Evolution of Sudokwon Landfill: from Waste Containment to Energy Generation

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SYNOPSIS : Since its opening in 1992, Sudokwon Landfill has become a landfill in which wastes generated from more than 22 million people are treated and disposed of. Its first phase landfill was closed in 2000 and the second phase landfill is in operation since then. The Korean environmental policies on refuse have drastically evolved for the last decade or so. From merely safe containment of wastes, the utilization of them as a source for energy generation and the minimization of waste volume to be filled in landfills are in the mainstream. Keeping in pace with the new trends, several challenging projects are in their way to blossom in Sudokwon Landfill. This paper briefs some important activities in the landfill. They are (1) geotechnical issues related to the construction and maintenance of the 1st and 2nd Landfills and (2) landfill gas and bioreactor which are recently emerging in the market.

Key words : municipal solid waste, landfill, leachate recirculation, bioreactor, landfill gas

1. Introduction

On a reclaimed area of 19.9 km^2, 30 km west of Seoul, Sudokwon Landfill, literally the Seoul metropolitan landfill, was constructed in order to receive wastes from Seoul, Incheon, and Gyeonggi Province with a population of more than 22 million combined. The site is sectioned into four independent landfill sites and its expected life of use is until 2044. Its first phase landfill (or The 1st Landfill) with an area of 4.1 km^2 began operations in February 1992 and was closed in October 2000. Subsequently an area of 3.7 km^2 is in use as the second phase landfill (or The 2nd Landfill). As of 2008, 344,240 trucks carried 4.75 Tg (10^{12}g or 10^6ton) of wastes into the landfill among which municipal wastes were 0.94 Tg (19.8%) and construction wastes were 2.00 Tg (42.0%) (SLC, 2009).

The Korean Waste Management Acts mandating the standardized criteria as what they are now for newly constructed sanitary landfills and closed landfills have been in effect since mid 90's. As for bottom contaminant barrier in which geotechnical engineering community have played a key role inherently in its progress, the regulations require either (1) minimum 100 cm thick compacted clay liner with a hydraulic conductivity of 1×10^{-9} m/s or less or (2) a combination of 2.5 mm thick HDPE geomembrane and underlying minimum 50 cm thick compacted clay liner. On slopes of a landfill where the construction of compacted clay liner is not of ease, geosynthetic clay liner can be used as an alternative. Final cover should consist of multi-layers of different functions. From bottom to top, there exists gas removal layer, barrier, drainage, and vegetation layer. The barrier can be either minimum 45 cm thick clay liner with a hydraulic conductivity of 1×10^{-8} m/s or less, or (2) a combination of 1.5 mm thick HDPE geomembrane and underlying minimum 30 cm thick compacted clay liner. Sudokwon Landfill lies on soft marine clay deposit, but its intact hydraulic conductivity is not low enough to the required value. In order for the 2nd Landfill to comply with the regulations and hold necessary bearing capacity for traffic and waste load, cement-stabilized contaminant barrier was selected as a substitute for compacted clay liner. Final cover was installed on the 1st Landfill following its closure. A collective monitoring program is being run on both the 1st and 2nd Landfills. Observed are settlement, horizontal movement, landfill gas, leachate, etc.

The Korean environmental policies on refuse and landfill have shifted from merely safe containment of wastes to the utilization of them as a source of energy generation and the minimization of waste volume to be disposed of in landfills

(Fig. 1). Sudokwon landfill is in front line to lead the new trends, thus several challenging projects are in their way to blossom.

A demonstration project in which high calorific inflammable materials in a form of pellet are produced from waste after selection and separation process has been underwent since 2007. This refuse driven fuel (RDF) project employs a waste pretreatment facility, a.k.a. mechanical biological treatment (MBT), with a capacity of 2,000 tons/day and RDF generation unit of 1,000 tons/day. The construction of the facilities is scheduled to complete in December 2009.

Utilizing landfill gases (LFG) from expired landfill sites is an emerging business in the solid waste treatment market due to the potential reduction of green house gases. This method of solid waste treatment is perceived as a win-win solution since it generates energy while also combusting hazardous gases from landfill sites, which otherwise would be a source of air pollution. LFG is collected from the both landfills and used as energy source for power generation. The capacity of power generation has reached almost 60 MW since 2007: 50 MW, 6.6 MW, and 3.39 MW.

The concept of operating a landfill as a bioreactor has recently received increased attention. A bioreactor landfill is operated to enhance refuse decomposition, and waste stabilization. A major aspect of bioreactor landfill operation is the recirculation of collected leachate back through the refuse mass. A full scale project of leachate recirculation into two fill blocks (300m by 300m each) was launched at the 2nd Landfill in 2009.

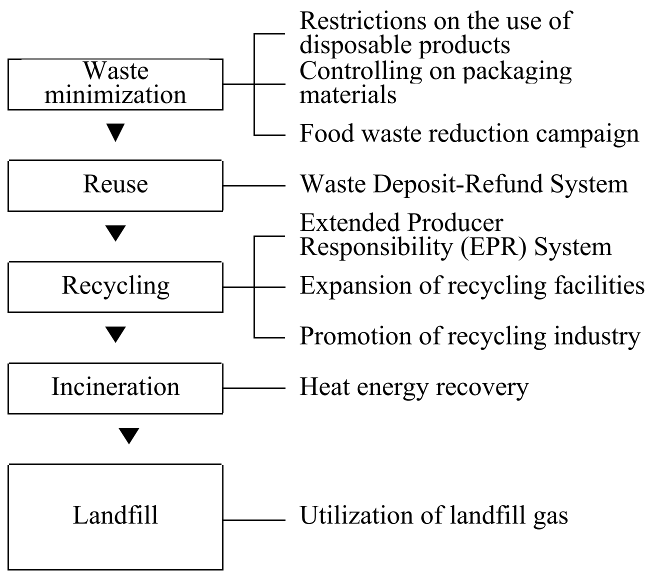

Fig. 1 Korean Practices for Waste Minimization (MOE, 2006)

2. Performance of Existing Facilities

2.1 Characteristics of Wastes

In 2008, a total of 4.7 million tons of solid waste were carried into Sudokwon Landfill. Approximately 20 % (942,462 tons) were municipal wastes, 42% (1,998,844 tons) were construction wastes, and 22 % (1,057,690 tons) were wastes from industry's discharging facilities including water treatment plants, wastewater treatment plants, and incineration plants. Table 1 summarizes the amount and type of wastes carried into Sudokwon Landfill. Table 2 shows the composition of municipal wastes and industrial wastes.

Municipal wastes consisting mainly of household wastes had significantly decreased since the introduction of nationwide prepaid standard garbage bags in 1995. In addition, promoting recycling policies have contributed to a consistent decrease of the amount of municipal wastes that are either disposed of in landfills or incinerated. In 1995 nationwide, the vast majority of municipal wastes up to 72.3% were disposed of in landfills while 23.7% of them were recycled and 4.0% were incinerated (MOE, 2006). The ratios turned to 36.4%, 49.2%, and 14.4%, respectively in 2004.

One noticeable change to landfill maintenance since mid 90's is that landfill has been operated to keep as possible dry condition as it can be in all procedures from waste placement to final covering. Wastes of high water contents such as sludge from sewage and wastewater treatment plants are dewatered before they are disposed of in landfill. This allowed the landfill to take control of order problem and to minimize the amount of leachate to be treated. As a result, the 2nd Landfill earned its alias the dry tomb. However, it should be noted that a dry tomb is not always favored when it comes to the generation of energy using LFG, which will be discussed later.

Table 1. The Amount and Type of Refuse Carried into Sudokwon Landfill (SLC, 2009)

Year (1)	No. of Truckload (2)	Amount of refuse carried into Sudokwon Landfill (ton)				
		Municipal Waste (3)	Domestic Waste (4)	Waste from Discharging Facilities (5)	Construction Waste (6)	Total
1995	780,141	4,441,752 (48%)	1,188,530 (13%)	1,128,494 (12%)	2,419,206 (26%)	9,177,982 (100%)
1996	717,943	4,315,433 (50%)	1,194,995 (14%)	1,245,822 (14%)	1,857,283 (22%)	8,613,533 (100%)
…	…	…	…	…	…	…
2006	399,333	1,264,537 (26%)	636,784 (13%)	436,046 (9%)	2,576,116 (52%)	4,913,483 (100%)
2007	394,231	1,158,661 (23%)	728,141 (14%)	526,124 (10%)	2,684,433 (53%)	5,097,359 (100%)
2008	344,240	942,462 (20%)	752,517 (16%)	1,057,690 (22%)	1,998,844 (42%)	4,751,513 (100%)

Note: Refused carried into Sudokwon landfill is categorized into municipal waste (Column 3) and industrial waste. Industrial waste divided into domestic waste (Column 4), waste from industry's discharging facilities (Column 5), and construction waste (Column 6). Extracted water from food waste is in the category of waste from industry's discharging facilities since 2007. Sludge from water and wastewater treatment plants, incinerated ashes, waste sand, etc, belong to waste from industry's discharging facilities shown in Column 5.

2.2 Settlement and Structural Stability

The 1st Landfill was closed in 2000 after having received 64 million tons of waste distributed to 11 inner blocks in 8 lifts. Unlike the 2nd Landfill, approximately 70 % of wastes placed in the 1st Landfill were municipal wastes and sludge of high water contents. Cover materials introduced to the landfill during its operating period amounted to 13 % of the total volume of waste fill. Park et al. (2007) reported that settlement of the landfill proceeded to so far maximum 7.7 m at Block M and minimum 4.7 m at Block H and that monthly settlement rates were 6.0 cm/month to 0.6 cm/month at the respective blocks. They also predicted that the landfill would continue to settle for more than 10 years and so with an additional settlement of 4.4 m to 5.0 m based on a rheological model (Ling et al., 1998) and hyperbolic function model (Gibson and Lo, 1961). Caution needs to be taken in predicting settlement at the 1st Landfill since the settlement plates are installed only on the top of the final cover in each block, from which settlement of the waste fill cannot be separated from that of the underlying soft clay deposit.

Table 2. Composition of waste (SLC, 2009)

Year	Municipal Wastes										
	Combustibles (%)							Incombustibles (%)			
	Total	Food	Papers	Plastics	Wood	Textiles	Others	Total	Glass	Metals	Others
2006	94.7	10.2	39.0	31.6	2.9	6.9	4.1	5.3	2.7	1.7	0.9
2007	93.8	11.3	41.0	27.7	2.2	6.6	5.0	6.2	2.8	2.2	1.2
2008	94.7	10.0	48.6	24.1	1.6	4.6	5.8	5.3	2.1	1.3	1.9

Year	Construction Wastes										
	Combustibles (%)						Incombustibles (%)				
	Total	Wood	Plastics	Papers	Textiles	Others	Total	Soil	Brick	Metal	Glass
2006	45.1	27.6	13.8	2.0	1.7	-	54.9	30.1	21.9	1.6	1.3
2007	41.0	26.8	10.0	2.8	1.3	-	59.0	32.7	23.2	1.7	1.3
2008	49.1	33.3	11.7	2.9	0.9	0.3	50.9	27.0	20.3	1.7	2.0

		2002	2005	2008
Bulk Density (kg/m^3)	Municipal Waste	208	127	153
	Construction Waste	756	347	315
Three Phased Composition (%)	Moisture	36.1	21.3	20.7
	Combustible	58.1	64.1	69.3
	Ash	5.8	14.6	10.0
Heating Value (kcal/kg)	High Level (H_h)	4,192	4,467	4,258
	Low Level (H_L)	3,569	3,940	3,761

Note: Values in three phased composition and heating value are only from municipal wastes.

Cracks and subsequent sinkholes were repeatedly found on the top of vegetation layer of the 1st Landfill at the interface between waste fill and dike which was used for the boundary of waste fill block and road for traffic. This is a typical settlement pattern observed in landfill where waste fill inherently undergoes far more settlement than dike. It took 15 days to 30 days for cracks to grow to an extent which immediate repair was needed and took another one month until a crack developed into a sink hole (Park et al., 2007; Kim et al., 2008).

The 2nd Landfill lies on soft clay deposit overlying hard clay layer. The thickness of the soft clay deposit ranges from 4 m to 13 m; the hard clay thickness is in between 3 m and 15 m. The northbound waste fill blocks facing inland sits on shallower soft clay deposit than the southbound blocks facing West Sea (Fig. 2). As of Feb. 2007, waste placement reached approximately 50 %. In all 25 blocks, waste filling up to the 3rd lift was completed and in 20 blocks excepting 5 blocks in the northern boundary waste was filled up to the 4th lift. Each lift is 5 m thick. Waste placement in the 5th lift is in progress in blocks located in the middle of the landfill.

One of the objectives of waste placement plan is to secure the structure safety of the landfill against ground and/or slope failure. A total of 290 measuring devices of various kinds including settlement plate, load cell, pore water pressure gage, inclinometer were instrumented in the landfill. Jang et al. (2008) and Choi (2007) investigated the relation between settlement and horizontal displacement measured beneath and at the edges of the dikes respectively as a safety index. It was found that blocks closer to the northern boundary exhibited higher values of the horizontal displacement to settlement ratio than blocks closer to the southern boundary, which was in opposite tendency in terms of the thickness of soft clay deposit. The rate of horizontal displacement with time is often used in monitoring the safety of embankment filled on soft ground. The same concept was employed to the landfill. In most of time, values did not exceed 2 cm/day which were thought to be safe.

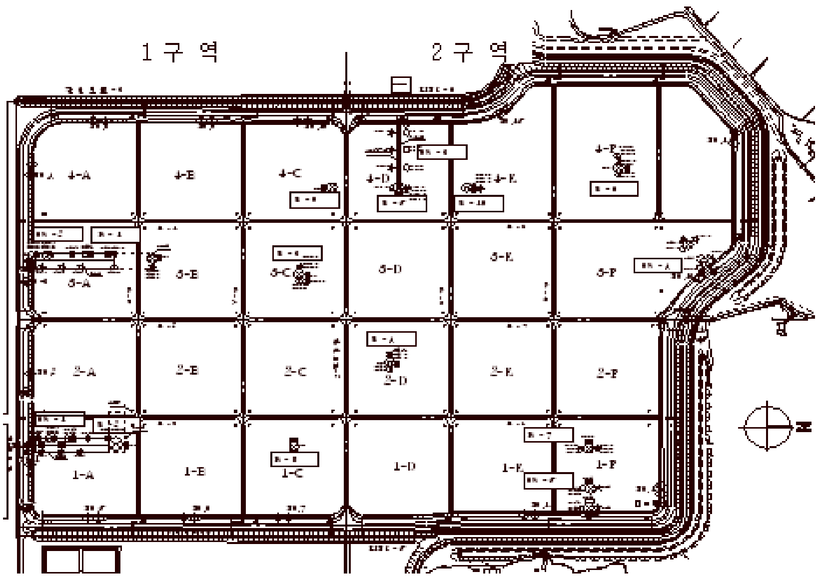

Fig. 2. Layout of fill blocks in the 2nd Landfill – The left end faces southbound to sea and the right end faces northbound to inland. The soft clay deposit overlain by the landfill is getting shallower from south to northbound.

3. Landfill Gas Generation and Bioreactor

One of the core issues in the improvement of landfills is landfill waste treatment including leachate. Landfill waste is characterized by different stabilization periods and leachate continues to be generated until landfill is finally stabilized (Chung et al., 2004). Because the quantity and quality of leachate are different from waste mass and characteristics, landfill elapsed time, cover soil, landfill management type, landfill design elements and climatic condition, more attention needs to be paid to the proper understanding of leachate quality and quantity. It also requires developing suitable processing technology considering the above situations. In addition, because cost of equipment for the leachate treatment facility accounts for more than 30% of the whole cost, the selection of economical and efficient method is important.

The methane gas produced at the landfill site is generally used as a source of energy. The methane composition of biogas and rate of gas production reach the most suitable condition in the methane fermentation phase of anaerobic degradation of solid waste in landfill. In final maturation phase, both methane composition and rate of gas production are maintained at a reduced level for an extended period of time. The collection and purification of methane gas produced is economically possible only for a limited number of years which is usually short as compared to the age of landfill; in other words, it is limited to methane fermentation phase of the anaerobic degradation of waste. In the final maturation phase, the collection and purification are uneconomical to be used as a source of energy (Kim et al., 1997).

Methane gas production in the final maturation phase lasts for an extended period of time due to the slow conversion of microbial resistant lingo-cellulosic materials into methane under the anaerobic conditions prevailing in a landfill. Therefore, generation of methane gas is inevitable. However, if the methane gas is not collected and escapes in the atmosphere, it leads to many problems, global warming being the most prominent one. Another problem is nitrogen removal in landfill leachate. The problems of leachate treatment are caused by: (1) the excess of organic matters and (2) the existence of materials disturbing coagulation of leachate.

Operating a landfill as a bioreactor is getting more attention recently. The operation of bioreactors provides several benefits including (1) more rapid settlement which results in increased effective density and air space, (2) in-situ leachate treatment, (3) increased gas production which can improve the economics of energy recovery, and (4) the rapid stabilization of a landfill to more environmentally benign state (Hossain et al., 2003; Chung et al., 2004; Kim et al., 2006; Sharma and Anirban, 2007). Besides, enhanced decomposition increases the rate of landfill settlement, which provides additional airspace prior to closure i.e. greater mass of waste can be buried per unit volume of landfills. Increased air space results in a reduction of total land use for landfills.

For the last ten years, a good number of research projects in laboratory scale were carried out in Korea (Kim et al., 2004; Park et al., 2004; Shin and Lee, 2004; Jeong et al., 2006; Kim et al., 2006; Jang, 2007). A full scale bioreactor has been launched at Blocks 3C and 4C of the 2nd Landfill to be performed for 18 months. Leachate would be circulated into the landfill through vertical injection wells as shown in Figure 3.

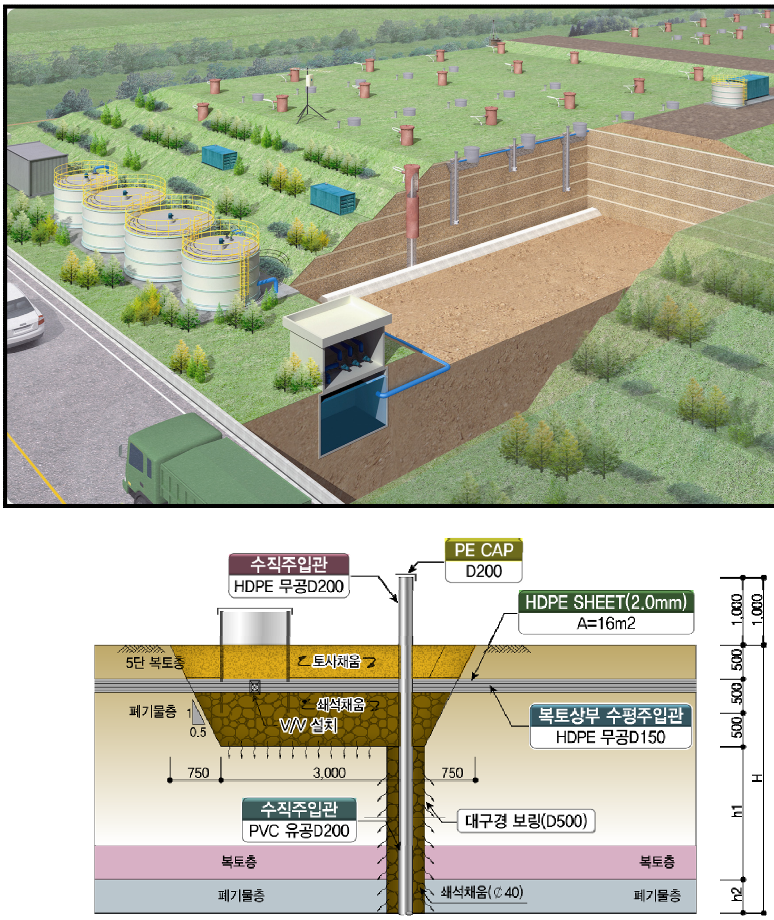

Fig. 3. A Schematic of Leachate Recirculation System as To Be Installed at Sudokwon Landfill

4. Conclusions

This paper presents some important activities at Sudokwon Landfill in which four independent landfill sites, so called the 1st to 4th Landfill, are positioned on a reclaimed area where thick soft marine clay deposit prevails. As of 2008, 4.8 x 10^6 tons of wastes generated form more than 22 million people in Seoul, Inchoen, and Gyeonggi Province were carried into the landfill. The 1st Landfill was in used from 1992 to 2000. But the engineered contaminant barrier system as required by the current regulation was not employed at the time of the 1st Landfill construction. It was since mid 90's that the standardized criteria as what they are for newly constructed sanitary landfills and closed landfills have been implemented. The total settlement of the 1st Landfill is reported to be 4.4 m at Block H to 7.7 m at Block M with settlement rate of 0.6 cm/month to 6.0 cm/month respectively. An additional settlement of approximately 5 m is expected for the next 10 years, after which golf course and park are planned to be constructed on it. For the 2nd Landfill, settlement and horizontal deformation along with other entities are monitored from 290 measuring devises which were installed from the beginning of its construction. The rate of horizontal displacement with time is used as an index for the stability of waste fill and is reported to be not exceeding 2 cm/day. As the Korean policies on wastes have evolved, many challenging projects have been in implementation at Sudokwon Landfill. They include power generation suing LFG and production of fuel from wastes aka RDF. The capacity of power generation has reached 50 MW. The facility for a RDF demonstration project is to be completed in 2009. As for a bioreactor landfill in which leachate is recirculated in a landfill to enhance biomass decomposition, a full scale project at the 2nd Landfill has been launched in 2009.

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