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Evaluation of Cigarette Filters Rods as a Biofilm Carrier in Integrated Fixed Film Activated Sludge Process

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***Abstract*—**The purpose of the experiments described in this article was the comparison of integrated fixed film activated sludge (IFAS) and activated sludge (AS) system. The IFAS applied system consists of the cigarette filter rods (wasted filter in tobacco factories) as a biofilm carrier. The comparison with activated sludge was performed by two parallel treatment lines. Organic substance, ammonia and TP removal was investigated over four month period. Synthetic wastewater was prepared with ordinary tap water and glucose as the main sources of carbon and energy, plus balanced macro and micro nutrients.

COD removal percentages of 94.55%, and 81.62% were achieved for IFAS and activated sludge system, respectively. Also, ammonia concentration significantly decreased by increasing the HRT in both systems. The average ammonia removal of 97.40 % and 96.34% were achieved for IFAS and activated sludge system, respectively. The removal efficiency of total phosphorus (TP-P) was 60.64%, higher than AS process by 56.63% respectively.

***Keywords*—**Wastewater; biofilm carrier; cigarette filters rods; Activated Sludge; IFAS; nitrification.

I. INTRODUCTION

THE activated sludge process (AS) does exist in a large number of modifications and variations. In the last decade or so the most important development in practice can be observed in industrial wastewater treatment, nutrient removal (N and P), and bulking control technologies [1].

Biofilm reactors are used in biological wastewater treatment for the removal of organic carbon and nitrogen species. High accumulations of biomass in the biofilm process ensure the high treatment capacity and operational stability [2]. Long solids retention times make biofilm reactors suitable for the retention of slow-growing organisms such as nitrifiers[3].

IFAS systems add the benefits of Fixed Film systems into the suspended growth Activated Sludge process. Activated Sludge has process flexibility and provides a high degree of treatment. Fixed Film processes are inherently stable and resistant to organic and hydraulic shock loadings. Placing Fixed Film media into Activated Sludge basins combines the advantages of both of these approaches [4].in addition to organic removal, biofilm reactors specially MBBR and IFAS processes have proved to be reliable for nutrients removal without some of the problems of activated sludge process [5],[6].

Biofilm carriers (media) are an important component of IFAS system. Several types of synthetic packing materials have been developed for use in activated sludge processes. The two main categories of IFAS media are free-floating and fixed media. The media is generally made of a plastic with a specific gravity less than, but close to 1.0. There are now more than 10, and counting, different variations of processes in which a packing material of various types is suspended in a aeration tank of the activated sludge process [4],[7].

Carriers such as sand or gravel have the advantage of their low or zero cost [8] but artificial supports are expensive and there are usually many problems for transportation and storage of these materials in developing countries. Many investigations have been done to use inexpensive carriers. Some cheap carriers such as biodegradable meal box, liquorice (Glycyrrhiza glabra), giant reed (Arundo donax) and cotton have been investigated for Denitrification of nitrate contaminated groundwater [9]-[11].

Many inexpensive carriers such as sisal fibre waste, pumice stone, porous glass beads and FLOCOR-RMP® have been investigated to wastewater treatment [12],[13].

Applying industrial and agricultural waste product such as Straw as a biofilm carrier has been investigated by many researchers [14]. These carriers are abundant and require only limited resources concerning handling and cost.

The main objective of this study was to evaluate cigarette filter waste as a biofilm carrier in integrated fixed film activated sludge process. 95% of cigarette filters are made of cellulose acetate, a plastic slow to degrade. Cellulose acetate fibers are thinner than sewing thread, white, and packed tightly together to create a filter; they can look like cotton. These filters are a rod of about 12,000 plastic-like fibers. Depending on conditions, estimates for the time taken for them to degrade range from British American Tobacco's 10 months - 3 years, to 10-15 years [15]; In fact Cellulose acetate is photodegradable but not bio-degradable [16].

One of the most important wastes in cigarette production factories is sliced cigarette filter rods. The cigarette filter emerges from the final stage of manufacture in the form of a continuous rod which is then cut into lengths, referred to as 'rods'. Each 'rod' so formed will subsequently again be cut as

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part of the cigarette manufacturing process to provide filter tips, normally for six cigarettes [17].

According to personal measurements, more than 1% of filter rods were wasted during cigarette manufacturing process that can be an important problem for environment.

The objectives that guided this study were: (1) to develop a new, inexpensive and efficient carrier;(2) to evaluate COD removal efficiency, Nitrification and Denitrfication by this carrier; (3) to determine the effect of operating conditions (i.e. organic loading rate and flow rate) on COD removal efficiency under continuous-flow conditions; and (4) comparing this method with a conventional method.

II. MATERIALS AND METHODS

A. The Lab-Scale Plants

Two similar lab-scale wastewater treatment plants were made of poleax glass according to the scheme in Fig. 1. Each treatment line consisted in an 8.1lit one-stage aeration tank and a final settler. All reactors were placed into a water bath were equipped with aquarium heaters in order to operate at the constant temperature of 20±1^{0}C. Sludge recycling was applied in both systems. The Q_R: Q was changed based on MLSS concentration (Ave. 15%). Fine bubble aeration was adopted for oxygen supply and mixing.

Synthetic wastewater was continuously fed into both reactors using a variable speed peristaltic pump from a storage tank.

Synthetic wastewater was prepared with ordinary tap water and glucose as the main sources of carbon and energy, plus balanced macro and micro nutrients. Synthetic wastewater with the following composition was used in this study: glucose (var.), KH_2PO_4 (13.2mg/l), $(NH_4)_3SO_4$ (72 mg/l), Yeast extract (30 mg/l) and 10 ml of trace element solution per liter. The trace solution consisted of the following compounds per liter: 0.7 g of $FeCl_3.6H_2O$, 0.024 g of $CuSO_4.5H_2O$, 1.8 g of $MnCl_2.H_2O$, 0.23 g of $Na_2MoO_4.2H_2O$, 0.189 g of $ZnSO_4.7H_2O$, 2.7 g of $CoCl_2.6H_2O$, 2.25 g of $CaCl_2.2H_2O$ and 0.01 g of $MgSO_4$. $NaHCO_3$ was used for alkaline pH adjustments [18]. Both reactors were inoculated with thickened sludge from the Isfahan Municipal Wastewater Treatment Plant. After a start up period of fifteen days, substrate was added and the reactors were operated continuously for 128 days. Both reactors were started at an organic loading rate (OLR) of 0.5 gCOD/l.d and a hydraulic retention time (HRT) of 16.1 h. Following this, the OLR was gradually increased together with reduced HRT.

One of the reactors was filled up with cigarette filter rods as a biofilm carrier (IFAS reactor). Many cigarette filter rods were prepared from an Iranian tobacco factory. They were added into IFAS reactor after preparation phase includes: 1-separating tobacco from the cigatte, 2- cutting the cigarette filters, 3-soaking in water for 5 minutes and 4-seperating filter paper wrap. The prepared cigarette filter rods (carriers) are shown in Fig. 2.

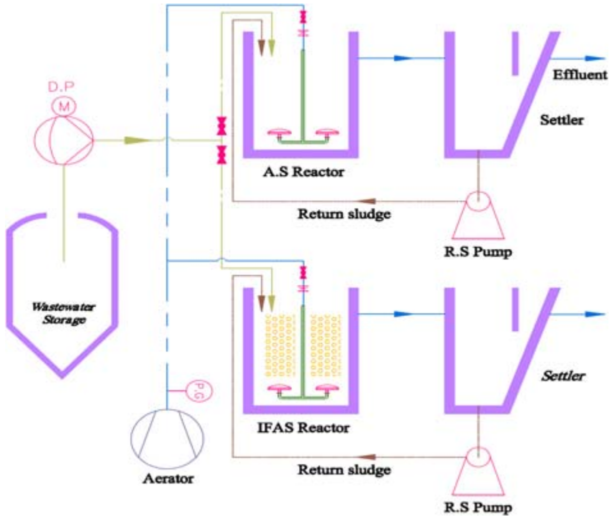


Fig.1 Schematic diagram of the lab-scale wastewater treatment plants

Fig. 2 Cigarette filter rods after preparation phase

TABLE I
CHARACTERISTICS OF THE CIGARETTE FILTER MEDIA

Parameter	Quantity (Range)
Material	Cellulose acetate
porosity	81.1-85.1%
Diameter	7 mm
Length	10 mm
Specific surface area	0.01-0.0127 m^2/no.
No. of filter media in the IFAS reactor	740 no(s).
Total surface area in the IFAS reactor	7.40-9.42 m^2

Bulk volumetric filling of 5% was used in IFAS reactor. Characteristics of the cigarette filter carriers are presented in Table I. Scanning electron microscopy (SEM) was applied to show biofilm on cigarette filter media.

As shown in Fig.1 another reactor was operated as activated sludge process (AS reactor). In fact the only different between two systems was biofilm carriers.

B. Analyses

Grab samples were collected to determine wastewater characteristics of influents and effluents. Chemical Oxygen Demand (COD) was measured right after filtration through 0.45μm filter papers according to standard methods. Temperature, dissolved oxygen and pH were measured in each reactor every workday, immediately before sampling.

The other lab analyses include Soluble COD, ammonium (NH_4-N), nitrate (NO_3-N) and soluble phosphorus (PO_4-P), MLSS and MLVSS were obtained through the Standard Methods [19].

The biomass in the IFAS reactor was measured by taking out a given water volume of cigarette filter with attached biomass. After being dried at 70 to 80 ^{0}C for 1 week, these samples were weighted. The carriers were then completely cleaned by ortho-phosphoric acid (88%) and detergent [20].

III. RESULT AND DISCUSSION

A. IFAS Performance

Biofilm formation was assessed by scanning electron microscopy (SEM). Scanning electronic micrographs of cigarette filter media before and after microbial colonisation with aerobic microbial biofilms are shown in Fig. 3 and 4. As shown in Fig.3-D, there are many spaces between the cellulose fibers, and then it has high porosity and roughness. It is clear from previous research that pore space and the fiber space are bi-continuous [21].

Cell growth on the surface of support carrier depends on the roughness and micropore. High porosity and roughness are good for cell growth [22].

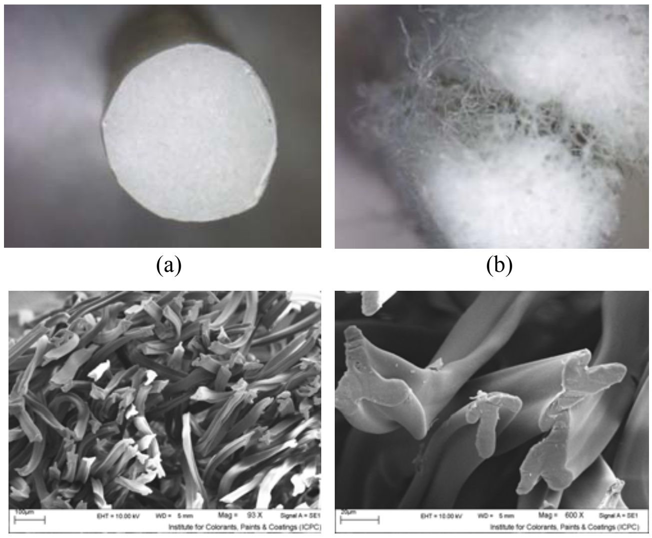
Both systems (IFAS and AS reactors) were operated at a same time, but quality parameters were measured only for IFAS reactor in the first month of operation.

The COD concentration variations of IFAS influent and effluent for each level of COD carrier loading rate are shown in Fig. 5. The values given are average values and standard deviations for 5–9 measurements over the final 6–10 days of operation at each OLR.

As shown in Fig. 5 during optimum conditions (COD= 425 mg/l, HRT= 3.8 h), COD removal efficiency of 82.25% occurred in IFAS system. The HRT was as short as previous investigation (about 30-90min) [23].

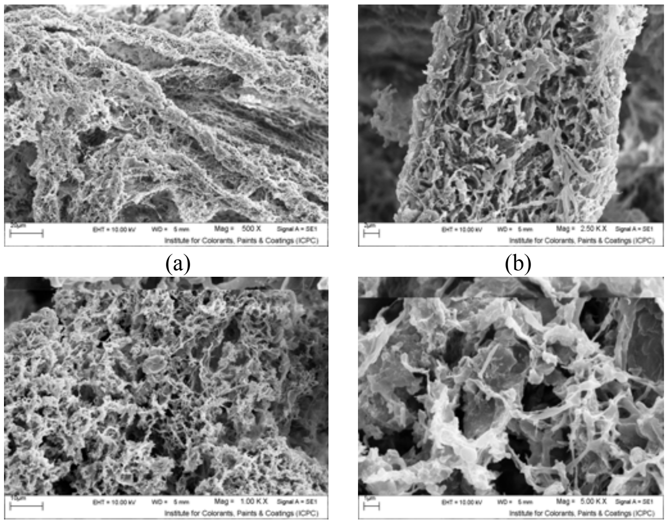
On the other hand, COD removal efficiencies in IFAS system were constant with changes in influent flow. In fact biofilm reactors had more flexibility on flow fluctuations [24].

The HRT was decreased from 16.1 d to 3.8 h with increasing COD concentration from 326.8 to 446.3 mg/l, which caused an increase of OLR (into aeration basin) from 0.5 to 2.8 kgCOD/(m^3. d). It is obvious that biofilm carriers have a significant effect on the performance of the IFAS system. The average effluent COD increased from 10.2 to 25.5 mg/l. The total COD removal efficiency decreased from 94% to 86%. In fact, a decrease in COD removal efficiency of only 8% was observed when the OLR was increased by six times.



(a) (b) (c) (d)

Fig.3 Optical microscopy and scanning electronic micrographs of cigarette filter media before microbial colonisation: (a) cigarette filter media surface (optical microscope), (b) cigarette filter media cross section (optical microscope), (c) cellulose acetate fibers (mag. ×93) and (d) cellulose acetate fibers (mag. ×600).



(a) (b) (c) (d)

Fig.4 Scanning electronic micrographs of cigarette filter media after microbial colonisation: (a) cellulose acetate fibers (mag. ×500), (b) a cellulose acetate fiber (mag. ×2.50k), (c) microbial biofilm on a cellulose acetate fiber (mag. ×1.00k) and (d) void spaces between microbial biofilms (mag. ×5.00k).

Nitrification and denitrification rate are important parameters to evaluate process efficiency in biofilm reactors. Fig. 6 shows TAN concentration versus TAN load rate and Fig. 7 Shows Denitrification rate versus TAN load rate in IFAS reactor. Dissolved oxygen concentration has a lot of changes, because some of the fine bubble diffusers were clogged by microbial biofilm.

The rate of return sludge from the settler was controlled and adjusted by an automatic timer. All samples were taken at least 15 min after returning sludge.

The influent concentration of phosphorus (P) had to be increased to more than 2 mg-P/l by the time that steady state. The average effluent P concentrations at steady state were 0.5 mg/l. The TP concentration variations of IFAS influent and effluent for each level of COD carrier loading rate are shown in Fig. 8.

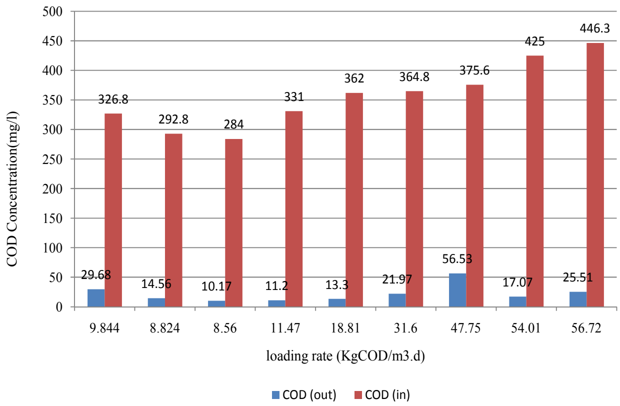


Fig.5 The COD concentrations in IFAS influent and effluent versus COD carrier loading rate
(HRT= 16.1h-3.8h, OLR=0.5-2.8gCOD/l (aeration basin).d)

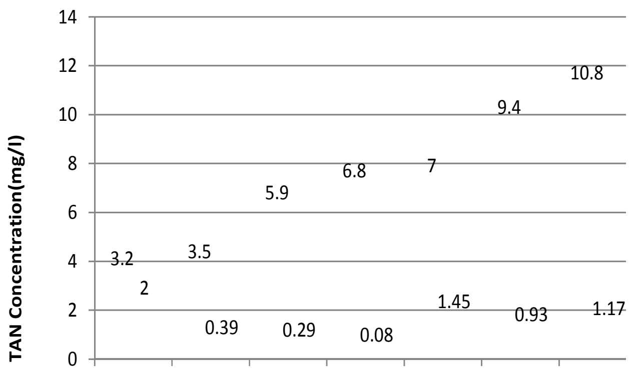


Fig. 6 TAN concentration versus TAN load rate in IFAS reactor
(HRT= 16.1h-3.8h, T= 20±1^{0}C, DO= 5.8±1.3 mg/l)

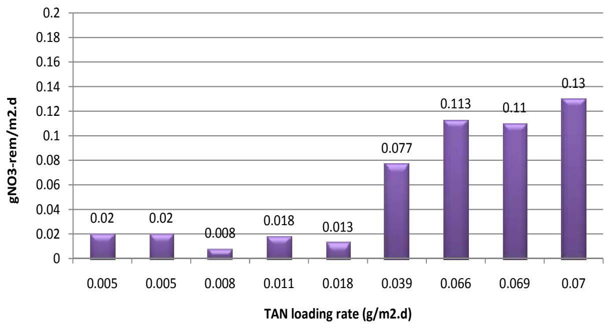


Fig. 7 Denitrification rate versus TAN load rate in IFAS reactor.

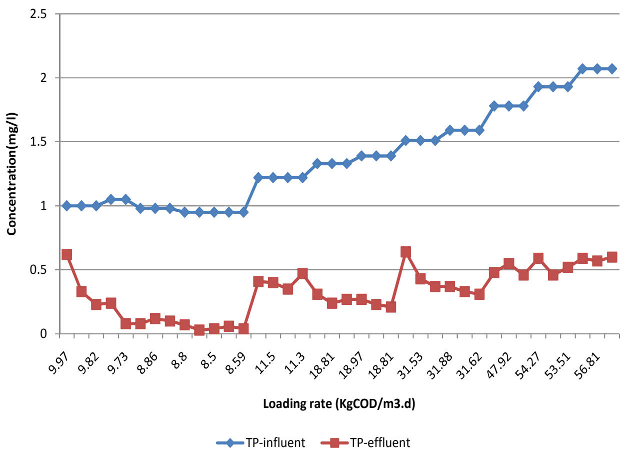


Fig.8 TP concentration variations of IFAS influent and effluent versus COD carrier loading rate

B. Activated Sludge VS IFAS

Operating conditions such as Hydraulic retention time was equal in both systems. The onle different between two system was moving media in IFAS reactor. Some white stable foam was formed on the aeration basin in activated sludge (AS) about 10 days after steady state operation.

The average efficiencies for COD removal were 94.55 % for IFAS and 81.62% for AS. These values are related to an average inflow concentration of 309.25 mg/l and average outflow concentrations of 15.86 and 56 mg/l for IFAS and AS respectively. The maximun influent concentration resulted 408 mg/l. The COD peaks in the effluent resulted 17.6 mg/l (IFAS) and 81.3 mg/l (AS). Total COD effluent concentration in activated sludge and IFAS reactor are shown in Fig. 9.

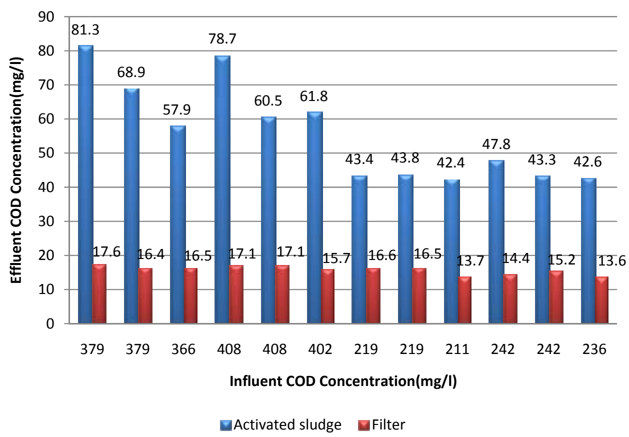


Fig.9 COD effluent concentration versus influent concentration in activated sludge and IFAS reactor
(HRT=9.4-3.8 h, Flow=20.79-50.84lit/d)

The different efficiency in the two systems is related to the different MLSS concentration which it is consistent with previous research [25]. The MLSS concentration ranged from

2500 to 3800 mg/l (average value: 3270 mg/l) in AS system and from 3414 to 6949 mg/l (average value: 5352 mg/l) in the IFAS system.

The removal of ammonium in both systems was also monitored during the operation. The influent and effluent concentrations of TAN for both systems are shown in Fig.10.

The average efficiencies nitrification were 97.40 % for IFAS and 96.34% for AS. These values are related to an average inflow concentration of 13.52 mg/l and average outflow concentrations of 0.35 and 0.49 mg/l for IFAS and AS respectively.

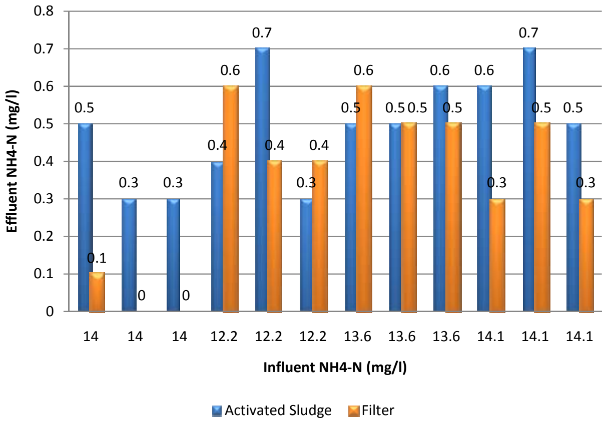


Fig.10 Effluent concentration versus influent concentration in IFAS and Activated sludge reactors
(HRT=9.4-3.8 h, Flow=20.79-50.84lit/d, NH_4-N=12.2-14.1mg/l)

On the other hand, it could be observed that along with the increase of MLSS concentration, also nitrogen removal rate was increasing. Much smaller concentration of MLSS in the tests performed with IFAS system is related to much higher nitrogen removal than that observed in the test with activated sludge only. Previous researches also demonstrate that ther is a significant Correlation between MLSS concentration and average nitrogen removal rate in the tests with biofilm reactors [26],[27].

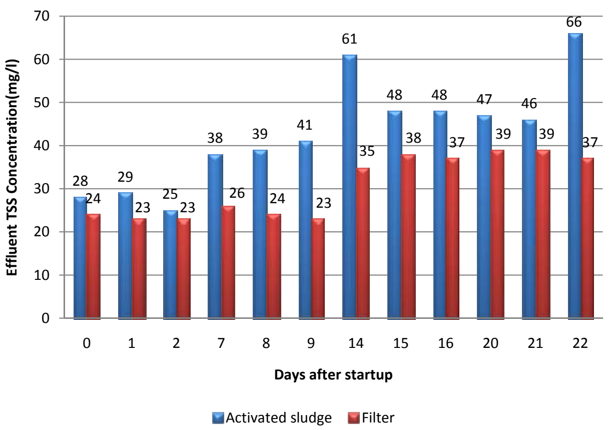


Fig. 11 Effluent TSS concentration in AS and IFAS systems

In both systems, When the HRT of the aerobic reactor was more than 5.6 h; the total ammonium removal efficiency was consistently above 97%.

The effluent TSS concentration ranged from 25 to 66 mg/l (average value: 43 mg/l) in AS system and from 23 to 39 mg/l (average value: 30.6 mg/l) in the IFAS system (Fig.11).

IV. Conclusion

This is the first investigation reporting the utilization of cigarette filter rods (wasted filter in tobacco factories) as a biofilm carrier in an IFAS reactor. High surface area, high porosity and roughness of this carrier can increase the effective MLSS in an aeration basin in aeration basin. This investigation demonstrated that the IFAS system with cigarette filter rods as a biofilm carrier was an effective and feasible process for simultaneous removal of organic matters and nutrients from wastewater.

This process can tolerate strong loading shock that can be related to high concentration of MLSS in aeration basin. On the other hand, the results from this study demonstrated that there was an efficient nitrifying activity in IFAS system. The cooperation of activated sludge and cigarette filter rods was sufficient for organic matter and nutrient removal.

Acknowledgment

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