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An investigation of the presence of methane and other gases at the Uzundere–Izmir solid waste disposal site, Izmir, Turkey

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Abstract

Izmir is a large metropolitan city with a population of 3,114,860. The city consists of 27 townships, each township has a population of not less than 10,000 inhabitants. The two major solid waste disposal sites are in the townships of Uzundere and Harmandalı. The amount of solid waste that is disposed at each of these sites is about 800 and 1800 t/day, respectively. In Uzundere, compost is produced from the organic fraction of urban solid wastes while the residual material is deposited at a disposal site with a remaining capacity of 700,000 m^3 as of 2001. Gas monitoring and measurements were carried out at the disposal site in Uzundere. For this purpose, nine sampling wells were drilled on selected locations. Each well was furnished with perforated metal pipes suitable for gas monitoring and measurements. The following gases were monitored: O_2, CH_4, CO, CO_2, and H_2S. The most important finding was that the concentrations of CH_4 in the wells ranged from 7 to 57%. Dilution of the CH_4 by O_2 down to the LEL levels (5–15%) is always possible and poses a continuing risk at the site. Furthermore, the levels of O_2 require that access to the site be limited to only authorized personnel.

1. Introduction

Various gases such as CH_4, CO_2, N_2, O_2, H_2S, NH_3, H_2, trace elements, and condensed water are emitted by the solid waste stockpiles (Table 1). Due to the anaerobic decomposition of the organic matter, the emissions are mainly in the form of CH_4 and CO_2, other constituents usually are present in relatively small concentrations (Solid Waste Landfill Guidance, 1999). Measurements of CH_4 and CO_2 in seven waste disposal sites in the UK showed that the concentration of the two gases varied between 37 and 65% and 24 and 42%, respectively (Allen et al., 1997).

The landfill is an extremely heterogeneous formation. Gas probe readings taken in the anaerobic zone of a "mature" landfill (between 2 and 20 m deep) showed that the gas phase was mainly represented by the mixture of CH_4 (50–70%) and CO_2 (30–50%). Impurities, consisting mainly of N_2, H_2, CO, H_2S, and NH_3 constituted only a few percent or less. The concentration of H_2 was usually not higher than 0.05%, sometimes reaching 1%. The concentration of CO varies from 0 to 0.01%. Maximum concentrations of H_2 of 8% and of CO of 2% were observed at a landfill where municipal and industrial wastes had been co-disposed (Minko et al., 1990; Nozhevnikova et al., 1993).

Production of CH_4 started after 2 months and reached a value of 50% by volume within 2 years and could continue for as long as 20 years. On the other hand, high concentrations of N_2 and O_2 were observed at the site within the first 2 weeks of dumping. Concentration of CO_2 reached its maximum value within 2 months and remained constant afterwards at around 45% by volume for 2 years. The development of H_2 was negligible (Onargan and Kucuk, 1999).

Although many variables influence landfill CH_4 generation, such as the presence of anaerobic conditions, concentration and quality of organic material, the state of methanogenic microbial community, water content, available nutrients/toxins, temperature and pH, one of the most important variables is the moisture content of the waste (Onargan, 1999). At high moisture contents,

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Table 1
Concentration and distribution of gases at solid waste disposal sites (Solid Waste Landfill Guidance, 1999)

Component	Concentration (by volume on dry weight basis excluding moisture)
CH_4	45–58%
CO_2	Up to 45%
N_2	0–3%
H_2	Less than 1%
CO	Trace (indicator of possible subsurface fire)
H_2S and other S compounds	Varies (normally 10–200 ppm)
H_2O	Up to 14% (increases with gas temperature)
Volatile organic compounds	Typically 0.25–0.50%

contact between microorganisms, nutrients, and degradable substrates are improved and microbial metabolism is accelerated, leading to increases in the production of CH_4 and total gas (Korol, 1997; Bogner and Spokas, 1993).

Uncontrolled release of landfill gas from solid waste disposal sites is an environmental risk. Inhalation of very small amounts of some of these gases is extremely dangerous. Exposure to concentrations of H_2S at 200–800 ppm and of CO_2 at 3–9% for 5–60 min may cause serious health problems. In addition to the hazards associated with inhalation of landfill gas, explosion of CH_4 is possible when this gas is present in the atmosphere at a concentration of 5–15% (Yalcin and Gurgen, 1995). This concentration is called the Lower Explosion Limit (LEL). However, the presence of O_2 and the ambient temperature are also important factors affecting the LEL. For example, an explosion due to the presence of CH_4 may take place at 5.5% at 100 °C, 5% at 175 °C, 4.5% at 250 °C and 3% at 600 °C. If the CH_4 concentration is below 5%, burning of the gas is possible but no explosion will take place below 100 °C (US EPA, 1993). If the concentration is above 14%, explosion is not possible due to the high specific heat of CH_4 ($C_p = 2.254$ kJ/kg) and the deficiency of O_2 (below 12%; Solid Waste Landfill Guidance, 1999). Limited amounts of O_2 within the waste are the main reason for the reduced risk of CH_4 explosions at solid waste sites.

In this study, quantitative determination of gases such as O_2, CO, CO_2, CH_4 and H_2S was carried out at the disposal site near the Uzundere Compost Plant of the Solid Waste Treatment Department of Izmir Metropolitan Municipality. Wells equipped with special tubing for gas monitoring and measurements were used for the purpose. The measurements of the various gases were correlated with each other in order to explain the observed differences in gas concentrations in various locations at the disposal site.

2. Uzundere disposal site

The Uzundere site is located near the Uzundere Suburb within the borders of the Uzundere Municipality. The Uzundere Municipality is situated in the southeastern part of the City of Izmir (Fig. 1). The disposal site is located adjacent to a waste processing facility where the waste is subjected to mechanical separation for the removal of the recyclable wastes such as glass, paper, metal, plastics, and other materials prior to entering the composting unit. The facility was planned in 1986 by the Izmir Metropolitan Municipality with a daily capacity of 500 t and was built by German, Swiss and Turkish contractors. The recyclables are pressed for sale while the organic material is transported to the composting unit.

The material which cannot be composted (the residue) is sent to the disposal site. One ton of household-waste delivered to the composting plant consists of about 400 kg of water, 450 kg of residue and 150 kg of organic matter. The composition of the waste received by the plant varies depending on the time of the year. For example, during the summer, the moisture content varies between 60 and 65% whereas in the winter months the moisture content ranges from 40 to 45%. In addition, the amount of ash from household stoves is around 30–35% during the winter months (Bogner and Spokas, 1993). The composition of the household solid waste delivered to the plant is given in Table 2. The inorganic material consists of glass, cans, and other materials whereas the organic material consists of food remains, paper, textiles and others. The concentrations of these materials in the residue that is deposited at the waste disposal site are given Table 3.

3. Determination of the layout and volume of the disposal site

A Garmin model hand-held GPS was employed in determining the actual layout of the Uzundere solid waste disposal site and the location of the wells. The

Table 2
Analysis of the household solid waste (US EPA, 1993)

Type	Weight,%
Organic material	51.9
Paper	12.3
Glass–glass bottle	4.4
Metal	2.9
Cardboard	2.1
Plastic	12.5
Miscellaneous wrapping material	1.8
Textile	7.9
Other	4.2

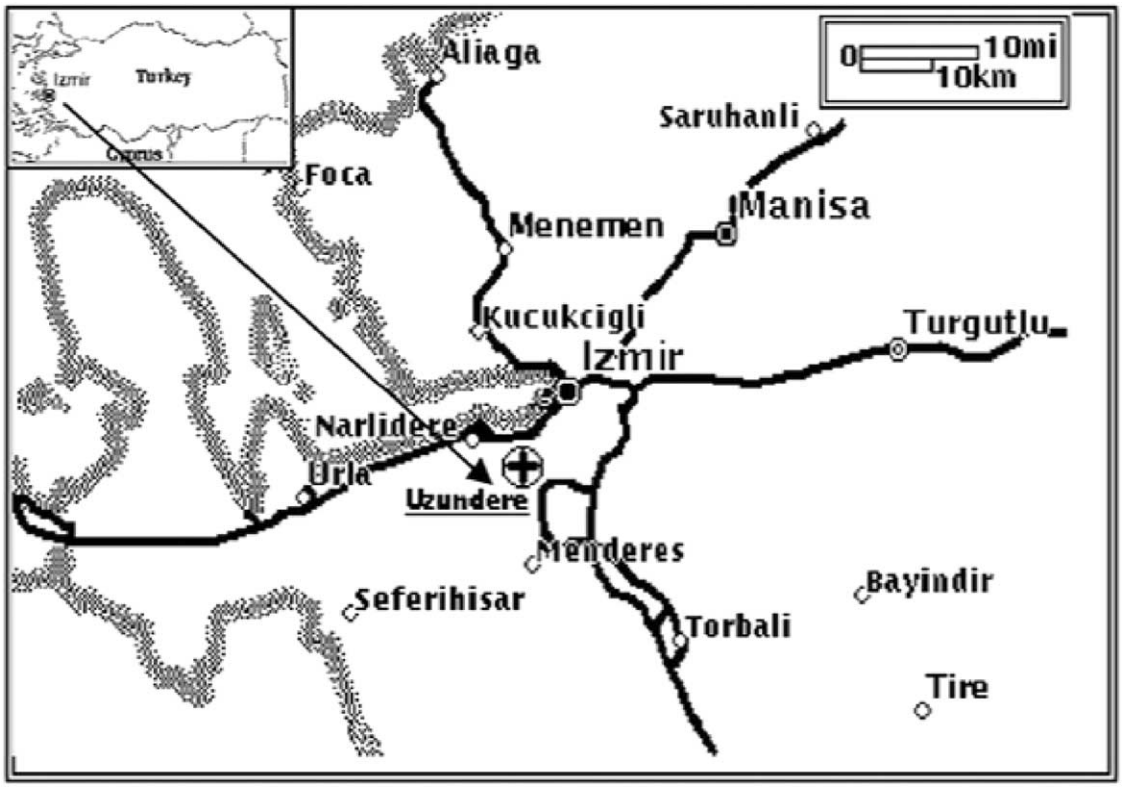

Fig. 1. Location of the area of the study.

coordinates were established by means of the Universal Transverse Mercator Projection System.

In order to determine the presence of CH_4 and other gases in the Uzundere Solid Waste Disposal Site, 9 locations were selected for drilling the wells used for the gas measurements. The locations and the depths of the wells are given in Table 4. Each well was 76 mm in diameter and was equipped with a 50-mm diameter perforated metal pipe suitable for gas measurements. Gas measurement tubing was placed on top of the holes, which were properly isolated for reliable gas monitoring. A photograph of well SK-U1 is shown in Fig. 2.

The total area of the disposal site covered by the solid waste was calculated to be 100,178.5 m^2 from the GPS readings. Combining these data with the results of the drilling work using the polygon method (thickness of the solid waste cut by the drilling and the effective field of the drilling), the volume of the solid waste in the site was calculated to be 720,775 m^3 (Fig. 3).

Table 3
Analysis of the residue from treatment plant (Archive, 2001)

	Coarse residue (%)	Fine residue (%)
Parameter		
Water (%)	40	41
Organic material (%)	51	18
Inorganic material (%)	9	41
Fraction (%)		
Food-based waste	39	19
Nylon	46	17
Plastic (PET, PVC)	5	–
Paper	10	5
Wood	–	2
Textile	–	15
Medical waste	–	43

4. Gas measurement studies

In situ gas measurements were conducted by means of the chimneys placed on the wells using a Pac EX model CH_4 detector from Draeger Safety Inc., USA and a Micro MAX model multi gas measurement device from Lumidor, USA. The results of these measurements for

Table 4
Information on the wells drilled for this study

Drill No.	*X*	*Y*	*Z*	Borehole length (m)	Perforated pipe length (m)	Thickness of the solid waste out by the well (m)
DEU/SK-U1	90,942	97,484	245	25	21	14
DEU/SK-U2	90,925	97,462	246	23	18.5	12.5
DEU/SK-U3	90,964	97,467	244	28	24	18
DEU/SK-U4	90,947	97,520	249	20	15	12
DEU/SK-U5	90,981	97,549	241	14	9	6.5
DEU/SK-U6	91,003	97,533	241	30	18	11
DEU/SK-U7	91,022	97,512	240	28	24	19.5
DEU/SK-U8	91,184	97,479	245	16	12	7
DEU/SK-U9	91,256	97,504	239	20	15	13
Total				**204**	**156.5**	

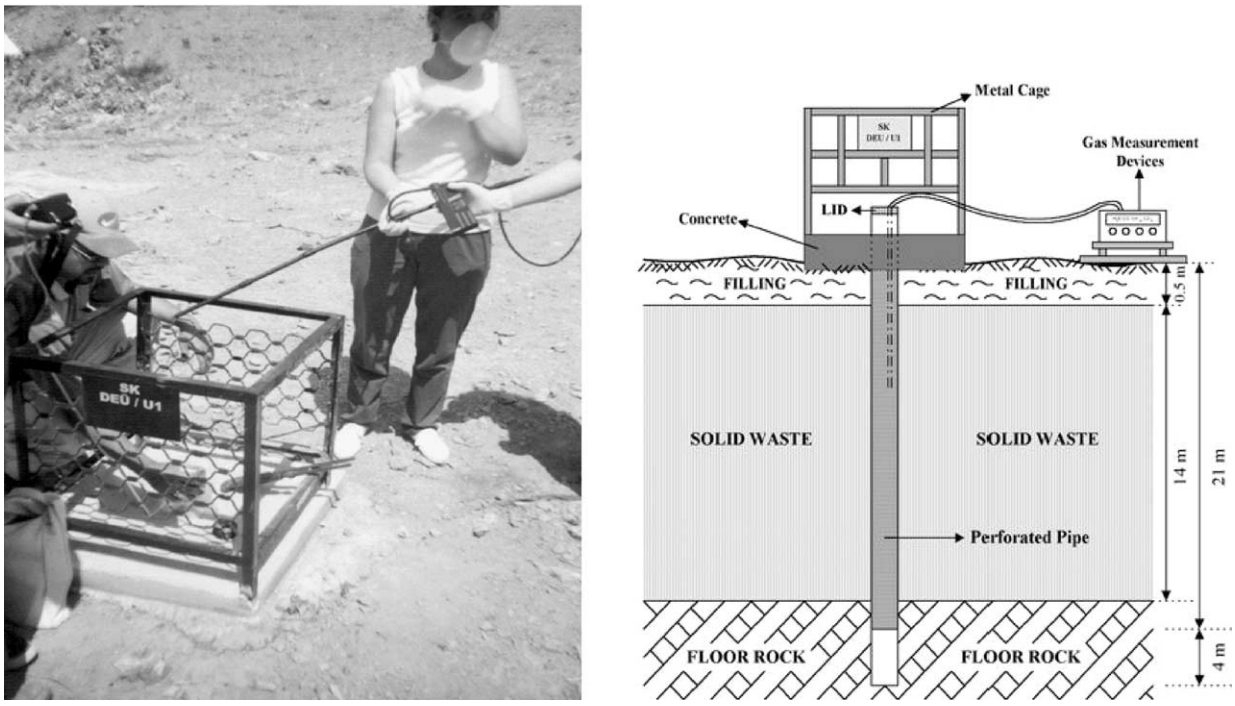

Fig. 2. Photograph and schematic of completed well No. SK-U1 for gas measurement (Onargan and Kucuk, 2000).

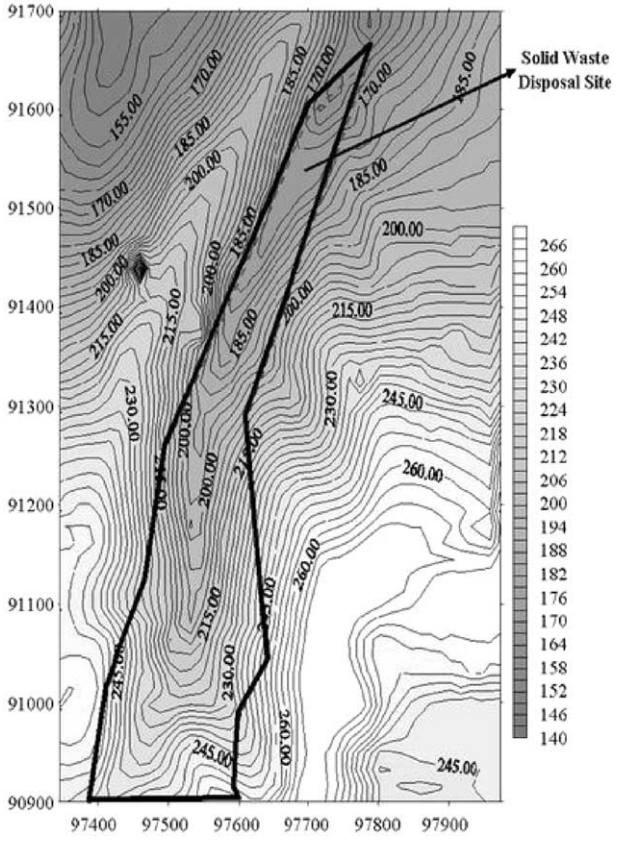

Fig. 3. A view of the topography of the Uzundere solid waste dump site.

CH_4, CO, H_2S, CO_2 and O_2 are presented in Table 5 while the distributions for CH_4, CO, H_2S, and O_2 throughout the disposal site are given in Figs. 4–7, respectively.

The data show that there is a relatively high concentration of CH_4 at the majority of the measurement locations; namely, at wells number U1, U2, U3, U4, U5, U6 and U7. The CH_4 concentrations in these locations were as high as 48–52%, which points out to the presence of large amounts of gas in the site. Varying concentrations were obtained for gases such as H_2S, CO_2, O_2 and CO depending on the location of measurement.

Anaerobic degradation takes place primarily in two stages. In the first stage, materials such as carbohydrates, proteins and fats are converted into organic fatty acids by fermentation and hydrolysis. In the second stage, these acids are converted into gaseous products, mainly CH_4, CO_2 and H_2S by the action of anaerobic bacteria. The anaerobic bacteria are susceptible to low temperature, low pH and the presence of O_2. When the O_2 levels in the wells are low, the data in Table 5 show that the concentrations of CH_4, H_2S and CO_2 are considerably high in the gas collected (wells U1, U2, U3, U5 and U9 are examples of such conditions). At these wells, the concentrations of CH_4, H_2S and CO_2 were in the order of 30–60%, 0–20% and ~20%, respectively, although well U9 was somewhat lower in CH_4 and U2, and U5 exhibited lower concentrations of H_2S than the rest of the wells.

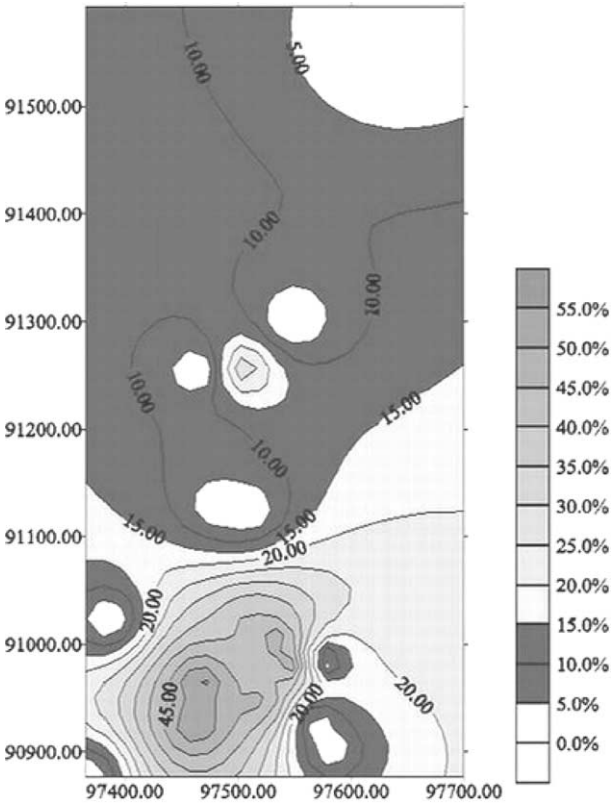

Fig. 4. Distribution of methane in the Uzundere dump site.

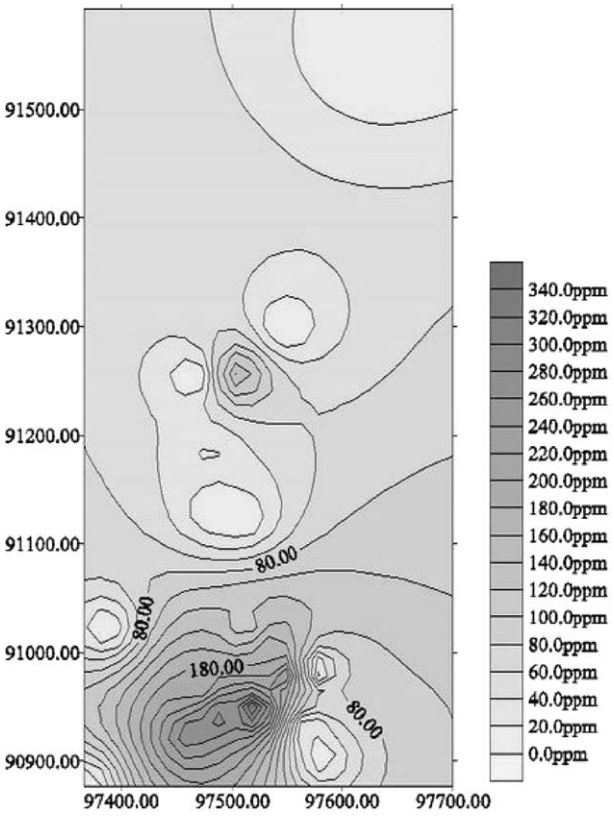

Fig. 5. Distribution of CO in the Uzundere dump site.

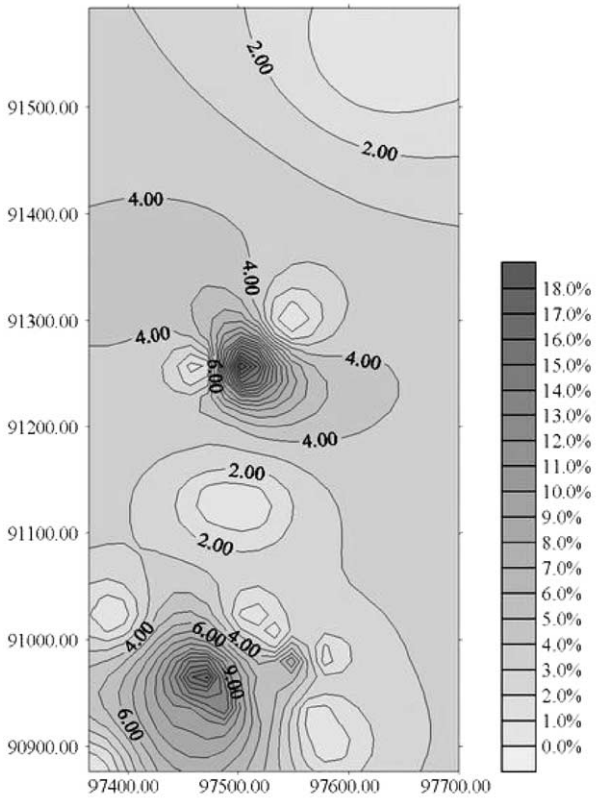

Fig. 6. Distribution of H_2S in the Uzundere dump site.

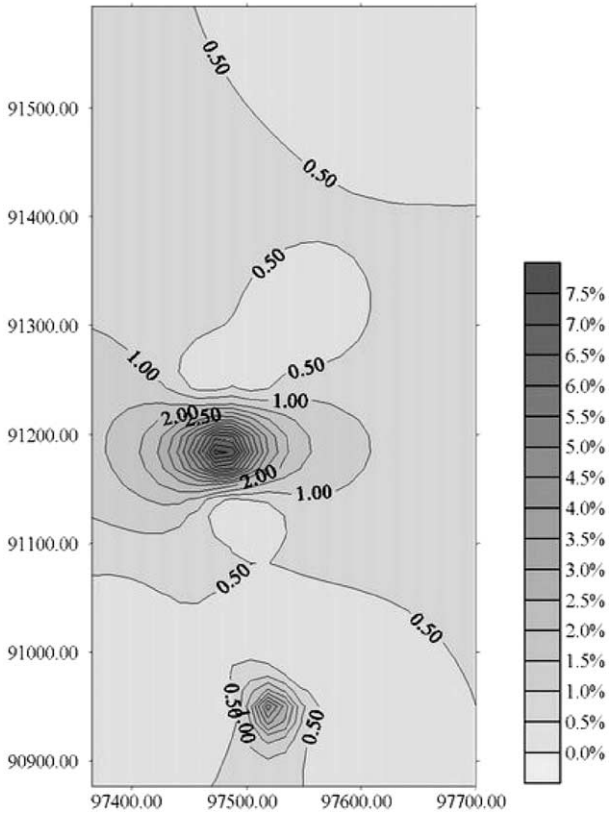

Fig. 7. Distribution of O_2 in the Uzundere dump site.

Table 5
Results of the gas measurements obtained from the gas detection chimneys set up at the disposal site

Well No.	Gas	Measurement period (month)	Number of measurements	Amount (Avg.)	Standard deviation
DEU/SK-U1	CH_4	1	10	50%	±3
	O_2			0.04%	±0.01
	H_2S			14%	±2
	CO			300 ppm	±5
	CO_2			20.4%	±2
DEU/SK-U2	CH_4	1	10	56%	±4
	O_2			0.05%	±0.01
	H_2S			9%	±1
	CO			280 ppm	±6
	CO_2			20.4%	±3
DEU/SK-U3	CH_4	1	10	57%	±5
	O_2			0.04%	±0.02
	H_2S			18%	±1
	CO			180 ppm	±3
	CO_2			20.5%	±1
DEU/SK-U4	CH_4	1	10	47%	±2
	O_2			4.5%	±0.01
	H_2S			5%	±1
	CO			348 ppm	±3
	CO_2			16.5%	±2
DEU/SK-U5	CH_4	1	10	48%	±3
	O_2			0.04%	±0.01
	H_2S			8%	±2
	CO			240 ppm	±5
	CO_2			20.5%	±2
DEU/SK-U6	CH_4	1	10	50%	±4
	O_2			0.03%	±0.01
	H_2S			265 ppm	±1
	CO			176 ppm	±6
	CO_2			20.6%	
DEU/SK-U7	CH_4	1	10	41%	±5
	O_2			0.05%	±0.02
	H_2S			290 ppm	±1
	CO			105 ppm	±3
	CO_2			20.4%	
DEU/SK-U8	CH_4	1	10	7%	±2
	O_2			8.1%	±0.01
	H_2S			3%	±1
	CO			17 ppm	±3
	CO_2			12.8%	±2
DEU/SK-U9	CH_4	1	10	29%	±3
	O_2			0.04%	±0.01
	H_2S			19%	±2
	CO			141 ppm	±5
	CO_2			20.5%	±2

On the other hand, when the concentration of O_2 was high in the gas, the concentrations of CH_4, H_2S and CO_2 were found to be lower, as was the case well U8. In this case, the concentration of O_2 was as high as 8.1% with such CH_4, H_2S and CO_2 concentrations of 7, 3 and 12.8%. Well No. U4 could also be put in this category with its lower H_2S and CO_2 concentrations though the CH_4 level was only slightly lower. Wells U6 and U7 also exhibited low concentrations of O_2. These wells hardly had any H_2S, but interestingly, contained significant amounts of CH_4 and CO_2.

These discrepancies may be attributed to the varying thickness of the solid waste cut by the wells, temperature differences and the escape of certain gases due to these types of geometrical variations. However, the inverse relationship between the CH_4, H_2S and CO_2 concentrations and the O_2 concentration is apparent and should be taken into consideration.

5. Results and conclusions

Measurements of gas concentrations were carried out in nine wells in the Uzundere solid waste disposal site. The findings of this study can be summarized as follows:

1. All nine wells showed relatively high concentrations of CH_4. The concentration of methane varied between 7 and 57%. The concentration of CH_4 in well DEU-SK/U8 was within the explosion limits (5–15%). In the presence of a suitable concentration of O_2 and other factors, this means a serious risk of explosion. The concentration of CH_4 in all of the other drill holes was outside of the explosion limits, especially considering the low O_2 concentrations. It should be kept in mind that danger zones, which are prone to explosion, could develop if O_2 enters into these CH_4-rich zones.
2. The CO_2 concentrations varied between 12.8 and 20.5% in the 9 wells.
3. The O_2 concentrations were in the range between 0.03 and 8.1%. The air on or around the disposal site could be classified as contaminated or poisonous. Hence, controlling unimpeded entry into the disposal site should be seriously considered such as by fencing the perimeter of the site. Also, precautions must be taken for those who are employed on the site to prevent poisoning and to provide suitable working conditions.
4. Since the concentrations of CH_4 were quite high at the site, it is suggested that CH_4 be collected and burned using a suitable method. It future plans exist to use the area for recreational purposes; detailed rehabilitation studies are also necessary.

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