ChemTech
International Journal of ChemTech Research
CODEN(USA): IJCRGG ISSN : 0974-4290
Vol.1, No.2, pp 126-134, April-June 2009

Sulphate concentrations at Mid Auchencarroch Experimental Site – Image Processing and Environmental Quality Assurance of Leachate Pond Treatment Units on Displaced Geological Surfaces

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Abstract: This paper analyzes characteristic chemical indexes of the biological waste biodegradation at landfill sites in terms of sulphate concentrations, which are produced at Mid Auchencarroch experimental landfill bioreactor cells with different disposed waste composition and dynamic solid waste management biotechnology techniques. However, open surface leachate ponds should be operated for the proper treatment of produced leachate discharges and final recirculation of them. In addition a continuous monitoring of leachate pond installations on a landfill site should take place. Special maintenance and confrontation works should be given on leachate treatment units, when there are displacements on ground surfaces due to geological layer movement by natural collapses. A useful methodology for the latter case is presented for spatial monitoring of leachate pond units on a topographic surface so as to calculate displacements in time and to risk assess the operation of a liner under these conditions. Image processing principles are discussed for environmental investigation and protection. Useful conclusions are presented for efficient solid waste management units not only to avoid associated risks to any surrounded land uses next to landfill boundaries but also for public health protection and regional development.
Key words: Landfill leachate emissions, waste biodegradation, environmental quality assurance, geoinformatics, digital image processing, environmental impact assessment, lining methods, economic project management, risk assessment software.

Introduction

Nowadays, the progress and the evolution of our civilization increased the landfill leachate and wastewater volume in wastewater treatment units, as well as the waste volume in sanitary landfills. Sanitary landfill remains an attractive disposal route for household, commercial and industrial wastes, because, it is more economical than other waste disposal methods [2,5,9,10,14,15,28]. Efficient sustainable waste biodegradation solutions to the current environmental problems of our planet should be given as soon as possible so as to save the global environment and to protect public health by any long term leachate chemical threats. Treated leachate discharges could be used for irrigations or for fire brigate rescues[16,28].

Modern computer software should be focused on the usage of digital databases for the quality assurance of landfill sites following the ISO 14001 standards for environmental systems quality assurance investigation, utilizing properly geographic analysis's tools like digital image processing computer software and remote sensing databases. Continuous remote sensing observation of a landfill operation is necessary for relative risk assessment of landfill leachate emissions, project management of technical reclamation works and public health protection [1,2,3,4,17,29]. Computer client server IT internet applications and intelligent image processing software are becoming necessary so as to process properly big quantities of image databases, remote sensing data, geographic information systems, development of orthophotomaps and digital maps [7,13,19,20,21,22,24,26,27,30,31].

Geographic analysis tools like G.I.S, G.P.S. data, digital image processing, lining methods of reclamation works and orthophotomaps could be used properly not only for a landfill site investigation but also for regional development covering several water agronomic necessities to agricultural land uses next to a landfill topography (ie cover water demand for irrigation, for mountainous agrotourism, for waterways etc) [6,8,11,12,13,20,23,24,31]. The selection of proper sites for sanitary landfills, and the design, construction and operating practices used at these sites, should take into account the environmental impacts to neighboring land uses next to landfill boundaries, utilizing hydrological, geological maps and landfill topography's characteristis related to any associated reclamation and monitoring works of landfill leachate emissions. Moreover, a quality assurance should exist for a landfill bioreactor life cycle analysis utilizing proper risk assessment tools so as to avoid any hazardous chemical treahts to the environment [8,11,12,13, 23, 31]. Below are investigated different waste fractions at Mid Auchencaroch (MACH) experimental cells, provoking several different leachate chemical emissions to the environment [9,10,14,15,16]. The main aim is to evaluate the waste biodegradation based on sulphate chemical indexes and to utilize a proper risk assessment software for leachate ponds' operation achieving an environmental protection and public health protection.

Experimental

According to the literature variations on landfill leachate emissions arise from factors affecting waste biodegradation. These factors vary between sites according to different disposed waste fractions, microbiological conditions, different physical and chemical properties of the disposed materials, different waste quantities disposed of to landfill each year and existing facilities for leachate recirculation[16,28].

During each biodegradation stage there are several different bacterial colonies, which exist under particular favourable physical, biological and chemical conditions for them during the life cycle of a labdfill bioreactor. During the methanogenesis stage pH equals to 7, neutral environment. On the other hand, during the hydrolysis and acetogenesis stages the pH has low values indicating an acid environment and the COD, TOC values have big magnitudes during an initial time since the waste was disposed and later they are decreasing in time. Investigating the landfill bology, the biodegradation stages, which exist within landfill life cycle and its respective biogas and leachate stabilized chemical emissions, include the hydrolysis, acidogenesis, acetogenesis, methanogenesis and mature stage [16,28]. However, sulphates concentrations should be monitored as they are useful for monitoring the monitoring and the life cycle analysis of landfill emissions on a given topography. Below in figures 1, 2, 3 and 4 is presented the sulphates concentration of leachate emissions in time for each MACH cell respectively.

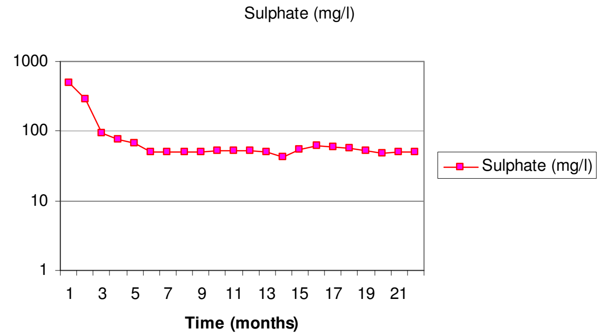

Fig. 1 Leachate characteristic emissions, sulphate concentration at Mid Auchencarroch experimental cell 1 site

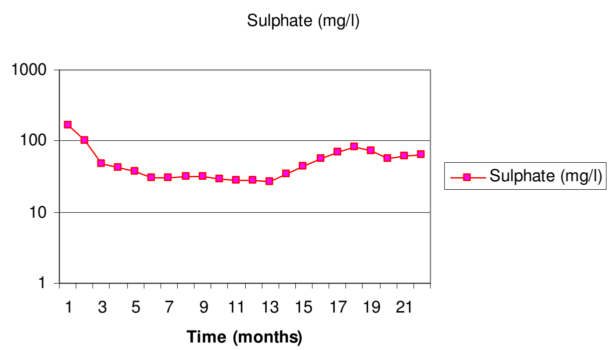

Fig. 2 Leachate characteristic emissions, sulphate concentration at Mid Auchencarroch experimental cell 2 site

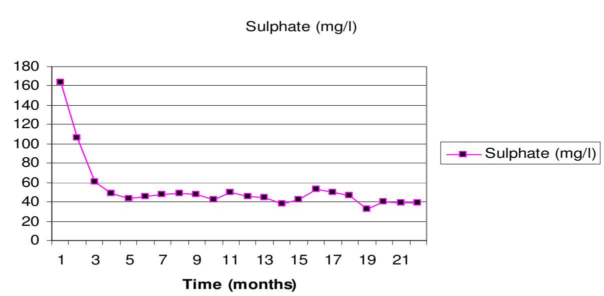

Fig. 3 Leachate characteristic emissions, sulphate concentration at Mid Auchencarroch experimental cell 3 site

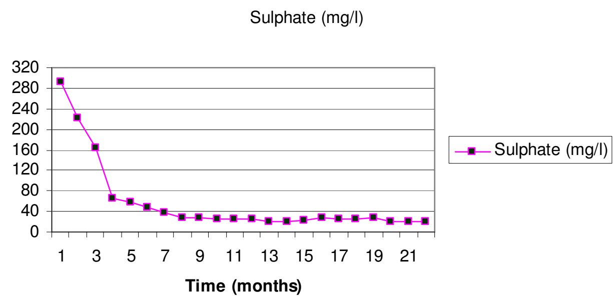

Fig. 4 Leachate characteristic emissions, sulphate concentration at Mid Auchencarroch experimental cell 4 site

According to the above figures, sulphate decreased concentrations achieved in short time period in short time, which means that methanogemesis biodegradation stage took place rapidly. MACH's experimental field data showed that waste can be treated properly by the application of efficient sustainable landfill design biotechnologies like MACH one. In both four MACH cells acid environment exists in cases that there is high TOC concentrations with pH less than 7. At cell 2 there is a variation between 14th and 21st month of TOC concentrations due to the leachate recirculation that existed at that cell.

In case that there are not high sulphate concentrations during the first months after waste disposal at a landfill site then there is an indication that there leachate leakage at landfill topography due to several reasons (ie bad installation of geomembrane, liner deformation due to surface heavy traffic loads, seismic loads, geological strata deformation due to deep excavations etc). For the latter cases a site investigation is demanded by an extended monitoring based on particular landfill topographic characteristics and image processing principles which are discussed below. Then the existence of any leachate ponds that are operating on a landfill topography should be investigated for maintenance and reclamation works.

Results and Discussion

According to the MACH's experimental field data is clear that anaerobic design under favourable landfill's physical, biological and chemical conditions assists the pH environment to take neutral values in short time period. The latter facts verify that methanogenesis stage achieved in short time period at MACH site as well as that MACH's biomass treatment biotechnology principles are sustainable. Moreover, the presented digital image processing software is necessary not only for landfill leachate level control in leachate ponds, regional development proposals and proper combination with relative spatial analysis models in normal situations of an integrated biomass management unit but also it is useful for taking the right measures in emergency cases like ground surface deformation by particular natural disasters.

However, updated databases with archives of monitoring data by geographic analysis applications like remote sensing air photo databases, photo-constant points defined G.P.S. data on a given topography, G.I.S. and digital image processing software are necessary for a comprehensive investigation of such environmental systems[16,22,25,27]. New comprehensive risk assessment methodologies are demanded utilizing proper image processing software for quick and accurate detection of displacements at leachate ponds treatment units and landfill site investigation in emergency cases due to ground deformation. The fulfilment of ISO 14001 standards at integrated biomass units is becoming necessary in the present time for environmental impacts minimization and regional development. Below is presented an efficient environmental digital image processing software not only for a landfill site operational control but also for regional development of an area next to a landfill topography.

Modern computer aided mapping software, could be utilized for the development of a photomosaic based on edited orthophotomaps[19,33]. The combination of dynamic numerical simulation spatial models and efficient digital image processing modules is necessary so as to develop an improved monitoring system of environmental impacts and to line proper confrontation works in emergencies [1,3,7,8,9,11,13,14,15,16,18]. Several useful image processing modules could be utilized according to the literature for image processing of orthophotomaps, landfill topographies investigation, determination the extent of uncontrolled leachate ponds and for confrontation to chemical accidents in emergency cases[34]

However, for the reclamation works of leachate treatment units within liner manufactures at a deformed ground surface which they are under risk efficient mapping out, lining methods should be applied, utilizing image processing tools, aerotriangulation and development properly of orthophotomaps in order to apply in a quick and accurate way any relative efficient iterative lining method of reclamation works based on digital terrain given by orthophotomaps' details [31,33,37,38,39]. The allowable movement(s) in liner geomembrane design is not yet regulated and is a matter of engineering judgement. A limit of 15 cm has been used in practice to avoid tearing of geomembrane but actual limits must be site specific. Optimum safety conditions in public works of high environmental risk should be of first priority following the right reclamation design. The right determination of material properties, slope stability analysis and ground displacement evaluation are necessary for an effective management of infrustructure works[31,33,35,37,38,39]. However, leachates' treatment ponds at landfills could be used for covering several spatial necessities i.e. water for irrigation, fire protection etc. Waste recycling eco-design units should be located at sites that serve better the particular civic necessities, according to the trends of waste production at urban or semi urban areas and suburbs' centroids regional development spatial trends [32,36,41]. For the cases that leachate ponds or water reservoirs with geomembrane liners are located next to slopes and heavy traffic exists next to them (with weight approximately 5 ton or more) then frequent measurements of reservoir's water surface area; height; and its centroid coordinates respectively, should be measured and monitored so as to take the right measures in time i.e economic solution with rock retaining walls or reinforced concrete walls ones for slope stability. A quick area calculation for big dimensions of water reservoirs could be achieved by aerotriangulation based on specific photoconstant points so as to develop the digital terrain next to water reservoir boundaries [31,33,37,38,39]. When displacements of water reservoir's area or centroid's coordinates have been detected for particular reasons then a slope stability analysis should take place, analysing the collected results [35,42]. However, in the case that we have a pond with a geosynthetic liner manufacture (fig. 5) we can find between times t1 and t2 by aerotriangulation the respective areas and volumes for water levels z1, z2, where the next formula is valid:

$$Vt = (E1 + E2) * h / 2, \quad h = z1 - z2, \quad E1 > E2 \qquad (1)$$

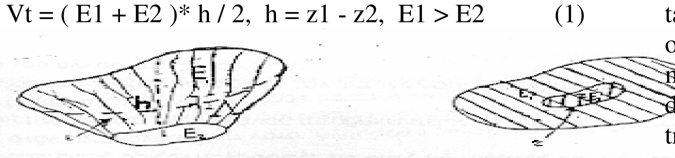

Fig. 5 Topographical characteristics of ponds' liner manufactures for two water surfaces with areas E1,E2.

The problem is becoming more complex when the liner manufacture is located next to a slope and there is slope instability due to heavy traffic loads that exist on top soil next to the pond and an earthquake event. In the latter case should be examined the centroids and areas Ei of the lake at specific characteristic pond's height zi before and after the event so as to determine the magnitude of pond's centroid movement at investigating areas Ei in time. For the calculation of Ei new constant photo points should be determined for the aerotriangulation based on surrounded characteristic points that have not been moved after the hazardous event, which should be verified by in situ measurements with a GPS unit. Also should be investigated the geolocical inclination of the geological strata where the pond is located above it. Three boreholes are necessary for the inclination and azimuth calculation of the examining examining geological strata. If the pond's centroid coordinates before and after the hazardous event are not following the inclination change of the geological surface that is located surrounded the pond then there are additional movements of the pond's liner manufacture due to slope instability. Then frequently in situ measurements should take place based on constant points, which are not affected by the hazardous event. In this way, could be compared the movements of digital terrains in time as well as their respective centroid movement in time, taking the right actions in time like the quick installation of rock retaining walls and quality assurance of liner manufactures. Infrared cameras could be used for better determination of pond's boundaries by aerial triangulation in emergencies like smoke, fog etc. For each three co-surfaced points their centroid in (x,y,z) co-ordinates should be archived in time utilizing a proper database of in situ measurements. Then the trends of centroids movements in time could be calculated by the method of least squares predicting the most critical areas, which are under risk of collapse and they need immediate lining of maintenance and reclamation works for particular slope inclinations, geometries and topographies. Then the calculation of the geological strata inclination and azimuth when there are three or more borehole field data could be calculated so as to evaluate the relative deformation of liner manufactures [13]. Three appropriate points $P_1(X_1,\Psi_1,Z_1)$, $P_2(X_2,\Psi_2,Z_2)$, $P_3(X_3,\Psi_3,Z_3)$ could be examined on the ground surface. On those points were made vertical boreholes, so as to determine the geological layer roof, in depths H_1, H_2, H_3 respectively. It is assumed, that the geological layer does not present tectonic irregularities in the area between the boreholes. These points are points of the Euclidian Space R^3 (Figure 6).

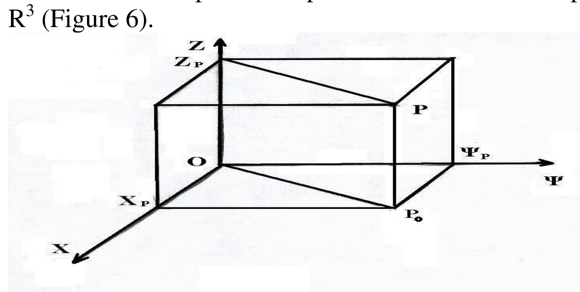

Fig. 6 The ground points P are presented in the Euclidean space R^3 for the analysis of ground deformation of leachate treatment units.

However, we can work in two different ways, for the determination of the inclination angle W of the geological plate in space, in relation to horizon, which are described below.

1st Solution Way. From the horizontal projection of a random point in space Pi(Xi,Ψi,Zi) i=1(1)n, where its distance Di=1(1)n from the common line of the plates which is not zero, is calculated the inclination angleW, from the following formula

$$W = \arctan\left(\frac{Z_i}{D_i}\right) \quad , \quad \forall i = 1(1)n \qquad (2)$$

where

$$D_i = \frac{|AX_i + B\Psi_i + 1|}{\sqrt{A^2 + B^2}} \qquad (3)$$

2nd Solution Way. A new mathematical theoreom is used, which is approved below. **"The square of the area of a flat plate in space, equals to the sum of the squares of the areas of the coordinates of its projections".**

If E is the area of a flat plate in space and E_1, E_2, E_3 the areas of its projections on the plates XOΨ, ΨOZ, XOZ of a cartesian reference system OXΨZ, according to this theorem, we have

$$E^2 = E_1^2 + E_2^2 + E_3^2 \qquad (4)$$

it is obvious, that the inclination angle W of the plate in spacein relation to the horizon, will verify the following equations

$$\cos W = \frac{E_1}{E} \qquad (5)$$

$$\tan W = \sqrt{\left(\frac{E}{E_1}\right)^2 - 1} \qquad (6)$$

$$W = \arctan\left(\sqrt{\left(\frac{E}{E_1}\right)^2 - 1}\right) \qquad (7)$$

The mean standard error of the calculations SE (Standard Error) is given by the following formula

$$SE = \pm\sqrt{\frac{\sum_{i=1}^{n} U_i^2}{n-3}} \qquad (8)$$

where

n	is the number of the measurements
U_i (i=1(1)n)	the errors of the measurements

It is obvious that, in order to be calculated the mean standard error SE, it is necessary to have a superfluous number of n measurements for n>3. Thus, when the number of measurements of n boreholes is greater than 3 (n>3), the problem is examined by the use of the Method of Least Squares [32].

Moreover, the numbering of the boreholes, is good to be made in a way that the formed polygonto be a cambered geometrical design. The latter case safeguards a stability in the calculation of several areas.

THEOREM."The square of the area of a flat plate in space, equals to the sum of the squares of the areas of the coordinates of its projections".
The latter theorem could be used for the evaluation of systematic errors, which are affected by meteorological conditions, in measurements made by laser devices on given known surfaces so as to determine photoconstant points for aerotriangulation measurements and leachte treatment unit displacements due to geological strata deformation. Applying the Method of Least Squares the latter measurement errors properly could be corrected [32].
PROOF. A flat plate is examined in 3D space R^3, S(OXΨZ) (Figure 6) with coordinates of the projections S_1(XOΨ), S_2(ΨOZ), S_3(XOZ), S(S_1,S_2,S_3). Assuming that the plate on which there is a plate S(S_1,S_2,S_3), extended cut the axes of the coordinates OX, OΨ, OZ at points A, B, Γ respectively (Figure 7).

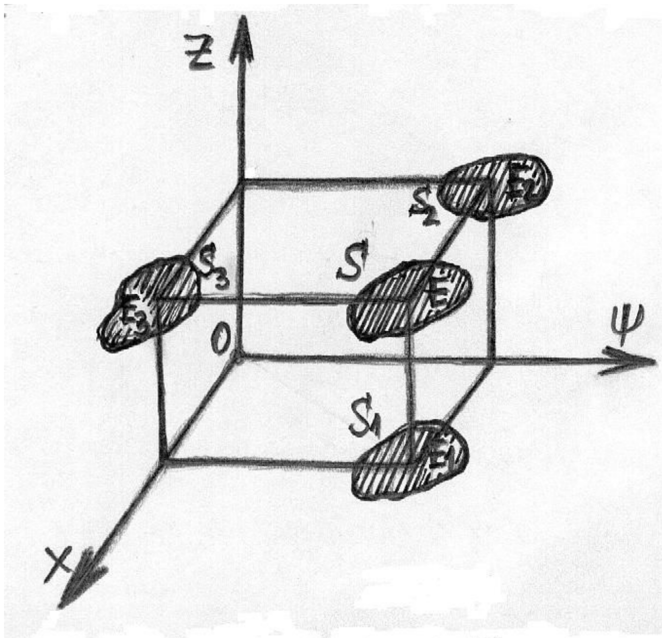

Figure 6. Flat plate S(OXΨZ) in 3D space with coordinates of the projections S_1(XOΨ), S_2(ΨOZ), S_3(XOZ), S(S_1,S_2,S_3).

We design the straight lines (OΔ), (OE), (OZ) perpendicular to the lines (AB), (BΓ), (ΓA), which are located on the plates XOΨ, ΨOZ, XOZ respectively (Figure 5). According to the theorem of the three perpendicular, the straight lines (ΓΔ), (AE), (BZ), are perpendicular to the lines (AB), (BΓ), (ΓA) respectively. Hence, the plates (OΔΓ), (OEA), (OZB) are perpendicular to the plate (ABΓ), as well and their common cutting (OK) and that the point K is center of perpendicular angles of triangle (ABΓ).

If W_1,W_2,W_3 are the inclination angles of the plate (ABΓ) of the surface S(OXΨZ) in relation to the projection plates XOΨ, ΨOZ, XOZ respectively. If E(E_1,E_2,E_3) are the areas of the surfaces S(S_1,S_2,S_3), it yields

$$E^2 = E_1^2 + E_2^2 + E_3^2 \qquad (9)$$

The validation of equation (32) can be found easy, because of

$$E_1 = \cos W_1, \quad E_2 = \cos W_2, \quad E_3 = \cos W_3 \qquad (10)$$

and should pretend the following formula

$$E^2 = E^2\cos^2 W_1 + E^2\cos^2 W_2 + E^2\cos^2 W_3 \qquad (11)$$

or

$$\cos^2 W_1 + \cos^2 W_2 + \cos^2 W_3 = 1 \qquad (12)$$

From the orthogonal triangles (AOE), (BOZ), (ΓOΔ) and according to the previous cosine formula it yields

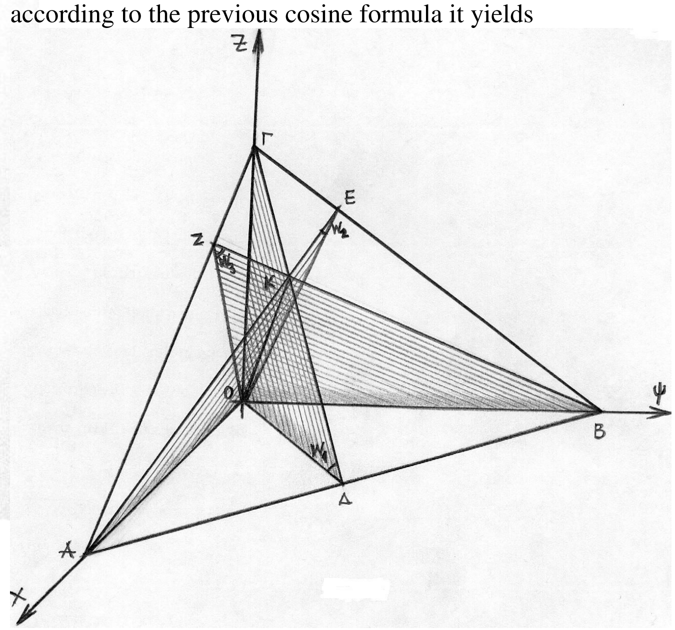

Figure 7. The plate on which there is the surface S(S_1,S_2,S_3), extended cut the axes of the coordinates OX, OΨ, OZ on the points A, B, Γ respectively.

$$\frac{(O\Delta)^2}{(\Gamma\Delta)^2} + \frac{(OE)^2}{(AE)^2} + \frac{(OZ)^2}{(AE)^2} + \frac{(OZ)^2}{(BZ)^2} = 1 \qquad (13)$$

or

$$\frac{(A\Delta)(\Delta B)}{(\Gamma\Delta)^2} + \frac{(BE)(E\Gamma)}{(AE)^2} + \frac{(AZ)(Z\Gamma)}{(BZ)^2} = 1 \qquad (14)$$

or

$$\frac{(A\Delta)(\Delta B)}{(\Gamma\Delta)(\Gamma\Delta)} + \frac{(BE)(E\Gamma)}{(AE)(AE)} + \frac{(AZ)(Z\Gamma)}{(BZ)(BZ)} = 1 \qquad (15)$$

or

$$\cot A \cdot \cot B + \cot B \cdot \cot \Gamma + \cot A \cdot \cot \Gamma = 1 \qquad (16)$$

The previous formula (16) is true and becomes easy from the triangle (ABΓ). For each triangle is valid the following formula

$$A + B = \Pi - \Gamma \qquad (17)$$

therefore

$$\cot(A+B) = \cot(\Pi-\Gamma) \qquad (18)$$

Equation (18) yields

$$\frac{\cot A \cot B - 1}{\cot A + \cot B} = -\cot \Gamma \qquad (19)$$

or finally

$$\cot A . \cot B + \cot B . \cot \Gamma + \cot A . \cot \Gamma = 1 \qquad (20)$$

Conclusion

The addition of the squares of the cosines of the inclination angles of a flat surface in space, in relation to the coordinate plates of an examining system, equals to one.

<u>Proof.</u> If W_1, W_2, W_3 are the inclination angles of a flat surface in space R^3, in relation to the coordinate plates of the system OXΨZ, there will valid the following equation

$$\cos^2 W_1 + \cos^2 W_2 + \cos^2 W_3 = 1 \qquad (21)$$

The true of this conclusion, becomes easy by the proof of the previous theorem, which is subject to the embadometry.

Based on the above mathematical methodology could be evaluated the displacements of leachate treatment ponds due to geological deformation by natural collapses and reclamation works should take place with good timing in order to avoid tearing of leachate ponds' liner which will cause hazards to the environment. Movements of particular pond's points should have a limit of 15 cm, which has been used in practice to avoid tearing of liner [35]. The presented methodology could be a useful scientific tool not only for particular management of ponds' liners but also for any associated environmental protection following proper ISO environmental quality standards.

Conclusion

At the examining MACH cells showed that the decrease of sulphate concentrations achieved in short time period avoiding long term chemical threats to the environment. Long-term liability can be minimized if waste is quickly treated to a point that will not be occured further chemical emissions to the environment. In this way will be protected not only could be exploited properly leachate treated discharges for several regional development purposes (ie agrotourism applications, water usage for irrigation, waterways, other regional development works etc) but also will be minimized any environmental impacts to surrounded land uses next to landfill boundaries.

However, a flexible and useful methodology has been presented in this paper for the quality assurance of liner manufacture deformation on given geological slopes at technical works by proper utilization of aerotriangulation and use of orthophotomaps. The latter methodology could be a used as a scientific tool not only for particular management of ponds' liners but also for any associated measurements for environmental protection. Movements of particular pond's points should have a limit of 15 cm, which has been used in practice to avoid tearing of liner.

Acknowledgements

The author would like to thank U.K. Energy Technology Support Unit (ETSU), U.K. Department of Trade and Industry (DTI), U.K. Environment Agency (EA), Envirocentre, the University of Strathclyde and its Centre for Environmental Management Research for the opportunity given to him to collaborate with their praiseworthy staff and other professionals from the industry so as to work within Mid Auchencarroch experimental project. Also the author would like to thank several colleagues within the academic institutes, research centres and other sectors, which have been collaborated with him and gave a moral support to his scientific and professional work. The conclusions expressed herein represent the findings of the author and are based on his expertise and experience in this topic area and his findings in the professional literature. It does not necessarily represent the views of EA, or of the participants in the Mid Auchencarroch Experimental Project.

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