Water Science and Technology **Vol 48 No 4 pp 37–44** © IWA Publishing 2003

Evaluation of the current status of operating and closed landfills in Russia, Finland and Ireland with regard to water pollution and methane emission

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Abstract The annual production of municipal solid wastes (MSW) in Russia, Finland and Ireland in the late 1990s accounts for 37.5, 2.5 and 2.05 mln. tonnes or 252, 488 and 566 kg per capita, respectively. 96.5, 64 and 91% of these wastes (for Russia, Finland and Ireland, correspondingly) are currently disposed of via landfilling. However, nowadays, MSW management in these countries is undergoing drastic changes (source separation, closure of old landfills, reduction of the number of landfills etc.) forced by recent legislation set by the European Union and Russian authorities. This paper evaluates the current status of MSW landfills, as well as information on current leachate and methane emissions in the three above mentioned countries. Landfill leachates are highly variable in each country and between different countries due to different rainfall and climatic conditions and also due to poor landfill top insulation/cover. Leachates in poorly structured landfills are very dilute, whereas leachates with total COD and nitrogen contents as high as 33,700 mg COD/l and 4,030 mg N/l, respectively, have been detected from state-of-the-art sites. Currently, on-site treatment of leachates exists at only a few landfills in Russia, Finland and Ireland but this situation will be considerably improved during the next years. The annual methane emissions from landfills are estimated as 500–900 and 77 ktonnes for Russia and Finland, respectively. Recent estimates from Ireland suggest an annual landfill methane emission of c. 2.1 Mt CO_2 equivalent. Several systems of methane recovery have been developed in all three countries and these are currently in different stages of implementation.
Keywords Anaerobic treatment; landfill; leachate; methane emission; municipal solid wastes

Introduction

Landfilling has been the most common way for disposal of municipal solid wastes (MSW) in Russia, Finland and Ireland (Table 1). However, nowadays, MSW management in these countries is undergoing drastic changes (source separation, closure of old fashioned landfills without bottom insulation, general reduction of the number of landfills, change of wastes to be placed in landfills etc.) forced by recent legislation set by the European Union (EC directive 1999/31/EU) and Russian authorities (Federal law of Russia, 1998). The aim of these stringent environmental laws and directives is to ensure that landfills will not cause danger or damage to health or the environment. The current and coming regulations consider sorting and controlling waste flows, location, base and surface structure of landfills, as well as leachate and gas collection and treatment. This paper, prepared in the framework of INCO Copernicus grant ICA2-CT-2001-10001 "Development of cost effective biotechnological methods for abatement of water pollution and mitigation of methane emissions

Table 1 Production, composition, treatment and disposal methods for MSW in Russia (1996), Finland (1997) and Ireland (1998)

Parameters	Russia			Finland	Ireland
	In general	Moscow	Rostov		
Source of information	Cherp and Vinichenko (1996)		Privalenko (2001)	Statistics Finland (2001)	National Waste Database (1998)
Total annual production, mln. tons	37.5	2.5–3	0.35	2.5	2.05
Annual production per capita, kg	252	300	339	488	566
MSW composition (%)					
Paper and cardboard	20–36	37.7	25.3	40	35.5
Glass	5–7	3.7	5.8	5	4.7
Metals	2–3	3.8	2.2	5	2.8
Plastics	3–5	5.2	11.6	10	11.4
Textile	3–6	5.4	2.3	2	2.0
Rubber and leather	1.5–2.5	0.5	1.0	No data	No data
Wood	1–4	1.9	0.4	No data	No data
Food residues	20–38	30.6	45.9	33	25.7
Other	10–35.5	11.2	5.5	5	18.2
Treatment methods (%)					
Re-use	1.3	No data	No data	33	9
Incineration	2.2	No data	No data	3	0
Landfilling	96.5	>95	>90	64	91

from landfills in different climatic zones", attempts to evaluate the current status of typical landfills (both modern operating and old closed ones) in Russia, Finland and Ireland, as well as their leachate and methane emissions.

Current status of landfills

Russia

Although the annual production of MSW per capita in Russia is approximately two times less than in western countries (Table 1), the exact number of landfills in Russia is unknown because of its huge territory, not very comprehensive statistics and the existence of thousands of non-sanctioned sites for waste disposal. However, the estimates show that, in total, Russian landfills occupy 0.8 mln. ha, i.e., an area equivalent to 8 cities of the size of Moscow. Meantime, these landfills not only occupy waste grounds, ravines and quarries, but also fertile black soils. On a geographical scale, however, landfills do not occupy too much space in Russia. For example, all the MSW which will be produced at current rates in Russia during the next 500 years can be disposed of on an area of 600 km^2 with a waste layer thickness of 25 m (Cherp and Vinichenko, 1996). By the end of the 1980s, 88% of landfill sites, according to the inspection of the USSR State Committee of Nature (1989), were in unsatisfactory sanitary conditions emitting many dangerous pollutants to the environment (Cherp and Vinichenko, 1996). However, due to federal and provincial programs of MSW management accepted in the 1990s, there is an evident trend currently in Russia towards closure of old landfills and construction of large modern ones having reliable (bottom, walls and top) insulation. As a result, the number of operating landfills is decreasing (e.g., by 50% in Moscow province during the last 5 years). The other trend (especially for big cities) is a decreasing percentage of MSW being consigned to landfill. For example, the target value for Moscow city for 2005 is 60–65% of MSW to be disposed of via landfilling. The rest will be re-used, or composted (via source separation) or incinerated (Cherp and Vinichenko, 1996).

Finland

MSW management, which formerly relied almost exclusively on landfill disposal, is currently undergoing major changes in Finland (Tanskanen *et al.*, 1998). The number of operating municipal landfills was 190 and the number of closed landfills exceeded 1,600 in 2000, while ten years earlier there were still 475 operating municipal landfills. In the national waste plan, one of the aims is to reduce the number of operating municipal landfills to 80 in 2005 (Ministry of Environment of Finland, 2001). The trend is towards bigger, better constructed landfills, which are equipped with bottom barriers, leachate treatment, gas collection and recovery or burning systems. The focus during the 1990s has been on the recycling and utilisation of MSW constituents for material and energy recovery. Finally, the landfilling of solid municipal waste, without prior sorting out of the biggest part of biodegradable organic waste (biowaste), will be banned from 2005 onwards.

In general, municipal landfills have been quite small and poorly constructed in Finland. The landfilled waste has been mainly typical solid municipal waste, excluding hazardous waste, which has been source-sorted and separately treated since 1983. Typically the small landfills have been situated in water permeable soils without bottom barriers, leachate treatment and gas collection. Thus, air and water pollution risks caused by landfills have been apparent. Characteristic also is the cold climate, which restricts biodegradation and impacts on leachate formation. Most of the leachates are formed in spring when snow is melting, and thus leachates tend to be cold and dilute.

Ireland

In Ireland, the trend is also towards a reduction in the number of operational municipal landfills and the development of a relatively small number of large, centralised sites that will meet stringent licensing requirements for containment, leachate recovery and treatment, and landfill gas collection and use. In 1998, the number of local authority landfills receiving municipal waste was 76, a reduction from 87 in 1995. A total of 264 closed municipal landfill sites were identified in the 1998 National Waste Database study published by the Irish EPA. Of the active municipal landfills in 1998, 30 received less than 10,000 tonnes per annum (TPA), with 16 receiving greater than 40,000 TPA. The EPA Report “Ireland’s Environment – a Millennium Report” (2000) indicated that a further 26 municipal landfills had closed by 2000. At present, the number of operational sites is 43. Most of the closed sites were small and located in rural areas. The remaining life span of local authority landfills that are currently operational illustrates that 12 have an expected life span of more than 10 years, 13 are expected to remain open for between 5 and 10 years, with the remainder expected to close within the next 5 years (Ireland’s Environment – a Millennium Report, 2000). Six waste license applications for new municipal landfill sites were received by the EPA between 1998 and 2000. In Ireland, The Waste Management Act (1996) requires that all MSW landfill sites, transfer stations, storage facilities and recovery and treatment processes must be licensed by the EPA. The Waste Management Policy Statement issued by the Irish Department of the Environment in 1998 specified a diversion of 50% of household waste from landfill and a reduction of 65% of biodegradable waste to landfill within a 15 year period. These targets, coupled with the stringent licensing conditions set by the EPA for new landfills, mean that landfill disposal of MSW in Ireland will reduce sharply, will increase in cost, but will constitute a controlled and decreasing risk to the environment and public health.

Landfill leachate

As a result of microbial activity within a landfill, and resulting also from compression and water flows, a leachate containing a wide variety of intermediate organic degradation products, recalcitrant xenobiotics and inorganic and metallic contaminants inevitably leaches from an unconfined landfill.

Russia

The typical composition of leachates from some Russian landfills is presented in Table 2. In general, leachates can be characterised as wastewaters containing high concentrations of COD and nitrogenous constituents. Besides the bulk pollutants, landfill leachates usually contain heavy metals and other dangerous micropollutants. Some data about their concentrations are given in Table 3.

On-site specialised treatment of leachates is only applied in a few landfills in Russia. As an example, aerobic biofilters and biological ponds used in the Perm region should be mentioned (Vaisman *et al*., 2001). According to our knowledge, no high-rate anaerobic systems have been used in Russia for these purposes. There are some cases where the leachate (or part of it) is directed to nearby sewage treatment systems. However, in the majority of cases, the leachate is recycled back to the landfill or just filtrated to the ground and swamps. This poses dangerous environmental and health risks with respect to impact on surface and ground waters. However, due to continuous pressure of ecological organisations and stepwise improvements of legislation, many provincial and local governments have set special programs for implementation of collection and treatment of landfill leachates in the coming 5 years (Hangildin and Sharafutdinova, 2001; Vaisman *et al*., 2001). When these programs have been fulfilled, the situation with leachate impact on the environment around the landfills should be considerably improved.

Finland

In 1995, according to the national register in Finland, there were leachate treatment plants in 3 municipal landfills, 10 landfills directed leachate to municipal sewage treatment plants, but the most common disposal route (146 landfills) was to filtrate the leachate to ground or swamps. In other landfill sites, settlement or aeration basins, sand filtration or

Table 2 Composition of leachates (in mg/l except pH) from some Russian MSW landfills*

Landfill (location)	pH	COD	BOD	N_{tot}	Na^+	Cl^-	SO_4^{2-}
Zyuzino, Salar'yevo, Iksha (Moscow)	6.5–7.7	1,500–4,800	150–700	20–720		381–2,900	150–480
Timokhovo (Moscow)	7.6–8.6	8,740	1,500	4,030	1,726	4,663	221
Khmet'yevo (Moscow)	6.0–8.0	1,430–20,560	ND	128–1,642	ND	ND	61–355
Severnaya (Rostov)	8.0	6,500	ND	29	4,800	6.170	148
Zapadnaya (Rostov)	8.8	6,960	ND	1,000	8,320	7,870	4,300
Novoselki (St. Petersburg)	ND	ND	ND	1,610	1,700	2,300	35
Perm	7.5–8.2	500–1,120	280–519	ND	ND	640–3,080	1–246
Orel	4.0–8.5	20,000	13,300	ND	ND	3,480	ND
Essentuki, Georgiyevsk (North Western Caucasus)	ND	12,700	9,710	200–710	ND	22,750	ND
Voronezh	7.5–8.6	1,960	1,762	270–2,400	2,614	5,106	30–782

* Data taken from Batischev *et al.* (2001), Privalenko (2001) and Kalyuzhnyi *et al.* (2002)
ND – no data

Table 3 Micropollutant content (in mg/l) in leachates from some Russian MSW landfills*

Landfill (location)	Fe	Zn	Cu	Pb	Cd	Oil	Phenol
Timokhovo (Moscow)	50	0.9	0.6	0.5	7×10^{-3}	9.9	0.29
Khmet'yevo (Moscow)	4–170	1.1–28.8	0.04–0.24	0.04–0.1	$1–5 \times 10^{-3}$	ND	ND
Severnaya (Rostov)	2.3	0.4	0.3	0.04	ND	ND	0.09
Zapadnaya (Rostov)	2.4	1.5	1.3	0.64	ND	13.8	11.2
Ufa	0.04–1	0.01–0.07	0.01–0.1	$1–7 \times 10^{-3}$	<0.001	ND	0.1–0.2

* Data taken from Hangildin and Sharafutdinova (2001) and Kalyuzhnyi *et al.* (2002)
ND – no data

leachate recycling back to the landfill is practised. There was no leachate treatment in 123 of the landfills studied (Rytkönen, 2001). Characteristics of leachates in some typical quite small landfills as well as the performance of the leachate treatment processes are shown in Table 4. In general, the landfills were poorly insulated and the amount of surface and groundwater may have been substantial in these landfill leachates. In Finland, leachate collection and treatment must be implemented by 2002 in all operating landfills. Treatment methods include, for example, evaporation and biological denitrification-nitrification.

Ireland

In Ireland, virtually all of the municipal landfill sites operational in 1998 did not have leachate containment, with the result that the leachate filtered through to surface and groundwater, with resulting environmental pollution and public health risk. The requirement for all existing operational and proposed new landfills to obtain a license from the EPA will improve this situation. An effective leachate collection and removal system is a pre-requisite for all new sites. However, for closed landfills and for approximately 50% of the existing operational sites, engineering re-design to contain and collect the leachate is not feasible. Where collection is feasible, the most common practice is to transport the leachate to the nearest municipal sewage treatment works. This method of leachate management is currently employed at 37% of the active landfill sites. Given the high annual rainfall in Ireland and the poor top-covering of many landfill sites, the leachate can be highly diluted (COD of 300–400 mg l^{-1}) and transport costs are high. To date, on-site leachate treatment has been installed at three active Irish landfill sites. The typical composition of leachate from Irish landfills receiving mainly domestic waste is shown in Table 5.

Table 4 Characteristics of leachates and their treatment in Finland (Kettunen *et al.*, 2000)

Place	Iisalmi	Kemi	Joensuu	Lahti	Nurmijärvi
Temperature, °C	15	12	3–20	9–17	3
pH	6.8–6.9	6.4–7.2	7.1–7.3	7.9–8.0	7.0
Treatment method	Sand filters and settlement basins	Biological filter made of twigs of willow	Aerated basins, sand filters, settlement basins and root zone treatment plant	Settlement basins, sand filters, evaporator and pH- adjustment	Settlement basin, biological nitrification + denitrification
Conductivity, µS/m					
Inlet	498–570	133–149	77–157	314–411	130
Outlet	223–269	128–148	109–125	<1	155
COD_{tot}, mg/l					
Inlet	610–1,100	85–120	270–310	230–300	600
Outlet	250–400	73–110	91–94	<30	200
Reduction, %	58–64	7–14	65–71	>87	67
BOD_7, mg/l					
Inlet	120–490	3	11–14	11–20	240
Outlet	74–100	3	<3	<3	5
Reduction, %	38–80	0	>73	>73	98
NH_4-N, mg/l					
Inlet	160	4–19	61–73	76–96	74
Outlet	36–51	<1–16	9–26	<1	<1
Reduction, %	69–78	16–75	59–88	>99	>99
P-total, mg/l					
Inlet	1.5	0.4	0.2	0.3	–
Outlet	0.5	0.2	0.1	<0.05	1.0*
Reduction, %	67	50	50	>83	–

* phosphorus was added into the process, mean value of spring 2000

Table 5 Typical composition of leachate from Irish landfills receiving mainly domestic waste*

Parameters	Overall values		Overall range	
	Median	Mean	Minimum	Maximum
pH value	7.1	7.2	6.4	8.0
Conductivity (µS/cm)	7,180	7,789	503	19,200
Alkalinity (as $CaCO_3$)	3,580	3,438	176	8,840
COD (mg/l)	954	3,078	<10	33,700
BOD_{20} (mg/l)	360	>834	4.5	>4,800
BOD_5 (mg/l)	270	>798	<0.5	>4,800
TOC (mg/l)	306	717	2.8	<5,690
Fatty acids (as C) (mg/l)	5	248	<5	3,025
Kjeldahl-N (mg/l)	510	518	1	1,820
NH_4-N (mg/l)	453	491	<0.2	1,700
Nitrate-N (mg/l)	0.7	2.4	<0.2	32.8
Nitrite-N (mg/l)	<0.1	0.2	<0.1	1.4
Sulphate (mg/l)	70	136	<5	739
Chloride (mg/l)	1,140	1,256	27	3,410
Phosphate (mg/l)	1.1	3.0	<0.1	15.8
Sodium (mg/l)	688	904	12	3,000

* National Waste Database (1998)

Methane emission and recovery

The end product of anaerobic microbial activity within a landfill results in the generation of landfill gas (5–10 m^3/ton of waste per year with a composition of approximately 50–70% methane and 50–30% carbon dioxide). Landfill gas, if not contained and extracted, percolates upwards through the landfill and is released to the atmosphere, resulting in atmospheric pollution, enhancement of global warming and creation of the risk of on-site fires and explosions. Although modern landfill sites practise biogas extraction, recovery and use, the EU and Russia contain an historical legacy of closed or still operational, uncontrolled landfill sites. Proposed EU Directives will require at least 50 years of post-closure monitoring of new landfills in order to minimise their negative impact on the environment.

Russia

The annual methane emission from landfills in Russia is estimated as 0.7–1.3 Gm^3 or 500–900 ktonnes (Nozhevnikova and Lebedev, 1995). Several systems of biogas recovery and conversion into electricity have been developed and are now in different stages of implementation (Gurvich and Lifshits, 2001). However, the extraction and use of landfill gas is hindered in Russia by the fact that the produced electricity is, as a rule, 2–2.5 times more expensive currently than electricity produced from fossil fuels or by nuclear stations (Gurvich and Lifshits, 2001).

Finland

Landfills, together with livestock farming, are the biggest methane emission sources in Finland. In the 1990s, methane emission from landfills decreased by more than 50% because of gas recovery and sorting and separate treatment of organic wastes. Methane emission from landfills was 77 ktonnes in 1999 (Statistics Finland, 2001). Thus, landfilling of solid waste in 1999 was responsible for about 2% of total greenhouse gas emissions counted by CO_2-equivalents (Pipatti, 2001). New legislation (EC directive 1999/31/EU) has increased the number of gas collection and recovery systems in landfills. In 2000, there were biogas collection stations in 12 Finnish landfills, collecting around 30 mln. m^3 of biogas per annum. The heat and electricity produced by biogas from landfills was about 29 GWh in 1997, about 45 GWh in 1998 and about 46 GWh in 1999 (Leinonen and Kuittinen, 2000). It has been estimated that the total amount of generated biogas in landfills may be 200–300 million m^3

annually. Top cover structures designed to provide enhanced methane oxidation are commonly applied in small landfills with low methane emission potential.

Ireland

Prior to the adoption of the Waste Management Act (1996) in Ireland, methane gas emissions from Irish landfills were neither adequately monitored nor recovered. Data from 1990 suggested that c. 16% of the total CH_4 emissions in Ireland was contributed by emission from landfill sites. More recent estimates indicate that Irish landfill methane emissions are approximately 2.1 Mt CO_2 equivalent per annum. The licensing of all operational and new landfills by the EPA requires that all sites undertake landfill gas monitoring. In addition, all significant sites are required to have gas collection systems, with a requirement to either flare or produce energy from the collected gas rather than venting directly to the atmosphere. At present, the combustion of gas for energy generation is practised at five Irish landfill facilities, with the remainder either flaring the gas (approx. 30%) or in the process of installing facilities for flaring. Currently, installed combustion of or flaring of collected methane results in a reduction of methane emissions by c. 0.5 Mt CO_2 equivalent per annum. Irish National Waste Management Targets require a reduction of 80% of landfill methane emissions by 2015 (1.7 Mt CO_2 equivalent).

Conclusions

1. In spite of significant historical, cultural and climatic differences, all three countries have had a common approach to MSW management – the majority of these wastes (96.5, 64 and 91% for Russia, Finland and Ireland, respectively) are currently disposed of via landfilling. At present, however, landfilling practice in these countries is undergoing drastic changes (source separation, closure of old fashioned landfills without bottom insulation, general reduction of the number of landfills, change of wastes to be placed in landfills etc.) forced by recent legislation enacted by the European Union and the Russian authorities.
2. Although landfill leachates, usually having a high COD and nitrogenous content, pose a clear detrimental effect on surrounding ground and surface waters, their on-site specialised treatment now exists only at a few landfills in Russia, Finland and Ireland. However, this situation will be considerably improved during the next decade.
3. The annual methane emission from landfills is estimated as 500–900 and 77 ktonnes for Russia and Finland, respectively. Currently, the methane emissions from Irish landfill sites are estimated to be approximately 2.1 Mt CO_2 equivalent per annum. Several systems of methane recovery have been developed in all three countries and these are now in different stages of implementation.
4. The long-term environmental and health significance of both of these landfill emissions will depend on future regulations concerning treatment (incineration, gasification, biological/mechanical) of residual organic waste (source separated biowaste) and the placement in landfills.

Acknowledgement

The financial support of INCO Copernicus (contract N° ICA2-CT-2001-10001) is gratefully acknowledged.

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