VATTEN 62: 227–236. Lund 2006

ODOROUS WASTEWATER EMISSIONS

Lukter från avloppssystem

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Abstract

The objective of this article is to review odour problems of wastewater treatment facilities and air emission treatment methods. The malodorous wastewater emissions consist of a complex mixture of substances with different properties. A screening of volatile organic and reduced sulphur compounds revealed very low concentrations of individual compounds (< 50 ppb), and only dimethyl sulphide, hydrogen sulphide and methyl mercaptan were found at concentrations above threshold values. Indicating one single compound responsible for the foul odours was not possible.

Two case studies are presented and discussed. In the first, a compact biofilter was evaluated for the treatment of gas streams from a sewage pumping station. A rockwool filter media was inoculated with a mixed bacterial wastewater culture that established successfully. However, evaluating the biofilter's performance proved analytically difficult and expensive due to the low concentrations of incoming gases. In the second case study the odour nuisance situation around a wastewater treatment plant was evaluated and a holistic approach to manage the odour problems was developed. An odour panel of local observers worked well, since they got involved in the process. However, using the panel's reports on odour episodes to find the source of the odour was difficult.

Key words – wastewater, odour, air emissions, odorous compounds, H_2S, DMS, treatment methods, odour panel, case study, biofilter

Sammanfattning

Syftet med denna artikel är att ge en överblick av luktproblem kring avloppssystem och tänkbara behandlingsmetoder för dessa gaser. Illaluktande avloppsemissioner består av komplexa gasblandningar med olika fysiska och kemiska egenskaper. Genomförda mätningar av flyktiga organiska och reducerade svavelföreningar visar att alla ämnen fanns närvarande i väldigt låga koncentrationer (< 50 ppb) och bara svavelväte, dimetylsulfid och metylmerkaptan återfanns i koncentrationer över lukttröskelvärdet. Det gick inte att peka ut ett ämne som ensamt ansvarig för lukten.

Två fallstudier presenteras och diskuteras. I det första utvärderas behandling av ventilationsgas från en pumpstation i ett kompakt biofilter. Ett stenullsmaterial inympades med en bakteriekultur från avloppsreningsverket, som etablerade sig och växte till i filtret. Det var dock komplicerat och dyrt att utvärdera effektiviteten hos biofiltret eftersom inkommande gaskoncentrationer var så låga. Syftet med den andra fallstudien vara att utvärdera och att utveckla metoder för att arbeta med luktproblem kring ett avloppsreningsverk. Lokala observatörer användes i en luktpanel, något som skapade ett engagemang och en kunskap kring luktproblemen. Det visade sig dock vara svårt att använda panelens luktsamtal för att hitta källan till luktepisoden.

Background and aim

Wastewater treatment works, collection systems and wastewater treatment plants (WWTP) all have the potential to generate unpleasant odours. When considering the potential for the generation and release of odours, analysing the processing facilities of liquids and solids separately is common practice. Sewers exist as widespread networks in densely populated urban areas, and malodours are typically identified where the sewer atmosphere is in contact with anaerobic wastewater and sewer gas escapes into the urban atmosphere, e.g. at manholes and pumping stations. The headworks and preliminary treatment operations at a WWTP have the highest potential for odour release, especially for treatment plants with long collection systems where anaerobic conditions can be created. Typically, the most significant sources of odours are sludge-thickening facilities, anaerobic digesters, and sludge-load out facilities (Stuetz and Frechen 2001).

Sweden has just over 2,000 publicly owned sewage treatment plants and about 6,000 wastewater pumping stations (The Swedish Water & Wastewater Association 2005). In recent decades, the digestion of sludge and biogas production has gained increased popularity at municipal WWTPs, an activity with the potential to cause objectionable odours. As well, an increased awareness of the environment has highlighted air emissions inside and outside of the treatment works.

The objective of this article is to review odour problems around wastewater treatment facilities and possible treatment technologies for these air emissions. Two case studies involving wastewater odours are presented and discussed; a wastewater treatment plant and a sewage pumping station.

Methods

The literature review was conducted through databases with scientific journals, mainly Compendex, Science Citation Index and Water Resources Worldwide. Academic literature and reports and personal communication were used. The methods and experimental set-up used in the case studies are presented separately.

Results

Review of odour problems around wastewater facilities

Air emissions from wastewater treatment works may cause malodours at very low odour thresholds, defined as the concentration where the odour is detectable by 50 % of the subjects (Devos et al. 1990). These foul odours constitute a complex mixture possibly containing a thousand different substances, produced and emitted under varying process conditions (Stuetz and Frechen 2001). Table 1 presents the most frequent substances found in wastewater emissions, along with information of odour thresholds and boiling points. Threshold information varies in the literature and no information of mixtures is available. Other physical and chemical properties of these substances vary greatly and will have a large impact on treatment.

In addition to being malodorous, the emissions of these substances cause problems in terms of corrosion and health risks. Very small amounts (ppb levels) can be detrimental to human health, causing headaches and nausea, along with eye, respiratory, and neuropsychological symptoms (Kilburn and Warshaw 1995; Marttila 1995). This means that even trace levels can constitute important public health problems by creating objectionable situations for workers and for people who live close to these types of discharges. Besides, some of these gases also undergo photochemical reactions in the atmosphere that contribute to the formation of photochemical oxidants, principally ozone.

Emission concentrations

Only a few studies have measured specific odorous compounds in sewer systems and since one deals with such complex mixtures, comparing different systems is difficult. As well, large variations occur within each system. An investigation of sewer air composition showed the presence of hydrocarbons in concentrations up to 500 ppm, chlorinated hydrocarbons from 10 to 100 ppm, H_2S from 0.2 to 10 ppm, other sulphides (mainly DMS and MM) from 10 to 50 ppb, amines from 10 to 50 ppb, and aldehydes from 10 to 100 ppb (Thistlethwayte and Goleb 1972). Most samples were taken in a sewer transporting municipal wastewater with a maximum residence time of 4 hours. More recent studies of WWTP biofiltration have reported on lower VOC concentrations in the waste gas streams; 50 ppb to 10 ppm (Ergas et al. 1995; Webster et al. 1996). Several authors have carried out H_2S measurements. Fred (2005) found that concentrations of H_2S from pumping stations and networks in Helsinki were low (generally < 1 ppm), but concentrations as high as 250 ppm were found downstream from pressure mains and at passenger harbours. Shareefdeen et al. (2003) reported on diurnal variations of H_2S of 1 to 17 ppm from a wastewater pumping station in Canada.

Meteorological conditions

Meteorological conditions will affect odour release. The dispersion of pollutants into the atmosphere depends on the height of the emission point, the topography, and the atmospheric ventilation, which includes wind direction and force, turbulence and height of mixture. Temperature differences can create layers in the atmosphere that may obstruct vertical air rotation. Under quiescent meteorological conditions, odorous gases that develop at treatment facilities tend to stay at the point of generation because they are denser than air. It has been

Table 1. *Examples of volatile odorous compounds associated with wastewater.* (Dean 1999; Devos et al. 1990; Metcalf and Eddy 2003; Rafson 1998; Rosenfeld and Henry 2001; Stuetz and Frechen 2001; Vincent and Hobson 1998; Winter and Duckham 2000).

Substance	Compound	Formula	Characteristic odour	Odour threshold (ppb)	Boiling point (°C)
Volatile sulphur compounds					
	Hydrogen sulphide	H_2S	Rotten eggs	0.45–20	–60
	Methyl mercaptan (MM)	CH_3SH	Decayed cabbage, garlic	0.0014–21	6
	Ethyl mercaptan	C_2H_5SH	Decayed cabbage	0.2	35
	Allyl mercaptan	$CH_2{=}CHCH_2SH$	Strong garlic, coffee	0.05	69
	Benzyl mercaptan	$C_6H_5CH_2SH$	Unpleasant, strong	0.2	195
	Crotyl mercaptan	$CH_3\text{-}CH{=}CH_2\text{-}SH$	Skunklike	0.029	
	Dimethyl sulphide (DMS)	CH_3SCH_3	Decayed vegetables Cabbage, cowy	0.12–2.5	37–38
	Dimethyl disulphide (DMDS)	$CH_3S_2CH_3$	Putrefaction Rotting vegetable	0.1–15.5	108–110
	Diphenyl sulphide	$(C_6H_5)_2S$	Unpleasant	4.7	
	Ethylmethyl sulphide	$C_2H_5SCH_3$		4	66–67
	Diethyl sulphide	$C_2H_5SC_2H_5$		12	90–92
	Carbon disulphide	CS_2	Rotting radishes	0.3	46
	Isopropan ethiol	$(CH_3)_2CHSH$		4	57–90
	Thiocresol	$CH_3C_6H_4SH$	Skunklike, rancid	0.062–0.1	
	Sulphur dioxide	SO_2	Pungent, irritating, acidic	9	–10
Nitrogenous compounds					
	Ammonia	NH_3	Sharp, pungent, irritating	5000–50000	–33.4
	Methylamine	CH_3NH_2	Putrid, fishy, rotten	1–50	–6.4
	Ethylamine	$C_2H_5NH_2$	Ammonical	2400	17
	Dimethylamine	$(CH_3)_2NH$	Fish	20–80	7
	Trimethyl amine	$(CH_3)_3N$	Pungent, fishy	4	3
	Pyridine	C_6H_6N	Disagreeable, irritating	4	115
	Indole	C_8H_6NH	Fecal, nauseating	0.1–1.5	254
	Scatole	C_9H_9N	Fecal, nauseating	0.002–19	265
Acids (VFAs)					
	Acetic acid	CH_3COOH	Vinegar, sour	15	118
	Butyric acid	C_2H_5COOH	Rancid	0.1–20	162
	Valeric acid	C_3H_7COOH	Sweat	2–2600	185
Aldehydes and ketones					
	Formaldehyde	$HCHO$	Acrid, suffocating	370	–19
	Acetaldehyde	CH_3CHO	Fruit, apple	0.005–2	21
	Butyraldehyde	C_2H_5CHO	Rancid, sweaty	4.6–5	76
	Valeraldehyde	C_4H_9CHO	Fruit, apple	0.7–9	103
	Acetone	CH_3COCH_3	Fruit, sweet, mint	4600	56
	Butanone	$C_2H_5COCH_3$	Green apple	270	80
	Phenol	C_6H_5OH	Tar	60	79
Chlorinated compounds					
	Chlorine	Cl_2	Pungent, suffocating	314	–34
	Chlrorophenol	ClC_6H_4OH	Medicinal odour	18	175
	Trichloroethylene	C_2HCl_3	Sweetish, chloroform	500–100000	87
	Carbon tetrachloride	CCl_4	Sweet	10 000	77
	Ethylene dichloride	$C_2H_4Cl_2$	Chloroform like odour	50 000	83

Table 2. *Odour treatment technologies.*

Physical methods	Chemical methods	Biological methods
Dilution with odour free air	Chemical scrubbers	Biofilters
Oxygen/air injection	Chemical oxidation	Biotrickling filters
Adsorption	Chemical precipitation	Bioscrubbers
Absorption – scrubbing towers	Masking agents	

observed that odours may be found at undiluted concentrations at large distances from the point of generation (Tchobanoglous and Schroeder 1985).

Odour database

In Sweden, 290 municipalities are responsible for the planning, construction and operation of the facilities for water and wastewater, all of which are members of the Swedish Water & Wastewater Association (SWWA). SWWA has several working groups with experts from member municipalities that cover the whole field of municipal water and wastewater activities. The wastewater group has collaborated in an odour project with its sister organisation in Norway (Norwegian Water and Wastewater BA, Norvar), with the aim to investigate odour problems around wastewater treatment facilities. The gathered information is published on their website in an "Odour Database" (Norvar 2005) that is mainly a reference system to WWTPs where different odour treatment systems are used. Each method is briefly described with critical factors, maintenance needs, efficiency, space requirements and contractors, and a link is provided for practical experiences from different municipalities in Sweden and Norway.

Containment and treatment

Odour containment includes the installation of covers, collection hoods, and air handling equipment to contain and direct odorous gases to disposal or treatment systems. Cover materials should be corrosion resistant and durable enough for the aggressive wastewater environment. A number of technologies have been developed to treat odorous air emissions, from physical and chemical to biological methods, see Table 2. The choice of technology will depend on many factors, including regulations, the source and concentration of the emissions, and the costs to implement and operate the process. The specific treatment method will depend on the characteristics of the odorous compounds. Considering the vast number of substances and their different properties that can be present in a wastewater gas emission, choosing a technology is not an easy task and several treatment steps may be necessary.

Physical methods

Augmented ventilation and a raised emission point to increase dispersion are commonly used to reduce odour problems. To prevent anaerobic conditions, oxygen or air can be injected into the sewer net. Adsorbent systems generally consist of static beds of granular materials such as activated carbon. The adsorbents serve as media for removing odorous gases by retaining and concentrating them. These systems are usually also very efficient for mixed air streams and operate with short retention times and relatively small units. However, the cost of replacing and disposing of the adsorbent is fairly high, and moist gas streams will reduce its lifespan, since water vapour will occupy some of the adsorption sites. A scrubbing tower provides the opportunity for the compounds to absorb into a liquid solution, often water, and operates efficiently with moist gas streams. Using a packing material in the scrubber provides a larger interfacial area and promotes the gas-liquid transfer. However, adsorption only works for soluble components and might therefore not be so efficient in removing multiple odorous compounds.

Chemical methods

Oxidation (i.e. by ozone) or the addition of acidic or alkaline chemicals enhances the efficiency of a scrubbing tower. Complex airstreams with numerous odour-causing compounds may require multiple units with different chemicals or units combined with other control devices. No media disposal requirements exist, and the scrubbing liquid is usually treated in the regular WWTP processes. The disadvantages of chemical scrubbing include high costs, chemical storage and handling requirements, and the risk of complex chemical feed systems. Odours can also be removed from the liquid phase through chemical additions at different points, both in the collection system and at the WWTP. A variety of chemicals have been used to prevent anaerobic conditions: ozone, chlorine dioxide, sodium hypochlorite, potassium permanganate, hydrogen peroxide, and also ferric and calcium nitrates (Rafson 1998). The only way to establish the required chemical dosages for removal is through pilot-scale testing, and the use is complicated by the complex matrixes in which the odours exist. Iron salts, typically ferric chloride, sulphate or nitrate, are used for precipitation of dissolved sulphide. However, its effectiveness is affected by the pH value in wastewater. A disadvantage of using chemical dosing is the additional cost and the formation of residual products that must be taken care of. Chemicals can also be added to the wastewater or off-gases to mask an offensive odour with one that is less offensive, though they do not modify or neutralize the odour. Masking chemicals are based on essential oils with the most common aromas being vanilla, citrus, pine, or floral (Williams 1996).

Biological methods

In recent years, biofiltration has become more and more utilized at wastewater treatment facilities because of its efficiency in treating mixed odour emissions and its relatively low capital and operation costs (Devinny et al. 1999). Biofiltration utilizes microbial metabolic reactions to treat contaminated air. Through chemical and biological oxidations, contaminants are converted to carbon dioxide, water, and organic biomass. Biofilter, biotrickling filters, and bioscrubbers are the most common configurations of biological reactors. The basic removal mechanisms are similar, but differences exist in the phase of the microbes that may be fixed (biofilters and trickling filters) or suspended (bioscrubbers), and the state of the liquid that may be stationary (biofilters) or flowing (trickling filters and bioscrubbers). The technology is environmentally friendly, since it requires no chemicals or secondary treatment. Disadvantages include the large reactors usually necessary to obtain long enough residence times and change in head loss over time due to media ageing. Proper environmental conditions such as temperature, pH, moisture and nutrient control are also prerequisites for optimal function.

Case 1 – wastewater pumping station P017

In response to odour complaints around this wastewater pumping station, pilot scale studies were conducted with two objectives: to characterize the malodours and assess the feasibility of a compact multistage rockwool biofilter to treat the gas streams at relatively short residence times. Offsite facilities such as pumping stations may lack sufficient space to accommodate a traditional biofilter and therefore require more compact designs. The potential of using a synthetic rockwool material has previously not been examined for this type of application.

Description

The pumping station is situated at the entrance to the university in the town of Luleå, northern Sweden. Pedestrians and bicyclists passing this pumping station frequently complain of malodours. The biofilter experiments were conducted during the spring of 2002 (April–May) in cooperation with the municipality of Luleå. Data of the pumping station is provided in Table 3.

Experimental set-up and methods

A pilot-scale biofilter composed of three filter units operating in a side flow mode, and with each filter unit having a depth of 0.3 m and a square area of 0.6 x 0.6 m^2, was set-up inside the pumping station (Figure 1). An irrigation system with spray nozzles at the inlet and at the top of the biofilter was utilized intermittently during operation. Drainage was collected at the bottom of the filter. The filter media used was pre-set rockwool fiber mats with low density (around 30 kg/m^3), high porosity

Table 3. *Pumping station data during the experimental period.*

Volume of the building	156 m^3
Average volume of wastewater (pumping sump)	110 m^3 (depth: 2,85 m) at normal levels
Annual average wastewater flow	20 l/s
Pumps	Three submerged centrifugal pumps (Flygt CP 3300)
Pump capacity	55 l/s at normal operation
Connected sewage	Household (about 10 000 inhabitants) Industry (i.e. metallurgic and slaughterhouse)
Temperature	Inside the pumping station: 15°C. From the wastewater pipes and pumping sump: 10 ± 2°C.
Sewers in and out	Gravity sewers in: 800 and 600 mm (non submerged inlet) Force main out: 300 mm
Ventilation	Capacity of the fan: 1200 m^3/h (P_{max} 350 kPa)
Surroundings	Far from living areas, but adjacent to the bike path leading to the university (with a tunnel passage under the main road).

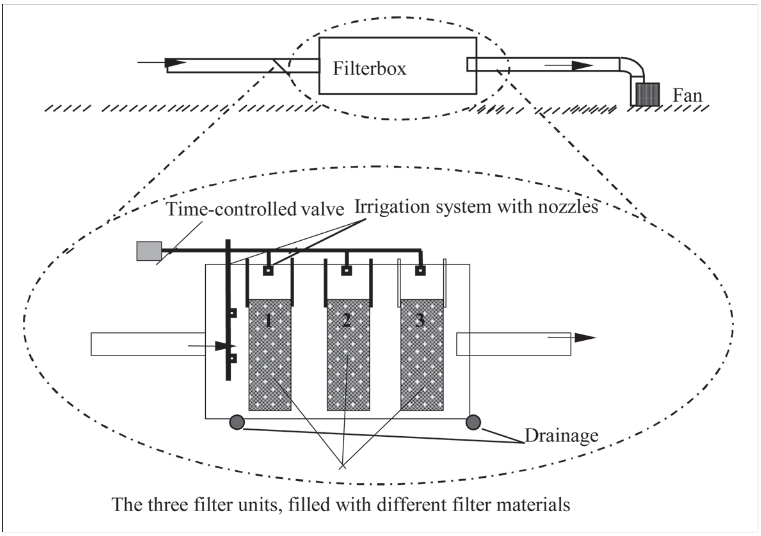

Figure 1. *Schematics of the pilot scale biofilter.*

(approximately 65 %), and a fiber diameter of around 4 µm. Since neither microorganisms nor nutrients were present, these had to be added separately. A mixed bacterial culture from the main wastewater treatment plant in Luleå was used as inoculum, and nutrient pellets were spread in the filter media. The biofilter was evaluated with respect to flow, temperature, pH, pressure drop across the filter bed, and media sampling (moisture, organic content and microbial counts). The composition of the waste gas was investigated through a screening of volatile organic and reduced sulphur compounds. Air was pumped into Tedlar bags and analysed with solid-phase microextraction and GC-MS. Input-output determinations of H_2S was attempted through a dynamic permeation tube method (Gastech) with hydrogen sulphide low range tubes (1–60 ppm).

Results and discussion

All ventilation gas from the pumping station was led through the pilot scale biofilter, resulting in a gas flow through the filter of 200 m^3/h (surface loading: 550 m^3/m^2h). The obtained empty bed residence time (EBRT) was 5–6 seconds, which may have been inadequate for the mass-transfer of contaminants, and in particular those with low solubility. The pressure drop across the filter bed was relatively low (350–500 Pa/m). The steady temperature of 10 ± 2ºC at the inlet of the biofilter may have negatively affected the microbial metabolism. The optimum temperature for various species ranges greatly, but most biofiltration applications have been performed at temperatures in the mesophilic range at 20 to 45°C (Van Lith et al. 1997). Rockwool media samples from the filter bed were taken on five occasions and the pH of media samples was stable around neutral (8.0 ± 0.5). This could be expected since humidification was carried out with drinking water with a pH of around 8. The moisture content of the rockwool was low (6 % ± 12 %), compared with the recommended values of 40–60 % for organic filter media (Ottengraf 1986). However, little information exists on the optimum moisture content for synthetic media. The humidification system with spray nozzles in the inlet was inadequate to humidify the gas, and intermittent, occasional spraying was applied on top of the filter, though because this was done manually it was not frequent enough. An attempt to lead the gas through a packed tower with plastic spheres and improve the gas-liquid interface did not greatly improve the situation. However, despite the dry conditions, the microbial counts showed the establishment and growth of both heterotrophic and autotrophic bacteria (*Thiobacillus*) in the filter media with 10^7–10^8 CFU (colony forming units)/ gram dry filter media. Nonetheless, it is known that too little moisture slows microbial activity, this being one of the most common operational problems with biofilters. Although the viable count on agar plates demonstrated a large amount of both heterotrophic and autotrophic bacteria, this method does not indicate the growth or activity of the bacteria. Unfavourable conditions might have led to biological limitations.

Low pollutant concentrations rendered the analytical evaluation of the biofilter performance difficult. The dynamic permeation tube method with H_2S low range tubes was not sensitive enough, and values before and after the biofilter were always below the detection limit (1 ppm); thus, input-output determinations were not feasible. The screening of volatile organic and reduced sulphur compounds in the waste gas showed no VOCs above the blank and only DMS, H_2S, MM and CS_2 present at levels above odour threshold values, see Table 4. Further measurements of DMS and MM were not feasible due to the high cost. Biological degradation of reduced sulphur compounds (RSC) has been shown to decrease in the following order: H_2S > MM > DMDS > DMS (Cha et al. 1999; Cho et al. 1991; Smet et al. 1998). DMS degraders appear to be those most strongly inhibited by the presence of other compounds, which may have led to biological limitations in the biofilter.

The composition and concentrations of the waste gas will likely vary significantly with time, depending on the incoming wastewater and the pumping activity. For example, a strong diesel odour occurred on occasion at the pumping station, indicating some discharge of this kind. Simple methods to evaluate biofilters in the field of odour applications are needed.

Case 2 – Wastewater treatment plant at Tuvan

Throughout the years, residents living in the neighbouring community have complained of foul odours associated with this wastewater treatment plant (WWTP). A collaborative project between the municipality of Skellefteå, Luleå Technical University (LTU), Miljø-Teknologi AS and Ambra Ventilation AB started in 2005. The aim of the project was to assess the odour nuisance situation around the wastewater treatment plant and develop managing strategies to deal with odour problems.

Description

The WWTP at Tuvan is situated 8 km southeast of Skellefteå, northern Sweden, and treats the water from about 43,000 inhabitants with mechanical, chemical ($AlCl_3$) and biological (activated sludge) treatment. The treated annual wastewater flow in 2005 was 3,000,000 m^3 and the sludge production (dry matter content 20 %) was 5,800 m^3. Biogas production from the sludge has been in the works since 1993; producing about 1,000,000 m^3 biogas in 2005. The enlarged biogas plant scheduled to start in 2006 will also receive household organic waste and organic waste from dairy plants, fisheries, and slaughterhouses. The future yearly biogas production is estimated to 3,000,000 m^3.

In 2004, the city decided to construct an enlarged biogas plant at Tuvan, a decision that has been appealed in several juridical instances. A requirement for the new operation from the local authorities is that "no foul odours should be emitted from the plant". Previous records indicate 37 odour complaints in 2003 and 34 in 2004. Several odour abatement measures have been taken in recent years to combat the odour nuisance impact:

- Instead of the stabilisation method of adding lime to the sludge, this is digested to biogas (1993)
- The dewatered sludge is no longer placed on an open foundation, but is pumped to a silo (2004)
- The trucks transporting the dewatered sludge from the WWTP are covered and not open (2005)
- Two open compost biofilters to treat the ventilation off gases from the WWTP were not functioning properly and replaced with a dual line of scrubbers with ozone and activated carbon filters (2005). One line treats the ventilation gas from the liquid processing facilities; the other treats the gas from the solids processing facilities.

Table 4. *Measured reduced sulphur concentrations of the pumping station waste gas (Case 1).*

Compound	Molecular formula	Measured concentration (ppb)	Odor threshold (ppb)*
Dimethyl sulphide (DMS)	CH_3SCH_3	45	2
Hydrogen sulphide (H_2S)	H_2S	29	1–2
Methyl mercaptan (MM)	CH_3SH	7	1
Carbon disulfide	CS_2	0.62	0.3
Isopropan ethiol	$(CH_3)_2CHSH$	< 0.25	4
Ethylmethyl sulphide	$C_2H_5SC_2H_5$	0.09	4
Diethyl sulfide	$C_2H_5SC_2H_5$	< 0.07	12
Dimethyl disulfide (DMDS)	$CH_3S_2CH_3$	< 0.02	95

*(Devos et al. 1990)

Experimental set-up and methods

Since odour is very individual and subjective, and consists of complex mixtures with many different components and variations of concentrations, the project has worked with a holistic approach that contained several different parts:

- Using local observers in an odour panel
- Keeping a journal of process parameters at the treatment plant
- Weather observations
- Chemical analyses

If the people living around the WWTP are not disturbed by foul odours the problem is solved. However, setting an emission limit or requirement of 99 % pollution reduction is useless if the neighbouring community still complains. Therefore, the focus of the project was put into a local odour panel rather than costly and extensive analytical measurements or dispersion modelling. It is also vital to demonstrate to the public that their ideas, comments and feedback are welcome and important to solve this community problem.

Local observers in an odour panel

The idea of using locals as observers to detect and survey foul odours has been used by others (Bjernesjö 2005; Ericson 2003; Solyom 2005). The odour panel in Skellefteå recruited 17 members from areas in different directions of the WWTP. A few were known to have previously complained of foul odours. The majority have their homes close to Tuvan, but some places of work were also chosen, i.e. daycares, where the personnel are outside for a good part of the day. Each member of the panel received a small card with a phone number – "the odour phone". By calling this number each time they noticed odour from Tuvan a record was kept of when and where foul odours occurred. The strength of the odour on a scale of 1 (hardly noticeable) to 5 (stench) was also indicated. For each call, current weather data was entered as well as the process parameters at the treatment plant to analyze each odour complaint and attempt to determine the source.

Journal of process parameters

Employees at the WWTP kept records of the processes, i.e. if there were upsets, stops, variations, etc. A few simple measurements, such as pH of the two scrubber liquids, were introduced.

Weather observations

At the WWTP Tuvan, a meteorological mast registers data every 15 minutes, from which the wind force and direction at a 24-meter height and temperature at a 2-meter height were entered for the time of each call to the odour phone.

Chemical analyses

Chemical analyses of some contaminants were carried out to characterize the odour and get an idea of the levels of concentrations. Air was pumped into Tedlar bags and analysed with solid-phase microextraction and GC-MS. Reduced sulphur compounds and hydrogen sulphide were measured quantitatively, and VOCs qualitatively.

Results and discussion

At the start of the project (June 2005), an initial information and educative meeting was held at Tuvan for the odour panellists to inform about the aim of the project and to learn more about the sources of the odours. A second meeting took place in October when more information of the future biogas plant was on the agenda. A few of the panellists occasionally called in and reported that they had not noticed any odours from Tuvan, whereas some never called in or participated in any of the information meetings. Two of the initial seventeen members quit halfway through the project. Inactive members are, of course, an uncertainty, and one needs to keep track of extended absences by members from their homes or workplaces.

Only 11 calls to the odour phone were received during the 7-month project period (1/6 2005 – 31/1 2006). This is only one-third of the complaints that was received in 2003 and 2004, even though this group had specifically been asked to call in when they smelled foul odours. The panel also declared a noticeable improvement of the odour situation compared to previous years, possibly due to the different measures taken regarding the sludge handling and installed treatment for the ventilation gas. Incoming calls from the panellists to the odour phone were registered, and the current weather data and process parameters at the treatment plant were entered to analyze each odour complaint and attempt to find the source. However, relating the calls to specific events at the WWTP proved difficult, and there was not always a clear correlation between the wind direction and the location from where the call was made. Calls were received at all times of the day and with all wind directions. The predominate wind came from northwest (NW), with 41 % frequency during the project period, but the majority of the calls came in when there were winds from the south (SE and SW).

pH of the scrubber liquid was registered every two weeks, and was stable at around 7–7.5, which is comparable to the pH of the raw water used in the scrubber. It was also difficult to relate the incoming odour panel calls to any incident at the WWTP. The largest source of

Table 5. *Measured reduced sulphur concentrations before air treatment at the WWTP Tuvan from the liquid and solid process facilities (Case 2).*

Compound	Molecular formula	Range of measured concentrations (ppb)	Odour threshold (ppb)*
Methyl mercaptan (MM)	CH_3SH	<0.15 – 33.5	1
Hydrogen sulphide	H_2S	<2.5 – 8	1–2
Dimethyl sulphide (DMS)	CH_3SCH_3	0.72 – 2.5	2
Carbon disulfide	CS_2	0.45	0.3
Isopropan ethiol	$(CH_3)_2CHSH$	< 0.25	4
Ethylmethyl sulphide	$C_2H_5SCH_3$	<0.04	4
Diethyl sulfide	$C_2H_5SC_2H_5$	0.13 – 0.25	12
Dimethyl disulfide (DMDS)	$CH_3S_2CH_3$	< 0.02 – 0.05	95

*(Devos et al. 1990)

odour seemed to be the silo for sludge storage located outside of the plant. As well, occasions when the sludge was emptied and loaded into trucks for transport gave rise to malodours for a short period of time (usually in the morning). Chemical analysis of the waste gas is presented in Table 5, as ranges of concentrations before air treatment from both the liquid and solid treatment facilities. Very low concentrations of individual components were found, with only MM, H_2S, DMS and CS_2 being above the odour threshold limit. From the volatile organic compounds, aceton, 1-propanol, 2-butanon, etylacetat, and 3-metyl-1-butanol were found in concentrations above the blank.

Further sampling is desirable to establish the variations of concentrations at different times, as well as quantification of VOCs and nitrogen-based compounds to give a more complete picture of the odour mixture. However, these measurements are costly and tedious and many samples are needed if one wants to analyse the fluctuations of concentrations.

Conclusions

Wastewater air emissions constitute a complex mixture that may contain a thousand different substances, produced and emitted under varying process conditions. The most frequent groups are volatile sulphur and nitrogenous compounds, fatty acids, aldehydes, ketones and chlorinated compounds. Possible air treatment technologies include physical, chemical and biological methods, such as adsorption, scrubbers, and biofilters.

A screening of volatile organic and reduced sulphur compounds in both case studies revealed very low concentrations of individual compounds, and only DMS, H_2S, MM and CS_2 were found at concentrations above threshold values. Determining one single compound responsible for the foul odours was not possible. In the first case study, evaluating the biofilter performance proved analytically difficult and expensive, since the concentrations of the incoming gases were so low (< 50 ppb). The rockwool filter media was inoculated with a mixed bacterial wastewater culture, and the establishment of both heterotrophic and autotrophic bacteria was successful.

The odour nuisance situation around the wastewater treatment plant in the second case study had greatly improved compared to previous years. The involvement of local observers in an odour panel proved successful in the sense that they took an active interest in and gained knowledge of the WWTP operation and the complexity of odour problems. However, relating the calls to specific events at the WWTP proved difficult, and the calls were sometimes not consistent with current wind directions.

Acknowledgement

For the case studies, the financial, technical, and operational support from the municipalities of Luleå and Skellefteå, Miljø-Teknologi AS, and Ambra Ventilation AB, are gratefully acknowledged. Thoughts, ideas, input and comments of all staff participating in the projects are much appreciated. Thanks also to Fräs Annika Andersson, Tekniska Verken, Linköping for the gas sample analysis.

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