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Improving anaerobic biodigestion of manioc wastewater with human urine as co-substrate

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ABSTRACT: This study investigated anaerobic co-digestion of cassava liquid waste (very acid and poor in nitrogen) and human urine. Three experimental digesters were used: manioc effluent; manioc effluent + urine; manioc effluent + urine + cow dung. All digesters have functioned with mesophilic temperatures between 24.0 and 35.6°C. Digesters without urine have a pH varying between 3 and 4 during experimentation. In reactors containing urine, the pH oscillated between 6.46 and 10.29.

The COD/TKN ratios recorded in digesters buffered with human urine are lower than those observed in digester without human urine. Volume of gas produced by the two digesters containing human urine was significantly higher than that of the digester without urine. The additions of human urine and cow dung improve highly the methane potential during anaerobic co-digestion of manioc effluent. The flammability test is positive except for the digester without urine.

Using human urine as a co-substrate for anaerobic digestion of cassava wastewater requires a large quantity of urine (40% in terms of proportion) for a best productivity. As well as allowing biogas production as a source of renewable energy, this system of co-digestion could help to resolve the sensitive problem of human excreta management in poor area. Indeed, human urine with an alkaline pH and richness in nitrogen can substitute chemicals commonly used to correct the pH during anaerobic biodigestion, in particular for the treatment of cassava wastewater which is very acid.

KEYWORDS: Anaerobic co-digestion, Manioc wastewater, Human urine, Biogas.

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1 INTRODUCTION

Basic food in many tropical countries in Africa, Asia and America, manioc (*Manihot esculenta* Crantz) is now considered as a key element in the fight against nutritional problems afflicting many countries in south of the Sahara ([1]). In Côte d'Ivoire, attiéké (semolina of manioc cooked with the vapor) is the main form of food produced with the tuberous roots of manioc ([2]). Attiéké is obtained after several stages of transformation of manioc: peeling, crushing, fermentation, pressing, granulation, drying, winnowing-sifting and cooking with the vapor ([3]). The production of attiéké starts to be done in the industrial form by numerous small manufacturing units. Indeed, women of native population of Abidjan District (Ebrié) have kept their traditional activities of attiéké production in their different villages sunken by urbanization. However, during the production of attiéké, large quantities of solid (cassava pulp and fiber) and liquid wastes (pressing juice of cassava) are generated ([4]). At present, in areas of high attiéké productions such as in District of Abidjan (Côte d'Ivoire), the most important part of the solid waste generated is valuated through a low cost animal feed. Manufacturing wastewater of attiéké, including pressing juice of manioc, is discharged into natural environment, particularly Ebrié lagoon adjacent to site of production, without prior treatment. These effluents constitute an important source of pollution in Abidjan. Indeed, these liquid wastes are rich in organic matter ([5], [6]) and highly toxic due to the high content of cyanide ([7]).

Those effluents must be considered as recyclable waste and must be eliminated in respect of laws and environment. Among solutions to regulate these problems, anaerobic digestion of these organic wastes appears as a viable alternative. Anaerobic digestion is a biologic process widely employed as technology for organic wastes treatment including municipal, industrial and agricultural wastes ([8] - [10]). This biologic process permits to produce combustible biogas, a renewable energy, from organic matter by bacteria in anaerobic conditions. This renewable energy is mainly composed of methane and can reduce half of organic matter ([11]). According to [9], the digestat is stable, deodorized, ridded in major part of pathogenic germs and can even be used as a fertilizer for agricultural purposes.

Given the large quantities available and the high biodegradable organic matter content, waste potential as source of energy, instead of a waste stream, has been increasingly realized ([10], [12]). However, the use of manioc effluents as a single substrate for anaerobic digestion has been complicated by problems such as the high acidity of these effluents and their poor C/N ratio ([3], [13], [14]), which inhibits the process of methanization.

Anaerobic co-digestion has emerged as an alternative concept with potentials to overcome these challenges ([10], [15]). Indeed, according to [3] and [16], anaerobic co-digestion has advantage of improving nutrient ratios in mixed substrates and enhancing pH buffering capacity, which could lead to more efficient waste treatment and biogas production.

Many successful studies have been conducted on co-digestion of sewage sludge with several other substrates, such as the source-sorted organic fraction of municipal solid waste ([17], [18]), confectionery waste ([19]), sludges from the pulp and paper industry ([20]), coffee waste ([21]), grease-trap sludge from meat processing plants ([22], [23]), glycerol ([15]), cassava pulp and pig manure ([24]), grease trap waste ([10]), pig manure with spent mushroom compost ([25]).

While anaerobic co-digestion has been studied and practiced for a broad range of organic wastes, few studies have been conducted on the co-digestion of manioc liquid waste derived from attiéké production with human urine as a co-substrate.

In addition, in Côte d'Ivoire the rate of access to appropriate sanitation does not exceed 60% ([26], [27]). Specific case of wastewater and excreta is very problematic. However, pH of human urine varies between 8 and 9 ([3]) with nitrogen concentrations ranging from 3 to 8 g/L depending on the mode and time of collection ([14]). These characteristics make human urine an ideal co-substrate for the anaerobic digestion of manioc liquid waste.

Mainly, this work aimed to evaluate the efficiently of the use of human urine as a co-substrate, in order to improve biogas production during anaerobic digestion of manioc liquid waste.

2 MATERIAL AND METHODS

2.1 REACTORS DESIGN AND EXPERIMENTAL CONDITIONS

Three anaerobic experimental reactors (R1, R2 and R3) were used (Fig. 1). Each reactor was composed of two metal barrels of 100 liters and 186 liters, each opened on one of the bases. The largest barrel contained digestion substrate and the smallest barrel was used as gasometer to store the produced gas. The three experimental reactors used were fed as follows: (*i*) 124 L of manioc effluent; (*ii*) 70 L of manioc effluent + 54 L of human urine; (*iii*) 70 L of manioc effluent + 54 L of human urine + 5 kg of cow dung.

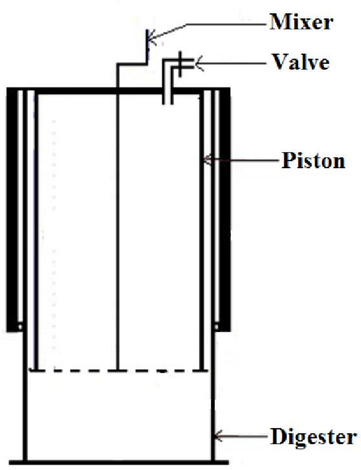


Fig. 1. Schema describing the experimental device

2.2 SOURCES AND CHARACTERISTICS OF SUBSTRATES

Liquid waste of manioc used in this study was collected from the attiéké factory of Azito (Ebrié village in Yopougon, District of Abidjan, Côte d'Ivoire). Its pH varied between 3.0 and 4.2 units pH. Human urine was collected from dry latrines with urine deviation and lavatories designed by the Water and Sanitation for Africa of Côte d'Ivoire (WSA - Côte d'Ivoire).

2.3 TECHNICAL ANALYSIS

Volume (V) of biogas produced was measured daily using this formula: $V = \pi \times R^2 \times H$; with H = height of rising of the gasometer (small barrel); R = Radius of the gasometer (small barrel).

Temperature, pH and Chemical Oxygen Demand (COD) were determined according to the standard methods ([28]). Total nitrogen was estimated by the Kjeldahl method. Temperature and pH were monitored daily in the reactors, while COD and TKN were determined twice per week.

Carbon is the principal component of the organic substances found in wastewater. By biodegradation process under anaerobic conditions, microorganisms use carbon compounds to generate energy. In this study, carbon and nitrogen compounds were respectively determined as COD and TKN.

2.4 STATISTICAL ANALYSIS

In order to determine whether the observed differences between reactors performances were significantly different, data were subjected to the non-parametric comparison tests (Kruskal-Wallis test and Mann-Whitney test). Differences between co-substrates' addition effects were compared with 0.05. All statistical analyses were carried out by the software Paleotological Statistic (PAST) version 2.15 ([29]).

3 RESULTS AND DISCUSSION

3.1 RESULTS

3.1.1 WASTE CHARACTERISTICS

Variation of temperature recorded in this study under diverse conditions is illustrated by Fig. 2A. Values obtained vary between 25.5 and 29.1 °C for reactor 1 (manioc effluents), between 25.0 and 32.2 °C for reactor 2 (manioc effluents + human urine) and between 24.1 and 35.4 °C for reactor 3 (manioc effluents + human urine + cow dung). Although all reactors functioned under mesophilic condition, values of temperature in the two reactors containing human urine (2 and 3) were significantly higher than those in reactor 1 without human urine ($p < 0.05$).

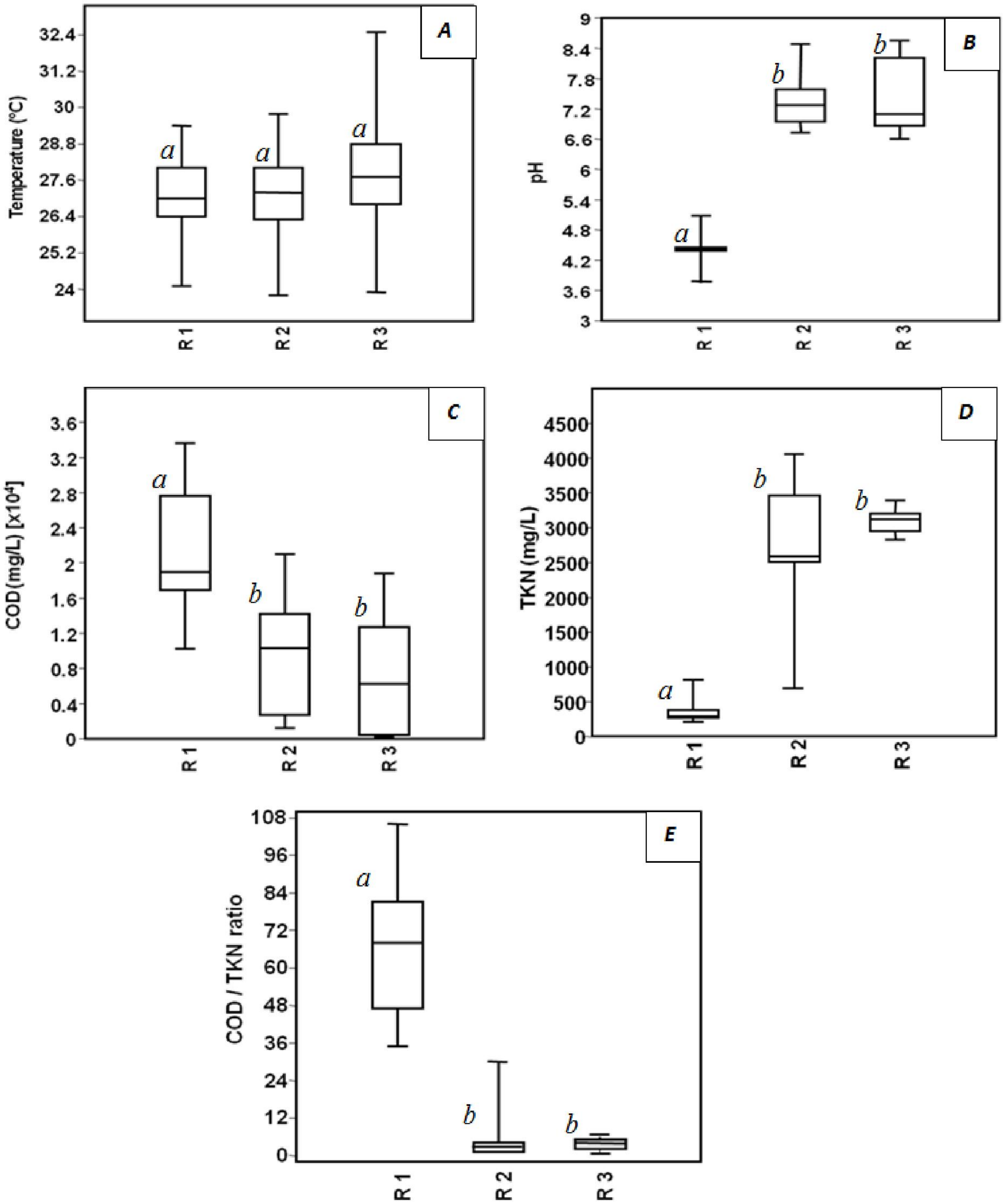


Fig. 2. Boxplots comparing *A)* temperature, *B)* pH, *C)* chemical oxygen demand (COD), *D)* total Kjeldahl nitrogen (TKN) and *E)* COD/TKN ratio in the three anaerobic digesters: R1 = effluent of cassava; R2 = effluent of cassava + urine; R3 = effluents of cassava + urine + cow manure. The different alphabets (*a, b, c*) indicate significant differences between the clusters based on the Mann-Whitney comparison test ($p < 0.05$).

Evolution of pH values obtained under different conditions is presented in Fig. 2B. The pH of reactor 1 oscillated between 3.7 and 4.5 during the experimentation. In reactors 2 and 3, the pH evolves in a similar way. Values fluctuated respectively between 6.75 and 8.47 and 6.72 and 10.29. Values of pH in reactor without urine remained significantly ($p < 0.05$) lower than those in reactors containing urine. Compared to the reactor without urine which had an acid environment, those neutralized with the human urine had an alkaline environment all along the experimentation.

Values of chemical oxygen demand (COD) recorded fluctuated from 10,247 to 33,686.4 mg/L in reactor 1, from 1,212.8 to 21,001.4 mg/L in reactor 2 and from 350.22 to 18,795.5 mg/L in reactor 3 (Fig. 2C). COD in reactor 1 was significantly ($p < 0.05$) higher than COD in reactors 2 and 3.

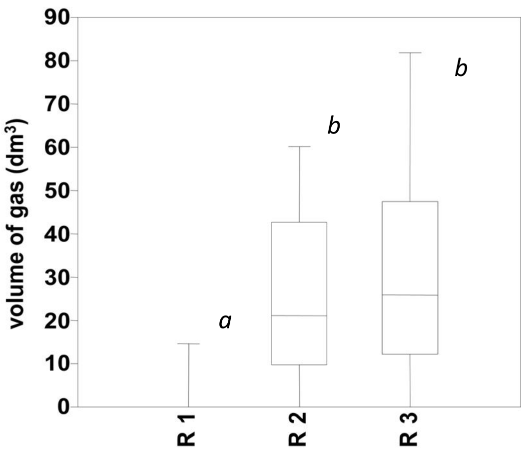
Total Kjeldahl nitrogen (TKN) measured varied between 210 and 812 mg/L for reactor 1, between 700 and 4060 mg/L for reactor 2 and between 2,828 and 3,388 mg/L for reactor 3 (Fig. 2D). The TKN concentrations varied significantly ($p < 0.05$) from one reactor to another. Higher concentrations were recorded in reactor 2 and the lowest in reactor 1.

The COD/TKN ratio varied between 34.85 and 105.66 in reactor R1, between 0.66 and 30.00 in reactor R2 and between 1.22 and 5.64 in reactor R3 (Fig. 2E). Values of COD/TKN ratio recorded in reactor R1 without human urine were significantly higher ($p < 0.05$) than those observed in reactors R2 and R3 buffered with human urine. No difference was appeared ($p > 0.05$) between the COD/TKN ratios of the last two.

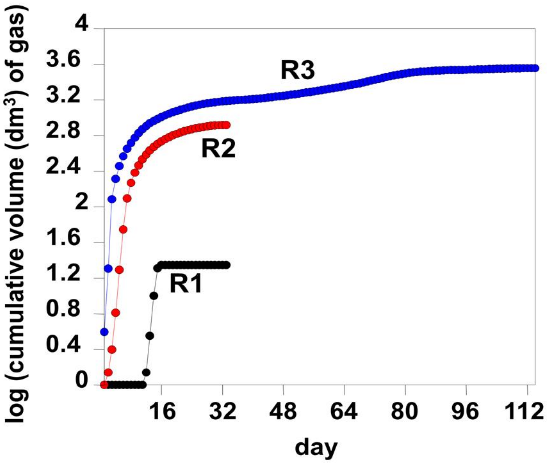
3.1.2 Biogas production

The production of gas in reactor 1 occurred on the 13th day of experimentation and this only during three day with a volume varied between 1.62 and 14.63 dm^3 (Fig. 3A). The flammability test of the gas produced by this reactor was negative. For the reactor 2, gas production has occurred from the 3th to the 34th day with a volume varied between 1.61 and 60 dm^3 (Fig. 3A). The flammability test of the gas produced was positive from the 7th to the 34th day. Concerning the reactor 3, the gas production was recorded from the second to the 113th day with a volume varied between 2.61 and 81.80 dm^3 (Fig. 3A). The flammability test of the gas produced by the digester 3 was also positive from the 4th to the 113th day.

Volume of gas produced by the two reactors containing human urine was significantly higher than that of the reactor without urine ($p < 0.05$). Cumulative volumes of gas produced by the three reactors were 21.13 dm^3 for reactor 1, 827.04 dm^3 for reactor 2 and 3, 601.95 dm^3 for reactor 3 (Fig. 3B).



A)



B)

Fig. 3. ***A)*** **Boxplots comparing biogas volume variation and** ***B)*** **cumulative volume of biogas in the three anaerobic digesters: R1 = effluent of cassava; R2 = effluent of cassava + urine; R3 = effluents of cassava + urine + cow manure. The different alphabets (*a, b, c*) indicate significant differences between the clusters based on the Mann-Whitney comparison test (*p* < 0.05).**

3.2 Discussion

Results from anaerobic mono-digestion in digester 1 indicate that pH of effluents was low (3.71 - 4.5) during the study. According to [5] and [30], this acidity of the effluents of cassava is due to their composition (rich in starch, presence of cyanogenic compounds). Reference [31] establishes that initial C/N ratio played an important role in the acidification efficiency of sewage sludge. Moreover, the acidity of brut effluent would be partly due to the fermentation step performed during the manufacturing process of attiéké. Indeed, according to [32] and [33], lower pH, in case of the production of fermented products, can be explained by the activity of the lactic microflora. These microorganisms hydrolyze the starch contained in the effluents to produce lactic and acetic acids. Reference [32] also indicated that the amylolytic activity observed during the fermentation can directly transform cassava starch into lactic acid. In addition, persistent acidity observed during the process of anaerobic degradation in the digester 1 could also be explained by the accumulation of volatile fatty acids and hydrogen introduced during the hydrolytic and acidogenic stages ([15], [34]).

Production of biogas occurred late (13th day of operation) and in a short period (3 days) with few volumes (between 1.62 and 14.63 dm^3). This occurred could be due to low values of pH observed in the digester 1 which inhibited the production of gas as reported by [15]. Moreover, the inflammability test is negative. This indicated that the average of methane content of the biogas produced from this digester is insignificant or zero.

The results of co-digestion showed that the pH increased to alkaline value in digester 2 (effluents of manioc + human urine) between 6.75 and 8.47 and in digester 3 (effluents of cassava + human urine + cow manure) between 6.72 and 10.29. The outlet pH value increased with the addition of human urine (as co-substrate) and cow manure. Indeed, according to [15], such observations are due to the process stability and the activity of methanogenic bacteria.

The substantial low COD concentration, high pH value and nutrients concentrations in digester 2 and 3, compared to digester 1, indicated that these systems operated at methanogenic conditions as confirmed by [35] in landfill.

The values of COD/TKN ratio are on average much higher than 50 in digester R1 without human urine. These ratios suggest that the concentrations of nitrogen are lower than what is required for anaerobic treatment of such wastewater. Therefore, nutrients, especially nitrogen, have to be added to the manioc wastewater for effective biological treatment as observed [36]. In this study, the treatment of the effluent of cassava with human urine has reduced the value of COD/TKN below 50 as recommended by [37] - [39] and [31] for the anaerobic treatment. In fact, human urine, with an alkaline pH (> 8.6) ([40] - [42] and richness in nitrogen (> 3 g/L) ([14], [41]), was used to neutralize the pH and fertilize the effluent of cassava in digesters 2 and 3, while the cow manure was used to inoculate the digester 3, boosting thus the production of biogas.

Analysis of gas production profiles when substrates are combined indicated that there were significant differences among the combinations tested. Compared to gas produced in the reactor containing only the effluent of cassava (21.13 dm^3), co-digestions of the effluent of cassava + human urine and effluent of cassava + human urine + cow manure enhanced the production of biogas with 827.04 and 3601.95 dm^3 respectively. These results showed that the high productivity was obtained by co-digestions of effluent of cassava/human urine/cow manure. Indeed for this co-digestions system, gas production was recorded during 111 days with a daily production varying from 2.61 to 81.80 dm^3. In digester 2 (effluent of cassava/human urine), gas production lasted only 31 days with daily production ranging from 1.61 to 60 dm^3.

Moreover, the flammability test of the biogas produced by these two co-digestions reactors was positive during 27 and 109 days respectively for digesters 2 and 3. In addition, the gas produced burns with a blue flame. This indicates the presence of a good deal of methane content in the biogas produced by those two co-digestions system. Results observed could be due to positive synergism in the digestion environment, especially for effluents of cassava/urine/cow manure combinations, supplying missing nutrients and reducing of inhibitory materials in feedstock by the co-substrates as mentioned by [43]. In addition, this higher biogas potential was probably due to the increased in available easily degradable compound ratio in the feedstock, as it was reported by [24]. The difference of results obtained in digester 2 and digester 3 may be due to differences in microbial communities for these two co-digestions system employed. Others reported that improvement periods of anaerobic digesters subjected to organic overload differed based upon the microbial communities initially present ([44] - [46]). Although, the rate of CH4 content of the biogas produced in this study is not quantified, but it can range between 64% and 66% which is normally obtained from conventional anaerobic digestion of organic wastes as noticed by [47].

The use of human urine as a co-substrate for anaerobic digestion of cassava effluent requires a large quantity of urine (40% in terms of proportion) for a best productivity. This system of co-digestion, as well as allowing the production of biogas as a source of renewable energy, could also help to resolve the sensitive problem of sustainable management of human excreta.

4 CONCLUSIONS

In this study, the anaerobic co-digestions of manioc wastewater and human urine were implemented in batch experiments to test for energy recovery. The findings were recorded as follows.

(1) The pollution generated in the manufactory of attiéké (cassava wastewater and urine) constitutes the raw material of the anaerobic biodigestion unit. Produced biogas can be used to prepare the attiéké, but can also be used as an energy source for lighting the site of the factory and for the machines used to crush cassava.

(2) Human urine can replace chemicals generally used to adjust the pH during anaerobic biodigestion, in particular for the treatment of manioc liquid waste which is very acid.

(3) Residues of the anaerobic bio-digestion (digestat), rich in nitrogen, can be used to fertilize agricultural parcels for the production of cassava, for example.

In this way, the work environment will remain healthy for women, the lagoon adjacent to the factory will be protected against acid and toxic effluents of cassava and women use less firewood for cooking attiéké.

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