ODOR EMISSIONS OF LARGE WWTP'S: SOURCE STRENGTH MEASUREMENT, ATMOSPHERIC DISPERSION CALCULATION, EMISSION PROGNOSIS, COUNTERMEASURES – CASE STUDIES

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ABSTRACT

Annoyance caused by malodors emitted by wastewater treatment plants is a most important problem in the FRG today. The legal regulations existing today in Germany are strict and under discussion with the aim to state even more restrictive stipulations. In the field of "odor-caused annoyance" it is necessary to use test persons as a detector to achieve results that correctly characterize the phenomenon to be assessed. In the case of odor, it is necessary to understand the basic concepts of sensoric measurement in order to assess the results correctly. In addition, special sampling techniques are necessary. On the emission side, olfactometric measurement is required. Olfactometric measurement programs were carried out on several wwtp's giving a picture of the emission strength of large wwtp's. On the immission side, field inspection with direct judgement by the test persons is used. If immission prognoses are required, it is necessary to do atmospheric dispersion calculations combining source strength data and meteorological data in order to gain a somehow correct prediction of future immission situations. If immission standards are exceeded, countermeasures, reaching from simple operational measures to covering and waste air treatment, may be necessary.

KEYWORDS
Odor; olfactometry; wastewater treatment; sensoric measurement; sampling technique; atmospheric dispersion; immission prognosis; covering; waste air treatment.

INTRODUCTION

Wastewater treatment plants can cause serious annoyance in the vicinity, especially residential areas, due to emission of malodors. Thus, location, construction and operation of wwtp's must consider minimization of nuisance and provide all available measures to reduce the release of odorous emissions.

At the moment most of the wwtp's in Germany have to be enlarged in order to meet the new legal requirements concerning effluent quality. In nearly every case it is necessary to supplement the design with an odor emissions prevention concept and usually with an immission prognosis concerning odors.

Odorous substances are named in the Federal law of immissions protection ("Bundes-Immissionsschutzgesetz" [1]) since 1974. Contrary to other air pollutants, it is most difficult to give any kind of maximum emission or maximum immission standard which has to be met, as annoyance caused by malodors is not an analytical problem, but a problem of assessment. Nevertheless the federal authorities today are forced to set standards which is as difficult a task as the design of technical measures to meet these standards. For both parts it is necessary to refer to the basic concepts of odor and odor-caused annoyance in order to understand the measurement results as well as technical possibilities available today to start up measures against odor emissions.
Besides this, the parameters given for the limits are different which complicates the situation. Thus, when concerned with problems connected with odor emissions, it is most important to know about the basic concepts of odor and odor measurement techniques in order to be able to judge the results of measurements.

**BASICS OF ODOR AND ODOR-CAUSED ANNOYANCE**

Odor is a human sensation caused by the presence of so called "odorants" and is based upon physiological recognition and psychological interpretation. Until today, the physiological part of the process is not known completely. In addition, psychological interpretation is an individual process that cannot be described in terms of general valid relations or equations. The extent of annoyance reported by various test persons differs and until today it is not possible to give equations that are able to predict the extent of annoyance in relation to the presence of different air compounds. Actually, the relevant problem in the case of odor is not the presence or absence of specific air compounds, which can be determined by means of analytical measurement techniques and would give compound-related measurement results. The main problem is to achieve knowledge about the effects of the air compounds present, this means to get an effect-related measurement result. As in general measurements must apply to the question that has to be answered, in the case of odor (or, even worse, odor annoyance) measurement techniques are necessary that base upon the judgement of test persons. As in the case of odor the judgement varies in a quite wide range from person to person, as an additional fact the laws of statistics must be obeyed to get somewhat like "true" measurement results. It must be understood that there is a big difference in exactness between the kind of measurement techniques technicians are used to and the results of measurements concerning odor and odor annoyance. This is important when evaluating measurement results, immissions prognoses or any other kind of results presented in this concern.

**MEASUREMENT TECHNIQUES FOR EMISSIONS AND IMMISSIONS**

**Emission measurement techniques**

It has already been pointed out that only techniques apply that are connected with the questions that have to be answered, and thus only sensoric measurement methods using test persons will apply in the case of annoyance caused by malodors. Figure 1 tries to give an overview over the situation.

The left part of the figure is concerned with the chemical aspect of the air to be analyzed. Different methods, ranging from tube tests to gas-chromatography in connection with various detectors, are applicable that give information about specific gas compounds. If the composition is unknown, usually mass-spectrography is used to detect the compounds present. But as it is not possible to derive statements concerning odor from these substance-related values, this part of the figure is headed with "no odor". The right part of the figure deals with odor. But as can be seen, different questions lead to different "measurement values". In the case of odor the measurement method depends upon the question to be answered.

Until today, only the measurement of "strength of odor - odorants concentration" is prescribed in a guideline in Germany, namely the VDI-guideline 3881 [4]. The basic concept of this measurement method is to dilute an air sample with clean, odorless air until half of the test panel does not smell anything whilst the other half of the test panel still smells something - odor threshold. The number of dilutions necessary to reach the odor threshold is called "odorants concentration o.c." and is given in the unit of "odor unit per cubic meter o.u./m³", although in fact it has no dimension. The concept behind this is that a certain amount of "odorants" is present that give the resulting odor impression. The connection between dilution and one cubic meter of air of course is arbitrary. As the device that is necessary to prepare the dilution between sample air and odorless air is called "olfactometer", this measurement technique is called "olfactometry". The measurements presented in this paper - as far as they concern odor - are olfactometric measurement results and thus are given as odorants concentration o.c., as this is the only standardized measurement described by a guideline yet and gives quite comparable and reproducible results.
The intensity of odor has to be assessed by the test persons. In order to assure some comparability, the semantic concept used must be identical. In Germany, today the following concept applies:

- 0 = no odor perceivable
- 1 = barely perceivable (odor threshold)
- 2 = faintly perceivable (recognition threshold)
- 3 = clearly perceivable
- 4 = strong
- 5 = very strong
- 6 = (stronger than 5)

The association with intensity numbers first is arbitrary but helps to judge. It becomes more important when describing the above-threshold intensity behaviour of different airs in accordance to different theories of psychometry such as the Weber-Fechner Law. The VDI-guideline 3882 which is issued as draft version gives details about this.

The other methods mentioned in figure 1 result from different kinds of questions. The kind of odor, given by direct judgement, free or according to different semantic concepts, is not too important with respect to landfills. Usually, with the examination of food, perfume etc. this aspect will be of decisive interest.

The hedonic tone is of high importance, as it gives the location of the odor impression on a scale representing the dichotomy of "pleasant" - "unpleasant". The respective VDI-guideline 3882 will cover this question and will give advice for the conduction of the test. Considering landfills, an easy answer may be given by saying that generally odor emitted from these facilities is "unpleasant". For practical purposes, this statement may be exact enough now, although with respect to [3] the extent of unpleasantness will have to be considered in the future.

Immissions measurement techniques

In contrast to some other countries, e.g. The Netherlands, in Germany it is accepted that usually it is not possible to use olfactometric measurement to determine odor immissions. Thus, two major approaches are made to describe the immission situation:

- short-term or long-term questionnaires according to VDI-guideline 3883 [6]
- determination of odour in ambient air by field inspection according to VDI-guideline 3940 [7]

Both methods are suitable to describe the level of annoyance in the vicinity of plants, and both are applicable only if the plant exists already. If a plant is under design, it is not possible to carry out measurements according to these guidelines. Usually, measurements then are carried out at comparable
plants/locations in order to achieve knowledge to estimate the emissions and the related immissions of the plant to be designed. In this case, usually the source parameters are determined and then a dispersion calculation/immission prognosis is made.

Possibilities to calibrate dispersion calculations

In order to describe the immission situation it is often necessary to work out an immission prognosis concerning odor. In Germany, this is done by doing atmospheric dispersion calculations using the Gaussian dispersion equation as basic formula. The application of the Gaussian dispersion model is prescribed in the Federal Technical Regulation for Clean Air ("Technische Anleitung zur Reinhaltung der Luft" [2]). Input data are statistical meteorological data, usually covering meteorological observations during the most recent ten-year-period, and the emission parameters. The decisive emission parameter is the emission mass flow in odor units per hour (o.u./h) as product of emission air flow and emission concentration.

As many parts of WWTP’s are area sources without defined emission air flow, e.g. sedimentation tanks, thickeners etc., it is difficult to determine a complete set of emission parameters. Thus, two approaches are possible to solve this problem.

The first approach is to use special sampling equipment as shown in figure 2.

![Sampling box](image)

Fig. 2. Sampling box

Whilst the sample air is sucked into the sample bag, odorless air can flow into the sample box. As the ground area of the box is known - 0.18 m² in this case - and as the flow of sample air in m³/h can be chosen, it is possible to determine the specific sample air flow in m³/(m²*h). Determining the odorant’s concentration in the sample in o.u./m³ leads to the specific odorants mass flow in o.u./(m²*h) and thus also to the total area mass flow in o.u./h, which is necessary as input for the dispersion calculation.

The second approach is to conduct field inspections at different meteorological situations. Then a recalculation considering actual meteorological circumstances can be made to determine the total emission mass flow of the plant which then is input for the dispersion calculation/immission prognosis.

LEGAL REGULATIONS

The Federal Technical Regulation for Clean Air ("Technische Anleitung zur Reinhaltung der Luft" [2]) is the most important regulation connected with the immissions protection act mentioned above. In order to handle this regulation, the government of Northrhine-Westfalia issued a guideline [3] that may be Germany’s only guideline concerned with immission standards related to odor annoyance today. But even this regulation does not contain exact stipulation of standard values, but instead gives an "upper limit" (probably no annoyance when meeting given immission standard) and a "lower limit" (probably annoyance when not meeting given immission standard). When producing immissions that are considered to be between these limits, an individual assessment and discussion will be necessary. Actually a new issue of this guideline is under discussion, but today’s version of this is strongly criticised by the experts working within the DIN/VDI-workgroups on odor.

At present the legal regulations in Germany concerning tolerable immissions, see [3], refer to perceptibility of odor, which represents an o.c. of 1 o.u./m² by definition, or to an odor intensity which may bedescribed...
Odor emissions of large WWTP's

as "clearly perceivable" (intensity number 3 in the numbered scale). Recognizing the lack of knowledge about fundamentals and general applicable objective standards, no explicit standard values are given, but at the moment it is conventional to recognize an odor immission exceeding the odor threshold (1 o.u./m²) within more than 3% to 5% of the hours of a whole year as illegal. According to the new issue of the Northrhine-Westfalia guideline mentioned above [3] it may be established that in the future the recognition threshold may be relevant. This draft points out that it will be recognized as illegal if an odorous immission above the recognition threshold is present

- during more than 3% of the hours of a year in residential areas and
- during more than 5% of the hours of a year in industrial areas,

whereby one hour will be recognized as "odor hour" even if the recognition threshold is exceeded during more than 6 minutes.

In this respect, connection between odor emission and immission is important to produce an immission prognosis. In Germany, the Gaussian dispersion model is prescribed by law to do dispersion calculations, and a reference computer program exists made by order of the government. In the future the VDI-guideline 3782/4 [8] may possibly be relevant to do dispersion calculations, but this will last until 1992 at least.

EMISSION MEASUREMENT RESULTS, MEASURES, IMMISSION PROGNOSIS

During the last years measurement programs and projects in Germany, Switzerland, France and South America were carried out at different WWTP's and with respect to slightly different types of questions. In recent times the necessary steps often are:

- evaluate emission concentrations using olfactometry
- evaluate connected emissions parameters which is very difficult especially at parts that show odor emissions, but no defined air emission, such as sedimentation tanks etc.
- draw up concepts for odor emissions prevention by using a wide variety of actual possible countermeasures including waste gas treatment systems
- re-calculate odor immissions in the vicinity by means of atmospheric dispersion models
- predict odor immissions after concepts for odor emissions prevention will be in operation and by doing so prove that the concepts chosen will work sufficiently and will meet the legal standards.

The following table shows the results of emission measurement using the special sampling technique described above. Thus, it was possible to estimate the emission mass flow without calibrating the values by means of field inspections at different meteorological situations.

**TABLE 1 Emission Measurement Results (Plant A)**

<table>
<thead>
<tr>
<th>No.</th>
<th>date</th>
<th>Part of plant</th>
<th>odorant concentration o.u./m²</th>
<th>specific volume flow m³/(m²*h)</th>
<th>area m²</th>
<th>odorant mass flow Mio o.u./h</th>
</tr>
</thead>
<tbody>
<tr>
<td>823</td>
<td>19.2.91</td>
<td>influent water</td>
<td>995</td>
<td>8.4</td>
<td>100</td>
<td>0.834</td>
</tr>
<tr>
<td>821</td>
<td>19.2.91</td>
<td>screenings container, filled</td>
<td>3,325</td>
<td>6.8</td>
<td>10</td>
<td>0.226</td>
</tr>
<tr>
<td>827</td>
<td>20.2.91</td>
<td>influent pump.+fecal sludge</td>
<td>4,842</td>
<td>11.2</td>
<td>156</td>
<td>8.472</td>
</tr>
<tr>
<td>824</td>
<td>19.2.91</td>
<td>influent pump.+filtrate</td>
<td>214</td>
<td>6.0</td>
<td>156</td>
<td>0.200</td>
</tr>
<tr>
<td>825</td>
<td>19.2.91</td>
<td>grit chamber surface</td>
<td>39</td>
<td>4.7</td>
<td>140</td>
<td>0.026</td>
</tr>
<tr>
<td>826</td>
<td>19.2.91</td>
<td>grit</td>
<td>64</td>
<td>6.3</td>
<td>10</td>
<td>0.004</td>
</tr>
<tr>
<td>828</td>
<td>20.2.91</td>
<td>connection channel to p.s.</td>
<td>141</td>
<td>5.6</td>
<td>30</td>
<td>0.024</td>
</tr>
<tr>
<td>829</td>
<td>20.2.91</td>
<td>primary sedimentation surface</td>
<td>93</td>
<td>6.7</td>
<td>1,376</td>
<td>0.855</td>
</tr>
<tr>
<td>830</td>
<td>20.2.91</td>
<td>primary sedimentation overflow</td>
<td>126</td>
<td>6.8</td>
<td>64</td>
<td>0.056</td>
</tr>
<tr>
<td>831</td>
<td>20.2.91</td>
<td>return sludge</td>
<td>63</td>
<td>6.8</td>
<td>25</td>
<td>0.011</td>
</tr>
<tr>
<td>832</td>
<td>20.2.91</td>
<td>aeration tank</td>
<td>63</td>
<td>7.1</td>
<td>1,820</td>
<td>0.807</td>
</tr>
<tr>
<td>836</td>
<td>21.2.91</td>
<td>aeration tank</td>
<td>43</td>
<td>6.7</td>
<td>1,820</td>
<td>0.518</td>
</tr>
<tr>
<td>844</td>
<td>21.2.91</td>
<td>aeration tank</td>
<td>49</td>
<td>3.1</td>
<td>1,820</td>
<td>0.273</td>
</tr>
<tr>
<td>833</td>
<td>20.2.91</td>
<td>final sedimentation surface</td>
<td>37</td>
<td>5.3</td>
<td>1,640</td>
<td>0.320</td>
</tr>
<tr>
<td>834</td>
<td>20.2.91</td>
<td>final sedimentation overflow</td>
<td>52</td>
<td>5.5</td>
<td>180</td>
<td>0.051</td>
</tr>
<tr>
<td>839</td>
<td>21.2.91</td>
<td>sludge storage tank</td>
<td>2,234</td>
<td>6.1</td>
<td>47</td>
<td>0.642</td>
</tr>
<tr>
<td>847</td>
<td>22.2.91</td>
<td>sludge storage tank</td>
<td>1,497</td>
<td>6.6</td>
<td>47</td>
<td>0.463</td>
</tr>
<tr>
<td>848</td>
<td>22.2.91</td>
<td>digester top during sludge disch.</td>
<td>1,449</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>845</td>
<td>22.2.91</td>
<td>digester top during sludge disch.</td>
<td>1,086</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>840</td>
<td>21.2.91</td>
<td>final thickener 1</td>
<td>1,045</td>
<td>5.4</td>
<td>95</td>
<td>0.536</td>
</tr>
<tr>
<td>841</td>
<td>21.2.91</td>
<td>final thickener 2</td>
<td>611</td>
<td>6.2</td>
<td>95</td>
<td>0.362</td>
</tr>
<tr>
<td>835</td>
<td>21.2.91</td>
<td>filtrate</td>
<td>61</td>
<td>5.9</td>
<td>5</td>
<td>0.002</td>
</tr>
<tr>
<td>837</td>
<td>21.2.91</td>
<td>dewatered sludge, fresh</td>
<td>102</td>
<td>6.0</td>
<td>50</td>
<td>0.030</td>
</tr>
<tr>
<td>842</td>
<td>21.2.91</td>
<td>surface sludge+foam disposal</td>
<td>70</td>
<td>5.8</td>
<td>40</td>
<td>0.016</td>
</tr>
<tr>
<td>846</td>
<td>22.2.91</td>
<td>surface sludge+foam disposal, fresh</td>
<td>735</td>
<td>5.8</td>
<td>40</td>
<td>0.172</td>
</tr>
<tr>
<td>843</td>
<td>22.2.91</td>
<td>storm water storage tank, dirty</td>
<td>71</td>
<td>6.3</td>
<td>1,700</td>
<td>0.767</td>
</tr>
</tbody>
</table>
At this plant an immission prognosis was not of high importance as everyone involved in the problem agreed that immissions were undoubtedly serious. Thus, main attention was drawn to detecting the main sources in order to take immediate action against the emissions. A three-step-concept was designed which as first step included covering of influent pumping station, thickeners, sludge storage tank, digester top, exhausting of waste air from these parts and treatment by means of biofiltration. These measures now are under construction. In addition, some operational measures were recommended as e.g. intensifying clean-up of storm water tanks after rainfall, changing treatment of fecal sludge and surface sludge+foam, intensifying control over the industry connected to the sewerage and strictly limiting the water quality of the water discharged into the sewerage system.

At another plant it was necessary to give an immission prognosis for the actual situation and the future situation after upgrading the plant. This plant (plant B) has no sludge treatment on-site. In this case both special sampling method and calibrating of emission mass flow by means of immission field inspection were carried out to calibrate the dispersion model. In this case the two calibration possibilities gave a factor of 1.26, which is a quite satisfying result when concerned with odor.

It is important to notice that all values given are odorants concentration related to the odor detection threshold, not the (in-field-) odor recognition threshold, which will be about 3 to 7 times higher.

<table>
<thead>
<tr>
<th>Table 2. Emission Measurement Results (Plant B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>influent pumping station</td>
</tr>
<tr>
<td>screening room</td>
</tr>
<tr>
<td>aerated grit chamber surface</td>
</tr>
<tr>
<td>sand container</td>
</tr>
<tr>
<td>aerated grit chamber overflow</td>
</tr>
<tr>
<td>primary sediment. tank surface</td>
</tr>
<tr>
<td>primary sediment. tank inflow</td>
</tr>
<tr>
<td>aeration tanks</td>
</tr>
<tr>
<td>final sedimentation</td>
</tr>
<tr>
<td>final sedimentation</td>
</tr>
<tr>
<td>2nd influent pumping station</td>
</tr>
<tr>
<td>total:</td>
</tr>
</tbody>
</table>

As an example, the results of the immission prognosis for the actual situation is drafted in the following figure, showing the wtwp and the isolines for probability of exceeding standards of 3%, 4% and 5% of the hours of a year according to the above mentioned "hour-definition (6 minutes in total per hour)", exceeding the detection threshold.

Fig. 3. Result of immission prognosis (plant B, actual situation)
The enhancement of this plant has not started yet due to financial reasons and due to the neighborhood which is very close to the plant.

Two projects just running with industrial wwtp’s (chemical industry and petrochemical industry) show that it also is most important to carefully check the industrial discharges into the sewerage system and to take special action, e.g. stripping of volatile before treating the wastewater etc.

In general, the steps to reach a low level of emissions are simple measures/operational measures/changings in process operation, covering of critical parts and treating the exhausted waste gas.

The following common advice may apply as simple measures:

In sewerage system:

- avoid clogging
- set standards for critical industrial discharges
- maintain sufficient flow speed
- let waste water aerate, avoid anaerobic zones
- if necessary, add chemicals (e.g. oxygen)

At wastewater treatment plant:

- avoid overload
- enhance oxygen supply
- upgrade constructions, tanks etc.
- optimize process
- cover critical parts
- change locations
- add chemicals, if necessary

Concerning covering, the following hints should be obeyed:

- covering means that measures have to be taken against danger of explosions (installing of detectors, installing of emergency-outlets including fans, use appropriate electrical installations) and that a safety concept has to be set up
- covering implies extended measures against corrosion
- when covering aerated basins, at least 1.3 times the amount of aeration air should be exhausted.
- at covered tanks/thickeners etc. regard maximum fill speed of tank. The amount of exhaust air should at least be 2 times the maximum fill flow
- a good waste air concept includes multiple use of waste air

Concerning waste air treatment, different technologies are available and appropriate, as described by Frenchen [9]. Recently biological methods, especially biofilters, have gained high interest. Biofiltration can be very efficient as has been proved by Frenchen and Kettern [5].

CONCLUSIONS

At the moment most of the wwtp’s in the FRG have to be enlarged in order to meet the new legal requirements concerning effluent quality. In nearly every case it is necessary to supplement the design with an odor emissions prevention concept and usually with an immission prognosis concerning odors.

Until now the only applicable measurement technique for odor emissions is the sensoric technique with a test person panel in order to determine the odorants concentration o.c. using olfactometry. The measurement technique is prescribed in a VDI-guideline.
Every plant needs a careful inspection in order to detect the plant's special circumstances, problems and possibilities to individually solve them.

General steps when approaching this task are:

- evaluate emission concentrations using olfactometry
- evaluate connected emissions parameters which is very difficult especially at parts that show odor emissions, but no defined air emission, such as sedimentation tanks etc.
- draw up concepts for odor emissions prevention by using a wide variety of actual possible countermeasures including waste gas treatment systems
- re-calculate odor immissions in the vicinity by means of atmospheric dispersion models
- predict odor immissions after concepts for odor emissions prevention will be in operation and by doing so prove that the concepts chosen will work sufficiently and will meet the legal standards.

The work mentioned above had to be carried out at several large wwtp's recently. The results of measurement programs, the designs of different waste air concepts and the application of atmospheric dispersion models at these wwtp's are demonstrated and discussed in detail.

REFERENCES

1. AA: Bundes-Immissionsschutzgesetz, BGBI, latest edition
2. AA: Technische Anleitung zur Reinhaltung der Luft, 1.3.1986, GMBI., 27. Febr. 1986, pp. 95
7. VDI-guideline 3940 - Determination of odour in ambient air by field inspections, draft edition 1991
8. VDI-guideline 3782/4 - Environmental meteorology - Dispersion of odorants in the atmosphere, draft edition 1991
9. Frechen, F.-B., Odour Emissions of wastewater treatment plants, Gewässerschutz • Wasser • Abwasser, Aachen, Band 108