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OPTIMIZATION OF MUNICIPAL WASTEWATER TREATMENT BY UASB REACTOR AND POLISING POND

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ABSTRACT

Upflow Anaerobic Sludge Blanket Reactor are mostly designed using empirical formulae derived either from past pilot scale studies or from performance of already existing sewage treatment plants elsewhere. Actual performance of the sewage treatment plant can differ from that of design mainly due to differences in sewage characteristics & local conditions. Anaerobic treatment of municipal wastewater has recently gained worldwide attention due to its effectiveness, low cost, and low energy requirements The Upflow Anaerobic Sludge Blanket (UASB) has been considered the most attractive reactor system due to its simplicity and low operation. Thus knowing actual performance and capacity of the sewage treatment plant becomes very important. This work is concerned with the detailed study of Asia's largest sewage treatment plant of 345 MLD capacity (based on Up flow Anaerobic Sludge Blanket reactor), installed at Bharwara, Lucknow, Uttar Pradesh, India. The design analysis of the sewage treatment plant has been carried out to comment on the adequacy of design and capacity

Key words: Anaerobic Process, India, Sewage Treatment, UASB.

INTRODUCTION

In developing countries like India where access to safe drinking water is not guaranteed for a majority of the population, it is of great importance to maintain the quality of surface water sources. Sewage Treatment Plants (STPs) are supposed to make the municipal sewage compatible for disposal into the environment (surface and underground water bodies or land), to minimize the environmental and health impacts of the sewage, and to make the sewage fit for recycling and reuse (agricultural and aqua-cultural uses and municipal and industrial uses). In recent years there has been a growing interest in anaerobic treatment of sewage. Compared to aerobic growth, anaerobic fermentation produces much less biomass from the same amount of chemical oxygen demand removal (Tchobanoglous, *et al.*, 1991). Advances in anaerobic treatment of domestic wastewater offer a promising options including Upflow Anaerobic Sludge Blanket (UASB -Heertjes and Van der Meer, 1978; Lettinga and Vinken, 1980; Lettinga, *et al.*, 1980). Upflow anaerobic sludge blanket (UASB) reactor is a popular anaerobic reactor for both high and low temperature (Dinsdale, *et al.*, 1997).

The UASB reactor is by far the most widely used high rate anaerobic system for anaerobic sewage treatment. The First UASB was developed by Dr. Gatze Lettinga and colleagues in the late 1970 at the Wagenigen University (Netherland) and was installed at Sugar beet refineries in Netherland. Khalil et. al. (2006)

studied the UASB technology for sewage treatment in India with special reference to Yamuna action plan (YAP) found that in 20 sewage treatment plant UASB reactor are performing satisfactorily with some adequate post treatment. It has been estimated that 22,900 million liters per day (MLD) of domestic wastewater is generated from urban center against 13,500 MLD industrial wastewater. The treatment capacity available for domestic wastewater is only for 5,900 MLD against 8,000 MLD of industrial wastewater.

Government of India is assisting the local bodies to establish sewage treatment plant under the Ganga Action Plan and subsequently under the National River Action Plan. UASB technology was adopted for the first time in India at Jajmau, Kanpur for the 5 MLD STP under Ganga Action Plan Phase-I in the year 1988-89. This scenario warrants an urgent need to develop technologies to treat huge volumes of wastewaters in shortest possible period.

Lucknow, one of the major cities in India is the best example for pollution of surface water bodies caused by discharge from sewer outfalls. It is the capital city of Uttar Pradesh and is situated at latitude $26^0 55'$ N and longitude $80^0 59'$ E. Its population of is 3,681,416 as per the census of 2011. It is part of the Indo-Gangetic plains and lies in the catchment of Gomti and Sai rivers. The natural water courses have divided the entire area into three physiographic divisions besides the minors, distributors of Sharda Sahayak and old Sharda Canal System has also sculptured the landscape with some relief-variations.

Gomti is the major natural water sources of this region and it originates from Gomat Taal near Madho Tanda, Pilibhit & meets River Ganges near Saidpur, Gazipur. Cities like Lucknow, Lakhimpur kheri, Sultanpur, Jaunpur are located on its bank. It is heavily polluted by Municipal waste water. The total Sewage produced in Lucknow city is 450 MLD. Only one STP at Daulatganj with capacity of 42 MLD treats the sewage and rest untreated sewage is discharged into River Gomti. To improve the water quality of River Gomti major initiatives have been taken up by government of India. National River Conservation Directorate (NRCD) of Ministry of Environment and Forests (MoEF), Government of India (GOI) has installed and commissioned till date two sewage treatment plants (STPs) under the Gomti River Action Plan (GoAP) for the treatment of the municipal sewage generated by these cities prior to discharge into the Gomti River.

Uttar Pradesh Jal Nigam is responsible for running these STPs and treating the municipal sewage and then discharging into the river Gomti. This work is concerned with the design analysis of the sewage treatment plant treating 345 MLD (based on Up flow Anaerobic Sludge Blanket reactor), installed at Bharwara, Lucknow.

MATERIALS AND METHODS

The methodology applied in the present study is illustrated here. The sewage treatment plant of 345 MLD capacities is installed and commissioned in Bharwara, Lucknow by Uttar Pradesh Jal Nigam under the Gomti Action Plan.

Study Area: 345 MLD Sewage Treatment Plant, Bharwara, Lucknow, India.

The salient features of the sewage treatment plant are as follows:

- Asia’s Largest Sewage Treatment Plant, Bharwara, Lucknow
- 345 MLD capacity
- Capital Cost 400 Crores
- Project Cost 169.7 Crores
- Operation Cost 4.80 Crores per annum
- Based on UASB & Polishing Pond
- Anaerobic and aerobic Treatment Procedure
- Area 120 Hectare
- 106 Drying Bed

The schematic diagram of the STP is given in figure 1.

Figure 1: Schematic process flow diagram of one stream of 345 MLD STP, Bharwara, Lucknow

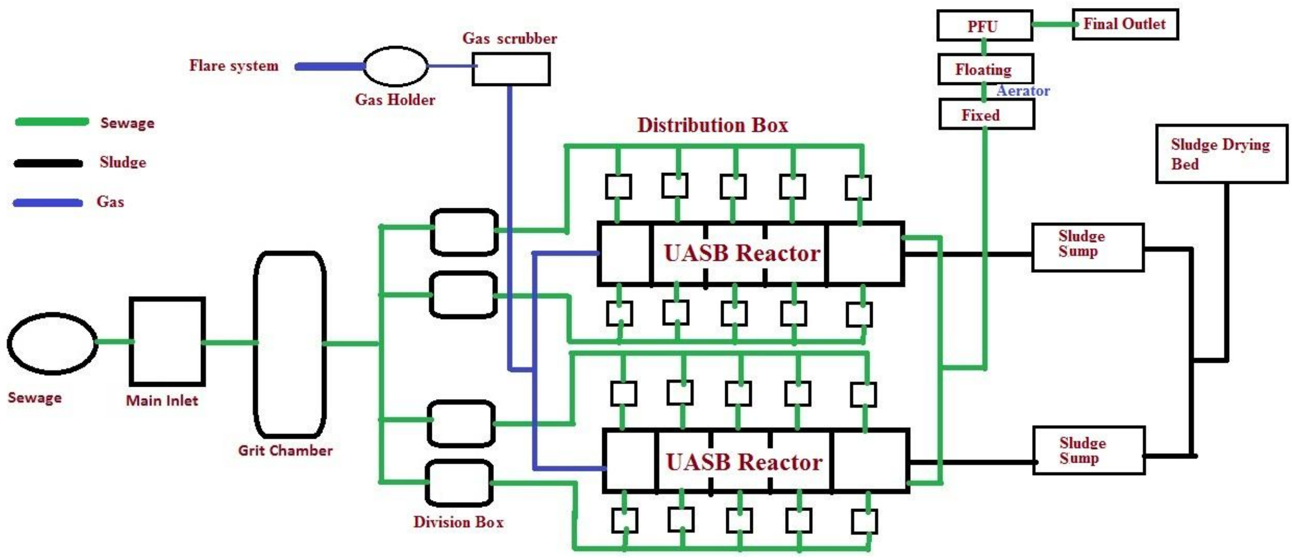

Table 1: Recommended hydraulic detention time for UASB reactor for treating domestic sewage

Sewage temperature (°C)	Hydraulic retention time	
	Daily average	Minimum during (4-6 hours)
16 to 19	>10 to 14	> 7 to 9
20 to 26	> 6 to 9	>4 to 6
> 26	>6	>4

Source: *Chernicharo, 2007 (adapted from Lettinga and Hulshoff Pol, 1991)*

Wastewater conveyed to the STP is collected into a raw sewage sump through mechanically cleaned bar screens, and from there, it is pumped with the help of four 500 HP and four 750 HP raw sewage pumps and passed through different units of the STP.

Design Analysis

The design analysis of the STP was done against commonly used design equations. The design equations and the typical values against which the design analysis was carried out are given below:

Design analysis of upflow anaerobic sludge blanket reactor:

One of the most important aspects of the UASB reactors is its ability to develop and maintain high-activity sludge of excellent settling characteristics. For this purpose, several measures should be taken in relation to the design and operation of the system. According to Metcalf and Eddy, (2003), Chernicharo, (2007) and Marcos Von Sperling, (2007), the standard design considerations the design analysis of UASB is determined by the following steps:

Volumetric hydraulic load and hydraulic detention time:

The volumetric hydraulic load is the amount (volume) of wastewater loaded per unit volume of the reactor per unit time. The hydraulic detention time is reciprocal of the volumetric hydraulic load.

VHL = Q/V - (2.1)

Where;

VHL =Volumetric hydraulic load (m^3/ m^3.d)
Q = Flowrate (m^3/d)
V= Total volume of the reactor (m^3)
t =V/Q
Where *t* is hydraulic detention time (d)

Organic loading rate (Lv):
The Organic loading rate of a reactor calculated as:

Lv =Q×So/V **- (2.2)**

Where:
Lv= volumetric organic loading rate (kgCOD/ m^3.d)
Q= flow rate (m^3/d)
So=influent substrate concentration kgCOD/m/d)
V=total volume of reactor (m^3)

Recommended volumetric organic loading for UASB reactors are shown in Table 3.

Upflow velocity and reactor height:
The upflow velocity of a reactor calculated as:

V=Q/A - (2.3)

Where:
V= upflow velocity (m/hr)
Q = flow (m^3/hr)
A = cross sectional area of the reactor

Recommended upflow velocities for design of UASB reactors treating domestic sewages are shown in table 2

UASB reactor efficiencies:
Efficiencies of the UASB reactors are estimated mainly by means of empirical relations.

$E_{COD}=100 \times (1- 0.68 \times t^{-0.35})$ - (2.4)

Where:
E = efficiency of UASB reactor in term of COD removal (%)
t = hydraulic detention time (hr.)
0.68 = empirical constant
0.35 = empirical constant

$E_{BOD}= 100 \times (1 - 0.70 \times t^{-0.50})$ - (2.5)

Where:
E = efficiency of UASB reactor in term of BOD removal (%)
t = hydraulic detention time (hr.)
0.70 = empirical constant
0.50 = empirical constant

From the efficiency expected for the system, the COD and BOD concentration in the final effluent can be estimated as below:
C = So - E×So/100 - (2.6)

Where:
C =effluents total COD and BOD concentration (mg/L)
So =influent total COD and BOD concentration (mg/L)
E=COD and BOD removal efficiency (%)

Table 2: Recommended upflow velocities for design of UASB reactors treating domestic sewages.

Influent flowrate	Upflow velocity (m/hr)
Average flow	0.5 to 0.7
Maximum flow	<0.9to 1.1
Temporary peak flow	<1.5

Source: *Chernicharo, 2007 (adapted from Lettinga and Hulshoff Pol, 1995)*

Bio gas Production:
Portion of COD converted into methane gas
COD = Q (So –S) –Y ×Q× So - (2.7)

Where:
COD = COD load converted in to methane (Kg $CODCH_4$/d)
Q = average influent flow (m^3/d)
So = influent COD concentration (kg COD/ m^3)
S = effluent COD concentration (kg COD/ m^3)
Y = Coefficient of solid production in the system, in term of COD (0.11 to 0.23 kg COD sludge/kg CODapplied)

Sludge production:
Estimation of the mass of sludge produced in UASB reactors can be done by:
P = Y × COD - (2.8)

Where:
P = production of solids in the system (kg TSS/d)
Y = yield or solids production coefficient (kg TSS/kg COD app)

Table 3: Recommended volumetric organic loading range for UASB reactors.

Category of waste water	COD(mg/l)	OLR, Kg COD/m^3.d	SLR,Kg COD/kg VSS.d	HRT, hours	Liquid upflow velocity, m/h	Expected efficiency
Low Strength	Up to 750	1.0-3.0	0.1-0.3	6-18	0.2-0.7	70-75
Medium Strength	750 -3000	2.0 -5.0	0.2 -0.5	6 -24	0.25 -0.7	80 -90
High Strength	3000 - 10000	5.0 -10.0	0.2 -0.6	6 -24	0.15 -0.7	75 -85
Very high Strength	>10000	5.0-15	0.2 -1.0	>24	- -	75 -80

Source:http://www.waterandwastewater.com/www_services/ask_tom_archive/toc.htm

COD = COD load applied to the system (kg COD/d)

Values of Y reported for the anaerobic treatment of domestic sewage are in order of 0.10 to 0.20 kg TSS/kg COD app. The volumetric sludge production can be estimated by:

$V = P/\gamma \times (C/100)$ -(2.9)

Design Analysis of Polishing Pond:

The design of facultative ponds focuses on BOD removal. Mara (1997) described how the design of facultative ponds is currently based on rational and empirical approaches. The empirical design approach is based on correlating performance data of existing WSP. The rational design approach models the ponds performance by using kinetic theories of biochemical reactions in association with the hydraulic flow regime. Empirical model for design of facultative ponds can be illustrated as follows:

Surface BOD loading ((kg BOD/ha/d):

$A_f = 10 L_i Q/\lambda_s$ **- (2.10)**

Where:
Li = influent BOD (kg BOD5/d)
Q = flow rate (m^3/d)
A_f = Area of facultative pond (m^2)
λ_s =surface BOD loading (kg BOD/ha/d)
Design value of λs:

$\lambda s = 350 \times (1.107 - 0.002 \times T)^{(T-25)}$ **- (2.11)**

Where T is mean temperature in the coldest month (°C).
The organic removal efficiency can be calculated as follows:

$\lambda r = 0.725\ \lambda s + 10.75$ - (2.12)
$\lambda r = 0.79\ \lambda s + 2$ -(2.13)
$\lambda r = 0.83679 \lambda s - 0.486$ -(2.14)
$\lambda r = 0.956\ \lambda s - 1.31$ -(2.15)

Retention time (t) was calculated from:
$t = A_f H/Q$ -(2.16)

Where:
H = pond depth (usually 1.5m)
Q = average flow, (m^3/.d)
A_f =Area of facultative pond (m^2)

Coliform removal:

$N_e/N_o = 1/(1+k_b t)$ -(2.17)

Where:
N_o= coliform conc. in influent (org/100ml)
N_e= coliform conc. in effluent (org/100ml)
t =hydraulic retention time of facultative pond
K_b =coliform die–off coefficient

$\mathbf{K_{bt} = K_{b20}\ \theta^{(t-20)}}$ -(2.18)

Where:
K_{b20}=coliform die-off coefficient at 20°C, taken as 2.6 (Marais, 1974)
T = Temperature (°C)
θ = Temperature coefficient, taken as 1.19 (Marais, 1974)

***Ammonical nitrogen removal*:**
Equation used when temperature is below 20°C.
$C_e = C_o/1+[(A/Q)(0.0038+0.000134.T).6(1.041+0 014 T) (pH -6.6)]$ - (2.19)

When temperature is more than 20°C
$C_e = C_o/1+[5.035\times10^{-3}(A/Q)(1.540\times(pH-6.6)$ **- (2.20)**

Where:
C_e= ammonical nitrogen concentration in pond effluent, (mg N/L)
C_o =ammonical nitrogen concentration in pond influent, (mg N/L)
A = pond surface area, (m^2)
T = temperature, (°C)
pH = 7.3exp (0.0005A) [where A = influent alkalinity (mg CaCO3/L)

Total nitrogen removal:
Equation used in case of facultative and maturation ponds (Reed, 1995):
$C_e = C_o \exp \{-[0.0064(1.039)^{T-20}] [t+60.6 (pH-6.6)]\}$ -(2.21)

Where:
C_e = total nitrogen concentration in the pond effluent, (mg N/L)
Co=total nitrogen concentration in the pond influent, (mg N/L)
T = temperature, (°C; range: 1-28°C)
t = retention time, (days; range: 5-231days)
pH = 7.3exp (0.0005A) [where A = influent alkalinity (mg $CaCO_3$/L).

RESULTS AND DISCUSSIONS

Design Analysis Outcome

Average ambient air temperature for the coldest winter month of the year for Bharwara, Lucknow is 17°C. Design capacity of the STP is 345 MLD. Both ambient air temperature and wastewater temperature, and flow rates of the sewage were recorded at the time of sampling. Grab sampling was practiced and the samples were mostly collected between 10:30 AM and 11:20 AM from March till June 2013.

UASB reactor:

Volume and area of the UASB reactor are 123,648 m^3 and its designed is HRT 8.6 hrs. Volume of the digestion zone is 87879.6 m^3 and design HRT of the digestion zone is 6.1 hours. Design volumetric loading rate according to the equation 2.1 was calculated as 3.9 m^3/ m^3.d. Typical organic loading rate (kg COD/ m^3.day) for Low strength of waste water is 1.96 kg/ m^3.d (table 3). Upflow velocity in the UASB reactor for the design flow is 0.54 m/hour. Methane production per kg of COD removed, according to the equation 2.7 is 0.052 m^3 and biogas production is 0.080 m^3 (assuming 65% methane in the biogas). Treatment efficiencies of the UASB reactor, according to the empirical equations 2.4 and 2.5, expected are 66% for COD and 74% for BOD. Nutrient removals in the UASB are usually insignificant and can be equated to the nutrients assimilated by the microbial biomass synthesized. For nutrient assimilation removal calculations, net biomass yield coefficient was taken as 0.1 of the COD removed and the microbial biomass was assumed to have 12.3% nitrogen and 2.3% phosphorus. For pathogen removal calculations the equation used for anaerobic ponds of the waste stabilization pond system was used.

The design analysis calculations which included volumetric loading are presented in the table 5 and 6. Volumetric loading rates were highly variable and ranged between 3.45 and 4.09 m^3/m^3.day and as a consequence the upflow velocity was also highly varying from 0.47 to 0.55 m/hour. This must be resulting in operational instability and reduced efficiency of working. Despite this, the treatment efficiencies were observed to be higher than the expected. Observed efficiencies were 59.3-67.7% for COD and 66.6-77.1% for BOD while expected efficiencies calculated according to the equations 3.4 to3.6 are 63.35-65.75% and 71.88 - 74.48% respectively. This indicates that the equations used were underestimating the efficiency, and this may be because of the differences in the characteristics of the sewage being treated. The equations used may require calibration. The STP was frequently overloading instead of 345 MLD the STP was loaded with as high as 360 MLD

Table 4: Design analysis calculations for UASB reactor

Months	Volumetric hydraulic loading rate ($m^3/m^3.d$)	Volumetric organic loading rate ($kgCOD/m^3.d$)	Upflow velocity (m/hr)	HRT (hr)	Estimated CH_4 production rate (m3)
March	3.34	1.03	0.45	7.1	592
April	4.09	1.21	0.55	5.85	567
May	3.52	0.87	0.48	6.8	390
June	3.45	0.81	0.47	6.9	349.7

Table 5: Efficiencies calculation for the UASB reactor

Month	COD removal efficiency (%)		BOD removal efficiency (%)	
	Expected	Observed	Expected	Observed
March	65.75	67.7	74.48	74.1
April	63.35	59.4	71.88	71.5
May	65.23	61.2	73.92	77.1
June	65.46	59.3	74.16	66.6

Table 6: Design calculation for final polishing pond

Parameter		March	April	May	June
HRT (days)		1.17	0.96	1.11	1.13
Surface loading rate (Kg/ha/d)	Design value at 17°C	200	200	200	200
	Maximum allowed sewage	330.50	423.80	423.80	440.35
	Temperature °C	24	29	29	30
Organic matter removal efficiency (%)	Actual value	47.8	51.9	62.5	46.6
	Efficiency expected	95.20	95.29	95.29	95.30
Pathogen removal (%)	Actual value	67.9	40.5	95.6	47.6
	Efficiency expected	87.2	74.7	98.15	78.4
Nutrient removal (%)	Actual value	-58	13	-25	8
	Efficiency expected	32	44	35	38

sewage. Biogas production rates were not being monitored. However expected biogas production rates have been estimated on the basis of the amount of COD actually being converted into methane or biogas. Amount of COD removed in the UASB minus the amount used up in the synthesis of active anaerobic microbial biomass was taken as the COD converted into methane. The amount of COD utilized in the biomass synthesis was taken 14.2%. Further, methane content of the biogas biogas generated per unit COD removal also increases. And the organic loading rates were also highly variable from 0.81 to 1.21 kg/ m^3.day.

Design of Final Polishing Pond:

Area of the polishing pond is 77000 m^2 and its designed HRT is 1days. Designed surface loading rate according to the equation 2.18 at 17°C was calculated as 200 kg/ha.d. Designed organic matter removal efficiency for winter coldest month, according to the equation 2.11 is expected as 94%. Expected designed pathogen removal efficiency calculated according to the equation 2.17 is 65%. Expected designed total nitrogen removal efficiency calculated from equation 2.21 is 25%.

Calculations related to the design analysis of the final polishing pond are given in table 7. In the design analysis, though the design equations are actually based on average ambient air temperature of the coldest month of the year, actual temperature of the wastewater was used for estimating maximum surface loadings allowed, and expected efficiency of organic matter removal and pathogen removal. As a consequence error in calculations was introduced. Further, the fact that the winter sewage temperature is usually higher than that of the ambient air, and that in summers the water temperature is lower than that of the ambient air was not taken into account in these calculations. Actual surface loading rate of the organic matter (BOD) was higher than the design surface loading rate during the four months of the study. The reason for this could be the variation in the hydraulic loading rate. Actual removal efficiencies were lower than expected removals (around 52% removal was observed against expected 95%). This is due to algal cell concentration in treated effluent is 46 mg/l which is around the prescribed limit 50 mg/l. Thus, proper attention should be given towards the growth of algal cell

CONCLUSION

In the present work, the study has focused on the design analysis indicates that the design of the sewage treatment plant is adequate and appropriate. According to the standard design considerations the design criteria has been found complying. The hydraulic loading rates have been found frequently going beyond the designed capacity. This indicates that the design is well suited and efficient. But proper attention should be given towards reduction of algal cell. Algaecide could be used taking into consideration that it should not affect the water quality of the river when treated effluent is discharge into it.

REFERENCES

1. **Chernicharo,** (2007) "Anaerobic Reactors", Biological wastewater treatment series, Vol. IV, IWA publishing, London, New York.
2. **Dinsdale, R. M., F. R. Hawkes, D. L. Hawkes,** (1997) Comparison of mesophilic and themophilic upflow anaerobic sludge blanket reactors treating instant coffee production wastewater. Wat. Res., 31: 163-169.
3. **Khalil.N, Mittal A.K., Raghav A.K, Sinha Rajeev** (2006)," UASB technology for sewage treatment in india: 20 year experience". Environmental Engineering and Management Journal, Vol.5, No.5, 1059-1069
4. **Letting G, van Velsen, AFM, Hobma SW, de Zeeuw W and Klapwijk A**, (1980),"Use of the upflow sludge blanket (USB) reactor concept for biological wastewatertreatment especially for anaerobic treatment, Biotechnol. Bioeng, 22:699-734.
5. **Mara, D.D.** (1997), "Design Manual for Waste Stabilisation Ponds in India", Lagoon Technology International Leeds, England, 18-42,65-66
6. **Marcos Von Sperling**, (2007), "Waste Stabilisation Ponds" Biological Wastewater Treatment Series, volume. 3, IWA Publishing, London, New York
7. **Metcalf and Eddy**, (2003), "Wastewater engineering treatment and reuse", Fourth edition, Tata McGraw Hill. Publishing.
8. **Tchobanoglous, G., Burton, F. L.,** (1991), "Wastewater engineering: Treatment, disposal and reuse", 3rd. Ed., New York, McGraw Hill, 394-426.
9. www.anaerobic.com
10. www.uasb.org
11. www.wastewaterengineering.com
12. www.upjn.org
13. www.waterandwastewater.com

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