VILNIAUS GEDIMINO TECHNIKOS UNIVERSITETAS

APLINKSO INŽINERIJOS FAKULTETAS

APLINKOS APSAUGOS KATEDRA

Dainius Kazlauskas

RESEARCHES OF H_2S GENERATION FROM MUNICIPAL LANDFILLS AND SYSTEMATICAL EVALUATION OF LANDFILLS POLLUTION

KOMUNALINIŲ ATLIEKŲ SĄVARTYNUOSE IŠSISKIRIANČIO H_2S TYRIMAI IR SĄVARTYNŲ TARŠOS SISTEMINIS ĮVERTINIMAS

Baigiamasis magistro darbas

Aplinkos apsaugos vadybos ir švariosios gamybos studijų programa

Vadovas doc. dr. Saulius Vasarevičius

Vilnius, 2005

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ANOTACIJA

Susidarančių komunalinių atliekų kiekis Lietuvoje kiekvienais metais didėja. Pagal nacionalinę strategiją, visos komunalinės atliekos Turi būti deponuojamos regioniniuose sąvartynuose, kurie teršia aplinka filtratu iš sąvartyno išsiskiriančiomis dujomis bei kvapais, kurių veina iš sudedamųjų dalių yra sieros vandenilis (H_2S). H_2S matavimai buvo atlikti Jerubaičių sąvartyne. Iš sąvartyno išsiskiriantis H_2S kiekis buvo tiriamas jo išsiskyrimo vietoje, t.y. sąvartyno teritorijoje. Šis matavimo metodas buvo pasirinktas remiantis tuo, kad iš sąvartyno išsiskiriančios taršos dydis ir poveikis priklauso nuo daugelio aplinkos faktorių. Matavimai, naudojant prietaisą GD/MG 7, buvo atlikti 59 matavimo taškuose ir 2 monitoringo šuliniuose, skirtingais metų laikai. Gauti tyrimų rezultatai parodė, kad šios medžiagos kiekis yra skirtingas įvairiose sąvartyno zonose bei įvairiais metų laikais. Norint ištirti H_2S sklaidą buvo atliktas skaitmeninis dispersijos modeliavimas naudojant programą AERMOD. Jo metu vienu atveju buvo pasirinktos stabilios meteorologinės sąlygos, o kitu pasirinkti dominuojančios konkrečiu metų laiku vėjo kryptys ir greičiai. Modeliavimo rezultatai parodė, kad vasarą H_2S didžiausia leistina koncentracija pasiekiama tik maždaug 2,5 kilometrų, rudenį ir pavasarį 1,5 kilometrų, o žiemą - už 800 metrų atstumu nuo sąvartyno teritorijos.

Reikšminiai žodžiai: sąvartynas, sieros vandenilis, kvapai, sklaidos modeliavimas, filtratas, sąvartyno dujos.

ANNOTATION

In Lithuania the amount of waste generation is increasing every year. According to national strategy, all wastes should be disposed in new regional landfills. Landfills pollutes environment with leachate and landfill gas and odours. Landfill gas consists of odorous compounds and one of them is hydrogen sulphide (H_2S). Hydrogen sulphide is highly toxic and affects the nervous system with low threshold. As the landfill gas and leachate generation was word widely investigated before this work, it is not necessary to provide new researches on them. The measurements of H_2S generation were provided in Jerubaiciai landfill. For the measurements was used "site-on" measurement method, measurements were provided with equipment GD/MG 7, in 51 measurement points and 2 monitoring wells, during different seasons of the year. Results of the measurement shows, that amount of H_2S varies in different areas of landfill and during different seasons. The results of dispersion modeling achieved with dispersion model AERMOD, provided under calm weather conditions and under wind dominated in that session winter speed and direction, during different seasons of the year shows, that H_2S spreads from landfill in longest distances from landfill's section during summer (almost in distance equal to 2.5 km the H_2S concentration is higher then Highest Allowable Concentration). In autumn and spring this distance is equal to 1.5 km, and in winter – 800 m.

Key words: landfill, odour, dispersion modeling, hydrogen sulphide, leachate, landfill gas.

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INTRODUCTION

Activity, provided by people, leads to generation of wastes. Waste amount is constantly increasing due to improvement of economic situation and rise of economical level, so the problem of final disposal of wastes is becoming more and more important. Problem relevant to final waste disposal has not been solved properly in Lithuania yet. As the reason of it we have big problematic landfill in each municipality, which pollutes environment with leachate, landfill gasses odours, damage landscape. The number of known illegal small landfills and dumpsites increases one thousand in our days. With it's entry to Europe Community, Lithuania has taken it's responsibility to solve all waste disposal problems.

The financial line for this activity is limited, so it should be used in the most rational way in the time period, defined by Lithuanian legislations and EC directives (till the year 2009), when all landfills ,that does not corresponds requirements, have to be closed and renovated. At first place the landfills that causes highest danger to environment has to be closed.

In these days only few landfills correspond to EC and Lithuanian requirements. The programs for closure of old landfills and for establishment of new regional landfill are provided in different regions of Lithuania. These programs are financed from three sources: 70 % of money comes from Europe Community, 20 % - from Lithuanian budget, 10 % - from loans. As landfills are sources of environmental pollution, it is very important to determinate the amount of this pollution and the ways of suspension of it.

Landfill pollutes several components of environment. Landfill has negative impact on landscape, gas and odour, that generates from landfill, pollutes atmosphere, leachate – groundwater and soil.

The negative opinion of public relevant to establishment of regional landfills is beginning to form in our days. Such opposition is understandable and simple explainable, because the word “landfill” to people of Lithuania associates with huge pile of different waste, from that generates huge unpleasant odour, leachate, a lot off birds, parasites and gnawer gathers near it.

The main aim of this work – to determinate the real pollution, that comes from municipal landfill, which was installed and operated according Lithuanian and EC requirements

In the first part of this work main Regulations, Laws, EU Directives, Standards relevant to Municipal Waste Management are reviewed. After this main physical, chemical and biological municipal waste characteristics are described.

As the regional municipal landfills will be established in Lithuania after few years, it is very important to appoint main landfill types, their characteristics and design singularities. Main types of pollutants, that comes from landfill is also described in this part.

Rest of this work is committed to the preformed researches of H_2S generation and dispersion modelling of its separation.

Aim of the work: overlook the kind of pollution, that can generate municipal landfill, investigate amount of odorant hydrogen sulphide that generates from municipal landfill that is under proper exploitation and dependence of this generation from different environmental parameters. With dispersion modeling program AERMOD to evaluate H_2S spread, predict it's concentration near residential area.

Problem of this work. The researches, preformed in municipal landfills were concentrated on generation of methane, carbon dioxide and leachate. The odour generation problem was forgotten. Complains from people that are living in close to landfill residential area, at first place are relevant to odour problem and the most important odorant is H_2S. Only after real amount of H_2S generation will be determinate, concrete devices of it's reduction can be proposed.

Relevancy of the work. To estimate the H_2S amount that generates in municipal landfill is important as the new big regional landfills will be established after few years and the amount of such kind of pollution will be few times bigger. The pollution from regional landfills can be prognosticated, if the amount of pollution, that goes from landfill, which is now under operation, will be estimated.

Novelty of the work. After the measurements committed to determinate H_2S amount that generates from municipal landfill will be preformed, the amount of H_2S generation from landfill under Lithuanian meteorological conditions and in different period of the year will be defined. The dispersion modeling of H_2S spread in different seasons of the year can be provided.

1. LITERATURE REVIEW

1.1. Regulations, Laws, EU Directives, Standards relevant to Municipal Waste Management

The 1996 Communication on the review of the Community Strategy for Waste Management reviews and updates Europe Union (EU) waste management policy. It confirms the “hierarchy of principles” established in the 1989 Community Strategy for Waste Management, i.e. that prevention of the generation of waste remains the first priority, followed by the recovery of waste, and finally the safe disposal of waste. Waste, which cannot be avoided, is to be recovered through re-use, recycling, or energy recovery, with disposal limited to waste for which no possibility of recovery exists. The medium-term goal is to ensure that only non-recoverable waste and inert waste is accepted in landfills.

Other principles fundamental to EU waste management policy are the principles of proximity and self-sufficiency and the polluter pays principle, i.e. that waste should be disposed of in one of the nearest appropriate installations, that waste generated within the Community should not be disposed of elsewhere and that the costs for disposal shall be born by the waste producers.

The overall structure for an effective waste management regime is set out in the Waste Framework Directive (75/442/EEC) and the complementary Hazardous Waste Directive. These basic laws are supported by two additional groups of “daughter Directives”. One group of acts sets down legal requirements for waste disposal facilities, e.g. incinerators and landfills. The other group deals with specific waste streams such as waste oils, packaging waste and batteries. Relevant to all of these acts is the Waste Shipment Regulation [1].

The aim of the Landfill Directive (1999/31/EC) is to provide measures, protection and guidance to prevent or reduce as far as possible negative effects on the environment as well as the resulting risks to human health from landfilling of waste. The directive sets standards for landfill construction and includes criteria for the acceptance of waste. The directive distinguishes landfills for hazardous waste, non-hazardous waste and inert waste.

The Directive requires phased reduction in the total quantity of biodegradable municipal waste sent to landfills (a reduction to 75% of 1993 levels by 2002, to 50% by 2005, and to 25% by 2010). Methane from both new and existing landfills will need to be collected and used, or flared off. Pre-treatment of waste (via sorting, composting, incineration, etc.) is required before the waste is landfilled. Co-disposal (the mixing of hazardous waste with municipal waste in the same landfill) is to be phased out. Prices for landfill disposal are to include the costs of closure and aftercare.

Other relevant directives are:

- Waste Incineration Directive (2000/76/EC);
- Titanium Dioxide Directive (78/176/EEC, as amended);
- Packaging and Packaging Waste Directive (94/62/EC);
- Waste Oils Directive (75/439/EEC, as amended);
- Waste electrical and electronic equipment (WEEE) Directive;
- PCBs and PCTs Directive (96/59/EC);
- Batteries and Accumulators Directive (91/157/EEC);
- Sewage Sludge Directive (86/278/EEC);
- End-of-Life Vehicles Directive (2000/53/EC).

The above listed Directives have status of Union law. However, before EU law can be applied and enforced, it has to be transposed into National law of the Member States. Here to all Directives include a sentence like "Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with the Directive …"

In addition to transposing Directives' requirements, the requirements shall be implemented. For this purpose Directives include provisions like "Member States shall take the necessary measures to comply with this Directive …" Also the establishment of competent authorities or special institutions for implementation and enforcement may be required as part of a Directive.

In general Member States are given a certain period of time for transposition (typically 1.5 to 2 years) and implementation (several years). In addition, transitional periods may be included for certain articles of Directives or Directives may include targets to be reached in steps during several years.

The main principles of environmental management in Lithuania are defined in the *Environmental Protection Law* (No.I-2223) passed by the Parliament in 1992 and amended in 1996. In waste management sector the Law requires that all persons follow waste management requirements set in laws and other legal acts and that all polluters reimburse waste management costs.

Waste Management Law (No. IX-1004) was adopted by the Parliament in 1998. Revised document transposed provisions of Waste and Hazardous Waste Directives and came into force from January 2003. The Law provides for the basic requirements for waste prevention, recording, collection, storage, transportation, recovery, disposal as well as for the principles of organization and planning of waste management systems.

National Strategic Waste Management Plan adopted by a resolution of Lithuanian Government Nr.519 of April 2002 determines waste management targets, measures and actions providing conditions for implementation of the EU waste management directives within a decade. The plan establishes the following hierarchy of waste management principles:

- Waste avoidance along with the precautionary, cost-recovery and integration principles;
- Waste utilization following the priorities of waste recycling and energy production from waste;
- Safe waste disposal.

The Strategic Plan defines waste management system as a system that covers planning and establishment of waste collection, sorting and utilization systems, closure and remediation of old landfills, construction of new, modern waste disposal facilities, effective operation and administration of the waste management infrastructure.

Municipal institutions are responsible for regulation, development and administration of municipal waste management systems and the inhabitants shall use this system. Municipalities are recommended to establish regional waste management systems. Systems are established in each County but to achieve savings limitation of the system within a single county is not recommended.

The Ministry of Environment issued the Regulations on Waste Landfill Construction, Operation, Closure and Aftercare in the year 2000.

The Regulation transposes the requirements of the EU landfill directive including:

- Classification of landfills;
- Requirements for environmental protection;
- Waste acceptance criteria and procedures;
- Permitting requirements;
- Control and monitoring procedures;
- Closure and rehabilitation of existing landfill sites;
- Closure and after-care procedures.

The landfill design shall assess the stability of geological foundation and its potential impact on the bottom liner, drainage and gas collection systems and top cover.

Design of the landfill shall take into account the hydrological, hydrogeological and meteorological conditions in order to minimise the amount of precipitation that enters the landfilled waste and to prevent the waste from penetration of surface water and groundwater. Special dikes shall divide the landfill into separate sections that shall be filled in sucessively, esuring that polluted water and leachate will be collected separately from unpolluted water. The landfill bottom slopes shall be designed so as to prevent from slope erosion [2].

The landfill shall be designed so that it would prevent the risk of polluting the soil, atmosphere, ground water and surface water. The landfill bottom shall be at least 1 m above the maximum groundwater level. The landfill bottom and sides shall contain an impermeable mineral layer which would ensure sufficient protection of soil and groundwater from pollution (filtration coefficient of impermeable natural mineral layer in a non-hazardous landfill shall be higher than 10^{-9} m/s, thickness – not less than 1 m). If the impermeable mineral layer fails to meet the above-mentioned requirements, it shall be strengthened or replaced by an artificial mineral layer which would ensure the same level of soil and groundwater protection; thickness of artificial mineral layer shall be not less than 0.5 m. In a municipal waste landfill above the impermeable mineral layer leachate collection system comsisting of an artificial liner and at least 0.5 m thick drainage layer shall be provided. Collection and treatment (utilisation) of landfill gas shall be effected in the regional landfill.

The main requirements for operation of the regional landfill are the following:

- disposal of hazardous, liquid, explosive, oxidizing, highly inflammable and inflammable, corrosive, medicine waste, ozone layer depleting substances, tyres, biodegradable waste from gardens, parks etc. in municipal waste landfills is prohibited;
- prior to landfilling the waste shall be treated if it is technically possible and if it reduces the waste amount and the impact of waste on the environment and human health;
- landfill operator shall determine and inform about waste acceptance criteria and specific waste acceptance procedures, indicate the documents to be submitted upon delivery of waste to a landfill;
- landfill operator shall obtain a Permit for the Use of Natural Resources in accordance with the procedure established in Regulation on Issuing Permits for Use of Natural Resources and for Setting Limits for Use of Natural Resources and Discharge of Pollutants into Environment;
- landfill operator shall check the documents for the waste delivered, visually inspect the waste in the landfill and record it in the landfill waste recording register;
- landfill shall be operated in such a manner that would enable to minimise negative impact on environment and human health that may be caused by emissions, waste scattered by wind, noise, transport, animals, generated aerosols and fires;
- when tipping waste stability of the waste mass and landfill structures, as well as prevention of landslides shall be ensured;

- Landfill Waste Disposal Regulations shall be prepared in accordance with the requirements established in the Waste Management Rules; the staff of the landfill shall be familiarized with the Regulations and shall strictly follow its requirements;
- during landfill operation and after closure, as long as the landfill, based on the assessment of the Ministry of Environment, may be considered dangerous to the environment and human health, the landfill operator shall conduct environmental monitoring in accordance with the procedure established in the Law on Environmental Monitoring.

Until this day Regional waste management system is only under foundation. No landfills that correspond to EU directives requirements and Lithuanian laws are established yet. This process is only ongoing and will continue about 2-3 years.

1.2. Main characteristics of municipal wastes

Physical parameters. Comparative weight, humidity, granulometrical composition of particles, rate of moisture absorption, and permeability of wastes are main physical waste parameters.

Comparative weight of waste shows, how much do the one volume unit weigh. The information about comparative weight of waste is used to plan the amount and mass of waste.

Humidity can be expressed in two ways: with method of moist weight and with method of dry weight. First method shows the moist part of the example, second method – dry part. Method of moist weight is usually used to determinate humidity of waste [3]:

$$M = \left(\frac{w - d}{w} \right) \cdot 100\% \tag{1.1}$$

M – humidity (%);

w – Original weighs of the example (kg);

d – weigh of the example after 1 hour that was died under temperature equal to 105 º C (kg).

The humidity of municipality waste varies from 15 % to 50%, according to waste capacity, session of the year, environmental humidity and meteorological conditions.

Information about granulometrical composition of particles is necessary for design of recycling equipment, especially mechanical and magnetic separators. Granulometrical composition of particles is characterized according to the highest measurement of waste size and possibility to pass net with concrete dimension.

Rate of moisture absorption shows the amount of moisture that can be absorbed by waste example under effect of gravitational power. This index is very important for landfill design preparation and for prediction of leachate generation amount. The excess of moisture will compound leachate and special drain system should be design for its collection. This index depends on waste level consolidation and waste decomposition degree. This index of municipality waste varies from 50 % to 60%.

Permeability of wastes depends on waste hydraulic resistance. This waste physical characteristic determinates the way and rate of landfill gas and leachate movement in municipal landfills.

Permeability of wastes (K) can be estimated as fallows [4]:

$$K = Cd^2 \frac{\gamma}{\mu} = k \frac{\gamma}{\mu} \tag{1.2}$$

C – coefficient, that depends from form and measurement of components;

D – average size of pore;

γ – comparative weigh of liquid;

μ – dynamical smear of liquid;

k – possessive permeability.

Possessive permeability $k=Cd^2$ depends only on characteristics of solid materials (pore size, porosity, tortuosity, relative of the body).

Chemical parameters. Most usually essential capacity of waste is identified according to carbon (C), Hydrogen (H), Oxygen (O), Sulphur (S) atoms and ashes amount in waste composition.

Sometimes the organic chlorine compound and halogens can be identified during essential analyze. The results of essential analyze shows the composition of waste. The results of these analyses are used for design of biological utilization processes.

The chemical waste composition can be expressed as $C_xH_yO_zN_iS_j$ [5]. Factious coefficients x, y, z, i, j shows, the amount of relevant element in waste composition.

Biological parameters. The main biological characteristic of waste organic components is such, that almost all organic components can be reproduced to gas and inertial organic and non-organic factions.

The rise of unpleasant odours and flies are assign to waste biological characteristics.

For the description of biodegradation of waste is used index, that rate the amount of lignin[6]:

$$BF=0.83-0.028\ LC \tag{1.3}$$

BF – faction, that cans biodegrade;

LC – amount of lignin.

It was noticed, that waste with higher lignin amount (for example paper) has less possibility to biodegrade.

Organic compounds of waste are often divided in to fast and slow decomposable.

When waste is kept in the original generation place in amenity sites, transpire stations and landfills for a long time, unpleasant odours generates. The reason of this generation is anaerobic a degradation of organic components. For example, under anaerobic conditions, sulphate reduces to sulphide (S^{2-}) that connects with hydrogen, and forms hydrogen sulphide (H_2S) [7]. Sulphide interacts with metal carbons and forms metal sulphids.

Waste, that decomposes under anaerobic conditions, color in black color because of formation of metal sulphids. If the sulphide will react only with hydrogen, the H_2S generation problem will become especially actual.

1.3. Final waste dispose in landfills

Sanitary landfills represent a common economical and environmentally acceptable method for the disposal of solid wastes. Even with implementation of waste reduction, recycling and transformation technologies, waste landfilling still remains an unavoidable step.

Modern landfills are well-engineered facilities that are located, designed, operated, monitored, closed, cared for after closure, cleaned up when necessary, and financed to insure compliance with EU regulations.

Landfill is the controlled deposit of waste to land. Often minerals working and extraction sites are used as landfills, providing a means to restore land. However, where such ‘holes in the ground’ are not available, it is possible to deposit waste onto the ground surface and build up a waste disposal site [8]. The disposal of waste to land has been an important method of waste management since the volume of waste arising has been sufficiently great to warrant specific consideration, and, although landfill is placed bottom of the waste management hierarchy, it is an important and necessary means of effective waste management [9].

The purpose of landfill disposal is to stabilize the solid waste and to make it hygienic through proper storage of waste and use of natural metabolic function. Landfill sites are classified into 5 types according to structure as shown in Table 1.1 and. In terms of quality of leachate and gases generated from landfill site, either semi-aerobic or aerobic landfill method is desirous.

Table 1.1 Classification of landfill structure [10]

Type of landfill	*The main landfill’s traits*
Anaerobic landfill	Solid wastes are filled; in digged area of plane field or valley. Wastes are filled with water and in anaerobic condition
Anaerobic sanitary landfill	Anaerobic landfill with cover like sandwich shape. Condition in solid waste is same as anaerobic landfill
Improved anaerobic sanitary landfill (Improved sanitary landfill)	This has leachate collection system in the bottom of the landfill site. Others are same as anaerobic sanitary landifll. The conditions are still anaerobic and moisture content is much less than anaerobic sanitary landfill.
Semi-aerobic landfill	Leachate collection duct is bigger than the one of improved sanitary landfill. The opening of the duct is surrounded by air and the duct is covered with small crushed stones. Moisture content in solid waste is small. Oxygen is supplied to solid waste from leachate collection duct.
Aerobic landfill	In addition to the leachate collection pipe, air supply pipes are attached and air is enforced to enter the solid waste of which condition becomes more aerobic than semi-aerobic landfill.

As shown in Fig.1.1, the semi-aerobic landfill allows inflow of air through leachate collection pipes laid on the bottom of the landfill, which helps to enlarge aerobic parts, and to make aerobic bacteria active, and fastens the waste decomposition [11].

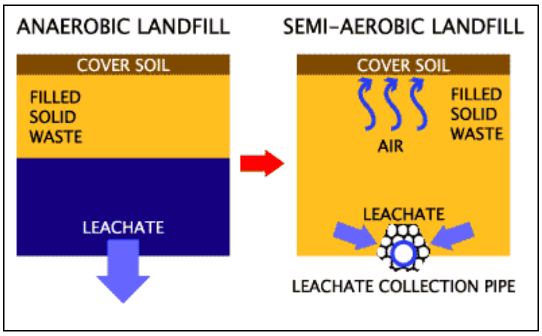


Fig.1.1. Landfill type and leachate collection system [11]

Most landfills behave as inefficient biological reactors in which degradation occurs in a way similar to that used in anaerobic digesters. Eventually, the bacteria will degrade the waste to a state, which will be relatively harmless if escape to the environment occurs. However, this can take many tens and perhaps hundreds of years. The liners used in landfill construction are not proven to be effective on this timescale and recognition of this has encouraged consideration of how to speed-up the biological waste degradation in the landfill, so that if escape does occur, the environmental risk is acceptable.

Landfills are designed to accept pre-treated wastes or are operated as bio-reactors. The environmental risk associated with either operation may be reduced by disposing of the waste by landraising rather than landfilling [12]. Many landfills within are located in former quarries and disposal of waste to such quarries has allowed the eland to be restored to a state similar to that before it was quarried. However, not all quarries are suitable for landfill as they may allow pollution of the surrounding environment and, when waste is deposited in a quarry, control of landfill gas and leachate and maintenance of the necessary control systems can be particularly difficult and expensive. Factors such as these have meant that fewer sites suitable for landfill disposal are being identified and, in the future, all small landfill sites will be replaced by a small number of larger sites.

Upon completion of the filling phase of a landfill, the land must be restored in accordance with the requirements of the local planning authority and in a way that controls environmental emissions. Site closure and aftercare require careful consideration from the initial stages of site planning and can determine whether or not a planned landfill site will be able to proceed. Effective planning will ensure that suitable materials for the site closure such as sub-soil and top-soil have been stored on site, or are available locally, and will thus reduce some of the costs associated with this stage of landfill management. Site license conditions may require that the site contours agree with specified levels, that the restored land is put to an agreed use (eg cereal farming, pasture, civic open space, golf course, forestry), and that landfill leachate and gas are managed until such time as they no longer constitute an environmental risk [13]. This post-closure management period may extend for tens to hundreds of years and now requires landfill operators to make financial provision against the potential costs incurred [14]. The costs associated with site closure and aftercare has increased considerably in recent years and is one of the factors that have led to increased charges for landfill disposal.

The 'liner' system is the key to the management of leachate [15]. This may either consist of a natural impermeable clay barrier or more frequently on modern sites, may also include a flexible membrane liner. A leachate collection and removal system is installed above the liner and a leak-detection system is installed beneath the liner. Operation of the site using cells with rapid cover of the waste ensures that large areas are not open to rain. It also minimises the potential for litter, dust and smell [16]. The leachate may be recirculated through the wastes and then collected and treated in a leachate treatment plant before disposal of the effluent to sewer. The operator of the site is required to show by the conduct of a risk assessment that they have assessed the potential risks and the adequacy of the proposed engineering. Applications for planning permission for new household waste landfills will usually be accompanied by an Environmental Statement [17].

Low permeability barriers such as flexible membranes also have the advantage of impeding the flow of landfill gas from a site. However, gas will still pass through a liner slowly so it is normal to also include a venting system which uses pumps to actively remove gas from the waste. Gas is either flared to atmosphere or used to generate electricity or to heat industrial and horticultural activities.

The other primary design feature of a landfill is the cap. Traditionally a clay cap with soil and vegetation, increasingly sites also include a membrane liner within the cap [18].

Landfill sites are licensed by the Environment Agency and are inspected regularly (the guidance requires four inspections per month for sites accepting household, commercial or industrial wastes) to ensure that activities on site are compliant with license conditions. Landfill operators are also required by the license conditions to monitor a range of parameters relating to the operation of the site, such as landfill gas and leachate control systems. These are reviewed at site inspections. Waste that is collected for disposal at landfills may be taken directly to a landfill or may be transported to a transfer station for re-packing with other wastes into large vehicles, including barges and trains, before eventually being taken for disposal. Once at the landfill the vehicles are weighed and the weight and type of waste in each load is noted. This information helps to ensure effective management of the site and to minimize the potential for environmental pollution. After weighing, the vehicles are emptied into the area of the landfill that is being filled and the waste is then compacted using a heavy vehicle which moves back and forth over the deposited material. This process ensures that as much waste as possible is emplaced within the landfill. It helps to physically break up the waste, thus aiding the waste degradation process, helps to prevent materials blowing from the landfill site into the surrounding area and reduces habitats where vermin may breed. Wheel cleaners are used to prevent mud etc from being spread by vehicles onto the public road. At the end of each day, the deposited waste is covered with a material such as spoil to limit the potential for pest infestation and littering of the surrounding land.

Landfills can cause more or less negative impacts on the environment and local people. As the natural waste biodegradation is very long, landfills present a potential environmental threat over several years. So, care, monitoring, and management of the sites are required for long periods, even after the sites are closed, and that involves many costs.

The landfill can make negative impact on the environment in different ways. The main types of pollution that can go from landfill site can be named as follows:

- *Water and soil contamination.* Leachate generated from landfill site, if not treated, contaminates river, sea and underground water. The leachate may carry toxic contaminants to underground water supplies and to the surrounding soil;
- *Gas generation.* Main gases generated from the landfill site are methane, ammonia, hydrogen sulfide and carbon dioxide. Fugitive release of landfill gases occurs even in highly engineered systems with active gas extraction. Greenhouse gas emissions remains difficult issues at most sites. Landfill gasses can have dangerous compounds in its composition and can have negative impact on human health;
- *Offensive odour.* There are two type of offensive odour generated from the landfill site. One is the odour generated from waste itself and the other is gases generated through waste decomposition;
- *Pests and vectors.* Kitchen waste tends to be the hotbed for flies, and attracts rodents and crows;
- *Noise and vibration.* Incoming waste transport vehicles and landfill equipment may be sources of noise and vibration;
- *Fire.* Fire may occur spontaneously due to methane gas generation or use of chemicals. Scavengers or other people also may cause fire;
- *Radiation.* Sources of radiation can be finding in some bad management landfills. Such sources can come from householders or institutions.

In this work for investigations on the impact to environment that goes from landfill was chosen landfill site in Plunge district, Jerubaiciai. As this landfill is under operation only in the fall of 2001 and was operated following all roles and regulations, the possibility of existing radiation sources in this landfill was rejected and not investigated.

Incoming waste transport frequency per 1 hour is about 1-2 vehicles and only one compactor is working in this landfill, so the noise level value can’t be very high and was not measured.

So the main attention must be taken to the quality and quantity of air and water pollution, that goes from this landfill site.

1.4. Mechanisms for biodegradation of organic matter in a landfill

It can’t be started to describe the leachate and gas generation, that can causes air and water pollution without description of biodegradation process of municipal wastes. This process has significant impact on gas and leachate generation quantity and quality.

The biodegradation of organic waste follows a pattern of five phases. These five phases are fundamental, and they affect the landfill gas (LFG) formation and the leachate composition. Through development of an enhanced bioreactor landfill, the time that elapses between these phases may be influenced. These five phases are illustrated in Fig. 1.2 .

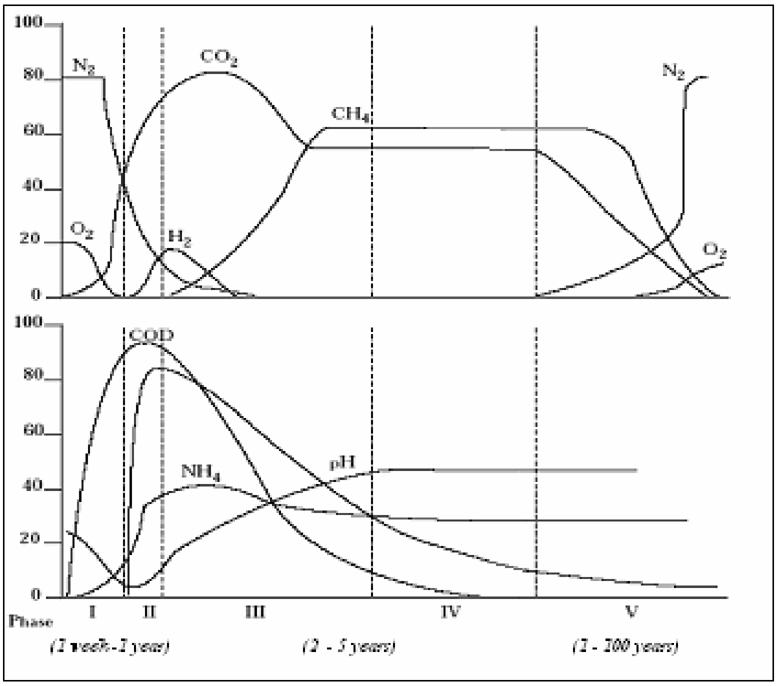


Fig 1.2. Idealistic Development of LFG and leachate within a Landfill [19]

Each layer of waste disposed of in a landfill undergoes the biodegradation phases illustrated in Figure 1.2. The main factors that influence the time that elapses for each phase are climactic conditions and operational factors.

The biodegradation of organic waste in a landfill has five distinct phases, all of which influence the leachate composition and the development of LFG. In an enhanced bioreactor landfill, the time that elapses between these phases may be reduced. They are as follows:

Phase I: This is an aerobic phase that takes place immediately after the waste is disposed of. Easily biodegradable substances are broken down by the presence of oxygen. In fact, this is a composting process where carbon dioxide is produced and the temperature rises. This phase may be very short-lived.

Phase II: This is an aerobic phase, with the development of anaerobic conditions. A fermentation process occurs, developing acids in the leachate and a significant drop in pH. This process may lead to the release of metals in the waste matrix. The LFG generated consists primarily of carbon dioxide.

Phase III: Anaerobic conditions are now established. Within the right microbial environment, methanogenic conditions will emerge. The LFG will start to contain increasing quantities of methane, and the concentration of carbon dioxide will decrease. Sulfate will be reduced to sulfites and will be capable of precipitating metals from the leachate. As the organic acids are converted into LFG, the pH levels rise in the leachate. The organic load in the leachate will decrease, and ammonia will increase since ammonia is not converted under anaerobic conditions.

Phase IV: This is the so-called stable *methanogenic phase*. This is also the anaerobic phase, where methane production is at its highest, with a stable concentration of 40-60% CH_4 by volume. Acidic organic components in the leachate are immediately decomposed into LFG. The organic load in the leachate is low and consists primarily of heavy biodegradable organic components. As the conditions are strictly anaerobic, the leachate will still have a high concentration of ammonia.

Phase V: During this stabilizing phase, methane production will begin to decrease and the presence of atmospheric air will reintroduce aerobic conditions. This condition may occur only after several decades in shallower landfills. In deeper landfills, this stage may be reached only after many decades.

In each biodegradation phase, different agent generates, as is illustrated in Figure 1.3.

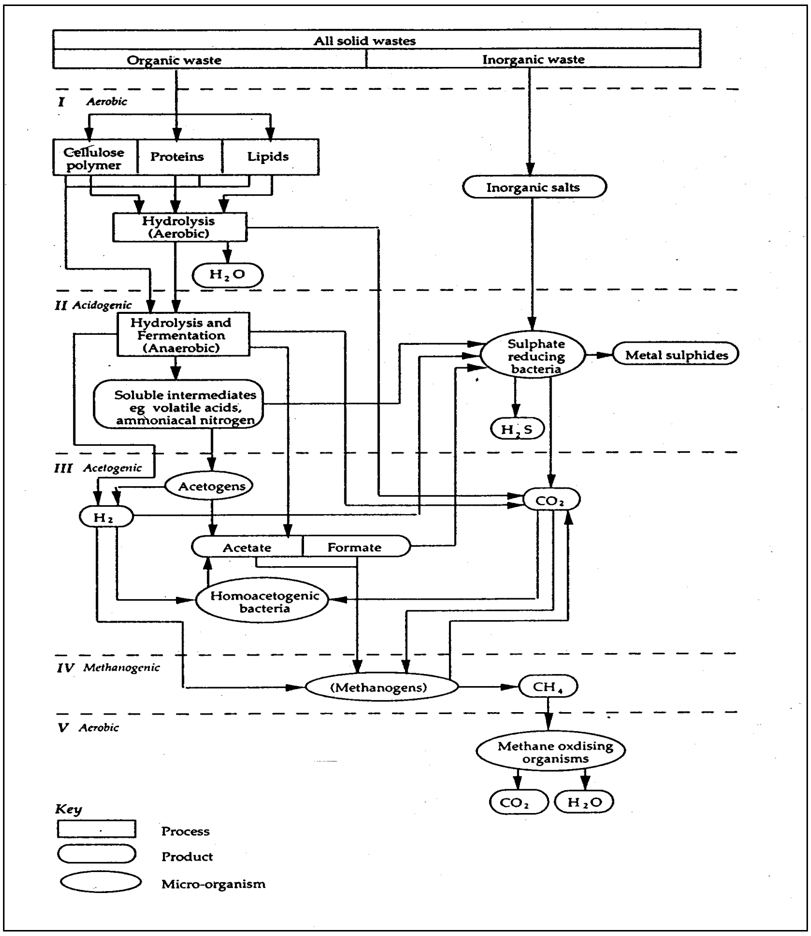


Fig 1.3. Stages of waste degradation in details [20]

The main factors that influence the time that elapses for each phase are climactic conditions and operational factors.

Phases I and II may last from several weeks to two years (or longer). A higher ambient air temperature will enhance the biodegradation processes. High compaction rates and placing waste in thin layers will also enhance the biodegradation processes. Landfilling waste in small cells will also reduce the elapsed time for Phases I and II.

Phases III and IV may last for approximately five years at high peak and fade thereafter, depending on the landfill operation and, in particular, the moisture content of the waste. Because high moisture content will significantly increase bioreactions, precipitation will reduce the time elapsed in Phases III and IV and thus increase the quantity of LFG generated over time. Operational measures to enhance biodegradation include recirculation of leachate and extraction of generated LFG.

Phase V of the landfill lifecycle depends to a great extent upon the operational steps taken earlier in the landfill's life. However, it may take several decades or even centuries before the disposed of waste is finally stabilized. Ammonia is the limiting factor and will constitute potential pollution for an anticipated 100 years or more [21].

1.5. Landfill leachate

1.5.1. Generation of landfill leachate

Leachate is generated as a result of the percolation of water or other liquid through any waste and the squeezing of the waste due to self-weight. Thus, leachate can be defined as a liquid that is produced when water or another liquid conies in contact with waste. Leachate is a contaminated liquid that contains a number of dissolved and suspended materials. Part of the precipitation (snow or rain) that falls on a landfill reacts (both physically and chemically) with the waste while percolating downward (Fig. 1.4). During this percolation process it dissolves some of the chemicals produced in the waste through chemical reaction. The percolating water may also dissolve the liquid that is squeezed out due to weight of the waste (e.g., squeezing out of pore liquid of peppermill sludge). Many studies were conducted to determine the role of microbial activities in decomposing municipal waste and subsequent formation. In a municipal waste, methane, carbon dioxide, ammonia, and hydrogen sulphide gases are generated due to anaerobic decomposition of the waste.

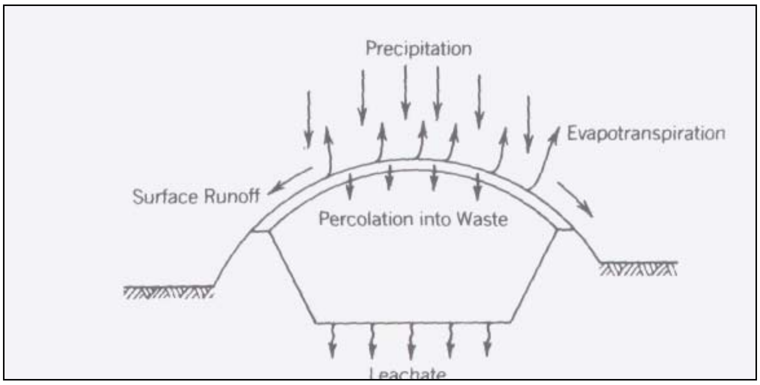


Fig 1.4 . How leachate is generated [22]

Several other chemical reactions also take place releasing a wide range of chemicals, depending on the waste type. The percolating water plays a significant role in leachate generation. It should be noted that even if no water is allowed to percolate through the waste, a small volume of contaminated liquid is always expected to form due to biological and chemical reactions. The concentration of chemical compounds in such liquid is expected to be very high. The percolating water dilutes the contaminants in addition to aiding its formation. The quantity of leachate increases due to the percolation of water, but at the same time the percolating water dilutes the concentration of contaminants. Both quality and quantity of leachate are important issues for landfill design.

Combined physical, chemical and microbial processes in the waste transfer pollutants from the waste material to the percolating water, landfill leachate may be characterized as a water based solution of four groups of pollutants:

Dissolved organic matter. These gases may dissolve in water and react with the waste or dissolved constituents of the percolating water. For instance, dioxide combines with water to form carbonic acid, which then dissolved organic matter, expressed as Chemical Oxygen Demand (COD) or Total Organic C (TOC), including CH_4, volatile fatty acids (in particular in the acid phase of the waste stabilization, and more refractory compounds for example, fulvic-like and humic-like compounds [23].

Inorganic macrocomponent. Ca, Mg, Na, K, NH_4^+, Fe, Mn, Cl, SO_4^{2+} and HCO_3^-.

Heavy metals. Cd, Cr, Cu, Pb, Ni and Zn.

Xenobiotic organic compounds. XOCs originating from household or industrial chemicals and present in relatively low concentrations in the leachate (usually less than 1 mg/l of individual compounds). These compounds include among others a variety of aromatic hydrocarbons, phenols and chlorinated aliphatics.

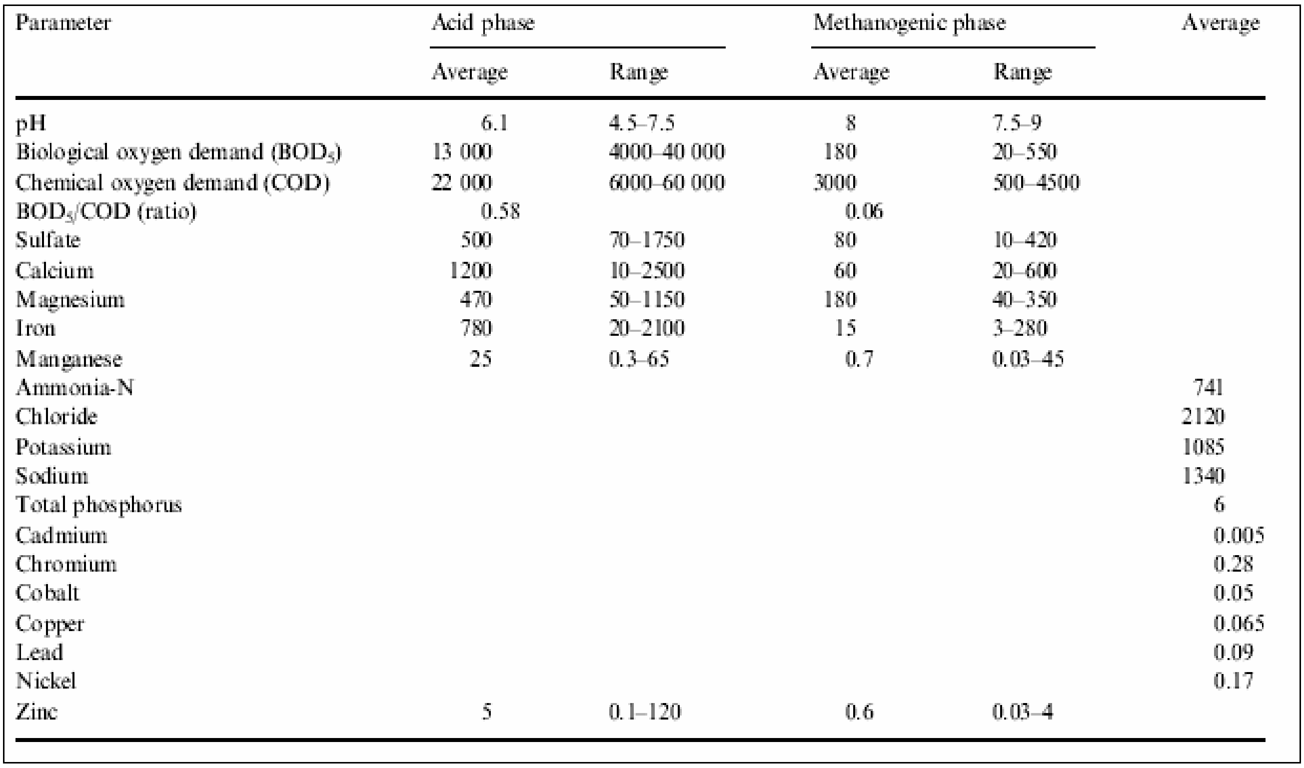
Other compounds may be found in leachate from landfills: e.g. B, As, Se, Ba, Li, Hg and Co. But in general, these compounds are found in very low concentrations and are only of secondary importance.

Fig. 1.5. Leachate pond in Jerubaiciai landfill

Leachate composition varies significantly among landfills depending on waste composition, waste age and landfilling technology.

Several parameters change dramatically as the landfill stabilizes. During the initial acid phase, the leachate may show low pH-values and high concentrations of many compounds, in particular high concentrations of easily degradable organic compounds as volatile fatty acids. In the later methanogenic phase, when CH_4 production is significant in the landfill, pH increases and the BOD_5/COD-ratio, reflecting the degradability of the organic C (biological O_2 demand measured over 5 days divided by chemical O_2 demand), is lowered dramatically. This again affects many of the inorganic parameters as illustrated in Table 1.2, where data are presented for acid phase leachate and methanogenic leachate. For parameters not significantly affected by landfill stabilization only average values are given.

Table 1.2. Leachate composition in terms of average values and ranges for parameters with differences between acid and methanogenic phase and average values for parameters with no observed differences between acid and methanogenic phase, all values in mg/l except pH and BOD_5/COD [24].



Parameter	Acid phase		Methanogenic phase		Average
	Average	Range	Average	Range	
pH	6.1	4.5–7.5	8	7.5–9	
Biological oxygen demand (BOD_5)	13 000	4000–40 000	180	20–550	
Chemical oxygen demand (COD)	22 000	6000–60 000	3000	500–4500	
BOD_5/COD (ratio)	0.58		0.06		
Sulfate	500	70–1750	80	10–420	
Calcium	1200	10–2500	60	20–600	
Magnesium	470	50–1150	180	40–350	
Iron	780	20–2100	15	3–280	
Manganese	25	0.3–65	0.7	0.03–45	
Ammonia-N					741
Chloride					2120
Potassium					1085
Sodium					1340
Total phosphorus					6
Cadmium					0.005
Chromium					0.28
Cobalt					0.05
Copper					0.065
Lead					0.09
Nickel					0.17
Zinc	5	0.1–120	0.6	0.03–4	

The data given in Tables 1.2 are based on leachate sampled from landfills of less than 25 of age, and the values are difficult to extrapolate beyond the first 25 of a landfill's life estimated by use of leaching tests on municipal solid waste that leachate from landfills would contain significant concentrations of several compounds for centuries. Especially the N content (and the organic C content) will be significant for several centuries.

In addition to the time-wise changes in leachate composition as the landfill changes from acid to methanogenic phase, short-term variations in leachate quality may also appear. Seasonal variations in leachate composition have been observed in several cases. Observed lower leachate concentrations in a Swedish landfill test cell in the wet season. Similar observations were found in Hong Kong landfill.

Investigations on leachate composition have often been based on only one or a few leachate samples from each landfill. This may suffice if the leachate collection system averages the leachate from different sections of the landfill and the leachate is pumped out of the landfill for treatment. But in the context of groundwater pollution, the spatial distribution of the leachate quality must be appreciated, and this would require a large number of sampling points. Only few such studies exist. Pronounced irregular spatial variation in leachate composition was found at four old Finnish landfills. Significant spatial variability in leachate concentrations was also observed in wells at the 10 ha large old Grindsted Landfill [25]. Very low concentrations of almost all parameters (including XOCs) were found in areas covering about 60–70% of the landfill. A "hot spot", occupying about 10% of the landfill area, was found with concentrations 20–1000 times higher than in the low concentration area. Especially for large landfills, information on spatial variability in leachate concentrations is very important as a basis for locating the main sources of the groundwater pollution plume and for selection of cost-effective remedial actions.

1.5.2. Dissolved organic matter

Dissolved organic matter in leachate is a bulk parameter covering a variety of organic degradation products ranging from small volatile acids to refractory fulvic and humic like compounds. Discussion of attenuation processes in aquifers is difficult without specifying the organic compound in question. Unfortunately, there is generally very little information on the composition of dissolved organic matter in landfill leachate. However a few investigations concerning DOC in landfill leachate are available [26].

Harmsen analysed an acid-phase leachate and a methanogenic-phase leachate. In the acid-phase leachate, more than 95% of the DOC content of 20 000 mg/l consisted of volatile fatty acids and only 1.3% of the DOC consisted of high molecular weigh (MW) compounds (MW>1000). Also, volatile amines and alcohols were detected. In the methanogenic-phase leachate, however, no volatile acids, amines or alcohols were detected, and 32% of the DOC (2100 mg/l) consisted of high molecular weight compounds (MW>1000). In a methanogenic-phase leachate Artiola-Fortuny and Fuller described more than 60% of the DOC content as humic-like material. Investigating anaerobic and aerobic leachates and leachates which have passed a model aquifer Frimmel and Weis found that only 6–30% of the DOC could be described as fulvic acids[27].

More detailed characterization of the DOC in leachate and leachate polluted groundwater is based on isolation and purification of the DOC. These procedures may potentially change the properties of the organic matter but it is necessary to purify the material in order to obtain results. Compared fulvic acids from landfill leachates with those from soil and bog lake water. The fulvic acids isolated from landfill leachate had higher C, H, and S content, lower quantities of phenolic groups, lower complexation capacities for Cu and lower molecular weight. It is characterized 82% of the DOC in leachate-polluted groundwater sampled less than 10 m downgradient from the Vejen Landfill (DK) [26] and found 49% fulvic acids, 8% humic acids and 25% hydrophilic fraction. Based on molecular weight (around 2000 MW), elemental composition and acidity, the fulvic acid fraction and the hydrophilic fraction resembled fulvic acids from other origins, where as the humic acid had rather low molecular weight.

1.5.3. Inorganic macrocomponents

The concentrations of some of the inorganic macrocomponents in leachate depend, as in the case of the dissolved organic matter, on the stabilization processes in the landfill. The cations Ca, Mg, Fe and Mn are lowest in the methanogenic phase leachate, due to a higher pH (enhancing sorption and precipitation) and lower content of dissolved organic matter, which may complex the cations. Sulfate concentrations are also lower in the methanogenic phase due to microbial reduction of SO_4^{2-} to S^{2-} [27].

Average values for parameters with no observed difference between acid and methanogenic phase. These are the macro components, Cl^-, Na and K, which only to a minor extent are governed by sorption, complexation and precipitation. Decreasing trends in concentration with time of these pollutants could be due to wash out by the leaching.

Many investigations report concentrations of NH_4-N in the range of 500–2000 mg/l, and no decreasing trend in concentration with time. Ammonia is released from the waste mainly by decomposition of proteins.

1.5.4. Heavy metals

The concentrations of heavy metals can be exemplified by the averages of methanogenic phase leachates from. In general the concentrations of the heavy metals in leachates from different landfills show major variations. The average metal concentrations, however, are fairly low. A survey of 106 old Danish landfills showed that metal concentrations for old landfills are also low: 0.006 mg Cd/l, 0.13 mg Ni/l, 0.67 mg Zn/l, 0.07 mg Cu/l, 0.07 mg Pb/l and 0.08 mg Cr/l. Metals like Hg and Co are rare in leachates and, together with the metalloid As, are not dealt with in this context [28]. Iron and Mn are usually not considered heavy metals and are dealt with in the section on inorganic macrocomponents.

Laboratory techniques have been used to divide the heavy metal content in landfill leachates into different species. Several investigations have determined Cd species in landfill leachate and found that free divalent Cd^{2+} only made up a small fraction of the total Cd content (between a few per cent and 1/3 of the total content)[29]. The complexes were both organic and inorganic. The proportion of the two groups of complexes very much depended on the composition of the leachate. Most of the complexed fraction was characterized as labile complexes that were easily redistributed. Investigations also showed that a significant, but highly varying, part of the heavy metals was associated with the colloid content of leachate. In all three investigations, comparison of the distribution of organic matter and heavy metals between the size fractions indicated that the heavy metals in the colloidal fractions were not simply related to organic matter, even though the colloidal humic substances are suspected to play a major role with respect to the speciation of the heavy metals.

1.5.5. Xenobiotic organic compounds (XOCs)

Table 1.3 presents concentration ranges of the most frequently found xenobiotic organic compounds (XOCs) in landfill leachate. The table is based on landfills with leachate collection systems. Very broad ranges are observed, reflecting differences in co-disposal practices, general waste composition, landfill technologies, and waste age. The most frequently found XOCs are the aromatic hydrocarbons (benzene, toluene, ethylbenzene, and xylenes) and halogenated hydrocarbons like tetrachloroethylene and trichloroethylene. These pollutants are also the ones found in the highest concentrations. Another major group of newly identified compounds in leachates is the phenoxyalkanoic acid herbicides. Especially MCPP (or Mecoprop) has frequently been observed.

Table 1.3. The most frequently observed xenobiotic organic compounds (XOCs) in landfill leachates. Only pollutants that have been observed in more than three independent investigations are included [30].

Compound	*Range (µg/l)*	*Compound*	*Range (µg/l)*	*Compound*	*Range (µg/l)*
Aromatic hydrocarbons		*Halogenated hydrocarbons*		*Phenols*	
Benzene	1-1630	Chlorobenzene	0,1-110	Phenol	1-1200
Toluene	1-12300	1,2-Dichlorobenzene	0,1-32	Cresols	1-2100
Xylenes	4-3500	1,4-Dichlorobenzene	0,1-16	*Miscellaneous*	
Ethylbenzene	1-1280	1,1,-Triclorobenzene	0,1-3810	Acetone	6-4400
Trimethylbenzenes	4-250	Tricloroethylene	0,7-750	Diethylphthalate	10-660
Napthalene	0,1-260	Tetrachloroethylene	0,1-250	Di-n-butylphthalate	5,0-15
Pesticides		Methylene chloride	1,0-64	Tetrahydrofuran	9-430
Mecoprop	2,0-90	Chloroform	1,0-70	Tri-n-butylophosphate	1,2-360

The concentration of XOCs in landfill leachate is expected to decrease over time, depending for each compound on its degradation in the landfill and its volatilization with the landfill gas. However, the time aspects of this are hard to evaluate.

1.5.6. Factors that influence leachate quality

Various factors influence leachate quality. In general, leachate quality of the same waste type may be different in landfills located in different climatic regions. Landfill operational practices also influence leachate quality. The following sections discuss the basic reasons why such variations are observed.

Waste Composition. Variation in refuse composition is probably at a maximum in municipal waste and at a minimum in industrial waste. Because of this variation in refuse composition, the quality of municipal leachate varies widely. In general, quality variation is higher for putrescible wastes than for nonputrescible waste.

Elapsed Time. Leachate quality varies with time. In general the overall quality of leachate generated in year 1 will be less strong than that generated in subsequent years. Leachate quality reaches a peak value after a few years and then gradually declines. Figure 1.6 shows an idealized relationship of leachate quality with time. For an actual landfill leachate the quality variation is not as smooth, although distinctive zones of upward and downward trends can be observed if quality variation is plotted with time. All the contaminants do not peak at the same time, and the time versus concentration variation plots of all contaminants from the same landfill may not be similar in shape.

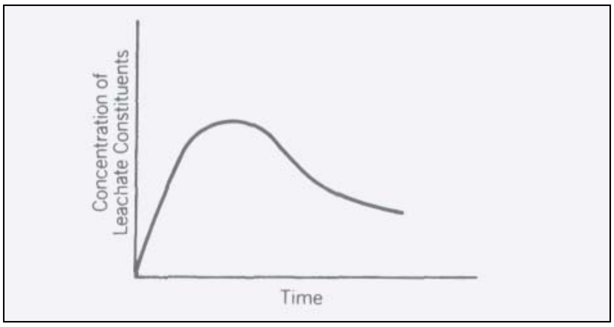


Fig 1.6 Idealized variation of leachate quality with time [31]

Ambient Temperature. The atmospheric temperature at the landfill site influences leachate quality. The temperature affects both bacterial growth and chemical reactions. Subzero temperatures freeze some waste mass, which reduces the leachable waste mass and may cause inhibition of some chemical reactions. There are no reports of freezing an entire landfill during winter in cold regions, although chunks of frozen mass may be found in landfill. There are several studies on landfill leachate temperature, but no study is reported relating ambient temperature with leachate quality.

Available Moisture. Water plays a significant role in biodegradation and subsequent leaching of chemicals out of a waste. Leachate quality from waste disposed in a wet climate is expected to be different from the leachate quality of the same waste disposed in a dry climate.

Available Oxygen. The effect of available oxygen is notable for putrescible waste. Chemicals released due to aerobic decomposition are significantly different from those released due to anaerobic decomposition. The anaerobic condition in a landfill develops due to frequent covering of waste with soil (daily/weekly cover) or with fresh waste. The supply of oxygen starts to become depleted as soon as the waste is covered (either with soil or with more waste). A predominantly anaerobic condition develops in thicker refuse beds [32].

1.5.7. Factors that influence leachate quantity

Like quality, leachate quantity is also dependent on weather and operational practices. The following sections discuss the basic reasons why such variations are observed [33].

Precipitation. The amount of rain and snow falling on a landfill influences leachate quantity significantly. Precipitation depends on geographical location.

Groundwater Intrusion. Sometimes landfill base is constructed below the groundwater table. In these landfills groundwater intrusion may increase leachate quantity.

Moisture Content of Waste. Leachate quantity will increase if, because of is own weight, the waste releases pore water when squeezed (e.g., sludges). Unsaturated waste continues to absorb water until it reaches field capacity (a water saturation state). So dry waste will reduce leachate formation. However, it must be noted that in actuality, channeling causes water to flow through the waste without being absorbed by the waste; thus, the water absorption is much less than that predicted by laboratory or small-scale field studies. Co-disposal of sludge or liquid waste in municipal landfills will increase the leachate quantity in a landfill.

Final Cover Design. Leachate volume is reduced significantly after a landfill is closed and finally covered because of two reasons: vegetation grown in the topsoil of a final cover reduces infiltratable moisture significantly by evapotranspiration and the low permeability layer reduces percolation. A properly designed final cover will reduce postclosure leachate quantity significantly.

1.6. Landfill gas generation

1.6.1. The process of landfill gas formation

Three processes—bacterial decomposition, volatilization, and chemical reactions—form landfill gas (LFG) [34]. In Lithuania all three processes are happening in almost every landfill, because no proper waste management system was implemented before.

Volatilization. Vaporization action is due to the change of chemical phase equilibrium that exists within the landfill. Some gas-generating materials will be present in the waste mass as it is received and deposited in the landfill. Organic compounds in the landfill cells will vaporize until the equilibrium vapour concentration is reached. This process is accelerated when the waste becomes biologically active, as a result of heat, which is evolved within the landfill as part of the biological process. The rate at which components are evolved depends on physical and chemical properties of the compounds.

Chemical reactions. Chemical reactions between materials in the waste can release gases. Such reactions are likely to occur in hazardous waste landfills unless considerable care is taken not to mix incompatible materials. Older landfills which have received hazardous wastes in the past and municipal landfills which receive household waste are still subject to unforeseen reactions. For example, aliphatic chlorinated solvents are incompatible with aluminium, so solvent-soaked rags which contact aluminium cans may produce hydrogen chloride gas. This will at least render the surrounding gas highly acidic, and may release some vapour through the landfill to the atmosphere. Many of the potential reaction problems are relatively buffered by the presence of water. Even some materials, which are vapours in their pure state (e.g., vinyl chloride) are relatively soluble in water, so the release rate is dampened. However, unpredictable reactions are possible with so many compounds potentially present. The heat generated from biological processes also tends to accelerate the release rate of compounds produced by chemical reactions.

Biological Decomposition. LFG generation occurs as a result of two conditions, aerobic and anaerobic decomposition. Generally, aerobic conditions degrade the larger molecules into smaller and smaller molecules leading to anaerobic degradation of organic acids that generates CH_4 and $C0_2$. It is important to understand that there is mixed aerobic and anaerobic degradation occurring at the same time. The facultative, degrading microbes (capable of growing and surviving with or without O_2) perform the necessary dual functions of degrading larger molecules and consuming O_2 to create and sustain the anaerobic environment which favours CH_4 production. The gas release rate into the waste void space is principally affected by the pH and the rate of water production in each of the modes of bio processing. Since water is a normal product of the first stage (aerobic), more water may be present in the matrix than would normally be expected based on the water content of the wastes. This water will compete for space with the air during compaction and will dissolve some of the bio reaction gases. The first two stages reduce the pH of the water and may affect the evaporation/volatilization rate accordingly [35].

Aerobic decomposition begins shortly after the waste is placed in the landfill and continues until all of the entrained O_2 is depleted from the voids and from within the organic waste. Decomposition products under aerobic conditions are CO_2, water, and nitrate. Aerobic decomposition produces the conditions and by products necessary for anaerobic decomposition. Limited aerobic decomposition from infiltration of O_2, as air or dissolved in water, into the landfill may continue for years.

This continuing oxidative degradation by aerobic and facultative organisms can continue to drive the subsequent anaerobic processes. Aerobic degradation generally degrades many of the larger polymers in the wastes, such as starches, cellulose, lignins, proteins, and fats into smaller, more available oligomers (polymer consisting of 2 to 4 monomers) which can then be further degraded into dimers (molecule consisting of two identical simpler molecules) and monomers such as sugars, peptides, amino acids, long-chain fatty acids, glycerol and eventually organic acids, as discussed below [36]. These less complex products of aerobic degradation are more readily degraded anaerobically than the larger polymers.

Anaerobic decomposition occurs in two distinct processes. When all of the entrained O_2 is depleted from the waste, the waste decomposition changes from aerobic to anaerobic, and two new groups of bacteria emerge which thrive in anaerobic environments. Facultative microbes convert the simple monomers into mixed acid products along with hydrogen and CO_2. Anaerobic bacteria convert the mixed volatile organic acids (e.g., formic, acetic, propionic and butyric acids), aldehydes and ketones into primarily acetic acid and hydrogen, using water in place of O_2 [37]. These organic acids reduce the pH, which increases the solubilization of some organic and inorganic wastes, thereby increasing the concentration of dissolved solids in the leachate. CH_4 production can be limited during this stage since the low pH (5 to 6) is somewhat toxic to the methanogenic bacteria. During the second anaerobic process, the methanogenic bacteria become more prominent. These methanogens degrade the volatile acids, primarily acetic acid and use the hydrogen to generate CH_4 and CO_2. This degradation results in a more neutral pH (7 to 8), a decrease in the COD, and a decrease in the conductivity, as the organic acids are consumed [38]. Anaerobic decomposition will continue until all of the volatile organic acids are depleted or until

O_2 is reintroduced into the waste, stimulating a resumption of aerobic decomposition of the remaining large polymeric materials and a new degradation cycle. Reverting to aerobic conditions temporarily retards CH_4 gas generation [39].

As the main amount of gasses forms during degradation phase of organic matter, in Article 1.4 following article is provided detail description of this process. It is important to state, this process has very huge influence both gas and leachate generation.

1.6.2. The LFG-compounds and their environmental impact

All these processes in landfill produce toxic gases that can directly affect the environment. LFG can be described as mixture of many chemical compounds, among that most significant are these [40]:

- Methane (CH_4);
- Carbon Dioxide (CO_2);
- Hydrogen (H_2);
- Non Methane Organic Compounds (NMOC´s);
- Hydrogen Sulphide (H_2S) and organosulphur compounds;
- Ammonia and Nitrogen;
- Carbon Monoxide (CO);
- Mercury (Hg);
- Silicon (Si).

Methane (CH_4). Methane is the first of the two main compounds of LFG, which is generated during the anaerobic degradation of the waste. Its concentration typically ranges between 30 and 60 % of the gas, under stable methanogenic conditions.

Methane is an important greenhouse gas. Despite its relatively low atmospheric concentration compared to carbon dioxide (currently 1.75 ppm as opposed to 358 ppm), the higher infrared absorption potential of methane makes its global warming potential around 25 times higher than that of carbon dioxide [41].

Methane is generally not considered toxic to plants or other organisms. The major effect of methane in soil is believed to be due to methane oxidation, which depletes the oxygen present increases the carbon dioxide levels and may also raise the soil temperature. This may lead to plants death by enhanced asphyxiation. A mixture of 5% to 15% methane in air will explode if ignited. A concentration of 5% methane in air, is the “lower explosive limit” (LEL), and concentrations equal to or greater than the LEL are considered hazardous [42].

The flammability range is lower than the normal concentrations of methane in pure landfill gas. However, during migration, landfill gas will mix with air and becomes depleted in methane, through dilution and/or oxidation, and therefore fall within the flammability range.

Methane constitutes both a very short term and acute explosion hazards and has a much more far-reaching and long-term effect on global warming.

Carbon dioxide (CO_2). Carbon dioxide is the second main compound of the gas generated in landfills, where it typically makes up between 20 and 50% of the gas [43]. It arises as one of the waste products of the biodegradation of organic compounds, both aerobic and anaerobic.

Atmospheric, carbon dioxide is a limiting factor in photosynthesis and is essential to plants. However, when present at high concentrations in soil, it can result in asphyxia due the oxygen displacement and can be directly toxic to plants.

The normal carbon dioxide concentration in soils varies between 0.04 and 2 %. An elevated concentration of carbon dioxide in a soil, a situation typical for landfill cover soils, is directly toxic to the plant roots, even if there is enough oxygen available. An indirect effect of carbon dioxide could be a lowering of the soil pH and the consequent changes in soil composition.

Carbon dioxide is classified as an intermediary between toxic and non-toxic substances. It acts by displacing oxygen in the respiratory system. It ambient concentration lies around 250 – 350 ppm [44].

Hydrogen (H_2). Hydrogen is a non-poisonous, odourless and colourless, but highly inflammable gas.

In landfills, it is produced both by the fermentative and acetogenic bacteria and consumed by the methanogens. As this last group of micro-organisms are the slowest to develop in the metabolic succession of anaerobic degradation, molecular hydrogen may accumulate during the initial stages of waste degradation and be transiently present at high levels (up to 20%) in the gas phase of young landfills, well above its LEL (4%) [45].

A variety of industrial wastes may have a potential of hydrogen formation on wetting. It is relatively easily oxidized in soils by micro-organisms and this has been documented experimentally in landfill top covers.

Non-Methane Organic Compounds (NMOC´s) The gas from landfills usually contains a variety of trace organics that may make up to 1% volume of the gas. Many research studies have generally detected between 100 and 200 different compounds. These compounds are either the sub-products of the biological and chemical processes occurring in the waste.

Examples are oxidised carbon compounds: alcohols, ketones, esters, organic acids, furans and sulphur compounds. The concentrations of these compounds are extremely variable from one site to another.

The nature of waste deposited and the rates and mechanisms of degradation occurring will have a decisive influence on the types of compounds and concentrations. The presence of these compounds in the gas phase will depend on their polarity: more polar compounds will tend to solubilize in the leachate, while the more apolar ones will be found in a higher proportion in the gas phase.

Hydrogen Sulphide (H_2S) and organosulphur compounds. Hydrogen sulphide and organosulphur compounds may all represent the most critical group of LFG compounds encountered to date, due to their toxicity, odour potential and corrosiveness. That's why, in this work the main attention was focussed on Hydrogen Sulphide.

Hydrogen sulphide is highly toxic and affects the nervous system. It also has a repugnant odour and is highly flammable. Its odour threshold is comprised between 5 and 40 ppm. Above 50 ppm it paralyses the olfactory system, which makes it a particularly pernicious intoxicant. Concentrations above 400 ppm affect the nervous system and above 700 ppm there is risk of death by respiratory failure [46].

When in contact with water, hydrogen sulphide gives rise to sulphuric acid, which may corrode gas utilization facilities. It may also result in high SO_2 emissions after LFG combustion. More detail information about this compound is be provided in Chapter

Organosulphur compounds, i.e. mercaptans and carbon or methyl sulphides, are important contributors to the foul smell of LFG formed on MSW landfills. They most probably arise from the degradation of proteins, which typically forms 6% of food wastes.

Generally, the levels of sulphur compounds are lower in LFG than in other biogases.

Sulphur is abundant in bottom ash and has been found in concentrations ranging from 1000 to 5000 mg/kg [47]. Most of the sulphur is in the form of sulphate. The most toxic of organosulphur compounds is methyl mercaptan, which affects the central nervous system.

Ammonia and Nitrogen Like the organically bound sulphur, ammonia and nitrogen compounds arise from the degradation of proteins.

Ammonia may be released during leachate treatment, for example during aeration. Ammonia stripping is an effective way to reduce the nitrogen load of the leachate.

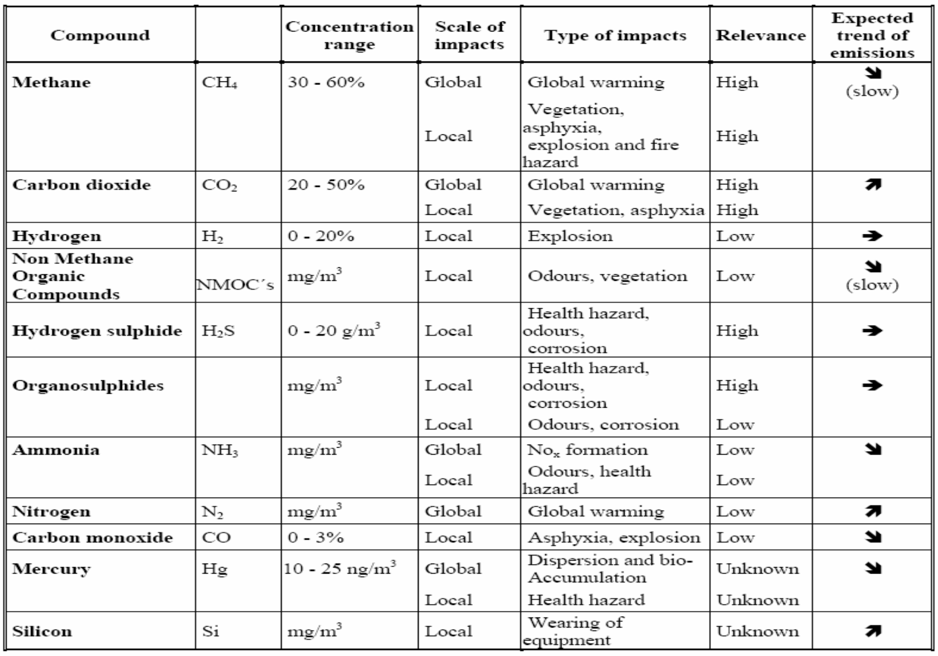
Oxidised forms of nitrogen are unwanted products of the combustion of LFG and are largely influenced by the combustion technology and by parameters such as temperature, reaction time and oxygen supply. Nitrous oxide (N_2O) emissions in particular are environmentally relevant as it is a greenhouse gas with a global warming potential 300 times that of carbon dioxide. Numbers say that nitrous oxide contributes for 9% to the greenhouse effect [48].

Carbon Monoxide (CO) Carbon monoxide has been found in LFG of landfills with concentrations between 0 and 3% volume. If higher concentrations are present, this may be a sign of oxygen-starved burning of the refuse. It is a highly toxic gas, which binds with hemoglobin in the blood and thus causing respiratory failure and death above 5000 ppm [49]. Carbon monoxide can be oxidised by bacteria to carbon dioxide, mostly occur in landfill top covers.

Silicon (Si) Siloxanes, or silicones are commercially produced compounds containing carbon, silicon, oxygen and hydrogen and must be distinguished from inorganic silicon which contains no carbon, but only SiO_2 units. When combusted however, the product will be inorganic, regardless of its original form and the impact is believed to be the same. Large variety of siloxanes compounds exist, due to their polymeric nature. Not only low molecular weight volatile siloxanes are entrained, but also high molecular weight siloxanes have been shown to aerosolise and thus be transported in gas streams. Naturally occurring silicon compounds are very common in landfill environments. Though they are exclusively non-volatile mineral species they may be transported with the gas as particulate matter or as solutes in water droplets.

Table 1.6 on the next page, shows a technical overview of the described LFG compound and their concentration range, scale of impact, type of impact, relevance.

Table 1.6 Technical overview of the LFG-compounds [50]



Compound		Concentration range	Scale of impacts	Type of impacts	Relevance	Expected trend of emissions
Methane	CH_4	30 - 60%	Global Local	Global warming Vegetation, asphyxia, explosion and fire hazard	High High	➘ (slow)
Carbon dioxide	CO_2	20 - 50%	Global Local	Global warming Vegetation, asphyxia	High High	➚
Hydrogen	H_2	0 - 20%	Local	Explosion	Low	➔
Non Methane Organic Compounds	NMOC´s	mg/m^3	Local	Odours, vegetation	Low	➘ (slow)
Hydrogen sulphide	H_2S	0 - 20 g/m^3	Local	Health hazard, odours, corrosion	High	➔
Organosulphides		mg/m^3	Local Local	Health hazard, odours, corrosion Odours, corrosion	High Low	➔
Ammonia	NH_3	mg/m^3	Global Local	No_x formation Odours, health hazard	Low Low	➘
Nitrogen	N_2	mg/m^3	Global	Global warming	Low	➚
Carbon monoxide	CO	0 - 3%	Local	Asphyxia, explosion	Low	➘
Mercury	Hg	10 - 25 ng/m^3	Global Local	Dispersion and bio-Accumulation Health hazard	Unknown Unknown	➘
Silicon	Si	mg/m^3	Local	Wearing of equipment	Unknown	➚

The emissions of LFG constitute one of the major environmental concerns regarding landfills as methane gas is widely accepted to contribute to global warming effects by around 25 times more than CO_2.

The gaseous compounds emitted from landfills have various environmental impacts on their surroundings and act on different scales, as illustrated by fig.1.7:

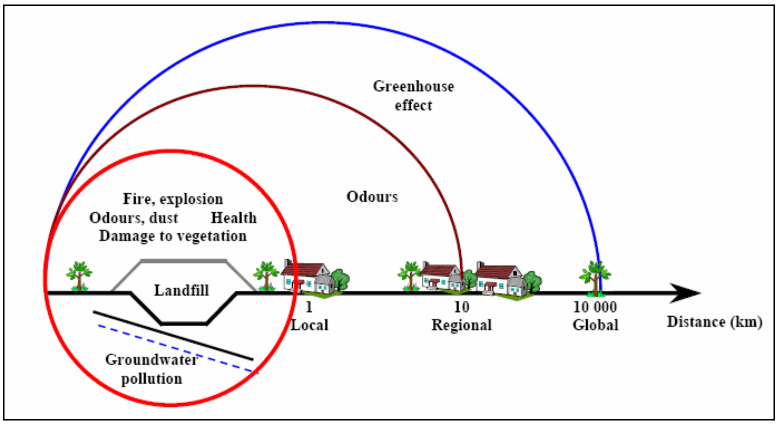


Fig 1.7. Different scales of environmental impact caused by LFG emission [51]

In addition to having impacts over a large spatial scale, gaseous emissions also act on different time scales. Compared to most other processes used in waste treatment, those occurring inside the landfill and the emissions they generate extend over a very long period of time after the waste has been disposed: from tens to hundreds of years.

Not only is the period of significant emissions long, but also the compounds emitted will themselves have effect and life-spans of varying duration. Odours and dust, for example, are mainly transient phenomena, while some of the anthropogenic trace compounds in LFG may persist and accumulate in organisms or natural ecosystems over very long periods of time.

1.6.3. Factors effecting landfill gas generation

Gas generation in a landfill is affected by several factors:

- availability of nutrients,
- temperature,
- moisture,
- pH,
- atmospheric conditions,
- age of waste,
- variation of water table,
- Presence of oxygen in the landfill.

*Availability of Nutrients***.** Bacteria in a landfill require various nutrients for growth: primary carbon, hydrogen, O_2 , nitrogen, and phosphorous (macronutrients), but also require small amounts of other elements such as sodium, potassium, sulphur, calcium and magnesium (micronutrients). The availability of macronutrients in the landfill mass has an effect on both the volume of water generated from microbial processes and the composition of the generated gases. Landfills which accept municipal wastes and use daily soil cover will, in general, have an adequate nutrient supply for most microbial processes to proceed. Landfills which do not use daily soil cover, may not have sufficient nutrients in the waste to sustain a microbial population [52]. Once the microbial processes are established, nutrients are regenerated from sloughing processes as bacteria die. The primary sources of macronutrients are green wastes, food wastes and soil cover, but will always be limiting if not supplemented from an outside source. Some loss of nutrients can occur as LFG components. The supply of micronutrients (primarily metals) is less certain, but evidence from hundreds of landfills suggests that municipal landfills also contain adequate supplies. The sources of these micronutrients are usually the trace elements found in almost all soils and many wastes. The micronutrient requirements are very small and can usually be met by these trace amounts in the wastes and leached from the soil cover.

If the nutrient supply is rich, the population of active microbes may become so high that they crowd the available pore spaces and restrict both water flow and LFG flow temporarily. In general, the situation will correct itself because the limited transport will cause some of the bacteria to die of starvation. Nutrient availability can be improved by the addition of sewage sludge, manure or agricultural wastes.

Temperature. Temperature conditions within a landfill influence the type of bacteria that are predominant and the level of gas production. The temperature of the landfill may vary dramatically from one section to another, as the temperature of the material is affected by several factors. The primary factors of temperature variations are depth, compacted density, *temperature* of the surrounding area, microbial or other chemical activity, *water content* and *climate.* Warm landfill temperatures favour CH_4 production; a dramatic drop in activity has been noted at temperatures below 10 ^{o}C . The optimum temperature range for aerobic decomposition is 54 to 71 ^{o}C, while the optimum temperature range for anaerobic bacteria is 30 to 41 ^{o}C. Landfill temperatures are reported to be typically in the range of 29.5 to 60 ^{o}C as result of aerobic decomposition, but may be expected to drop to the 19 to21 ^{o}C range as result of anaerobic activity[53].

Moisture. Moisture content is considered the most important parameter regarding refuse decomposition and gas production. A high moisture content of the waste (between 50 percent and 60 percent) by weight favours maximum CH_4 generation. This is contrary to standard landfill applications, where the waste is maintained as dry as possible in order to minimize leachate production. The moisture content of MSW as received typically ranges from a low of 15 to 20 percent to a high of 30 to 40 percent with an average of 25 percent on a wet weight basis. The moisture content can vary greatly in different zones of the landfill. Very low moisture content, such as the case of solid waste in arid regions, may prevent decomposition of waste and thus limit gas production. Leachate recirculation (if allowed) would permit control of the moisture inside the landfill. Typically, when a waste achieves a 50 percent moisture (on a wet basis) it has reached the field capacity, and will tend to leach continuously downward thereafter for additional moisture added. In-situ moisture content as high as 70 percent is possible [54]. At this level, a decrease in the efficiency of a gas collection system can be expected.

pH. The solid material placed in a landfill can vary widely in pH, but usually the average value for municipal waste will be between 5 to 9 standard units. The pH of hazardous wastes can vary widely, and known acids or bases are usually neutralized prior to landfilling.

The pH during CH_4 formation is in the range of 6.5 to 8.0, but the optimum pH of CH_4 fermentation is in the neutral to slightly alkaline range (7.0 to 7.2). Most landfills have an (7) acidic environment initially, but when the aerobic and acidic anaerobic stages have been completed, the methanogenic processes return the pH to approximately neutral (7 to 8) due to the buffering capacity of the system pH and alkalinity [55]. One concern during the acidic stages of the biological process is that the reduced pH will mobilize metals that may leach out of the landfill, or become toxic to the bacteria generating the gas. This is of particular concern where it is known that heavy metals are being placed in the landfill in large quantities.

Atmospheric Conditions. The atmosphere affects the conditions in the landfill in three ways: temperature, barometric pressure and precipitation. In a landfill where soils are used for cover layer, the air temperature not only affects the surface layer of the waste but may have an impact into the deeper layers, because the air permeability will generally be higher in the landfill. Cold climates will reduce biological activity in the surface layers, reducing the volume of gas generated. Deeper in the wastes, the surface temperature effects are often overcome by the heat generated by bacterial activities.

The atmospheric pressure influence is also stronger than would occur in soil systems, where the normal surface air interaction with the soil extends about 15 cm. Until the waste is consolidated to a typical soil density, the barometric pressure can affect the wastes near the surface by drawing air in or venting gas out of the top layer. Wind will also affect the diffusion rate deeper in the landfill by reducing the surface concentration of gas components and creating advection near the surface.

Precipitation dramatically affects the gas generation process by supplying water to the process and by carrying dissolved O_2 into the waste with the water. As the water percolates through the waste, it also extracts materials such as organics or metals as described above. High rates of precipitation may also flood sections of the landfill, which will obstruct gas flow.

In a landfill where geomembrane is used for final cover, the geomenbrane will isolate the waste and minimize many of the atmospheric effects described above.

Age of Waste. During the aerobic phase, the waste is close to the surface and the generated gas is difficult to capture. Aerobic metabolism is oxidative and generally more complete and rapid than anaerobic processes, so the initial rate of CO_2 production is relatively high. As the waste becomes depleted in O_2 and the acidic processes dominate, the LFG production rate decreases. When the acids have been consumed and the methanogens become dominant, the LFG production rate rises again through a peak and then stabilizes. The ideal time to start collecting LFG is at the beginning of site closure. This usually represents the maximum gas generation point, and gas quantities should remain significant for as long as a 10 years. After the landfill closes, the gas generation rate decreases as the organic substrate is consumed and not replaced. It may take as long as 50 years, however, for gas production to cease.

Variation of Water Table. The local geology which will affect the gas-generation rate is the depth and seasonal variation of the water table. Landfills are almost always designed to exist completely above the local water table. If the seasonal high water reaches the bottom of the fill, the hydraulic pressure will affect the waste, and LFG production, in several ways:

The pressure gradient may lift a liner system and rupture the liner, permitting air and water to penetrate the waste pack;

Air movement will be stopped in any saturated zone which may be created in the waste;

Biological activity may stop, change form as oxygenated water is introduced, or be enhanced by the presence of "fresh" water in the leachate;

Rupture in the liner may permit leachate to drain from the fill as the water table lowers after reaching its high point.

Presence of oxygen in the landfill. Methane will be produced only when oxygen is no longer present in the landfill. Only when oxygen is used up will bacteria begin to produce methane.

The more oxygen present in a landfill, the longer aerobic bacteria can decompose waste in Phase I. If waste is loosely buried or frequently disturbed, more oxygen is available, so that oxygen-dependent bacteria live longer and produce carbon dioxide and water for longer periods. If the waste is highly compacted, however, methane production will begin earlier as the aerobic bacteria are replaced by methane-producing anaerobic bacteria in Phase III. Methane gas starts to be produced by the anaerobic bacteria only when the oxygen in the landfill is used up by the aerobic bacteria; therefore, any oxygen remaining in the landfill will slow methane production. Barometric highs will tend to introduce atmospheric oxygen into surface soils in shallow portions of a landfill, possibly altering bacterial activity. In this scenario, waste in Phase IV, for example, might briefly revert to Phase I until all the oxygen is used up again [56].

1.6.4. Transport mechanisms

Once gases are produced under the landfill surface, they generally move away from the landfill. Gases tend to expand and fill the available space, so that they move, or “migrate,” through the limited pore spaces within the refuse and soils covering of the landfill. The natural tendency of landfill gases that are lighter than air, such as methane, is to move upward, usually through the landfill surface. Upward movement of landfill gas can be inhibited by densely compacted waste or landfill cover material (e.g., by daily soil cover and caps). When upward movement is inhibited, the gas tends to migrate horizontally to other areas within the landfill or to areas outside the landfill, where it can resume its upward path. Basically, the gases follow the path of least resistance. Some gases, such as carbon dioxide, are denser than air and will collect in subsurface areas, such as utility corridors. Three main factors influence the migration of landfill gases: diffusion (concentration), pressure, and permeability.

Several physical mechanisms describe the behavior of volatile compounds as they may be released into the atmosphere from a landfill. The transport may occur by the three principal mechanisms:

- molecular effusion,
- diffusion, and
- convection.

Molecular Effusion. Molecular effusion occurs at the surface boundary of the landfill with the atmosphere. When the material has been compacted, and not has been covered, effusion is the process by which diffused gas releases from the top of the landfill. For dry solids, the principal release mechanism is direct exposure of the waste vapor phase to the ambient atmosphere [57].

Liquid molecules that possess sufficient kinetic energy is projected out of the main body of a liquid at it are free surface and pass into vapor. The pressure exerted by this vapor is known as the vapor pressure.

The vapor pressure of a given compound is the single most significant factor affecting the performance of an off-gas collection system.

One physical effect on the release rate from the surface is wind speed. Wind serves to keep the ambient concentration at or near zero, which creates a concentration gradient for material to migrate to the surface [58]. Wind is also the dispersion mechanism to move the constituents into the surrounding area.

Diffusion. Molecular diffusion occurs in gas systems when a concentration difference exists between two different locations within the gas. Diffusive flow of gas is in the direction in which its concentration decreases. The concentration of a volatile constituent in the LFG will almost always be higher than that of the surrounding atmosphere, so the constituent will tend to migrate to a lower concentration area (the ambient air). Wind often serves to keep the surface concentration at or near zero, which renews the concentration gradient between the surface and the landfill on a continuing basis and thus promotes the migration of vapors to the surface. Geomembrane caps on landfills will have a significant effect on diffusion, because the geomembranes isolate the transport mechanism between the surrounding atmosphere and the landfill. The rate of diffusion is affected by the vapor density, but the concentration gradient will tend to overcome small differences in density.

Convection. Convective flow occurs where a pressure gradient exists between the landfill and the atmosphere; gas will flow from higher pressure to lower pressure regions, and also a flow from the landfill to the atmosphere. Where it occurs, convective flow of gas will overwhelm the other two release mechanisms in its ability to release materials into the atmosphere. The source of the pressure may be the production of vapors from biodegradation processes, chemical reactions within the landfill, compaction effects, or CH_4 generation at the lower regions of the landfill which drive vapors toward the surface. Variations in water table elevations can also create small pressure gradients which either push material out (rising tide) or draw material in. Even changes in barometric pressure at the surface can have an impact on the convective flow of gas. The rate of gas movement is generally orders of magnitude faster for convection than for diffusion. For a particular gas, convective and diffusive flow may be in opposing directions, resulting in an overall tendency toward cancellation. However, for most cases of LFG gas recovery, diffusive and convective flows occur in the same direction [59].

1.7. Odour

1.7.1. Odour from landfill site

Odours are an important subcategory of perceived air pollution that, together with noise and heat, is discussed as environmental stressors. Complaints from the public due to odorous emissions from municipal activities, e.g. landfills are significantly increasing in many countries. This leads to more emphasis on odour assessment. But presently, regulations and guidelines to avoid odour annoyance did not exist in Lithuania standardization system.

Landfill gas is a complex mixture of many compounds: principal compounds which are odourless (CH_4, CO_2, N_2) and many trace compounds among which some of them are responsible for odours. Other odorous compounds come from fresh waste emissions or leachate emissions. All these compounds can be classified in the following main families: sulphurous, nitrogenous, aldehydes, acids, ketones, alcohols, aromatics, esters and chlorinated compounds.

Information about odorous compounds that can be found in landfill emissions, as well as their principal properties in term of odours: specific odour, waste or process at the origin of odorous compounds and detection threshold values are submitted in table 1.5.

Table 1.5 Odorous compounds in landfill sites emissions [60].

Chemical	Formula	Family	Odour description	Sources	Odour detection threshold (ppm)
Hydrogen sulphide	H_2S	Sulphurous	Rotten egg	Anaerobics processes : landfill gas, composting activities, leachate	0.00047 - 0.0081
Methylmercaptan	CH_3SH		Rotten cabbage		0.0016
Ethylmercaptan	C_2H_5SH		Rotten cabbage		0.00076
Dimethyl sulphide	$2(CH_3)$-S		Deteriorated vegetables		0.001
Diethylsulphide	$2(C_2H_5)$-S		Etherated		0.0045 - 0.31
Dimethyldisulphide	$2(CH_3)$-2S		Putride		0.03 - 0.14
Carbon Oxysulphide	COS		Pungeant, sharp		
Carbon Disulphide	CS_2		Sweet		
Ammonia	NH_3	Nitrogenous	Pungeant, sharp	Landfill gas, waste (specially sewage sludge) composting activities and leachate	0.5
Methylamine	CH_3-NH_2		Fish in decomposition		3.2
Ethylamine	C_2H_5-NH_3		Pungeant		0.95
Dimethylamine	$2(CH_3)$-NH		Fish		0.34
Trimethylamine	$3(CH_3)$-N		Fish		0.00044
Methylindole (Skatole),	C_9H_8-NH		Feces		0.0008 - 0.1
Cadaverine	NH_2-$(CH_2)_5$-NH_2		Rotting meat		-
Indole	C_8H_6-NH		Faecal, nauseating		0.0006
Formaldehyde	H-CHO	Aldehydes	Acre	Landfill gas, waste	0.1
Acetaldehyde	CH_3-CHO		Fruit		0.05
Butyraldehyde	C_3H_7-CHO		Rancid		0.013
Propionalehyde			Rancid		0.072
Acetic acid	CH_3-COOH	Acids	Vinegar	Landfill gas, waste	0.48-1
Butyric acid	C_3H_7-COOH		Butter		0.001
Valeric acid	C_4H_9-COOH		Transpiration		0.0008
Formic acid	HCOOH		Pungeant		20-49
Propionic acid	CH_3-CH_2-COOH		Pungeant		0.16
Isovaleric acid	CH_3-CH_2-$CH(CH_3)COOH$		Cheesy		-
Ketone	CH_3-CO-CH_3	Ketones	Sweet fruit	Landfill gas, waste	0.42
Methyl ethyl ketone	CH_3-CO-C_2H_5		-		5.4
Methyl isobutyl ketone	CH_3-CO-CH_2-$CH(CH_3)_2$		-		0.68
Ethanol	CH_3-CH_2-OH	Alcohols	Sweet	Landfill gas, waste	84
Buthanol	C_3H_7-CH_2-OH		-		2.6
Phenol	C_6H_5-OH		Medicinal		0.04
Cresol	C_6H_4-CH_3-OH		-		0.00028

Benzene	C_6H_6	Aromatics	Gum-like	Landfill gas (and also present in landfill ambiance due to traffic)	2.3 - 43
Toluene	$C_6H_5CH_3$		Naphtalenes		0.082 - 42
Xylene	$C_6H_4(CH_3)_2$		Sour		0.0051 - 5
1,3,5 Trimethylbenzene	$C_6H_3(CH_3)_3$				0.04
Ethylbenzene	$C_6H_5CH_2CH_3$		Sour		2.3
Trichlorethylen	$CH\text{-}Cl\text{-}C\text{-}Cl_2$	Chlorinated	Solvent	Landfill gas	28
Propyl acetate	$CH_3\text{-}COO\text{-}CH_2\text{-}CH_2\text{-}CH_3$	Esters	Fruit	Landfill gas, waste	0.67
Butyl acetate	$CH_3\text{-}COO\text{-}(CH_2)_3\text{-}CH_3$		Rubber		0.39
Ethyl acetate	$CH_3\text{-}COO\text{-}CH_2\text{-}CH_3$		Grass		3.9
Limonene	$C_{10}H_{16}$	Terpenes	Lemon	Landfill gas, waste	0.5
Pinene	$C_{10}H_{16}$		Forest		10

According to the European Committee for Standardisation standardised method "EN 13725:2003 Air quality [57]. Determination of odour concentration by dynamic olfactometry", the detection threshold is the concentration at which 50% of people perceive the odour. The twenty five most significant odorous trace compounds in landfill gas have been listed and prioritised on the basis of the detection threshold value. It appears clearly that the sulphurous compounds dominate this odour importance list. That is one reason from the reason list, why the generation of H_2S from Jerubaiciai landfill was investigated.

It must be emphasised that the detection threshold value varies from one source of information to another because of inter-individual variability in olfactory sensitivity. As a result, a range of data is generally given for the detection threshold of compounds [58]. It is important to note that malodorous gaseous emissions of landfill sites are a complex mixture of many substances, and that odour concentration threshold for such mixtures cannot be inferred by simple superimposition of those from individual constituents. As it is shown in Table 1.5 for some families of odorous compounds, and particularly for sulphurous compounds, detection thresholds are very low. The human nose is able to detect very low concentrations, sometimes below the detection limit of measurement equipments, and high dilutions of landfill emissions are necessary to avoid nuisance generated by these compounds (e.g. depending on the landfill site, dilution factors over 1 000 could be necessary to avoid annoyance for surrounding residents)[61].

Odour control must be included in a continuous improvement approach for waste management facilities such as collection, sorting, incineration, composting and landfilling. Regarding sanitary landfills, odours associated with waste degradation processes are one of the main issues for landfill operators dealing with administrations and neighbourhood. In order to decrease this nuisance for the surrounding area, it is important to have a good knowledge of the sources of odours, their composition, and the critical conditions in which these odours are spread in the atmosphere. Identify, classify and characterise odours in landfill sites are necessary steps to implement appropriate methods to reduce odours [62].

1.7.2. Identification and prioritization of odour sources

According to the information collected from sanitary landfill sites, odour sources in landfill sites have been identified, located and qualified by more than one hundred operators over the world. The following areas have been proposed to the operators in order to target odour sources locations [63]:

- ***Tipping area:*** odours due to waste discharged from trucks and the first operations with engines to lay out fresh wastes.
- **Active cells:** this source includes the fresh Municipal Solid Waste (MSW) odours and landfill gas odours due to the beginning of aerobic processes.
- **Non active cells**: this source is due basically to landfill gas and reveals the limits of cell covers and the collection network efficiency.
- **Landfill gas:** this term gathers odours from the flare area, odours from leaks or failures of the gas collection network and the cells which are not connected to the collection network.
- **Leachate pond:** it deals with odours spreading from leachate in general and storage pond in particular, except from on site leachate treatment plants emissions.

Fig. 1.8 shows the distribution of sources identification frequency.

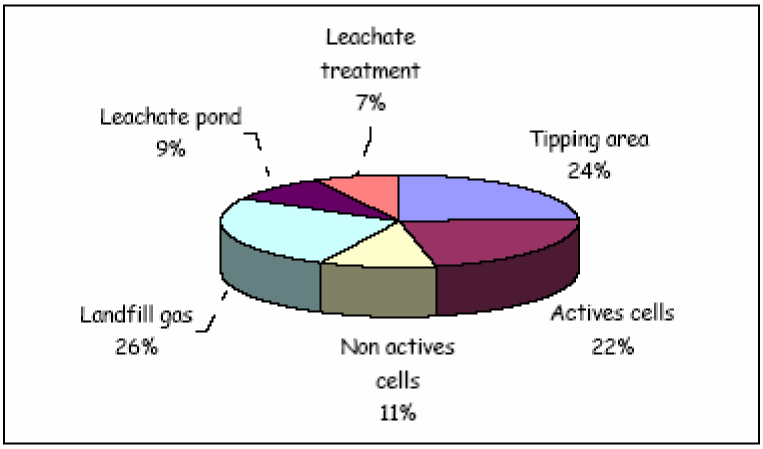


Fig. 1.8. Odour sources in landfill sites.

This figure shows that:

- Odours associated with landfill gas (landfill gas, active cells and non active cells) are the main sources of odours from a sanitary landfill (59%),

- Odours associated with fresh MSW (unloading area and active cells) represent the second source of odours (48%),
- Odours associated with leachate (leachate pond and treatment) are the third odour source in landfill sites (16%).

These results confirm that the three main sources of odours in landfill sites: landfill gas, fresh waste and leachate. The quantity of odorants influences the same factors as the quantity of LFG and leachate generation, that is discussed above.

The production of landfill gas gives rise to the greatest potential for odour impact due to the presence of trace compounds with a very low detection threshold value, such as sulphurous compounds. Fresh MSW odour emissions depend on variables including the methods of collection, intermediate storage and climatic conditions. The handling processes during waste disposal have an impact on odour production. Each time waste is disturbed, odours emissions occur. The typical odorous compounds of these emissions are organic acids, esters, alcohols, ketones, terpenes and sulphides. Leachate concentrates the most soluble compounds as opposed to the most volatile compounds found in landfill gas [63]. Leachate treatment facilities inducing air volatilization (e.g. agitation of the surface through pumping discharges) have the most important odour emission. In the chapter the main attention will be paid to one of most dangerous odorants, which generates from landfill site – Hydrogen Sulphide.

1.7.3. Generation of Hydrogen Sulphide

H_2S is one of the more important odorants in LFG. It is principally produced through the reduction of sulphate, mainly during the acetogenic phase by sulphate reducing bacteria. Measurements from portable instruments on gas within collection systems confirm that on the same sites where waste inputs have remained comparatively constant in terms of proportions and quantities, there is a noticeable trend in H_2S concentrations [64]. Concentrations of H_2S in LFG derived from recently deposited waste undergoing acetogenic decomposition where sulphate is still found in the leachate and are considerably higher than in LFG derived from firmly methanogenic waste where the sulphate has been reduced. This clearly has implications for both measurement and control, as the areas of landfill most difficult to control are the active areas, where H_2S generation is likely to be at its greatest [65]. Emissions of sulphuric odours depend on sorption in the waste, while sulphide binds to humic materials and metals such as iron, manganese and aluminium. Measured concentrations of H_2S in landfill gas in different landfills varies from 0 to 5000 ppm [66]. It is very important to estimate the rate, which generates in landfills under Lithuanian climate conditions. The odour threshold is reported to as low as 0.0001-0.0005 ppm.

Although H_2S is prevalent in landfill gas and has a very low threshold value (0.00047-0.0081 ppm), it is certainly not the only problematic odourant [67].

Hydrogen sulphide is colourless gas (Molecular weight: 34.08 g/mol) that has a distinctive smell of rotten eggs at low concentrations. It is one of the main compounds involved in the natural cycle of sulphur in the environment. This gas is very toxic at high concentrations. Hydrogen Sulphide is a potent chemical asphyxiant, combining with haemoglobin and with cytochromes and thus rapidly stopping oxygen from access to cellular metabolism (just like gases such as carbon monoxide and hydrogen cyanide). Hydrogen Sulphide very foul smells but very quickly paralyses the sense of smell, and can go on to overcome the victim and eventually cause death. Therefore smell cannot be relied upon to provide warnings of this treacherous gas. Hydrogen Sulphide is also an irritant of mucous membranes including the eyes and respiratory tract [68].

Sulphur is transformed to sulphate and sulphide as shown in Fig 1.9. Gaseous forms of S are corrosive, toxic and odorous.

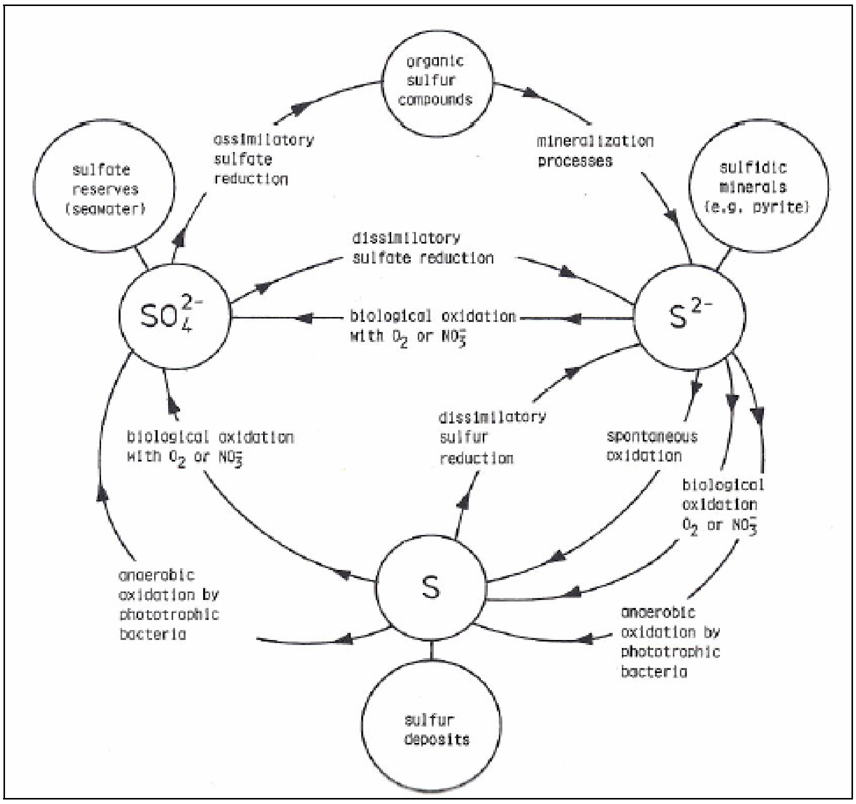


Fig 1.9. The S-cycle [69]

The reduction of sulphur takes place at a low redox potential [70]:

$$S + 2H^+ + 2e^- \rightarrow H_2S; \qquad (1.4)$$

Or with sulphate:

$$4\,H^{2} + SO_4^{-} + H^{+} \leftrightarrow HS^{-} + 4\,H_2O \qquad (1.5)$$

Under anaerobic landfill conditions (absence of air), sulfate-reducing bacteria produce H_2S from the sulfate (SO4-2) in gypsum and the organic carbon in waste material as follows:

$$SO_4^{-2} + 2CH_2O = 2HCO_3^{-1} + H_2S$$

From the above reaction, 100 tons of landfilled sulphate has the potential of producing 35 tons of H_2S [71]. Most of this "potential" likely will be realized during the active LFG production phase. Furthermore, since the sulfate-reducing micro organisms tend to out complete the methane-producing micro organisms (methanogens) until substantial sulphate depletion occurs, methane production - especially during the first few years - may be reduced at sites with high H_2S production [72].

1.7.4. Review of landfill odour investigation

The measurements of odour generation from landfills were provided in world countries. A solid-phase microextraction (SPME) method has been developed for the extraction of odourous compounds from waste gas emissions. The isolated compounds were characterised by GC-MS and GC-FID/Sniffing. Five different SPME fiber coatings were tested, and the Carboxen/polydimethylsiloxane (CAR/PDMS) fiber showed the highest ability to extract the odourous compounds from the waste gas. Further parameters like exposure time, desorption temperature, and desorption time have been optimised [73]. The SPME method was successfully used to characterise the treatment efficiency of a laboratory scale plant which consists of a bioscrubber/biofilter combination and an adsorption unit. The results correlate with the data obtained by olfactometric measurement. The developed instrumental-analytical method is a valuable approach to give detailed information of waste gas composition and complements existing methods for the determination of odours.

The measurements can be:

Subjective Assessments. At its most simple, daily logs of odours experienced are an effective method of tracking the nature and extent of odour emissions. The value of information gathered, improves as thenumber of people and locations increases and the descriptors increase. Public participation in the process described elsewhere marks a significant step forward. Where these assessments can be augmented by empirical measurements their value increases yet further.

Analytical measurements. Analytical measurements concern the physical or chemical properties of the odorous compounds, although the most common measurement made by far is odorant concentration. Analytical measurements have the advantage of objectivity, repeatability and accuracy. More importantly, they relate directly to theoretical models relating to odorant formation or emission. Unfortunately analytical measurements have several disadvantages reviewed by Stuetz [74]. Odorants are complex mixtures and usually necessitate a separation prior to analysis. Odorants may be present in very small concentrations. The limit of analytical detection may be below the threshold of smell. Non-odorous compounds will also be present in the sample in much larger concentrations than the odorants. It is difficult to relate analytical measurements to the intensity of odour as perceived by a human observer. This is especially the case for mixtures, as interactions between different odorants may lead to synergistic or antagonistic effects. Spectrometry (Gas chromatography coupled with mass spectrometry) is often used to chemically characterise odour samples. In many cases, a particular odorant may be dominant and can give an indication of the overall odour concentration.

Three municipal solid waste landfills in NSW, Australia were investigated to assess landfill odour emissions. The objectives of the investigation were to estimate landfill odour source emission rates, chemically "fingerprint" the odorants of landfill odour, and predict odour concentrations based on measured chemical composition. The tools used in this investigation are tools currently used in odour impact assessment, namely forced-choice dynamic olfactometry, gas chromatograph - mass spectrometry (GC-MS) and artificial neural networking (ANN). Odorous emission rates were found to be 0.335 ou.m3/m2/s for landfill tipfaces and less than 0.002 ou.m3/m2/s for the covered landfill surfaces and it was found that landfill gas odour and tipface odour had a “distinct” odour intensity (based on the German VDI 3882 Standard) at an odour concentration of 1.4 ou and 1.0 ou, respectively. Methylmercaptan, ethylbenzene, hydrogen sulfide and dimethyl sulphide were found to be the primary odorants. Artificial neural networks were also used to predict odour concentrations based on 79 VOC concentrations. Odour concentrations were predicted within 50% of the input odour concentration. [75].

The results of measurements of H_2S generation in Jerubaiciai landfill are provided in Section 2.3.

1.8. Conclusions

- Lithuanian legislations relevant to waste management sector are conducted to requirements of Europe Community directives and regulations and after the year 2009 only landfills that correspond to these requirements can be remain under operation. In such case, it is important to predict the impact of such landfill to the environment and design them in such way, that this effect will be minimized.
- To understand the physical and chemical processes, that are ongoing in municipal wastes landfill and that are the reason of environmental pollution is important to know the waste characteristics and main landfill types.
- From the review of main types of negative impact on environment from landfill it was come to conclusion, that the generally landfill pollutes environment with leachate, landfill gas, in which the main attention should be paid to methane, and odurants compounds.
- Environmental conditions and processes, that occures during waste degradation process has the crucial effect on leachate, landfill gas and odour quantity and quality. For future pollution prevention it is important to evaluate the connection between pollutant generation and environment factors.
- As the biogas and leachate generation was word widely investigated before this work, it is not necessary to provide new researches on them.
- Prediction of odour, that generates in from landfill site, is very important in these days. This factor can have negative impact on comfortability of the community and on human health. For such reason is important to provide mathematical modelling of odour spread way to predict the amount of odour, that can be fixed in living areas, situated near landfill site.
- The twenty five most significant odorous trace compounds in landfill gas have been listed and prioritized on the basis of the detection threshold value. It appears clearly that the sulphurous compounds dominate this odour importance list. The all attention must be paid to this compound.
- The measurements of Hydrogen Sulphide generation from landfill under Lithuanina climate conditions were not provided till this work.
- To evaluate the amount of Hydrogen Sulphide, that generates from landfill site is important to provide measures in different landfill areas, that are under proper operation, parallel providing measurements of environment parameters.

2. RESEARCHES OF H_2S GENERATION FROM JERUBAICIAI LANDFILL

2.1. Landfill site

2.1.1. Selection of site

For investigations on the impact to environment that goes from landfill was chosen landfill site in Plunge district, Jerubaiciai. Such decision was made because of following reasons:

- It is almost the first landfill in Lithuania, which design was close to EU and Lithuanian legislations requirements to landfills;
- Only household waste is disposed on the site;
- The area of this landfill will be extracted and after 2009 year it will be the single regional landfill in Telsiai County.

According to National Waste Management Strategy Plan all acting landfills that are not constructed regarding EU waste management legislation and relevant Lithuanian laws and regulations will be closed till 2009 year. In Lithuania there are no landfills that are constructed under all these legislations requirements. Jerubaiciai landfill is almost the first landfill in Lithuania, which design was close to EU and Lithuanian legislations and it is important to know, what quality and quantity of pollution will go to environment from such kind of landfill.

Another reason of such decision is that Jerubaiciai landfill will be rehabilitated and its operation will be adopted to meet all EU and Lithuanian requirements on landfills. This landfill will receive wastes not only from Plunge district as it is until this day, but from all Telsiai region.

Plunge district is almost the one district in Lithuania that successfully started implement waste management system from 1998 year. As the reason of that, only household waste is disposed to this landfill and this meets all EU requirements.

This landfill site has very serious problem with leachate collection, as leachate drainage system is not working properly. The leachate accumulation sites can be extra sources for odour formation.

2.1.2. Description of landfill site

The area for the landfill was chosen in 1998 by the confirmed commission of Plunge municipality. As the region has implemented the system of collecting waste with containers, the disposed waste is from the whole region. The place chosen for the landfill is located in a rather smooth relief zone with the slope towards the Plunge – Medingenai road.

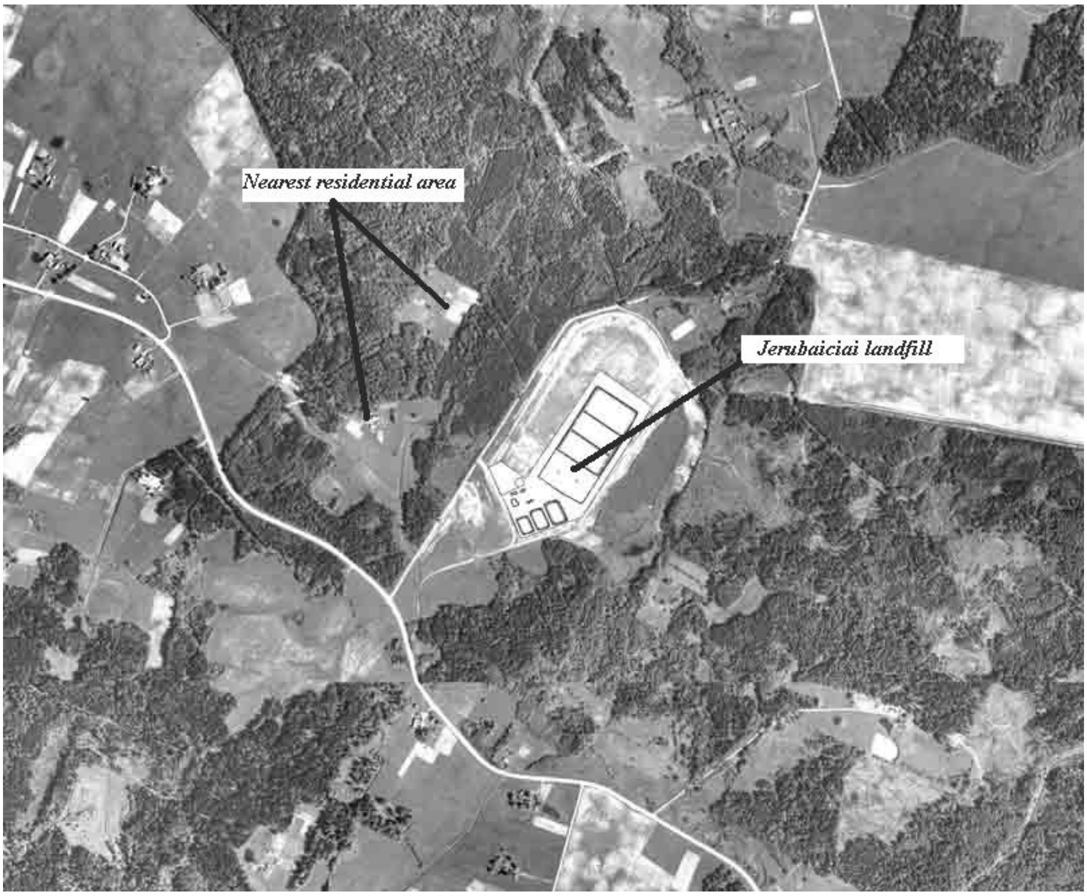


Fig.2.1 Jerubaiciai landfill

In order to establish the site, the topsoil was dug out. The local soil was dug until 2 m deep and later on used for construction and stored on the site for waste cover material. There are no residents in the sanitary protection zone. The site is surrounded with forests from all sides. The area chosen for the site is 16 ha, but at the moment a 2 ha area is established as landfill.

The current phase on landfill is divided into 4 sections with partition embankments. At present, the 1st section is in use. The waste is disposed by using 2.5 m thickness layers, later it is layered with 20 - 25cm of soil. The operations of the landfill began in the fall of 2001. Only household waste is disposed on the site. Other waste is sorted in a specially established field near the administrative building. The amount of the accumulated waste is 14900 cubic meters.

The composition of wastes, that are generated in this Telsiai region are shown in Table 2.1. These figures are the same for wastes that are disposed in Jerubaiciai landfill.

Table 2.1. Waste composition analysis in Telsiai Region

	Apartments	Town houses	Rural houses	Overall
Paper and board	4.9%	1.1%	1.1%	2.5%
Plastic film	0.5%	0.4%	1.3%	0.8%
Plastic bottles	2.0%	1.5%	2.6%	2.1%
Other plastic	1.0%	0.7%	0.6%	0.8%
Glass	5.0%	4.0%	11.3%	7.3%
Green waste	1.5%	21.0%	1.1%	5.7%
Kitchen waste	50.0%	21.0%	26.6%	33.9%
Cans	0.8%	0.2%	0.9%	0.7%
Other metals	0.5%	0.5%	2.9%	1.5%
Textiles	2.3%	1.8%	3.2%	2.6%
Misc. combustible	10.0%	4.8%	9.3%	8.5%
Misc. non-combustible	21.5%	43.0%	39.1%	33.5%

Before the establishment of the landfill, geological boreholes for the analysis of ground water were installed. According to the geological report, it was found that the prevailing loam soil according to the filtration properties do not comply with the properties and requirements for natural clay screen. In situ permeability for the brown loam that underlies the site is approximately 1 x 10^{-7}m/s. The ground water is from 120 mAD until 125 mAD. The bottom levels of the site are from 121.60 -123.48 mAD. The flow direction of the groundwater is south of the site towards the Plunge – Medingenai road.

All the required engineering network is established on the site, i.e. lowering drainage of ground water (ground water is 1m lower than the bottom screen of the site), protective embankments from all sides from local soil, HDPE 2mm thickness screen is installed on the bottom and slopes of the landfill, which is protected with 30cm thick sand soil on the bottom and 50 cm thick clay soil on the slopes.

A system of collecting leachate is installed on the bottom of the whole site using PVC perforated pipes. There are gas collection wells in every section that can be adapted according to the growing height of the pile. Roads with gravel covering for traffic and waste loading are built on the pile crests on the site. Biological purification equipment is installed for purification of leachate and in case of chemical pollution of filtrates the chemical purification equipment is installed too. There is an administrative building for operators, garage maintenance of machinery. Near the administrative building there is a fire prevention water reservoir. There is also weighbridge and wheel wash and a container washing system. A fenced field for temporary disposal of hazardous waste was also installed.

The landfill is the main landfill for the municipality and was constructed with a HDPE lining and leachate treatment facility to a design that was intended to be in accordance with EU standards. However, the design does not meet exactly the requirements of the EU Landfill Directive.

The lining system is of a modern composite design but does not strictly conform to current EU standards. Removal and replacement of this lining would involve considerable expense and could have negative impact on the environment due to moving existing waste and is therefore not recommended. However, improvement to the leachate collection layer can be carried out to bring it to EU/Lithuanian standard by increasing the thickness of the gravel layer to 500mm and adding a geotextile filter. The existing landfill will be retained and operated to modern standards and monitoring of groundwater quality from boreholes and streams should continue to ensure water quality is maintained.

The current lining system does not include a natural mineral lining. The requirement of the EU standard is for either 1m thickness of clay with permeability less than $1x10^{-9}$m/s, or a minimum 0.5 m thickness of modified soil (bentonite/sand mix) with permeability less than $5x10^{-10}$m/s. The natural soil below the existing lining is a silt with permeability around $1x10^{-7}$m/s and is not suitable as a natural mineral liner. Also there appears to be no source of suitable clay in the region and use of a sand/bentonite mix will be required to form a mineral layer suitable to comply with EU requirements..

The existing landfill includes a system for collection and biological treatment of leachate. The required volume for storage for leachate in winter months can be improved by diverting clean surface water away from the leachate collection system so it does not mix, but the existing leachate system will be retained. It is possible that leachate quality could be improved if necessary by use of a floating aerator. The need for this will be assessed from monitoring of water quality at the discharge point into the local stream.

2.1.3. Climate conditions

The climate of Telsiai County is strongly influenced by the vicinity of Baltic Sea, which is about 50 km to the West. Summer air temperature is lower, autumn and winter is higher than the temperature in other districts, which are further from the sea.

Lithuanian climate depends not only on geographical position, but also on the atmosphere's circulation. This process assures uninterrupted metabolism of warmth and damp between land and water, also between the earth surface and atmosphere. Telsiai district weather statistics (2004):

Average January temperature	**-5**°C
Average July temperature	**16.5**° C
Average February wind speed	**2.9** m/s
Average April wind speed	**3,8** m/s
Average August wind speed	**3.4** m/s
Average November wind speed	**3,8** m/s
January precipitation	**42.1** mm
July precipitation	**81.5** mm

Temperature. The coldest month is January, when the monthly average temperature is between -4,5°C and -5°C, the warmest month is July but the monthly average temperature does not exceed +16,5°C.

Minimal daily average temperature in winter is -22ºC, and absolute daily minimum temperature monitored was -31ºC.

Average daily temperature higher than 10ºC occurs during 142 days in a year. Sunshine (no cloud) is about 45 days in a year.

The heating period is about 200 days (6.7 of month).

The soil begins to freeze around 20th of December and ends on 6th of April. During warmer winters the soil freezes to about 3 cm depth and in very cold winters the depth of frozen soil can be 80 cm or more.

Wind rose. The prevailing winds in autumn are from North West and in winter - from south. In spring and summer it starts to blow more from the northwest and west. The average speed is in Plunge district (mostly on southern west sides Zemaiciai highland slopes) – 3,8 m/s. The strongest winds blow during the cold season (second part of October - January). In this period there are sometimes local squalls and vortexes, when the wind speed becomes 32-35 m/s. Wind roses of winter and summer periods are shown in Figure 2.2 a wind rose is a graphical illustration of the percentages of time that the wind is blowing from specific directions and for specific speeds.

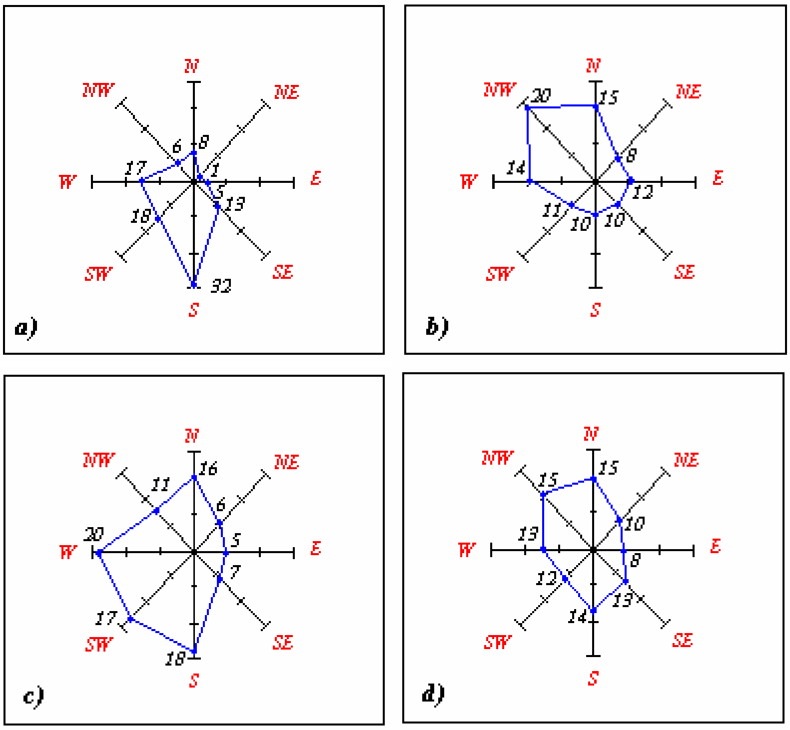


Fig 2.2. Wind rose at Telsiai meteorology station (a) winter, b) spring, c) summer d) autumn)

Wind analyses were done for weather data from the Telsiai station for summer months (June, July, August) and winter months (December, January and February). The wind in winter blows from south 32% of the time.

Rainfall. There is a rainy period from July to December (avg. rainfall monthly 70 – 90 mm) and dry period from January to June (avg. rainfall monthly 30 – 40 mm). Rainfall annual average is about 800 mm.

2.2. Methodology of H_2S amount measurements in landfill site

2.2.1. Methodology of measurements

To analyse the amount of hydrogen sulphide that generates from landfill was chosen on-site method of measurements. Such decision was based on the outputs from literature revue of Hydrogen Sulphide generation. First of all, as it was described above, landfill is an environmental system and the volume of Hydrogen Sulphide that generates in landfills depends from a lot off environmental parameters. That’s why the simulation model can’t reflect real situation and was not used.

Providing measurements on site, hydrogen sulphide emissions can be obtained from an interpretation of wind velocity and hydrogen sulphide concentrations at different points over the landfill surface. The measurements were provided in different points that are in different landfill areas. In such case emissions from all part of the landfill are sampled, so this method also provides some special information about high and low emission areas in landfill site. With this method automated, continuous measurement is possible.

Advantages of this measurement method:

- Gives representative emission levels for large parts of the landfill.
- Continuous measurements over a longer period and in different time of the year or day are feasible.
- The interpretation is straightforward.

H_2S emissions can be measured as well on the condition that suitable analysing equipment is present. Hydrogen sulphide is the priority trace component that can be reliably quantified in the field–though only if the readings are below 50 ppm. If concentrations are higher, then laboratory measurement is required for accurate quantification. Measurements were provided with a hand-held instrument specific for hydrogen sulphide and the results were fixed on field. The description of gas analyzer GD/MG 7 is provided in section 2.2.2.

Parallel to hydrogen sulphide amount measurements the measurements of temperature and air humidity were provided. The means of atmospheric pressure were obtained from meteorological station, situated in Telsiai region.

During measurement, gas sample is drawn through gas analyzer and the volume of H_2S is provided in the monitor. The achieved result is Hydrogen Sulphide concentration in ppm.

Measurements points. Measurements were provided in 59 points and in 2 monitoring wells. The whole scheme of all measurement points is presented in Apendix 1. Such number of points and its location was chosen to identify the zones in landfill, where the highest amount of hydrogen sulphide is generating and to investigate the way in which H_2S moves from landfill. These results will be compared with results from mathematical modeling.

The area of landfill's 1 st cell was divided in to the squares and the corners of them were measuring points. The side's length of these squares was equal to 15 meters (only in the North part of landfill the side's length was equal to 11 meters). All these measurement points were numbered from 1 to 35 starting from the most northern point in territory of landfill's 1 st cell. The points, those are situated in the 1 st landfill cell and near it are presented in fig 2.3.

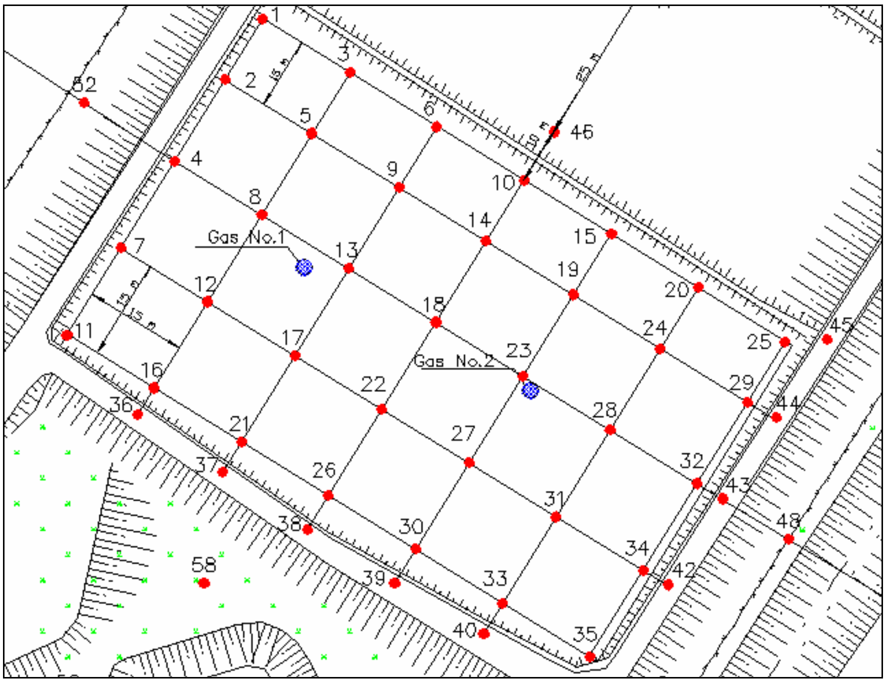


Fig. 2.3. Measurement points in 1 sty Jerubaiciai landfill cell

Such number and location of measurement points were selected to investigate the real amount of H_2S that separates from landfill. This landfill is operating landfill, and in different parts of it, different chemical and physical processes of waste degradation takes a place. If the measurements will be provided in less number of measurement points, inexact results of H_2S separation can be obtained and the most "dangerous" zones of H_2S can't be predicted.

Two additional measurements (Gas No. 1 and Gas No. 2) were provided in the monitoring wells (fig. 2.3), which were arranged in the very beginning of the functioning period of landfill. These points are different from others because the amount of H_2S, that can be definite here, separates from the bottom layers of the landfill cell. In these points the measurements of gas spreading speed and temperature was measured with Testo 435.

Fig 2.4. Monitoring well (Gas. No. 1) in Jerubaiciai landfill cell No 1.

As it is known, that leachate concentration pounds is additional source of H_2S generation the measurement was provided near such places. Measurement points No. 36 – 45 were chosen with the reason, as the leachate concentration pounds were defined near landfill cell No. 1. Such pounds have appeared as the result of bad function of leachate collection system in Jerubaiciai landfill.

Measurement points No. 58 and No. 59 are located near leachate biological treatment ponds. The reason of such points selection is the same as for points No. 36-45.

Measurement points No. 46 –54 were allocated beyond landfill territory. These points are in distance 25, 50 and 100 meters from acting landfill cell. The measurements in these points were provided with aim to predict the amount of H_2S that is fixed near landfill site in the east, north and west directions.

Measurement points No. 55, 56 and 57 are in the landfill service area, where landfill operators spends most of their working time. To measure the amount of H_2S in this area is very important, as H_2S can provide harmful influence on staff that is working in landfill.

Measurement were provided near residential area to determinate if the H_2S has influence on residents, who lives in a distance approximately equal to 1 km from landfill site.

Time and frequency of measurements. Measurements were provided to identify the amount of H_2S that separates from Jerubaiciai landfill during whole year period and to predict the differences of it's separation quantity. In this reason measurements were provided in different time of the year (in August, November, February and April months).

The selection of these months for measurements was based on the climate and atmospheric conditions that were noted during whole year:

- August was the hottest and the most dry month of the year so it can represent summer climate conditions. The measurements were carried out on 20 th, 21th and 22th of August 2004.
- In the year 2004, the firs two months of Autumn was rather worm, and only in the beginning of November it was like real Lithuanian autumn. The measurements were carried out on 5th, 6 th and 7 th of November 2004.
- From observation conditions during winter session 2004-2005 it is clear that the real Lithuanian winter climate conditions was achieved only in the February. The measurements were carried out on 25 th, 26th and 27 th of February 2005.
- The Lithuanian spring climate conditions can be observed in April. The measurements were carried out on 8 th, 9th and 10 th of April 2005.

The measurements were provided during the working hours of Jerubaiciai landfill (from 8:00 – 20:00), three times in each measurement points during the day period except gas wells and few “hot” points.

The “hot” points are those, where the highest H_2S concentration was observed during the first measurement of the day. The measurements were provided with frequency of half an hour in such points. The results are provided in section 2.3.

Used Equipment for the measurements of H_2S generation. The measurement of Hydrogen Sulphide can be as adequately analyzed using certain types of dedicated, real-time analyser. Such instruments are able to detect hydrogen sulphide at levels from 0,1 ppm to 50 ppm, which is comparable with most laboratory-based techniques. he measurements were carried put with gas measuring instrument GD/MG 7. Detail description of this device and work with it is provided in section 2.2.2.

2.2.2. The equipment for landfill gas consistence measure and work with it

The H_2S amount that generates from landfill was determined with equipment GD/MG 7, that is committed to determinate amount of toxic, explosive gases and oxygen. The fallowing gas sensors are installed in this equipment:

- Semiconductor sensor for explosive gasses;
- Electrochemical sensor for toxic gasses;
- Electrochemical sensor for oxygen;

This equipment is used to:

- Estimate concentration of toxic, explosive gasses and oxygen;
- Detect presence and amount of gasses in stick holes, pump stations and waste treatment facilities;
- Air monitoring;
- Personal safety.

Standard characteristics of this equipment are: explosivity – 0-40% bellow lowest explosive limit (LEL), discretion of measurements 1% LEL; H_2S – 0-50 ppm, discretion of measurements 0.1 ppm, oxygen 0-25 %, discretion of measurements 1%.. Measurements can be provided under temperature from -10 °C to + 45 °C.

If the temperature is lower the -5° C, the measurements will prolong for longer time as is usual. Furthermore, in such cases the time period of continuous measurement decreases from 8 hours to 4 hours.

Equipment can measure three kinds of gasses at the same time, but only one concrete estimated amount of gas will be submitted on screen. During the measurement, only the estimated kind of gas will be measured. The choice of gas kind can be preformed by entering in to another level.

Equipment is installed in plastic corpus and covered with special electrostatic material. It can be handled on the neck. All buttons and screen is on the front panel of the equipment, and the sensors are situated in the bottom of the corpus fig 2.5 .

Fig 2.5. GD/MG 7 equipment and screen with bottoms

Depend on the kind of gasses that are measured, the relevant light of color switches on. Yellow lamp is lightning when the amount of H_2S concentration is measured. Description of colors and levels is provided on the front panel of equipment. When the level definition bottom is pushed on, the kind of measured gasses are changed. Meanings provided in screen can be readied at the same time, when the level is change. Equipment can estimate the level of H_2S from 0.1 to 50 ppm.

Acoustical and optical alarm system, that is installed in equipment, switches on, when the measured level of H_2S exceeds 15 ppm. When H_2S concentration returns to the limits, that did not increases 15 ppm, this signalization switches off.

Measurements of H_2S amount. The measurements of H_2S amount determination in each measurement point were provided in fallowing order:

1. Probe should be connected to the equipment;
2. The equipment is switched on and prepared for work. After this equipment should be appointed to measure H_2S amount (the yellow light is switched on). The equipment is automatically preparing for work about 60 s, so the measurements during this time period can't be provided.
3. The probe should be hold in the right had in 1.5 m above ground level and after this the bottom, that is situated in probe box should be pushed;
4. It should be waited till date provided in screen stabilizes. This value should be fixed on the paper. After this, the bottom should be axed.

Next measurement can be provided immediately in the same order.

2.2.3. Equipment, used for measurements of environment parameters

Air humidity. Psychrometers are based on the principle of heat exchange. They determine the relative humidity by means of the temperature difference between one dry and one moistened temperature sensor.

The psychrometer consists of two ventilated temperature sensors. One of them is moistened by a water soaked fabric. By means of a passing air stream a certain amount of water vapour is supplied to the ambient air dependent on its temperature and humidity. The moistened temperature sensor cools off because of evaporation. The temperature difference (psychrometric temperature difference) between the two temperature sensors is a measure for the relative humidity existing in the air.

Air humidity measurement were provide with Asmano Psychrometer.

Measurements of temperature and velocity. These measurements were provided with equipment Testo 435. It can calculate volume flow (m^3/h, m^3/min, ...) combines the advantages of thermal and vane anemometers. Temperature probes can also be connected. Additional practical accessories are also available.

Testo 435 has all the advantages of thermal and vane anemometers The following can be connected to Testo 435: vane probes; thermal probes, and temperature probes.

As these instruments were provided only for measurements of environment parameters, the detail description of these equipments will not be provided in this work.

2.3. Results of measurements

The emission of hydrogen sulphide was fixed in different landfill areas and in different time of the year. The results of measurements are provided in Annex 2.

First of all it must be mentioned, that during measurement, that were provided in August, November, February and April the amount of hydrogen sulphide (H_2S) is different in the same measurement points. It was noticed, that the H_2S values in August is 2-3 ppm higher than in November and April and almost 5-6 ppm higher than in February, almost in all measurements points. Also it was noticed, that amount of H_2S various from 0,9 ppm (in February) to 8,6 ppm (in August) in different landfill areas (fig 2.6).

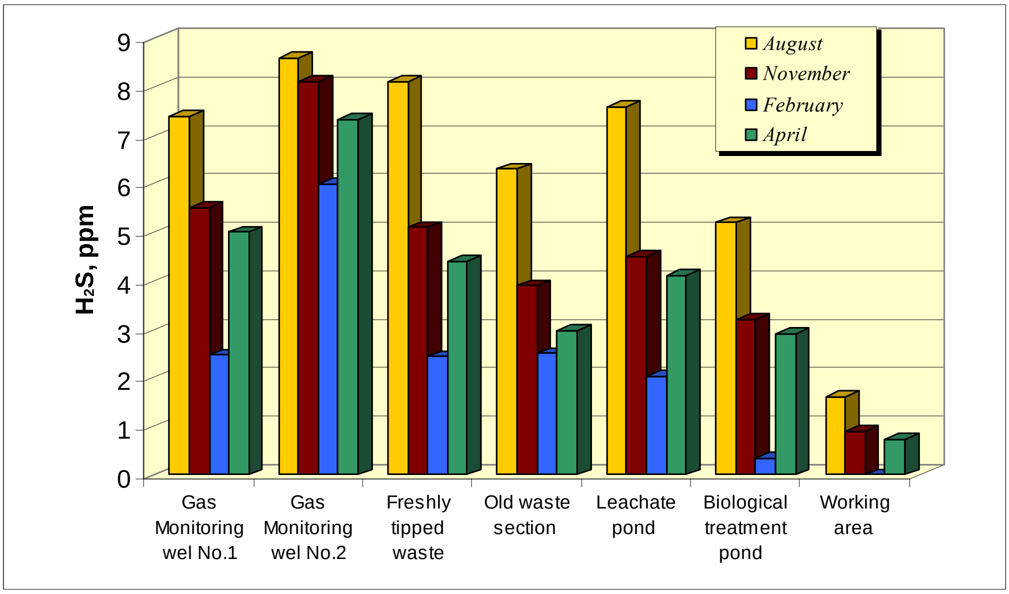


Fig. 2.6. Comparison of H_2S emission rate (ppm) from the different landfill odour sources

The highest H_2S rate was fixed in gas monitoring well (Gas No. 2) and it's average value is equal to 8,6 ppm in August, 8,1 ppm in November, 6,0 ppm in February and 7,3 ppm in April. In this monitoring point, the H_2S amount estimated in August is only 2,6 ppm then H_2S amount estimated in February. Such rate of H_2S can be explained as this monitoring well was installed in the beginning of landfill operation. It reaches the level of wastes, that are 3-4 years old. This amount of H_2S generates from wastes, that are disposed in 10 meters depth and the temperature of these layers are different from temperature, estimated in the top of landfill's surface.

Gas monitoring well Gas No.1 was installed in the beginning of landfill operation as well, but it is situated in the landfill's section, that is now under exploitation. It reaches the level of wastes, that are only 1-2 years old and it's boundary layer are in 3-4 meters depth. In this point, H_2S amount varies in different period of the year. The H_2 S generation in this measurement point (as well as in others) depends from meteorological conditions It is highest in August (7,4 ppm) and lowest in February (2,5 ppm).These months represents period of the year with completely different climate conditions. In November and in April, H_2S amount is accordingly equal to 5,5 ppm and 5 ppm.

Concentration of H_2S near biological treatment pond was estimated 5,2 ppm in August, 3,2 ppm in November, 0,3 ppm in February and 2,9 ppm in April. This odour deals with odours spreading from leachate in general and storage pond in particular, except from on site leachate treatment plants emissions. Leachate concentrate the most soluble compounds as opposed to the most volatile compounds found in landfill gas.

The same explanation can be provide and for H_2S amount estimated near leachate concentration ponds, that are situated near 1 st landfill cell. Here H_2S values are: 7,6 ppm in August 4,5 ppm in November, 2,0 ppm in February and 4,1 ppm in April.

H_2S concentration in area, where landfill operating staff is spending most of their working time, is 1,6 ppm in August, 0,9 ppm in November and 0,7 ppm in April. The H_2S amount was not fixed in this area during the measurements, that were provide in February. This area is approximately in 30 meter distance from 1 st landfill cell and about 15 meters from biological leachate treatment pond.

In 1 st landfill cell the measurements were provided in 35 points. The H_2S value varies from 8,1 ppm in August and 5,1 ppm in November to 6,1 ppm in August and 3,9 ppm in November 3,9 (fig. 2.7).

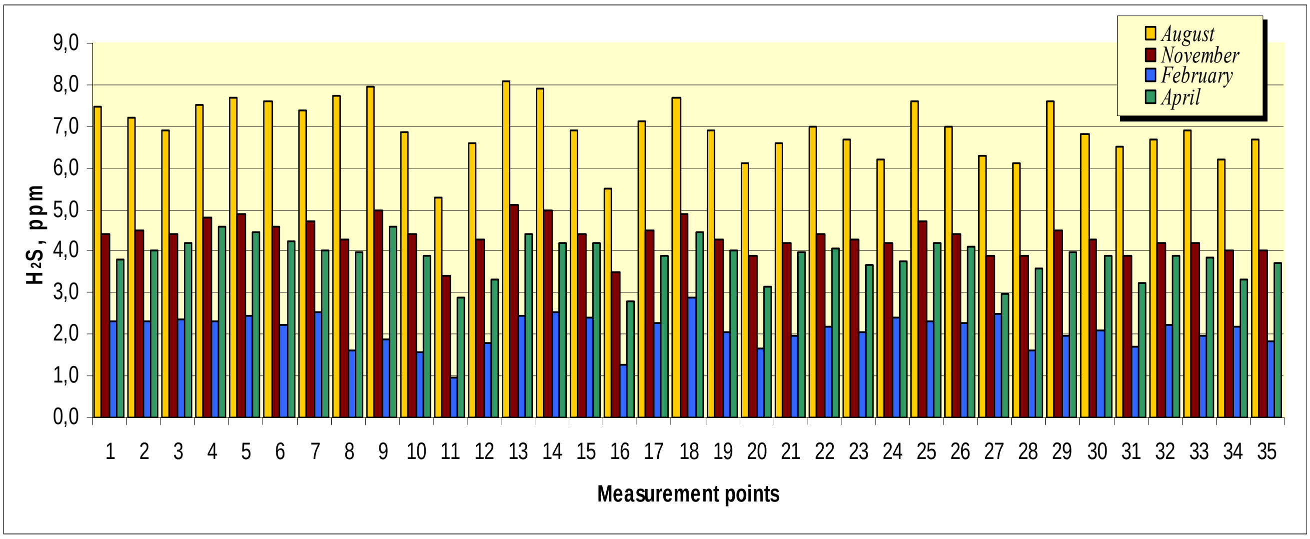


Fig. 2.7. Fixed H_2S values in Jerubaiciai landfill's cell No.1

The highest H_2S value was fixed in measurement point No 13, No 14 and No 9. These points are situated in fresh waste tipping area. Concentration of H_2S in area, where is deposited freshly tipped wastes is equal to 8,1 ppm in August, 5,1 ppm in November 2,4 ppm in February and

4,4 in April. In this section odour generates due to waste discharged from trucks and the first operations with engines to lay out fresh wastes.

The age of wastes, that are disposed in this area is approximately 1 year and they are under daily impact of landfill daily operating processes.

The lowest H_2S value was fixed in measurement point No. 11 and No. 16 (approximately 5 ppm in August, 3 ppm in November, 1,1 ppm in February and 2,8 ppm in April). The thickness of waste layer in this area hardly reaches 0,3 meter. No leachate concentration ponds were identified here. The highest and the lowest values differ from each other only in 2-3 ppm.

It must be paid attention to measure points of No. 31, No. 28 and No. 24. The H_2S value in these points was 6,5 ppm, 6,1 ppm and 6,2 ppm in August, 3,9 ppm and 4,2 ppm in November, 1,7 ppm, 1,6 ppm and, 2,4 ppm in February, and 3,2 ppm, 3,6 ppm and 3,8 ppm in April. In this section of landfill is disposed old wastes, which age varies from 3 to 2 years old. This area is now not under operation so the H_2S is generating only from old waste.

The measurement points No. 22, No.18 and No.14 are situated in landfill's plot, which is situated in compactor's working area. The value of H_2S is approximately 1 ppm higher then in old waste sector and reaches 7 ppm in August, 4,4 ppm in November, 2,9 ppm in February and 4,5 ppm in April.

Measurement points No. 33, No. 35, No. 32 and No. 34 are situated in waste piles borders, but the H_2S value in these points reaches 7 ppm in August, 4,2 ppm in November, 1,8 ppm in February and 3,7 ppm in April, and almost equal to the odour level, that was fixed in compactor's working area. Such H_2S value can be explained, that leachate concentration ponds are near these point.

From these results are clear, that one of the factors, that influents amount of H_2S generation from landfill's cell is meteorological conditions. The characteristics of meteorological parameters are provided in Table 2.2.

Table 2.2. Meteorological parameters

	August	November	February	April
Air temperature, ^oC	+20	+8	-3	+5
Air humidity, %	40	73	30	60
Atmospheric pressure, mmHg	745	740	750	760

The impact of environment parameters (temperature, air humidity and atmospheric pressure) on H_2S generation rate is shown in Fig. 2.8., Fig. 2.9 and Fig 2.10. In these figures H_2S concentration rate in different landfill areas are provided.

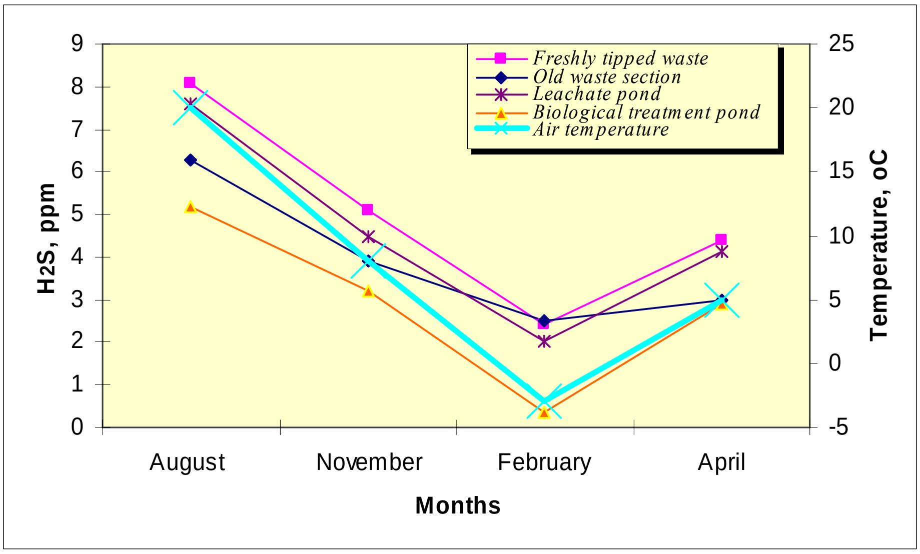
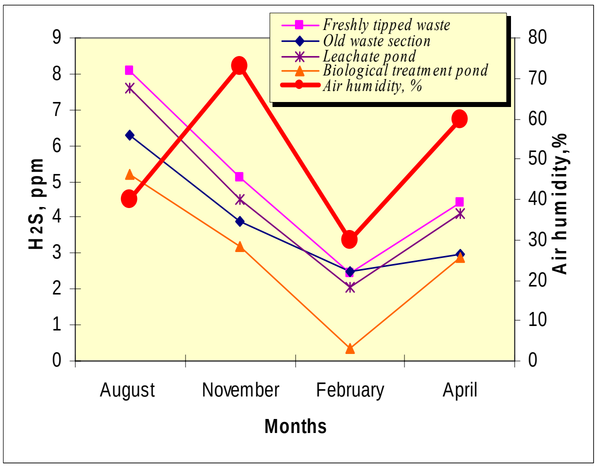


Fig 2.8. H_2S concentration dependence from air temperature.

The highest air temperature (+20 ^{o}C) was in August and the lowest (-3 ^{o}C) in February. The same is with H_2S concentration in different landfill areas. In November air temperature is about 12 ^{o}C lower the in August and the H_2S amount differs almost in 3,5 ppm during these months. From February, the air temperature starts increasing till 5 ^{o}C in April. In the same way acts and H_2S amount. Difference between H_2S amount that is estimated in February from H_2S amount in April is equal to 2-3 ppm. The amount of H_2S that generates from freshly tipped waste, mostly depends from air temperature as it is reflected in fig 2.8.



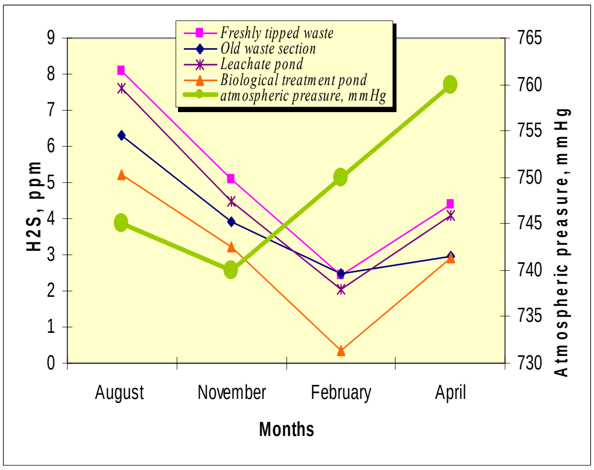


Fig 2.9. H_2S concentration dependence from air humidity

Fig 2.10. H_2S concentration dependence from atmospheric pressure.

It was tried to find out if the air humidity and atmospheric pressure has the same influence on H_2S generation as the air temperature. The highest air humidity was estimated in November, but during this month the H_2S generation rate is not highest in the year. The lowest air humidity was fixed in February, as well as lowest H_2S generation amount.

The same situation is with H_2S concentration dependence from atmospheric pressure. Atmospheric pressure, that was estimated in August is higher then in November (as well as H_2S amount), but lower then in February and April. As it was discussed above, the H_2S amount acts different during these months.

From the results, provided in fig 2.9 and fig 2.10, the clear conclusions about dependence between of H_2S generation rate and air humidity or H_2S generation rate and atmospheric pressure can't be maid.

The daily measurements were provided in "hot" measurement points. The daily H_2S generation values in different period of year in point Gas No.1 is provided in Fig. 2.11.

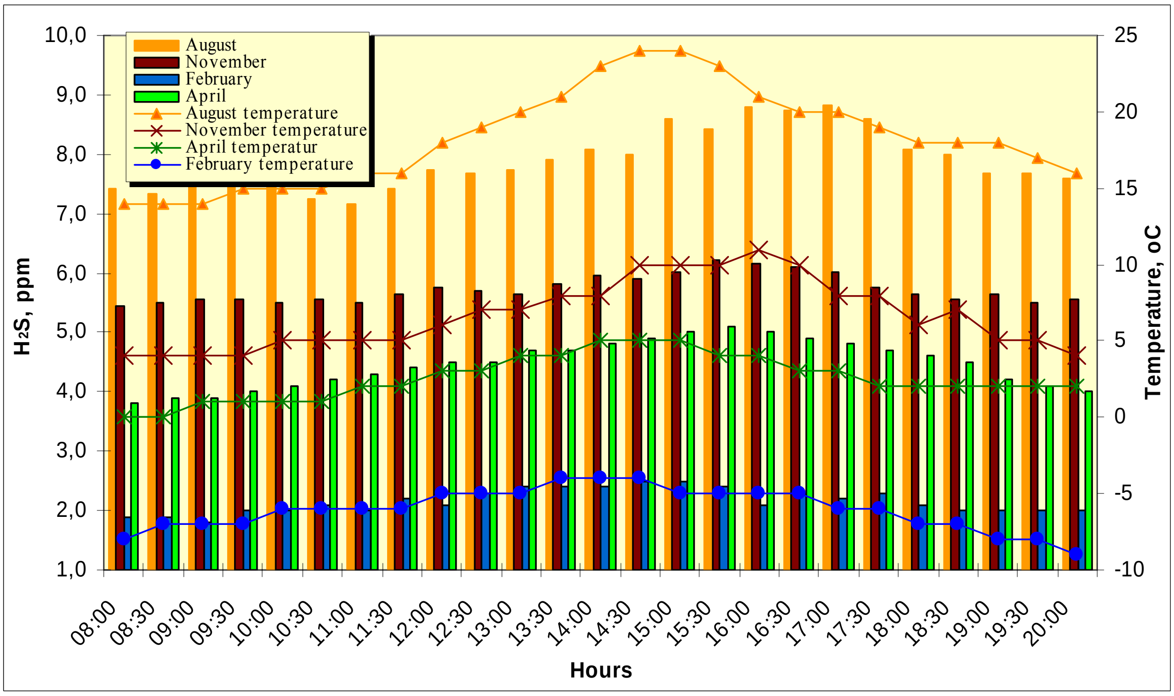


Fig 2.11. H_2S value during day period (point Gas No. 1)

In the morning (at 8:00), the H_2S amount is lowest during day period and is equal to 7,4 ppm in August, 5,4 ppm in November 1,9 ppm in February and 3,8 ppm in April. The amount of H_2S generations starts to rise up to 12:00 and reaches it's pike (8,8 ppm in August, 6,2 ppm in November, 2,5 ppm in February and 5,1 ppm in April). The results submitted in this figure shows that the highest H_2S amount separates in day period from 14:30 till 17:30 hours during all seasons of the year. From 18:00 H_2S generation rate starts to fall down and at 20:00 reaches 7,6 ppm in August, 5,6 ppm in November, 2 ppm in February and 4 ppm in April.

In the same way acts and daily temperature. It is lowest in the morning, at 8:00 (+14 ^oC in August, +4 ^oC in November, -8 ^oC in February and 0 ^oC in April), highest at 14:30 (+24 ^oC in August, +10 ^oC in November, -4 ^oC in February and +5 ^oC in April). From this hour it starts falling down till +16 ^oC in August, +4 ^oC in November, -9 ^oC in February and +2 ^oC in April at 20:00. From these date can be reached conclusion, that H_2S daily generation depends on daily temperature.

The daily H_2S generation values in different period of year in point Gas No.2 is provided in Fig. 2.12.

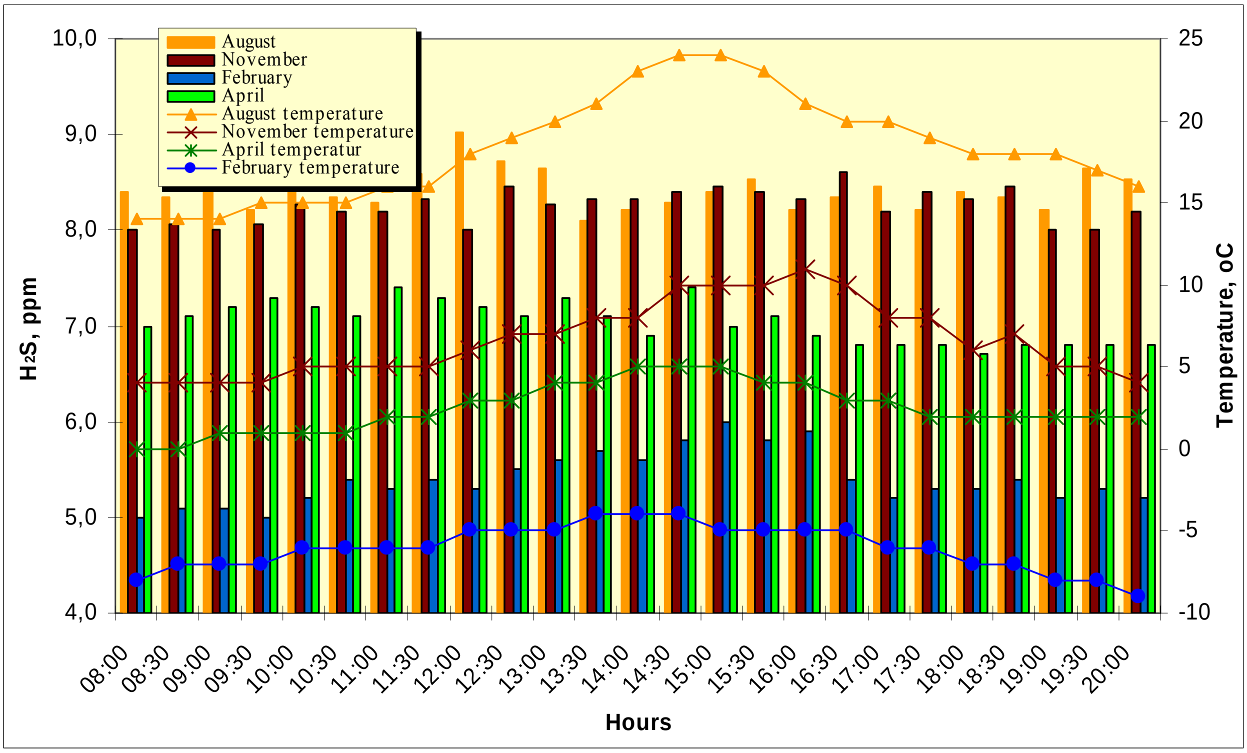


Fig 2.12. H_2S value during day period (point Gas No. 2)

In monitoring well Gas No. 2 fixed H_2S values differs during day period and session of the year. From the measurement results achieved in August month, the highest H_2S amount, equal to 9 ppm, generates at 12:00 and the lowest (7.3 ppm) at 9:30 and at 16:00. In November, the highest H_2S amount (8,6 ppm)was estimated at 16:30 and 18:30, in April – at 14:30 (7,4 ppm) but the lowest (8 ppm) – at 12:00 and in April (6.8 ppm) at 16 :30. Only during measurements, provided in February, some H_2S dependence from day time could be estimated. In the morning (at 8:00) , the H_2S amount is lowest during day period and is equal to 5 ppm. The amount of H_2S generations starts to rise up to 5,5 at 12:00 and reaches it's pike (5,9 ppm) at 16:00. From this hour H_2S generation rate begins fall down and reaches 5,2 ppm limit at 8:00.

From these date can be reached conclusion that in Gas No. 2 the H_2S generation rate did not depend from day period and air temperature, except winter session.

The daily measurements were provided in “hot” measurement points. The daily H_2S generation values in different period of year in measurement point No.9 is provided in Fig. 2.13.

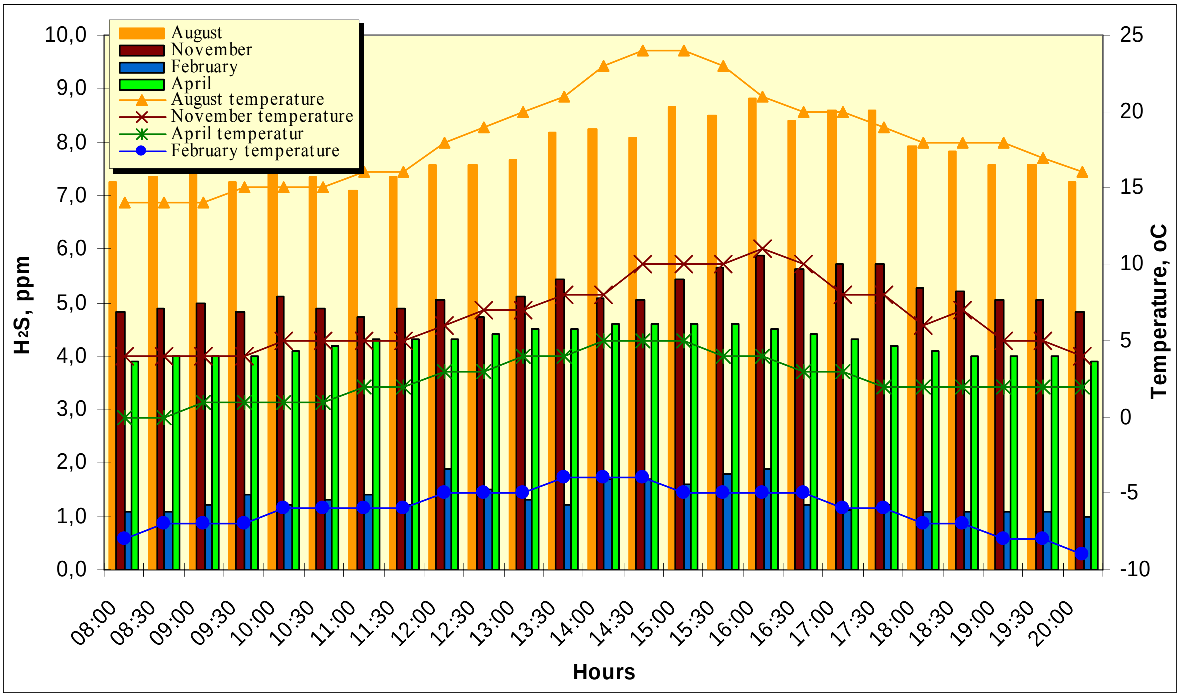


Fig 2.13. H_2S value during day period (point No. 9)

In the morning (at 8:00), the H_2S amount is lowest during day period and is equal to 7,3 ppm in August, 4,8 ppm in November, 1,1 ppm in February and 3,9 ppm in April. The amount of H_2S generations starts to rise up to 12:00 and reaches it’s pike (8,8 ppm in August, 5,9 ppm in November, 2,4 ppm in February and 4,6 ppm in April). The results submitted in this figure shows that the highest H_2S amount separates in day period from 14:30 till 17:30 hours during all seasons of the year. From 18:00 H_2S generation rate starts to fall down and at 20:00 reaches 7,3 ppm in August, 4,8 ppm in November, 1,0 ppm in February and 3,9 ppm in April.

The daily measurements were provided in “hot” measurement points. The daily H_2S generation values in different period of year in measurement point No.13 is provided in Fig. 2.14.

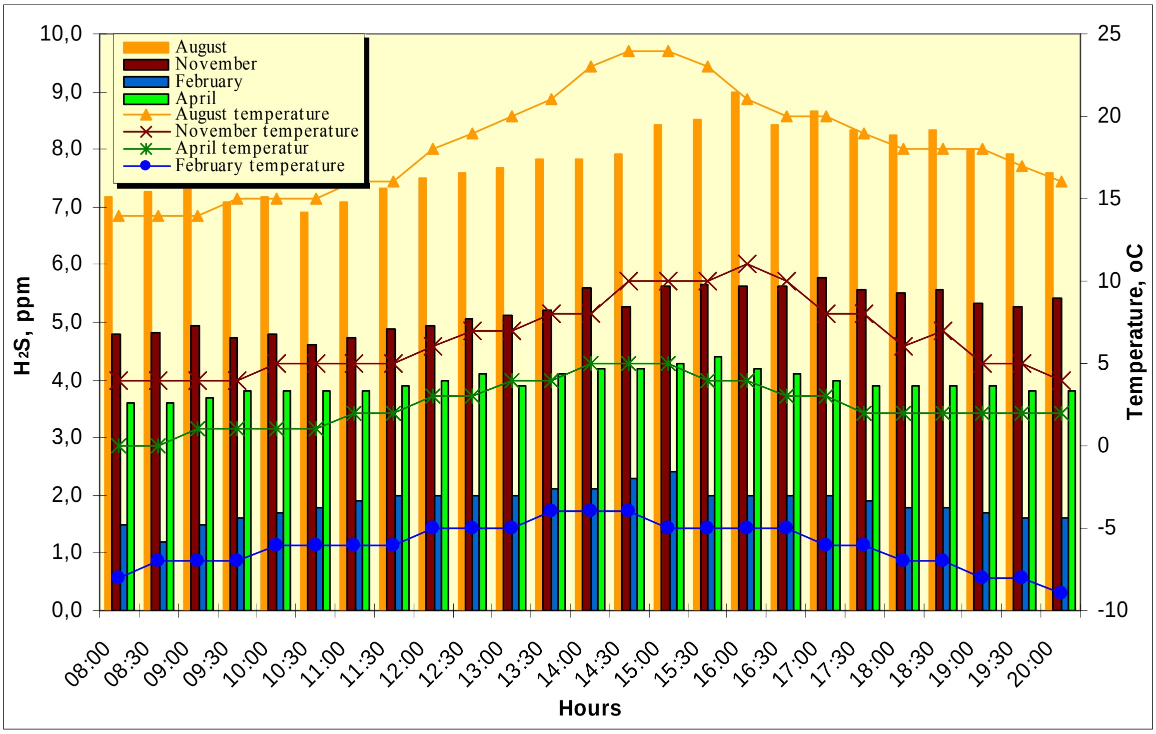


Fig 2.14. H_2S value during day period (point No. 13)

In the morning (at 8:00), the H_2S amount is lowest during day period and is equal to 7,2 ppm in August, 4,8 ppm in November, 1,5 ppm in February and 3,6 ppm in April. The amount of H_2S generations starts to rise up to 12:00 and reaches their pike (9,0 ppm in August, 5,8 ppm in November, 2,4 ppm in February and 4,2 ppm in April). The results submitted in this figure shows that the highest H_2S amount separates in day period from 14:30 till 17:30 hours during all seasons of the year. From 18:00 H_2S generation rate starts to fall down and at 20:00 reaches 7,6 ppm in August, 5,4 ppm in November, 1,6 ppm in February and 3,8 ppm in April.

From information, provided in fig. 11, fig 13, and fig. 14 can be done conclusion, that the H_2S, that generates from landfill's surface layer differs during daily period abut 1-1.5 ppm. It's generation rate depends from daily temperature.

The H_2S amount measurements were provided near residential area in all seasons of the year, but measurement equipment GD/MG 7 did not fixed any H_2S amount.

Measurements, that were provided in the points that are situated in 25, 50 and 100 meters provided results, that the H_2S amount in these points is equal to 0-1 ppm in all time of the year.

2.4. Conclusions

- For investigations on the impact to environment that goes from well operated landfill has to be chosen the household waste landfill, which installation and operation is due to EU and Lithuanian legislation. Jerubaiciai landfill in Plunge district matches such requirements.
- As the landfill is an environmental system and the volume of Hydrogen Sulphide that generates in landfills depends from a lot off environmental parameters the simulation landfill's pollution model can't reflect real situation. To analyse the amount of hydrogen sulphide that generates from landfill was chosen on-site method of measurements.
- The measurements were provided in different points that are in different landfill areas and also in points that are in some distance from landfill cell. In such case emissions from all part of the landfill are sampled and the areas with different amount of H_2S generation was established.
- Measurements were provided to identify the amount of H_2S that separates from Jerubaiciai landfill during whole year period and to predict the differences of it's separation quantity. In this reason measurements were provided in different time of the year (in August, November, February and April months).
- During measurement, that were provided in August, November, February and April the amount of hydrogen sulphide (H_2S) is different in the same measurement points. H_2S values in August is 2-3 ppm higher than in November and April and almost 5-6 ppm higher than in February, almost in all measurements points.
- Also it was noticed, that amount of H_2S various from 0,9 ppm (in February) to 8,6 ppm (in August) in different landfill areas.
- The highest H_2S value was fixed in measurement point No 13, No 14 and No 9. These points are situated in fresh waste tipping area. In this section odour generates due to waste discharged from trucks and the first operations with engines to lay out fresh wastes.
- The lowest H_2S value was fixed in measurement point No. 11 and No. 16 (approximately 5 ppm in August, 3 ppm in November, 1,1 ppm in February and 2,8 ppm in April). The thickness of waste layer in this area hardly reaches 0,3 meter.
- H_2S average value in gas monitoring well (Gas No. 2) in August is only 2,6 ppm higher then H_2S amount estimated in February. Such rate of H_2S can be explained as this monitoring well was installed in the beginning of landfill operation. It reaches the level of wastes, that are 3-4 years old. The generation of H_2S in this point does not depends from air temperature.

- H_2S generation from top layer varies during day period and session of the year. It depends from the temperature of the air. The dependence between H_2S generation rate and air humidity or H_2S generation rate and atmospheric pressure were not determinated.
- As shows the measurement equipment GD/MG 7, the H_2S amount near residential areas is equal to 0 during all seasons of the year.

3. DISPERSION MODELLING OF H_2S SPREAD FROM JERUBAICIAI LANDFILL

3.1. Dispersion modelling

Atmospheric motion. Atmospheric motion serves both to advect and to diffuse air pollutants. Motion in the atmosphere or flow can be viewed as consisting of two components: a steady component (mean) combined with a superimposed fluctuating component (turbulence).

The mean component in the atmospheric boundary layer generally has a logarithmic dependence of height above the surface. Turbulence consists of eddy structures, which occur randomly in space and time in a spectrum of sizes and intensities. These eddy motions create fluxes of momentum, heat and moisture, which characterise the structure of the atmospheric boundary layer. If a cloud of pollutant is released into the atmospheric boundary layer, these eddies lead to the "advection" (or dispersion) and "mixing" of the pollutant [76]. That is, if the size of these eddies are smaller than the pollutant cloud or plume they will diffuse it; if they are larger they will advect it.

Characteristics of the atmospheric boundary layer. Effective dispersion of gaseous material released into the atmosphere near the ground depends on natural mixing processes. Mixing is a consequence of turbulence generated in the atmospheric boundary layer.

The atmospheric boundary layer is the region, which extends upwards from the surface to a height where turbulence resulting from surface friction has fallen to zero.

The boundary layer is also known as the mixing layer. By day, the mixing layer over land typically extends to between five hundred meters and two kilometers above the ground. No clear top may mark the boundary layer under these conditions and the turbulent fluxes decrease gradually with increasing height. At night however, especially when the sky is clear and the wind light, the mixing layer is confined to a shallower layer than in the daytime and may be capped by a well-marked temperature inversion.

The flow properties are determined partly by the aerodynamic friction of the underlying surface and also by the density stratification of the atmosphere.

The changing state of the weather introduces variability into the ability of the atmosphere to advect, dilute, transform and remove pollutants. In general the atmosphere has a tremendous capacity for dispersion, but at certain times and locations this may be substantially curtailed. This depends on the stability of the atmosphere.

Stability of the atmosphere can be split into three categories associated with vertical temperature gradients:

- Near-zero gradient - neutral stability;

- Lapse (decrease of temperature with height) – unstable;
- Inversion (increase of temperature with height) – stable;

These stability classes characterise the role of buoyancy forces in the flow. Neutral stability is characterised by the absence of significant buoyancy forces. Buoyancy forces in unstable conditions are destabilising such that if a fluid particle is displaced vertically, buoyancy forces act to increase the displacement. The opposite is true in the stable atmosphere. Buoyancy forces in the stable atmosphere are restoring such that if a particle is displaced vertically, buoyancy forces act to restore the particle to its original position.

The atmospheric boundary layer is constantly in evolution between these three states. The best conditions for pollutant dispersion usually occur in unstable conditions with a deep mixed layer. Unstable conditions are characteristic of sunny, daytime conditions, especially in summer.

Conversely, the worst conditions for dispersion occur when there is a low-level temperature inversion and the atmospheric boundary layer is stable. Stable conditions are the usual nocturnal situation, and are not conducive to vertical mixing because the buoyancy forces act to suppress vertical turbulent motion. Nocturnal boundary layers result from the cooling of the land surface. An inversion usually results at a height where turbulence is completely suppressed. The wind velocity below the inversion decreases and turbulence decays, resulting in non-diffusive conditions.

Within the atmospheric boundary layer there is a layer adjacent to the surface, where the shear stress may be regarded as approximately constant. This layer is known as the “surface stress layer” or “constant stress layer”. The vertical fluxes of momentum, heat and moisture are nearly constant in this layer.

The wind field in the boundary layer is largely controlled by the frictional drag imposed on the flow by the underlying rigid surface. The drag retards motion close to the ground and gives rise to a sharp decrease in mean horizontal wind speed as the surface is approached due to frictional drag.

The actual form of the wind variation with height under neutral conditions (neither stable nor unstable conditions) has been found to be described by a logarithmic form [77]:

$$U(z) = \left(\frac{u_*}{\kappa}\right)\ln\left(\frac{z}{z_0}\right) \tag{3.1}$$

where:

U(z) - mean wind speed at height z;

z_o - roughness length;

The log law has been extensively verified in the boundary layer, and typically applies up to a height of approximately 100 metres as well as in our case.

The logarithmic velocity distribution is consistent with an eddy length scale distribution, $L_t(z)$, which increases linearly with height. Fig.3.1 shows a typical log profile. Therefore as a diffusing cloud released from ground level grows it comes under the influence of larger and larger eddies. This process leads to “accelerated” diffusion in the sense that the effective diffusivity increases in time.

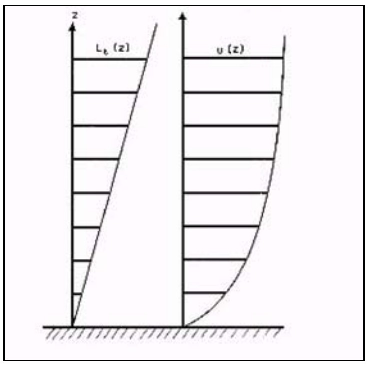


Fig.3.1. Schematic illustration of the idealised velocity and eddy length scale variations with height [77]

Effects of topography on mean flow and turbulence. Terrain has an important effect on dispersion. Both by directly influencing the dispersion characteristics of individual plumes and their path of migration.

Obstacles such as uneven ground level affect the path of a plume in two ways. Firstly, a plumes average trajectory is deflected as an obstacle is approached. Secondly, there is also the effect of the flow disturbance on the intensity of turbulence, which affects the rate of spread of the plume and the distance at which contact with ground level occurs.

The characteristics of airflow over non-uniform terrain are not easily generalised. Different shapes and obstructions create unique perturbations to the flow pattern. It is, however, possible to describe some typical flow patterns around specific features.

Flow over a flat surface is usually smoothed adjacent to the surface. However, it is possible for the flow to become separated from the surface if it passes over a sudden discontinuity thereby generating additional local turbulence.

Moderate topography (with slopes up to about 17°) usually allows the boundary layer to adjust without separation while for slopes exceeding about 17°, flow separation can occur. Separation from the top and both sides of a hill produces unsteady lee eddies. Therefore, in the immediate lee of the hill the wind direction near the surface may be counter to the general flow (i.e. upslope) and speeds are considerably reduced. The turbulent wake of the hill extends downstream for a considerable distance.

3.2. Dispersion model AERMOD

Dispersion model is required to formulate the odour concentration predictions. Odour dispersion models have to meet an unordinary requirement: odour impact is reflected by a peak concentration rather than a hourly mean concentration and odour exposure is reflected by a percentile of concentration rather than a long-term-averaged concentration.

In this study the AERMOD dispersion model was employed, since some of its chief features are particularly suitable for H_2S impact assessment. The main reasons for selection AERMOD are:

- The main algorithm of AERMOD implements is popular Gaussian-plume dispersion model that allows the right treatment of calm wind and weak wind conditions;
- Dispersion can be modeled from point sources as it is required in this study;
- Where appropriate, a plume is modeled as either impacting and/or following the terrain;
- In the stable boundary layer, the concentration distribution is assumed to be Gaussian in both the horizontal and the vertical;
- For each reception point the peak concentration of H_2S concentration in ppm can be defined;
- Dispersion modeling can be provided in more then 4 km radius from source.

American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee (AERMOD) is an update of the widely used regulatory model, ISC3. ISC3's input/output formats were retained, but the ISC3 algorithms were updated with new state-of-the-art modelling techniques. Additional functions, such as the incorporation of a complex terrain module, where also added. The end result was a dispersion model with two pre-processors, one for meteorology, AERMET, and the other for characterising the terrain named AERMAP.

One of the basic inputs to AERMOD is the runstream setup file which contains the selected modeling options, as well as source location and parameter data, receptor locations, meteorological data file specifications, and output options. Another type of basic type of input data needed to run the model is the meteorological data. AERMOD requires file, that is provided by the AERMET meteorological preprocessor program. This file consists of meteorological data, such as temperature, wind speed, direction and etc. These meteorological data files will not be described in this work. Pre-processor AERMET was not applied in this work. Modelling results were provided in map, designed by SURFER™ program [78].

AERMOD is a steady-state plume model. In the stable boundary layer, the concentration distribution is assumed to be Gaussian in both the horizontal and the vertical. In convective conditions (Unstable boundary layer), the horizontal concentration distribution is assumed to be Gaussian, but in the vertical AERMOD uses atmospheric boundary layer scaling to describe the distribution with a bi-Gaussian form. AERMOD also tracks any plume mass that penetrates into the elevated stable layer, and then allows it to re-enter the boundary layer when and if appropriate.

AERMOD models complex terrain, and where appropriate, a plume is modelled as either impacting and/or following the terrain. AERMOD caters for point, area and volume sources. AERMOD is a steady-state, plume model. That is, it is designed to apply to source releases and meteorological conditions that are assumed to be steady over individual modeling periods. AERMOD has been designed to handle the computation of pollutant impacts in flat and complex terrain within the same modeling framework. In fact, with the AERMOD structure, there is no need for the specification of terrain type (flat, simple, or complex) relative to stack height since receptors at all elevations are handled with the same general methodology. To define the form of the AERMOD concentration equation, it is necessary to simultaneously discuss the handling of terrain.

AERMOD incorporates, with a simple approach, current concepts about flow and dispersion in complex terrain. In very stable conditions, the flow, and hence the plume embedded in it, tends to remain horizontal as it encounters a terrain obstacle. Generally, in stable flows, a two-layer structure develops in which the lower layer remains horizontal while the upper layer tend to rise over the terrain. These layers are distinguished by the concept of a dividing streamline. In neutral and unstable conditions, the lower layer disappears and the entire flow (with the plume) tends to rise up and over the terrain. Associated with this is a tendency for the plume to be depressed toward the terrain surface, for the flow to speed up, and for vertical turbulent intensities to increase.

AERMOD deals with the two-layer concept in the following way. The model assumes that the plume exists in two states and that the concentration at a receptor, located at a position (x,y,z), is the weighted sum of the two concentration estimates: one where the plume is horizontal (representing plume material below the dividing streamline) and the other where the plume travels over the terrain (representing plume material above the dividing streamline). In stable conditions, the horizontal plume "dominates" and is given greater weight while in neutral and unstable conditions, the plume traveling over the terrain is more important (heavily weighted). In flat terrain, the concentration equation reduces to the form for a single plume. The general form for the total concentration at any terrain elevation is [77] :

$$C_T(x,y,z) = f \cdot C(x,y,z) + (1-f) \cdot C(x,y,z_{eff}) \tag{3.2}$$

Where

f - the weighting factor related to the fraction of plume material that is below the height, H_c, of the dividing streamline,

C(*x,y,z*) - the flat-terrain concentration equation appropriate for given stability conditions (defined in subsequent sections),

z - the height of the receptor (this includes the height above local terrain),

z_{eff} - an "effective" receptor height (which is equal to *z* in flat terrain).

The first term on the right-hand side of equation (3.2) represents the contribution from the horizontal plume and is evaluated at a receptor height, *z*, while the second represents the contribution from the plume adjusted by terrain and is evaluated at an effective receptor height.

The weighting factor, *f*, is a function of the fraction of plume mass that is below H_c at the downwind distance of the receptor.

The form of the AERMOD concentration expression C(*x,y,z*) in eq. 3.2 that is appropriate for stable conditions (L > 0) in flat terrain (and is similar to that of ISC2) is the Gaussian expression:

$$C(x, y, z) = \frac{Q}{U} \cdot F_z(x, z, h_p) \cdot F_y(y) \qquad (3.3)$$

Where :

$$F_z = \frac{1}{\sqrt{2\pi}\sigma_z} \cdot \sum_{n=\infty}^{\infty} \left[\exp\left(-\frac{(z - h_p + 2nh_a)^2}{2\sigma_z^2} \right) + \exp\left(-\frac{(z + h_p + 2nh_a)^2}{2\sigma_z^2} \right) \right] \qquad (3.4)$$

And

$$F_y = \frac{1}{\sqrt{2\pi}\sigma_y} \cdot \exp\left[-\frac{y^2}{2\sigma_y^2} \right] \qquad (3.5)$$

In equations 3.4 and 3.5, plume dilution and plume spread are calculated using effective boundary layer variables, h_p is the plume height, σ_v and σ_w are discussed below, and h_a is the level where vertical mixing is limited (= MAX(h_p,h)) where h is the stable (mechanical) mixed layer height. h_p is equal to the stack height plus plume rise (Δh), where plume rise is:

$$\Delta h = 2.66 \cdot \left[\frac{F_b}{N^2 U} \right]^{1/3} \cdot \left[\frac{0.7 \cdot N \cdot F_m}{F_b} \cdot \sin\left(\frac{0.7 \cdot N \cdot x}{u} \right) + 1 - \cos\left(\frac{0.7 \cdot N \cdot x}{u} \right) \right] \qquad (3.6)$$

Where

x is downwind distance,

N is the Brunt-Vaisala frequency, given by

$$N = \left(\frac{g d\theta}{\theta dz} \right)^{1/2}; \qquad (3.7)$$

and θ is potential temperature. Wind speed, u, and N are evaluated at stack height (subject to change after development evaluation). The plume buoyancy flux, F_b, and momentum flux, F_m, are functions of stack parameters and ambient temperature. Equation (3.7) applies while the plume is rising. Weil^0 defines the distance, x_{max}, to final rise.

The plume dispersion parameters, σ_y and σ_z, are given by the familiar formulas:

$$\sigma_y = MAX\left[\frac{\sigma_v \cdot x}{U}, 0{,}1 \cdot x \right]; \qquad (3.8)$$

and

$$\sigma_z = \frac{\sigma_w \cdot x / U}{\left(1 + t / 2T_{Lz}\right)^{1/2}}; \qquad (3.9)$$

where t is plume travel time (x/U) and T_Lz is the Lagrangian integral time scale. Note that the values of σ_v, σ_w, U, and T_Lz used in equations 3.9 are effective values representative of the layer over which the plume is diffusing .

3.3. Dispersion modelling input and output data

Source type specification. In dispersion models, sources can typically be modelled as point, area, line or volume sources. As the measurements were provided in 45 points and they covers all landfill's filling area, the H_2S dispersion was modeled as an point source. Another reason to provide modeling from point sources was that the results of measurement in different landfill area varies 1- 3 ppm. Emissions from point and area sources are modeled with different algorithms and differences in predicted concentrations can arise and errors can be achieved.

It was decided to run Simulations for a single point sources and for weather data characteristic of neutral and stable atmospheric conditions.

Exit velocity and mass emission rate. The parameters that need to be determined in order to characterize the source are the mass emission rate (mass per unit time) and the volume flow rate (volume per unit time). The mass emission rate divided by the volume flow rate is the source concentration (mass per unit volume).

The volume flow rate is equal to the area of the source multiplied by the emision exit velocity:

$$Q = V*A \qquad (3.10)$$

where :

Q - Volume flow rate (m^3/s);

V - Exit velocity (m/s);

A - Area of source (m^2).

In order to run a dispersion model it is necessary to provide a value for the emission exit velocity for which no measurements were available, except Gas No.1 and Gas No. 2 monitoring wells. In these points were provided detail exit velocity and temperature measurements. Also, the diameter of these monitoring wells was measured.

All other 45 measurement points were specified as unorganized pollution sources. The parameter needed to characterize the source for modelling purposes is the strength or rate of emission of material from the source (units of mass per unit time). This parameter could not be determined from the sampling carried out the value of this parameter therefore needed to be calculated theoretically or estimated. The Lithuanian Government [79] have prepared a document recommending methods of estimating emission rates from a wide variety of sources and for a wide variety of applications. The mass emission rate for the unorganized pollution sources needed to be assumed for 45 measurement points. For convenience the value of the total exit emission was assumed to be 5 m/s. Given that the diameter of this type of sources is 0,2 m, volume flow rate equates to 1 m^3 /s, with the condition that temperature in these sources are 0^oC. As the H_2S concentration is determinated in all measurement points (in ppm), the mass emission rate can be obtained. Gas No.1 and Gas No. 2 diameters are 0,3 m, volume flow rate equates to 1,5 - 2,1 m^3 /s. Since mass is conserved, the predicted concentrations downstream of the source simply scale in proportion to the mass emission rate.

Model setup. The main aim of dispersion modeling is to estimate, how odour diffuses in landfill surrounding area and residential or working area. Various options are available in AERMOD, many of which were not applied for H_2S dispersion modeling. It is also only possible to run certain options in combination, which limits the scope in some cases.

Dispersion modeling was provided in boundary two-dimensional. Girded system with receptors up to 2000 m from the landfill to all sides were set with the steps equal to 100 m. Terrain roughness coefficient in this Lithuanian region is equal to 164. To all point sources x and y coordinates were set from local system of coordinates. As the modeling was provided to H_2S odorant, the coefficient, that describes characteristics of gas substances is equal to 1.

Meteorological input date. The dispersion modeling was run due to the different meteorological conditions, that were chosen ore set during measure period and that depends from season of the year. These conditions are weather temperature, wind direction and wind speed, provided in AERMET file.

Output date. SURFER™ was used for the graphics output of dispersion modeling. SURFER™ is a contour and 3D surface plotting software package produced by Golden Software. SURFER™ takes columns of data in x, y, z format (x and y being co-ordinates and z being a variable such as height or concentration), interpolates the data and then creates a plot. SURFER™ also has it's own scripting program, so that tasks can be automated.

A contour map of the landfill has been constructed in SURFER™. The map can be digitised in SURFER™ allowing the user to identify the location of the point sources using a pointing device (e.g. mouse). In such way the x and y coordinates of point sources were estimated and saved to a file. The coordinates are then written to the AERMOD input file. Once AERMOD has run, output file is created, containing the concentration at each girded receptor point. This AERMOD's output file needs to be processed into a format that SURFER™ is familiar with. A script has been written to create contour plots of concentration from the processed AERMOD output data. These result are provided in 3.4 section.

3.4. Results of dispersion modelling

The modeling of H_2S dispersion from Jerubaiciai landfill was based on the results received from the measurements. The main aim of this modeling was to predict the way of H_2S spread from landfill's waste dispose section to the territory, that surrounds landfill in 2 km radius. Also dispersion modeling was provided to predict the way of H_2S spread during different time of the year and under different wind speed and air temperature.

The results of dispersion modeling are provided in contour map. In the left side of them is provided Y coordinates with relevant scale, in the bottom of it coordinates with relevant scale. Shown on the right of the contour plot, is the wind speed and direction for the particular run. The arrow depicting the direction of the wind is rotated clockwise relative to the direction of north as shown. The scale bar shows the scale used for the color scheme in the contour plot.

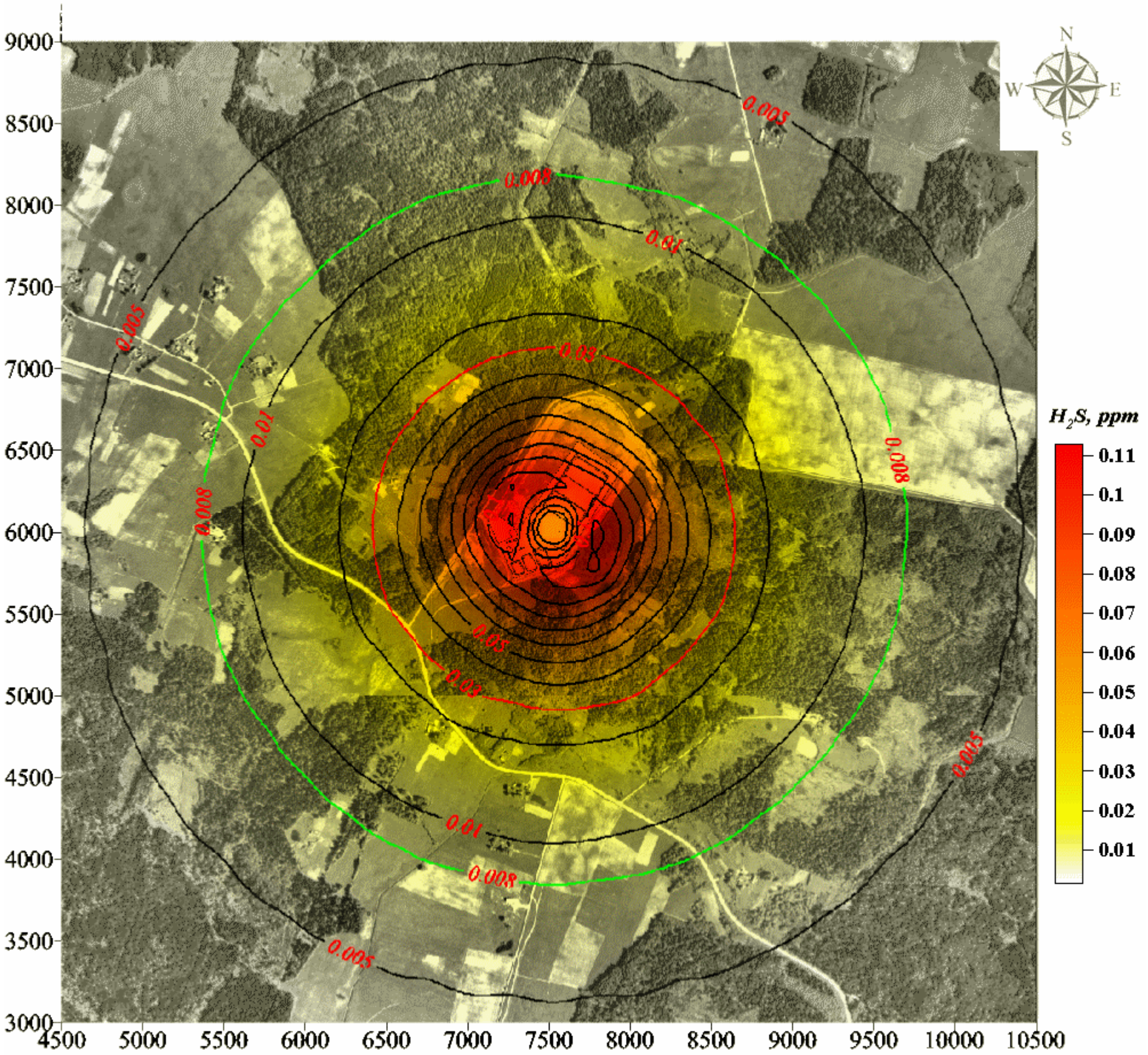


Fig. 3.2 H_2S dispersion from Jerubaiciai landfill, under calm weather conditions in August (Wind speed 0.5 m/s)

Results of H_2S dispersion modeling, under August meteorological conditions is provided in Fig. 3.2. For the dispersion modeling was used results of measurements, provided during this moth. The aim of this modeling was to determinate the spread way of odour under calm summer weather conditions (Air temperature +20 ^{o}C, wind speed 0,5 m/s, wind direction is not indicated). From the results, provided in this figure, is clear, that in the regions, that are in 100-150 distance from the landfills dispose section, the H_2S concentration is more then 0,9 ppm. The Highest Allowable Concentration (HAC) in residential areas for H_2S, that is defined in Lithuanian legislations [80], is reached only in 2 km distance from the landfill territory. There and further the concentration is less the 0.008 ppm. The beginning of this area in contour map is presented as green line. Attention should be paid at the territory, of this beginning, that is marked with red line. Houses of the nearest to landfill residents are situated in this area and the H_2S concentration varies from 0,4 ppm to 0,2 ppm. Here H_2S concentration is almost 50 times higher then Highest Allowable Concentration. Odour control tools should be installed in landfill territory to improve this situation.

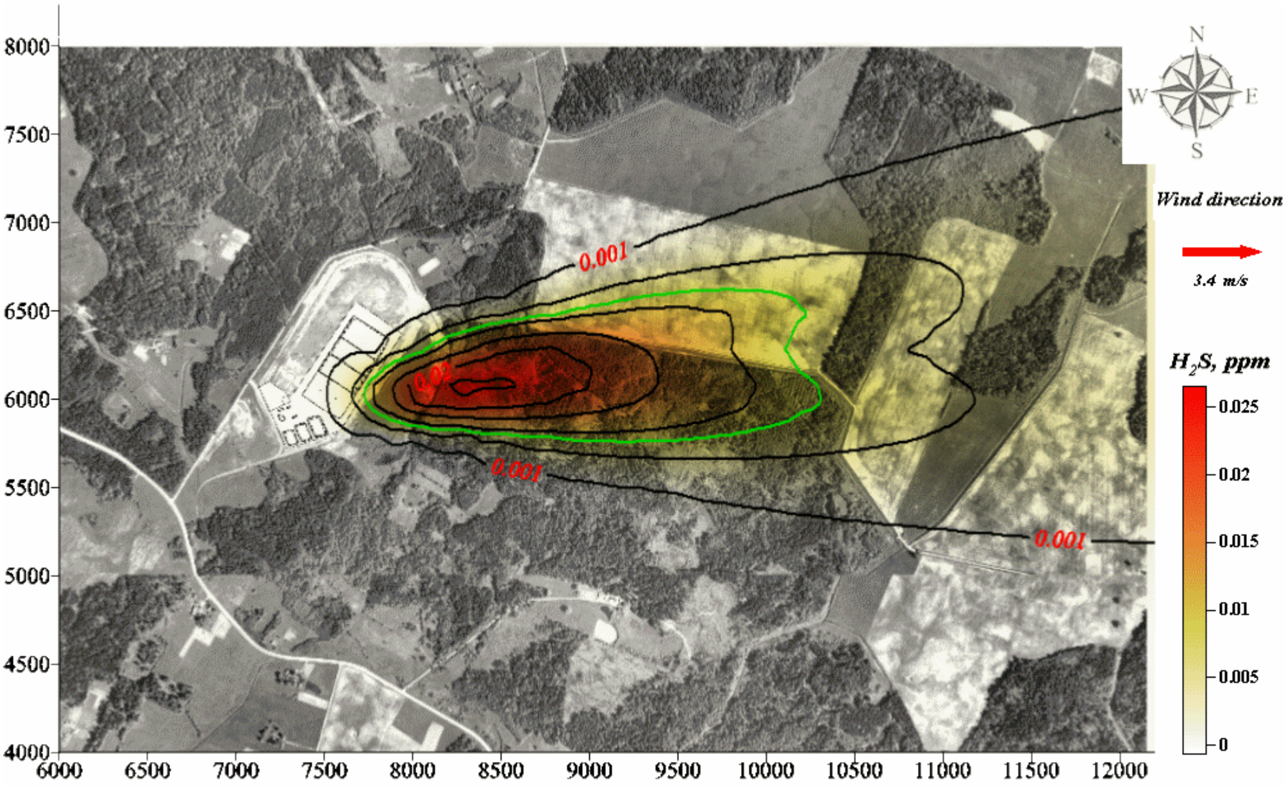


Fig.3.3 H_2S dispersion from Jerubaiciai landfill in August (Wind blows from West, wind speed 3.4 m/s)

As the wind rose shows, the prevailing winds in summer is from west with average speed of 3,4 m/s. Dispersion modelling results, submitted in Fig 3.3 shows, that the centre of highest H_2S concentrations is in 800 m distance from landfill cell. Here H_2S concentration reaches 0.025 ppm level. No residential areas are situated in the area, where H_2S concentration is higher then allowable HAC. Area, where H_2S concentration is less then 0.008 ppm, starts in 1.5 km distance to the east from the highest H_2S concentration area. The beginning of this area is presented as green line. The concentration of H_2S in nearest residential area and in landfill area is less then 0.001 ppm under such meteorological conditions.

As the nearest residential area is situated to the west from landfill territory, dispersion model was provided under such conditions, that wind blows from the east with prevailing summer average speed equal to 3.4 m/s. The results of such numerical modelling are provided in Fig.3.4.

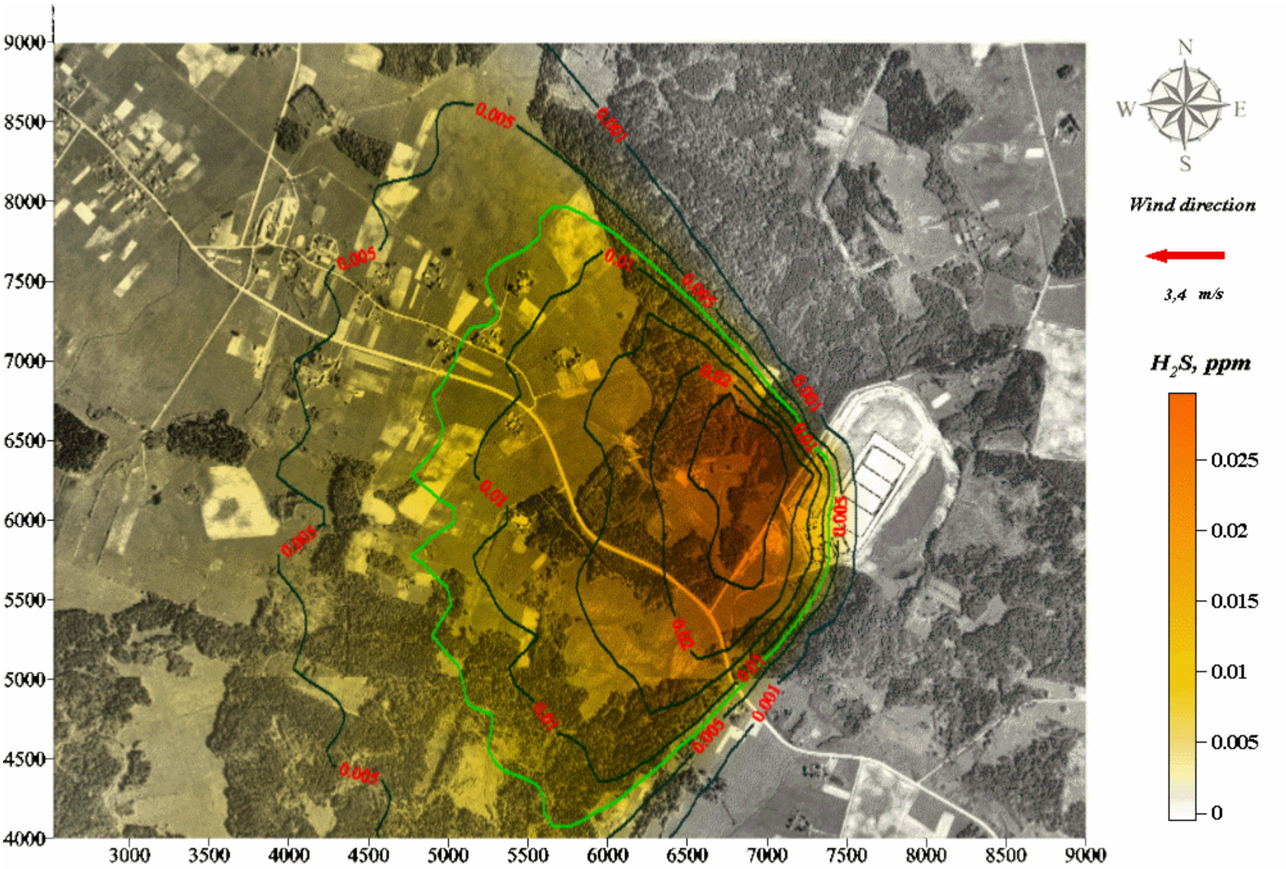


Fig.3.4 H_2S dispersion from Jerubaiciai landfill in August (Wind blows to residential area, wind speed 3.4 m/s).

The centre of highest H_2S concentrations is in 800 m distance from landfill cell. Here H_2S concentration reaches 0,03 ppm level. Nearest residential areas are situated exactly in this area. Here H_2S concentration is almost 3,5 higher then allowable HAC and this area covers other 3 houses that are in 2 km distance from landfill. Area, where H_2S concentration is less then 0,008 ppm, starts in 1,5 km distance to the west from the highest H_2S concentration area. The beginning of this area is presented as green line.

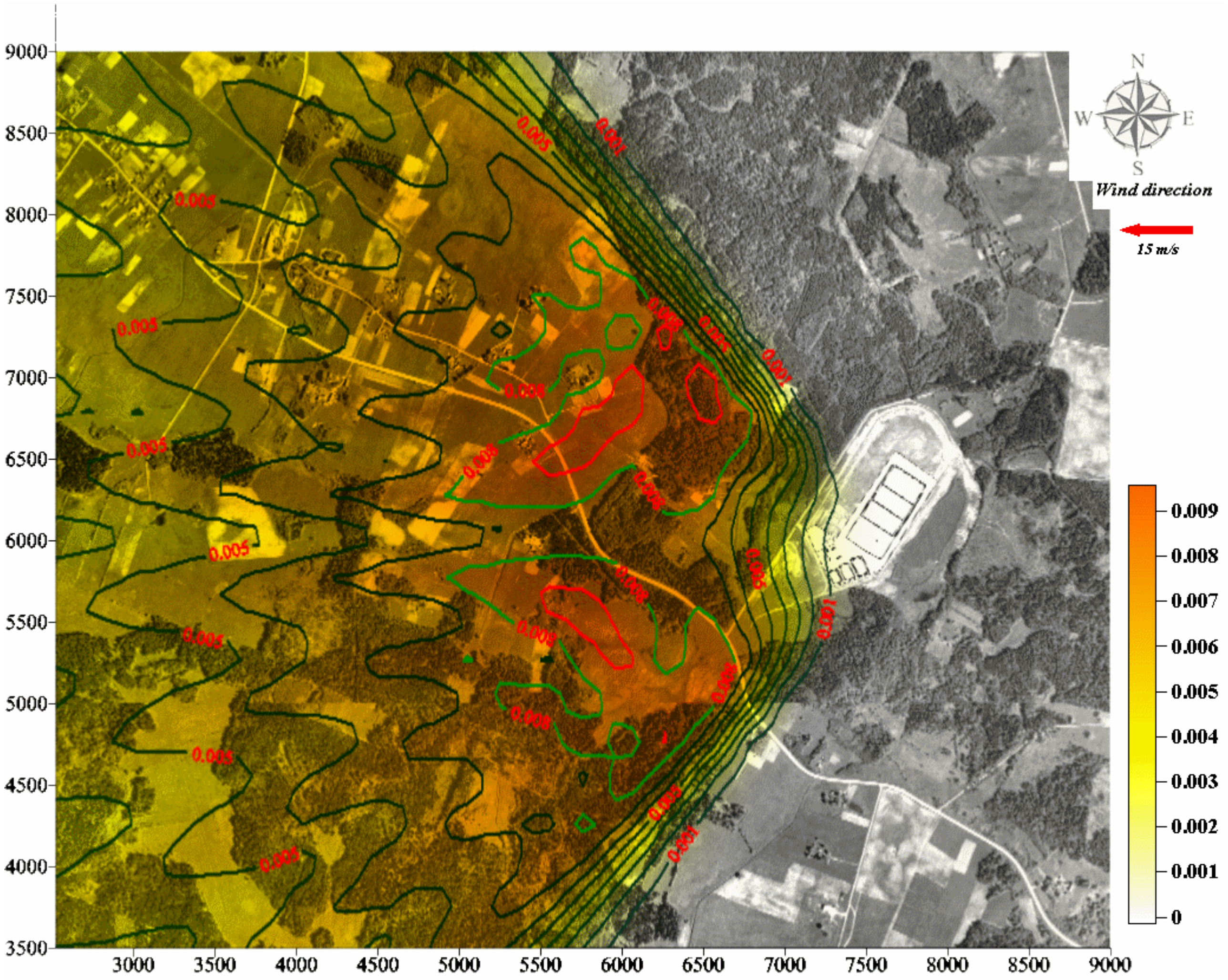


Fig.3.5 H_2S dispersion from Jerubaiciai landfill in August under dangerous meteorological conditions (Wind blows to residential area, wind speed 15 m/s)

In this region there are sometimes local squalls and vortexes, when the wind speed becomes 32-35 m/s. Dispersion model was provided under extreme meteorological conditions, then wind blows from the east with speed equal to 15 m/s. The results of H_2S dispersion are submitted in Fig . 3,5. From the results, provided in this figure, is clear, that H_2S concentration less ten 0,005ppm spreads in almost 5 km from landfill site. The centre of highest H_2S concentrations is in 1.5 km distance from landfill cell. The area, where H_2S concentration is less then 0,008 ppm, starts in 1 km distance to the west from the landfill and continues to all sides.

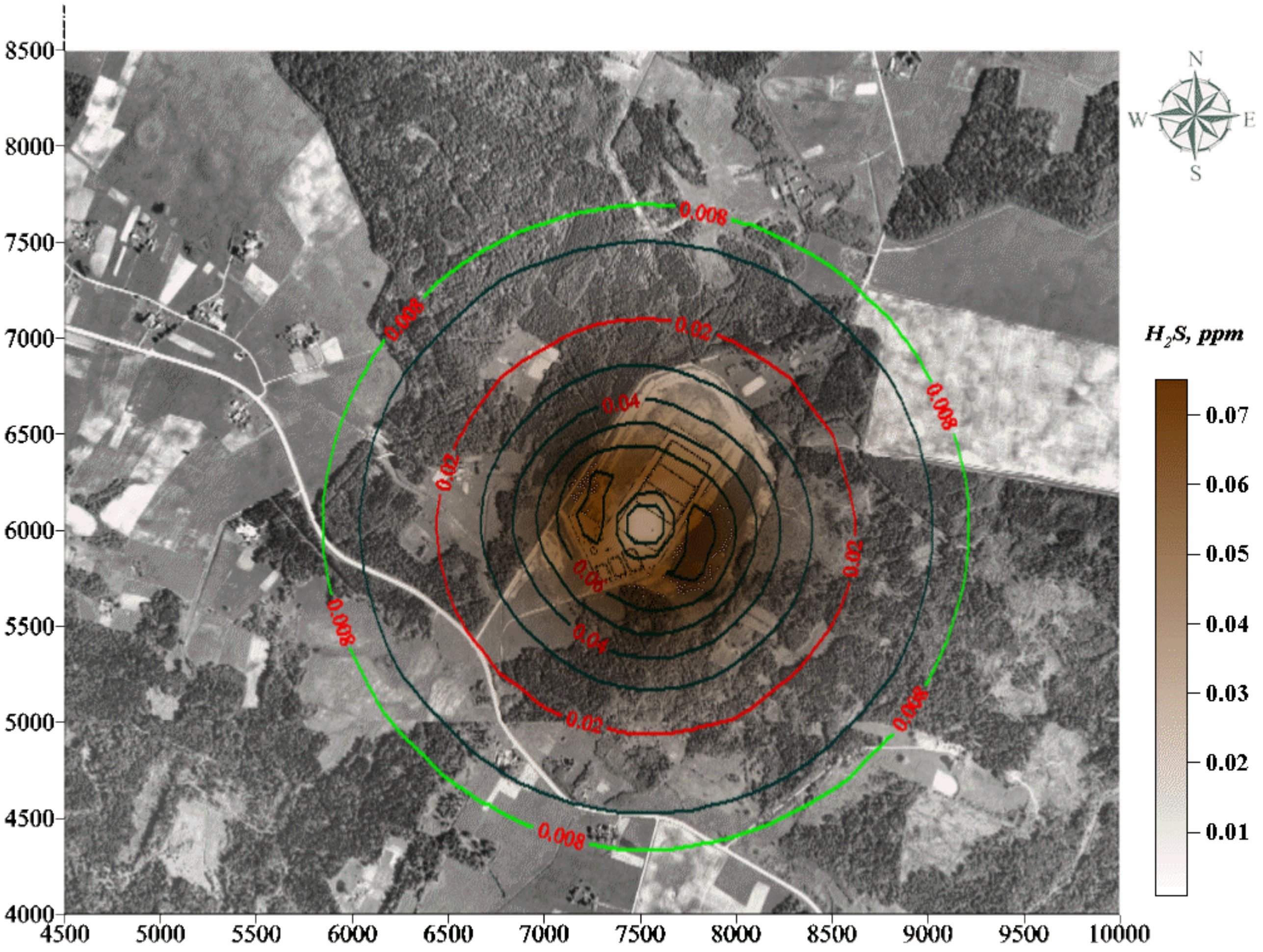


Fig 3.6. H_2S dispersion from Jerubaiciai landfill, under calm weather conditions in November (Wind speed 0.5 m/s)

Results of H_2S dispersion modeling, under November meteorological conditions is provided in Fig. 3.6. For the dispersion modeling was used results of measurements, provided during this moth. The aim of this modeling was to determinate the spread way of odour under calm autumn weather conditions (Air temperature +8 ^{o}C, wind speed 0.5 m/s, wind direction is not indicated). From the results, provided in this figure, is clear, that in the regions, that are in 100-150 distance from the landfills dispose section, the H_2S concentration is more then 0,06 ppm. HAC of H_2S is reached only in 1,5 km distance from the landfill territory. In this area and further the concentration is less the 0,008 ppm. The beginning of this area in contour map is presented as green line. Attention should be paid at the territory, of this beginning, that is marked with red line. Houses of the nearest to landfill residents are situated in this area and the H_2S concentration varies from 0,03 ppm to 0,01 ppm. Here H_2S concentration is almost 4 times higher then Highest Allowable Concentration. Odour control tools should be installed in landfill territory to improve this situation.

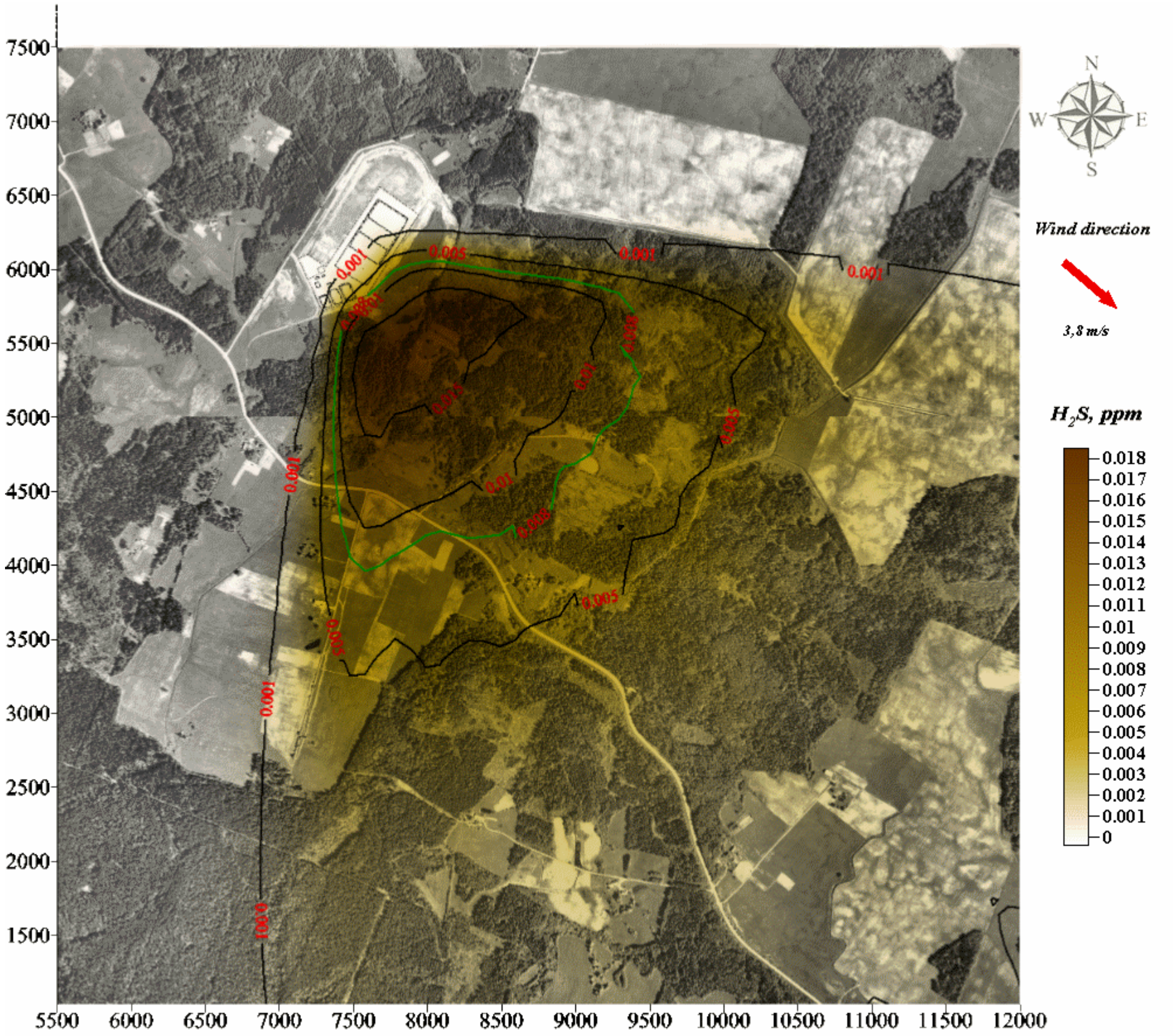


Fig.3.7 H_2S dispersion from Jerubaiciai landfill in November (Wind blows from North west, wind speed 3.8 m/s)

As the wind rose shows, the prevailing winds in autumn is from north west with average speed of 3,8 m/s. Dispersion modelling results, submitted in Fig 3.7 shows, that the centre of highest H_2S concentrations is in 500 m distance from landfill cell to south east. Here H_2S concentration reaches 0,018 ppm level. No residential areas are situated in the area, where H_2S concentration is higher then allowable HAC. Area, where H_2S concentration is less then 0,008 ppm, starts in 1.5 km distance to the north west from the highest H_2S concentration area. The beginning of this area is presented as green line. The concentration of H_2S in nearest residential area and in landfill area is less then 0.001 ppm under such meteorological conditions.

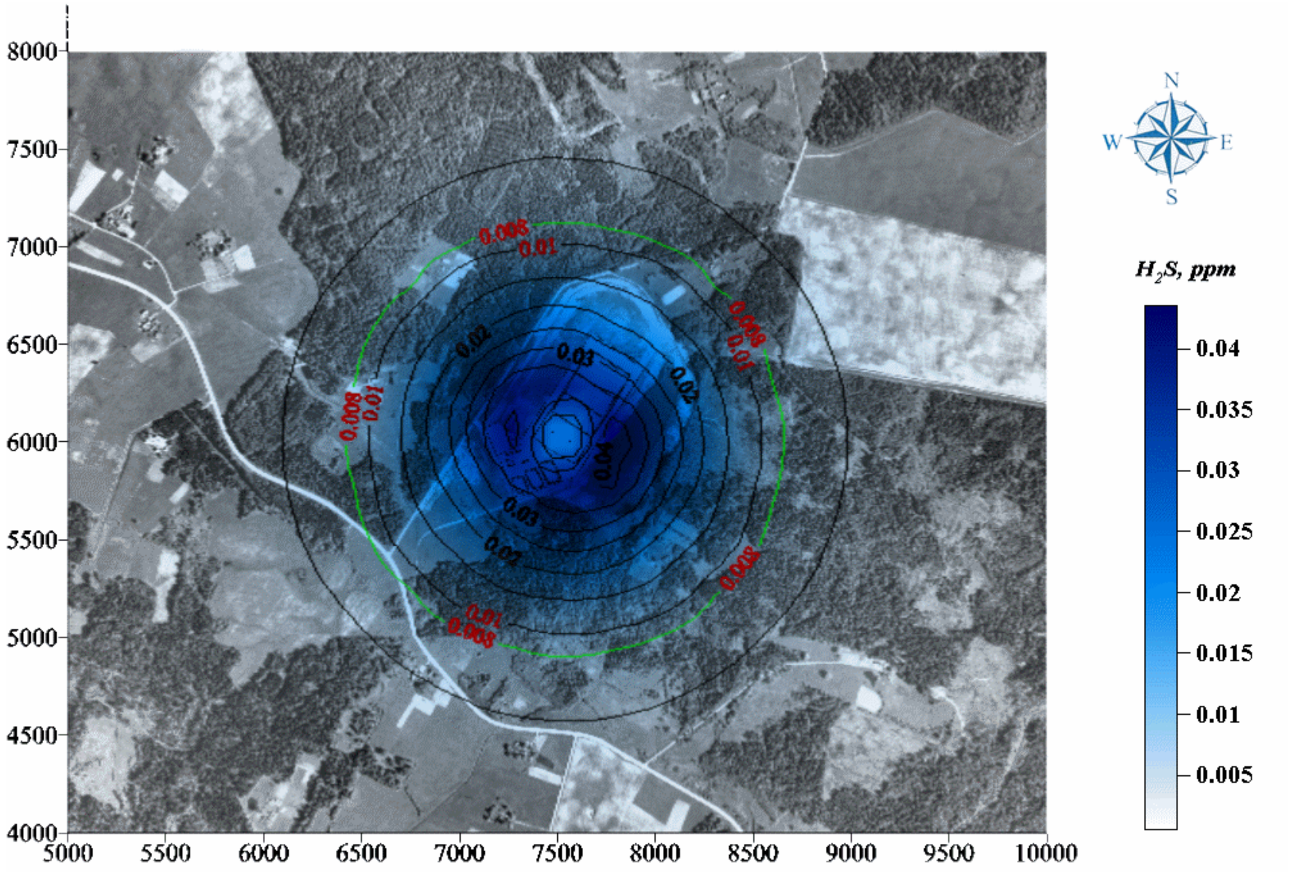


Fig.3.8 H_2S dispersion from Jerubaiciai landfill, with calm weather conditions in February (Wind speed 0.5 m/s)

Results of H_2S dispersion modeling, under February meteorological conditions is provided in Fig. 3.8. For the dispersion modeling was used results of measurements, provided during this moth. The aim of this modeling was to determinate the spread way of odour under cal winter weather conditions (Air temperature -6 oC, wind speed 0.5 m/s, wind direction is not indicated). From the results, provided in this figure, is clear, that in the regions, that are in 100-150 distance from the landfills dispose section, the H_2S concentration is more then 0,03 ppm. HAC of H_2S is reached only in 1 km distance from the landfill territory. In this area and further the concentration is less the 0.008 ppm. The beginning of this area in contour map is presented as green line. Attention should be paid at the territory. In the area of nearest to landfill residents he H_2S concentration varies from 0.01 ppm to 0.008 ppm. Here H_2S concentration is almost not higher then Highest Allowable Concentration.

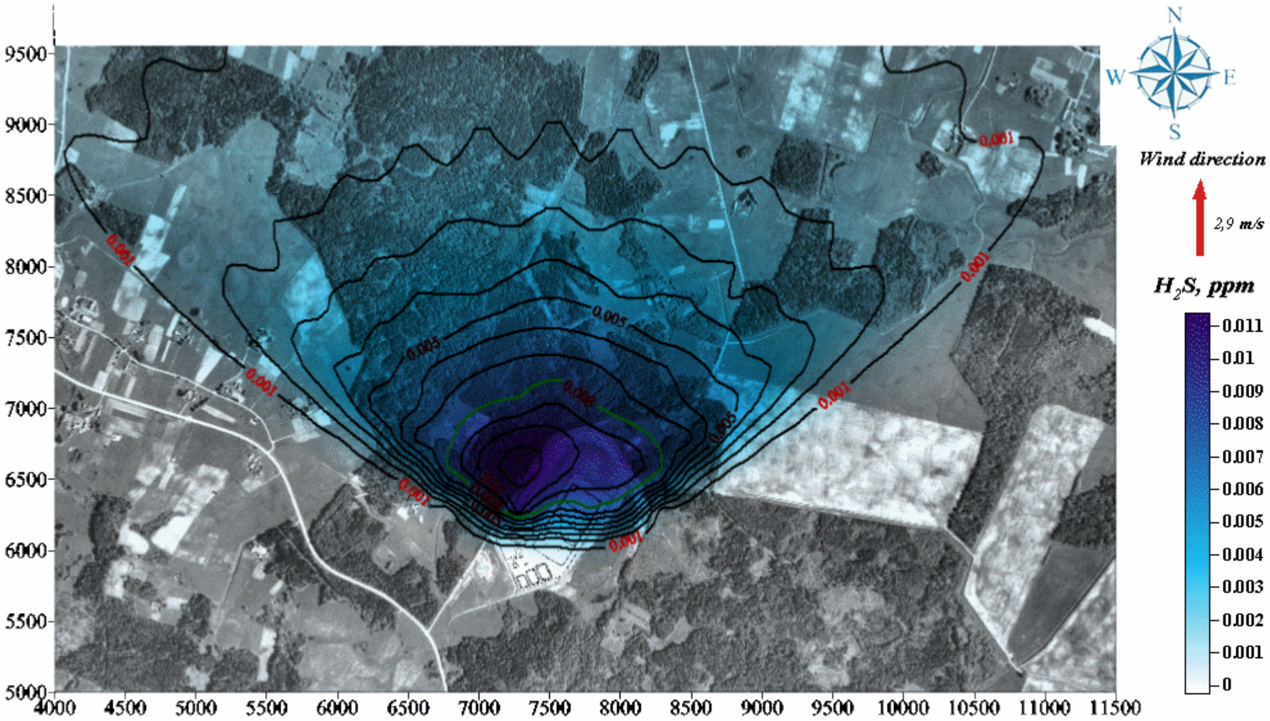


Fig.3.9 H_2S dispersion from Jerubaiciai landfill in February (Wind blows from South, wind speed 2.9 m/s)

As the wind rose shows, the prevailing winds in winter is from south with average speed of 2,9 m/s. Dispersion modelling results, submitted in Fig 3.9 shows, that the centre of highest H_2S concentrations is in 500 m distance from landfill cell to north west. Here H_2S concentration reaches 0.011 ppm level. Residential areas are situated in 50 m from there. Here H_2S concentration is not higher then allowable HAC. Area, where H_2S concentration is less then 0.008 ppm, starts in 500 m distance to the north from the highest H_2S concentration area. The beginning of this area is presented as green line.

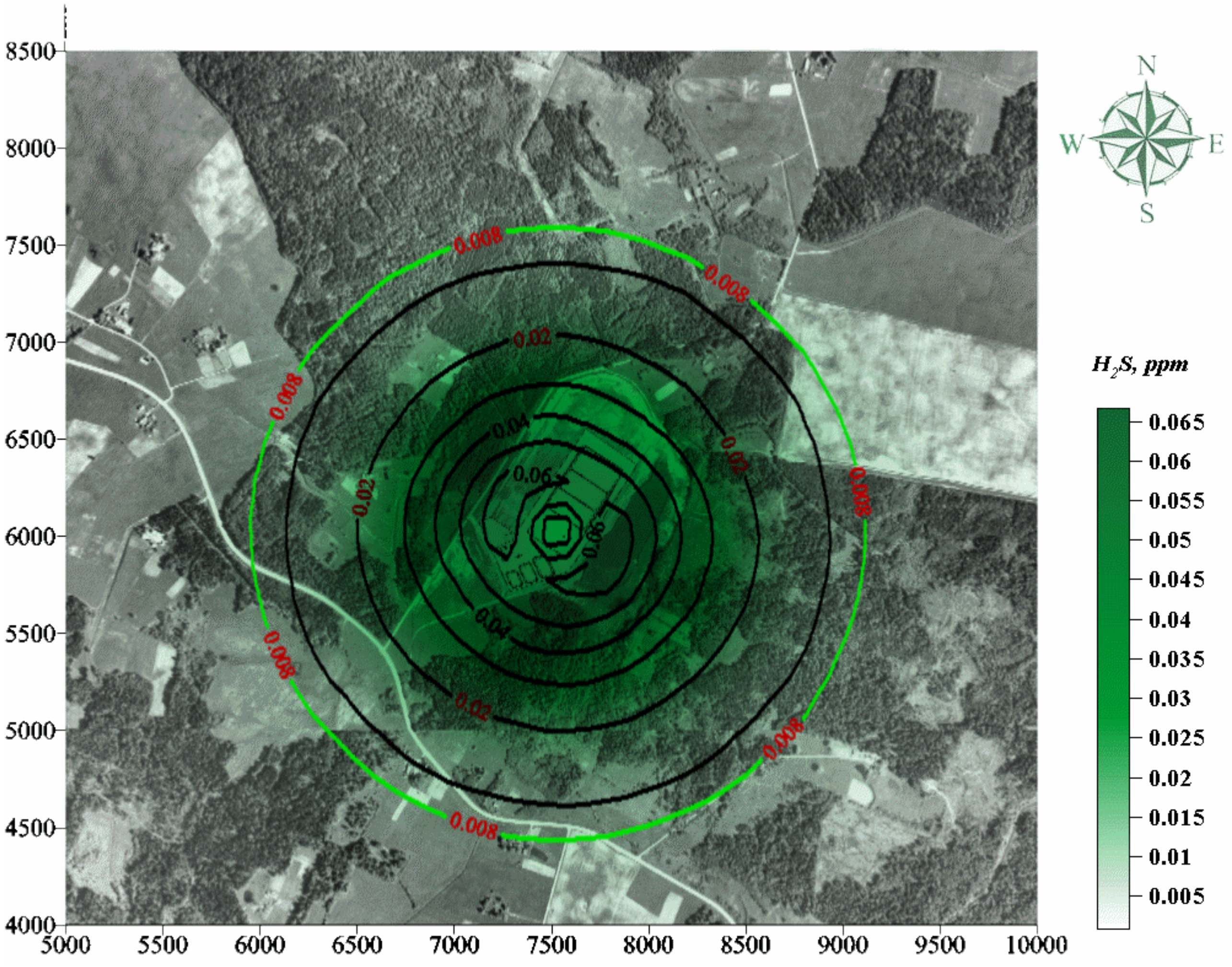


Fig.3.10 H_2S dispersion from Jerubaiciai landfill, with calm weather conditions in April (Wind speed 0.5 m/s)

Results of H_2S dispersion modeling, under April meteorological conditions is provided in Fig. 3.10. For the dispersion modeling were used results of measurements, provided during this moth. The aim of this modeling was to determinate the spread way of odour under cal springweather conditions (Air temperature +4 °C, wind speed 0.5 m/s, wind direction is not indicated). From the results, provided in this figure, is clear, that in the regions, that are in 100-150 distance from the landfills dispose section, the H_2S concentration is more then 0.06 ppm. HAC of H_2S is reached only in 1.5 km distance from the landfill territory. In this area and further the concentration is less the 0.008 ppm. The beginning of this area in contour map is presented as green line. Attention should be paid at the territory, of this beginning, that is marked with red line. Houses of the nearest to landfill residents are situated in this area and the H_2S concentration varies from 0.03 ppm to 0.01 ppm. Here H_2S concentration is almost 4 times higher then Highest Allowable Concentration. Odour control tools should be installed in landfill territory to improve this situation.

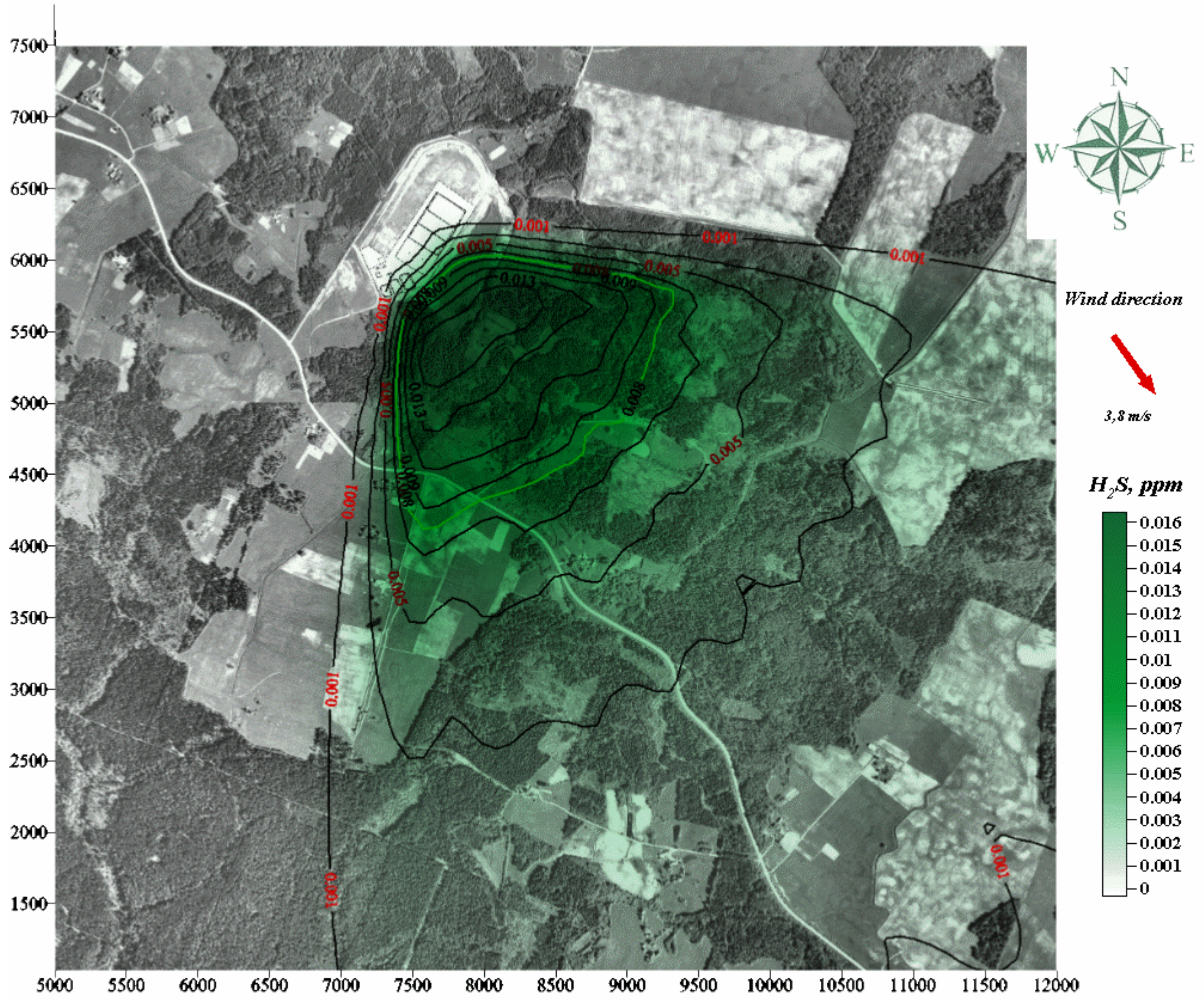


Fig.3.11 H_2S dispersion from Jerubaiciai landfill in April(Wind blows from north west, wind speed 3.8 m/s).

As the wind rose shows, the prevailing winds in spring is from north west with average speed of 3,8 m/s. Dispersion modelling results, submitted in Fig 3.11 shows, that the centre of highest H_2S concentrations is in 500 m distance from landfill cell to south east. Here H_2S concentration reaches 0.016 ppm level. No residential areas are situated in the area, where H_2S concentration is higher then allowable HAC. Area, where H_2S concentration is less then 0.008 ppm, starts in 1.5 km distance to the north west from the highest H_2S concentration area. The beginning of this area is presented as green line. The concentration of H_2S in nearest residential area and in landfill area is less then 0.001 ppm under such meteorological conditions.

From modelling results is clear, that the H_2S concentration near residential areas is higher then Highest Allowable Concentration. Especially this problem is actual in Summer time.

Operational procedures at a landfill can play a major role in odour minimization. Daily operations at Jerubaiciai landfill can help to minimize the odour emanating from the landfill, are:

- A gas collection/transportation system is in gas flaring facility.

- Determination of leachate collection and disposal problems;
- Final covering of old waste section;
- The daily covering of waste prior to closure of the landfill.

One area of operational strategy of particular relevance is the covering of fresh waste. Cover of recently placed material is a simple and effective way of minimising odour from the working face. The following are important factors to consider regarding cover material :

- Cover should be applied at least once a day (usually at the end of each working day) but it may be beneficial to cover more than once a day. For instance cover could be applied before lunch at midday and then again at the end of the working day.
- Cover material should have an average particle size that is small enough to create an effective barrier against odour emissions escaping into the atmosphere. For instance, builder's rubble or demolition material is typically not good enough to use as cover material as it has a high porosity.
- The depth of cover should also be substantial enough to minimize escape to the atmosphere. Regulations around the world require a minimum of 15 cm of cover.

If all these devices will be implemented, the H_2S concentration can decrees about 70 %.

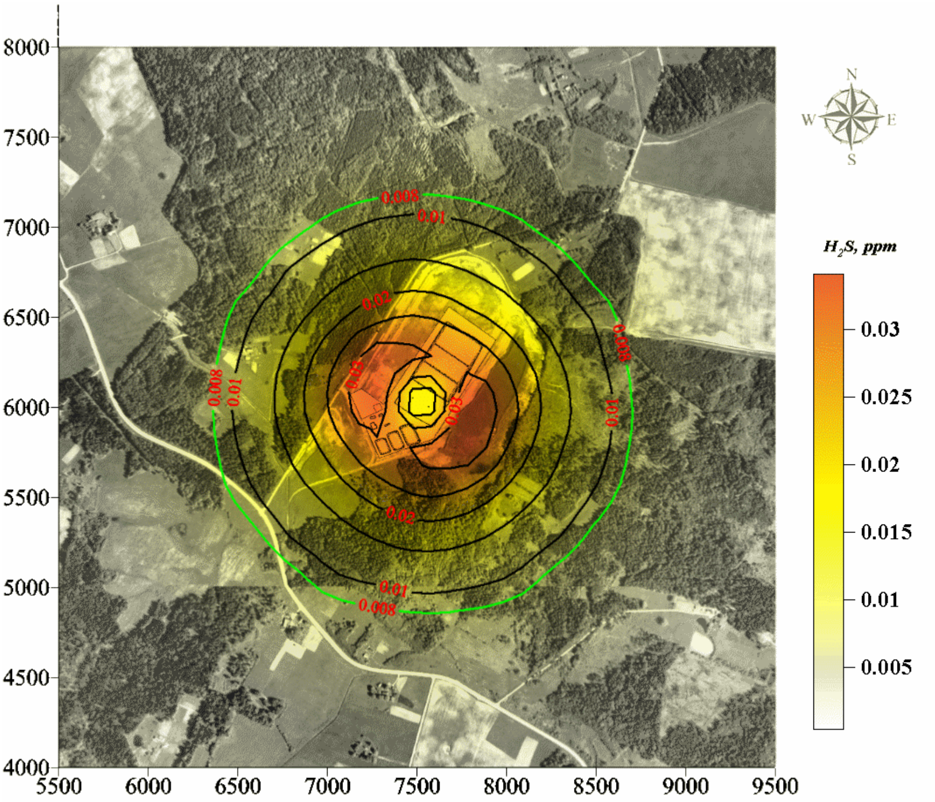


Fig.3.12 H_2S dispersion from Jerubaiciai landfill in August , when odour control devices are applied

Dispersion modelling results, submitted in Fig 3.12 shows, that the highest H_2S concentrations in residential areas is not more then HCA, when all these devices are applied.

3.5.Conclusions

- To determinate H_2S spread and it's concentration in residential area, that is situated near Jerubaiciai landfill, the dispersion modeling should be provided.
- AERMOD dispersion model was employed, since most of its chief features are particularly suitable for H_2S impact assessment.
- The modeling of H_2S dispersion from Jerubaiciai landfill was based on the results received from the measurements. The main aim of this modeling was to predict the way of H_2S spread from landfill's waste dispose section to the territory, that surrounds landfill in 2 km radius.
- The results of dispersion modeling, provided under calm weather conditions, during different seasons of the year shows, that H_2S spreads from landfill in longest distances from landfill's section during summer (almost in distance equal to 2,5 km the H_2S concentration is higher then Highest Allowable Concentration (HAC)).In autumn and spring this distance is equal to 1.5 km, and in winter – 800 m.
- The results of dispersion modeling, provided under dominated wind speed and direction, during different seasons of the year shows, that the center of highest H_2S concentrations (0.025 ppm) is in 800 m distance to the east from landfill cell, in autumn and spring centre of highest H_2S (0.018 ppm and 0.016 ppm) concentrations is in 500 m distance from landfill cell to south east, in winter the centre of highest H_2S concentrations (0.011ppm) is in 500 m distance from landfill cell to north west.
- Under dominated wind speed and direction, H_2S concentration in residential area is almost 4 times lower then estimated highest H_2S concentration during calm meteorological conditions.
- In nearest to landfill residential area, H_2S concentration in summer (almost 40 times), in autumn (4 times) and in spring (4 times) higher then Highest Allowable Concentration.
- Daily operations at Jerubaiciai landfill can help to minimise the odour emission from the landfill and guarantee that the highest H_2S concentrations in residential areas can be not more then Highest Allowable Concentration.
- Measurements, which were provided in the points that are situated in 25, 50 and 100 meters provided results, that the H_2S amount in these points is equal to 0-1 ppm in all time of the year. H_2S concentration, achieved by dispersion modeling in these points varies from 0.2- to 1 ppm in these points.

4. WORK CONCLUSIONS

- From the review of main types of negative impact on environment from landfill it was come to conclusion, that the generally landfill pollutes environment with leachate, landfill gas, in which the main attention should be paid to methane, and odurants compounds.
- As the biogas and leachate generation was word widely investigated before this work, it is not necessary to provide new researches on them. The measurements of Hydrogen Sulphide generation from landfill under Lithuanian climate conditions were not provided till this work.
- To evaluate the amount of Hydrogen Sulphide, that generates from landfill site is important to provide measures in different landfill areas, that is under proper operation, parallel providing measurements of environment parameters.
- For investigations on the impact to environment that goes from well operated landfill has to be chosen the household waste landfill, which installation and operation is due to EU and Lithuanian legislation. Jerubaiciai landfill in Plunge district almost matches such requirements.
- During measurement, that were provided in August, November, February and April the amount of hydrogen sulphide (H_2S) is different in the same measurement points. H_2S values in August is 2-3 ppm higher than in November and April and almost 5-6 ppm higher then in February, almost in all measurements points.
- The highest H_2S value was fixed in fresh waste tipping area. In this section odour generates due to waste discharged from trucks and the first operations with engines to lay out fresh wastes. The lowest H_2S value was fixed in area, where he thickness of waste layer hardly reaches 0,3 meter.
- The H_2S generation from top layer varies during day period and session of the year. It depends from the temperature of the air. The dependence between H_2S generation rate and air humidity or H_2S generation rate and atmospheric pressure were not determinated.
- As shows the measurement equipment GD/MG 7, the H_2S amount near residential areas is equal to 0 during all seasons of the year.
- The results of dispersion modeling achieved with dispersion model AERMOD, provided under calm weather conditions, during different seasons of the year shows, that H_2S spreads from landfill in longest distances from landfill's section during summer (almost in distance equal to 2.5 km the H_2S concentration is higher then Highest Allowable Concentration (HAC)).In autumn and spring this distance is equal to 1.5 km, and in winter – 800 m.

- The results of dispersion modeling, provided under dominated wind speed and direction, during different seasons of the year shows, that H_2S spreads that center of highest H_2S concentrations (0.025 ppm) is in 800 m distance to the east from landfill cell, in autumn and spring centre of highest H_2S (0.018 ppm and 0.016 ppm)) concentrations is in 500 m distance from landfill cell to south east, in winter the centre of highest H_2S concentrations (0.011ppm) is in 500 m distance from landfill cell to north west.
- Daily operations at Jerubaiciai landfill can help to minimize the odour emanating from the landfill and guarantee that the highest H_2S concentrations in residential areas can be not more then Highest Allowable Concentration.

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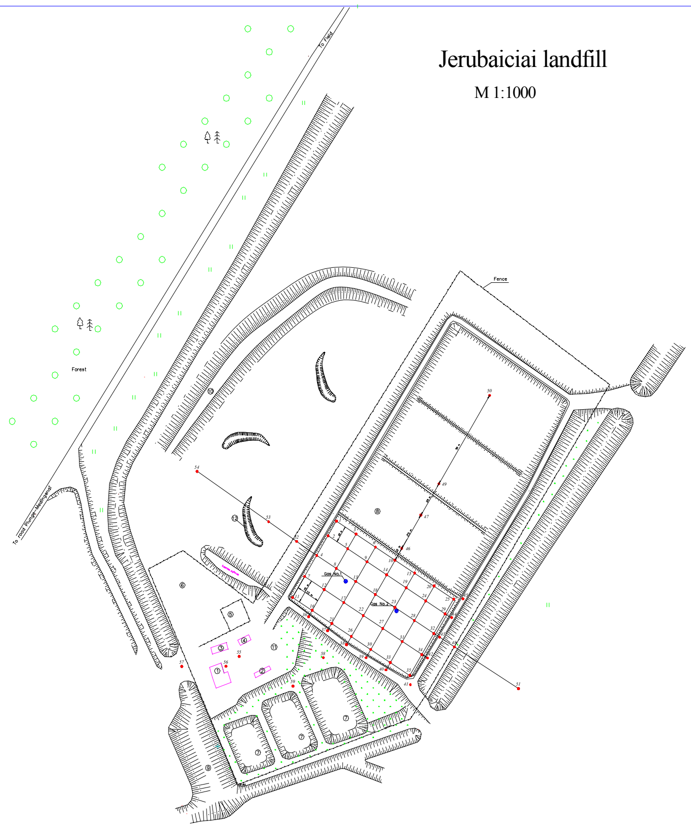
ANNEX 1

Jerubaiciai landfill

M 1:1000



LEGEND

- Fence
- Ditch
- ● Gas monitoring well
- ● measurement point

EXPLICATION

Position Number	Name
1	Service building and garage
2	Chemical treatment plants
3	Weighbridge
4	Wheels cleaning pit
5	Site for temprorary storing
6	Amenity site
7	Biological treatment ponds
8	Waste storing site
9	Fire pond
10	Stored soil
11	Container cleaning site
12	Pit

ANNEX 2

1. Results of measurements (20th, 21st, 22nd August)

Measurement No.	*Measurement points*											
	Gas 1	***Gas 2***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
1	7,0	8,3	7,6	7,2	7,3	7,4	7,7	7,6	7,5	8,0	8,1	7,2
2	7,5	8,9	7,3	7,5	6,8	7,2	7,3	8,0	7,2	7,8	7,9	6,7
3	7,6	8,7	7,4	6,9	6,7	7,9	8,0	7,2	7,4	7,3	7,8	6,7
Average value:	**7,4**	**8,6**	**7,5**	**7,2**	**6,9**	**7,5**	**7,7**	**7,6**	**7,4**	**7,7**	**7,9**	**6,9**

Measurement No.	*Measurement points*											
	11	12	13	14	15	16	17	18	19	20	21	22
1	5,4	6,7	7,8	7,5	7,3	5,4	7,6	7,7	7,1	5,7	6,7	6,9
2	4,9	6,3	7,9	7,8	6,7	5,4	6,8	7,3	6,7	6,2	6,3	7,2
3	5,7	6,7	8,4	8,3	6,6	5,7	6,9	8,0	6,8	6,4	6,7	6,8
Average value:	**5,3**	**6,6**	**8,1**	**7,9**	**6,9**	**5,5**	**7,1**	**7,7**	**6,9**	**6,1**	**6,6**	**7,0**

Measurement No.	*Measurement points*											
	23	***24***	***25,0***	***26***	***27***	***28***	***29***	***30***	***31***	***32***	***33***	***34***
1	6,6	6,1	7,8	6,9	6,0	6,1	7,6	7,2	6,6	6,9	6,9	6,7
2	6,8	6,3	7,8	6,7	6,1	6,5	7,7	6,4	6,3	6,7	6,7	5,8
3	6,6	6,4	7,2	7,3	6,7	5,9	7,5	6,9	6,6	6,4	6,9	6,1
Average value:	**6,7**	**6,2**	**7,6**	**7,0**	**6,3**	**6,1**	**7,6**	**6,8**	**6,5**	**6,7**	**6,9**	**6,2**

Measurement No.	*Measurement points*											
	35	***36***	***37***	***38***	***39***	***40***	***41***	***42***	***43***	***44***	***45***	***46***
1	6,9	5,3	5,9	6,3	7,5	8,3	7,8	7,3	6,9	7,4	7,1	6,5
2	6,7	5,0	5,4	5,7	6,7	7,4	7,4	7,0	6,7	7,2	7,4	6,4
3	6,4	5,4	5,4	5,8	7,3	8,0	7,4	7,3	6,4	7,3	7,2	6,1
Average value:	**6,7**	**5,2**	**5,6**	**5,9**	**7,2**	**7,9**	**7,6**	**7,2**	**6,7**	**7,3**	**7,2**	**6,3**

Measurement No.	*Measurement points*												
	47	***48***	***49***	***50***	***51***	***52***	***53***	***54***	***55***	***56***	***57***	***58***	***59***
1	1,5	5,4	1,7	1,6	1,3	3,7	0,7	0,6	2,2	1,6	1,1	5,9	5,4
2	1,4	5,6	1,0	1,7	1,5	3,8	0,5	0,7	2,2	1,7	1,5	6,7	5,0
3	1,3	5,4	1,9	1,6	1,2	3,8	0,9	0,6	2,1	1,6	1,5	6,6	5,2
Average value:	**1,4**	**5,5**	**1,9**	**1,6**	**1,4**	**3,8**	**0,9**	**0,6**	**2,2**	**1,6**	**1,4**	**6,4**	**5,2**

2. Results of measurements (5 th, 6 th , 7 th November)

Measurement No.	*Measurement points*											
	Gas 1	***Gas 2***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
1	5,5	7,6	4,9	4,6	4,6	4,7	4,9	4,5	4,7	3,7	5,1	4,6
2	5,9	8,1	4,1	4,4	4,3	4,6	4,6	4,7	4,6	5,0	5,0	4,3
3	5,2	8,5	4,2	4,4	4,2	5,0	5,1	4,6	4,7	4,3	5,0	4,2
Average value:	**5,5**	**8,1**	**4,4**	**4,5**	**4,4**	**4,8**	**4,9**	**4,6**	**4,7**	**4,3**	**5,0**	**4,4**

Measurement No.	*Measurement points*											
	11	12	13	14	15	16	17	18	19	20	21	22
1	3,4	4,3	5,0	4,8	4,6	3,4	4,8	4,9	4,5	3,6	4,3	4,4
2	3,1	4,0	5,0	4,9	4,2	3,4	4,3	4,6	4,2	3,9	4,0	4,6
3	3,6	4,2	5,3	5,2	4,2	3,6	4,4	5,1	4,3	4,1	4,2	4,3
Average value:	**3,4**	**4,2**	**5,1**	**5,0**	**4,4**	**3,5**	**4,5**	**4,9**	**4,3**	**3,9**	**4,2**	**4,4**

Measurement No.	*Measurement points*											
	23	***24***	***25,0***	***26***	***27***	***28***	***29***	***30***	***31***	***32***	***33***	***34***
1	4,2	4,2	5,0	4,4	3,5	3,8	4,8	4,5	3,8	4,4	4,4	4,2
2	4,6	4,0	4,6	4,2	3,9	4,1	4,9	4,0	3,6	4,2	4,2	3,9
3	4,2	4,4	4,5	4,6	4,2	3,7	3,8	4,4	4,2	4,1	4,1	3,8
Average value:	**4,3**	**4,2**	**4,7**	**4,4**	**3,9**	**3,9**	**4,5**	**4,3**	**3,9**	**4,2**	**4,2**	**4,0**

Measurement No.	*Measurement points*											
	35	***36***	***37***	***38***	***39***	***40***	***41***	***42***	***43***	***44***	***45***	***46***
1	4,3	3,3	3,6	3,8	4,6	5,1	4,8	4,5	4,3	4,2	4,4	4,0
2	3,8	3,1	3,3	3,5	3,8	4,2	4,2	4,3	4,1	4,1	4,5	3,9
3	3,9	3,3	3,3	3,5	4,5	4,9	4,5	4,1	3,9	4,5	4,4	3,7
Average value:	**4,0**	**3,2**	**3,4**	**3,6**	**4,3**	**4,7**	**4,5**	**4,3**	**4,1**	**4,2**	**4,4**	**3,9**

Measurement No.	*Measurement points*												
	47	***48***	***49***	***50***	***51***	***52***	***53***	***54***	***55***	***56***	***57***	***58***	***59***
1	1,8	3,1	1,7	1,0	1,1	2,4	0,7	1,0	1,4	0,7	0,7	3,7	3,1
2	1,1	3,6	1,9	1,1	0,6	2,1	0,9	1,1	1,4	1,1	1,0	4,2	3,2
3	1,7	3,4	1,9	1,0	1,0	2,4	0,9	1,0	1,3	1,0	0,9	4,2	3,3
Average value:	**1,9**	**3,3**	**1,8**	**1,0**	**0,9**	**2,3**	**0,8**	**1,0**	**1,4**	**0,9**	**0,9**	**4,1**	**3,2**

3. Results of measurements (25th, 26th, 27th February)

Measurement No.	*Measurement points*											
	Gas 1	***Gas 2***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
1	2,5	5,6	2,1	2,1	2,4	2,4	2,2	2,1	2,5	1,2	1,4	1,5
2	2,7	6,1	2,3	2,6	2,7	2,5	2,5	1,9	2,1	2,0	1,7	1,3
3	2,2	6,3	2,5	2,3	2,0	2,1	2,7	2,7	3,0	1,7	2,6	1,9
Average value:	**2,5**	**6,0**	**2,3**	**2,3**	**2,4**	**2,3**	**2,5**	**2,2**	**2,5**	**1,6**	**1,9**	**1,6**

Measurement No.	*Measurement points*											
	11	12	13	14	15	16	17	18	19	20	21	22
1	1,1	1,5	2,3	2,3	2,3	1,5	2,0	2,9	2,1	1,2	2,1	2,1
2	0,9	1,7	2,4	2,1	2,1	1,2	2,3	2,7	2,0	1,7	2,0	2,3
3	0,9	2,2	2,6	3,2	2,8	1,1	2,5	3,0	2,1	2,1	1,8	2,1
Average value:	**1,0**	**1,8**	**2,4**	**2,5**	**2,4**	**1,3**	**2,3**	**2,9**	**2,1**	**1,7**	**2,0**	**2,2**

Measurement No.	*Measurement points*											
	23	***24***	***25,0***	***26***	***27***	***28***	***29***	***30***	***31***	***32***	***33***	***34***
1	2,1	2,1	2,4	2,1	2,5	1,7	2,0	2,1	1,7	2,4	2,0	2,5
2	2,3	2,7	2,3	2,8	2,9	1,9	2,1	2,0	1,4	2,2	2,1	2,1
3	1,8	2,4	2,2	1,9	2,1	1,2	1,8	2,2	2,0	2,1	1,8	2,0
Average value:	**2,1**	**2,4**	**2,3**	**2,3**	**2,5**	**1,6**	**2,0**	**2,1**	**1,7**	**2,2**	**2,0**	**2,2**

Measurement No.	*Measurement points*											
	35	***36***	***37***	***38***	***39***	***40***	***41***	***42***	***43***	***44***	***45***	***46***
1	2,3	0,9	1,2	2,1	2,1	2,0	2,2	2,5	2,1	2,0	2,2	2,0
2	1,8	0,7	1,5	1,7	2,2	1,9	2,0	2,1	2,0	2,3	2,5	2,1
3	1,4	0,7	1,3	1,2	2,1	1,5	1,9	1,2	1,9	2,1	2,1	1,5
Average value:	**1,8**	**0,8**	**1,3**	**1,7**	**2,1**	**1,8**	**2,0**	**1,9**	**2,0**	**2,1**	**2,3**	**1,9**

Measurement No.	*Measurement points*												
	47	***48***	***49***	***50***	***51***	***52***	***53***	***54***	***55***	***56***	***57***	***58***	***59***
1	0,2	1,0	0,0	0,0	0,1	0,3	0,0	0,0	0,0	0,0	0,0	1,0	0,2
2	0,0	1,1	0,0	0,0	0,1	0,1	0,1	0,0	0,0	0,0	0,0	1,2	0,3
3	0,3	0,5	0,1	0,0	0,2	0,7	0,1	0,2	0,0	0,0	0,2	0,3	0,5
Average value:	**0,2**	**0,9**	**0,0**	**0,0**	**0,1**	**0,4**	**0,1**	**0,1**	**0,0**	**0,0**	**0,1**	**0,8**	**0,3**

4. Results of measurements (8 th, 9 th , 10 th April)

Measurement No.	*Measurement points*											
	Gas 1	***Gas 2***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
1	5,1	7,0	3,7	4,2	4,1	4,5	4,2	4,1	4,0	3,7	4,7	3,9
2	4,7	7,6	4,1	3,8	4,0	4,8	4,5	4,5	4,1	3,9	4,3	4,0
3	5,2	7,4	3,6	4,1	4,5	4,4	4,7	4,1	4,0	4,3	4,8	3,7
Average value:	**5,0**	**7,3**	**3,8**	**4,0**	**4,2**	**4,6**	**4,5**	**4,2**	**4,0**	**4,0**	**4,6**	**3,9**

Measurement No.	*Measurement points*											
	11	12	13	14	15	16	17	18	19	20	21	22
1	2,9	3,7	4,7	4,2	4,1	2,9	4,1	4,7	4,1	3,1	3,9	3,9
2	3,0	3,0	4,4	4,1	4,2	2,8	3,7	4,1	4,0	2,8	4,0	4,3
3	2,7	3,2	4,1	4,3	4,3	2,7	3,9	4,6	4,0	3,5	4,0	4,0
Average value:	**2,9**	**3,3**	**4,4**	**4,2**	**4,2**	**2,8**	**3,9**	**4,5**	**4,0**	**3,1**	**4,0**	**4,1**

Measurement No.	*Measurement points*											
	23	***24***	***25,0***	***26***	***27***	***28***	***29***	***30***	***31***	***32***	***33***	***34***
1	3,7	4,0	4,1	4,2	3,0	3,2	4,2	4,1	3,5	3,9	3,8	3,3
2	3,5	3,7	4,2	4,1	2,9	3,9	4,0	3,8	3,2	3,9	3,7	3,5
3	3,8	3,6	4,3	4,0	3,0	3,7	3,8	3,7	3,0	3,8	4,0	3,1
Average value:	**3,7**	**3,8**	**4,2**	**4,1**	**3,0**	**3,6**	**4,0**	**3,9**	**3,2**	**3,9**	**3,8**	**3,3**

Measurement No.	*Measurement points*											
	35	***36***	***37***	***38***	***39***	***40***	***41***	***42***	***43***	***44***	***45***	***46***
1	4,0	2,9	2,9	2,9	4,1	4,1	4,1	4,0	3,8	3,8	4,0	3,5
2	3,7	2,7	3,0	3,0	3,4	4,2	4,2	3,9	3,5	3,1	4,5	3,9
3	3,5	2,4	2,5	3,1	3,9	4,3	4,0	4,1	3,7	3,7	4,4	3,3
Average value:	**3,7**	**2,7**	**2,8**	**3,0**	**3,8**	**4,2**	**4,1**	**4,0**	**3,7**	**3,5**	**4,3**	**3,6**

Measurement No.	*Measurement points*												
	47	***48***	***49***	***50***	***51***	***52***	***53***	***54***	***55***	***56***	***57***	***58***	***59***
1	1,0	2,5	1,0	1,0	1,7	1,4	0,9	1,0	0,9	0,7	0,7	2,5	2,5
2	0,6	2,9	1,1	1,1	1,6	1,0	1,3	1,1	1,4	0,5	1,0	3,6	2,9
3	1,2	3,0	0,9	1,0	1,5	1,4	1,9	1,0	1,3	1,0	0,3	4,2	3,3
Average value:	**1,3**	**2,8**	**1,0**	**1,0**	**1,6**	**1,7**	**1,4**	**1,0**	**1,2**	**0,7**	**0,7**	**3,4**	**2,9**

ANNEX 3

1. Results of measurement that were provided during day time in monitoring wells Gas No. 1, gas No. 2, and in measurement points No. 9 and No.2. (August)

Date: 21-08-2004				
Time	**Gas No. 1 H_2S, ppm**	**Gas No.2 H_2S, ppm**	**No. 9 H_2S, ppm**	**No. 13 H_2S, ppm**
08:00	7,4	8,4	7,3	7,2
08:30	7,3	8,3	7,3	7,3
09:00	7,6	8,5	7,5	7,4
09:30	7,5	8,2	7,3	7,1
10:00	7,6	8,4	7,7	7,2
10:30	7,3	8,3	7,3	6,9
11:00	7,2	8,3	7,1	7,1
11:30	7,4	8,6	7,3	7,3
12:00	7,8	9,0	7,6	7,5
12:30	7,7	8,7	7,6	7,6
13:00	7,8	8,7	7,7	7,7
13:30	7,9	8,1	8,2	7,8
14:00	8,1	8,2	8,3	7,8
14:30	8,0	8,3	8,1	7,9
15:00	8,6	8,4	8,7	8,4
15:30	8,4	8,5	8,5	8,5
16:00	8,8	8,2	8,8	9,0
16:30	8,8	8,3	8,4	8,4
17:00	8,8	8,5	8,6	8,7
17:30	8,6	8,2	8,6	8,3
18:00	8,1	8,4	7,9	8,3
18:30	8,0	8,3	7,8	8,3
19:00	7,7	8,2	7,6	8,0
19:30	7,7	8,7	7,6	7,9
20:00	7,6	8,5	7,3	7,6

2. Results of measurement that were provided during day time in monitoring wells Gas No. 1, gas No. 2, and in measurement points No. 9 and No.2. (November)

Date: 6-11-2004				
Time	**Gas No. 1 H_2S, ppm**	**Gas No.2 H_2S, ppm**	**No. 9 H_2S, ppm**	**No. 13 H_2S, ppm**
08:00	5,4	8,0	4,8	4,8
08:30	5,5	8,1	4,9	4,8
09:00	5,6	8,0	5,0	4,9
09:30	5,6	8,1	4,8	4,7
10:00	5,5	8,3	5,1	4,8
10:30	5,6	8,2	4,9	4,6
11:00	5,5	8,2	4,7	4,7
11:30	5,6	8,3	4,9	4,9
12:00	5,8	8,0	5,1	4,9
12:30	5,7	8,5	4,7	5,1
13:00	5,6	8,3	5,1	5,1
13:30	5,8	8,3	5,4	5,2
14:00	6,0	8,3	5,1	5,6
14:30	5,9	8,4	5,1	5,3
15:00	6,0	8,5	5,4	5,6
15:30	6,2	8,4	5,7	5,7
16:00	6,2	8,3	5,9	5,6
16:30	6,1	8,6	5,6	5,6
17:00	6,0	8,2	5,7	5,8
17:30	5,8	8,4	5,7	5,6
18:00	5,6	8,3	5,3	5,5
18:30	5,6	8,5	5,2	5,6
19:00	5,6	8,0	5,1	5,3
19:30	5,5	8,0	5,1	5,3
20:00	5,6	8,2	4,8	5,4

3. Results of measurement that were provided during day time in monitoring wells Gas No. 1, gas No. 2, and in measurement points No. 9 and No.2. (February)

Date: 26-02-2005				
Time	**Gas No. 1 H_2S, ppm**	**Gas No.2 H_2S, ppm**	**No. 9 H_2S, ppm**	**No. 13 H_2S, ppm**
08:00	1,9	5	1,1	1,5
08:30	1,9	5,1	1,1	1,2
09:00	1,8	5,1	1,2	1,5
09:30	2	5	1,4	1,6
10:00	2	5,2	1,2	1,7
10:30	2,1	5,4	1,3	1,8
11:00	2	5,3	1,4	1,9
11:30	2,2	5,4	1,2	2,0
12:00	2,1	5,3	1,9	2,0
12:30	2,3	5,5	1,5	2,0
13:00	2,4	5,6	1,3	2,0
13:30	2,4	5,7	1,2	2,1
14:00	2,4	5,6	1,7	2,1
14:30	2,5	5,8	1,7	2,3
15:00	2,5	6	1,6	2,4
15:30	2,4	5,8	1,8	2,0
16:00	2,1	5,9	1,9	2,0
16:30	2,3	5,4	1,2	2,0
17:00	2,2	5,2	1,1	2,0
17:30	2,3	5,3	1,2	1,9
18:00	2,1	5,3	1,1	1,8
18:30	2	5,4	1,1	1,8
19:00	2	5,2	1,1	1,7
19:30	2	5,3	1,1	1,6
20:00	2	5,2	1,0	1,6

4. Results of measurement that were provided during day time in monitoring wells Gas No. 1, gas No. 2, and in measurement points No. 9 and No.2. (April)

Date: 9-04-2005				
Time	**Gas No. 1 H_2S, ppm**	**Gas No.2 H_2S, ppm**	**No. 9 H_2S, ppm**	**No. 13 H_2S, ppm**
08:00	3,8	7	3,9	3,6
08:30	3,9	7,1	4,0	3,6
09:00	3,9	7,2	4,0	3,7
09:30	4	7,3	4,0	3,8
10:00	4,1	7,2	4,1	3,8
10:30	4,2	7,1	4,2	3,8
11:00	4,3	7,4	4,3	3,8
11:30	4,4	7,3	4,3	3,9
12:00	4,5	7,2	4,3	4,0
12:30	4,5	7,1	4,4	4,1
13:00	4,7	7,3	4,5	3,9
13:30	4,7	7,1	4,5	4,1
14:00	4,8	6,9	4,6	4,2
14:30	4,9	7,4	4,6	4,2
15:00	5	7	4,6	4,3
15:30	5,1	7,1	4,6	4,4
16:00	5	6,9	4,5	4,2
16:30	4,9	6,8	4,4	4,1
17:00	4,8	6,8	4,3	4,0
17:30	4,7	6,8	4,2	3,9
18:00	4,6	6,7	4,1	3,9
18:30	4,5	6,8	4,0	3,9
19:00	4,2	6,8	4,0	3,9
19:30	4,1	6,8	4,0	3,8
20:00	4	6,8	3,9	3,8

ANNEX 4

LIST OF PUBLICATIONS

1. D. Kazlauskas, S. Vasarevičius. Atliekų sąvartyno išskiriama tarša. Vilniaus Gedimino technikos universiteto 7-osios jaunųjų mokslininkų konferencijos, įvykusios 2004 03 25, medžiaga, 2004, p. 126-133.

2. D. Kazlauskas, S. Vasarevičius. Iš sąvartyno išsiskiriančio H_2S tyrimai ir pasklidimas Jerubaičių buitinių atliekų sąvartyne. Vilniaus Gedimino technikos universiteto 8-osios jaunųjų mokslininkų konferencijos, įvykusios 2005 03 24.

3. P. Baltrėnas, D. Kazlauskas, E. Petraitis. Testing on noise level prevailing at motor vehicle parking lots and numeral simulation of its dispersion. Environmental Engineering and landscape management, Vol XII, No 2. Vilnius: Technika, 2004, p.63-70.

ANNEX 5

LIST OF REPORTS IN CONFERENCES

1. D. Kazlauskas, S. Vasarevičius. Atliekų sąvartyno išskiriama tarša. Report from Seven‘s Conference of Lithuania Junior Scientists March 25th 2004, Vilnius Gediminas technical university, 2004 03 25.

2. D. Kazlauskas, S. Vasarevičius. Iš sąvartyno išsiskiriančio H_2S tyrimai ir pasklidimas Jerubaičių buitinių atliekų sąvartyne. Report from Eight‘s Conference of Lithuania Junior Scientists March 24th 2005, Vilnius Gediminas technical university.