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ECOLOGICAL LANDFILLS: RULES AND STRUCTURE

Ştefan NEGREANU[1], Sorin AVRAM[1]

Abstract. From the point of view of waste integrated management, landfills are regarded as a high priority option by most of the public local administrations in Romania, but involve considerable economic investment and relatively large land areas. "Best available technology" becomes a mandatory option when opening such a site, as well as the choosing of the construction technology using the logic analysis Life Cycle Assessment, amortization of the investment, and also the environment protection. Community legislation provides a series of conditions, which must be followed, regarding location, structure, materials and general rules in terms of ambient impact studies, meant to ensure an increased degree of environmental protection accepting the increase in the limits of sustainable development.

Key words: ecological landfills, Life Cycle Assessment, community legislation

Since antiquity, along with formation and development of human communities, there appeared more or less the problem of managing the daily produced waste. The handiest solution was to throw it in the proximity of populated areas, where sometimes it was incinerated as we find out about the Ghe Hinnom valley, from the Bible. During the period without a strong technological development, there did not occur major changes in the way this problem was tackled. But the industrial development and the increase of population involved new types and greater quantities of waste. Nowadays, the great number of Earth's inhabitants implies an increasing consumption of goods and, consequently, huge amounts of industrial and domestic waste (Fig. no 1). The common solution used today for waste disposal is landfills. The European directive 31 from 1999, through annex 1, anticipates a series of rules that waste deposits should *fulfill*, and directive 12 from 2006 stresses out and clarifies the disposition of the afford mentioned.

Thus, in the case of deposits conforming to the principles elaborated by the two directives, a series of norms are to be met: ***1. regarding the location***, it must be chosen considering: the distance between the site limit and the residential, recreational areas, hydric bodies, agricultural terrains and cities must be determined by an environment impact study; the geological and hydrogeological aspects; flooding risk, subsidence, sliding etc.; the protection of national and cultural patrimony and finally the construction certificate of a waste deposit, in a certain location, must be approved by an environment license stating that the objective does not pose a critical problem regarding the environment; ***2. the hydric***

[1] The Faculty of History, Philosophy, Geography, University of Craiova

implications management must be considered (Fig. no 2): the precipitation infiltration control inside the deposit; prevention of water percolation; collecting contaminated water inside the deposit and of leaks (if through scientific analysis, performed by accredited organizations, it is proven that the leaks do not pose a contamination threat on the natural and human patrimony then this norm does not apply); contaminated water treatment according to present legislation before eliminating them in the hydric bodies; ***3. soil and water protection*** states the observation of the following parameters: geological and hydrological condition from beneath and around the landfill, for controlling and preventing an eventual phreatic or soil contamination; base and lateral sides of a landfill should contain a impermeable mineral layer of the following thickness:

- ecological deposits for dangerous wastes: water speed K ≤ 1.0 x 10-9 m/s; layer thickness ≥5m;
- ecological deposits for non-dangerous wastes: water speed K ≤ 1.0 x 10-9 m/s; layer thickness ≥1m;

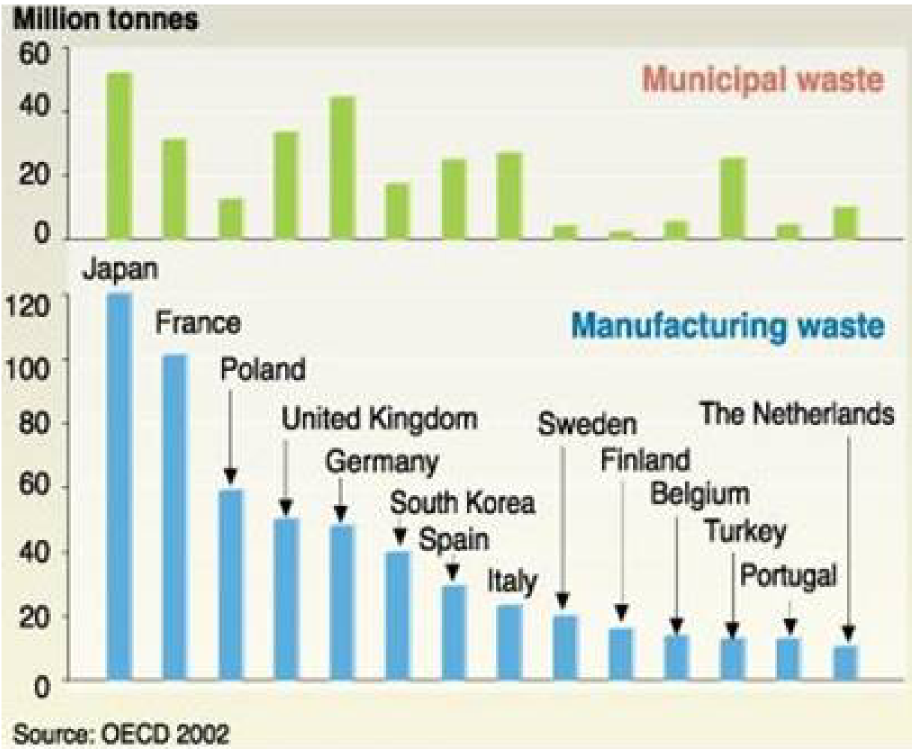

Fig. no 1. Total waste generation in selected OECD countries in mid-1990's

- ecological deposits for inert wastes: water speed K ≤ 1.0 x 10-7 m/s; layer thickness ≥1 m (where the natural conditions do not allow the needed impermeability, artificial materials can be used, but with a thickness of at least 0.5 m); additionally to the litho-pedological, there barrier must be interposed an artificial membrane (geomembrane) and a drainage horizon ≥ 0.5 m must be made; regarding the deposit coating, it must exist a gas drainage layer (this is not needed for safe wastes), an artificial coating layer (this is not needed for safe wastes), an impermeable mineral layer, a drainage layer of >0.5m, and a soil layer thicker than 1m. ***4. Gas control*** imposes all the measure necessary to prevent and control biogas escaping. The biogas must be collected, treated, and transformed into energy where possible (when it is not possible to use biogas to obtain energy, it is flared); capture, treatment, and use of biogas should be made in such a way to minimize the environmental impact; ***5. hazardous elements*** such as dust, odors, materials that might be lifted by wind, noise generated by landfill equipments and from waste collecting cars, potential fire generator elements, must be monitored; ***6. stability*** refers to choosing the safest landfill site, in order to prevent future stability loss, as well as to prevent new constructions within the buffer zone; ***7. barriers*****,** the landfill area must be secured by fences in order to restrict the access of unauthorized personal during and after work period.

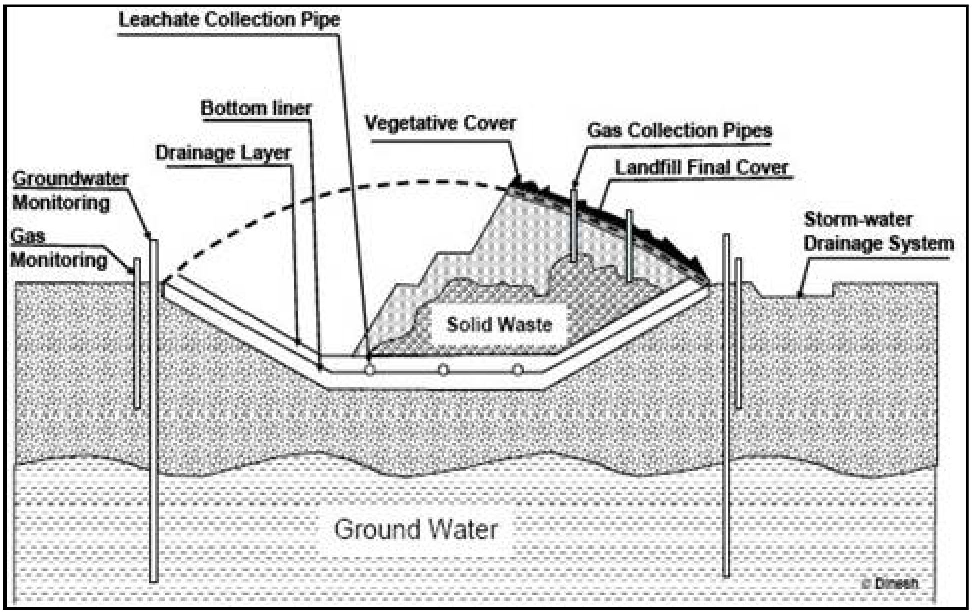

Fig. no 2. **Schematic diagram of a typical landfill**

Today, there are approved only monitored landfills, while uncontrolled landfills, with negative effects for all environment components, are closed or are going to be closed. The controlled sites have waste disposed in superposed layers, waste disposal being realized using methods with the lowest environmental impact.

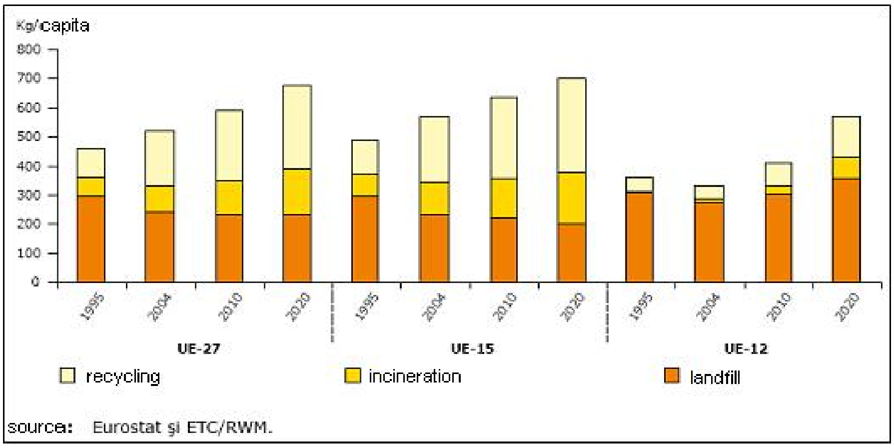

Fig. no 3. Generation and management of municipal waste in Europe (per capita)

STRUCTURE OF LANDFILL

Considering the method used to make a landfill, we may separate next landfill types:

I. *area method* (Fig. no 4), which implies waste filling of an existing excavation (an abandoned quarry for example);
II. *trench and fill method* (Fig. no 5), in this method of landfilling, waste is spread and compacted in an purposely for landfill excavated trench;
III. *mound method* which implies, placing the most of the landfill above natural level of the used area;
IV. *valley or change topography method*, consist from filling of a natural depression area;
V. *dry tomb* (Fig. no 2) is actually the method required by present environmental protection rules, and provides the greatest safety from all types already listed;
VI. *bioreactor type* which by various methods accelerate, in a controlled way, waste decaying. This type has some subtypes considering methods used to accelerate the decaying:
    - aerobe type, biodegrading is caused by aerobic bacteria in presence of air pumped into vertical or horizontal pipes;
    - anaerobe type, biodegrading is caused by methanogenic bacteria in presence of permanent moisture;
    - hybrid type, in the upper part is used the method of the first type, while in the lower zone, it is used the method of the second type.[1]

All landfill types have to have security elements to prevent nearby areas contamination. To avoid ***leachate*** contamination of phreatic or surface waters base and lateral sides of landfill are isolated, acting in the same manner for the upper part of the landfill once the maximum capacity scheduled in the initial project, to avoid infiltration of rain water (Fig. no 2, Fig. no 6). Isolation of a landfill is realized by using, in a combined or not manner, natural materials such as silt, clay and geosynthetic ones.

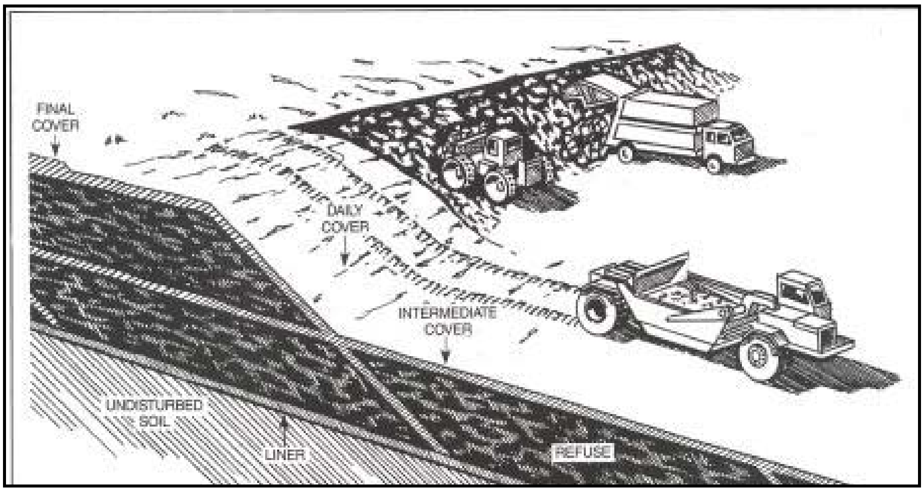

Fig. No 4. Area method

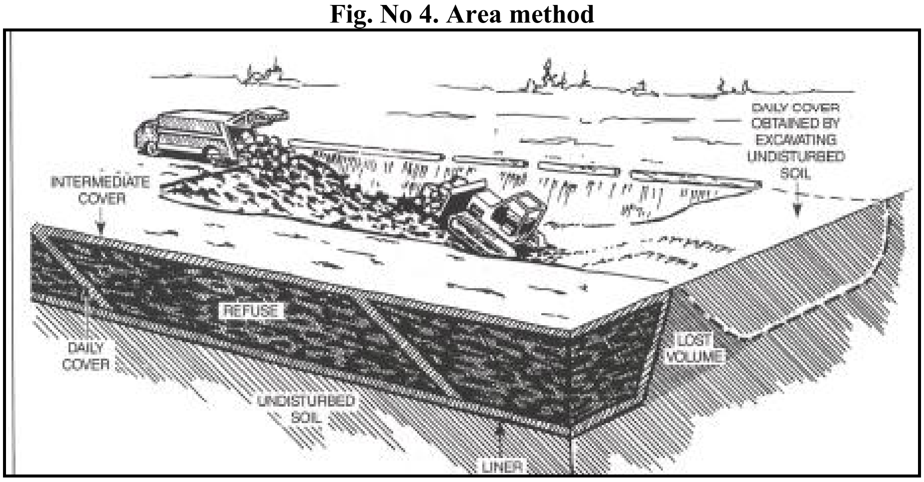

Fig. no 5. Trench method of landfilling

Geotextiles are usually produced as either woven or non-woven textiles fibers of polypropylene, polyester, polyethylene, polyamide.

Geogrids are made from the same materials as geotextiles, but they are more rigid than these, being used to consolidate instable slopes.

Geomembranes are the most used items in landfills, retaining the leachate and preventing its infiltration in adjacent area of landfill. To increase mechanical resistance, geomembranes are used together with geotextiles. They are made from LDPE Low Density PolyEthylene, HDPE High Density PolyEthylene, polyvinyl chloride PVC, polypropylene PP. To increase the isolation of a landfill, there are usually used combinations of geomembrane and bentonite or other clay material called Geosynthetic Clay Liner, GCL. Montmorillonite rich (more than 70%) bentonite is the most convenient material for this purpose. Sodium rich bentonite can increase its volume six times compared to the initial state. Another advantage of sodium bentonite is its high cationic exchange capacity, property which makes it accumulate a great part of noxious elements.[2].

Geocomposites are obtained by combining the above mentioned geosynthetic materials.

Beside liquid products the spreading of which outside the landfill, is limited using geosynthetic materials, gases resulted from waste decaying should be controlled too. Gases are collected through PVC or other chemical resistant materials, pipes. These pipes are surrounded by gravel or other material which will allow free circulation of gases and leachate. Collected gas should be either burned or treated and used as an energy source.

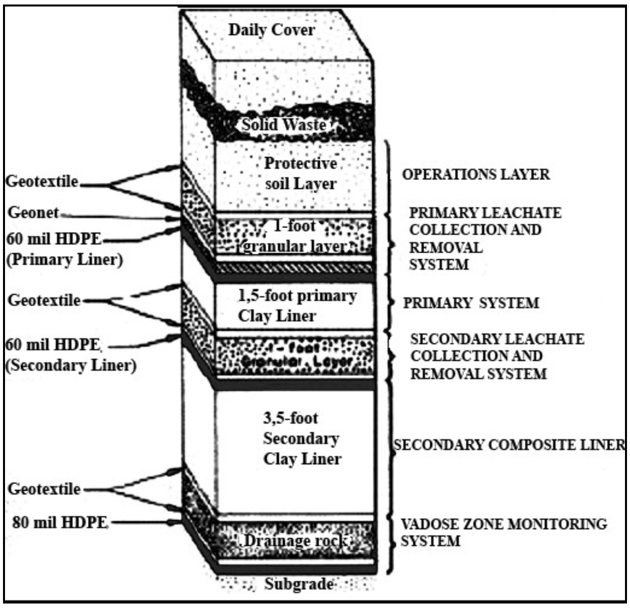

Fig. no 6. Liner system source DCCEE North Carolina

A controlled organic deposit should provide waterproof side walls and base, as stipulated in the European directives; during its existence (Life Cycle Assessment), it has to meet several conditions:

- a water treatment plant for percolation water;
- the waste should be deposited on a 2 ÷ 2.5 m thick layers – the daily coverage of the waste with a soil layer having a minimum thickness of 15 cm;
- biogas uptake and disposal.

After the activity suspension, the deposit must be sealed with clay and biomass of 1.5 - 2 m thickness and a soil layer of 30 ÷ 50 cm. As for the location, in addition to the above mentioned conditions, the minimum distance of 200 meters has to be specified. This is the distance up to the targets listed at number 1, set up by the WHO (World Health Organization), or 300 m in a temperate climate; 500 m in a subtropical climate, distances recommended by the IIS (Institute of Sanitary Polytechnics Engineering -- Milan).

The controlled waste deposits represent the most economically profitable alternative, but they should be taken into consideration together with other methods of storage, which are the final destination of the waste, from the Romanian local authorities' point of view. However, in the countries with a strong ambient vocation, the waste percentage that ends up in the ecological deposits, represents 7% of the total volume of the waste (Fig. no 3). The waste controlled deposits require relatively large areas and if used monopolistically they cause an important loss of raw material and energy.

LEACHATE AND BIOGAS

Wastes cause two types of pollution, which correspond to the migration into the natural environment of:

- leachate, defined as water that has percolated through the wastes (rainwater or groundwater seepage), a source of soil and groundwater contamination,
- biogas produced by the fermentation of organic matter by microorganisms (bacteria), represent a source of air pollution.[3]

In addition to the type of waste involved (industrial, domestic), leachate characteristics are determined by the sitting, the design and the mode of operation of the landfill, and also depend on its evolution through time.

Organic and inorganic contaminants of landfill leachate are released from the waste due to successive biological, chemical and physical processes.

Leachate contains water, organic matter in various stages of decay, ammonia, sulphates, and metallic cations (Table no 1). For 20 years time period there are separated three main phases of waste decaying:

- the first phase corresponds to the period right after waste deposition. During this initial aerobic phase, the oxygen present in the void spaces of the freshly buried refuse is rapidly consumed, resulting in the production of CO_2 and heat. Leachate produced during this phase results from the release of moisture during compaction, as well as from the short-circuiting of precipitation through the buried refuse;
- the second phase is called the acid phase. Now, as oxygen sources are depleted, the waste becomes anaerobic, which supports fermentation reactions. Due to bacterial activity, acids are formed and this causes a lower pH. As it is acid, the leachate causes decomposition of various compounds. BOD and COD display the greatest values during this phase.
- the initial methanogenic phase, the third one, occurs when measurable quantities of methane are produced by methanogenic bacteria, which now can develop because the pH of the refuse became sufficiently neutralized for at least limited growth of bacteria. During this phase, the acids that accumulated in the acid phase are converted to methane and carbon dioxide by

methanogenic bacteria, and the methane production rate will increase.

The chemical composition of the leachate undergoes the most important changes regarding the quantity and type of organic matter represented by the fat volatile acids in the first 10 years and by fulvic and humic matter after this period. The values of the inorganic compounds remain constant during landfill activity.[3]

Biogas resulted from the decaying of organic matter by microorganisms, in the absence of oxygen, is formed mainly from methane (CH_4) and carbon dioxide(CO_2).[1]

For a period of 100 years, methane is 20 times more important in causing greenhouse effect than carbon dioxide.[4] To understand the influence of methane we should remember Paleocene-Eocene Thermal Maximum, which was caused by releasing methane from oceanic sediments, where it was trapped as methane hydrate.

Landfills represent a important methane source, an EPA (Environmental Protection Agency) report for 1997 shows an approximately 11.6Tg produced in 1997, which is equivalent with 37% from all human generated methane.[5]

Table no 1

Leachate composition (in mg/l)

(after Peter Kjeldsen & Al *Present and Long-Term Composition of MSW Landfill Leachate: A Review*)

Parameters	**Value**	**Parameters**	**Value**
pH	4,5 - 9	Chloride(Cl^-)	150 - 4 500
Total solids	2000 - 60000	Sulphate (SO_4^{2-})	8 - 7750
Organic matter		HCO^-_3	610 - 7 320
BOD_5	20 - 57 000	Sodium(Na^+)	70 - 7 700
COD	140 - 152 000	Potassium(K^+)	50 - 3 700
BOD_5/COD	0,02 - 0,08	N-NH4	50 - 2 200
Organic nitrogen	14 - 2 500	Calcium(Ca^{2+})	10 - 7 200
Heavy metals		Magnesium(Mg^{2+})	30 -15 000
Arsenic	0,01- 1	Iron(Fe^{2+})	3 - 5 500
Cadmium(Cd^{2+})	0,0001 - 0,4	Manganese(Mn^{2+})	0,03 - 1 400
Chromium (Cr^{3+})	0,02 - 1,5	Silica(SiO_2)	4 - 70
Cobalt	0,005 - 10		
Lead(Pb^{2+})	0,015 - 13		
Mercury(Hg^{2+})	0,00005 - 0,16		
Nickel(Ni^{2+})	0,015 - 13		
Zinc(Zn^{2+})	0,03 - 1 000		

Because of this situation, rules were established to reduce methane discharge into the atmosphere. One of these rules refers to the collection and ulterior use of gas (to obtain electricity, to heat buildings, car fuel) or immediate burn of CH_4, when landfill capacity exceeds 2.5 million cubic meters.[5]

The quantity of methane generated in a landfill is calculated using the following formula:

$$Q_{CH4}=L_0 R (e^{-kc} - e^{-kt})$$

where:

Q_{CH4} = methane generation rate at time t, m^3/yr

L_0 = methane generation potential, m^3 CH_4/tone of refuse

R = average annual refuse acceptance rate during active life, tone/yr

e = base log, no units

k = methane generation rate constant, yr^{-1}

c = time since landfill closure, years (c = 0 for active landfills)

t = time since the initial refuse placement, yr [6]

For a million tones landfill, five years old, biogas production is about 3,760,500 m^3, from which methane is around 50%.

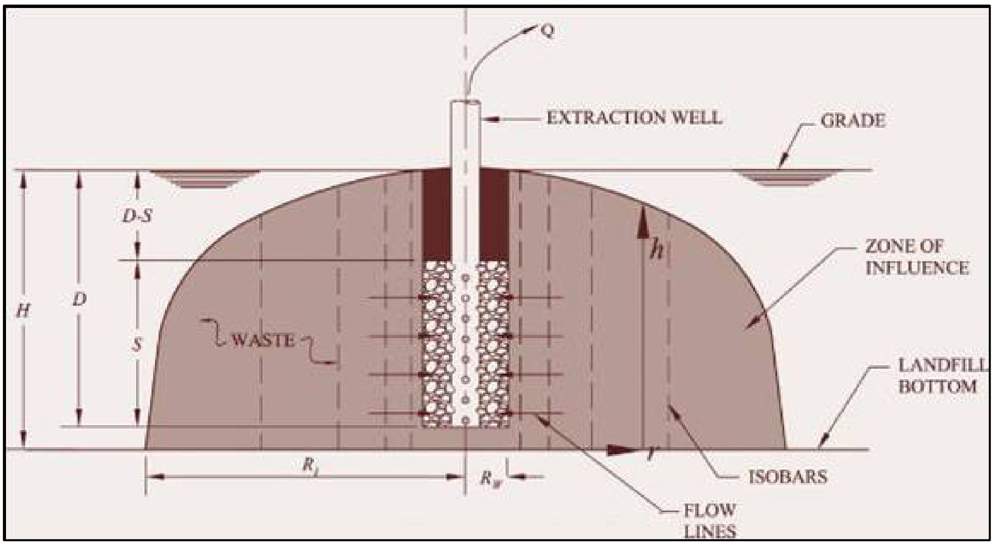

Fig. no 7. Vertical section of a biogas extraction zone, with representation of extraction pump influence area (after Thiel and Narejo)

From 4 millions cubic meters of biogas, in a year, it can be produced 4.50 MWh [7] which could supply 660 to over 1,400 homes, depending on medium annual energy consumption which is between 3,500 and 7,500 Kwh [8].

Distances between vertical gas wells are set considering activity area of extraction pumps, area which depends on depth and pressure of upper part of the well.

For approximately 7,500m^3 of waste should be a venting head[11], the influence area of which looks like in Fig. 7, where it is represented the vertical section of a gas collecting zone. In this figure abbreviations means:

D = well depth

H = maximum depth of influence

S = length of gravel pack around the well screen

R_I = radius of influence

r = radial coordinate (centered on the well), where $0 < r_I$

h(r) = height of the influenced volume at radius, r

Q(r) = flow rate to the well at radius, r

R_w = borehole radius

People living near solid waste landfills where biogas is escaping have a four-fold increased chance of bladder cancer or leukemia (cancer of the blood-forming cells).

As the methane and carbon dioxide form, pressure builds up inside a landfill, forcing the gases to move. Some of the gases escape through the surrounding soil or simply move upward into the atmosphere, where they drift away. Typically, landfill gases that escape from a landfill will carry along toxic chemicals such as paint thinner, solvents, pesticides and other hazardous volatile organic compounds (tetrachloroethylene, trichloroethylene, toluene, benzene, vinyl chloride, xylene, ethylbenzene, chloride, and chloroform).[9]

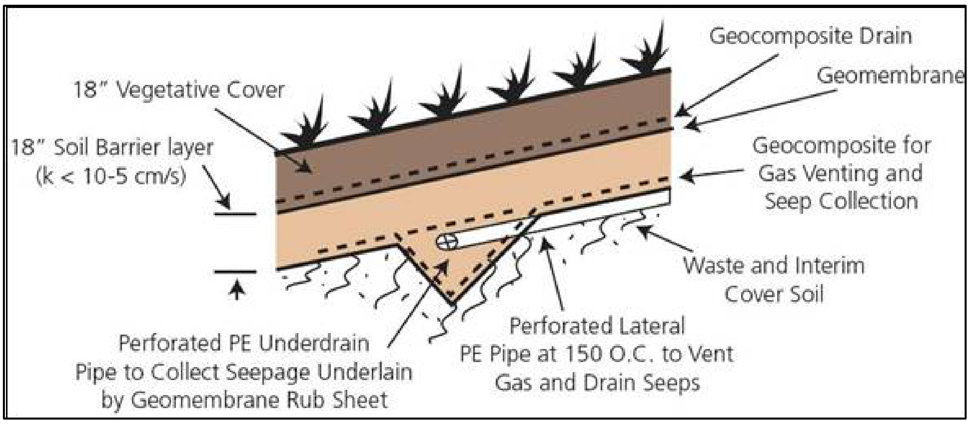

Fig. no 8. Seep collection at toe of gas collection layer under final cover system (after Thiel and Narejo)

Because of these negative effects, after landfill closure, beneath the grass layer, there should be installed gas collecting systems like shown in figure 8.

CONCLUSION

Evolved from simple waste to real power plants, as it is the case of the most advanced types of ecological deposits, ecological landfills do not fully resolve the problem of waste. Beginning with 1970, the concern for the improvement of these areas, led to the identification of new threats for human health and the environment, generally. The adopted solutions initially aimed at preventing the leachate infiltration in the ground and especially in the area of groundwater, by using synthetic and natural materials, the best solutions are achieved by combining these two types of material. Increased awareness of powerful hazards determined by uncontrolled landfills led in years ‘80 to first legislation which was subsequently amended, the laws becoming more detailed and punctual. Gaseous and liquid products of landfills are still a problem for many of the deposits considered modern because of the lack of materials able to ensure a total isolation (for example, synthetic membranes covering the final deposits can distort and tear, because of gas pressure and the action of vegetation). With an increasingly complex structure, landfills removes a major part of the issues raised by their presence, landfill gases and leachate are still the products whose effects should be reduced as much as possible.

The relatively short period of time when the preoccupation regarding the reduction and elimination of the effects generated by the waste deposits did not allow the exact knowledge of the behavior of the materials used on long term in the conditions of the interaction with the products resulted from the waste decay. The data used for the projection of the deposits that acquire the minimum requests stipulated by the environment protection laws, due to the above-mentioned motif is not totally based on concrete data directly obtained from the ecological deposits, part of them being the result of the laboratory experiments and computer modeling of different processes introducing the temporal factor.

In order to avoid the present and future problems related to the evolution of the waste deposits, the present tendency in the countries with great experience in the field is not only to do them more efficient thus implying higher costs, but also to ideally eliminate the accumulation of waste in deposits without sorting, as it happens in certain cases. This is already achieved in different percentages through the differentiated collecting and recycling and the programs on longer periods of time stipulate the increase of these procedures which would reduce the surface and the effects of the domestic waste deposits.

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