodies are recognized by the public as “odor” (Miedema et al., 2000; Dincer et al., 2004).

Odor perception is largely dependent on the concentration of the odorous compound in the air, its odor threshold and the pleasantness of the odor which may also change with concentration and the period of exposure. On the other hand, co-presence of several odorous gases may create different perceptions in contrast to the levels of perceptions due to each one of the specific components in pure form at the same concentrations.

This study is carried out in order to find out a correlation between public odor complaints and toxic air pollutants. Complaints and air toxics concentrations in the western Louisville area were taken as the two main independent variable groups. The monitoring data for the chemicals has been taken from the West Jefferson County Community Task Force website (http://www.wjcctf.org/air) and from the University of Louisville. Daily average chemical measurements in the air were paired with the public odor complaint data belonging to the same day as a first step.

2. MATERIALS & METHODS

2.1. Site description

Rubbertown is the largest source of industrial emissions in the Jefferson County area with its petrochemical complex located in west part of Louisville. The complex is composed of 11 large chemical plants that account for approximately 20% of the Kentuck’s total industry releasing the air toxics and 42% of all industrial air emissions in Jefferson County. Also, the county’s largest wastewater facility is located in close proximity to the Rubbertown.

Products made in Rubbertown are widely used in thousands of different products, including acrylic paint; adhesives for labels and stickers; disposable diapers; ink; bottles; plastic toys, PVC and CPVC pipe and fittings, vinyl house siding, etc.

2.2. Monitoring sites, air toxics and odor characteristics

Presently, 77 toxic chemicals are measured every 12^{th} day at 6 different air pollution monitoring stations in the western part of the city of Louisville. In the city, odor complaints coming from urban dwellers are recorded for the last six years. Among the 77 compounds, 20 compounds were found to be important levels. These compounds include hydrocarbons, aromatic compounds (e.g. benzene, toluene and xylenes), and some chlorinated hydrocarbons (chloromethane, methylene chloride). Freons are non-odorous but are studied anyhow, thinking that they may occur together with an odorous substance that is not monitored but coming from the same industrial source. Table 1 lists these compounds as well as their odor threshold values and odor characteristics. Among these 20 compounds, it is seen that 8 compounds including benzene, chlorinated hydrocarbons and some aromatics are USEPA priority pollutants while 15 compounds are in the USEPA hazardous air pollutants (HAPs) list.

As it can be seen from Table 1, information about odor thresholds and odor characteristics are available only for some compounds. In this table both recognition and detection thresholds are submitted as taken from the literature. The detection threshold is defined as the lowest concentration at which a specified percentage of the panel (usually 50%) detects a stimulus as being different from odor-free blanks. The recognition threshold is the lowest odorant concentration at which a specified percentage of the panel (again, usually 50%) can ascribe a definite character to the odor. In general, recognition thresholds are approximately two to ten times higher than the detection thresholds (Hellman and Small, 1974).

Table 1. Odor thresholds and odor characteristics of monitored VOCs in Lousville (AIHA, 1989; USEPA, 1992)

Compound	Odor Thresholds (ppm)	Odor characteristics
1.2.4-trimethylbenzene	n.i.	
1,3 butadiene	1.6 (D)	Aromatic/rubber
Acetone	100 (R)	Chemical, sweet, pungent
Acrylonitrile*	21.4 (R)	Onion, garlic, pungency
Benzene*	61 (D)	Aromatic/sweet/solvent
Carbon Disulfide	0.21 (R)	Vegetable sulfide/medicinal
Carbon Tetrachloride *	141 (D)	Sweet/dry/cleaner, distinctive
Chloroform*	133 (D)	Sweet/suffocating, characteristic
Chloromethane*	10 (D)	Faint sweet smell
Chloroprene	n.i.	
Freon 12	n.i.	
Freon 22	n.i.	
Freon 113	n.i.	
Hexane	130 (D)	Faint peculiar odor
m,p xylenes*	0.12 (D)	
Methyl acetate	n.i.	
Methylene Chloride*	1.2 (D)	Sweet/ethereal, penetrating
Methyl Ethyl Ketone	2 (D)	Sweet/sharp, acetone like
Methyl Methacrylate	0.21 (D)	Pungent, sulfidy
MTBE*	n.i.	
Styrene	0.033 (D)	Sharp/sweet/aromatic, unpleasant
Toluene*	0.021 (D)	Sour/burnt, benzene-like
Vinyl chloride*	3000 (D)	mild, sweet

n.i.: No information
* : USEPA priority pollutant
+ : recognition threshold

3. RESULTS & DISCUSION

During the monitoring period of air toxics between 1999-2005, totally 424 odor complaints were recorded in the city of Louisville mostly around the monitoring sites. The original size of the complaints data obtained from Air Pollution Control District (APCD) of Louisville Metro administration is 6000. this database is consisted of public complaints and include some Air Pollution Control District (APCD) investigation reports (http://www.apcd.org). Numbers of usable complaint reports belonging to the air toxics on the sampling days at the six monitoring sites have been reduced to 53 for Site I, 76 for Site C, 75 for Site A, 74 for Site E, 74 for Site F and 72 for Site M after pairing the datasets.

In order to find out a correlation between the odor complaints and air toxics concentrations, Pearson statistical analyses were performed. The Pearson coefficients of each air pollutant at the monitoring sites and the corresponding number of complaints were found and presented in Table 2.

Table 2. Pearson coefficients between the number of complaints and pollutant concentrations

Pollutant	Site I	Site C	Site A	Site E	Site F	Site M
1.2.4-trimethylbenzene	*	*	*	*	*	*
1,3 butadiene	0.12	*	0.17	*	*	*
Acetone	*	*	*	0.14	*	*
Acrylonitrile	*	*	**0.29**	*	**0.25**	*
Benzene	*	*	**0.29**	*	*	*
Carbon Disulfide	*	*	**0.24**	*	**0.25**	*
Carbon Tetrachloride	**0.24**	*	*	0.12	*	*
Chloroform	*	*	*	*	**0.29**	*
Chloromethane	**0.23**	*	*	*	*	*
Chloroprene	*	*	*	**0.20**	*	*
Freon 12	*	*	*	0.12	*	*
Freon 22	*	*	*	**0.30**	*	*
Freon 113	0.18	*	*	0.13	*	*
Hexane	*	*	**0.32**	*	*	*
m,p xylene	*	*	**0.23**	*	0.10	*
Methyl acetate	0.12	*	*	*	**0.46**	*
Methylene Chloride	*	*	*	0.12	*	*
Methyl Ethyl Ketone	*	*	*	*	**0.23**	*
Methyl Methacrylate	*	*	*	-	*	*
MTBE	0.12	*	*	**0.23**	**0.34**	**0.28**
Styrene	*	*	*	-	*	**0.54**
Toluene	**0.43**	*	*	-	*	0.10
Vinyl chloride	**0.23**	*	**0.23**	-	0.13	0.13

* no correlation

- insufficient concentration data at the monitoring site

In Table 2, statistical dependencies between odor complaints and air toxic measurements for the compounds are shown in bold. The Pearson coefficient values for the correlations suggest that 20-54% of the variance in odor complaints can be explained by some of the air toxic levels in the city. All of these compounds are in the USEPA hazardous air pollutants (HAPs) list. These air toxics or any other compound that was not monitored routinely but coming from similar sources should be controlled for the maintenance of a better life quality for the urban dwellers.

4. CONCLUSIONS

Odor is a human sensory experience usually caused by mixtures of compounds. The human nose is a highly sensitive instrument capable of detection even at extremely low concentrations of certain chemicals. Very low concentrations of an odorous substance can produce an odor sensation indicating the presence of odorous vapors and gases depending on its odor threshold.

Studies which have reviewed community odor and health problems caused by air toxics reveal that a variety of nuisance records and public complaints are related to exposure of odorants. In many cases, this occurs even though the identified odorant is way below the thresholds for toxicity. This indicates that further studies are necessary to define the link between odor complaints and chemical exposure of air toxics. This requires more controlled studies for the odor annoyance part than the public complaint records in this study.

In this study the public complaints database has been evaluated to pair the odor sensing with the concentrations of toxic substances in the air. The 12 day intermittency of the air toxic determination caused several losses in pairing the datasets. Also the random and subjective character of the public complaints data created rather low correlation coefficients between the concentrations versus the number of complaints on a specific day.

Yet, the rather weak correlations for a few airborne gases such as styrene, MTBE, methyl acetate, hexane and toluene at the stations near the petroleum industries could be interpreted as the important starting points for more controlled studies. However, it must also noted that some of these compounds also might have originated from heavy traffic lanes around the monitoring sites.

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ODOUR DISPERSION MODELLING AROUND A SUGAR BEET FACTORY IN ANKARA

Aysel T. Atimtay*, Wolfgang J. Müller, Achim Lohmeyer*** and Ulf Janicke******

* Department of Environmental Engineering, Middle East Technical University, Ankara 06531, Turkey, aatimtay@metu.edu.tr
** Industrial Inspectorate, Hildesheim, Germany, wjmueller@web.de
*** Lohmeyer Consulting GmbH & Co. KG, Karlsruhe, Germany, achim.lohmeyer@lohmeyer.de
**** Janicke Consulting, Meersburg, Germany, uj@janicke.de

ABSTRACT

Odour measurements were carried out by executing field inspections in the vicinity of a sugar beet factory in Ankara, Turkey. Emission estimation and dispersion modelling was done in this study to gain some additional insight into the odour problem. This paper contains an overview over the field inspections, the model used – the German regulatory model AUSTAL2000 – and some findings: In this case of missing reliable emission and meteorological data, the model can nevertheless provide some support for the results of the inspections.

Key Words*:* Odour Immission, Field Measurements, Odour Dispersion Modelling, Odour from a Sugar Beet Factory, AUSTAL2000

1. INTRODUCTION

The neighbourhood of a sugar beet factory was selected for the immission measurements in Ankara for a project (carried out between 2002 and 2005) related with "Odour Emission and Immissions Management Policy in Turkey" supported by the LIFE program of the EC. The sugar beet factory under consideration is located within a residential area. Although the location of the factory during establishment was selected at the outside of the city, due to the tremendous expansion of the city, the sugar factory today is surrounded by residential areas. Therefore, the people living around the factory are the direct receptors of odour and many complaints arise from the public.

In this factory approximately 4000 tons of sugar beets are processed per day. 12% of this amount is converted to sugar. In the sugar manufacturing process sugar beets are washed in a pond near the factory and the waste water is sent to the waste water treatment plant. The plant lies within the factory boundaries and consists of equalization basin, sedimentation pond and aeration chambers. All these processes create a special kind of odour peculiar to the sugar factory, like a sweaty, aromatic odour. The treatment plant does not work properly.

The factory works in shifts and emits odour 24 hours per day during the campaign period which lasts for 3-4 months. The intensity of odorous emissions increases during this period 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. Field measurements were conducted to learn more about these complaints and dispersion modelling studies were carried out to gain additional information about the odour problem in this area.

2. FIELD MEASUREMENTS

The location of odour emitters in the plant is shown in Fig.1. An area of 1.7 km^2 was chosen as the assessment area. For measurement purposes, the assessment area was gridded according to the principles stated in VDI 3940. The distance between measurement points is defined according to the desired resolution. In this case, it was taken as 250 m. The grid system is shown on a 1/25 000 topographic map in Figure 2. Grids were located especially in the NE – WSW direction according to the wind rose. The cells were numbered and each corner was visited according to a time plan for 12 months covering the four seasons of spring, summer, fall and winter.

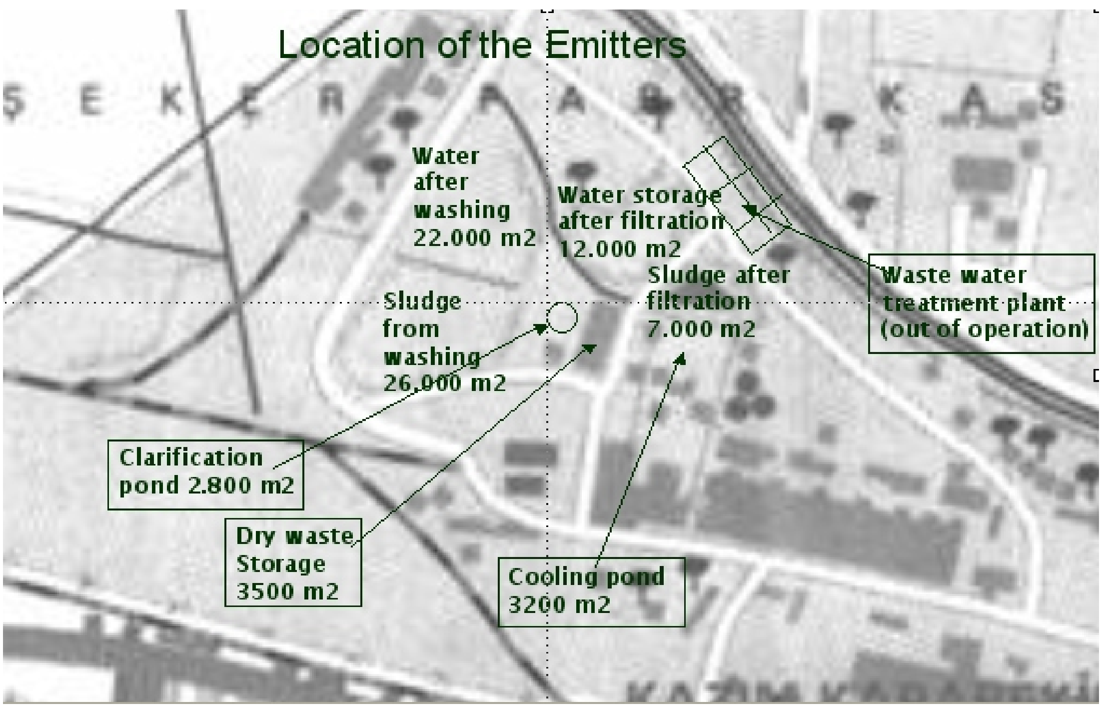

Figure 1. Location of the odour emitters in the sugar plant

The time plan involved visits to the same site for at least 52 times during the year. These visits took place at different days of the week and at different hours of the day. During the visits a protocol on odour perception (according to the German guideline VDI 3940) was filled in. For 60 times within a time period of 10 minutes (i.e. every 10 seconds) the perception of odour was recorded in the form of a yes/no decision.

Figure 2 (left) shows the percentages of hours with odour perceptions as a result of the field inspections and thus the great influence of the odour emissions of the factory. Within the time period of the sugar beet processing campaign (September – December), the perceptions are even more frequent as can be seen in Figure 2 (right), showing the frequencies outside the campaign period. The odour emissions of a sugar beet factory during the campaign are usually dominated by the stack emissions. The other main source usually is the waste water: The sugar beet washing ponds, the sedimentation ponds for the soil washed away from the beets, the waste water treatment plant and the final sludge and water maturation ponds with their residence time up to 1 to 2 years before the water can be released into the discharge system. The waste water emissions, therefore, usually exist for the whole year and odour emission depends on the season (lower in winter, higher in summer). For the detailed description of the immission measurements and odour percentage determination around the sugar beet factory, see Güvener et al., 2004.

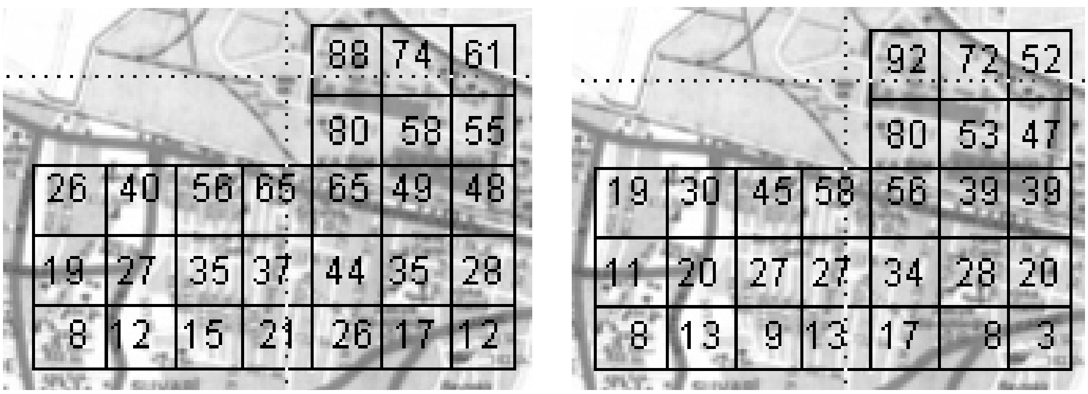

Figure 2. Percentage of odour hours in the neighbourhood of the sugar factory. Result from field inspections. Left side: annual. Right side: outside the campaign period.

No emission measurements could be done for the plant within the study period of the project and no further details about the emissions could be obtained. This is the classical case where field inspections are particularly helpful. Additionally, the location contains water surfaces whose emissions are difficult to measure. Modelling around the factory was done to gain some additional understanding of the situation.

3. THE FLOW AND DISPERSION MODEL

3.1 Model used

Odour dispersion calculations were carried out with AUSTAL2000, the official reference model for licensing procedures (TA Luft, 2002) and odour assessments (GIRL, 2004) in Germany. It implements the odour dispersion model AUSTAL2000G.

AUSTAL2000 is a Lagrangian particle model that is set up and verified according to the German Guideline VDI 3945 Part 3, 2002. Main advantages of a Lagrangian dispersion model over other model types are:

- The model is applicable to the near field of sources, where the classical equation of diffusion does not apply.
- Time-dependent dispersion situations can be handled.
- The model does not rely on calibration parameters.
- Arbitrary source geometries can be accounted for (e.g. a point source is truly modelled as a point source or area source).
- Source dynamics can be accounted for explicitly.
- Complex meteorological profiles and three-dimensional wind and turbulence fields can be applied.

For complex terrain (terrain profile, buildings), AUSTAL2000 invokes a diagnostic wind field model for the calculation of the three-dimensional wind fields. Alternatively, the fields calculated by more sophisticated wind field models can be applied. Program, source code, and documentation of AUSTAL2000 are available free of charge (AUSTAL2000). The program package is available in German, and the English version is intended for next year.

3.2 Development of AUSTAL2000G

AUSTAL2000G was developed in 2003/2004 by Janicke Consulting on behalf of several federal states in Germany (Janicke, L. and Janicke, U., 2004). Starting point was the model of a meandering plume. From the concentration fluctuations of the odourous substance, the frequency of odour perceptions can be deduced which is the basis for the assessment of odour impact. In German regulations, for example, odour assessment is based on the concept of the so called odour hour. An hour is called "an odour hour" when at least at 10% of the time within this hour odour is perceived (VDI 3788, Part 1, 2000). The frequency of occurrence of "odour hours" within a year is then compared to given limit values. These limit values are 10% for the residential areas and 15% for the industrial areas in Germany. In the draft Turkish Odour Regulation these limits are taken as 15% and 20%, respectively.

Concentration fluctuations in meandering plumes had been studied in detail by means of LIDAR measurements which were reviewed and evaluated recently within the project COFIN (Nielsen et al., 2002 and Janicke, 2004). In other data sets, the dispersion of a passive tracer (SF_6) was investigated concomitant with the odour dispersion (Bächlin et al., 2002). By means of a sensitivity analysis, possible and desirable simplifications of the modelling concept were investigated with the aim to broaden the range of application and to reduce computational expenses. The resulting modelling variants were tested on various experimental data sets. The simplified modelling variant (with the working title AUSTAL2000G), in which the presence of an odour hour is deduced from the hourly mean concentration of the odourant, gives in general a satisfactory agreement with the more sophisticated model variant. Subsequently AUSTAL2000G was implemented into the existing dispersion model AUSTAL2000.

The basic result of a dispersion calculation with AUSTAL2000 is the concentration distribution near ground level for the trace substance of interest in form of a time series of hourly means. From this data base, short-time values according to EU directives, annual means, and the frequency of odour hours are deduced by the program. The capability of calculating the concentration of trace substances simultaneously and consistently with the frequency of odour hours turns out to be of great practical advantage for assessment - licensing procedures for authorities.

The frequencies of odour hours predicted by AUSTAL2000 are valid for receptor points. However, odour assessment often refers to area averages. A post processor exists to perform the required averaging in the model.

3.3 Model calculations

AUSTAL2000 can be used to re-calculate measurement campaigns. Here, the actual time series of meteorological parameters (wind velocity, atmospheric stability) and odourant emissions as well as the actual topographical situation (terrain profile, nearby buildings, surface roughness) can be accounted for.

It is a “state of the art” in Germany now to make dispersion calculations by using AUSTAL2000. In former times a Gaussian type model was used for the licensing procedures. But the restrictions of the old model often resulted in serious disagreements in the licensing process. This lead to unreasonable situations that for quite some projects “official” concentration predictions by the old official Gaussian type model AUSTAL86 had to be prepared plus additionally a more believable 3-dimensional flow and dispersion calculation had to be made. The disagreement arose from the following deficiencies:

a) Influence of buildings
   Especially in the near field (up to say 200 m) of emissions from low source heights, where the concentrations might still be relatively high, the influence of buildings on the dispersion might be important. The effect might as well increase as decrease the concentrations.
b) Dispersion parameters
   The Gaussian plume dispersion parameters σ_y and σ_y in TA Luft, 1986, were determined from measurements in distances much greater than 100 m downwind the source. Theoretical considerations indicate, that they might not be applied for downwind distances smaller than 100 m. Additionally σ_y and σ_y should depend on the height of the plume above the ground and the aerodynamic roughness of the location. Both parameters were not contained in AUSTAL86.
c) Low source height emissions
   The proper wind velocity in the Gaussian dispersion equation has to be the velocity in the actual height where the plume travels. For large source heights, say 100 m, that is not a problem as the wind velocity does not change significantly in these heights with distance from the source. But for ground level sources, it is difficult to provide the proper wind velocity. On the first meters downwind the source the wind velocity is near zero (as the plume is near the ground level). Further downstream it increases as the plume thickness increases, and only further downstream than say 100 m the wind velocity in a height of 10 m might be appropriate. Using just 10 m reference height for the wind speed for all distances downwind of the source might easily result in an error of a factor of 2 in the concentration calculation near a ground level source.

d) Topography
The former German regulatory model AUSTAL86 was unable to properly account for influences of topography. This was corrected by the new model.

All these restrictions lead to the development AUSTAL2000 where AUSTAL2000G is contained.

3.4 Input data used

The following input data were used to do first runs with the model AUSTAL2000 for this study. The odour emissions are first rough estimates. Table 1 contains more detailed estimations. But the calculations, displayed in this paper, were executed with the first estimates:

a) Emission data
Number stacks: 1
Stack height: 20 m
Exhaust volume: 10.000 m^3/h
Exhaust temperature:105 °C
Relative humidity: 100 %
Odour concentr. in the stack: 10.000 OU/m^3, thus emission of 100 MOU/h
(MOU/h = Million Odour Units/hour)
Duration of emission: 1. August 2003 to 30. November 2003 (campaign period)
Area of waste water lagoons: 20.000 m^2
Emission factor: 10.000 OU/m^2h in November – March
30.000 OU/m^2h in April – October
thus emissions of 200 and 600 MOU/h

b) Meteorological data

Meteorological data for the study has been taken from the Esenboga meteorological station. Instead of Esenboga meteorological data, data from Etimesgut meteorological station would be better. However, this station is a very small one and all the required parameters for the model runs are not measured here or are not available..

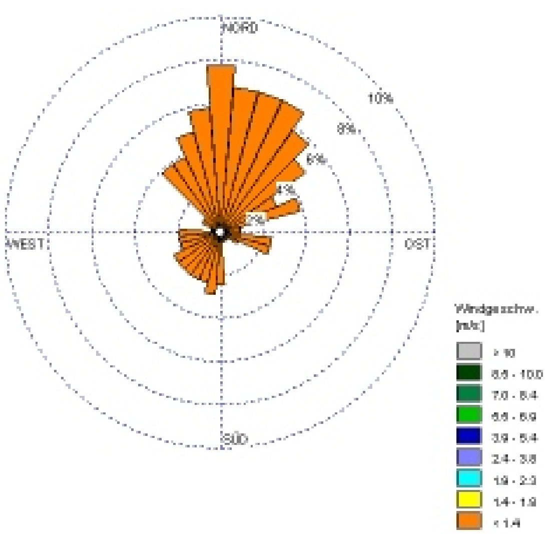

Figure 3. Wind rose of meteorological station Esenboga

c) More detailed emission estimates

Odour sources containing water surfaces have emissions being difficult to measure. The odour emission from these sources may be determined by using emission factors from the literature or gained by comparison between inspection an modelling. The results of the emission factors estimated for the sugar plant on the basis of such emission factors are given in Table 1. As can be seen, emissions depend on the month of the year because of the temperatures. The highest emissions are expected in the summer months.

Table 1. Odour emissions in MOU/h of the Ankara sugar plant, estimated for the water surfaces by application of emission factors [OU/(m^2 h)], observed for plants in Germany. (MOU/h = Million Odour Units/hour).

Name of module	Surface area [m^2]	Emiss. [MOU/h] August	Emiss. [MOU/h] Septem.	Emiss. [MOU/h] Octob.	Emiss. [MOU/h] Novem.	Emiss. [MOU/h] Dec.-Apr.	Emiss. [MOU/h] Mai-July
Clarification pond	2.800	2.8	7	14	28	0	0
Sludge from washing beets	26.000	13	26	78	78	2.6	78
Water after washing beets	22.000	22	55	110	220	0	330
Water storage after filtration	12.000	6	15	30	60	0	90
Sludge after filtration	7.000	3.5	7	21	21	0.7	21
TOTAL	69800	47.4	110	253	407	3.3	519

4. RESULTS AND CONCLUSIONS

The results of the dispersion model calculations are given in Figure 4 and 5 for the percentage of odour hours including the campaign period (annual) and for the percentage of odour hours outside the campaign period, respectively.

As can be seen from Figure 4, the percentage of odour hours including the campaign period (annual) with the area sources and stacks (h=20 m) are quite high. The percentage of odour hours goes as high as 73% just around the factory. A little further away the percentage is about 50%. Along with the dominating wind direction in most of the areas in the southern part of the factory, the percentage of odour hours are approx. 20%. This is the limit for the industrial areas according to the draft Turkish Odour Regulation. Modelling and field inspection leads to the same conclusion in this case.

As far as outside the campaign period (January to August) is concerned (Figure 5), the percentages are at first expected to be lower than in the previous case because the odour emissions during the campaign period are dense. However, it was not surprising to find out that the percentages of odour hours are more or less the same as in the "campaign case" in most of the areas around the plant. This is on one hand attributed to the ponds where water and sludge is stored before they are given to the wastewater treatment plant of the Ankara municipality, thus representing a low level source. On the other hand it is due to the low height of the stack, also representing a low level source, leading to a low level concentration field.

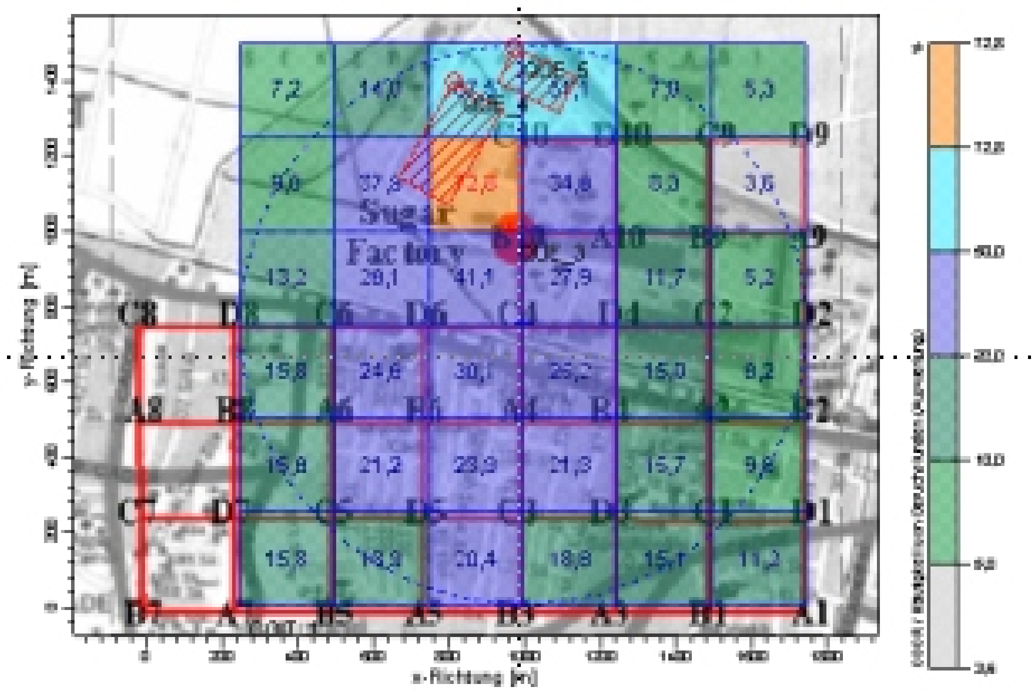

Figure 4. Percentage of odour hours including the campaign period (annual)

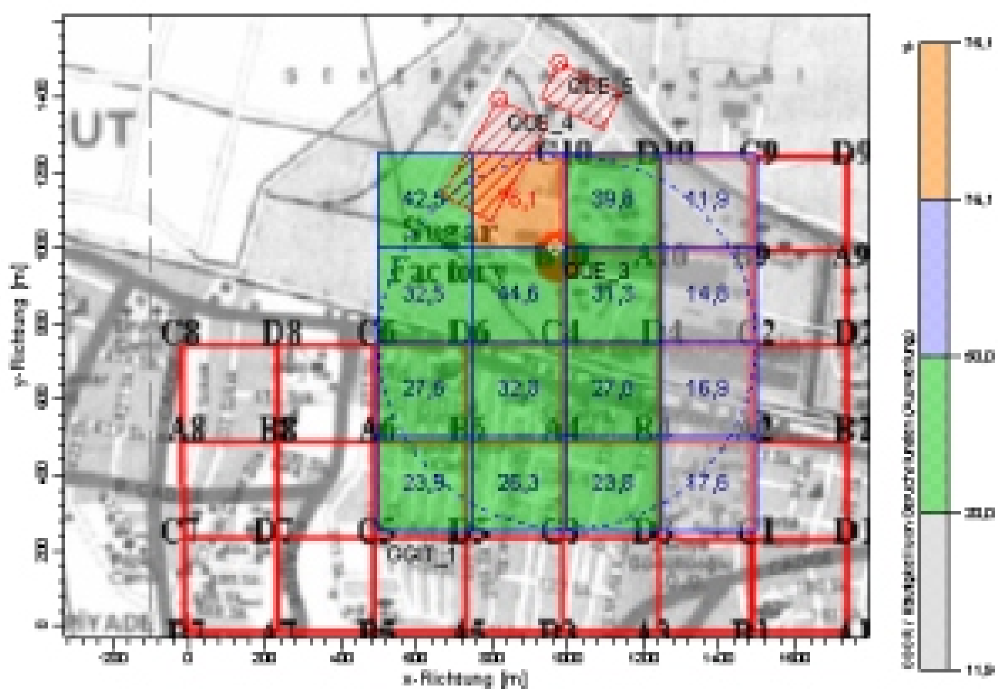

Figure 5. Percentage of odour hours outside the campaign period

Figure 6 shows the distribution of percentage of odour hours found by immission measurements. Again around the immediate vicinity of the plant highest percentages are found. Since the dominating wind direction is from N-NE to S, the percentages get smaller towards the south (about 20-40%).

The model results by AUSTAL2000 were in principle in accordance with the results of the immission measurements. The combination of immission measurements and model calculation is needed to gain additional information about the odour problem and possible solutions in such an area. However, because of some assumptions (meteorological data, emission data etc.) made for the model inputs because of the lacking these data, the results obtained from model runs do not fit exactly with the results obtained from immission measurements.

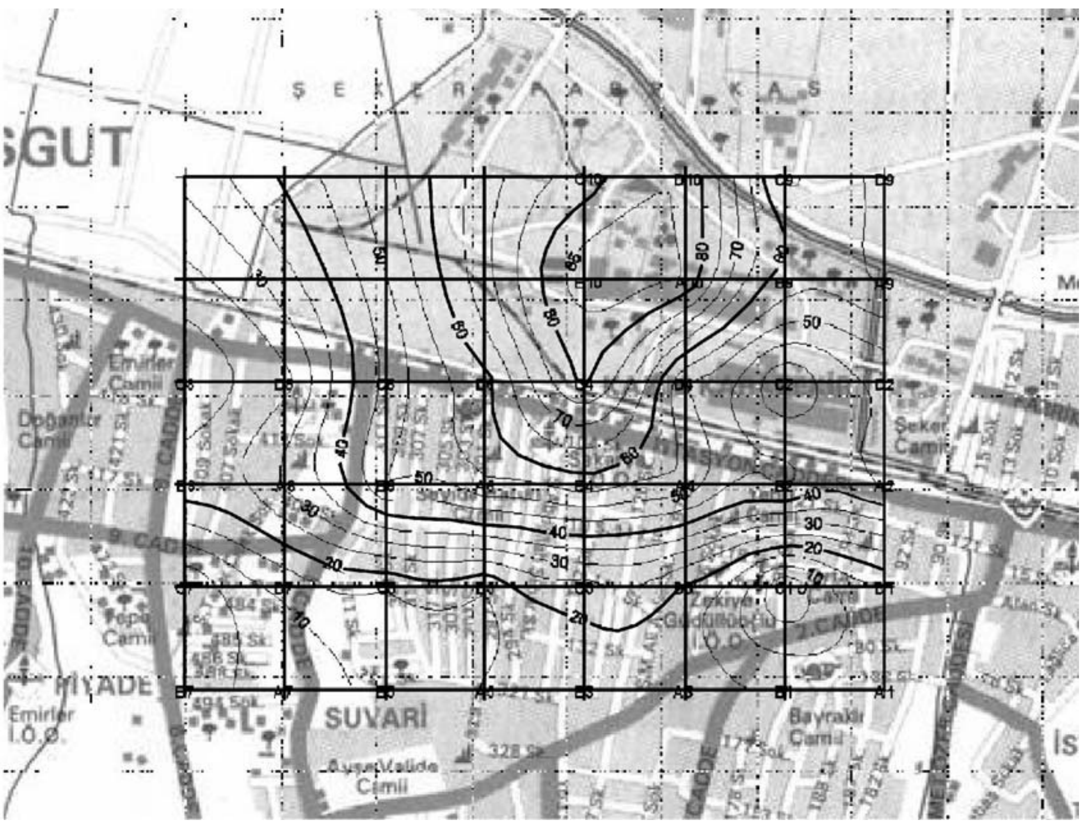

Figure 6. Lines of equal percentages of odour hours determined by immission measurements for the whole period (annual)

5. ACKNOWLEDGEMENTS

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ADAPTATION OF BIOLOGICAL WASTE GAS PURIFICATION SYSTEMS TO MEDITERRANEAN REGION

Emine Bolcu

University of Stuttgart, Institute for Sanitary Engineering,Water Quality and Waste Treatment, Bandtäle 2 D-70569 Stuttgart (Büsnau) / Germany
Emine.Bolcu@iswa.uni-stuttgart.de

ABSTRACT

Biofiltration technology has proved to lend itself not only to the reduction of odor emissions, but also to the prevention of air contamination with undesirable components. The goal of this study is to introduce this low-cost system to the developing countries especially in Mediterranean region. For this purpose, various agricultural and industrial waste products from Mediterranean region of Turkey were tested in a pilot biofilter plant to determine if they could be used as filter material in biofilters. In order to find out if they could be proposed as filter materials, the purification efficiency of a contaminated gas stream should be determined. Results of the researches propose that most of the tested waste products have the potential to be used as filter media.

Key Words: biofilter; Mediterranean region; waste gas treatment; filter material

1. INTRODUCTION

Biological waste gas purification processes, namely biofiltration, bioscrubbing, biotrickling have the advantage that they cause nearly no environmental problems as the pollutants are oxidized to harmless end products. They are preferred when large amounts of air with low pollutant concentrations have to be treated. These systems are based on the absorption of the contaminants in liquid phase and subsequent degradation of the absorbed contaminants into harmless oxidation products (carbon dioxide, water and inorganic compounds) by microorganisms. Compared with physical and chemical air treatment techniques, like adsorption and incineration, biological treatment techniques can offer advantages such as lower investment and operation costs.

The application of biological waste gas purification processes is based upon the ability of many microorganisms which oxidize a variety of organic and inorganic compounds into intermediate and/or mineral end-products (carbon dioxide, water etc.) and new cell material under aerobic conditions.

Since the early sixties biological methods have been employed for the purification of waste gases. It is somewhat surprising that the technological development of these methods, which are already being applied for the purification of wastewater at the beginning of this century, has taken a long time.

BIOFILTRATION TECHNOLOGY

Biofiltration technology has proved to lend itself not only to the reduction of odor emissions, but also to the prevention of air contamination with undesirable components. A small part of a long list of proven applications of biofiltration is: used oil processing, sewage treatment plants, slaughterhouses, animal feed production, bone processing, fat processing, lacquer production, plastics processing, polyester manufacture, sugar industry, coffee roasting and fish meal production.

Biological waste air treatment is based on the aerobic oxidation of the pollutant compounds by microorganisms. Among the biological waste air treatment processes namely bioscubbers, biofilters and biotrickling filters, *biofilters* are the most cost-effective and simple systems and they have the widest application area. They are applied mainly for the treatment of odorous gas streams and volatile organic compounds (VOC) containing waste gases with high removal efficiencies.

In general, the most important factor for an efficient biofilter is an optimum filter media. A biofilter consists of a box form filter bed which is filled with a solid media. As long as the environmental conditions like temperature, pH and moisture content in the filter media are optimal; the microorganisms would grow-up over the filter material and degrade the contaminants in the crude gas into harmless end products.

In biofilters, the treatment efficiencies are in general at high levels of till about 75-99 % if maintenance problems are not met. The primary maintenance problems in biofilters arise due to the filter material and difficulty in control of the moisture content in the filter bed.

The aim of this work was to propose agricultural and industrial waste products as alternative filter materials for biofilters especially in the regions with Mediterranean or similar climate.

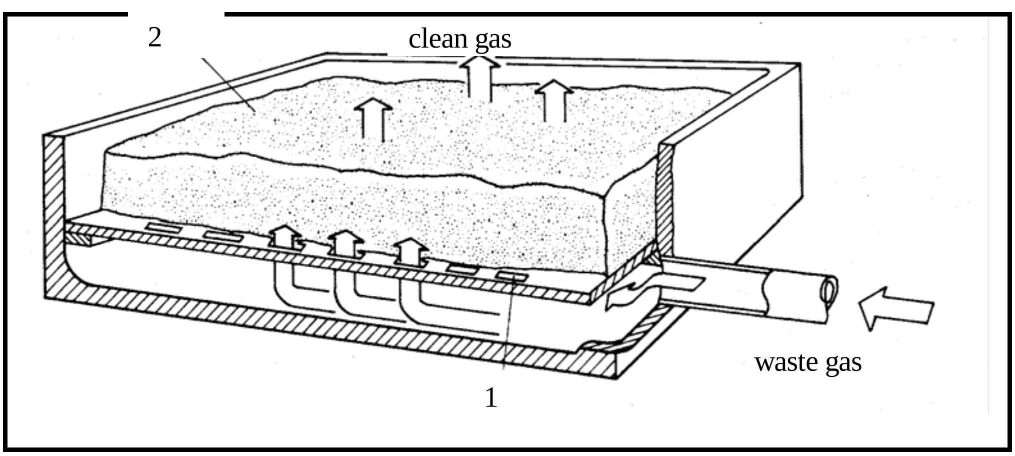

Figure 1: Single-level (open) biofilter (1 filter layer; 2 concrete base with slots for crude gas) (VDI 3477, 1991).

DETERMINATION OF POTENTIAL FILTER MATERIALS

The filter material, in other words the carrier material must simultaneously supply inorganic nutrients for the growth of the microorganisms. Therefore, mostly natural materials with a high content of organic compounds are used as filter material. But in some cases additional nutrients are needed to increase the removal efficiency. Other factors important for the selection of filter materials are: low pressure drops in the filter bed, high surface area, minimum addition of chemicals, long service life and minimum operation and maintenance costs.

The most commonly used filter materials are compost (of garbage, bark, leaf and paper) and peat. In order to decrease the pressure drop and to create a stable filter bed structure, these materials are mixed usually with a coarser fraction of other materials such as heather, bark, plastics, wooden chips etc. Some other inert materials are expanded clay and lava.

As stated by Devinny et al. (1999) careful consideration must be given to the choice of filter bed material so that its life expectancy is optimised and performance is maintained. It is important to choose a material with optimal chemical, physical and microbiological properties. As reported by Curran et al. (2000) smaller grain sized media would increase the elimination capacity, but the increased differential pressure would bring higher operation costs.

In Izmir, at the west coast of Turkey approximately 35 different materials through the agricultural and industrial waste products were collected. Some of those materials are bark of black pine tree, cotton seeds, bark of beech tree, pressed cotton capsule, branches of red pine tree, cones of black pine tree. The agricultural and industrial waste products are cheap and easy to obtain. In addition, they should not be processed before application. Therefore, they were chosen as alternative filter media.

Based on the experience, proven information and facts about the factors affecting the biofiltration process which are related with filter material, above mentioned materials were characterized in the laboratory in order to determine if they can be tested as filter materials in a pilot biofilter plant. *pH, conductivity, wet and dry density, porosity and nutrient content* determinations were implemented**.**

The results of these analyses were evaluated to determine only four of these to be tested in the removal efficiency measurements: *Pressed olive kernel (after oil production), bark of red pine tree (5-15 cm), grape vine (10-20 cm), branches of olive tree (10-25 cm)*. They were then tested in a pilot biofilter plant which is shown in Figure 2 to determine their performance as filter material.

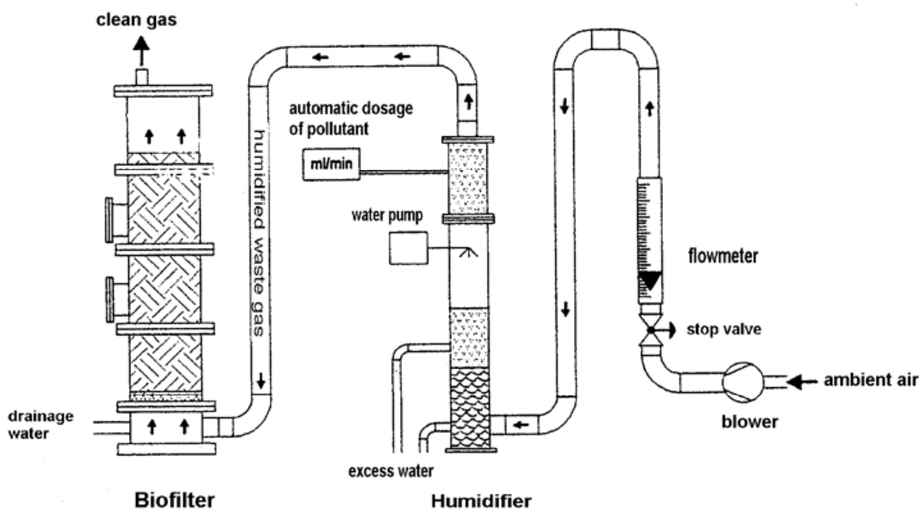

Figure 2: Schematic presentation of the pilot biofilter plant.

In order to determine if they could be proposed as filter materials, the purification efficiency of a contaminated gas stream was determined. In addition, pressure drop measurements were performed. Four experiments were implemented in a pilot biofilter plant to test each of the materials as a filter medium. Each experiment consisted of phases. In each phase, the treatment efficiency of a contaminated gas stream with different concentrations was measured. The flowrate and the dosage of contaminants were changed in each phase. As contaminants *2-butanon, 1-propanol and n-butyl acetate* were used. Typical biofilter loadings and extreme loadings were applied to see the difference in the removal efficiency by use of these alternative filter media. In addition, pressure drop in the filter height was regularly measured during each experiment.

The results of the total carbon removal efficiency measurements with the branches of olive tree as filter material in the first 30 days of the experiment are presented In Figure 3. The average purification efficiency was 80 %. This material was tested for five months in the pilot biofilter plant. The results of removal efficiency in the following days which are shown in Figure 4 were also above 80 %. This proves that the branches of olive tree are a good alternative to be used as filter material for the applications of biofilter in the Mediterranean region.

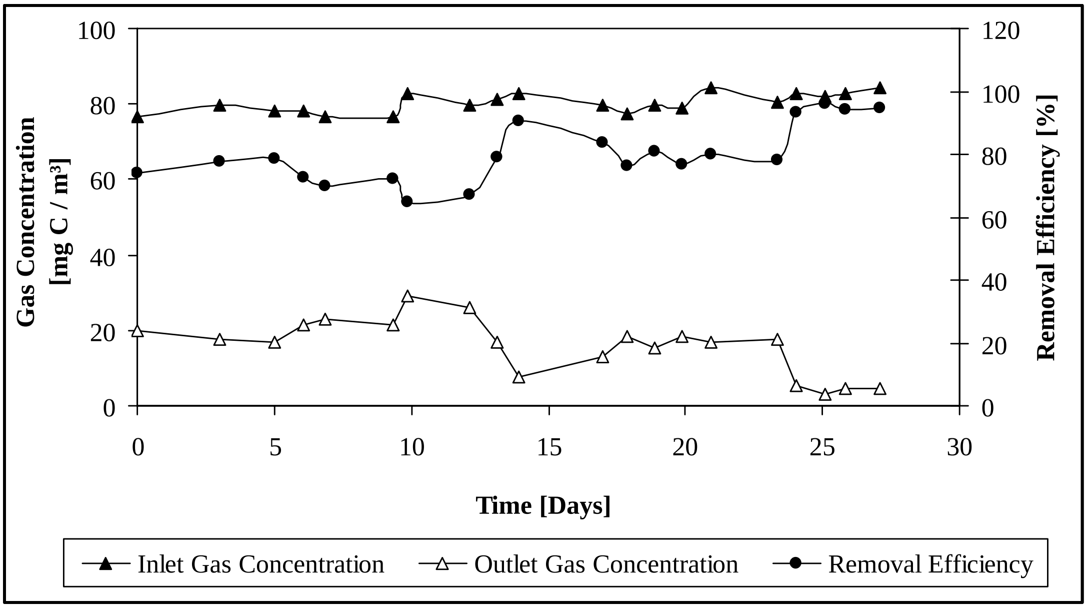

Figure 3: The results of removal efficiency measurements in pilot biofilter plant using grape vine as filter material during Phase A.

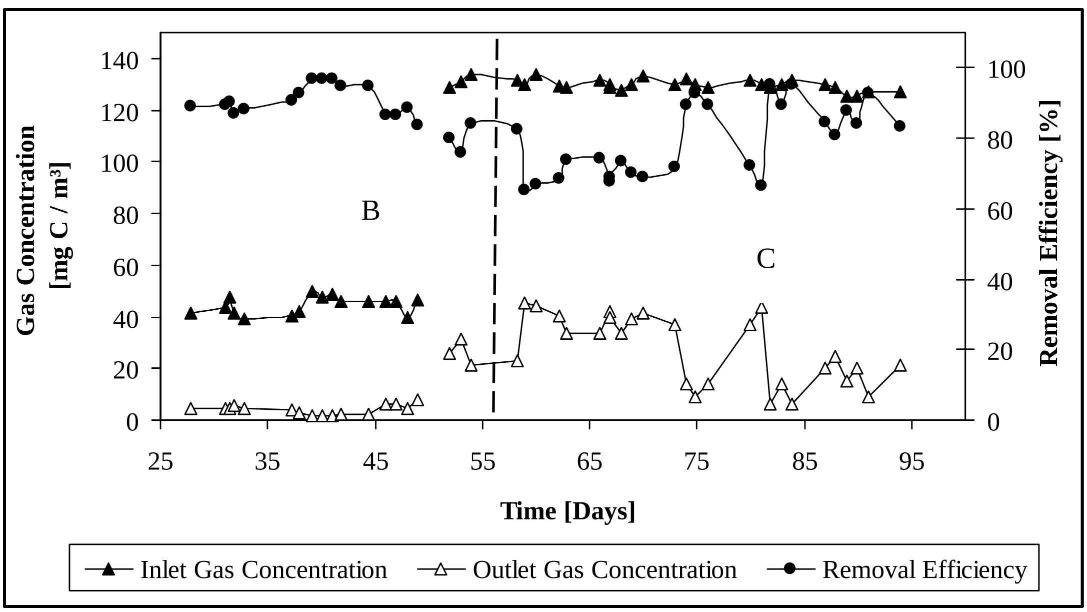

Figure 4: The results of removal efficiency measurements in pilot biofilter plant using grape vine as filter material during Phase B and C.

Changes in the process parameters during the series of measurements using grape vine as filter material are presented in Table 1. The average removal efficiency for the whole operation period was **80 %** for the inlet gas concentration in the range of 45-315 mg C/m³. Even for the extreme high inlet gas concentration of 315 mg C/m³ removal efficiency was almost 80 %. For the inlet air loading rates of 7-26 g/(m³.h), elimination capacity was in the range 5-20 g/(m³.h). As a result, grape vine may be proposed as a filter material.

Table 1: Changes in the process parameters during the series of measurements using grape vine as filter material.

PHASE	**A**	**B**	**C**	**D**	**E**
Time [day]	0-27	28-49	50-94	95-122	123-140
Residence time [sec]	44.87	22.44	44.87	22.44	44.87
Flowrate [m³/h]	10	20	10	20	10
Inlet gas concentration [mg C/m³]	80	44	130	73	315
Outlet gas concentration [mg C/m³]	16	4	27	14	73
Volumetric loading rate [m³/(m³.h)]	80	160	80	160	80
Elimination capacity [g /(m³.h)]	5.1	6.4	8.3	9.5	19.4
Removal efficiency [%]	80	91	79	80	77

The performance of **olive kernel** was not good. The average removal efficiency for the whole operation period was **55 %** for the inlet gas concentration in the range of 80-170 mg C/m³ as the filter bed was filled with olive kernel. Pressure drop in the filter bed was extreme high which makes the material less suitable to be used as filter medium.

During the filter operation with **bark of red pine,** the raw air loading rates varied between 5 and 20 g/(m³.h) and the average removal efficiency for the operation period was **70 %** for the inlet gas concentrations in the range of 55-135 mg C/m³.

Branches of olive tree showed a good performance. The average removal efficiency for the whole operation period was **80 %** for the inlet gas concentration in the range of 30-110 mg C/m³ and inlet air loading rates of 5-14 g /(m³.h).

3. CONCLUSION

Results of the researches propose that *bark of red pine tree, grape vine and branches of olive tree* have the potential to be used as filter media. Considering the removal efficiency, the optimal loading rate for these natural materials is up to 10 g/(m³.h). Only grape vine may be operated with a loading rate of till about 25 g/(m³.h) with a high removal efficiency.

Elimination capacity of the proposed materials is lower than the elimination capacity of well-known filter materials for the same contaminants. Consequently, these materials may only be proposed for crude gases with low concentrations of volatile organic compounds at this stage.

Finally, it can be concluded that bark of red pine tree, grape vine and branches of olive tree can be used as filter material for raw gases with a loading rate of till about 10 g/(m^3.h) with removal efficiencies of around 80 % especially in the Mediterranean and Aegean Regions. The proposed materials are most available in the countries of Mediterranean and Aegean Regions, especially in **Greece, Italy, Spain, France and Turkey**. So, the experiments show that the biofiltration can be adapted to the Mediterranean region by using materials which are available in the region as filter.

Biofiltration which is a simple and cheap system would find more application areas by the introduction of these cost effective filter media. These advantages increase the possibility of further applications of this technology in the developing countries of Mediterranean region which have financial problems in the field of environmental protection. The environmental conditions in these countries can be improved in this way.

4. ACKNOWLEDGEMENT

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