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RESEARCH ARTICLE

Developing Cost-Effective and Efficient Drinking Water Treatment Technology for the Removal of Salinity and Suspended Solids

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Abstract

Although a variety of economical water treatment options are available, rural residents struggle to have safe drinking water. Therefore, developing cost-effective and efficient drinking water treatment technology for the removal of selected ionic compounds and suspended solids is necessary. The present study aims to establish a cost-effective water treatment method by employing the following adsorbents Graphene Sand Composite (GSC), GSC with *Moringa Oleifera* seeds, *Phyllanthus emblica* seeds, *Strychnos potatorum seeds*, tea waste, sawdust, coal, coconut charcoal, and clay pot (an indigenized filter). X-ray diffraction of GSC confirms SiO_2 nanoparticles, a broad peak centred at 22.5°, Graphene peaks are found at 26.73 (200), 45.8 (110) and 54.959 (222). In FT-IR, graphene oxide has a strong and wide O-H/ Si-OH stretching vibration peak at 3444 cm^{-1}. In the Raman spectrum, the graphitic vibration band from its first-order scattering of E_{2g} photons using sp^2 carbon appeared at 1589 cm^{-1}. Moreover, the graphitic vibration band contributes to the presence of stretching C-C bond; which is common in all sp^2 carbon systems. Water's pH, TDS, hardness, and chloride content also increased considerably in a few adsorbents. Fabricated pots with an indigenous filter using GSC and *Moringa oleifera* seed as filter disc has also been designed and evaluated in the present study. In this research, 100% salinity removal is achieved using GSC as an adsorbent. While there is an interesting rise trend in fluoride and calcium content to 33% and 39%, respectively. The reason for the rise in fluoride and calcium can be studied further.

Keywords: Adsorbents, Calcium, Drinking Water, Fluoride, Graphene Sand Composite, Salt

1. Introduction

One of the major environmental issues encountered by living organisms is the contamination of the freshwater system by the mixing of industrial and agricultural waste[1,2]. In India, 600 million people are facing an extreme water crisis and every year 0.2 million people die owing to water pollution[3,4]. The *NITI Aayog*, Government

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of India has a target to solve the water crisis by 2030[5,6]. The present scenario of the water crisis is expected to cause a loss of 6% to India's GDP by 2050[5,6]. In India, rural residents consume a major percentage of water from springs, shallow wells and bore wells without any treatment methods[4,7]. Water consumed from various ground sources has pathogens such as bacteria, viruses, protozoa, and helminthes that lead to various diseases such as cholera, diarrhea, and other diseases[8,9]. Apart from pathogens, the drinking water is also contaminated by human feces[8,10]. Drinking water is a problem not only in India but also around the world, approximately 2.2 billion people do not have access to sufficient sanitation[8,11]. The presence of chemical contaminants in drinking water such as organic compounds, inorganic compounds, and heavy metals can cause several health issues problems in humans[12,13]. A study reported on the presence of selected contaminants in drinking water in India shows that there are high salinity, arsenic, iron, fluoride, and nitrates[5,14]. High salinity causes high blood pressure, heart disease and stroke[14,15]. Fluoride-contaminated drinking water causes skeletal fluorosis, teeth degradation, and joint weakness[16,17]. Arsenic contamination leads to long-term health problems like cancer, diabetes, cardiovascular diseases, and skin lesions[18-20].

There is a variety of advanced technologies to eliminate the contaminants from water such as adsorption, chemical precipitation, membrane process, ion exchange, electrolysis, nanotechnology, ozonization, membrane filtration, photocatalysis, reverse osmosis, etc. that are being studied in wastewater treatment[21,22]. These advanced technologies are economical and efficient in removing the contaminants/pollutants from wastewater[23-25].

There are many scientific techniques reported to purify water using low-cost plant extracts. In this connection, researchers have successfully extracted many active molecules from various parts of the plants[24-26]. The people of rural India have traditionally adopted the precipitation method to settle the suspended solids in turbid water using seeds from Nirmali tree (*Strychnos potatorum)*[27,28]. These types of plant-based materials like Cactus *latifaria* and *opuntia, Strychnos potatorum (*Nirmali*), Prosopis juliflora (*Mesquite bean*), Fabaceae* (Guar gum), *Jathropa curcas* were employed to remove turbid in drinking water in many countries[28-30]. Whereas people sailing in ships to solve their drinking water problems have used *Zea mays*, *Moringa oleifera* seed, and *Carica papaya* seeds as a settling agent for bacterial removal with 90–99 % efficiency[29,31,32]. Apart from this, a few plant-based materials such as *Hibiscus sabdariffa*, *M.oleifera*, *P. uberrregium sclerotium, Jatropha curcas, Pleurotus,* and alum have been successfully employed as coagulants and disinfectants[33,34]. It is reported that plant-based materials efficiently remove about 90 % of the suspended particles in the drinking water and significantly decrease the number of coliforms using *M. oleifera*[27,32,33,35]. This method of eco-friendly, non-toxic, and simple wastewater treatment method using *M. oleifera* seeds has been practiced by people living in rural and peri-urban areas[27,36,47]. The bamboo trees were employed to filter drinking water due to their robustness and longevity[37,38]. *Citricidal* (grapefruit seed extract) and oconut shell Activated Carbon (AC) have been recognized as filter materials for bacterial disinfection, heavy metal removal, and pesticide[36,39]. The removal of Volatile Organic Compounds (VOCs) and the adsorption of chlorine from water has been achieved using AC[35,40].

Our research group has decided to synthesize graphene oxide apart from plant-based materials for drinking water treatment. This graphene oxide was first synthesized by Benjamin Brody in 1859 with the combination of chemical oxidation and exfoliation of natural crystalline graphite which yields a significant amount of single-layer graphene oxide[21,41,42]. In the continuation of this invention, researchers have developed silica and carbon using bio-synthesis methods with multifaceted substances for water purification[43,44]. Synthesized graphene oxide was placed on soil pots for filtering and storing drinking water[38,45]. Silica from sand acts as a porous media due to its ability to adsorb metal ions such as OH and also the existence of the Si-O group in the aqueous solution has the ability to adsorb metal ions residing in water[44,46].

The current project aims to reduce the salt, fluoride, calcium, and suspended solids in drinking water. The aim of this study is to biosynthesize graphene from abundantly accessible materials like common sugar and river sand[48,49]. The synthesized material is considered as GSC (Graphene Sand Composite) and characterization studies were performed on the synthesized GSC. The various adsorbents were prepared by mixing GSC with *Moringa oleifera* seeds, *Phyllanthus emblica* seeds, *Strychnos potatorum seeds*, tea waste, sawdust, coal, and coconut charcoal. We have selected few adsorbents which are available widely in rural areas. The efficiency of these adsorbents was examined through various experiments to identify the cost-effective and efficient adsorbent that can be utilized by people in rural areas for filtering drinking water. A clay pot with an indigenous filter has also been designed as a part of this work to implement the traditional approach of filtration with adsorbents to have better efficiency in the filtration process.

2. Materials and Methods

The materials required for the preparation of Graphene sand composites were Sugar, River sand and Concentrated Sulfuric acid. The chemicals required for the water test were Isochem water testing kits (Chloride, Fluoride kits) that were procured from Eswarr Scientific and Co, Tiruchirappalli, Tamil Nadu, India.

2.1 Preparation of GSC

Common sugar in the form of sucrose crystals was considered as a carbon source that was mixed with river sand in appropriate quantities to make GSC[26,41]. The mixing of sugar and sand was performed in various ratios and the mixture was placed for drying at 90 °C for 6 hours in a magnetic stirrer with constant stirring. After 6 hours of drying, it forms GSC sand with sugar coating on it. The prepared mixture was then positioned in a silica crucible and dried hot air oven. After drying the mixture was placed in a furnace under 100°C for 30 minutes followed by further drying at 200 °C for 60 minutes. The melting point of sucrose was 186°C and hence by placing the GSC at 200 °C for 60 minutes, sugar molecules get melted and form a homogeneous coating on the surface. This was followed by heating the material at 400 °C for 1 hour. To have an absolute graphitized sugar the synthesized material was further maintained at 400 °C for 6 hours.

The furnace was then turned off and the material was cooled at room temperature. The cooling rate was not controlled with any special attention. Graphene Sand Composite was the designation given to the black sample (GSC). Then 5 g of the prepared material was treated with 10 mL of Concentrated sulfuric acid and left at ambient temperature for 30 minutes for activation. The concentrate was then filtered and subjected to drying process at 120°C. The final product was considered as activated GSC[26,41]. The GSC image is shown in Figure 1.

2.2 Design of Drinking Pot

Our group designed a clay pot with a filter to improve the quality of water. The filter was made from a porous clay pot, whereas a filter disc was made up of the prepared GSC and *Moringa oliefera* grained seed powder. The water was filtered through the pot and the important parameters of the water were tested before and after the filtration process.

Figure 1. Graphene Sand Composite in crucible.

Figure 2. Fabiricate clay pot with filter discs.

2.3 Fabrication of Porous Clay Pots and Filter Disc

The fabricated clay pot and filter disc with *Moringa oleifera* seed and GSC are shown in Figure 2.

2.4 Contaminated Drinking Water Tested Through the Porous Clay Pot

The groundwater was collected and tested through the porous clay pot with the filter disc as shown in Figure 3.

2.5 Design and Testing of the Clay Pot Water Filter

The overall design and testing of the contaminated water through the clay pot water filter as illustrated in Figure 4.

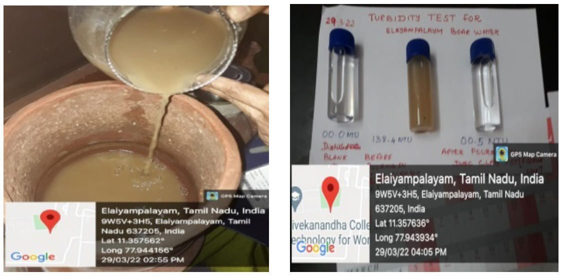

Figure 3. Treatment system of muddy water using clay pot with discs.

Figure 4. Indigenous porous clay pot with filter disc to remove mud in water.

3. Result and Discussion

Drinking water samples were collected from rural areas in the Thanjavur district. Different types of low-cost effective adsorbents were used to treat the water. The low-cost-effective adsorbents included GSC, *Moringa oliefera* seeds, Amla (*Phyllanthus emblica*) seeds, sawdust, tea waste, coal, alum, and *thetrankottai* (*Strychnos potatorum*). A sugar-derived material with the properties of graphite designated as GSC was successfully synthesized which was confirmed using Raman, Fourier Transform Infra-Red (FTIR), and X-Ray Diffraction (XRD). Afterward, the effects of various parameters on the adsorption process were evaluated to identify the cost-effective adsorbent. The synthesized Graphene Sand Composite (GSC) and GSC with half slice of lemon juice effectively reduced NaCl but there is no significant reduction in calcium and fluoride content. When coal is used as an adsorbent it reduced salt from drinking water effectively. Sawdust and tea waste were found to be less efficient in removing salt but removing fluoride from water effectively. When 1 g of *Moringa oliefera* seed-grained powder along with GSC was considered as adsorbent it is effective in removing 100% turbid, 18.8% Total hardness, 1.75% TDS, and 1.19% chloride content in drinking water. Amla (*Phyllanthus emblica*) and *thetrankottai* (*Strychnos potatorum*) increased the calcium content in drinking water effectively. The results obtained were elaborated on below in detail.

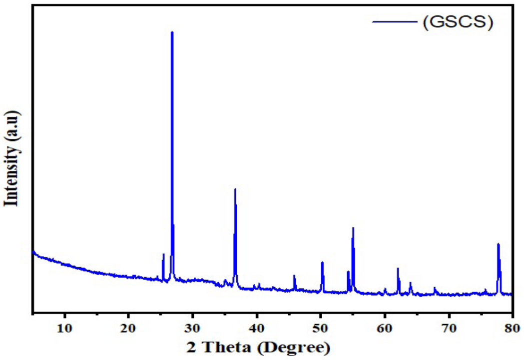

Figure 5. The above XRD graph shows the conformation of Graphene in the prepared sample.

3.1 XRD

Figure 5 displays the XRD pattern of the synthesized solid GSC sample. The multilayer graphene structures were displayed as the peak at 20.97, which corresponds to the (002) facet of graphite[39]. The d-spacing value of 3.325 represents perfect graphene[47]. The XRD pattern of GSC displaying a broad peak centered at 22.5° typically correspond to the amorphous nature of the synthesized material[49]. Graphene peaks were found at 26.73 (200), 45.8 (110), and 54.959 (222)[47,50]. One of the allotropic properties of amorphous carbon is the black carbon coating on the sand's surface. A single quartz crystalline phase appears to exist in silica sand with a high concentration of Silicon Oxide (SiO_2). According to that investigation, the heating impact must have caused the crystalline phase transition of the prepared sample[48].

3.2 Raman Spectrum

Raman spectra were used for the face determination and the Raman spectra of the synthesized material were shown in Figure 6. The graphitic vibration band from its first-order scattering of E_{2g} photons by sp^2 carbon displayed at 1589 cm^{-1} for GO. Furthermore, the graphitic vibration band also contributes to the existence of stretching C-C bond; which is absolute in all sp^2 carbon systems. Hence, the synthesized material structure is confirmed by Raman analysis[51].

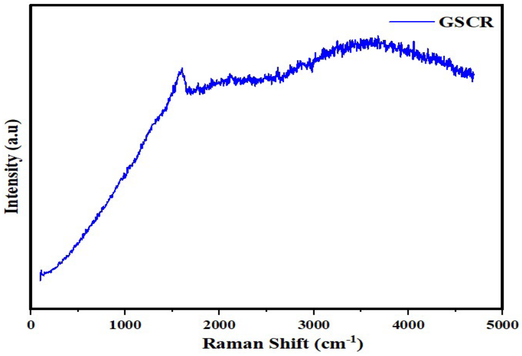

Figure 6. The Raman spectrum shows Graphene's conformation in the prepared sample.

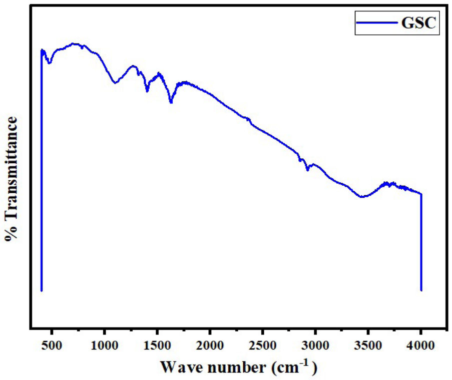

Figure 7. The FT-IR Spectrum illustrates the conformation of graphene in the prepared sample.

3.3 FT – IR Analysis

FT-IR studies were carried out to validate the bonding and the functional group residing in the synthesized materials as given in Figure 7. In the FT-IR spectrum of GO, because of the extensive oxidation, GO has a strong and broad O-H/Si-OH stretching vibration peak that was absorbed in 3444 cm^{-1}. The peak noted at 2923 cm^{-1} was due to the asymmetric and symmetric CH_2 stretching of GO. The peak at 1625 cm^{-1} was contributed to C=C stretches from an oxidized graphitic domain. The peak observed at 1095 cm^{-1} was related to C-O stretching vibration of the C-O-C bond. The peak at 466 cm^{-1} corresponds to the Si-O-Si asymmetric stretching and bending vibration. Thus, the outcome are illustrated as the absolute structural origination of the synthesized material[21,46].

3.4 Adsorption Experiments

In this experiment, different adsorbents were tested to examine the adsorption efficiency of various elements considered for the study such as GSC, *Moringa oliefera* seeds, Amla (*Phyllanthus emblica*) seeds, sawdust, tea waste, coal, alum, and thethankottai (*Strychnos potatorum*). The adsorbents were placed in a separating funnel, and a salt solution was poured through it as shown in Figure 8. The setup was placed for hours at different rates to examine the change in the adsorption of the salt solution. The estimation of the adsorption efficiency of different elements with the use of different methods such as the Argentometric titration method, EDTA titration method, chloride kit, and fluoride kit was then carried out. The variation in the adsorption pattern of the different elements used for adsorption was then compared[21].

Figure 8. Removal of salt using mixed adsorbents.

3.5 Removal of Salinity

Water with excess salt leads to hypertension, high blood pressure, and stroke[14,15]. In this experiment, seven adsorbents (Table 1) were tested to select the most effective adsorbent for removing salt from water. The adsorbent that was found to be most effective was GSC with the dosage of 1 g, 2 g and 15 g. In addition, coal was also observed to be an effective adsorbent with a dosage of 10 g. Sawdust and tea waste both had less effective adsorption abilities in removing salt, while 1 g of *Moringa oliefera* seed-grained powder was found to have the optimum level of adsorption for this particular experiment.

3.6 Fluoride

The water with excess fluoride leads to teeth, bone, dental and skeletal problems[16,17]. To remove fluoride, six adsorbents have been tested (Table 2). The first adsorbent was GSC, Alum *Thetrankottai* and cotton wool like GSC, the second adsorbent was GSC, the third adsorbent was GSC, Coconut Charcoal and Cotton wool fourth adsorbent was Alum piece, the fifth adsorbent was Tea

Table 1. Different adsorbents used to reduce salinity

Adsorbent	Water Sample	Methods	Level	Initial (ppm)	Final	% of removal
GSC	Synthetic Sample	Chloride Kit	Less	500	No End Point	100
	Kodimarathumullai Bore well salt water	Chloride Kit		500 5170		
	Alakkudi bore well salt water	Argentometric Titration		2580		
Coal				344		
Saw dust			No significant reduction	1327	1237 ppm	6.78
Tea waste			No significant reduction	1372	1290 ppm	5.98
GSC with half lemon slice		Chloride kit	No significant difference	2500	920	63.2
Grained *Moringa seed*	*Kodimarathumullai* Bore well salt water	Argentometric Titration	Optimum level	315	304.9	3.21

Table 2. Different adsorbents used to reduce fluoride

SI.NO.	Adsorbent	Water Sample	Method	Level	Initial ppm	Final ppm	Result
1	GSC, Alum *Thetrankottai* and cotton wool	Synthetic sample	Fluoride kit	Less	1	0	100% removed
2	GSC			High	1.5	2	33% increased
3	GSC, Coconut Charcoal and Cotton wool				1	2	100% increased
4	Alum piece			no changes	1	1	Equal
5	Tea Waste and Cotton wool						
6	Saw dust						

waste and Cotton wool, and sixth adsorbent was Saw dust. Surprisingly, all the adsorbents increased fluoride levels instead of removing them.

3.7 Calcium

Water with excess calcium leads to bone weakness, kidney stones, stomach upset, nausea, vomiting, and constipation[55]. The research was carried out to remove chloride using four adsorbents (Table 3) such as GSC, coconut charcoal, cotton wool as the first adsorbent, *thetrankottai* (*Strychnos potatorum*) as the second adsorbent, alum as the third adsorbent, and Amla (*Phyllanthus emblica*) as fourth adsorbent. Surprisingly, calcium concentration increased in the water sample instead of reducing. Hence, none of the above materials are effective in removing calcium from the water sample.

3.8 Turbidity

Turbidity determines the quality of the drinking water and it also has an impact on the water purification procedures[56]. In the current work the turbidity of the distilled water, muddy water, and the filtered water purified using clay disc were noted using a turbidity meter and the reading was displayed in Table 4. NTU refers to the Nephelometric Turbidity unit.

3.9 Water Testing in Different Samples

The pH, TDS (Total Dissolved Solids), Total hardness, and chloride content of Trichy Corporation water were

Table 3. Different adsorbents used to reduce calcium

SI.NO.	Adsorbent	Water Sample	Methods	Level	Initial	Final	Result
1	GSC, Coconut charcoal and Cotton wool	PMIST Tab water	EDTA Titration	Very high	289 ppm	1401 ppm	39% Increased
2	*Thetrankottai*				289 ppm	4724	15% increase
3	Alum	*Alakkudi* Tank water			289 ppm	4724 ppm	15% increased
4	Grained Amla seeds				-20 ppm	900 ppm	97.7% Abnormal increased

Table 4. Turbidity reading of the water

S.NO.	Distilled water NTU	Turbidly sample is taken from muddy water NTU	After filtration with a Clay disc pot NTU
1	00.0	138.3	00.5
2	00.0	138.6	00.3
3	00.0	138.3	00.5

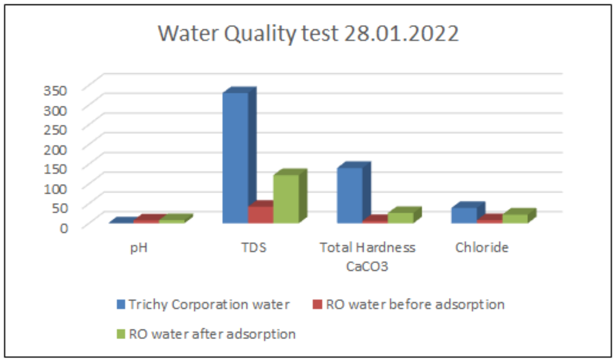

Figure 9. Examination of water quality.

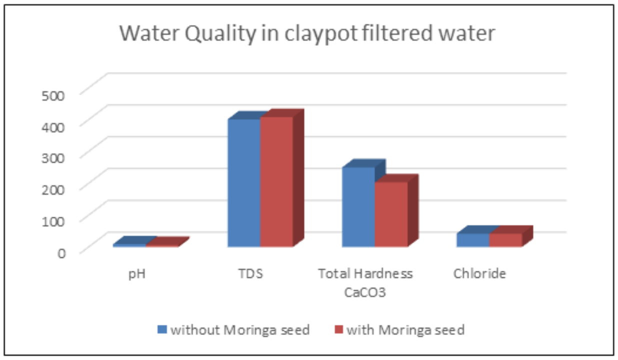

Figure 10. Examination of water quality in clay pot filtered water.

found to be 7.64, 330 mg/l, 140 mg/l, and 39 mg/l. The pH, TDS (Total Dissolved Solids), Total hardness, and chloride content of RO water were found to be 7.48, 42 mg/l, 6 mg/l, and 8 mg/l. The reduction in pH, TDS (Total Dissolved Solids), Total hardness, and chloride content in water after RO treatment can be noted down considerably. To understand the effectiveness of adsorption in the reduction of pH, TDS (Total Dissolved Solids), Total hardness, and chloride content of drinking water, the RO water was placed for the adsorption process overnight and the values such as pH, TDS (Total Dissolved Solids), Total hardness and chloride content were examined. But unfortunately, a significant rise in the values of pH, TDS (Total Dissolved Solids), Total hardness, and chloride content of RO water after the adsorption process was observed. The graphical representation of the obtained result was displayed in Figure 9. The efficiency of the designed clay pot was examined by analyzing the pH, TDS (Total Dissolved Solids), Total hardness, and chloride content of drinking water before and after the filtration process. The obtained result was displayed in Figure 10. It can be noted that the pH, TDS (Total Dissolved Solids), Total hardness, and chloride content of filtered water reduced considerably after the filtration process displays the efficiency of the filtration through a designed clay pot using GSC and *Moringa* seed as filter disc.

4. Conclusion

To identify a cost-effective and efficient adsorbent for the treatment of drinking water for rural people, a graphite-based adsorbent coated with sugar material was synthesized successfully with the help of easily available materials such as sucrose and sand. The synthesized material was designated as GSC. The successful synthesis of GSC was confirmed through characterization studies such as Raman spectrum, FTIR, and XRD. The efficiency of various other adsorbents such as *Moringa oleifera* seeds, *Phyllanthus emblica* seeds, *Strychnos potatorum seeds*, tea waste, sawdust, coal, and coconut charcoal was also examined in the current study. It was noted that among the used adsorbents GSC has reduced salinity in the water sample by 100% and hence it is found to be effective. While the fluoride and calcium content of the water raised considerably after treatment with adsorbents, the reason for rise in fluoride and calcium can be studied further to examine the water quality before and after the adsorption process, the pH, TDS, hardness, and chloride content of the Trichy Corporation water, and RO water before and after the adsorption process were examined. It was noted that after the treatment process, the pH, TDS, hardness, and chloride content of the water samples increased considerably. Hence a clay pot has been designed with a filter disc of GSC and *Moringa oleifera* seed to identify the efficient filtration process of drinking water. The significant reduction in pH, TDS, hardness, and chloride content in water was noted after filtration with a clay pot containing GSC and *Moringa oleifera* seed filter disc. Hence, the clay pot with GSC and *Moringa oleifera* seed filter disc can be considered as a filtration method by the people of rural areas to have good quality drinking water.

5. Acknowledgements

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