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Industrial odour control

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Preface

The purpose of this guideline is to provide the basis for uniform consideration of complaint and approval cases relating to odour problems in the ambient air.

Purpose

The guideline aim at furnishing enterprises as well as permitting and supervisory authorities with a framework for measurement, evaluation, prevention and measures against odour nuisances from industries. The guideline is intended for dealing with enterprises emitting large quantities of odorants (see section 2). In general agricultural activities and animal farming, including fur farms, in rural areas are however, not covered by the guideline. Also, the health aspects of odorants are not included.

Complicating factors

The extent of odour nuisances depends on complex interrelationships between odour intensity, frequency and duration, but other factors are also involved. We know for instance that people working in or living close to an odour emitting plant feel less annoyed by the smell than other people. Moreover, smell that gives a pleasant immediate impression, may be perceived as a nuisance if occurring frequently. Therefore, odour nuisances cannot be predicted precisely, not even in well-defined emission conditions and meteorological situations.

Dispersion calculation model

The dispersion calculation model described below is based on guidelines from the Danish EPA No. 7/1974 and No. 3/1976, and on experience gained in Denmark and abroad in connection with dimensioning of emission heights for odorous compounds.

Uncertainty

Great uncertainty is involved in the measurement of odour, in odorant dispersion and acceptability. Moreover, the costs of odour control in certain types of industries may be considerable. The approval and supervision authorities must, therefore, in all concrete cases decide whether the limit value specified here shall be strengthened or lightened, depending on the character of the smell and the surroundings.

Experience

The guiding limit is laid down on the basis of practical experience gained so far in the Danish EPA in concrete decisions where corresponding limits were used with acceptable conditions for the enterprise involved and the local residents.

1 Introduction

Suitable objective physical/chemical measurement methods to determine smell do not exist. The guideline is, therefore, based on a number of concepts related to the subjective smell perception of a number of people (a smell panel). The most important concept is the odour threshold value. Reference odorants are used in order to make the detection threshold value independent of the technical equipment used and of the composition of the panel.

Calculation of emission/dilution

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

The main principle is that the concentration of odorants at soil surface shall not exceed the odour threshold concentration by a factor 5- 10 in specific atmospheric conditions (neutral -moderately unstable, wind speed 4,5 m/s). From experience gained in Denmark and abroad we know that the resulting conditions are in general satisfactory (PALGREN JENSEN and FLYGER, 1983), (WSL, 1980), (BEDBOROUGH and TROTT, 1979), (KEDDIE, 1984). The practical experience in Denmark gained by the Danish Boilers' Association supports this principle.

Satisfactory conditions can be achieved either by cleaning of exhaust air, by dispersion into the atmosphere by means of stacks, or by a combination of these methods. Below a description is given both of cleaning measures and or calculations of outlet heights.

Odour nuisances/harmful effects

Some substances may cause both harmful effects in the environment and odour nuisances. Both these problems must of course be considered separately in connection with complaint and approval cases.

2 Odour nuisances

Odour from process plants

Odorants often appear in connection with chemical processes and form part of the process discharge, unless they are cleaned before emission from the plant. But the most thorough cleaning of discharges cannot prevent odour from a plant in which process equipment is badly maintained, with leakages through which odorous gas emitted in the atmosphere. Gas may also escape in connection with emptying/filling of tanks or with repair and cleaning of manufacturing equipment.

Odour sources

It is not possible to make a complete list of odour-producing plants. Below are given some examples of plants, processes and activities which are well-known emitters of odorous compounds and, thus, sources of offensive smell:

- Oil refinery
- Foundry
- Paper mill
- Plastics processing
- Fertiliser production
- Oil seed factory
- Pharmaceuticals manufacture
- Detergent manufacture
- Tobacco factory
- Sugar mill
- Waste incineration
- Refuse disposal
- Transport infrastructure
- Rubber manufacture (vulcanising)
- Sewage and sludge treatment
- Meat meal and bone meal manufacture
- Fishing port (unloading of trash fish)
- Fishing industry (fish meal, fish oil, fish products)
- Food processing (coffee roasting, onion roasting, canned products manufacture, smokehouse, slaughter house)

Odour generation

Odours are generated in many different situations, in industry sometimes in connection with processing of natural products, e.g. oil distillation or synthesis of chemical compounds.

A variety of substances are involved, and special literature should be studied for further details. In some plants smells are generated by microbial decomposition of organic compounds, e.g. hydrogen sulphide, mercaptans, but also nitrogen compounds in the form of ammonia, amines, and skatole may cause malodour.

Smell generating reactions often occurs where organic substances are kept in containers without oxygen or in anaerobic water, for instance sewers, wells, settling tanks etc. Some of the problems may be solved by adequate circulation or supply of oxygen or oxidising substances.

Problems relating to odour control

Odour nuisances are sometimes very difficult to prevent, because even negligible amounts of some odorants are sensed by humans. Hydrogen sulphide and mercaptans for instance can be sensed in concentrations far below concentrations which are harmful to Man. Due to our ability to detect odorants in very small concentrations, otherwise insignificant air pollution sources (valve and joint leakages, small spills, evaporation from wells, sewers or open basins) may give rise to complaints from neighbours.

3 Perception of smell

3.1 Olfactory sense

The olfactory sense works with sensory cells in the upper nasal cavity and sensory threads all over the nasal mucosa. The impression of smell is the result of a chemical effect on sensory cells in the upper nasal cavity. When sensory threads are activated we get the characteristic pricking sensation known from acid vapours. This type of smell is biologically speaking very different from the perception of smell as such. The pricking sensation is only released at concentrations so high that normally there would be other problems than the mere smell impact. This impact need not be considered when dealing with environmental problems caused by odour.

The region of the mucosa that releases the impression of smell, is placed in the upper nasal cavity. By normal breathing only small quantities of the inspired air passes this region. Sniffing can temporarily increase the sensitivity of the olfactory process. The sensation of smell thus depends on the passage of air through the nose.

3.2 Description of smells

The extent of the smell impact can normally not be determined by physical or chemical measurement methods. Most often the smell intensity must be determined by measurements based on the perception of smell by Man. The most important reasons for this are discussed below.

Odour from mixtures of substances

Pollution sources often emit very complex mixtures of odorous and non-odorous compounds. To make an overall evaluation of the smell, a quantitative and qualitative determination is required, and also determination of or knowledge of a large number of substances. This requires extensive analyses, which are most often impossible because the analysis methods are not sensitive enough. Moreover, odour in the ambient air is often a result of different substances the smell of which, taken together, gives a specific impression of smell. In this case we cannot use the interaction of individual elements in the calculation of the resulting odour.

Odour attributes

The following four odour attributes can be measured by means of human perception of smell, and are used to describe odour: threshold, intensity, character (resemblance or differences from other smells) and acceptability expressed by reactions of annoyance or pleasantness.

Odour threshold

If a panellist is only just able to distinguish between samples with and without odorous compounds they appear in air mixtures in concentrations corresponding to the odour threshold. Normally we can perceive smells before we can recognise them.

Intensity

Intensity is a measure of the perception of the odour magnitude. It is a measure of the strength of the sense impression.

Character

The character describes the type of the smell. Typical descriptions of smell characters are sweet, like rotten eggs, fruity, metallic or like a diluent.

Acceptability

The acceptability or hedonic quality of smell indicates whether it is pleasant or offensive. Acceptability depends on the odour intensity, some smells being pleasant at low intensities and very unpleasant at high intensities. However, the feeling of unpleasantness is not only caused by nauseating smells. The acceptability of smell depends, apart from the intensity also on the frequency, duration and variation of the impact and of the conditions in which the smell is perceived. This also applies to smells which are normally considered pleasant (coffee, food, perfume etc.). The acceptability of odours in laboratory conditions is not easy to assess; on the spot assessments are more appropriate.

3.3 Special aspects of the perception of smell

Most odour abatement measures are based on measurements of the odour threshold.

The threshold value is defined as the concentration of an odorant that produces positive reactions from 50% of a panel of observers and negative reactions from the other 50%. with different threshold values.

The sense of unpleasantness felt by different observers varying greatly, it is difficult to lay down usable air quality standards for odour. It is also difficult to relate sensory impressions measured by means of a panel of observers to instrumental methods. The reason is that the relation between the odour threshold and the chemical composition is difficult to find because an odour sample may consist of hundreds of different odorants with different threshold values.

Interaction between intensity and concentration

As regards concentrations above the threshold value the interaction between odour intensity and concentration of odorants is described by Stevens law (STEVENS 1961):

$$I \approx b C^a$$

where I is the intensity described in an arbitrary and subjective scale; C is the concentration of the odorant; a and b are constants, a is normally between 0,2 -0,8, so that by dispersion the odour intensity reduction is smaller than the corresponding concentration reduction. For $a = 0.5$ a 4-fold reduction in the concentration will only lead to an odour intensity reduction by a factor of 2; b varies within wide limits depending on units, substances and observers exposed to the odour.

Adaptation

When exposed to a smell for some time the observer's sensation of intensity changes. He adapts and the perceived odour intensity decreases. As will appear from figure 1 this happen very quickly, typically within minutes. The change is greatest by low intensities, so that the sensory experience by high concentrations changes far less. When the impact stops the observer's sensitivity is back to normal within 5 - 10 minutes.

Due to the importance of adaptation to the ability of observers to describe intensity, character and acceptability of different odours, rules governing the presence of odour shall be based on very short sampling times (KEDDIE, 1984), contrary to harmful substances where measurement times are normally 30 minutes in Denmark.

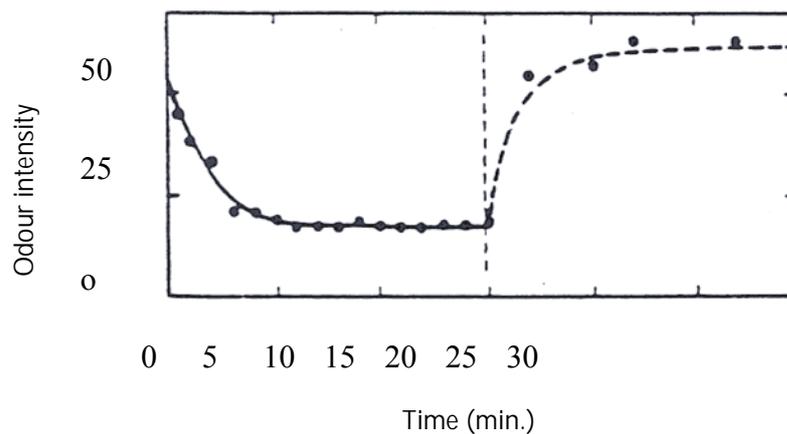


Figure 1. Example of adaptation by observer's exposure to an odorant (LINDVALL, 1970), (VDI, 1982). In the first 15 minutes the impact is constant, then the constant exposure is removed and the observer is only exposed to the odorant during measurement

4 Measurement of odour

4.1 Methods

The threshold value of a sample is determined by means of an odour panel, determining the dilution where 50% of the observers have a conscious sensation of odour. The sample is said to be diluted to the odour threshold value. Most odour panels consist of 6-10 panellists.

Determination of odour thresholds

In Denmark two methods for determination of odour thresholds have been used in particular (MØLHAVE, 1980). One is a high volume method developed in Sweden (LINDVALL" 1970), the other is a method developed in the USA on the basis of the triangle olfactometer (DRAVNIEKs, 1975). Both methods were used to determine dilution factors for industrial exhaust air. However, in general odour measurements with different equipment and different procedures do not yield the same results, because, as explained above, the sensation of smell and thus, the odour threshold value depends on a number of conditions, i.e. air speed, temperature and humidity, and the background odour of the equipment/room. Another important factor is the degree of dilution before air reaches the odour sensitive regions of the nasal cavity. If the air speed in the apparatus is low, the degree of dilution will vary during sniffing.

Determination of odour threshold value

The determination of the odour threshold value of a substance depends on the measurement method used. Therefore we cannot in general compare threshold values found in literature with measurements we have made ourselves, unless the methods used were identical.

Measurement methods should fulfil the following general requirements:

1. Air should be dosed dynamically.
2. The flow rate of sample gas to panellists should be 20 l/min.
3. The dilution steps should not exceed a factor of 2.
4. The odour presentation should be short, to avoid adaptation.
5. Panellists' answers should be by the forced choice principle or other principles to avoid anticipation biases.
6. Loss of odorant and contamination should be eliminated by correct choice of material etc.

The Danish EPA is aware that these requirements can hardly be fulfilled by all currently used measurement methods.

Odorant unit

The results of threshold determinations can be expressed by a figure describing the *odorant unit, LE, defined as the amount of odorants mixtures which distributed in 1 cubic metre of air results in odour intensities corresponding to the*

threshold value determined by a given procedure. The odorant unit is, thus, defined by a physiologically measured amount of substance.

Odorant concentration

If as a result of the threshold value determination, a sample must be diluted 100 times to reach the threshold value, the odorant concentration is 100 LE/m³. Below the symbol C is the odorant concentration.

4.2 Measurement procedure

Below a measurement procedure is described which must be used to determine the odorant emission in exhaust air.

Reference substances

Odour thresholds are determined using l-Butanol and hydrogen sulphide as reference substances. The panellists must regularly determine the threshold concentration for l-Butanol and hydrogen sulphide. Threshold value concentrations of 0.05 ppm for l-Butanol and 0.0006 ppm for hydrogen sulphide were used as a basis for assessing the panellists' sensitivity.

Sensitivity factors

If a panel determines the odour threshold concentration at C_b (ppm) and C_s (ppm) respectively, the sensitivity factors relating to l-Butanol and hydrogen sulphide are said to be

$$P_b = \frac{0.05}{C_b}$$

and

$$P_s = \frac{0.0006}{C_s}$$

respectively, and the resulting sensitivity factor is defined as

$$P = \sqrt{P_b P_s}$$

If the odorant concentration C is determined by this panel, the odorant concentration C₅₀ is used to calculate the effective outlet height and/or dimensioning of cleaning measures. C₅₀ is calculated by

$$C_{50} = C/P$$

So with a dilution of C₅₀, the odorant concentration of a sample with concentration = C₅₀ corresponds to the odour threshold value determined by a panel with a sensitivity factor P = 1.

Selection of panellists

The panellists should be selected along the lines described by MØLHAVE (1980). The following general requirements should also be applied:

The panel must consist of at least 6 persons between 18- 50 years.

1. All age groups, between 18 and 50 years should be represented.

2. The panel must be able to determine threshold values of l-Butanol and hydrogen sulphide with reproducibility $\pm 30\%$.
3. The geometric dispersion of panellists' responses should be less than 1.5 for l-Butanol. The geometric dispersion is determined by means of measurement values around the median. At least 2 measurement points different from 0% to 100% should be used.

4.3 Sampling odours

Odour sampling, collection and storing

Samples for determination of the odourant emissions must be taken according to the directions described in Guideline No. 7/1974 (Miljøstyrelsen, 1974) on measurement of gas emissions. Collection and storage of samples are described by several authors (i.e. MØLHAVE, 1980). Change or contamination of the sample during collection or storage can for instance be avoided by using polyvinyl fluoride plastic bags (PVF-TEDLAR) connected to the measurement point by a teflon pipe not more than 2 m long. The bag is placed in a rigid container, which is evacuated, allowing the tedlar bag to inflate. If exhaust air is hot or contains dust or a liquid, it must be cooled, filtered or dried without loss of odourant. It may be difficult, and requires a thorough physical/chemical evaluation of the conditions. The durability of the air sample should be examined by physical/chemical measurement methods, allowing the maximum allowable storage period to be fixed (normally not over 24 hours). The sampling time should be 1-5 minutes with suction speed = 4-20 l/min. The samples should be taken when the odourant emission is at a maximum in normal conditions of operation. The volume of the odourant emission is calculated as the arithmetic mean of measurements made with maximum odourant emission. Further details can be obtained from the Danish EPA or consultants working with odour measurements.

5 Establishment of immission limits

5.1 General odour immission limits

This guideline deal only with odour nuisances, which do not cause physical damage to the environment. Therefore the emission limits are derived directly from immission limits. The limit value for cellulose diluents specified in The Danish EPA Guideline 2/1978 can, however, still be applied to odour from these substances.

Some odorants which otherwise harm the environment may be covered by other guidelines. For some of these substances (for instance sulphur dioxide), the limits recommended in these guidelines are dimensioned for outlets or cleaning measures.

Aspects which influence the extent of odour nuisances

As mentioned earlier the degree of annoyance caused by odour is determined by the odour intensity, the frequency and duration of the impact, and the acceptability. The annoyance felt by different people is also influenced by their perception of smell, which varies with time and with the conditions in which each individual is exposed to smell.

Dimensioning of outlet and/or cleaning measure

It is recommended that the outlet and/or cleaning measures against emission of odorous compounds are dimensioned so that the maximum concentration (sampling time: 1 minute) of the odorant does not exceed the concentration at 5-10 times the odour threshold. The maximum concentration, which should not be exceeded at ground level outside the plant site in residential areas, is calculated as the average of anticipated peak values in neutral to moderately unstable atmospheric conditions and wind speed of 4.5 m/s.

In industrial areas and open rural areas this concentration may *in some cases* be increased by a factor of 2-3.

Meteorological situations influencing dimensioning

In Denmark meteorological conditions are for about 60% of the time neutral or moderately unstable. In much of the remaining time the meteorological conditions result in smaller ground level concentrations of odorants emitted through outlets. Only in very small percentages of time, meteorological situations result in higher concentrations at ground level. Some of these situations are difficult to describe and, thus, to make calculations for.

When dimensioning requirements are fulfilled

If the dimensioning requirements are fulfilled a minor part of the population living where the odorant occurs in concentrations corresponding to the odour threshold will, however, still be able to perceive the smell, even if this does not necessarily mean that they are annoyed, and even if, in practice, each of them

is only exposed to the smell for smaller periods of time. Please note that the recommendation given above is used as a basis of calculation made with due regard to the frequency of different meteorological situations.

5.2 Addition of odour contributions

Odour contributions from one industrial plant must be added up. Odour contributed by several plants emitting substances with different odour properties can be dealt with separately. If several plants of the same type are expected in one area, plans must be made to ensure that the total emission from new and existing plants is limited so that the total immission concentration contribution does not exceed the values recommended in this guideline (see also section 7.3.).

6 Measures to reduce odour emissions

6.1 Measures relating to production and technical design

It is not possible to give a complete description of how odour nuisances can be prevented or removed. However, below are listed a number of factors, which should be considered in connection with the establishment of new plants and control of odour from existing plants.

Odour emissions and temperature

Temperature can considerably influence odour emissions in three different ways. The generation of odorous compounds depends on the temperature. Odorous compounds are produced more quickly at high temperatures (summer/winter, not cooled/cooled). Heating of heat-sensitive substances may lead to generation of odorants. Also the release of odorants to the ambient air is influenced by temperature (e.g. processes with hot liquids result in greater release than if cold liquids are used). Very high temperatures may decompose odorants during incineration with sufficient oxygen and appropriate incineration throughput rates.

Pressure

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

Air exchange

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

Supervision and maintenance

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

Decay

Evaporation of odorants from stored decaying material may often lead to odour emission (e.g. food, waste products). Good housekeeping may

eliminate the problems. It is recommended to process animal products quickly, and not to store them in the open air.

Containment

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

6.2 Odour removal techniques

Below is given a brief survey of the efficiency of various equipment for cleaning of air containing odorous constituents. For more detailed information, see for instance (NRC, 1979), (HANSEN, et al., 1979) and (MENIG, 1977).

A number of methods are used to remove odorants from gases, based on adsorption, absorption, incineration, catalytic oxidation or biological cleaning.

Adsorption

During adsorption gases are retained and concentrated on the surface of a solid substance consisting of very porous material. Activated carbon is used most frequently for adsorption of odorants and poison.

To achieve the most efficient operation of the carbon filter, substances like dust, tar, mineral oil and large quantities of steam must be removed from the gas before it passes through the filter bed, to prevent these substances from clogging up the small charcoal pores, thus reducing their adsorption capacity. Also certain metal compounds quickly reduce the charcoal adsorption capacity, often as a result of heavy oxidation of the coal and destruction of the pore structure. To improve the adsorption capacity of activated carbon for certain purposes the coal is impregnated with various agents so that the substances intended for retention react chemically with the impregnation agent. Activated carbon can often be regenerated in a process where odorants are removed with steam. The condensed steam may present wastewater problems.

Absorption

Odorants are often removed from the air by means of washing in scrubbers. Scrubbers are for instance used to remove odorant compounds with chlorine sulphur and fluoride.

A scrubber is a fairly simple device, which is able to treat large volumes of air. Gas washing in a scrubber is, therefore, often a cheap way of removing odorants from process gases.

In order to achieve the most efficient scrubber operation, an acid, alkaline or oxidising agent is added to the water, depending on the circumstances. Chemicals should be added very carefully to prevent overloading of the plant. In a well-operated scrubber the reaction products are often salts and non-smelling acids.

Heavily oxidising liquids, e.g. hypochlorites, are often used for removal of odorous compounds from fish and meat meal processing plants. Acid gases are needed for alkaline solutions and vice versa.

There are different types of scrubbers, for instance packed tower scrubbers, spray and venturi scrubbers etc. A common characteristic is the effort to make the efficient contact area between air and liquid as big as possible.

Thermal incineration

By thermal incineration odorous chemicals are oxidised into less odorous or non-smelling substances, for instance carbon dioxide, water and sulphur dioxide. The incineration temperature is normally 500-1200 °C.

Odour abatement by incineration in combustion plants is well suited in plants with large consumption of energy (fishmeal, meat meal, bone meal factories etc.). The air required for the boiler plant can be taken from the exhaust system. This method allows the factory to clean large volumes of air at low costs.

In plants with serious odour problems and low energy consumption the operation costs of afterburning are often so high that other methods must be used. Here the best and cheapest solution is often a combination of adsorption and incineration, and the heavily contaminated air emitted from regenerated plants is then cleaned in an incineration process.

The combustion temperature shall be so high and the residence time so long that the odorants are completely burnt. In order to reduce the operation costs the afterheat must be used to the greatest possible extent. The plant should for instance always be fitted with a combustion air preheater.

Catalytic oxidation

Operating temperatures in catalytic oxidation are lower (250-500 °C) than incineration temperatures.

The usual catalyst is a metal, for instance platinum or vanadium, or a ceramic porous material. Given the high price of these metals the catalytic afterburner is normally rather expensive to buy. On the other hand the operating costs are small because the combustion temperature is low.

If catalytic oxidation is based on a metal removing malodorous gas, care should be taken to avoid that the gas contains compounds, which may poison the catalyst. Poisons are for instance silicates, silicones, phosphorous compounds and metal compounds.

Biological cleaning

In recent years new methods for biological odour abatement have been developed. The odours are treated in a microbially active bed or particles with microbes. The filter material is humus-like products (sphagnum, compost, etc.). The filter bed is placed at soil surface, and the odorant gases are fed in through a network of pipes (GUST et al., 1979).

7 Calculation of outlet height

As mentioned in section 3.3., odour intensity does not decrease proportionate to the odour concentration, and therefore the odour emission should primarily be reduced either by cleaning measures or by changing design and production features. After that odour nuisances can be reduced through dilution via outlets. The odorant emission concentration, C_{50} , before dilution must not exceed 100.000 LE/m³.

7.1 Emission from well-defined outlets

The following calculation is based on the assumption that emission takes place centrally through a well-defined outlet.

The emission height calculations are based on the same formulae as those used in the Danish EPA guidelines No. 7/1974, 3/1976 and 2/1978. However, these guidelines also take account of plume downwash (buoyance or thermal lift).

Units

All formulae use the following consistent units:

Length	meter
Time	seconds
Odorant unit	LE
Temperature	°C

Symbols

The following symbols are used in the formulae relating to odour:

B_1	Biggest difference in level between outlet base and building roof top	m
B_2	Biggest difference in level between outlet base and ceiling in building top storey	m
C	Odorant emission concentration (before use of reference substances)	LE/Nm ³
C_g	Acceptable odorant concentration contribution from outlet (odorant immission concentration contribution)	LE/Nm ³
C_{50}	Odorant immission concentration	LE/Nm ³
H	Physical outlet height	m
H	Plume rise (buoyance or thermal lift)	m
H_e	Effective outlet height	m
H_s	Theoretic outlet height	m
Q	Emission (momentum)	LE/s
R	Air volume from outlet (dry air)	Nm ³ /s
t	Temperature in outlet	°C

V_s	Air speed in outlet	m/s
d	Outlet diameter	m
h	Outlet height correction value	m
h_1	Outlet height correction value	m
h_2	Outlet height correction value	m
u	Average wind speed	m/s

The calculation procedure described below shall not be used in plants with modest odour emission, where the following inequality applies:

$$R (C_{50} - C_g) < 100 \text{ LE/s}$$

Effective outlet height

The calculation of the effective outlet height, H_e , in the Danish EPA guideline no. 7/1974, is based on the following formula (LEE and STERN, 1973):

(1):

$$H_e = 0.437 \left(\frac{Q}{C_g} \right)^{0.444}$$

where Q is expressed in g/s, C_g in g/m^3 .

In formula (1) the characteristic measurement time for the concentration C_g is approximately 30 minutes. The formula can be used for the average of maximum concentration values of short averaging times (= 1 minute), if Q/C_g is corrected. The correction factor 5.5 is chosen on the basis of literature (GIFFORD, 1960), (HINO, 1968) and (WSL, 1980) in order to assure validity of the method at different H_e .

(2):

$$H_e = 0.437 \left(5.5 \frac{Q}{C_g} \right)^{0.444}$$

$$H_e = 0.93 \left(\frac{Q}{C_g} \right)^{0.444}$$

The momentum is calculated as:

(3):

$$Q = RC_{50}$$

The effective outlet height is calculated from the formula:

(4):

$$H_e = 0.93 \left(\frac{RC_{50}}{C_g} \right)^{0.444}$$

Q is expressed in LE/s and C_g in LE/m^3

Thermal lift

If the stack is fitted with an efficient jet cap (plume downwash does not occur) the thermal lift, H , of the jet cap can be calculated from

(5):

$$\Delta H = d \left(\frac{V_s}{u} \right)^{1.4}$$

For u the value 4.5 m/s is used, corresponding to typical wind speed in Denmark.

Downwash

If $V_s \leq 1.5 u$ (for $u = 4.5$ m/s: $V_s \leq 7$ m/s), downwash will occur and must be considered in the calculation by using

(6):

$$H_{\text{sug}} = 2d (1.5 - V_s/4.5)$$

for $V_s \leq 7$ m/s. If downwash occurs, H_{sug} shall be deducted from H_s in equation (7).

The efflux speed of the gases at the outlet top should always be greater than 10 m/s.

Thermal lift

For hot gases or flue gases the plume rise, H , should be calculated from

(7):

$$\Delta H = 0.151 (Rt)^{0.6} H_s^{0.15}$$

Theoretic outlet height

The theoretic outlet height, H_s is calculated from the effective outlet height less the greater of either buoyance or thermal lift, and with possible addition in the case of downwash.

(8):

$$H_s = H_e - \Delta H$$

If the resulting H_s is more than 80 m, emissions should be controlled by means of construction or design features or by cleaning.

Physical outlet height

The physical outlet height, H , is calculated from

(9):

$$H = H_s + h$$

The outlet height correction value h is, first, calculated according to a) below, and, second, according to b) and the greater of the two values is used as correction value.

a) The correction value h_1 is calculated taking account of buildings within an area limited by a circle with a range of $2H_s$ from the outlet. Buildings here mean any kind of buildings, and B_1 is the largest difference of level between the outlet base and roof ridge of buildings.

By $\frac{B_1}{H_s} \leq 0.3$ we get $h_1 = 0$ m

By $0.3 < \frac{B_1}{H_s} \leq 1.0$ we get $h_1 = \frac{B_1 - 0.3 H_s}{0.7}$

By $\frac{B_1}{H_s} \geq 1.0$ we get $h_1 = B_1$ m

b) The correction value h_2 is fixed at $h_2 = B_2$ where B_2 is the largest difference of level between outlet base and ceiling in top storey of buildings within an area limited by a circle with an outer range of $20 H_s$ and inner range of $2 H_s$ from the outlet. (Buildings here mean any kind of buildings in which people stay for some time (living, office work, production etc.).)

Account need not be taken of isolated buildings with a small horizontal extent ($< 30^\circ$) at right angles to the outlet and located between $10 H_s$ and $20 H_s$.

outlet

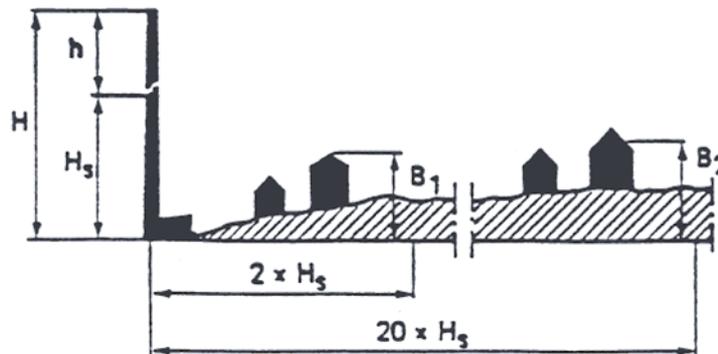


Figure 2:
Values for calculation of outlet height corrections resulting from buildings

7.2 Emission from low sources/open plants

Large quantities of odorous gases should not be emitted from open plants, because the emission can generally not be controlled and/or reduced. The odour emission from open plants varies greatly, influenced by a number of factors such as temperature and wind speed. In practice it is not possible to determine.

New plants

New plants, which may be potential odour sources, should therefore in certain circumstances be fitted with covers or hoods enabling treatment of exhaust gases or dilution by means of stacks.

Existing plants

If complaints are raised against odour from existing plants, the odour emission must be estimated roughly, and the decision then taken whether design or production improvements are required and whether hoods and/ or stacks to central outlets should be established.

7.3 Abatement zones

The abatement zone surrounding an odour source can be estimated from the following expressions:

$$\begin{aligned} L &= 1.6 (RC_{50})^{0.6} && \text{for low sources} \\ L &= 5.62 H_e^{1.16} && \text{for high sources where } H_e \text{ is calculated according to} \\ &&& \text{equation (2).} \end{aligned}$$

from experience we know that odour can be perceived within a circle with this radius (m) (WSL, 1980), (MILJØSTYRELSEN, 1982).

Higher outlet

If a outlet height exceeds the value resulting from calculations based on the method described in this guideline. The abatement zone shall be calculated by inserting the effective height of this outlet in the high sources equation. The odorant concentration contribution is, then sufficient to allow later extensions of the plant without new odour abatement measures having to be taken.

Location of abatement zone

If the abatement zone of a low source is within the factory site, the conditions are satisfactory. However, to make this estimate, emissions from several sources of the same type in the same factory must be added up. If the abatement zones of several sources of the same type overlap each other, the contributions from the sources shall be considered together along the lines specified in (MILJØSTYRELSEN, 1982), in order to determine the odour concentration contribution, see section 5.2.

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