INNOVATIVE TECHNICAL AND ENVIRONMENTAL ASPECTS IN PLANNING, CONSTRUCTING AND OPERATING THE SANITARY LANDFILL OF LARISSA

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EXTENDED ABSTRACT

The aim of this paper is to present the technical and environmental aspects as well as the acquired experience in designing, construction and long-term operation of the Sanitary Landfill (SL) of Larissa, which started its operation in February of 1998.

The SL of Larissa is located about 25 km to the NW of the city of Larissa. The total area of the plant is 56 hectares, 20 of which will be developed as landfilling area. For the time being the SL of Larissa serves mainly the Municipality of Larissa, of 160.000 inhabitants and 60.000 tons of municipal solid waste (MSW) per year, however it has been planed to accept the MSW of the whole Prefecture of Larissa with an equivalent population of 300.000 inhabitants, as well as to accept 100.000 tons of MSW per year for ~ 30 years.

The design and the operation of the SL of Larissa complies with the most advanced technical specifications, as well as empirical data and current practice and is in conformity even to the latest Directive of the European Union.

In order to achieve an optimum control of the leachate and landfill gas, the landfill has been gradually developed in independent Phases.

For the prevention of ground and groundwater pollution, a sophisticated lining as well as drainage system was applied to the floor and sides of the existing Phases, having the potential to be easily extended in steps, for the construction of future Phases. The principle of leachate management includes the minimization of leachate production, the prevention of any uncontrolled migration as well as the handling of emergency situations in cases of heavy rainfall and finally, the efficient leachate collection and treatment.

The method used for leachate treatment is biological treatment in aerated lagoons in the Leachate Treatment Plant situated in the landfill area.

Regarding biogas management, there are horizontal gas collection pipes, which have been buried in the waste mass. The necessary collection pipework and pumpstation have also been installed.

The method of gradual restoration, which is employed In the SL of Larissa has been designed according to the EU Directives, so that the site can be restored in phases in an environmental friendly manner.

Environmental monitoring is conducted in a stable and very frequent basis in order to ensure that no contaminants that may affect public health and the surrounding environment are released from the landfill.

Key Words: Sanitary landfill, groundwater protection, leachate minimization, leachate treatment, biogas management, landfill economics.

1. INTRODUCTION

Over the last decades the landfilling of waste has developed dramatically, in spite of the implementation of integrated waste management plans and politics. In recent years considerable information in sanitary landfill design has been obtained, which suggests that if a Sanitary landfill has been designed to the state-of-the-art technology, it could offer a relatively straightforward and affordable option for the disposal of the MSW [1].

For that reason a lot of countries including Greece, give high priority to the construction of sanitary landfills that involve fully engineered facilities, which are supposed to overcome the environmental impacts of the open dumps or uncontrolled landfill sites [2]. However, recent experience in this matter suggests that very few sanitary landfills meet the current environmental standards [3], as well as the construction and operation of sanitary landfills present a number of practical challenges and potential failures that should be adequately handled or avoided to ensure that the problems commonly associated with open dumping, do not occur [1]. The experience gained from our visiting many sanitary landfills in Greece, Europe and USA in the late nineties, supports the above statements.

In view of the increasing demand for information regarding proper design, construction and operation, taking into account that there is a lack of relevant integrated information, it is the aim of this paper to provide our existing relevant knowledge on the **"what and why to do or to avoid"**, according to our experience during the design, construction and long-term operation of the Sanitary Landfill (SL) of Larissa.

It was 1985 when it was evident that the (then in use) "controlled" landfill of Municipality of Larissa in Greece could hardly accept the MSW of the city of Larissa for the forthcoming years, being very close to saturation, whereas the MSW of the neighbouring municipalities was being forwarded to the numerous open dumps spread around the region. In order to resolve this crucial issue because the situation had already reached a crisis, the Municipality of Larissa proposed the construction of a new, modern, with high standards sanitary landfill, which could be able to serve the wider area of Larissa and the neighbouring municipalities and communities, as a part of the general programme for the management of municipal solid waste of the Prefecture of Larissa.

In 1998, after 13 years of tergiversations between the appropriate Authorities of Larissa, the new sanitary landfill was finally ready, being able to serve an equivalent population of at least 160.000 inhabitants, having the ability to accept 60.000 tons or more of municipal solid waste per year and to be in operation for more than 30 years. Furthermore it has the ability to be extended (with minor modifications) in order to accept the MSW of the whole prefecture of Larissa.

The design of the SL of Larissa, the supervising of the relevant works, as well as its operation have been worked out mainly by the engineering team of the Waste Management Department of Municipality of Larissa. It complies with the most advanced specifications, taking into account the local conditions of ground, groundwater and surface runoff, the demands for planned phased operation and gradual site restoration, the demands for effective lining, leachate and landfill gas management, the requirements for sufficient infrastructure for independent operation and continuous environmental monitoring, as well as the demands for reasonable operational costs.

2. CHOICE OF THE SITE

The new S.L.L. is located in the Municipality of Makrichori of the Larissa Prefecture, 3 km NW of Maurolithos village and about 25 km to the NW of the city of Larissa. The choice of this site was anything but easy. It took more than a decade of searching for the appropriate Authorities of Larissa, as well as the relevant Ministries in order to finally settle in the location where the SL is located today.

All these years a lot of efforts had been wasted mainly in contentions and retractions between those authorities, mainly on the issue of which was, or better was not competent to choose the site. Furthermore, if finally a site seemed to meet unanimously the criteria for use as sanitary landfill, it was the reactions of the neighbouring communities as well as individuals that led the authorities to cancel their decision and the search for a new site to start once more. Apart from the NIMBY (Not In My Back Yard) effect of the public, the NIOT (Not In Our Tenure) syndrome was registered concerning the Authorities.

This way, more than 10 sites had been chosen and then rejected all those years. Some of them, compared to the one where the SL of Larissa is finally located, were by all means much more feasible. However their great “disadvantage” was that all those areas were public ownerships, most of them being more or less land – grabbed. It is not by chance that the finally chosen site for the SL of Larissa was privet property, as well as that the owners of this site and the neighbouring communities co-operated with the Authorities without any protest. Total land acquisition cost ~ 960.000 € (rates of 1997).

Nevertheless, the finally chosen site, proved to meet adequately the geotecnical design criteria, having excellent hydrogeology, natural topographical relief, as well as appropriate location, concerning the distance from critical habitat areas, highways, airports, etc. Its main disadvantages were the small depth of the sandy clay soil (up to 4 m), the high permeability of the underneath gneisses, its distance from the Peneus river (2 Km), and finally that it is located very far from Larissa (25 Km). Total costs (all referred prices include VAT of 18%) for geological and hydrological researches (rates of 1996)~ 80.000 €

3. DESCRIPTION OF THE SITE AREA

The total acquired land is 150 hectares. The total area of the plant (green coloured in Fig. 1, depicted with the Phase I completed) is 56 hectares, 20 of which will be developed as landfilling area. It has a total volumetric capacity of 3.240.000 m^3 MSW and an expected lifetime grater than 30 years. The landfill site is constructed in a natural depression with smoothly dipping sides (15%-25%, No 1 and 2 of Fig. 1). The depression floor is 850m long along its axis and dips 5% (No 3 of Fig. 1) to the NNW, and the vertical height of the sides is circa 20m. The altitude of the landfill area varies between +180m to +230m. The area, in which the landfilling takes place, is not immediately visible from the surrounding area, with urban and cattle-breeding activities. The landfill site is situated in gneisses and locally, up to 4m depth, the sandy clay soil from the weathering of the gneisses crops out. The existing in situ clay is hardly adequate (concerning the quantity) as artificial geological barrier, but of excellent quality (permeability lower than $1x10^{-9}$ m/sec). The groundwater table in the wider area is encountered at +60m above sea level containing very poor but not at all polluted aquifers and the unsaturated zone under the landfill has a thickness of 140m.The area is characterized by a relatively low annual precipitation, in average 450mm, with dry and very hot summers and humid and cold winters.

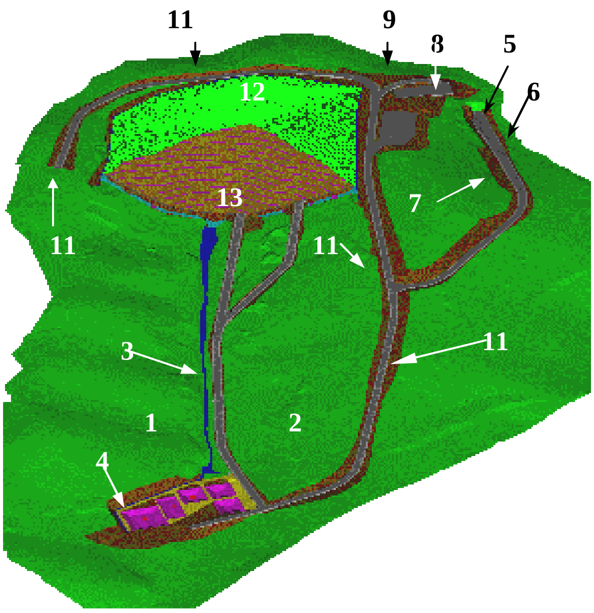

Figure 1: Site Layout

4. DEVELOPMENT OF THE LANDFILL – LAYOUT

The main issue of concern was for the landfill to be gradually developed in independent Phases, in order to achieve, separately for each Phase, an optimum control of the leachate and landfill gas. Each Phase is designed to accept MSW up to 4 years, and it is independent from the other ones by means of separate collection of the leachate and landfill gas. Concerning the leachate collection, the phases are hydraulically separated by boundary clay berms (No 1 for Phase I and No 2 for Phase II of Fig. 2). With regard to separate gas collection, the phases are separated by construction of a temporary cover immediately after the closure of each separate landfill phase. This cover blankets both the upgradient sides (dome) of each phase (No 3 of Fig 2, No 12 of Fig. 1) and the sides

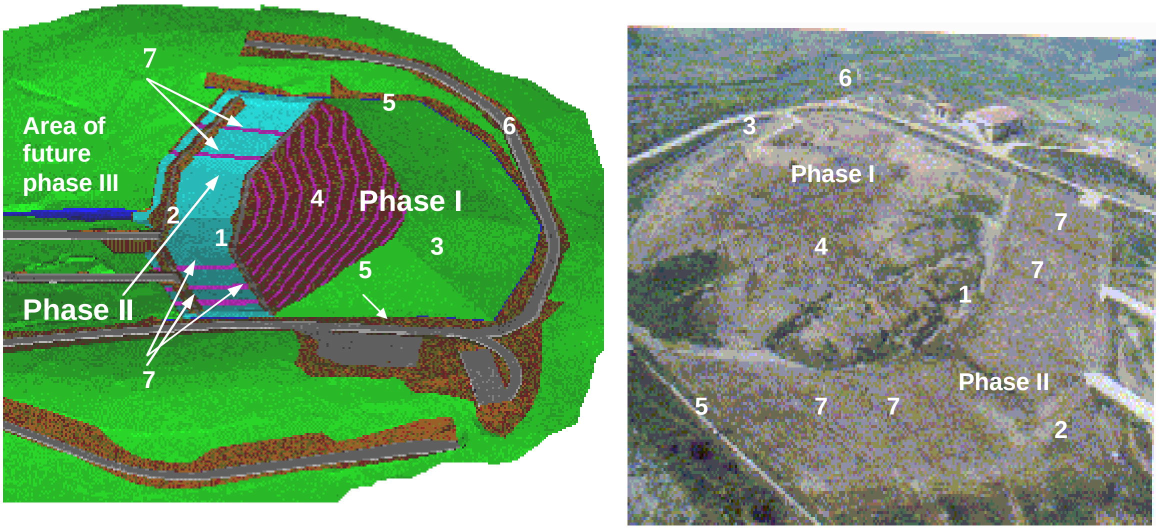

Figure 2: Phase I (completed) and Phase II (ready to accept MSW)

(downgradient slope) adjacent to the next operational phase (No 4 of fig. 2, No 13 of Fig.1), reducing efficiently the migration of gas to the adjacent phases or to the air. Furthermore, during the gas pumping, it restricts the absorption of air from outside or the absorption of inferior quality and quantity gas (due to younger MSW) from the adjacent next Phase.

Let us stress out that it is crucial to avoid constructing the lining and drainage of all the phases at one step. First of all it is very important for the designers, constructors and operators of a specific landfill to be able to embody to the next phases their experience acquired from the previous ones, as well as to apply in those future phases new improved technologies, materials, etc. Furthermore it is likely that major ruination could happen, due to the prolonged exposure to weather conditions, to the lining (cracking, deformation) or to the drainage (the roots of growing weeds cause clogging). Finally in most cases it could create troubles to the internal routing as well as to the unobstructed access of the working phase.

Taking into account the topographical relief of the area, as well as the efficient leachate and landfill gas management, our experience dictates that the optimum Phase size is that which effectively combines a capacity of 250.000 up to 350.000 tons of MSW, duration of 4 up to 5 years, as well as average lined area of 1.5 up to 3 hectares.

The SL of Larissa would be developed in ~8 phases, starting Phase I from the higher part of the depression to the lower part. We think that starting from the lower part could force everybody to deal with a great number of inconveniences and risks, such as to prevent the accumulation of water upgradient the working Phase, the routing of the leachate transfer pipes of the upgradient (newer ones) Phases to the downgradient treatment plant, etc. Phase I of the landfill was prepared and lined, with an area of 4 hectares (it was located in the shallower part of the depression) and expected operation time 4,3 years (finally it was 5 years, due to better compaction that we achieved). It is bounded to the SSE from the upgradient peripheral drainage trench (No 5 of Fig.2) and the peripheral access road (No 6 of Fig.2), whereas to the NNW it is terminated at the downgradient boundary berm (No 1 of Fig. 2).

Phase I (depicted completed in Fig. 1 and 2) has been developed with a basin morphology, having max slopes of 8%-15% along, and 10%-25% across its long axis. Phase I being completed (see paragraph No 9), the disposal of MSW has continued (from 01-01-03) to the adjacent Phase II (Fig. 2) of an area of 1,7 hectares and expected operation time of 4 years. Following the Phase II is the Phase III (now under construction) and so on, until the completion of all the available landfilling area of 20 hectares and the end of operation of the landfill, estimated from the design in more than 30 years.

At the NNW part of the site, downgradient of the active landfill area, the leachate treatment plant (No 4 of Fig. 1), the main groundwater monitoring well, as well as the power building for the operation of the plants are situated. Two more groundwater monitoring wells have been constructed, one west of the landfill and one more close to the administration building, used as the reference well and also for the water supply of the facilities. The site entrance (No5 of Fig. 1), weighbridge and entrance office and weigh room (No 6 of Fig.1), the administration building (No 7 of Fig. 1), the equipment service building (No8 of Fig.1), the car tires shredder (No 9 of Fig. 1) and the MRF building are all situated in the western part of the site. The SL of Larissa is provided with sufficient paved access roads to all facilities and an all-weather access road along the perimeter of the landfill area (No 11 of Fig. 1).

5. LINING SYSTEM

For the efficient collection of leachate and gas and the prevention of ground and groundwater pollution, a lining system was applied to the floor and sides of Phase I, as well as of Phase II. The main issues of concern were to apply a safe, failure free, cost effective lining system, in order to achieve a long-term sealing and protection of the groundwater table taking into account the local subbase permeability, as well as simultaneously to obtain the optimum landfill capacity. The lining system of the SL of Larissa complied with the specifications of the then relative Directive of the EU, but it proved to be in conformity even to the today's latest Directive of the EU (1999/31), as well as the latest Greek Legislation (29407/3508/2002 Joint Ministerial Decision).

It is a single composite lining system, comprising from bottom to top:

- Artificial subbase of 20 up to 30 cm of earthy materials densely compacted.
- Artificial geological barrier, 60m thick in three layers (20 cm each), with a permeability coefficient $k \leq 6x10^{-10}$ m/sec, constructed of bentonite-enriched natural clayey soil.
- Geomembrane HDPE, 2mm thick, used for the total lining of each Phase.
- In crucial points where leachate could lie stagnant for a while, Geosynthetic Clay Liner (GCL) of a thickness of 6 mm and a $k \leq 5x10^{-11}$ m/sec was placed beneath the membrane to enhance the permeability of the clay liner, as well as to give more penetration protection to the membrane. Such points are the No 7 of Fig.2 trenches (drainage terraces), as well as the No 2 of Fig. 2 upgradient slope of the boundary berm of each Phase in construction, including the adjacent lower parts of the Phase's basin.
- Geotextile for the protection of the membrane. It is a heavy duty, non-woven continuous fibre polypropylene geotextile, 6 mm thick.
- Drainage layer, 0.50m thick. A drainage blanket - leachate collection layer, covered the whole lined area, with a total thickness of 0.50m. The drainage blanket consists of a lower 16-32mm gravel sub-layer, 0.35m thick and an overlying clean sand layer, 0.15m thick, which prevents the clogging of the gravel sub-layer due to the waste particles. The two sub-layers are separated by separation-filtering geotextile, 2mm thick.

Total cost (rates of 2002) of the above described works of lining and drainage ~660.000 € per hectare.

Quality control and assurance are conducted and repeated frequently during the construction, including sampling and testing of all geosynthetics before installation. Prior to the construction of the artificial geological barrier, laboratory analyses of the suitability of the natural clay soil, as well as in situ compaction and permeability tests in a test area under site conditions were performed. The above quality control tests were performed regularly during all phases of construction of the geological barrier.

Some rules of the acquired field experience:

- The landfill designer in seeking maximum possible landfill volume, has to provide simple, no-complex geometries for the landfill base, otherwise the quality is reduced and the use of effective technology is prevented [4].
- Do not underestimate the importance of the subbase. Compaction to 95% modified Proctor's density and grading of the subbase are necessary in order to achieve an easy and efficient actual liner [5].
- The direct use of non-treated natural clays does not meet either material or procedural demands. In order the clay to act as a sealing medium, certain properties of the material must be achieved prior to placement. The pre-treatment procedure should include crushing and homogenisation of the raw clay, taking into account that the existence of medium size clay clods and stones should be detrimental to the compaction and sealing process [4]. This is much more important when clay should be mixed with bentonite, considering that direct spreading and rotovation for mixing in site should be strictly avoided (it destroys the underneath previous compacted clay lift). It is our conviction that, independently of the relevant high costs, the appropriate pre-treatment is achieved only by the (in situ) use of Mixer (fixed or mobile) including Roll Crusher [4].
- It would appear, based on current information [6], that clay- bentonite mixtures may not perform well in the long term as landfill liners, due to the fact that the mixture tends to shrink when in contact with the leachate, developing cracks that result in increased permeability. Taking into account this information, as well as the high costs resulting from the mixing procedure and the difficulty caused by the wet mixture to be sufficiently lined and compacted, we think that it should be worthwhile for the Authorities to encourage tender offerings that use good quality plain clay as a liner instead of clay-bentonite mixtures.
- The smoothing of the final surface of a mineral layer poses the greatest difficulties and demands a special procedural implementation. The following technique has been proved favourable [4]: The top, final layer must be superelevated (about the height of the pad feet of the in use sheep's foot roller), then compacted by a nonvibratory sheep's foot roller. A light, fine levelling machine, i.e. a grader, should then take down the additional millimetres. A nonvibratory, smooth drum roller could then complete the final smoothing. Furthermore we strongly recommend a very careful inspection of the smoothed surface. It should not be surprising to find a lot of sharp edged stones to rising over the smoothed surface, which must be removed; otherwise the precious membrane could end up as a useless strainer.
- In order to avoid the above time and money consuming procedure, for a moment we thought that we could place a geotextile above the non-smoothed final surface, to protect the membrane. This proved to be false for at least two reasons: Firstly, because the friction of the membrane laying on a geotextile is half the friction of the membrane laying directly on the smoothed mineral layer, a fact that (considering the very long, as well more or less steep side slopes) could create stability problems. Secondly, taking into account that according to field experience [7], an average of 15 leaks per hectare of inspected membrane has been detected, it is likely that the leaking would be spread, through the underneath geotextile, contaminating major surface of the mineral layer, increasing the risk for groundwater contamination.

- The damage of the membrane due to the traffic can be severe, but will probably remain undetected. Even the utmost precaution and quality control during installation will be meaningless if proper care is not taken when covering the membrane. 'Slow" and "Carefulness" are the key words [5]. In order this care to be ensured, we strongly recommend the relevant works to be under strict supervision by the appropriate Authorities. Anyway, we think that it would be much safer if the 6 mm thickness Geotextile for the protection of the membrane would have a thickness of at least 10 mm.
- A lot of air is trapped beneath the membrane, which must find its way out, otherwise, during the placement of the drainage, the trapped air is concentrated in the higher places just before anchoring trenches, creating large "air bubbles" that could be harmful to the membrane. The following technique has been proved favourable: In those specific places, holes of 20 cm diameter must be opener for the proper ventilation, that would be properly sealed after the placement of the drainage.

6. LEACHATE MANAGEMENT

The main issues of concern for the effective leachate management were: On one hand, the minimisation of leachate production. On the other hand, the efficient and continuous leachate drainage and collection, with easy inspection and cleaning of the leachate collection system, in order to prevent any uncontrolled migration. Furthermore, to secure landfill stability because of the significant height of the waste mass, reaching locally 25m.

For the minimisation of leachate production, a planned phased operation and restoration is employed as described in paragraph 4. It has been taken care that the surface water collected in the basin of each next Phase (not yet contaminated by MSW but already constructed) to be drained out and disposed downgradient, without being mixed with the leachate of the current Phase or of the previous ones. Furthermore, for the efficient separation of surface water produced in those upper sectors (of each working Phase) where the disposal of MSW has not been reached yet, the sides are shaped with 5m wide benches (drainage terraces) every 10m of vertical height (No 7 of Fig. 2). Before each bench covered by MSW, a drainage pipe (which goes through the boundary clay berm) drains out the (upgradient of this bench) collected surface water. When each bench is about to be covered by MSW, then the drainage pipe is closed permanently due to leachate production in this area. Additional drainage works should be constructed in the cover of the upgradient sides (dome) of each completed phase, combined with the construction of benches on the sides of the landfill in order to collect and remove downgradient the surface water.

Concerning the efficient leachate collection, the floor of the landfill is shaped with sufficient slopes and the landfill is lined. Leachate collection and treatment systems are also installed, including the construction of the network of leachate collection pipes into the drainage layer, the dimensioning of which aimed at maintaining the leachate hydraulic head over the lining to a max of 0.30m. The leachate collection pipes are perforated HDPE pipes, 250mm in diameter, placed radially along specially formed trenches in the floor and sides of each Phase. The perforated pipes of each current Phase, as well as of the previous (completed) ones lead to a leachate collection sump, located at the outer side of the boundary berm of the current Phase. From this sump, departs the central leachate pipe leading to the treatment plant. The main leachate pipe, 315mm in diameter, runs along the axis of the floor of the whole landfill area and transfers the leachates with gravity flow to the inlet well of the leachate treatment plant. At regular intervals, the main pipe is equipped with outlets for inspection and cleaning. It is also designed and constructed in such a way to allow the efficient and continuous flow of leachate, even during the construction of each new phase, downgradient of each operating phase of the landfill. The whole system has been designed to cope with heavy rainstorms with precipitation of 30mm into 30 min or 120mm in 4 hours.

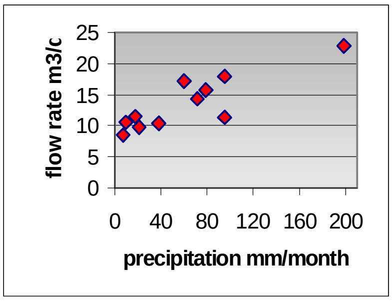

Figure 3: flow rate of leachates according to precipitation

Respectively, the following leachate quantities coming from landfilling area have been measured: 8 m^3/day in normal winter days, 5 m^3/day in normal summer days, 15 m^3/day in normal rainy day and 130 m^3/hour maximum, in a day with a heavy rainstorm. In this case, due to the hysteresis created by drainage and waste volume, the leachate flow needs 2-3 hours to reach a significantly increased flow in comparison with the normal one, and needs 7-8 hours to reach its maximum.

Total cost (rates of 2002) of the above described works of piping, wells, collection sumps etc. (excluding the main leachate pipe, 315mm in diameter) ~120.000 € for an area of ~3 hectares.

7. LEACHATE TREATMENT PLANT (LTP)

The main issue of concern was to achieve pre-treatment of leachate, to an effluent quality appropriate for recirculation in the mass of the landfilled MSW, or alternatively the disposal in the wastewater treatment plant of the city of Larissa.

The leachate treatment (LT) method is that of biological treatment in aerated lagoons and takes place in the LTP situated downgradient (NNW) of the landfill area (No 4 of Fig. 1). The LTP, is designed to treat 50 m3/day leachates, having a total 2350 Kg BOD/day load. The basic design criterion of LT, regarding the removal of pollutants, was the removal of the biodegradable organic carbon.

Figure 4: Leachate Treatment Plant

Leachate from the inlet well (No 1 of Fig. 4) flows by the aid of gravity to three consecutive aerated lagoons (500 m3 each), with a total aeration power of 75KW (No 2 of Fig. 4). The total retention time in all the aerated lagoons is at least 33 days. From there it flows to a settling tank, for the removal of suspended solids (No 3 of Fig 4). Finally, it flows to the stabilisation lagoon (800 m3) (No 4 of Fig 4) from where it is removed and transported with a tank-truck (~ 170.000 €) to the Wastewater Biological Treatment Plant to an effluent quality set at a max of 150kg BOD/day or 3 kg BOD/m^3 effluent**.** Additionally, there is also the possibility of re-circulating treated leachate in the waste mass of the completed Phase I, as well as to the future completed Phases, from the stabilisation lagoon through a pump-station (No 5 of Fig. 4) and the re-circulation piping. The LTP can also re-circulate sludge from the settling tank back to the lagoons or from a lagoon back to other lagoons. Separate bypassing of each lagoon is provided, for maintenance and repair reasons, during which the rest LTP treats leachate freely.

For the handling of emergency situations in cases of heavy rainstorm (where polluted rainwater and/or diluted leachate flows from the operational phases), in the LTP inlet well is provided an arrangement of automatic veer of the lechate stream to a separate emergency collection lagoon of 3300 m3 (No 6 of Fig. 4) been empty under normal conditions, equipped with a second pumpstation and recirculation pipe network, allowing more intense leachate recirculation. It is noted that leachate recirculation in the SL of Larissa is considered as a secondary leachate management option and will take place in a controlled manner, depending on the operational needs of the landfill, taking into account that extended use of recirculation could harm the landfill stability. To meet potential future needs for further improvement of the LTP operation, enough area has been reserved in the site. Lagoon's lining is almost similar to the lining of each Phase, comprising from bottom to top:

- Artificial subbase of 20 up to 30 cm of earthy materials very well compacted.
- Artificial geological barrier, 60m thick in three layers (20 cm each), with a permeability coefficient $k \leq 6x10^{-10}$ m/sec, constructed of bentonite-enriched natural clayey soil.
- Geotextile underneath the membrane for its protection. In the case of lagoons it was impossible to smooth freely the final surface of a mineral layer because of the small surfaces with very steep slopes. It is a heavy duty, non-woven continuous fibre polypropylene geotextile, 6 mm thick.
- Geomembrane HDPE, 2,5mm thick, used for the total lining of each lagoon.
- Concrete, 15 cm thick, above the membrane to protect it from accidental sinking of aerators.

The rule of the acquired field experience is that the proper construction of subbase, as well as of artificial geological barrier of lagoons is very difficult because of the small surfaces with very steep slopes. If we had to construct a new LTP, probably the lagoons would have been substituted by tanks of reinforced concrete, which overall has lower constructional costs without compromising the permeability issue.

Total cost (rates of 2002) of the above described works and equipment of LTP (including the main leachate pipe, 315mm in diameter, pumpstation and recirculation pipe network) ~700.000 € being able to treat leachates of a landfill area of 20 hectares.

The operation of the LTP is controlled by a data acquisition and control system, with a PC and PLCs. The field data are stored and processed with a PC, which controls the operation of the surface aerators. A generator, driven by a diesel engine, is also installed to provide power in case of failures in the public electricity network. The efficiency of the LTP is monitored by a series of chemical analysis and carried out in the laboratory of the LTP. Apart the analyses, various other parameters are measured and recorded per day, such as leachate flow, precipitation, temperatures of waters and air, mode of aerators operation and addition of nutrients. The LTP removes the biodegradable organic carbon of the leachates totally and it also achieves almost complete nitrification and partial denitrification. The degree of the denitrification depends on the age of the leachates. In young leachates the concentration of biodegradable organic carbon is high, which demands denitrification. The opposite occur with aged leachates. So far, leachates have not shown any toxic effects to the biomass of the lagoons. Also, bulking never appeared in this plant.

The concentration of the basic pollutants, in the produced (untreated) leachates, varies from 15.000 mg/l COD from young leachates to 3000 mg/l for aged leachates. BOD respectively varies from 7500 mg/l to 650 mg/l and ammonia nitrogen (NH4-N) varies from 800 mg/l to 2000 mg/l. The treated effluent has a COD of 850 mg/l, containing less than 20 mg/l ammonia nitrogen and around 350 mg/l nitrate nitrogen, as well as small quantities of mineral salts and non-biodegradable organic compounds.

Conclusively LTP of SL of Larissa is constructed in a simple way but it uses a quite functional and self-reliant system of LT without any demanding needs of supervision and operating cost. In Fig. 5 and 6 the results from the operation of LTP of SL of Larissa are represented.

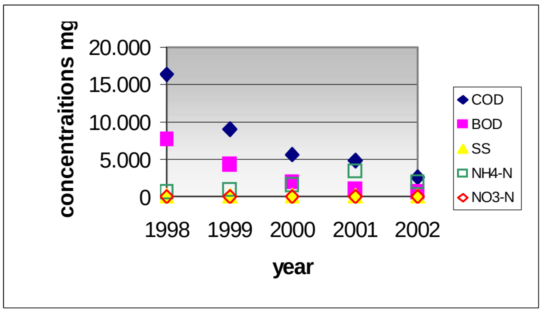

Figure 5: Quality fluctuation of leachates incoming to LTP

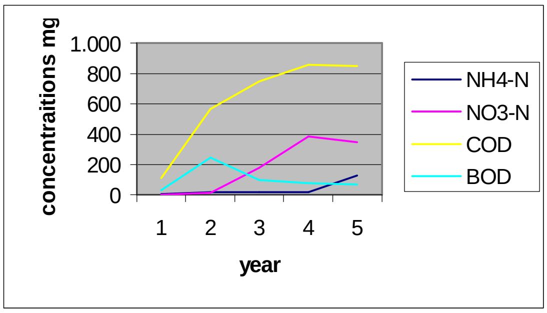

Figure 6: Quality fluctuation of treated leachates

8. LANDFILL GAS MANAGEMENT

The main issues of concern were to design an active gas collector system, which would take the following factors into account very seriously:

- The expected (and already detected) increased production of landfill gas after the first six months of the beginning of landfilling in Phase I, urged us to actively collect gas as soon as possible for odor, as well as safety and health reasons.
- The fact that each Phase is (or has been designed to be) completed in 4-5 years, which is very long period of time for waiting its closure in order to afterwards drill vertical gas collecting wells [8], [1].
- The fact that the daily tipping face is usually very busy due to heavy track traffic and manoeuvring, even in the night, which was obliged us to avoid rising over vertical wells.
- The fact that, the gas collection system comprising vertical wells installed as the refuse is placed, is in continuous contact with air, which means that inadmissible concentrations of oxygen could intrude the pumped gas while suctioning the gas.

Having all those factors in mind, we decided to favour the use of horizontal landfill gas collection system, following the disposal of sufficient volume of waste (usually after every two lifts have been completed), allowing an easy installation and covering of landfill gas extraction facilities.

The system includes horizontal collection trenches excavated in the solid waste and filled with (from bottom to top) gravel, horizontal perforated pipes with open joints, gravel, covered by geotextile and compacted clay to ensure the sealing against air suction. Thus, gas extraction trenches remain functional even with the differential settling that will occur in the landfill with the passage of time. The trenches have an approximate horizontal distance of 25-30m; all of them in both sides are ended up in a collector pipe (not perforated), which is based in the non-settling drainage layer of the lining (where the trenched lift meets the drainage). This way the collector pipes are not susceptible to differential settling, as well as they could be arranged properly in a way that the condensates easily find their way back to the drainage, avoiding clogging.

The collector pipes of each Phase are connected to collector substations, where the trained personnel is able to cut of the suction from those collection pipes that suck inferior quality of gas with elevated concentrations in oxygen and nitrogen. The collector substations are connected to the pumpstation. This way, the extracted from the Phase I (as well as from future Phases) landfill gas is burned in a suitable (1000 m^3/h max.) flare, which today has reached a stable quantity of 650-700m^3/h, which is a sufficient and stable flow rate for gas utilisation with energy production to come into effect.

Total cost (rates of 2002) of the above described works (excluding the main piping connecting substations to the pump-station, as well as flare) ~160.000 € , for a Phase of ~350.000 m^3 of landfilled MSW. Additional cost for the flare is estimated in 130.000 €.

9. THE LANDFILLING OF MSW

Filling of Phase I with MSW (according to the cell method) started in February of 1998, from the lower parts of the basin and moved progressively upgradient. Typical cell height is 2.5 to 3m; length of working face is 15 to 20m, with daily steps of 2 to 3 m. All exposed faces of the daily cell are covered with a thin layer of 15 to 20cm soil (the remaining from the lining earthworks), excluding the working face, which is continuously covered by MSW (due to 24 hours per day collection and direct disposal of the MSW). It has been measured that the volume of the daily cover soil is ~25% of the compacted volume of MSW. In order to avoid the creation of impending leachate tables that reduce the landfill stability, the part of the cover of the underneath lift that is going to be covered by each day's working face, is daily removed, mixed and landfilled together with the MSW of the day, achieving sufficient vertical hydraulic continuity.

MSW is discharged to the working face having a density of up to 200 kg/m^3. Compaction of the landfilled MSW has been measured to rates of 900 to 1000 kg/m^3. We have found that 5-6 compactor passages are needed for each MSW layer to achieve the above rates. Total operational cost of compactor (including the orerator) is estimated in 0.30 € per ton of compacted MSW. 0.32 € and 0.20 € respectively are the relevant costs for the accompanying bulldozer and excavator.

In the completed Phase I, 325.000 tons of MSW, have been landfilled (for a time period of 4 years and 10 months) covering a volume of 345.000 m^3 plus the volume of daily cover.

Internal routing (earth road) was necessary to be constructed to ensure access to the daily tipping face, which started upgradient, from the peripheral road of the landfill (No 6 of fig. 2) and was directed towards the floor of Phase I, supported on the of drainage (with the interposition of a geotextile). Before a part of this road been covered by a cell of MSW, it was excavated down to the drainage top and the excavated materials were used for the daily cover. For enhanced stability, downgradient slopes of each Phase (No 4 of fig. 2, No 14 of fig.1) have been constructed with a max. slope of 4H: 1V [5], including terraces from lift to lift [8] that permit sufficient management of side leaking leachates, as well as access everywhere to the slope. The average settlement of compacted MSW has been measured to be 90cm for a two-year period.

A number of small movable screens (made of chicken wire) are placed near and around the active face to catch windblown light waste, which is manually pickuped at the end of the week [8]. Dust is controlled by spraying water (by the appropriate vehicle) on the approach and internal access roads, as well on the active face area [8].

Operational costs (including restoration and post-closure costs, excluding contribution to landfill aftercare fund, depreciation of capitals for plant construction, machinery procurements, and acquisition of land) are ~15 € per ton of landfilled MSW (the 40% of which are operational costs of LTP). This cost is considered low for sanitary landfilling compared to the ones of other European countries cities [9]. Nevertheless, most of the neighbouring municipalities consider them very high (comparing them to the close to zero ones of open dumping), so that their MSW are still finding their way to the closest open dumps, though the SL of Larissa is supposed to have been constructed in order to serve the whole Prefecture of Larissa. The few Municipalities that dispose their MSW in SL of

Larissa do not pay (or delay the payment for long periods) the relevant gate fees, claiming financial recession.

10. LANDFILL RESTORATION

In the SL of Larissa the method of gradual restoration will be employed, with an initial construction of a temporary cover immediately after the closure of each separate landfill Phase. Following sufficient time for the completion of waste settlement in each phase, the final cover would be designed according to the EU Guidelines valid at each time, so that the site can be restored in phases in an environmental way.

The waste relief that will be formed after the closure of the whole landfill area will have a shape of an elongated hill, parallel to the long axis of the site. The final relief will feature hillsides with slopes ranging between 1:5 and 1:8 (V: H).

11. INFRASTRUCTURE FACILITIES-MACHINERY-PERSONNEL

The new S.L.L. is provided with the infrastructure facilities, machinery and necessary personnel for the continuous and independent operation of the whole plant (~8 Phases). Within the scope of the present project the following facilities were constructed:

- Entrance facilities - Fencing. Strong fencing protects the landfill. The entrance gate is automated for further protection. Adjacent to the site entrance, the guardhouse-weighroom building and the electronic weighbridge, of 70tons capacity, are located.
- Administration Building. It covers the operational needs of the site and houses personnel facilities, as well as the laboratory and the conference room. The surrounding area is developed with paved pedestrian roads for the communication of the buildings.
- Equipment service building. It serves the maintenance and small repairs of the landfill equipment, whereas an exterior car-wash ramp is provided for the washing of vehicles.
- Shredder of vehicle useless tires (Fig. 7). For the time being the shreds are landfilled.

Figure 7: Shredder of useless tires

Figure 8: MRF

- Material Recovery Facility (MRF) (Fig. 8) where manual separation of recyclable materials is going to take place in the next months. Total cost (rates of 1998)~ 992.000 €.
- Infrastructure networks. The landfill is provided with electricity, water supply from groundwater wells, sewerage and telephone network. It is also provided with lightning protection (of buildings, landfilling area, gas flare area and LTP), external lighting along all access roads and wireless communication facilities.
- Automation and monitoring facilities. The Leachate Treatment Plant is equipped with an automated operation and monitoring system, through a PC installed in the power building of the plant.

All data are also recorded and transported via a modem to a PC in the administration building (from where the remote control and operation of the treatment plant are enabled) and to a monitoring panel in the entrance guard room, in order to allow for the continuous monitoring of the operation of the treatment plant, 24 hours per day.

- Machinery includes an excavator (~ 150.000 €) with a track for the daily cover, a bulldozer (~170.000 €) for layering the daily cover in the working face and a compactor (240.000 €) for layering and efficiently compacting the MSW in the working face.
- For 24 hours per day, 365 days per year operation, 16 skilled persons (2 engineers, 3 machinery operators, 4 attendants as well as weighers) are provided, been under systematic medical observation of a dedicated (for the Municipality's personnel) doctor.
- Total cost of Phases I and II, including all infrastructure facilities (rates of 2000) ~3.344.000 €, funded by a Regional Operation Program. Estimated cost of Phase III (rates of 2003) ~ 2.700.000 €, which should be funded by the Cohesion Fund of the EU.

12. ENVIRONMENTAL MONITORING PROGRAMME

Environmental monitoring is conducted to ensure that no contaminants are released from the landfill to the air, ground, as well groundwater. Within the scope of the present project, the relevant facilities were constructed and the necessary equipment was installed for conducting the required number of measurements both during the operation and post-closure phase of the landfill. The environmental monitoring programme manages as well the appropriate meteorological data, the quantity and quality of leachate and gas, the quality of groundwater. Finally it includes mapping and continuous calculation of the landfilled waste volume, as well as monitoring of the progress of waste settlement, and monitoring of potential gas migration off the landfill sides.

13. CONCLUSIONS

The safe and reliable long-term disposal of MSW is, and in the foreseeable future would continue to be, an important component of integrated waste management. The planning, design, construction, operation and aftercare of modern sanitary landfills is crucial to involve the application of a variety of scientific, engineering, and economic principles.

However, due to the fact that the behaviour of landfilled solid waste is unpredictable, it must be realized that those principles should be successfully balanced in the light of the acquired relevant field experience, as well as to be coupled with continuous vigilance especially during operation and postclosure, in order to avoid risky situations, or to be forced to finally deal with luxury open dumps of high constructional and operational costs.

We sincerely hope that the above described decisions of ours in crucial issues, namely effective lining with reasonable construction costs, minimization of leachate, biogas management during disposal of MSW in each current Phase, simple construction of the Leachate Treatment Plant combining relatively low operation and maintenance costs, as well as the recorded and classified data, would help the landfill designer to verify or to optimise his own alternative options.

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