Air Dispersion Model for Prediction Fugitive Landfill Gaseous Emission Impact in Ambient Atmosphere

Moustafa Osman Mohammed

Abstract—This paper will explore formation of HCl aerosol at atmospheric boundary layers and encourages the uptake of environmental modeling systems (EMSs) as a practice evaluation of gaseous emissions ("framework measures") from small and medium-sized enterprises (SMEs). The conceptual model predicts greenhouse gas emissions to ecological points beyond landfill site operations. It focuses on incorporation traditional knowledge into baseline information for both measurement data and the mathematical results, regarding parameters influence model variable inputs. The paper has simplified parameters of aerosol processes based on the more complex aerosol process computations. The simple model can be implemented to both Gaussian and Eulerian rural dispersion models. Aerosol processes considered in this study were (i) the coagulation of particles, (ii) the condensation and evaporation of organic vapors, and (iii) dry deposition. The chemical transformation of gas-phase compounds is taken into account photochemical formulation with exposure effects according to HCl concentrations as starting point of risk assessment. The discussion set out distinctly aspect of sustainability in reflection inputs, outputs, and modes of impact on the environment. Thereby, models incorporate abiotic and biotic species to broaden the scope of integration for both quantification impact and assessment risks. The later environmental obligations suggest either a recommendation or a decision of what is a legislative should be achieved for mitigation measures of landfill gas (LFG) ultimately.

Keywords—Air dispersion model, landfill management, spatial analysis, environmental impact and risk assessment.

I. INTRODUCTION

ENVIRONMENT, is a complex subject to model physical, chemical and biological components for interaction practice science to reality [1]. When modeling systems become an obligatory skill in the scientists' kit, decisions will be based upon integration of multidisciplinary data and knowledge, with an ultimate goal of sustainability [2]. The disposal of organic waste at landfill sites generates aerosols by either biological decomposition or particulates coagulation. Both chemical constituents and diffusion mechanism are unconfined flow beyond landfill site unless fumigation from marine boundary layers. Organic vapors are the latter result of either aerobic bacteria or evaporation processes. The contraption of "aerodynamic forces" that cause the removal of

Moustafa Osman Mohammed is a general manger of Environmental Management Department, Alexandria Regional Branch Office (RBO), Egyptian Environmental Affairs Agency (EEAA) Egypt. He is a professor of environmental engineering at the faculty of engineering, Alexandria University (phone: +203-302-44775; fax: +203-302-16209, e-mail: moustafa_o@yahoo.com).

aerosols from the surface, is determined by balance of the "wind friction velocity", a measure of wind shear at the surface, with other forces that resist aerosols diffusion such as "gravitational and inter-particle cohesion forces" [3]. The aerosols get entrained into the atmosphere when wind speed exceeds a critical value, that is called the "threshold friction velocity" [4], [5].

The threshold friction velocity is the minimum velocity required to initiate particle motion. The ability of aerosol to disperse and deposit depends on their shape and size [6], with other factors as temperature, moisture and chemical composition affect the coagulation of emitted gaseous [7].

Currently, the existing models can only be utilized for "screening-level" purposes due to the many fundamental over simplifications made, which may seriously compromise the accuracy of the predictions. A wide approach is needed to accurate estimation of source emissions and evaluates the risk posed to either humans or species in the areas near landfill site. Further to design control, air quality model broadens the scope of integration parameters for estimating downwind gaseous dispersion and approach concentration for risk assessment [8].

The United States Environmental Protection Agency (USEPA) has approved a wide range of atmospheric dispersion models [9]. These models can predict concentrations of various pollutants on both local and regional scale; however, most of the well validated models have limitations in estimating concentrations from fugitive dust sources [10]. One of the most commonly used models to compute concentration levels of fugitive gaseous emission is a computerized Gaussian air quality model developed by USEPA [11].

The accuracy of an AQ model depends on the accuracy of the measured input pollutant emission rates [12]. Emission rates can be estimated using data from air quality monitors, or by using empirical emission factors developed by governmental agencies such as, USEPA, 1995 [13] "Emissions Factor" is a representative value or algorithm (for complex cases) that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant

II. METHODS FOR PREDICTION IMPACT

The systematic approach of air quality model is broadly an intermediate stage, that based on definitions of quantitative measures between both midpoint abiotic and endpoint biotic

impact assessment as classified in Fig. 1 [14]. The installation of landfills can pose a range of risks to the ecological receptors and amenity. No matter how the terms are used in recognition ecologic impact when air quality model is predicting environmental impact assessment for possible— positive or negative—processes that intersect to contain entirely natural, social and economic aspects of the ecosystems. The advection of pollutants from unstable marine environment influences dispersion and affect levels of gaseous dispersion. The plume originally emitted into a stable layer in the ambient atmosphere and mixed rapidly to unstable plume in ground level. The accumulation in enclosed spaces above or below ground level, where it could remediate off-site, cause dieback in neighbouring vegetation tissues to increase levels of greenhouse effects. The model is simplified as a central stage median abiotic and biotic endpoint impact assessment as classified in Fig. 1 [14].
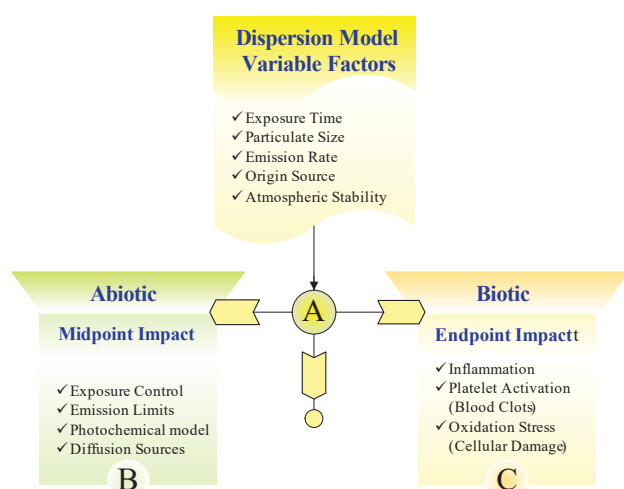

Fig. 1 The Model as central point of EIA policy [14]

A. Approach Analytic Photochemistry

Recently, aerosol processes indicate formation of HCl, as a consequence of sodium chloride photolysis in the presence of methane and carbon dioxide. The polarity of hydrogen chloride molecule makes it very soluble in water and hygroscopic in air to form an aerosol of dense mists or fog by acting as a nucleation center and accreting water from the air. In order to model the behavior of methane, as a simple hydrocarbon with other important reactive components in air, interpretation is based on both equilibrium phase and physical properties of the air flow and the surface. It extends to the chemical contaminants when attributed to the presence of impurities. The formulation of HCl could be a result of the photochemical reaction between methane and chlorine in the presence of ultraviolet light as–typically sunlight. The $[Cl^-]$ and $[H^+]$ radicals insert into specific chain condition to form internally excited species, and respectively hydrogenation to form hydrogen chloride as an example of a photochemical formation – a reaction simply brought about by light (e.g. [15]).

$$H^\bullet + Cl^\bullet \longrightarrow HCl$$
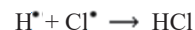
Kumar et al. [16] reviewed aerosol microphysics and electrolysis recovery to chlorine species. However, HCl is known as "temporary reservoirs" for chlorine, since active chlorine can be regenerated via both the photochemical and diffusive equilibrium for recovery formulation [17]

$$HCl + OH^\bullet + hv \longrightarrow H_2O + Cl^\bullet$$

$$2\,HCl + CO_2 + hv \longrightarrow H_2O + CO + Cl_2$$
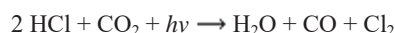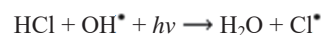
The age of the landfill, the type and amount of deposited waste as well natural recovery of environmental equilibrium systems are influence emission rates and hence, fumigation.

B. Experimental Measurement Campaign

Quantitative measurement of aerosols is more difficult and requires collecting the aerosol over a period of time. The capture of hydrogen chloride gas phases requires several minutes or more to collect the sample and therefore does not yield ceiling concentration results. The immediate analysis (by colorimetric tube) or later laboratory analysis can be applied to express HCl values in micron per dry standard cubic meters (μg/dscm), parts per million dry volumes (ppmdv) [18].

EPA (TR-147) method specifies aerosols sample to determine the concentration for HCl present in the raw LFG. The EPA method specified isokinetic samples that withdrawn from gas stream source at the landfill location (i.e. through a glass nozzle, a heated, Teflon lined probe and a heated Teflon filter). Samples have passed through the probe and filter detained in a series of impingers containing a dilute sulfuric acid (H_2SO_4) solution. Dilution enables the use of non-heated transfer lines to deliver a clean, cool gas with low particulate concentration to the ion chromatography (IC) analyzer [19].

OSHA ID-174SG method specifies sample collection with a silica gel tube with glass fiber filter plug for particulate and analysis by ion chromatography, with a recommended sample volume of 7.5 liters collected at a rate of 0.5 liters per minute; this translates to a 15-minute sampling period [20].

The EEAA laboratory specifies a colorimetric tube to indicate airborne measurement of HCl which composed in boundary layer. The measurement systems indicate the formation of HCl in the lower atmospheric layers as a result of active species of high chlorine radicals $[Cl^-]$ atom or hydroxyl $[OH^+]$ molecules from marine boundary layer [20].

III. Spatial Analysis System Architecture

The advection, transport and deposition nature of atmospheric pollutants has proposed the simulation of air quality models at computer systems. Mostly, data are included in the map layers as attributes for virtualization of physical properties such as point and area sources of pollution, spatial description of terrain elevations, meteorological data, real time air quality monitoring networks and exposure hazards. These require a huge volume of numerical calculations; so that two– dimensional interpolations in the horizontal layers are used to

interpolate three-dimensional atmospheric data as a model grid system, Fig. 2 [21].

In case of large scale air quality modeling, more detailed spatial data are needed to include the endpoint biotic impact of diffusion pollutants in surrounding receptors [22], [23]. Statistical theory is also used to indicate temporal interactions as described by [24]. In spite of air pollutant simulation, air dispersion is carried out by standalone computer systems; the spatial database in the frame of the GIS is used to support more detail virtualization for efficient decision-maker processes.
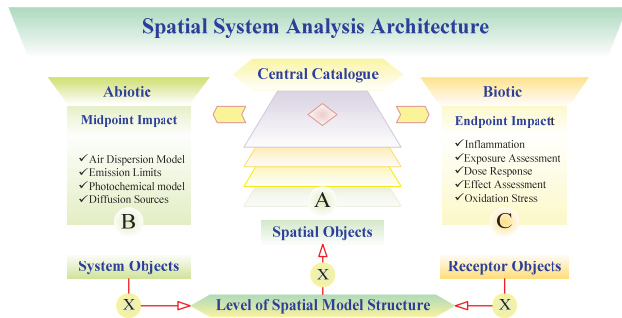

Fig. 2 The Spatial Analysis Model Landfill System Objects [21]

The spatial analysis associated intermediate results of plume dispersion and the potential airborne measurements to be attributed to RDBMS of environmental impact assessment. The concentration reflects health hazardous effects as a biotic endpoint impact assessment. Next section will characterize risk from point's exposure in detail concentration contours levels and model risk assessment of formation HCl aerosols.

A. Equations for Quantitative Assessment

Generally, the most widely used model handle air dispersion phenomenon is based on well-known Gaussian plume formulation. The model uses mass-balance correction factors in order to predict concentrations with improved gradient– transfer deposition algorithms. The model is not designed to handle buoyant sources or any emission in ambient conditions since it does not contain any plume-rise algorithms. The Gaussian plume model used here is the ISCST3 model (Industrial Source Complex, Short-Term, Version 3), and is expressed as [25]:

$$C_{(x,y,z)} = \frac{E_r}{\pi\, u\, \sigma_y \sigma_z} \exp\left\{-\frac{1}{2}\left(\frac{y}{\sigma_y} + \frac{z}{\sigma_z}\right)^2\right\} \qquad (1)$$

where, C is the concentration averaged over time t (g/m^3); x is the distance downwind in meter; y is the distance crosswind in meter; z is the height above ground level in meter; E_r is the rate of emission from the source (g/sec); σy and σz are the 'dispersion coefficients' representing the crosswind and vertical spread distance of the plume, respectively, which are increasing functions of distance x at averaging time t; and u represents the vertically and time averaged wind speed.

B. Determination of Diffusion Coefficients

Atmospheric temperature and pressure influence the buoyancy of air parcels, when parcel raise to extend diffusion and influence area according to the temperature of the surrounding air. As long as the parcel's temperature is greater, it will rise; as long as the parcel's temperature is cooler, it will descend. When the temperatures of the parcel and the surrounding air are the same, the parcel will neither rise nor descend unless influenced by wind flow.

Scheme for determining diffusion coefficients, based on categories of atmospheric stability class, are developed by many individuals. The commonly used in Gaussian Plume model is based on Passquill – Gifford as attributed according to site conditions [26].

In approach requirement solution, a number of assumptions have been used to approximate coefficients of various atmospheric conditions. The equation in case of area source of fugitive gaseous emission is simplified as a guideline to be comparable between field measurements or modeling framework as [27]:

$$\sigma_y = cx^d \qquad (2)$$

$$\sigma_z = a\,x^b \qquad (3)$$

where, *x* is the downwind distance from the origin source in meters. The values for a, b, c, and d are taken according to field measurements as parcel advection and diffusion in atmospheric layers.

TABLE I
POWER LAW EXPONENTS AND COEFFICIENTS FOR σz [25]

Atmospheric Stability Class	Passquill Gifford	Downwind Distance meters					
		$100 < x \leq 500$		$500 < x \leq 5000$		$x > 5000$	
		a	b	a	b	a	b
Extremely unstable	A	0.0383	1.2811	0.0002539	2.089	0.00025	2.089
Unstable	B	0.1393	0.9457	0.04936	1.114	0.04936	1.114
Slightly unstable	C	0.1120	0.9100	0.1014	0.926	0.1154	0.9109
Neutral	D	0.0856	0.8650	0.2591	0.6869	0.7368	0.5642
Slightly stable	E	0.0818	0.8155	0.2527	0.6341	1.297	0.4421
Stable	F	0.1094	0.7657	0.2452	0.6358	0.9204	0.4805
Extremely stable	G	0.06645	0.8060	0.1930	0.6075	1.505	0.3662

Atmospheric Stability Class	Passquill Gifford	Downwind Distance meters			
		x < 10000		x ≥ 10000	
		c	d	c	d
Extremely unstable	A	0.495	0.873	0.606	0.851
Unstable	B	0.310	0.897	0.523	0.840
Slightly unstable	C	0.197	0.908	0.285	0.867
Neutral	D	0.122	0.916	0.193	0.865
Slightly stable	E	0.0934	0.912	0.141	0.865
Stable	F	0.0625	0.911	0.081	0.884
Extremely stable	G	0.0468	0.986	0.072	0.896

C. Wind Speed Correction

In the lower layers of the atmosphere, wind speed normally increases with height. Most wind speed measurements of national weather service are taken at a height of 10 meters above the surface and listed as "ground level" wind speeds. The wind speed at fumigation sources has the greatest effect on the plume diffusion. Wind speed may be adjusted to the desired surface boundary layer [28]:

$$\mathbf{u} = \mathbf{u}^* \left(\frac{z}{z_o}\right)^{p} \tag{4}$$

where: u_z is the wind speed at height z, u* is the wind speed at anemometer height, z is the desired height z_o is the anemometer height (usually 10 meters) and p is defined constant a function of atmospheric stability condition for both rural and urban areas (Table III).

Stability Condition	Pasquill-Gifford	Rural Exponent	Urban Exponent
Extremely unstable	A	0.07	0.15
Unstable	B	0.07	0.15
Slightly unstable	C	0.10	0.20
Neutral	D	0.15	0.30
Slightly stable	E	0.35	0.30
Stable	F	0.55	0.30
Extremely stable	G	0.66	0.39

IV. MOTIVATION RISK ASSESSMENT

Motivation vulnerability criteria can broaden scope of impact assessment to determine dose levels that result in specific consequences as partial context of biotic endpoint impact. This integration encompasses total surroundings for both physical and societal installation dimensions. Traditional assessment procedures are based on Monte Carlo simulation. However, the steps involved in Risk Assessment1 are (1) Hazard identification, (2) Dose response assessment, (3) Exposure assessment, (4) Risk characterization, and (5) Risk management. The assessment will be limited to define components of exposure dose and its effects. In other words, the assessment is intended to ensure that the general public would not be adversely affected by the composed HCl [29]; [30].

A. Exposure Assessment

The assumption of the exposure point concentrations is ultimately examined through sensitivity analysis. A sensitivity analysis identifies input concentrations variables of the myriad which have the most significant impact on the risk values results. The calculation of administrated dose is summarized in the following generic equation [31]:

$$I = \frac{C \times CR \times EF \times ED}{BW \times AT} \tag{5}$$

I is the intake (mg/kg of body weight per day); C is concentration at exposure point (e.g., mg/L in water or mg/m^3 in air); CR is the contact rate (e.g., L/day or m^3/day); EF is the exposure frequency (days/years); ED is the exposure duration (years); BW is the body weight (kg); AT is the average time (day).

Equation (5) is typical modified for specific exposure pathway, for the intake dose from inhalation of fugitive gaseous may be calculated as:

For Fugitive Emissions Intake dose

$$I = \frac{C \times CR \times EF \times ED \times RR \times Abs}{BW \times AT} \tag{6}$$

RR is the retention rate (decimal fraction); Abs is the absorption into bloodstream (decimal friction).

The concentration in the air is determined as a partial ratio which explored by

$$C = C_s \times P_c \tag{7}$$

Cs is the concentration of chemical in fugitive dust (mg/mg); Pc is the concentration of fugitive gaseous in air (mg/m^3).

Appropriate parameters may be considered for professional judgment such as the exposure frequency and duration rate

B. Effect Assessment

The biotic endpoint impact requires setting a lethal dose, in possible cause damage for 3% fatality, as stipulated by the hazardous installation control rules [32]. Probit equation is the most common expression of acute/lethal dose-response relationship in safety risk assessment [33].

$$P_r = k_1 + k_2 \ln (C^n \times t) \tag{8}$$

C is the hazard concentration (ppm); t is the time in minutes; k1, k2, n are constant relative to type of chemical (a).

The probit constants have been examined by various sources including "Green Book" [34] as listed and there are significant variations in the effects of dose values in Probit equation as expressed hazard. The CPD (Green Book) parameters in probit equations for lethality of hydrogen chloride are taken as k1 = - 6.7 (mg/m^3), k2 = 1 (mg/m^3), n=1 (min) [35].

C. Risk Characterization

The assessment of threats is integrating the effect of four interrelated tasks define of: Potential receptors population;

toxicity assessment; evaluation of potential exposure; risk characterization. The model focused mainly on hydrogen chloride (HCL), which is non-carcinogenic chemical as per United States Environmental Protection Agency classification [31]. However, the limitation of relative criteria responsible to normally characterized risk in terms of a hazard index. This hazard index is simply the ratio of estimated intake dose from exposure to the reference concentration (RfC):

$$\text{HI} = \frac{I_c}{\text{RfC}} \qquad (9)$$

HI is the hazard index (dimensionless); Ic is the chronic day intake of carcinogen (mg/kg.day); RfC is reference concentration (mg/kg.day)

If the acceptable level of intake is deemed to equal the reference dose, then by definition, the hazard index less than 1.0 is acceptable. The EPA's Integrated Risk Information System (IRIS), lists all the RfC's established, and discusses the UF's used in their determination. The toxicologic index in the IRIS database are updated continuously and available at: *www.epa.gov/iris* [36].

V. RESULTS AND DISCUSSION

A few scenarios are established to integrate air quality models into the GIS. The basic level is represented by the standalone software application for simulation of air quality models (ISCST3, ISCPRIME), which is accompanied by data inputs and outputs. All data can be used independently by other software systems (GIS, RDBMS, Surfer®, MS Excel® and WWW–presentations). The individual programs form heterogeneous data structures that require the transport of data into various data formats.

The limitations of available data impose a preliminary estimation of initial emission rate, expressed as hydrogen chloride at regulatory default value (10) g/sec. The observation of uncovered hydrogen chloride reflects an increase in landfill boundary layer (LBL) in frequently managed operations as concentration level (43 ppm) and extends to disperse at long distance up to 2 km downwind direction from centerline of landfill area. Fig. 4 illustrates contour lines of HCl concentrations as final result of transformation scenario for virtual output steps carried out during the simulation of air quality models in landfill site.

The model is simplified to determine a non-dimensional concentration $C(x, y, z)$ at specified points downwind as area source. The source is centred on the origin to specify contamination diameter by its width Y and depth X in the wind direction (angle θ to the x-axis) as illustrated in Fig. 4. The receptors can be specified, at any point by a lateral distance y and longitudinal distance (x) from the centre of the source. Other data required are the aerodynamic roughness height (z_o) and the atmospheric stability class.
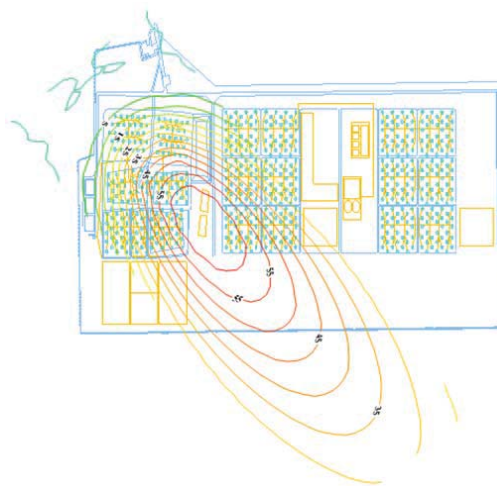

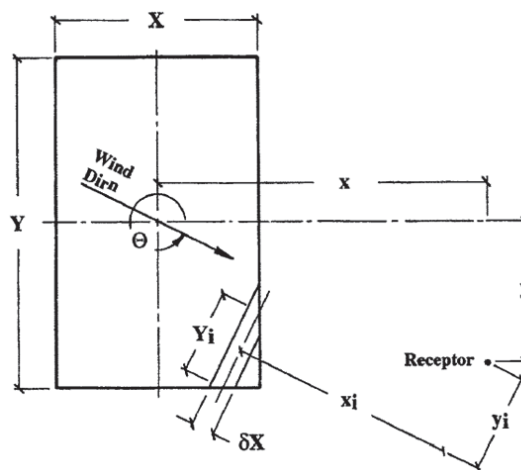Fig. 3 Contours of HCl concentrations downwind direction

Fig. 4 Sketch defines receptor by its width Y and depth X

The chronic daily inhalation of noncarcinogenic exposure, by adults in residential area, is specified as a function of concentration results of applied air dispersion model. The parameters used for this type of calculation are based assumed exposure conditions (the selected exposure scenario). As an example, the air breathing rate for adults is 0.83 m³/hr. However, this rate can vary by an order of magnitude from 0.6 m³/hr at rest to 7.1 m³/h for vigorous physical exercise. So that CR = 0.83 m³/h × 24 h/day =19.92 m³/day; EF = 365 day. For residential exposure, a default value for ED =30 years is typically used [38].

In the absence of better information, a conservative approach would assume the retention rate (RR) and the absorption into bloodstream would be 100 percent or (RR = Abs =1.0); BW = 70 kg: AT = 365 days/year × 30 year = 10,950 days.

$$I = \frac{C \times 19.92 \times 365 \times 30 \times 1.0 \times 1.0}{70 \times 10950}$$

$$\text{Intake Dos } I_c = 0.285 \; \frac{\text{m}^3}{\text{kg . day}} \times C$$

where C is the exposure point concentration (mg/m^3).

The limitation of relative criteria for hydrogen chloride reference concentration makes it hardly to define its RfC in IRIS. So, the worst case scenario is considered and normally characterized for non–carcinogenic as assumed to be equal to:

$$1.00 \times 10^{-2} \; \frac{mg}{kg \, .day}$$

The average concentration level is measured at receptor point in range (43 ppm ~ 64 mg/m^3):

$$HI = 0.285 \times 64 \times 1.00 \times 10^{-2}$$

$$HI = 10.24 \times 10^{-2} \; < 1.00$$

The IRIS database contains both qualitative and quantitative data regarding non carcinogens and carcinogens. At present the EPA has defined acceptable risk for carcinogens as within the range of 1×10^{-4} to 1×10^{-6} (one in million) in excess the person's risk of cancer from all source combined over lifetime. As hazard index of noncarcinogen less than 1.0 as defined criteria [37].

VI. CONCLUSION

The spatial analyses expand our knowledge for virtual interpretation the effect of landfill site as reaction substrates. HCl is one of the major results from emitted gases from incineration municipal and hazardous waste. The measured airborne HCl in landfill site is largely unknown origins, but fugitive gaseous emission contains five fugitive sources associated with the production of carbon dioxide (e.g., biodegradation, volatilization, fugitive dust generation, leaching and combustion), are predicted the ecologic impact of specific landfill site.

The hydrogenation of chlorides reaction resulting from photolysis of sea – salt aerosols in presence of hydroxyl (OH) and other volatile organic compounds (VOC) can produce HCl [39]; [40]. On the other hand, the safety risk assessment is carried out to maintain the balance between efficient land use and adequate protection of the general public against the hazardous installation.

REFERENCES

[1] UE: Public Policy Initiatives to Promote the Uptake of Environmental Modeling Systems in Small and Medium-Sized Enterprises. Final report of the best project expert group January 2004.

[2] Robert K H, "*Tools and Concepts for Sustainable Development, how do they relate to A General Framework for Sustainable Development, and to each other*", Journal of Clearner Production: pp12.", 2001.

[3] Shao Y, "*Physics and Modeling of Wind Erosion*", 2009.

[4] Kon L C, Durucan S., and Korre A., "*The Development and Application of a Wind Erosion Model for The Assessment of Fugitive Dust Emissions from Mine Tailings Dumps*", International Journal of Mining, Reclamation and Environment, 21(3): p. 198-218. 2007.

[5] Park Y K, and Park S, "*Development of a New Wind-Blown-Dust Emission Module Using Comparative Assessment of Existing Dust Models*", Particulate science and technology, 2010. 28(3): p. 267-286, 2010.

[6] Kouznetsov R, and Sofiev M, "*A Methodology for Evaluation of Vertical Dispersion and Dry Deposition of Atmospheric Aerosol*", Journal of Geophysics Research, 117, D01202, doi:10.1029/2011JD016366, 2012.

[7] Lui F, Cheng J X, Nui R T, Zhang X K, and Sun W," *The Compassion of Wedge and Hotspots Radioactive Aerosol Diffusion Mechanisms*", Frontiers of Energy and Environmental Engineering, Sung Kao and Chen (eds), © Taylor and Francis Groups, London ISBN 978-0-415066159-1, 2013.

[8] McKenna Neuman C, Boulton J W, and Sanderson S, "*Wind Tunnel Simulation of Environmental Controls on Fugitive Dust Emissions from Mine Tailings*", Atmospheric Environment, 43(3): p. 520-529. 2009.

[9] U.S. EPA, Revision to the guideline on air quality models, "*Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and other Revisions*", Federal Register, 9 November 2015, Vol.70 (216), pp.68218-68261, 2015. 70 (216): p. 68218-68261.

[10] Turner D B, "*Workbook of Atmospheric Dispersion Estimates: An Introduction to Dispersion Modeling*", 2nd Edition, CRC Press. ISBN 1-56670-023-X, www.crcpress.com., 1994.

[11] Schnelle Karl B, and Dey Partha R, "*Atmospheric Dispersion Modeling Compliance Guideline*", McGraw-Hill, ISBN 0-07-058059-6, 2000.

[12] Kon L C, Durucan S, and Korre A, "*The Development and Application of a Wind Erosion Model for the Assessment of Fugitive Dust Emissions from Mine Tailings Dumps*", International Journal of Mining, Reclamation and Environment, 21(3): p. 198-218, 2007.

[13] U.S. EPA, "*Emissions Factors & AP 42, Compilation of Air Pollutant Emission Factors*", 1995.

[14] Kukkonen J, Karl M, Keuken M P, Denier van der Gon H A C, Denby B R, Singh V, Douros J, Manders A, Samaras Z, Moussiopoulos N, Jonkers S, Aarnio M, Karppinen A, Kangas L, Lützenkirchen S, Petäjä T, Vouitsis I, and Sokhi RS "*Modelling the Dispersion of Particle Numbers in Five European Cities*", Geosci. Model Dev., 9, 451–478, doi:10.5194/gmd-9-451- 2016, 2016.

[15] Kumar P, Ketzel M, Vardoulakis S, Pirjola L, and Britter R, "*Dynamics and Dispersion Modelling of Nanoparticles in the Urban Atmospheric Environment – A Review*", Journal of Aerosol Science, 42, 580–603, 2011.

[16] Soares J, KousaA, Kukkonen J, Matilainen L, Kangas L, Kauhaniemi M, Riikonen K, Jalkanen J-P, Rasila T, Hänninen O, Koskentalo T, Aarnio M, Hendriks C, and Karppinen A, 2014Ss "*Refinement of a Model for Evaluating the Population Exposure in an Urban Area*", Geoscience Model Development, 7, 1855–1872, doi:10.5194/gmd-7-1855-2014, 2014.

[17] Lawrence, W G, K C Clemishaw, and V A Apkarian, "*On the Relevance of OClO Photodissociation to Destruction of Stratosphereic Ozone*", Journal Geophysics Research, 95, 18591 – 18595 (1990)

[18] Annual Book of ASTM Standards, "*Atmospheric Analysis*", American Society for Testing and Materials, Philadelphia, Pennsylvania, 2015.

[19] Grosjean D, and Fung K, "*Collection Efficiencies of Cartridges and Micro-Impingers for Sampling of Aldehydes in Air as 2,4-Dinitrophenylhydrazones*", Chemical Analysis, 54, 1221-1224, 1982.

[20] John H N, and Scott C S, "*Laboratory and Field Evaluation of a Methodology for Determination of Hydrogen Chloride Emission from Municipal and Hazardous Waste Incineration*", Atmospheric Research and Exposure Assessment Laboratory, Office of Research and Development, EPA Contract No 68-02-4442, US Environmental Protection Agency, Research Triangle Park, North Carolina, April 1989

[21] Longley, P.A., M.F. Goodchild, D.J. Maguire, D.W. Rhind, "Geographic Information Systems and Science", John Wiley & Sons, 27-58, New York, 2001

[22] Civis S, Zelinger Z, Strizik M, and Janour Z., "*Simulation of Air Pollution in a Wind Tunnel*", In: *Spectroscopy from Space*, (Demaison, J., Ed.), Kluwer Academic, Dordrecht, 275-299, 2001.

[23] Zelinger Z, Strizik M, Janour Z, Berger P, Cerny A, "*Comparison of Model and in-Situ Measurements of Distribution of Atmospheric Pollutants*", Proceedings of PHYSMOD 2003: International Workshop on Physical Modeling of Flow and Dispersion Phenomena, Italy, 6 pp., 2003

[24] Briggs D J, "*A Regression-Based Method for Mapping Traffic-Related Air Pollution: Application and Testing in four Contrasting Urban Environments*", the science of the total environment 253, 151-167, 2000.

[25] U.S. EPA, "*User's guide for the Industrial Source Complex (ISC3) Dispersion Models*", Volume I – user instructions, Washington, DC, 1995.

[26] Pssquill F., and F.B Smith, "*Atmospheric Diffusion*", 3'd edition, Ellis Horwood, Chichester, UK, (1983).

[27] Hanna S R, Briggs G A, and Hosker Jr, "*RP: Handbook on Atmospheric Diffusion*", edited by: Smith J S, DOE/TIC-11223, Technical Information Center, US Department of Energy, Springfield, USA, 1982.

[28] Irwin J S, "*Proposed Criteria for Selection of Urban Versus Rural Dispersion Coefficients*", Meteorology and Assessment Division, U.S. Environmental Protection Agency, Research Triangle Park, NC, (Docket No. A-8046, II-B-8), (1978).

[29] Office of Environmental Health Hazard Assessment, OEHHA, 2012a, "*Air Toxics Hot Spots Program Risk Assessment Guidelines*", Technical Support Document for Exposure Assessment and Stochastic Analysis, 2012. Available online at http://www.oehha.ca.gov

[30] U.S. EPA. (2009), "*Metabolically Derived Human Ventilation Rates: A Revised Approach Based Upon Oxygen Consumption Rates*", U.S. Environmental Protection Agency, National Center for Environmental Assessment, Washington, DC; EPA/600/R-06/129F, 2009

[31] U.S. EPA, "*Risk Assessment Guidelines*", Office of Health and Environmental assessment USEPA, Washington DC 20460, 1989

[32] Lees F P, 1996, "*Loss Prevention in the Process Industries: Hazard identification, assessment and control*", 2nd ed, Butterworth-Heinemann, Oxford.

[33] Eisenberg N A, Lynch C J and Breeding R J, "*Vulnerability Model: a simulation system for assessing damage resulting from marine spill*", Reported by enviro control Inc. to US coast guard, DOT-CG-33377-A, National Technical Information Service No Ad-A015, 1975

[34] Louvar J F, and Louvar B D, "*Health and Environmental Risk Analysis: Fundamentals with Applications*", Prentice Hall Environmental Management and Engineering Series Volume 2. 1998.

[35] Seller J G, "*Quantification of Toxic Gas Emission Hazards*", The institute of Chemical Engineers, Symposium Series, No 47, 127-134 1976.

[36] U.S. Environmental Protection Agency: "*EPA's Integrated Risk Information System (IRIS) Program*", Progress Report and Report to Congress, Office of Research and Development, February, 2015

[37] WHO (World Health Organization), "Environmental *Health Criteria*", IPCS International Programme on chemical Safety, Geneva, 1986.

[38] U. S. EPA, "*Superfund Exposure Assessment Manual*", 1988

[39] Behnke W, George C, Scheer V, and Zetzsch C, "*Production and Decay of CINO$_2$ from the Reaction of Gaseous N2O$_5$ with NaCl Solution: Bulk and Aerosol Experiments*", Journal of geophysics Research, 36, 3795-3804,1997

[40] Schweitzer F, Mirabel P, and George C, "*Multiphase Chemistry of N$_2$O$_5$, CINO$_2$ and BrNO$_2$*", Journal of Atmospheric Chemistry and Physics, 102, 3942-3952,1998