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Concentration and Seepage rate of Leachates from the Oji river Sanitary Landfill of Enugu State, Nigeria

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ABSTRACT

A study on the movement of leachates in the soil has been undertaken. The identified leachates were phosphate (PO_4^{3-}) and Nitrate (NO_3^-) emanating from solid wastes in a sanitary landfill. The soil samples used for the tests included laterite soil, sandy soil and clay soil. Results showed that the emanating leachate that came out had the highest value from clay at 0.257 $ugml^{-3}$, followed by sand at 0.202 $ugml^{-3}$ and laterite at 0.151 $ugml^{-3}$; all for nitrate. For the phosphate, it was 0.201, 0.116 and 0.085 ugml-3 for clay, sand and laterite respectively. The characterization of solid waste constituent extraction was also carried out and it was observed that the concentration of the leachates was subject to the time the solid wastes were allowed into water. The results gave insight into the proffered management strategies which would stem the pollution of both ground and surface water bodies from the ingress of leachates.

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1.0 INTRODUCTION

Leachates are noxious, mineralized liquids from dissolving organic and inorganic solid waste materials under the ground such as sanitary landfills (Agunwamba, 2001). They observe gravitational movement in the soil by way of seepage, percolation or leaching. Their diffusion into ground or surface water bodies result in severe bacteriological, toxic and other physico-chemical pollution. This is because they contain concentration of substance such as ions of chlorides, sulphates, metals especially iron, sodium, potassium calcium magnesium and zinc. Scott (1982), remarks that their concentrations are subject to great variations.

Prior to the formation of leachates in sanitary landfill are a number of different interactive processes. First is biological degradation of organic putrescible materials. This can be either aerobically or anaerobically. Gases such as Ammonia NH_3, Carbondixide CO_2, Carbonomonoxide CO, Hydrogen H, Hydrogen Sulphide H_2S, Methane CH_4, Nitrogen N, Oxygen O and some liquids are evolved. Secondly, thorough chemical oxidation of the solid waste material takes place in the process. The third interactive process is the escape of gases from the landfill and the lateral diffusion of gases through it. Fourthly is the movement of liquids caused by differential heads (pressure). The fifth process is the dissolution and leaching of organic and inorganic materials by water and the movement of leacheates through the landfills. Sixthly is the movement of dissolved material by concentration gradient and osmosis. Finally, uneven settlement which results from consolidation of material into voids takes place. Maier (1998) holds similar views on these bio-chemical degradation processes in landfills and that since the constituents of sanitary landfill leachates show them as grave chemicals of surface and underground water pollutants, there is the need to estimate the amount produced. This will aid its effective management in the area of treatment and prevention of its intrusion into water bodies. The estimation of the quantity of leachates produced can be difficult because of some reasons. The texture of solid waste is extremely coarse and this prevents homogeneous moisture content.

This lack of homogeneity is responsible for the different drainage paths and uneven saturation. In this situation, ordinary equations of flow through porous media cannot correctly describe the flow of leachates in the soil. The landfill water balance is greatly affected by the surface characteristics of each particular site. The dispositions of surface depressions, extent of vegetation cover and the problems of run-offs which do not percolate but drain from the waste are examples of these surface characteristics. The moisture content dictates the extent of degradation during which the retention of the waste material can be altered.

However, despite the afore mentioned problems, production of leachates from sanitary land fills from this expression was advanced by Veit et al (1983).

$$Q = \frac{1}{t} PAK \text{---------------------}(1)$$

Where Q stands for average flow (l/s) per hectare of superficial area; P represents average rainfall per year in mm; A is area (m^2); t is the number of seconds per year and K is a constant, dependent on the waste concentration and conditions of the site.

A number of drainage structures are put in place to ensure safe draining of leachates in such a manner that their ingress into water bodies is guard against. This can be by way of employing any modern drainage approaches such as the Agunwamba (2001) method.

To collect the leachates, a drainage system is made at the natural ground layer. These are trenches formed at the bottom of the valleys of the sanitary landfills. They are matted with a layer of geotextile blanking. A bored -through amoured concrete tube is laid down on top of the blanking. The trench is than packed with crushed stones up to the edge after installing the tube. The whole upper part of the trench is covered with geotextile blanket. A second layer of crushed stones is applied on the blanket in order to protect it. These pipes that drain the site convey the produced leachate into the tank. The major drains run from the highest point of each cell or site sub-unit until it gets to a predetermined point. The minor draining pipes run perpendicular to the major draining pipes, thereby making a fish skeleton structure. Uchegbu (2009)

1.1 Movement of Leachate Modelling

The material balance approach in a controlled volume can be employed in the modelling of leachate movement in a landfill. In this method,

Inflow = accumulation + outflow or (depletion)

Its inherent assumptions are:

(a) There is a complete mixing of the waste material.
(b) It has full reactor volume which comprises of solid waste, moisture and gas or void.
(c) The spatial volumetric moisture content denotes moisture stored. If the net rate at which the contaminant gets into waste is R/unit volume moisture; C is the spatial uniform concentration of the leachate contaminant; Ø represents the moisture content and Q stands for the net rate of leachate flow, then the mass balance for both moisture and dissolved contaminant would result in;

$$\frac{d}{dt}(V\varnothing) = Qi - Q - - - - - - - - - - (2a)$$

$$\frac{d}{dt} = Ci - Qi - CQ - V\varnothing R - - - - (2b)$$

Where i stands for the inflow and the out flow parameters do not have subscripts. Reinhart (1996) and Maier (1998) also applied this conceptualization in their studies on leachate movement and recirculation in landfills.

The grave consequences of leachates and their contamination to both ground and surface water bodies have been looked at both descriptively and empirically. A better comprehension of the movement of inorganic phosphates and nitrogen in soil is very important for the prediction of the dynamism of through-soil movement of pollutants into groundwater from solid waste. These pollutants are responsible

for eutrophication of surface water bodies when they find their way into them.
These and other evils of leachate movement in soil as well as the proffering of their management strategies are the intentions of this study. Environmental management is all about being proactive to phenomena that militate on the sustenance of environmental resources.

2.0 Literature Review

Waste management has become increasingly complex due to the increase in human population, industrial activities and technological revolutions. The processes that control the rate of wastes in the soil are intricate and many of them are poorly understood (Akinbile and Yusoff, 2011). Toxic chemicals that have high concentration of nitrate and phosphate derived from wastes in the soil can filter through a dump and contaminate both ground and surface water. Insects, rodents, snakes and scavenger birds, dust, noise, bad odour are some of the aesthetic problems associated with sanitary landfills (Ogbuene et al, 2013). Liquid waste can contaminate land and pollute surface as well as ground water. This needs to be managed in a way that the environment and community are protected. Garbage landfill processes inevitably produces leachate pollutant leakage. In the landfill process, pollutants will experience degradation, chemical reactions caused by the interaction of fluid and temperature (Wu, 2010).
Municipal solid waste (MSW) landfill leachate contains a number of aquatic pollutants. A specific MSW stream often referred to as household hazardous waste (HHW) can be considered to contribute a large proportion of these pollutants (Slack et al, 2006). Emissions from landfills take a number of forms from landfill gas and airborne particulates to leachates. The migration of leachates from ‘‘dilute-and-disperse’’ landfills ensuing contamination of soil and groundwater have been reported in the literature, as having the toxicity of MSW leachate. These types of landfills are designed to permit the rapid dispersion of leachates into the surrounding environment (Slack et al., 2005). Landfill leachate is a potentially polluting liquid, which unless managed and/or treated, and eventually returned to the environment in a carefully controlled manner, may cause harmful effects on the ground and surface water that surrounds a landfill site (Environment Agency, 1999). Many of these compounds have attracted concern as emerging contaminants mainly because of potential risks associated with bioaccumulation and endocrine disruption effects. Leachates have certain environmental and health impacts. The most commonly detected xenobiotic organic compounds (XOCs) in leachate plumes are BTEX compounds (particularly toluene), aromatic hydrocarbons and chlorinated hydrocarbons (e.g. tetrachloroethylene and trichloroethylene) (Kjeldsen et al., 2002).
In recent times, the impact of leachate on groundwater and other water resources has attracted a lot of attention because of its overwhelming environmental significance. Leachate migration from wastes sites or landfills and the release of pollutants from sediments (under certain

conditions) pose a high risk to groundwater resource if not adequately managed (Ikem et al., 2002). Leachate from MSW landfill is a latent pollution source and the occurrence of leachate leakage, due to poor management can result in serious environmental contamination in the surrounding area. For example, in the Cao mountain landfill site of Anhui province in China, water quality determinations have identified high levels of contamination (Wu, 2010). Therefore, numerical simulation of the environmental pollution process from MSW landfill leachate is important to the evaluation of environmental risk associated with MSW landfills and also to the environmental pollution control process. A leachate may be formed at certain times of the year when, following periods of wet weather, the windrow can exceed its drainable limit leading to seepage from the base. Leachate can also be generated by high moisture content wastes such as fruits and Vegetable (Environmental Agency, 2001). If the windrow has been sited on an impermeable surface, this seepage has to be collected and stored to avoid uncontrolled runoff and pollution of water courses (The Composting Association, 2001). In addition to leachate derived from the windrow, polluted runoff from contaminated hard surface and machinery is also likely to be produced. MSW landfills are long-term repositories of potentially harmful substances. The simulation demonstrated the potential release of pollutants to ground water in violation of the limitations imposed by the Ground water Directive and for a few of these, namely heavy metals and cyanides, to exceed drinking water standards (Council of the European Union, 1998). Hazardous and non-hazardous landfills may produce leachate that has elevated concentrations of contaminants, such as ammonia, nitrogen, heavy metals and organic compounds. These could, if not contained and managed, affect both surface and groundwater resources.

It is important to realize that groundwater and surface water are both path ways and receptors. Once the conceptual site model has been formulated, it is possible to determine both the hazards and the risks presented by the landfill to potential receptors. Monitoring programmes should be tailored to the site-specific conditions using the knowledge of the hazards and risks presented by the landfill (Environment Agency, 1999). Silage leachate and contaminated runoff can reduce farm profitability and contaminate surface and ground water sources. Wells can be contaminated and fish and other aquatic organisms killed by these high strength discharges. Those charged with environmental protection have become more aware of these situations and have responded by developing rules and standards to help reduce the environmental impacts (Liu et al, 2006).

It is the minor problem of compost production. Besides considerable organic matter content in leachate causing structure improvement and infiltration increase, they include a lot of micro and macro elements such as N, P, K, Fe, Zn, Cu, Mn and Mo that can have negative effects on soil fertility. They also involve toxic elements causing environmental pollution and as such wastes need to be assessed (Andrew et al., 2006).Turbidity value tends to be slightly higher in the water body close to landfill. This may be due to proximity to the landfill indicating higher sediment flow. Presence of suspended particles and other materials are usually responsible for high turbidity values. Metals such as zinc, damaged battery cells (lead, mercury and alkaline) and improperly disposed used cans of aerosol and other disinfectants deposited in the landfill as wastes are hazardous. Where these wastes have been exposure to air and water through seepage, they can give rise to higher toxicity and acidity level. Hence, the need to determine the rate of leachate seepage from landfills cannot be overemphasized as sustainable mitigation measures are of critical importance for a healthy plant and animal lives.

3.0 MATERIALS AND METHOD

Since this study is geared towards leachate movement in soil, it is of prime importance that the classification of laterite soil, sandy soil and clay soil are shown (table 1). According to the international scale for naming soil particles (The Atterberg System) soils are classified according to the ped sizes of individual particles that constitute the sample.

TABLE 1: ATTERBERG SYSTEM FOR SOIL PARTICLE CLASSIFICATION

S/NO	PARTICLES	RANGE
1	Gravel (laterite)	Above 2mm diameter
2	Coarse sand	between 2mm and 0.2mm diameter
3	Fine sand	between 0.02 and 0.02mm diameter
4	Silt	between 0.02 and 0.002mm diameter
5	Clay	below 0.002 diameter
6	Colloids	less than 0.0002 diameter

Source: Methods of testing soil for civil Engineering Practice, British standard BS1377 (1967)

For any soil sample, the proportions of particle sizes have important effect on soil physical and chemical properties. The voids or spaces between the particles which are called pores permit the movement of air and water. These movements depend on soil porosity. This study therefore utilized laterite soil, sandy soil and clay soil samples which are dominant in the site to investigate leachate movement in the area.

3.1 Characterization of Solid Waste Constituent:

This is aimed at ascertaining the concentration of nitrate (NO_3) and phosphate (PO_4^{3-}) in the solid waste samples collected for investigation.

Procedure: After removing the top soil surface layer at the Oji River refuse landfill of Enugu state, the sample was collected. The sample quantity weighing 500g each was measured and put into 5 small plastic buckets of 2000cm^3 each.

Thereafter, 1500cm^3 of clean water was poured into the buckets and kept in a laboratory cupboard for time intervals of 1hr to 3hrs for 1,3 and 5 days. After these time intervals, water samples were collected from these buckets and tested for phosphate (PO_4^{3-}) and Nitrate (NO_3^-) concentrations with the same instrument. These pollutants are the leachates formed from the solid wastes.

3.2 Leachate Movement Test:-

This test aimed at investigating the rate of movement of the pollutants or leachates in the different selected soil samples of laterite, sand and clay.

Procedure: A 1.4m x 0.85m x 0.85m rectangular tank was constructed. Pipes of 12.5mm diameter that open at both ends were welded at the bottom of the tank to drain it. Tiny nets were filled at the end of the pipes inside the tank to prevent its blockage by soil samples. Thereafter the tank was loaded with the selected soil samples which are laterite, sand and clay soils at various heights of 0.320m respectively with the exception of solid waste which was at the topmost level to a height of 0.17m. Water of 0.015m^2/s flow rate was introduced into the tank by means of shower for 30mins. After approximately 1 hour; water started dropping out of the pipes. At regular intervals of 10, 20,30,40,50 and 60 minutes; up to 2 to 4hrs, water samples were collected from the pipes. The samples were tested for phosphate (PO_4^{3-}) and nitrate (NO_3^-) concentration with the same instrument.

After 30-days, the soil in the tank were collected by layer after layer and tested for phosphate (PO_4) and Nitrate (NO_3-) concentration by reduction of NO_3- with the Devard's Alloy and distillation of Kjeldahl Macro Method. For phosphate PO_4^{3-}, the Bray and Kurtz Extraction Method was employed. Ukachukwu (2010) also applied these in his study on pollution movement in soil.

4.0 RESULTS

The characterization of solid waste constituents and leachate movement tests has variously been carried out. Their results are presented in tables 2 and 3 below. This would be followed by discussions and inferences drawn, from the tests.

Table 2: Results of the Characterization of solid waste constituents

S/NO	TIME	LEACHATE NO_3^-	CONCENTRATON PO_4^{3-}(μgml^{-1})
1	1hr	0.143	0.153
2	3hrs	0.150	0.159
3	1day	0.130	0.165
4	3days	0.264	0.179
5	5days	0.290	0.282

Source: Authors' lab work, 2017.

TABLE 3: LEACHATE MOVEMENT TESTS

S/N	TIME	NO^{3-} (μgml^{-3})			PO_4^{3-} (μgml^{-3})		
		Laterite	**sand**	**Clay**	**laterite**	**Sand**	**Clay**
1	10min	0.114	0.129	0.175	0.056	0.042	0.039
2	20mins	0.119	0.138	0.189	0.062	0.049	0.069
3	30mins	0.124	0.144	0.222	0.063	0.051	0.114
4	40mins	0.135	0.152	0.226	0.067	0.0µ54	0.119
5	50min	0.142	0.153	0.227	0.069	0.079	0.124
6	60min	0.145	0.173	0.239	0.074	0.093	0.162
7	3hrs	0.148	0.191	0.246	0.080	0.105	0.180
8	4hs	0.151	0.202	0.257	0.085	0.116	0.201

Source: Authors' lab work, 2017.

Table 1: Laboratory Result of Physico– Chemical Properties of Water Sample from the Study Locations in Oji River

S/n	**Tests**	**Laboratory Results**						**WHO Standard**
		2014		**2015**		**2016**		
		Dry Season	Wet Season	Dry Season	Wet Season	Dry Seaso n	Wet Season	
1.	Electrical Conductivity	52.1	39.6	44.5	29.1	32.4	19.8	1000
2.	Temperature	33.4	29.0	30.7	18.33	28.5	20.5	Ambient
3.	Total Dissolved Solid mg/l	21.6	17.9	19.82	13.91	19.32	15.2	500
4.	Turbidity (NTO)	6.2	8.4	4.7.	7.22	4.4	6.1	5
5.	Suspended solid mg/l	9.18	6.23	5.3	8.86	5.8	7.92	<10
6.	Dissolved oxygen (CO2)	0.35	0.51	0.43	0.60	0.51	0.74	
7.	Total Alkalinity	0.81	0.63	2.67	1.94	2.01	1.24	100 – 200
8.	Acidity	3.44	2.01	4.01	3.80	4.02	3.31	45 – 82
9.	Total Hardness mg/l	43.0	35.0	51.9	43.80	53.1	40.8	500
10.	Selinity	0.02	0.001	0.01	0	0.011	0	0.5
11.	Cadmium (cd)mg/l	2.01	1.31	1.90	1.01	1.79	1.08	0.03
12.	Lead (pb) mg/l	1.23	0.76	1.1	0.41	1.04	0.55	0.01

13.	Chromium (G54)mg/l	0.02	0.011	0.01	0.0	0.025	0.000	0.05
14.	Mercury (Ho) mg/l	0.32	0.27	0.28	0.15	0.30	0.22	0.001
15.	Iron (Fe) mg/l	0.09	0.06	0.05	0.02	0.015	0.001	0.3
16.	Zinc (Zn) mg/l	0.03	0.01	0.02	0.01	0.02	0.010	3
17.	Copper (Cu) mg/l	0.042	0.028	0.031	0.017	0.036	0.015	0.9
18.	Fluoride (f) mg/l	UR-0.015	UR-0.03	UR-0.162	UR-0.041	UR-0.02	UR-0032	1.5
19.	Cyaride (Cm) mg/l	0.002	0.000	0.0014	0.001	0.0017	0.0011	0.01
20	Barium (Bo) mg/l	2.01	0.99	1.72	1.33	1.87	1.21	
21	Chloride (Cl) mg/l	0.38	0.14	0.21	0.13	0.30	0.10	250
22.	Solenium (Se) mg/l	0.01	0.009	0.009	0.004	0.004	0.007	0.05
23.	Aluminum (Al04) mg/l	0.01	0.002	0.015	0.011	0.012	0.001	
24.	Manganese mg/l	0.46	0.29	0.22	0.14	0.31	0.11	<0.1
25.	Aluminium mg/l	1.33	0.80	1.53	1.11	1.88	1.09	50
26.	Phosphate (PO43-) mg/l	0.20	0.09	0.16	1.12	0.24	0.10	3.5

Source: Authors' Lab Work, 2018.

Table 2: Laboratory Results of Bacteriological Status of the Water Samples from the Study Location in Oji River

S/n	Tests	Laboratory Results						WHO Standard
1.	Year	2015		2016		2017		
2.	Season	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season	
3.	Quantity of E. Coli per 100ml	81.0	98.0	92.0	96.0	183	191	< 1 CFU/100mL
4.	Total Quantity of Coliform per 100ml	106	110	101	116	203	213	< 1 CFU/100mL

Source: Authors' Lab Work, 2017.

4.1 DISCUSSIONS

Characterization of solid waste constituents: The observations from this result are that the concentration of phosphate PO_4^{3-} and Nitrate (NO_3^-) increases with time. Since the concentration of solid waste leachate increase is subject to time increase, and then the concentration of the leachate is directly proportional to time, t. this can be mathematically expressed as follows:

C αt

$\therefore$ C = Rt ------------------------(3)

Or R= C/t

Where R is a constant for solid waste leachate, C is the concentration and t is time.

The corollary is that the concentration of solid waste leachate is subject to water, time and nature of the refuse.

4.2 Leachate movement test:

The test result showed that clay came out with the highest concentration of NO_3^- and PO_4^{3-}. Next in that order is sand and finally laterite soil sample layer as the least. This shows their filtrate or permeability status.

This also shows that the concentration increases with time. It follows that the concentration increase is directly proportional to time increase. This can also be expressed as:

C α R

$\therefore$ C = Rt ------------------------- (3)

or R = C/t.

Where R stands for a constant for leachate rate of movement, C is the concentration of the leachate and t stands for time. Hence, the rate of leachate movement can be said to be dependent on water, time, and type of solid waste flow rate of water and soil porosity.

Leachate movement in the soil is affected by these parameters in the following ways.

a. Water: Water helps in the decay of the solid waste and the leaching out of the leachates. Without water the leachate will just remain in dry state inside the waste
b. Time: As time increases, the concentration of the leachate increases. This is because as time increases, the decay of the solid waste becomes more thorough and as such increases the leachate concentration.
c. Type of solid waste: The type of solid waste affects the concentration because constituents of wastes vary. Their decay rates also vary.
d. Flow rate of water: The flow rate of water determines to some extent the velocity of the leachates.
e. Soil porosity: velocity or rate of leachate movement is dependent on the soil porosity.

5.0 RECOMMENDATIONS AND CONCLUSION

Leachates have been found to be of grave consequences to ground and surface water sources. These recommendations will serve as management strategies to curb their negative environmental effects.

5.1 Management of Leachates:-

Reduction of leachate production:

The limiting of run off flows into land fills reduces leachate production. This is because the wetting of solid wastes by the runoff water increases leachate production. The limiting of these run off water entry into landfill is by:

a. Formation of contours or terracing to slow down or reduce the momentum of run of flows into landfills.
b. Run off water can be diverted into other terrains away from the landfills. They can be channeled into grasslands or other vegetated pasture lands.
c. The surface of landfills should be made of low permeability materials such as clay, slate, synthetic membrane, tar and mass concrete. This would create surface sealing.
d. The landfill area should be re-vegetated to guard against soil erosion of the cover material. This is because the root capillaries hold the soil structure firmly and the leaves serve as protective cover from raindrop impacts. This arrangement also encourages evapo-transpiration.

5.2 Leachate collection and treatment:

Leachates are usually channeled into tanks. Their collection is from these drainage channels. The appropriate treatment method of every leachate depends on their constituents. Scott (1982) categorized leachates into 3 groups of soluble organic materials in decreasing order of their rates of biodegradability:

The first group is short chain fatty acids of low molecular weight. They account for approximately 90% of the soluble organic content.

Next is humic carbohydrate- like substances with high molecular weight.

Thirdly, is the fulvic- like substances accounting for only a small proportion of the entire volume.

This first group is mainly found in newly or recently used landfills while the third group which made up a very minimal biologically degradable is that physico-chemical treatment methods which would be more effective in old landfills where natural biological treatment has long taken place on the leachates. To know the appropriate treatment method for leachates, it is necessary to compute the COD/TOC or the BOD/COD ratio. Lower ratios indicate best biological treatment.

The removal of organic and other leachate constituents have been carried out with the use of anaerobic and aerobic treatment systems. The production of high quality, effluent has been most effective with the physico-chemical method.

5.3 Surface impoundment

The surface of landfills should be made of geotextile, concrete, fired clay or thick synthetic membrane. These are to prevent the movement of leachate into ground water. Blackman (2001) adopted special synthetic liners for the impoundment of hazardous landfill floors to guard against leachate intrusion into ground water.

The improvement of liner technology would introduce more durable membranes for this purpose. Sand beddings or other finer material that do not consist of sharp aggregates can be used to protect these membranes from puncture. All non-synthetic impoundment material must not exceed 10^{-6} cm/sec permeability.

5.4 Ground Water Monitoring

A well articulated ground water monitoring plan is made to provide ground water quality data. With this put in place any intrusion of leachate into the ground water will be quickly detected and its remediation carried out promptly. There is gadget now used for early detection of leakages in landfill liners.

6.0 CONCLUSION

Leachate movement in the soil is of immense importance in the investigation and assessment studies of leachate pollution of ground and surface water sources. The study shows that the pollutant with the highest concentration was in clay soil followed by sand and finally laterite soils. This calls for very proactive awareness that all environmental management and control strategies that are concerned with leaching of all pollutants into ground water sources must note that the presence of fine particle soils such as clay must be adequately addressed. The permeability tendencies and concentration of phosphate (PO_4) and Nitrates (NO_3-) leachates have been also observed. These dispositions of the selected sample soils and leachates informed the proffered management measures which if stringently applied would control leachate intrusion into ground and surface water sources in the area.

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