A Comparative Review on Physical – Chemical and Bacteriological Analysis of Wastewater Used in Microbial Fuel Cell

Nathan W. Fundji[1] and John Kabuba[1]

Abstract**—**As the increase in human population, conventional ways of energy production are not sufficing human wants. Wastewater from industrial, agricultural and urban activities has been considered a precious resource for the recovery of drinkable water, nutrients and energy. A study was conducted on four samples of synthetic wastewater with addition of compounds such as acetic acid, table salt and brown sugar to produce biogas of up to 189 ppm. FTIR tests revealed that table salt was not organic. The Biochemical Oxygen Demand (BOD) test was performed and the amount of oxygen used by microorganisms for organic decomposition was less than 0.300 mg/L. The chemical oxygen demand (COD) was below 5 mg/L with the use of oxidizing agents. Despite these low levels, Total Coliforms and Heterotrophic Plates counts were able to produce electricity after 30 days of synthesizing wastewater.

Keywords**—**Biogas, Electricity, Microbial Fuel Cell, Wastewater

I. Introduction

Scientific Research is progressing into sustainable biological products, carbon capture, storage and reuse as a result of the increasing requirement for clean and renewable energy [1], [2], [3], [4]. The example of simultaneous wastewater treatment and energy recovery through electrochemical process can be described as a multi-dimensional approach to reducing the reliance on fossil fuels and, at the same time, reducing the direct release of organic substances in the form of effluents into the natural environment. This type of integrative approach will be correlated with the modern sustainability goals, which make it more efficient in protecting the environment and preventing resource waste [2], [4], [5]. The combinations of techniques, including electrocoagulation with hydrogen recycling and the use of aluminum-air fuel cells, help to aptly realize that purification and energy recovery could be combined into a coherent set and, consequently, decrease the total carbon footprint [6], [7], [8], [9], [10]. Besides maximizing efficiency of operations, it also pioneers the shift towards a low-carbon infrastructure system. Renewable energy presents an opportunity to decrease climate change and ensure energy security in low-income communities that have historically been less connected to the energy distribution infrastructure. Some authors have examined microbial fuel cells (MFCs) as a bi-electrochemical reactor capable of converting chemical energy present in organic matter to electricity through microbe metabolic activity. In contrast to the chemical fuel cells that are based on the traditional electrochemical reaction that often require costly catalysts and very controlled conditions, microbial growth and viability are used to convert energy in MFCs. The aspect provides energy recovery opportunities on varied organic waste materials besides aiding in water or industrial effluent treatment. Advantages of MFCs are low sludge volume, product recovery and high substrate to power conversion efficiency. But the economic problems still exist. Electrons generated by the degradation of the organic materials in the MFCs are captured and transferred to the cathode. This electron flow can be used to produce electrical energy because of the differences in the rates of chemical reaction of anodic and cathodic electrons [11], [12], [13], [14], [15]. Microorganisms decompose organic molecules and complexes of heavy metals, enhancing metabolism because the electrons move to electrodes. They form biofilms on the electrode surface and this facilitates their ability to take on electrons more effectively as compared to soluble acceptors. Low oxygen and isolated environments can support the growth and communication of bacteria via the use of conventional electron acceptors that are insoluble to cells, with the aid of systems of extracellular electron transfer. The variants of MFC devices are two- and single-chamber devices. The kind of substrate selected also affects power density to a significant degree and microbiological stability. MFCs are capable of harnessing energy and lowering the oxygen demand in chemical reactions, though their performance relies on the operating conditions, namely, proper pH, temperature, and concentration of starting substrates [11], [16], [17], [18], [19]. Studies show that organic matter with the same Biological Oxygen Demand (BOD) value can generate a 30% difference in coulombic efficiency. Microbial fuel cells (MFCs) with constant wastewater flow provide a more regular production profile, better correlated to hydraulic load, which is advantageous for smart electricity grids. MFCs can also provide decontamination and energy recovery, unlike solar or wind power. Anaerobic digestion units have higher energy efficiency if heat production is considered. This research compared physical-chemical parameters and produced biogas

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from low BOD and COD wastewater with table sugar and salt [10], [20], [21].

II. Materials and Methods

The microbial fuel cell (MFC) construction process involved the production of the parts, which produce bioelectricity by the activity of bacteria. The electrode was in the form of steel mesh on electrical tapes with the electrodes wrapped in PVC tanks which held the anode and cathode. Water was added to the cathode chamber and dirt in a municipal septic leak was added to the anode chamber. To exchange the ions and produce energy, a salt bridge was used. Aldrich provided us with high grade potassium hydroxide pellets, zinc chloride and glacial acetic acid. The artificial wastewater was stored in 1-liter bottles in the span of about 1.5 months having 700 cc of tape water per bottle. The bottles were also locked well with PVC electrical tapes to prevent leakages. The RSM CCD was used to get the number of total runs in the experiment and the analysis of variance was used to determine whether the model was significant and suitable.

III. Results

A. Fourier Transform Infrared Spectroscopy (FTIR) of materials

In Figure 1, the FTIR spectra of sugar, salt as well as of the initial mud were examined to determine the polymeric nature of pollutants. Fingerprint areas of polysaccharides appeared in sugar spectra, and were at 850, 990, and 1020 cm^{-1}, which is the alpha and beta linkages in the polymer structure. The salt spectra were found to contain absorption bands related to the synthetic polymers used widely, with large peaks at 1710–1740 cm^{-1} (stretching of C=O) and 1210–1000 cm^{-1} (stretching of C–O) stretch. Differences in concentrations of polymers and possibly the complexity of compositions were observed among brands. The absorption pattern within the range 1000-1500 cm^{-1} indicates the contamination of the product through packaging and processing products [10], [22], [23]. The spectra of muds indicated that there were three main regions with NH_2 and OH bending vibrations of clay minerals and soil organic matter, Si–O–Si bending in clay minerals, and C–O bending in polysaccharides. The particular mineral–related vibrations may be characteristic of some soils, e.g. the shoulder of OH stretching at approximately 3500 cm^{-1} [24], [25]. In Figure 2, there is no spectra of salt nor of sugar, because these two substances were dissolved in the wastewater. These changes have impacted the mud functional groups: from 3700 to 3200 cm^{-1}, there was OH stretching that was detected in kaolinite and in water adsorbed on it.

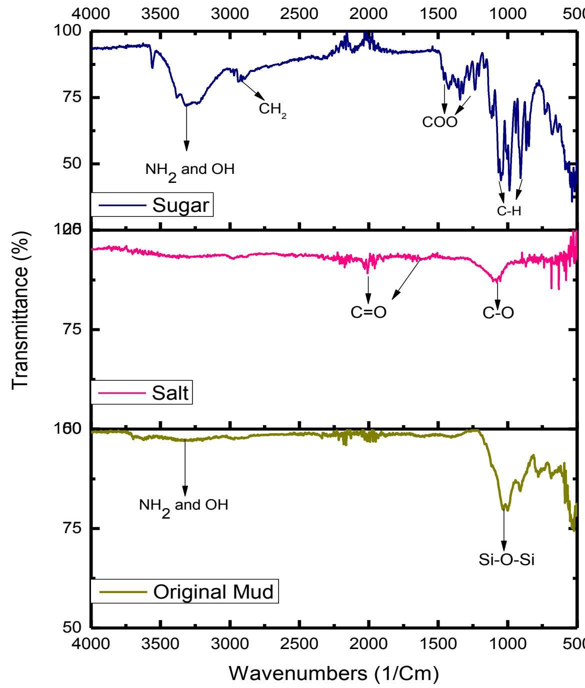

Fig. 1. FTIR of the Original mud, Salt and Sugar

The initial and post-experiment samples had a wide spectral band, which is an indicator of the presence of moisture and surface hydroxyl groups; the slight decrease in the band intensity likely indicates the loss of water or dihydroxylation of the clay matrix; from 2920 to 2850 cm^{-1}, C–H stretching Aliphatic hydrocarbons and related organic matter were observed. The band intensity in the sample marked as After Experiment was less, which suggests that organic constituents may have been degraded or erased in the course of the process; from 1650 to 1630 cm^{-1}, H–O–H bending Cyclopentanol adsorbed, reducing the intensity of this band in the post-experiment mud shows that the content of water or the breakdown of organic matter in the sample has reduced; from 1450 to 1380 cm^{-1}, C–O and OH deformation producing Carbonates or organic acid. The decrement or shift of this peak in the assay can be attributed to the vigorous mineral reactions or gradual emission of CO_2 in the course of the experiment; from 1100 to 1000 cm^{-1}, Si–O–Si vibration caused by Silicate minerals (clays, quartz and feldspar). The existence of a strong and persistent spectral band in the two samples indicated the integrity of the main silicate structure during the experimentation processes; from 800 to 500 cm^{-1}, there were Si–O–Al bending ingredients of clay minerals. The slight variations in the band may indicate slight changes in the clay mineral structure, which might possibly be due to the changes in the cation exchange reaction or slight reconfigure of the silicate network [25], [26], [27], [28], [29].

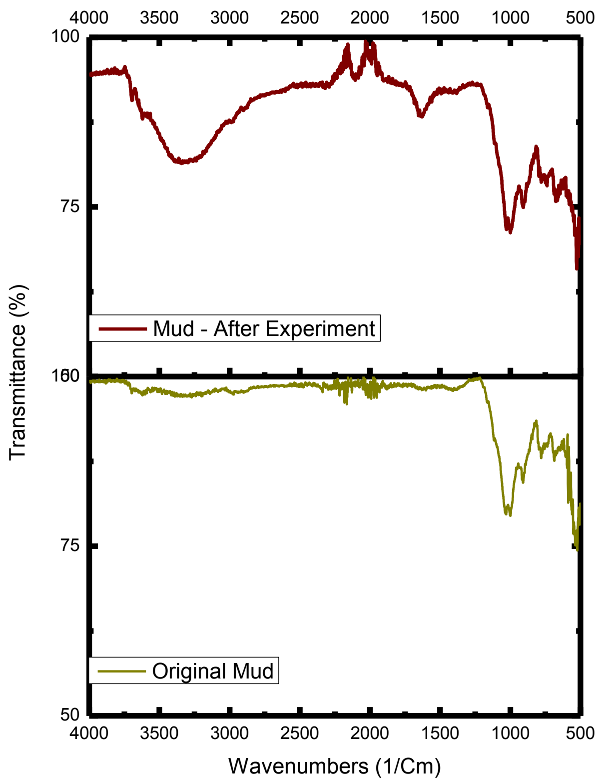

Fig. 2. Change observed in the FTIR of the Mud

B. Data from MFC experiments based on different types of synthetic wastewaters.

TABLE II.
DIFFERENT TYPES OF SYNTHETIC WASTEWATERS USED

Parameters	Wastewater only	Salt	Sugar	Acetic acid
pH	3.49	3.46	3.53	3.68
ORP (mV)	113	144	86	147
Cond. (µS/Cm)	2530	49.4	2060	1900
TDS (ppm)	1260	25.9	1030	959
BOD (mg/L)	< 0.3	< 0.3	< 0.3	< 0.3
COD (mg/L)	< 5	< 5	< 5	< 5
Total Coliforms	Presence	Presence	Presence	Presence
Biogas (ppm)	175	189	130	59

The results of MFC studies in Table III reports results of various synthetic wastewater compositions on parameters and biogas production. The first wastewater, which was composed of rotting fruit and meat, was treated with various additions (salt, sugar and acetic acid) and left for the period of 30 days, which is indicative of an anaerobic process. The pH values of all the samples were between 3.46 and 3.68 hence proving the environment was always acidic. However, methanogenic archaea are inhibited in a pH of less than ~4.0. Other species of methanogens need slightly basic to very neutral conditions. Some acid-tolerant microbial populations are able to adjust to anaerobic digestion although the methane production is reduced or the composition of the biogas changes. The addition of acetic acid as a substrate shifted the pH of the samples slightly higher than other samples because its role as an intermediary in methanogenesis could lead to a slight increase in pH [30], [31], [32]. The quality of ORP in these samples ranged from 86 mV to 147 mV i.e., more decreasing situation. High conductivity and TDS may be deemed dangerous to microbial activity, especially for methanogens, by way of osmotic stress and enzyme inhibition. High salinity decreases the biogas production potential and the structure of the microbial communities [33], [34], [35]. The study shows that a number of factors play a role in the biogas generation process in an anaerobic digestion plant, the presence of total coliforms and nutritional deficit or other "salt" effects. The "Salt" sample showed the highest potential to produce biogas and lowest level of conductivity/TDS, which is an indicator of nutritional shortage or "salt" effect [36], [37], [38], [39]. The "acetic acid" sample yielded the lowest amount of biogas, presumably because of its acidic pH or concentration of the inhibitory concentration. The "Wastewater only" and "Sugar" samples resulted in the production of intermediate biogas, suggesting that the original feedstock and sugar addition supported some sort of anaerobic digestion [22], [40], [41].

C. Different MFC wastewaters with their electrical values

TABLE III
ELECTRICAL READINGS ON THE DIFFERENT MFC WASTEWATER

Data Collection Time	Voltage (mV)	Resistance (MΩ)	Intensity (µA)
	Mud with Salt		
Day 1	0	0	0
Day 2	-9	0.7	0
Day 3	12	1.2	0.02
Day 4	-5	0	0
	Mud with Acetic acid		
Day 1	8	0	0.30
Day 2	40	0	0.02
Day 3	14	0	0.52
Day 4	164	0.8	0.49
	Mud with sugar		
Day 1	0	0	0
Day 2	87	0.3	0.39
Day 3	155	0.6	0.047
Day 4	164	0.8	0.49
	Mud with wastewater only		
Day 1	0	0	0
Day 2	125	0.6	0.38
Day 3	127	0.6	0.40
Day 4	130	0	0.37

This study analyzed the performance of four mud-MFCs for

24 hours and observed no measurable voltage or current at Day 1. The most stable power was obtained with the wastewater-fed MFCs, with transient peaks occurring at approximately 80 nW on day 4. In practice, the salt-modified MFC generated little power, which is consistent with the previous behavior of MFCs. Near-zero performance of the salt-modified reactor is probably due to saline inhibition, and not to increased ionic conductivity [30], [42], [43], [44].

D. Curvatures of TDS, Conductivity, and ORP responses

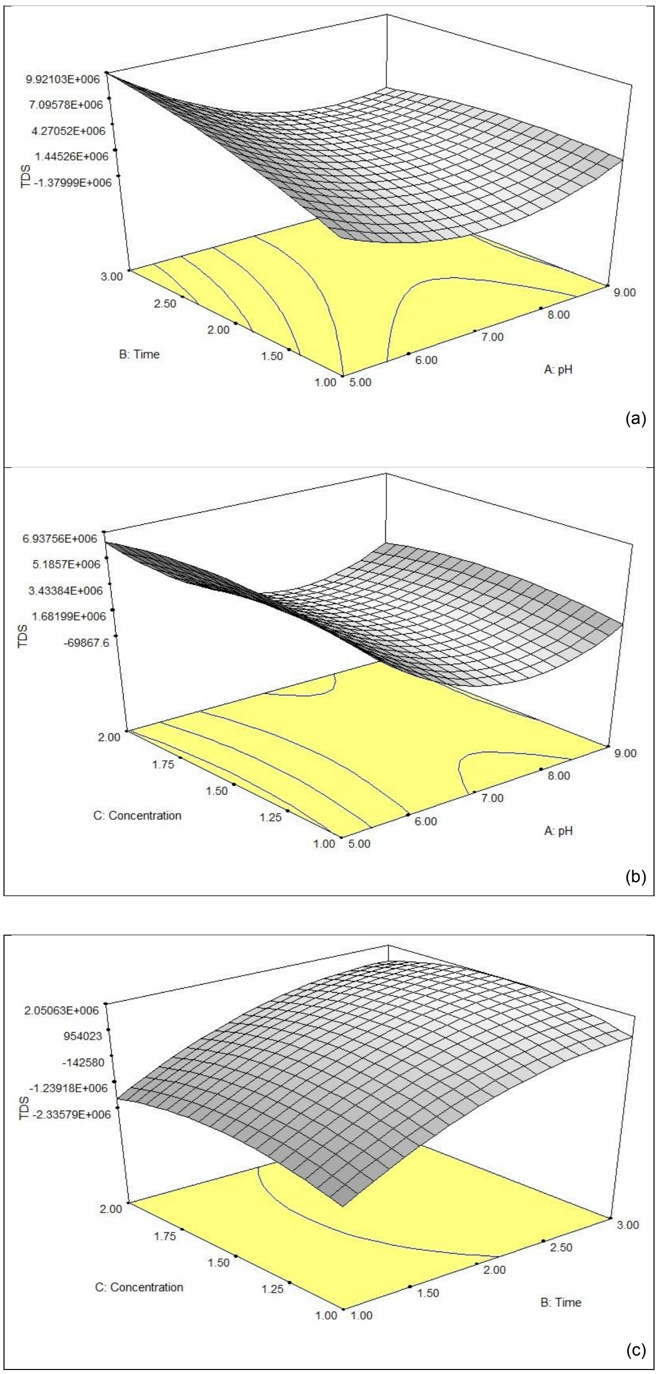

Fig. 3. (a – c) 3D graphs of TDS response vs two variables

Figure 3 shows 3D response surface plots that are used to identify the interactive effect of paired variables on the TDS by holding the third variable constant. Curvature in surfaces shows the amount of interaction between factors and nonlinearity in a system. Response surfaces have curved geometries, which means that there are strong interactions between pH, conductivity, and operating time on the levels of TDS.

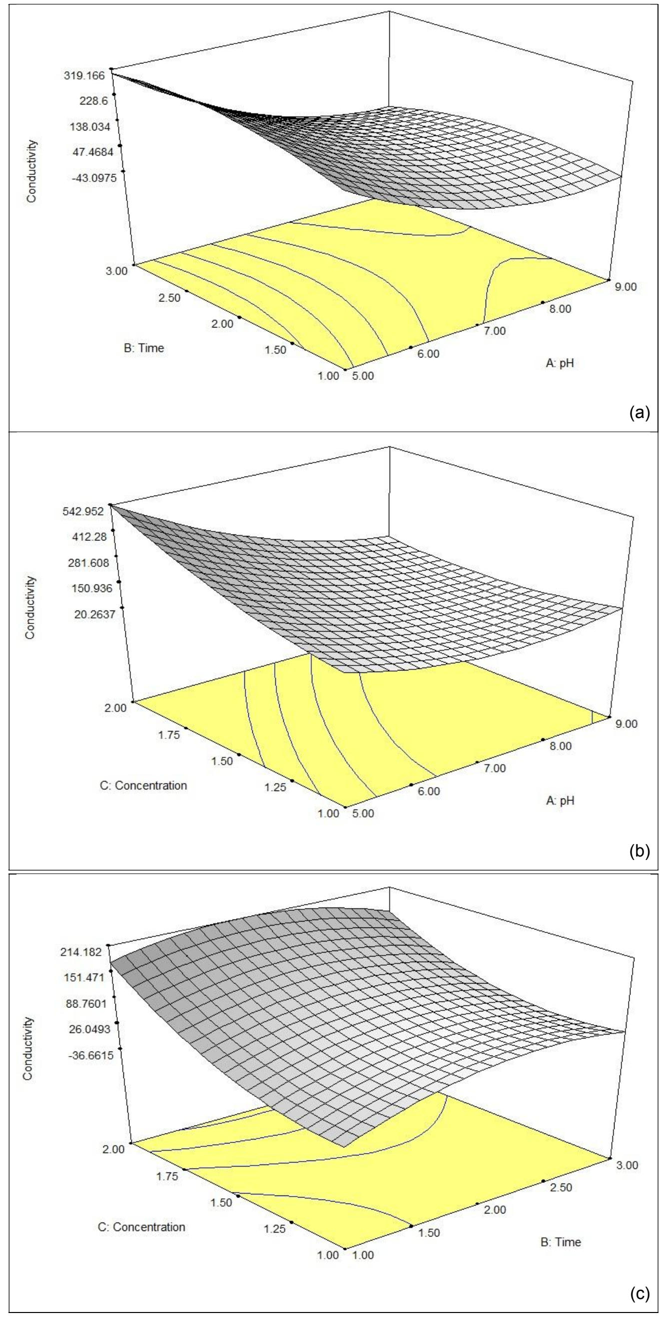

Fig. 4. (a – c) 3D graphs of Conductivity response vs two variables

Figure 4 represents 3D surface plots of the cumulative effect of variable combinations on conductivity. Curvature and Regions of maximal ionic conductivity are used to demonstrate interactions. These surfaces show the conductivity increasing synergistically with both TDS and the time of operation up to the point of saturation at which the surface precipitates or clusters as conductance decreases.

Figure 5 shows 3D surfaces of the combination effects of pH, conductivity and time of operation on ORP. The 3D ORP surfaces have a significant curvature, which shows that redox dynamics in the MFC system are governed by the pH and conductivity combination.

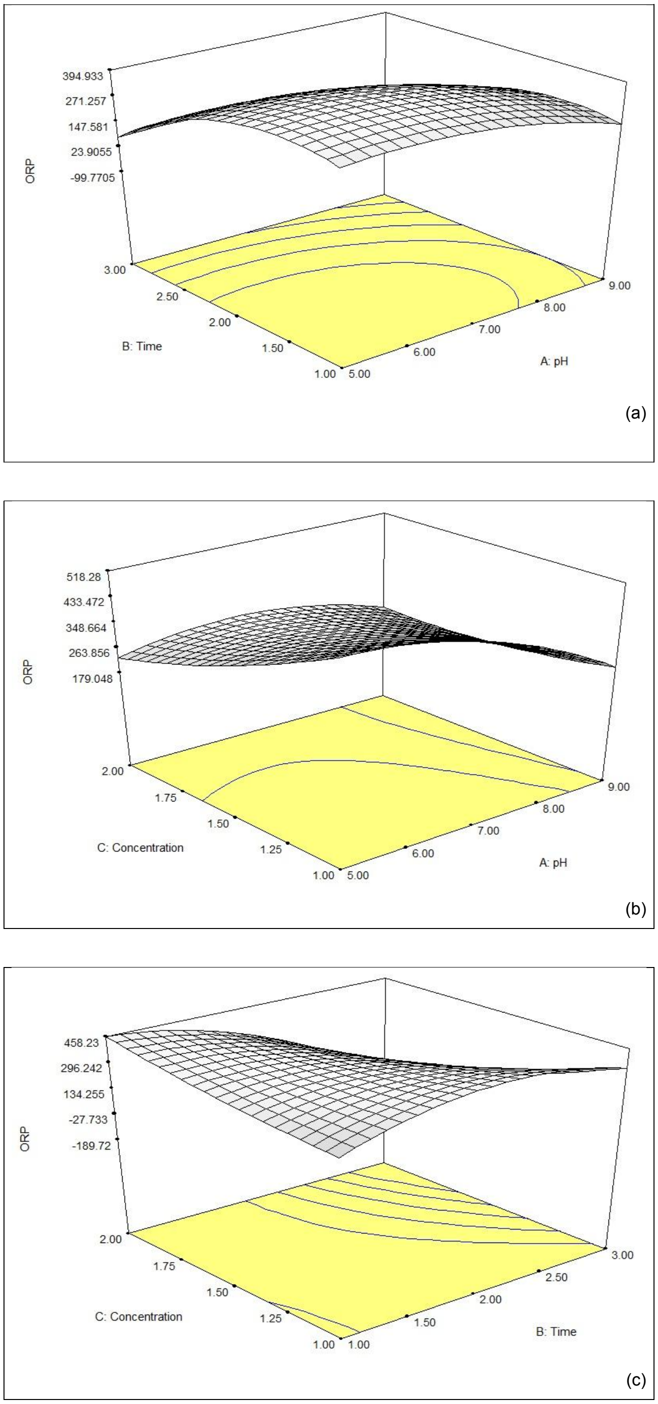

Fig.5. (a – c) 3D graphs of ORP response vs two variables

By the use of RSM, the localization of these interaction redox regions offers simple implemented ideas to keep the efficacy of the microorganisms and the electrode potential balance.

IV. Conclusion

The effects of the synthetic wastewater compositions on MFC parameters and biogas production are studied. The first effluent was obtained from the fermentation of fruit and meat, and treated with salt, sugar, and acetic acid, suggesting an anaerobic process. The pH was observed to be in the range 3.46-3.68, which means it was acidic conditions. Lower methane yields or altered biogas composition are not always detrimental to the adaptation of acid-tolerant bacteria populations to anaerobic digestion. Four mud-MFCs were tested for 24 h and no voltage and current could be detected on Day 1. However, the salt-modified MFC had a low power output, which most likely was a result of the saline inhibition rather than increased ionic conductivity. In addition, the study found significant correlations between pH, conductivity and operating time on TDS loadings.

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