



Coffee Processing Wastewater Management: An Overview

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Authors' contributions

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ABSTRACT

Globally, one amongst the major agro-based industry contributing significantly is Coffee. Coffee growing estates use water for pulping and the wastewater generated from coffee pulping activity is generally discharged to the water bodies. The objective of this study was to evaluate the impact of effluents from traditional wet coffee processing plants on the water quality. Coffee fruits are processed by two methods, wet and dry process. The wet processing produces a drink of higher quality and has the advantage of reducing the drying space area and time required. However, this preparation step generates high volume of coffee wastewater as it involves utilizing large volumes of water with concurrent generation of wastewater. Throughout wet processing, coffee fruits generate enormous quantities of high strength wastewater. The so generated wastewater is characterized by high concentrations of organic matter, low pH, nutrients, suspended matter associated with odor and dark color with high chemical oxygen demand and biochemical oxygen demand requiring systematic treatment before disposal. The inadequate disposal of the coffee wastewater into environment directly without proper management and handling will pose a pollution risk to receiving water body. Efforts have been made by various researchers to evolve an alternative method for the treatment of coffee pulping waste and the same is discussed in this paper.

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1. INTRODUCTION

Industrial effluents contain a wide variety of pollutants, including bio-refractory organic compounds causing taste and odor problems in surface water bodies. These bio-refractory organic compounds are potentially toxic in nature and resist conventional treatment techniques [1]. The presence of colored and organic substances exhibits intense color, high Chemical Oxygen Demand (COD), high Biochemical Oxygen Demand (BOD) and suspended particles constituting source of pollution. Colored wastewater can cause environmental problems such as absorption of light and interfering with fundamental aquatic biological processes [2]. Complete removal of color and organic matter is not possible by biological treatment alone, henceforth additional physical and /or chemical treatments are in demand to enhance the biodegradability of the wastewater and to improve the receiving water quality [1].

The effluent generated from agro-based industries are characterized by high COD concentration which may cause severe irreparable damage to the environment if not disposed safely. Traditional methods of treating and disposing coffee processing wastewater arising from more than 3000 small and medium coffee estates are not considerable. In and around Coorg and Chikkamagaluru districts it is been a challenge to the nearby receiving water bodies. The treatment of wastewater generated by coffee processing remains a significant environmental pollution issue because of its huge quantity and its complex organic compounds like caffeine, lignin, pectin, tannin, melanoidin, sugar etc. Therefore, adequate treatment of these effluents is essential before discharging into nearby water bodies.

Efforts have been made by various researchers to evolve an efficient method for the treatment of coffee pulping waste. From previous studies, it can be observed that the conventional treatment methods like anaerobic - aerobic lagoons are often inadequate to completely remove pollutants from coffee processing wastewater, which often fail during start-up since they are operated in winter at low temperatures and they get overloaded, accumulate Volatile Fatty

Acid (VFA), become malodors, pose potential hazards to ground and surface water resources etc. The attempt of separating the solids and concerning on the wastewater cleanup did not succeed due to failure in handling mucilage problems and costlier. The usage of Upflow Anaerobic Sludge Blanket (UASB) reactor along with a biological filter system was failed due to impartment of color by the presence of flavonoid compounds in coffee skin. Performance of thermophilic digester was not successful in terms of COD removal and gas production, since the potassium is one of the most significant components of the mineral content of coffee beans, which was found to be inhibitory at 55°C. During anaerobic digestion, the low methanogenic activity of the seed sludge used, its poor granulation, settleability characteristics and its lack of acclimatization to coffee wastewaters were a serious constraint for the treatment process.

Considering all the limitations discussed above it was found that there is a need to identify alternate treatment method to handle the high BOD, COD, low pH and dark brown in color coffee pulping wastewater. It has been a challenge to the nearby receiving water courses as the partial treated wastewater generated by existing coffee processing units remain a significant environmental pollution issue because of its huge quantity and its complex organic compounds. Thus, considering the volume generated and the pollutants present in wastewater, using a combination of electrocoagulation and biological methods is found appropriate. This is in accordance with Asha [3], the electrochemical methods do not require any addition of chemicals for removal of pollutants and has proven to be a promising method for the destruction of organic pollutants in wastewater. The reaction can be carried out at room temperature and at normal pressure and terminated easily by switching off the power supply.

1.1 Coffee Crops – India and Worldwide

Ethiopia is the place of coffee origin and world's third largest coffee exporter after Burundi and El Salvador [4,5]. Ethiopia is the place of coffee origin and world's third largest coffee exporter after Burundi and El Salvador

[4]. Mexico takes up the ninth position in the world coffee production with 2.4×10^3 tonne annually [6]. The coffee plant belongs to the family *Rubiaceae*, genus *coffea*. More than 80 coffee species have been identified and amongst them two are of economical importance. They are *Coffea Arabica*, popularly known as *Arabica* coffee, responsible for approximately 70% of the global coffee market and the other is *Coffea canephora* popularly known as *Robusta* coffee contributing to the remaining portion. The major coffee crop grown all over the world with three common species like *Robusta*, *Arabica* and *Liberica* [7]. Currently India grows about 3 lakh tonnes annually ranking sixth in the world coffee production. In India, the coffee cultivation is primarily carried out in several States that includes Karnataka, Kerala, Tamilnadu, Andhra Pradesh, Orissa, West Bengal and Northeastern states. In India, Karnataka State is the largest coffee growing area accounting for about 72% of total coffee produced. Around 0.305 million hectare is the area under coffee cultivation with *arabica* and *robusta* being cultivated.

1.2 Processing in India

The superiority enhancement of coffee production leads to increased use of processing forms with increased water use which leads to enormous increase of wastewater generation with organic load which requires proper treatment prior to disposal. Coffee is processed either by wet method or dry method. During processing, the coffee berry is subjected to mechanical and biological operation to separate the bean or seed [8]. Most of the coffee farms in India are categorized under small and medium sized which are less than 15 hectares [9]. It is estimated that nearly half the coffee grown in India (40-50%) is processed by wet pulping method to yield a superior quality product compared to the dry processing option. The wet pulping method requires mechanical removal of pulp using water with simultaneous generation of wastewater. The coffee industry uses very large quantities of water at various stages of the processing and production. About 50% of the total water used is consumed during pulping process. The wet method is applied for *arabica* coffee and requires a higher degree of processing [10]. In India, around 75% to 80% of *Arabica* and 15% to 20% of *Robusta* are processed by wet

method [11]. The generation rate of coffee wastewater is a fluctuating flow with uniform loadings of contamination. In the wet method of coffee processing, the fruit is soaked in water overnight and then pulped by pulping machines. The coffee beans obtained from pulping machines are washed and later the skin and mucilage are removed mechanically. The washed coffee beans are dried using suitable drying platforms. The wastewater from the pulping machines and washers contains coffee effluents which need to be treated before discharge.

1.3 Water Consumption and Wastewater Generation during Coffee Pulping

The coffee industry uses large quantities of water during the various stages of the production and concurrently generates large quantity of wastewater for the production of coffee powder in various stages of processing which in turn generates approximately 40 -45L of wastewater per kilogram of the product brewed [12-16]. Due to the seasonal nature of the coffee industry operating during November to January, the quantity of water used and the volume of wastewater generated in each coffee industry vary from one another depending upon the processing adopted. The process which includes pulping of fruit to remove outer skin and mucilage and cleaning of seeds requires more water and generates about 5 m^3 wastewater per tonne of fresh coffee fruit processed [17]. The overall impact of coffee on Environment takes place in stages namely growing, processing and consumption of coffee. Water consumption and concomitant wastewater discharge range from 1.5 to 23 m^3 per tonne of fruit processed. No water is consumed by the process. The pollution resulting from 1 tonne of clean processed coffee is estimated at being equivalent to 273 m^3 of crude domestic sewage. This corresponds to a daily sewage from a population of approximately 2000 persons. As reported in Chanakya and Alwis [18] the average water consumption per tonne of fruit processed is 8.4 m^3 and the water usage for coffee processing in Indian coffee estates vary from 2.25 to 23 m^3 per tonne of fruit processed [19]. Field studies have determined coffee processing to discharge up to 45 kg of COD per tonne fruit processed.

Using conventional pulper and washer for the production of one tonne of coffee, the water requirement is 80 m^3 for *Arabica* and 93 m^3 for

Robusta [20]. The wastewater generated is disposed to the nearby surface water sources like rivers that carries the remaining of mucilage and pulp [21,22]. The volume of wastewater generated from coffee processing in India estates is estimated to be 2.078×10^6 m³ per annum [11]. As the wastewater fluctuates in quantity and composition, the final disposal of the wastewater containing mucilage and pulp extracts generated by the coffee agro-industry is causing an increased environmental problem [23] owing to recalcitrant nature of the compounds present in the effluents. The amount of water used varies significantly with location and hence there is significant variation in the strength of wastewater generated.

The coffee processing wastewater has the ability to pollute the receiving water bodies due to its high organic load, low pH, suspended and dissolved organic matter [24], color containing different macromolecules that includes polyphenols (e.g., melanoidins), sugars and pectin, [25], lignin, tannin [18], alkaloids, polyphenolics [9], flavonoid, caffeine and melanoidin [26], organic minerals such as carbohydrates, lipids and proteins [27], high content of suspended and dissolved organic matter [20] like sugars i.e. fructose and glucose [28], proteins, pectin, sugar [26,21,29,10,18,30,11], lignin, cellulose, hemicellulose [15,31] and polyphenols i.e. caffeine, tannic acid [32,28], carbohydrates [21], tannins, caffeine [33,34], soluble salts [11], nutrients [35], COD [23]. It is clearly evident that there is an immediate requirement for treating the coffee pulp wastewater before discharging into surface water courses [36]. The coffee fruits wash and parching activity, necessary for reducing the grains drying costs and improving the beverage quality, generates material matter in suspension and organic and inorganic components in solution [37].

1.4 Environmental Issues

It has been a challenge to the nearby receiving water courses as the treatment of wastewater generated by coffee processing units remain a significant environmental pollution issue because of its huge quantity and its complex organic compounds. Thus, considering the volume generated and the pollutants present in wastewater, this industry represents one of the major contributors to the severe pollution problems. To meet the disposal standards, treatment of these effluents is essential before discharging into

nearby water bodies.

Coffee processing takes place after the monsoon fades away and there is little flow of water in the various streams arising from the Western Ghats. To overcome this shortage, water from natural and man-made lakes are pumped out and the resultant spent water is treated. This partially treated effluent becomes the main source of water to the next water body (usually another lake / tank) downstream. There are very few coffee plantations that have the capability to remove all undesirable organics and minerals from the coffee effluents before they reach various water bodies downstream. Sometimes the problem is so severe that in many towns downstream, drinking water pumped from natural tanks possesses a deep purple color - characteristic of partly treated coffee effluents reaching these water bodies [29]. Today, coffee cultivation has gradually spread from the wetter hill slopes to the adjoining drier rolling lands where natural and manmade water bodies are important water reservoirs. Coffee processing has now created a great demand for water stored in these reservoirs and is adding a new dimension to this problem. The improper disposal of coffee processing wastewater produces objectionable odor, leads breeding of insects and vectors at the point of disposal. This leads to acidity with subsequent depletion of dissolved oxygen in the receiving surface water zones [38].

The main environmental issue at the coffee pulping process is due to the consumption of large quantity of water and simultaneously generating enormous quantity of wastewater. The pollutants in coffee wastewater emerge from the organic matter that is difficult in degrading the mucilage layer surrounding the beans. The wastewater is acidic with pH as low as 3.8 due to organic matter and acetic acids from the fermentation of the sugars. In this acidic condition the plants and animals cannot survive. The digested mucilage, when precipitated out of the solution consists of high concentration of total suspended solids. These build a crust on the surface, clogging up waterways and contributing to the anaerobic conditions [38]. In addition, the presence of some toxic chemicals like alkaloids, tannins and poly-phenolic compounds makes the biological degradation of organic material in the wastewater more difficult [9].

If the untreated coffee pulping wastewater is discharged to surface water bodies, the mucilage reduces dissolved oxygen (DO) in water. The reduction of DO kills fish, insects, and aquatic plants resulting in unpleasant odor, insect infestation, and downstream human health problems. Further, the receiving water contaminated by coffee pulping wastewater is twice as acidic as household wastewater. The people residing in the vicinity of the processing units suffer from many diseases like skin irritation, stomach problem, nausea and breathing problem [30].

1.5 Treatment Technologies

The low BOD₅ to COD ratio indicates the non-suitability of coffee wastes for biological treatment. Macromolecules are difficult to degrade by conventional biological treatment process, hence to obtain a high removal efficiency of organic matter including recalcitrant organic compounds, a combination of physical, chemical and biological treatments are to be employed. Coffee Pulping Wastewater Management Techniques used by coffee pulping operators in India are based on the use of lagoons. From previous studies, it can be observed that the conventional treatment methods like anaerobic - aerobic lagoons are often inadequate to completely remove pollutants in coffee processing wastewater, which often fail during start-up, they are operated in winter at low temperatures, they get loaded often fail during start-up, they get overloaded, accumulate VFA, become malodors, pose potential hazards to ground and surface water resources etc. Thus, there is a need to identify alternate treatment methods to handle the high BOD, COD, low pH and dark brown in color bearing coffee process wastewaters.

The potential of reducing COD and BOD from coffee processing wastewater was studied by Devi (2010), using Avocado Seed Carbon (ASC) in comparison with Commercial Activated Carbon (CAC), which showed 98.28% and 99.19% with ASC and 99.12% and 99.45% with CAC respectively under optimum operating conditions.

Attempts were made by Tokumara et.al., [39] for decolorization of coffee effluent prior to disposal by Photo-Fenton reaction, since melanoidins have strong Fe²⁺ binding ability, Photo-Fenton and Fenton processes attributed to the oxidation power of OH[•], which is formed during the decomposition of hydrogen peroxide catalyzed by ferric ion may be effective to degrade

melanoidins and as a result decolorize coffee effluent. For comparison, the combination of advanced oxidation process and biological treatment to treat coffee wastewater of high organic load was investigated by Kondo et al, [28] using Fenton, Solar-Fenton followed by Upflow Anaerobic Sludge Blanket (UASB) process the removal efficiency with the Solar-Fenton alone was 60% of BOD after 2 hour of irradiation while the Coupling systems using photo-Fenton and UASB treatments showed that the use of the sequence UASB and then solar photo-Fenton reaction resulted in BOD and TOC removal of 95% and 80% respectively.

Efficiency of batch aeration in treating wastewater of previously treated coffee processing wastewater by the Upflow Anaerobic Hybrid Reactor (UAHR) by continuous and intermittent aeration system showed that the maximum BOD, COD and Total Solids removal efficiency of 74.5%, 68.6% and 49.3% respectively. Hue et al, 2003. In their findings showed that treatment of coffee pulp with aerating the sample for 7 days with 1% lime helped reducing BOD from 8,000-11,500 mg/L to < 300 mg/L and Phosphorus levels in the receiving water.

Aguilera and Consuegra, [40] evaluated the effect of an ionizing radiation on coffee wastewater in order to decompose chemical organic refractory substances which cannot be degraded by biological treatment i.e. in the presence of air it was possible to destroy only up to 70% of the COD at different air flow rates while the irradiation processing of coffee wastewater can contribute in an important way to solving this problem as well as the possibility of using irradiation for the disinfection of this waste.

Chandrashekar et al., [12] has investigated the performance of an integrated membrane bioreactor process using aerobic reactor manned with a side stream high flux ultrafiltration membrane followed by reverse osmosis as a post treatment for the treatment of coffee industrial effluent. The method has proven to be simple, compact, easy to operate when compared to other treatment processes but the initial investment (6.5 lacs) and operating costs is high to bear by the low and medium coffee growers in India.

2. BIOLOGICAL METHODS

Coffee wastewater is characterized as acidic, high content of suspended and dissolved organic

matter rich in sugars and pectins and thus is amenable to rapid biodegradation. The high BOD to COD ratio is an indication of the suitability for biological treatment. Conveniently coffee pulping wastewater is treated through physical, chemical and biological methods. These methods have their own drawbacks therefore to enhance the efficiency of the biological processes; a pre-treatment process is always in demand to destroy the recalcitrant compounds.

Efforts have been made in various parts of the world to develop an efficient and economic process for treating the wastewater from wet coffee processing. The first recorded effort to treat such wastewater was made in Kenya in the 1950s'. The East African Industrial Research Organization (EAIRO) worked on it in Uganda in the early 1960s' while IDRC, Canada sponsored research projects in South America in the 1970s'. The first attempt to separate the solids and concentrate on the wastewater cleanup was made in Costa Rica during the 1980s'. However, it did not succeed in handling the mucilage problems and proved to be costly on a large scale [10]. In Papua New Guinea, an UASB (Upflow Anaerobic Sludge Blanket) reactor was used for treating coffee wastewater, along with a biological filter system. In spite of this, the flavonoid colour compounds in coffee skins continued to discolor the rivers and other discharge areas [10]. The presence of high organic content of cell debris (cellulose), pectic material and small extent of polyphenolic material makes it possible to precipitate a small fraction using CaO, bleach etc., but these methods are not practiced in India. Most plantations prefer simpler anaerobic – aerobic ponds and lagoons. There appear to be two strategies in wastewater management: Pond/lagoon –based treatment of wastewater and discharge into water bodies; Treatment of wastewater and reuse on coffee and other crops. The latter method is rarely followed in India. At best, partially treated wastewater is let into paddy croplands functioning as shallow ponds. The use of stabilization ponds has emerged as the most preferred option in many instances where direct discharge to water bodies is not practiced. However, use of these stabilization ponds and lagoons is still not being followed in an acceptable 'scientific/best practices' manner. As reported in Chanakya and Alwis [18]; Gathuo et al., [41] found that the stabilization ponds operated improperly in Kenya have become breeding sites for disease-spreading

mosquitoes, emit unpleasant odours and cause nuisances. Aerobic lagoons were used for treatment in a coffee production facility in Brazil. This method facilitated recycling of wastewater back into production plants.

Wastewater management techniques used by the coffee pulping operators in India are based on the use of lagoons. The National Environmental Engineering and Research Institute (NEERI) Nagpur, developed wastewater processing based on the existing water usage pattern of 16000-23000 L water per tonne of fruit processed. The treatment process is based on the use anaerobic (21 days) and aerobic (7 days) lagoons after an initial chemical pretreatment (neutralization). The Karnataka State Pollution Control Board website states that at present the coffee estates mainly use unlined 'Kutchra' pits instead of the recommended stone-lined, acid proof masonry structures. Major advantages of the stabilization ponds are the low initial costs and ease of operation. Some disadvantages include odor problems and mosquito breeding (public health issues), loss of cultivable area, unsatisfactory treatment, potential for groundwater contamination and low loading rates.

The low COD to BOD relation and the high proportion of volatile solids in relation to total solids indicate the use of biological treatments suitable for these wastewaters (Matos et al, 2001). The coffee processing wastewater has a very high concentration of phosphate which is a good indication in using activated sludge methods in wastewater treatment [8]. Coffee pulping adopting wet processing is characterized by high BOD (8,000-11,500 mg/L) which has to be reduced to the permissible level in order to dispose it to irrigable lands.

Hue et al, (2003), in their study observed that treating with lime followed by aeration significantly lowered the BOD and phosphorus levels in the wastewater thereby making it amenable for irrigation reuse. Anaerobic digestion to the treatment of liquid and solid wastes from the coffee industry was adopted by Bello-Mendoza and Castillo-Rivera, 1998 as it contains carbohydrates which makes them more suitable for biological treatment but the seasonal nature of coffee pulping effluents, poses a challenge to anaerobic digestion technology, since quick start-ups and good process stability are required for the efficient treatment of these wastewaters. The low methanogenic activity of

the seed sludge used, its poor granulation and settleability characteristics and its lack of acclimatization to coffee wastewaters were a serious constraint for the treatment process.

The potential of using degreased coffee beans for the removal of malachite green from dyeing process wastewater as adsorbent was investigated by Baek et al., [42] and showed that removal slowly increases with increase in pH from 2-6, wherein the maximum color removal was observed at pH 10-12 consequently, adsorbed amount of malachite green by degreased coffee beans increased with increasing degreased coffee beans dosage and initial malachite green.

Owing to excellent capacity of retaining microorganisms on the supporting media for immobilization Fia et al., [42] used various supporting materials like blast furnace slag, polyurethane foam and crushed stone which provided greater retention and fixation of biomass. Accordingly, the biomass with the presence of a larger quantity of microorganisms in the biofilm reactor was responsible for the higher efficiency of COD removal from coffee processing wastewater.

Anaerobic digestion of coffee pulping waste has been reported by various researchers at both mesophilic and a thermophilic temperature whereby the dissolved and suspended organic carbon of wastewater is converted to biogas is an extremely effective way of handling a high strength effluent [18].

Fernandez and Foster, [43] reported that performance of thermophilic digester was not as successful as the mesophilic digester in terms of COD removal and gas production, since the potassium is one of the most significant components of the mineral content of coffee beans, which was found to be inhibitory at 55°C.

The disposal and management of highly polluted coffee processing wastewater poses serious environmental problems due to recalcitrant nature of the compounds in the effluents. Generally aerobic biological treatment is a preferred to deal with urban and industrial effluents. Nevertheless, some drawbacks may be found when applying aerobic biological treatment, for instance some pollutants with complex chemical structures are difficult to biodegrade because of their refractory nature and some are toxic to

microorganisms and some chemicals are resistant to biological treatment. In most cases such toxic substances escape the conventional biological treatment process. Some of the organic compounds are of such kind and nature, a pretreatment of such substance is necessary in order to increase their biodegradability and to minimize the environmental impact on the biota. Hence, to enhance the efficiency of the biological processes for industrial wastewater treatment, an effective pre-treatment process is always in demand to destroy these recalcitrant substances.

Asha and Kumar [44], have evaluated the efficacy of electrocoagulation batch reactor as pretreatment for anaerobic sequencing batch reactor to treat coffee processing wastewater by using aluminum electrodes. The electrocoagulation treatment resulted in the enhancement of BOD₅ to COD ratios greater than 0.5 indicating the increase in biodegradability of the wastewater. Since, the coffee pulping wastewater is a high strength wastewater and after electrocoagulation treatment the COD concentration reduced to 512 mg/L and other parameter such as nitrate nitrogen and phosphorus was reduced to nearly Below Detection Level (BDL). The COD, ammonia nitrogen, nitrate nitrogen and phosphorus removal were found to be 93%; 89%; 90.36% and 83.85% respectively. Consequently, authors concluded that the electrocoagulation treatment method is a promising process for the treatment of coffee pulping wastewater. Further, study revealed that electrocoagulation treatment with aluminum electrodes operated for 90 minutes followed by biological treatment in anaerobic sequencing reactor operated for 150 minutes will bring down the coffee pulping wastewater characteristics to well below the dischargeable standards.

To overcome the above problem, it is necessary to investigate alternate wastewater treatment method. The application of electrochemical techniques started with production of high-volume chemicals, extraction and refining of metals. Today electrochemical technique such as Electrooxidation (EO), electrocoagulation, Electrodialysis (ED), direct electrochemical process, indirect electrochemical process, electrochemical activation process is emerging out as practical technologies

replacing conventional physicochemical methods of wastewater treatment. Electrocoagulation approach can be useful to degrade recalcitrant industrial wastewater or markedly enhance the biodegradability and biocompatibility in the treated effluents. The electrocoagulation technology offers simple, efficient and cost-effective solution of environmental problems and superior over conventional treatment process. Asha [3] has evolved that electrocoagulation followed by anaerobic sequencing batch reactor provides a feasible solution for coffee pulpers for treating wastewater generated from coffee pulping activity. Electrocoagulation treatment of raw coffee pulping wastewater using aluminum plates (7 cm x 7 cm) as anode and cathode at 16 V resulted in 88% COD removal, while ammonia nitrogen, nitrate nitrogen and phosphorus removal was \approx 100% removal respectively at current density of 55.1 A/m² and 2.7 kWh per Kg removal of COD, 1.9 kWh per Kg removal of ammonia nitrogen, 1.6 kWh per Kg nitrate nitrogen removal and 1.7 kWh per Kg phosphorus removal. This treated effluent can be fed to anaerobic sequencing batch reactor which yields nearly 100% removal.

3. CONCLUSION

Based on the previous literatures, the method adopted by Asha and Kumar [44] can be applied in the field so that possibility of river water pollution is prevented. The proposed method utilizes less energy consumption with minimum land requirements.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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