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ENERGY-EFFICIENT WASTEWATER TREATMENT: DESIGN AND EVALUATION OF UASBR-ASP SYSTEM FOR BIOGAS GENERATION AND CO_2 MITIGATION

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Abstract

This paper is about the process description and design both for Up flow Anaerobic Sludge Blanket Reactor (UASBR) followed by Activated Sludge Process (ASP) for the treatment of wastewater of potato processing industry. The estimation of biogas generation reveals CO_2 emission reduction under scope 1 by replacing piped natural gas (PNG) uses in boiler and electricity reduction under scope 2 by reducing the organic load to ASP after UASBR, resulting in lower oxygen demand which was expected to be supplied by surface aerators. The design detail states that removing 9000 kg COD/day in UASBR with 90% efficiency will reduce the load on ASP resulting reduction of approximately theoretical oxygen demand of 9000 kg of oxygen excluding quantity of oxygen requirement for amonical nitrogen. The estimation of biogas will help further to estimate the CO_2 emission reduction at plant scale. Hence wastewater treatment through UASBR followed by small polishing unit ASP will help in reducing CO_2 emissions under scope 1 and scope 2 both with concept of waste to energy, waste to economy for sustainable development.

Keywords; Design of UASBR, ASP, Biogas, Scope1 and scope 2 CO_2 emission reduction

Introduction

Wastewater in the food industry is a particular problem, due to the presence of significant amounts of organic components **[1]**. The use of resources like water, electricity, compressed air, and boiler steam having significant environmental concerns with the impact of wastewater generation, CO_2 emissions and treatment cost **[2]**. Food processing industries produce substantial quantities of wastewater which have high intensity of organic pollutants in terms of BOD and COD **[3]**. Anaerobic wastewater treatment technology is a biological process that takes place in UASBR to produce biogas from organic pollutants present in wastewater in terms of BOD and COD using a series of anaerobic microbial reactions. There are many operational factors in UASBR which affect the performance of methanogens, these are the pH, total volatile fatty acids (TVFAs) produce during acidogenesis processes, alkalinity, temperature, and hydraulic retention time (HRT) **[4]**. UASBR is a favorable alternative of the fundamental flaws of the conventional anaerobic and aerobic wastewater treatment system. UASBR is more popular and has high acceptance because of minimum sludge production comparative to another wastewater treatment system, energy recovery, low HRT and high solids retention time **[5]**. Anaerobic wastewater treatment systems UASBR is encouraged with several advantages as compared to the biological aerobic wastewater treatment which include plain design, simple construction, operation and maintenance, small land, low operating cost, high organic load removal efficiency, survival with fluctuations in temperature, pH and wastewater characteristics, fast biomass recovery after shutdown, and energy production in the form of biogas or hydrogen. Hence many researchers have recommended UASB technology **[6,7.8]**. In this paper process brief description of UASBR include the hydrolysis, acidogenesis, acetogenesis and methanogenesis and ASP include the Biosorption, bio-oxidation, bio flocculation and nitrification. The UASBR itself a not capable to meet the industrial wastewater treated parameters prescribed by regulatory body hence polishing unit like Activated sludge treatment process is required after UASBR. Here the process description and design of UASBR and ASP both are covered as complete treatment system along with CO_2 emission reduction under scope 1 by utilizing the biogas in boiler instead of PNG and CO_2 emission reduction under scope 2 by mitigating electricity requirement for surface aerators to treat the organic load in big capacity of ASP which was minimized due to UASBR.

Process operation Description of UASBR: There are 4 stages in anaerobic wastewater treatment in a UASBR.

Hydrolysis: Hydrolysis is the first step of process where Hydrolytic bacteria (e.g. clostridium) excrete enzymes which transform complex, heavy, un-dissolved matters like proteins, carbohydrates, fats into monomers, lighter, simpler compounds like amino acids, sugars and alcohols **[9]**. The biochemistry of hydrolysis is as per given reaction.

$$\text{Biomass} + H2O \rightarrow \text{monomers} + H2$$

The source of biomass are cellulose, starch, sugars, fats, oils and Products are mono-sugars glucose, xylose, etc., fatty acids **[10]**.

Acidogenesis: Acidogenesis is the second step of the anaerobic treatment where dissolved monomers like short chain acids convert into simple forms like volatile fatty acids, lactic acid, formic acid, butyric acid, propionic acid, carbon dioxide, hydrogen sulfide, hydrogen. Ammonia and new biomass. In the process of acidogenesis, monomers are transformed into small organic compounds, ketones like glycerol, acetone, and alcohols like ethanol, methanol **[11]**.

$C_6H_{12}O_6 + 2H_2 \rightarrow 2CH_3CH_2COOH + 2H_2O$

$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2$

Acetogenesis: Acetogenesis is the third step of the process where digestion products are converted into acetate, H_2, CO_2 and new cell-matter. The acetogenic bacteria processes propionate and other organic acids, alcohols and some perfumed compounds like benzoate into acetate and Corbon dioxide **[12]**. $CH_3CH_2COO^- \rightarrow CH_3COO^- + CO_2 + H_2$

Acetate, which is the substrate for methane generation. The bacteria that use H_2 and CO_2 include methanogenic and acetogenic bacteria **[12]**.

$CO_2 + H_2 \rightarrow CH_3COOH + 2H_2O$

Many bacteria promote to acetogenesis process and these bacteria are Syntrophobacter wolinii, propionate decomposer Syntrophomonos wolfei, butyrate decomposer Clostridium species **[11]**.

Methanogenesis: Methanogenesis is the fourth and last step of the process where H^+, carbonate, format or methanol are transformed into CH_4, CO_2 and new cell-matter. Two classes of methanogens that metabolize acetate to methane are: Methanosaeta (old name Methanothrix): Rod shape, low Ks, high affinity, Methanosarcina (also known as M. mazei): Spherical shape, high Ks, low affinity. Different reactions involved in the degradation of hexose to CH_4. The methanogenic bacteria species Methanothrix do not use H_2 in combination with carbon dioxide to produce methane and known as non-hydrogen oxidizing acetotrophs (NHOA) and The methanogenic bacteria species Methanosarcina are able to utilize hydrogen (H_2) and carbon di oxide (CO_2) both as acetate, methylamines and methanol as substrate for methane production and growth and known as hydrogen oxidizing acetotrophs (HOA) **[13]**.

$C_6H_{12}O_6 \rightarrow 2CH_3CHOHCOO^- + 2H^+$

$CH_3CHOHCOOH+2H2O \rightarrow 2CH_3COOH + 2CO2 + 4H_2$

$4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$

$2CH_3COOH+ H^+ \rightarrow 2CH_4 + 2CO_2$

$4H_2 + 2CO_2 \rightarrow CH_3COO^- + H^+ + 2H_2O$

Sum Reaction $C_6H_{12}O_6 \rightarrow 3CH_4 + 3CO_2$

Stoichiometric calculation of anaerobic degradation of 1 kg COD at STP:

Step 1: Calculation of COD equivalent of CH_4:

CH_4 + $2O_2$ ------------------> $CO_2 + 2H2O$

16 g 64g

=> 16 g CH_4 ~ 64 g O_2 (COD)

⇒ 1 g CH_4 ~ 64/16 = 4 g COD ------------ (1)

Step 2: Conversion of CH_4 mass to equivalent volume

Based on gas law, 1 mole of any gas at STP (Standard Temperature and Pressure) occupies a volume of 22.4 L.

=> 1 Mole CH_4 ~ 22.4 L CH_4

=> 16 g CH_4 ~ 22.4 L CH_4

=> 1 g CH_4 ~ 22.4/16 = 1.4 L CH_4 ---------- (2)

Step 3: CH_4 generation rate per unit of COD removed

From eq. (1) and eq. (2), we have,

=> 1 g CH_4 ~ 4 g COD ~ 1.4 L CH_4

=> 4 g COD ~ 1.4 L CH_4

=> 1 g COD ~ 1.4/4 = 0.35 L CH_4

or 1 Kg COD ~ 0.35 m^3 CH_4 ----------- (3)

complete anaerobic degradation of 1 Kg COD produces 0.35 m^3 CH_4 at STP **[12].**

Process operation of Activated Sludge Process: Activated sludge process is a process for treating sewage and wastewater commonly referred as effluent using bacteria (to degrade the biodegradable organics) and air (Oxygen for respiration). Activated sludge refers to a mixture of microorganisms and suspended solids. Bacterial culture is cultivated in the treatment process to break down organic matter into carbon dioxide, water, and other inorganic compounds **[14]**. The organisms use waste as food and an energy source for survival and for reproduction. The most effective and quickest decomposition of waste is achieved by organisms that thrive in an oxygen-rich environment. These organisms are called aerobes (or aerobic organisms) and they require the presence of molecular oxygen to survive. Another class of organisms found in activated sludge is facultative organisms, which can utilize either molecular oxygen or oxygen bound in inorganic compounds, such as nitrate, NO_3^-. Using the term COHNS which represents the elements carbon, oxygen, hydrogen, nitrogen and sulphur to represent organic waste. The organic matter and amonical nitrogen removal in ASP process are Biosorption, Biooxidation, Bioflocculation, Nitrification and denitrification. The term $C_5H_7NO_2$ represents the cell tissue, the three processes are defined by the following generalized chemical reactions.

Bio-Oxidation:

$COHNS + O_2 + Nutrients \xrightarrow{Bacteria} CO_2 + NH_3 + C_5H_7O_2N$ + Other end products +energy
(organic matter present in wastewater)

Synthesis:

$COHNS + O_2 + Bacteria + Energy \longrightarrow C_5H_7O_2N$ (New cell tissue)

Endogenous Respiration:

$C_5H_7O_2N + 5O_2 = 5\ CO_2 + 2\ H_2O + NH_3$

113 g VSS $\rightarrow$ 32* 5gO $\rightarrow$ 160 g COD i.e., 1 mg VSS $\rightarrow$ 160/113 = 1.42 mg COD

COD/VSS (fcv) = 1.42 mg COD/mg VSS

Nitrification Process: Nitrification is a two-step process takes place in activated sludge treatment process and requires higher oxygen concentration. In the first step the ammonical nitrogen convert into nitrite nitrogen and in second step nitrite to nitrate nitrogen.

$\mathbf{NH_4^+ + 3/2\ O_2 \xrightarrow{Nitrosomonas} NO_2^- + H_2O + 2H^+}$ + new biomass

$\mathbf{NO_2^- + 1/2\ O2 \xrightarrow{Nitrobactor} NO_3^- + energy}$

The conversion of ammonical nitrogen to nitrate (as N) requires 4.57 mg O/mg NH_3-N. Nitrifying bacteria tolerate specific conditions to really thrive—such as a pH range of 6.5–8.0. They also require 3.22kg of alkalinity for every 0.45kg of ammonia that is oxidized, and they prefer temperatures at 77°F with DO (dissolved oxygen) above 2mg/L. Retention times need to be longer than five hours, and the F:M (food to microorganism) ratios must ideally be less than 0.25.

Denitrification: This process takes place when oxygen is <0.1mg/l and nitrate nitrogen converts into nitrogen gas by denitrifying bacteria.

$\mathbf{6\ NO_3^- + 5CH_3OH \longrightarrow 3N_2 + 5CO_2 + 7\ H_2O + 6OH}$

Materials and Methods: The average wastewater characteristic of one year taken of potato processing industry. Process descriptions referred to from literature review cited here, handbook of water wastewater engineering and industrial visits, and interviews with professionals involved in erection and commissioning of UASBR and ASP. The standard values required for design, taken from, handbook of wastewater treatment and reuse. The CO2 emission factors taken from relevant source as cited.

Design of Up flow Anaerobic Sludge Blanket Reactor (UASBR):

In general, there are two ways to design a UASB reactor

1. If input COD: 5,000 - 15,000 mg/l or more, the design method should be used based on Organic Loading rate, (OLR)
2. If input COD < 5000 mg/l, the design method should be calculated based on velocity.

Key Components of UASBR: Reactor tank: A cylindrical or rectangular tank made of concrete, steel, or fiberglass. **Inlet:** A pipe or channel for feeding wastewater or organic matter into the reactor. **Sludge blanket:** A layer of anaerobic sludge that settles at the bottom of the reactor. **Gas collection system:** A network of pipes and valves for collecting and processing biogas. **Effluent outlet:** A pipe or channel for discharging treated wastewater and **Internal three-phase GSL device, [15]**. **Factors affecting biogas production:** Biogas' potential of feedstock, Design of digester, Inoculums, Nature of substrate, pH, Temperature, Loading rate, Hydraulic retention time (HRT), C : N ratio, Volatile fatty acids (VFA), etc. influence the biogas production **[16]**.

Table 1. Design consideration for UASBR, assuming no primary treatment.

Flow 1500 m^3/day, COD 7500 mg/l, BOD 4500 mg/l, TSS 3000 m^3/day, pH 5.0, Organic loading rate (OLR) 6.0 Kg COD/ m^3.day (Taken from standard), recirculation rate 50%

A) Required Volume of UASBR = Organic load (kg COD/day) / Design organic loading rate

Organic load in kg COD/day = (Flow m^3/day * COD mg/l) / 1000 = (1500*7500)/1000 = 11250 kg COD/day, Design organic loading rate considered = 6 Kg COD/ m^3.day, Required Volume of UASBR = 11250/6 = 1875 m^3

B) Hydraulic retention Time (HRT in Hours) = Volume m^3 / flow m^3/hr = 1875/62.5 = 30 hrs Area required = Volume of UASBR (m^3) / Liquid depth (assumed 6 meters) = 1875 m^3/6m = 312.5m^2 and considered free board 0.25 meters above liquid level hence total height =6.25 m

C) Diameter (D) of circular UASBR = $\sqrt{(4\times Area/\pi)} = \sqrt{(4\times 312.5/3.141)}$ = 19.9 meters.

D) Up flow Velocity = (flow in m3/h) / π*(D^2 / 4) = 62.5 / 3.14 * (19.9^2 / 4) = 0.20 m/h, considering the 50% recirculation the up flow velocity shall be = 0.30 m/h

E) Area required for settling = (62.5 m^3/h) / settling velocity (assumed 0.70 m3/h) = 89.29 m^2

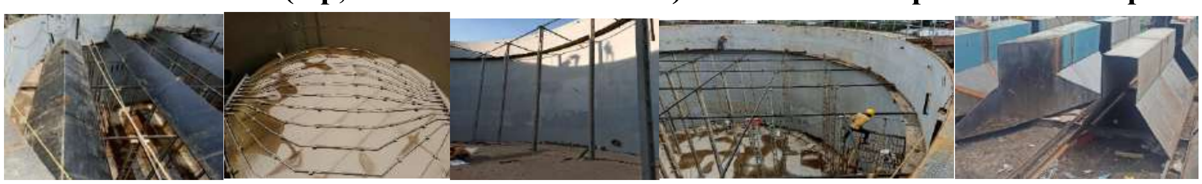
F) Solid loading Rate (SLR) = (feed flow * COD) / (Volume of reactor * VSS in reactor),

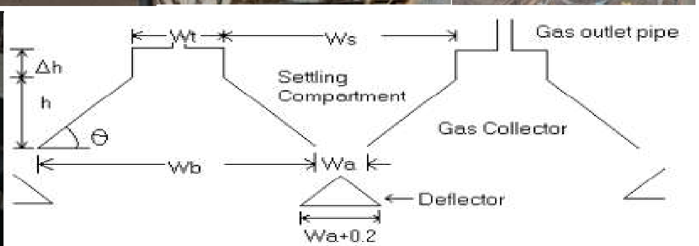
Volume occupied by sludge bed should be about 50% of reactor volume, Assumed VSS in reactor sludge = 25 g/l =2.5kg/m3 then SLR = 11250/ (1875*0.5*2.5) = 0.48 kg COD/kg VSS.day

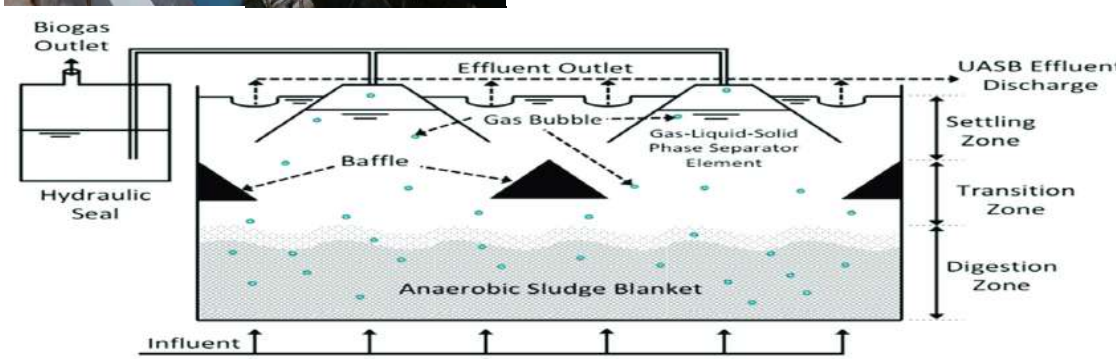
G) Sludge generation from UASBR = The BOD in feed wastewater is 4500mg/l and after 90% removal the outlet BOD will be 450 mg/l. The kg BOD removed = 1500 m^3.day * (4500-450) / 1000 = 6075 kg/day. The percentage sludge generation in UASBR = 10 so sludge generation per day = 607.5 kg/day, The sludge consistency 2% so volume of sludge m^3/day = 607.5 / (10*2) = 30.4

H) Internal three-phase GSL device: Takes place at the topmost of the UASBR, the Gas, solid, liquid separation (GSL) system establishes critical part of a UASBR with given subsequent roles: Collection, separation and discharge of produced biogas in and reduce the feed wastewater turbulence, resultant of the biogas production, in the settling section **[10]**. The GLSS reduces and prevents the passing-over of anaerobic digested sludge granules and particles from bottom of the UASBR**.** The GLS separator must provide the sufficient gas-liquid boundary inside the gas dome, allowing the easy release of the gas entrapped in the sludge and enough settling area, to guarantee the proper surface overflow rate - Enough dome area to avoid liquid turbulence, which can lead to a bad solids separation - Proper sludge retention, allowing the solids to return to the bottom of the reactor **[13, 17]**. **Design of GLS separator Height of dome** = 0.25 x ht. of reactor = 0.25 x 6 = 1.5 m. Provide 1.5 m height of the dome and 0.3 m free board above the water surface for gas collection. Provide max liquid velocity at aperture i.e. inlet of the settler = 3 m/h, Area of opening at inlet of settler = 1500 / (3*24) = 20.83 m2, Total width of opening = Area of opening / width of reactor i.e. $r^2 = V/(\pi h)$ = 1875 / (3.14*6) r =9.98 m so width = 19.96 m, Now Total width of opening = 20.83 / 19.96 =1.04 m, Provide width of each gap = 0.2 m then number of gaps = 1.04/0.2 = 5.2, provide 5 number of domes which will make 4 openings in the middle of the domes and two opening along the side wall.

Figures: UASBR internal structure: Feed distribution network in bottom, Structure to hold GLSS (top, middle and lower dome) and GLSS after placement on top of reactor







Schematic diagram of UASBR system [18].

Calculation of Biogas Production: Expected COD removal in UASBR = 80%, The COD removal on 80% efficiency = 7500 mg/l*0.80 = 6000 mg/l i.e. (6000mg/l * 1500 m^3/day)/1000 = 9000 kg COD So kg COD to be removed / day = 9000. The total COD removed in the reactor = 9000 kg/day , But not all the organic matter present in the influent is carbonaceous. The influent also consists of sulphates which are reduced to sulphides and consume about 0.67 kg of COD per kg of sulphate $SO_4^{2-} \rightarrow S^{2-}$. Assuming sulphate removal of 80%, the total sulphate reduction. The sulphate in wastewater is 50mg/l then total sulphate load = (0.8*50*1500) / 1000 = 60 kg/day So COD consumed in sulphate reduction = 60*0.67 = 40.2 kg/day, Hence COD available for methane production = 9000–60 = 8940 kg/day. As calculated theoretically above, the complete anaerobic degradation of 1 Kg COD produces 0.35 m^3 CH_4 at STP so total methane gas production will be (0.35*8940) = 3129 m3, some portion of biogas will remain in soluble form in the reactor effluent due to high partial pressure of biogas inside the reactor. Typically, about 16 mg/L of methane will be lost along with the effluent **[13]**. So, methane can be collected = 3129-(1500*16/1000) = 3129-5.25 =3123.74 m^3 Assuming 65% is methane content in biogas then biogas production will be 3123.74*0.65 = 4805.75 m^3/day or 200.23 m^3/h of biogas.

I) Gas Holder design: The standard holding time is 15 minutes = 0.25 hr. The capacity of biogas holder = 200.23 m3/hr * 0.25 hr = 50.05 m^3/hr. Assumed Gas space height = 3 meters, Area = volume/depth =50.05/3 = 16.68 m2 Hence Dia of Gas holder = √(4×Area/π) =4.6 meters

J) Energy from Biogas and CO_2 emission reduction by replacement or reduction of PNG and Electricity : The biogas has composition of Methane (CH_4) 55-60%, Carbon dioxide (CO_2) 35-40%, Trace elements of Ammonia Hydrogen Sulphide (H_2S) and moisture with calorific value of 4800 to 6900 kcal/m3 and equivalent to 0.42 kg of LPG. The calorific value of biogas depend on type of substrate and methane % in biogas **[19].** 1m³ of biogas can be converted only to around 1.7 kWh **[20].** One m^3 of biogas contains an equivalent of 6 kWh of thermal energy. However, when converting biogas into electrical power, about 2 kWh of electricity is generated, the rest is converted into heat energy **[19].** 1 m3 biogas will yield 2.14 kWh (electricity) and 1 m 3 methane will yield 10kwh **[21].** The CO2 emission factor from grid electricity reported by The Energy and Resources institute (TERI) is 0.71kg CO2 / kwh. The PNG has CO2 emissions of 2.75kgCO2/kg of fuel **[22].** Natural gas has emission of 53.06kgCO2/mmbtu **[23].** Total biogas production from UASBR will be 4805 m3/day with calorific value in range of 4800 to 6900 kcal/m3. The calorific value of biogas is considered 6000kCal/m3. The gross calorific value (GCV) of PNG is 10000kCal/SCM and net calorific value (NCV) is 90% of GCV then value will be 9000 kCal/SCM. Now 1 SCM of PNG is equivalent to 1.5m3 of biogas so 4805 m3 of biogas will replace to 3203 scm of PNG. The PNG in SCM will be converted into mmbtu by dividing it with the factor 30.17959 hence 3203 scm of PNG is equivalent to 3203/30.17959=106.2. As stated above, the natural gas has emission of 53.06kg CO2/mmbtu so 106.2 mmbtu will have emission of = 106.2*53.06 =5631.91 kg CO2emission. So, 4805 m3/day of biogas will replace 106.2mmbtu of PNG equivalent to 5631.91kg CO2 emissions per day. The 9000 kg/day of organic load in terms of COD to be removed in UASBR as per design, Now if this organic load supposed to be treat in

ASP then theoretically oxygen demand will be 9000kg which is minimum and excluding oxygen demand for amonical nirogen and this will require electricity for surface aerators which shall be prevented proactively by installation of UASBR.

Design of Activated Sludge Process (ASP) on outlet (Overflow) of UASBR: (Metcalf & Eddy).

Design parameters: Flow 1500 m^3/day, BOD_5 450mg/l, COD 1500 mg/l, TSS 200mg/l, VSS 170 mg/l, Soluble BOD_5 = 350 mg/l, amonical nitrogen 50 mg/l, SRT 5days, MLSS 2500mg/l.

Table 1 : Actvated Sludge operational parameters – Typical Ranges

Activated Sludge Process Name	SRT (Days)	MLSS g/m3	F/M (kgBOD/Day)/kgMLVSS	Q_r/Q_0 %
Complete Mix	3 - 15	1500 - 4000	0.2 – 0.6	25 - 100
Extended Aeration	20 – 40	2000 - 5000	0.04 – 1.0	50 - 150

Table 2: Standard values adopted from Metcalf & Eddy: Wastewater Engineering

Coefficient	Unit	Range	Typical Value	θ
Activated Sludge Kinetic Coefficient for Heterotrophic bacteria at 20°C				
Coefficient	**Unit**	**Range**	**Typical Value**	**θ**
Maximum specific growth rate (µm)	gvss/gvss.day	3-13.2	6	1.07
half velocity constant (Ks)	gbCOD/M3	5 - 40	20	1.0
Biomass Yield, Mass of cell formed/Mass of substrate consumed (Y)	gvss/gbCOD	0.3 – 0.5	0.40	
Endogenous Decay Coefficient (Kd)	gvss/gvss.day	0.06 – 0.2	0.12	1.04
Fraction of cell mass remaining as cell Debris (fd)	unitless	0.08 – 0.2	0.15	
Activated Sludge Nitrification Kinetic Coefficient for Heterotrophic bacteria at 20°C				
Coefficient	**Unit**	**Range**	**Typical Value**	**θ**
Maximum specific growth rate (µmn)	gvss/gvss.day	0.20 – 0.90	0.75	1.07
half velocity constant (Kn)	gNH4-N/M3	0.5 - 1	0.74	1.053
Biomass Yield, Mass of cell fomed/Mass of substrate consumed (Yn)	gvss/gbCOD	0.10 – 0.15	0.12	
Endogenous Decay Coefficient (Kdn)	gvss/gvss.day	0.05 – 0.15	0.08	1.04
Half Saturation Coefficient for DO (K0)	unitless	0.08 – 0.2	0.15	

- Calculated the biodegradable COD (bCOD)

$$\boldsymbol{bCOD} = \sim\mathbf{1.6}(BOD) = 1.6(450 \text{ mg/l}) = 720\text{mg/l}$$

- Calculated the nonbiodegradable particulate COD (nbpCOD)

$$\text{nbCOD} = \text{COD} - \text{bCOD} = (1500 - 720)\text{mg/l} = \mathbf{780\ mg/l}$$

- Find effluent sCODe. Soluble COD in UASBR outlet =800mg/l, Soluble BOD = 350mg/l, TSS =200 mg/l, VSS =170 mg/l

$$sCODe = \text{sCOD} - 1.6\text{sBOD} = 800 - 1.6\,(350) = 240\text{mg/l}$$

Amonical nitrogen in UASBR overflow (outlet) considered = 50mg/l

$$\text{BpCOD/Pcod} = ((\text{Bcod/BOD})(\text{BOD} - \text{Sbod}))/(\text{COD} - \text{Scod}) = (720 / 450)(450 - 350)/ (1500 - 800)$$

$$= (1.6 * 100)/700 = 0.23$$

- $\text{nbVSS} = (1 - \text{bpCOD / pCOD})\text{VSS} = (1 - 0.23)(170\text{g VSS/m3}) = 130.9\text{mg/l}$

- Calculated the biomass production from heterotrophic biomass and cell debris

$$\mathrm{Px,vss} = (\ \mathrm{QY(S0 - S)(1kg/1000g))/(\,(1 + (kd)SRT)\ ) + ((\,fd\,)(\,kd\,)YQ(So - S)SRT(1kg/1000g)\ \ )/(\,(1 + (kd)SRT)\ ) + \ QYn(NOx)(1kg/1000g)/(\,(1 + (kdn)SRT)\ ) + Q\,(nbVSS)}$$

$$Q = \mathrm{Q} = 1500\ \mathrm{m3/day, Y} = 0.40\ \mathrm{gVSS/gbCOD, (std\ value\ from\ table\ 2), So} = 720\mathrm{mg/l\ \ i.e.\,bCOD}$$

- Calculated the Value of S (substrate utilized), Now,

$$S = Ks\ ((1 + (kd)SRT))/\ SRT\ ((\mathrm{\mu m} - \ \mathrm{kd}) \ - 1$$

Find out the value for above written equation, Ks = 20 g/m3 (Typical value taken from table)
Maximum Specific growth rate

$$\mu m,t = \mu m\ \theta^{\ (T-20)} = (6.0g/g.day)\ (1.07)^{27-20} = (6.0)\ (1.60) = \mathbf{9.6\ g/g.day}$$

(Typical values taken from table)
The endogenous decay k_d and θ value taken from table

$$k_{d,t} = k_d\ \theta^{\ (T-20)} = \ (0.12g/g.day)\ (1.04)^{27-20}$$

$= (0.12)\ (1.32) = \mathbf{0.16}$ g/g.day, Yn= $0.12(1.04)^{27-20} = \mathbf{0.16}$, kdn $=0.08(1.053)^{27-20} = \mathbf{0.11}$

SRT considered 5 days (Std value of SRT taken from table)

$$Now\ S = \mathrm{Ks}\ \ (1 + (\mathrm{kd})\mathrm{SRT})/(\mathrm{SRT}\ (\mathrm{\mu m} - \ \mathrm{kd}) - 1\ )$$

$$(= 20\ \mathrm{g/m3}(1 + \ (0.16\mathrm{g/g.day})5\mathrm{days})\ )/\ (5\mathrm{days})(9.6\ \mathrm{g/g.day} - 0.16\mathrm{g/g.day}) - 1$$

$$= 36/\ 46.2 = 0.78\ bCOD/m3$$

$$\mathrm{Px,vss} = 1500\ (\ \mathrm{m3/d}\ (0.40\ \mathrm{gVSS/gbCOD})(720\ \mathrm{g\ bCOD/m3} - \ 0.78\mathrm{g\ bCOD/m3}))/((1 + (0.16g/g.day)5days)\ \ heterotrophic\ biomass$$

$$+(0.15)(0.16)1500\ (\ \mathrm{m3/d}\ (0.40\ \mathrm{gVSS/gbCOD})(720\ \mathrm{g\ bCOD/m3} - \ 0.78\mathrm{g\ bCOD/m3}) * 5days)/((1 + (0.16g/g.day)5days)\ \ Cell\ debris$$

$$+ 1500\ (\ \mathrm{m3/d}\ (0.16\ \mathrm{gVSS/gbCOD}) * 50\mathrm{g/m3}\ nitrifying\ bacteria)/((1 + (0.11g/g.day)5days) + 1500m3/d\ (130.9g/m3)nbVSS$$

$$= (239.74) + (28768.8) + (1741) + (196350)$$

$$= \ 239.74\ (1\mathrm{kg}/1000\mathrm{g}) + \ 28768.8\ (1\mathrm{kg}/1000\mathrm{g}) + 7741\ (1\mathrm{kg}/1000\mathrm{g}) + 196350\ (1\mathrm{kg}/1000\mathrm{g})$$

$$= \ 0.24\ + \ 28.769\ + \ 7.741\ + \ 196.35 = 233.1\ \mathrm{kgVSS/day}$$

$$\mathrm{Px,tss} = (0.24/0.85) + (28.769/0.85) + (7.741/0.85) + 196.35\ + 1500(200 - 170)(1\mathrm{kg}/1000\mathrm{g})$$

$$= 0.282 + 33.84 + 9.11 + 196 + 45 = 284.23\ \mathrm{kg/day}$$

Note- The heterotrophic biomass, cell debris and nitrifying bacteria biomass contain inorganic solid and VSS fraction of the total biomass is about 0.85, thus above written formula divided by

0.85 to calculate the solid production in terms of TSS i.e. Px,tss including inert TSS i.e.(TSS-VSS) in inlet waste water along with flow/day

- **Calculated the mass of VSS and TSS in the aeration tank**

$$\text{Mass of MLVSS} = (\text{Xvss})(\text{V}) = (\text{Px, vss})\text{SRT} - (233.1\ \text{kg/day})(5\ \text{days}) = \mathbf{1165.5kg}$$

$$\text{Mass of MLSS} = (\text{Xtss})(\text{V}) = (\text{Px, tss})\text{SRT} - (284.23\ \text{kg/day})(5\ \text{days}) = \mathbf{1921.5kg}$$

- **Design MLSS mass concentration and determine the aeration tank volume and detention time**
- $\mathbf{Aeration\ Tank\ Volume} = (\text{V})(\mathbf{Xtss}) = \mathbf{2997.54kg, at\ (Xtss) and\ MLSS} = \mathbf{2500mg/l = 2500g/m3 = 2.5kg/m3}$

The Volume of Aeration Tank = (1921.15 kg)/(2.5kg/m^3) = 768 say **800 m^3**

The depth of the aeration tank = 3 meters, then area required = 800/3 = 266 m^2

Calculate the detention time: $\tau = V/Q$ **= 800 m^3 / (62.5 m3/hr) = 12.8 hrs**

- **Calculated the MLVSS**

$$VSS\ fraction = \mathbf{(233.1/284.23) = 0.82}\ \mathbf{, MLVSS = 0.85\ (2500g/m3) = 2125\ g/m3}$$

- **Determined the F/M and BOD volumetric loading**

$$\text{F/M} = (\text{QS0/XV}) = (1500\ \text{m3/day})(720\ \text{g/m3})/\ (2550\ \text{g/m3})(800\text{m3})$$
$$= (1080000/2040000) = \mathbf{0.53}\ \text{kg of BOD / kg of MLVSS}$$

- **Calculated the BOD volumetric loading**

$$= \text{QS0} / \mathbf{V} = (1500\ \text{m3/day})(720\ \text{gBOD/m3})(1\text{kg}/1000\text{g})/1000\text{m3}$$
$$= \mathbf{0.68kgBOD/m3.day}$$

Calculate the Observed Yield based on TSS & VSS

$$\boldsymbol{Observed\ yield\ on\ TSS} = \mathbf{Yobs = Px, tss\ /\ bCOD\ removed = Px, tss\ /\ Q(S0 - S)}$$
$$= (284.23\text{kg/day})/(1500\text{m3/day})\ (720\ \text{g Bcod / m3} - 0.78\text{g Bcod/m3})\ (1\text{kg}/1000\text{g})$$
$$= \mathbf{0.26\ g\ TSS/g\ bCOD = 0.42g\ TSS/g\ BOD}$$

- **Observed yield based on VSS** $= Yob == \text{Px, vss / bCOD removed} = \text{Px, vss / Q(S0} - \text{S)}$

$$= (233.1\ \text{kgVSS/day})/\ (1500\text{m3/day})(720\ \text{g bCOD / m3} - 0.78\ \text{g bCOD/m3}))/(1\text{kg}/1000\text{g})$$
$$= \mathbf{0.22\ g\ VSS/g\ bCOD = 0.35g\ VSS/g\ BOD}$$

- **Calculated the O2 requirement.**

$$\mathbf{R0} = \text{Q(S0} - \text{S)} - 1.42\ \text{Px, bio} + 4.33\ \text{Q (NOx)}$$
$$\text{(NOx)} = \text{(TKN0)} - \text{Ne} - 0.12\text{Px, bio/Q}$$
$$\text{(NOx)} = \text{Nitrogen oxidized, mg/l,}$$
$$\text{(TKN0)} = \text{Influent TKN concentration, mg/l}$$

(NOx) = Nitrogen oxidized, mg/l (TKN$_0$) = Influent TKN concentration, mg/l

Ne= effluent NH_4-N concentration, mg/l (assumed 10 mg/l)

$$= (0.05\text{kg/m3}) - (0.01\ \text{kg/m3}) - (0.012\text{kg N/kgVSS})(239.74\text{kg/day})/\ (1500\ \text{m3/day})$$
$$= 0.0044 kg/m3 = 4.4\ g/m3$$

Now calculated the Oxygen demand

$$\mathbf{R0} = Q(S0 - S) - 1.42\ Px,bio + 4.33\ Q\ (NOx)$$
$$= 1500m3/day(0.720\ kg\ bCOD\ /m3 - 0.00078kg\ bCOD/m3)$$
$$- 1.42(239.74kg/day) + 4.33(0.0044kg/m3) = \mathbf{738.41kg}$$

Remark: The value 1.42 introduced from
$C_5H_7NO_2 + 5O_2$ + Bacteria ⟶ $5\ CO_2 + NH_3 + 2H_2O$ + energy
(113) 5(32)
The COD of cell tissue = 5 (32g/mole) / (113g / mole) = **1.42g Oxygen/g cells Theoretically**
The Value 239.7 kg/day include heterotrophic biomass only as Px,vss

R_0= 738.41 kg/day the additional 10% of O2 of theoretical oxygen requirement is added as safety factor then

$$\mathbf{Oxygen\ Requirement\ R0} = 738.41 + (738.41 * 0.1) = 738.41 + 73.84$$
$$= \mathbf{812.25\ kg\ /\ Day} = \mathbf{33.84kgO2/hour}$$

- **Design calculation for Secondary Clarifier**

$$\boldsymbol{Return}\ \mathbf{sludge\ recycle\ (RAS)ratio\ QrXr} = (Q + Qr)X$$

(Assumed waste sludge mass is insignificant)

Qr=Return activated sludge flow rate m3/day, Xr= Return sludge mass concentration g/m3

$$RAS\ recycle\ ratio = Qr/Q = R\ \text{then}\ RXr = (1 + R)\ X, \mathbf{R} = (\mathbf{X})/(\mathbf{Xr - X})$$

The sludge in recirculation assumed 8000mg/l = Xr

$$Now\ R = (2500g/m3)\ /\ (8000 - 2500)\ g/m3 = 0.45$$

Assumed the hydraulic application rate of 30 m3/m2.day a typical value then

$$Area = (1500\ m3/day)\ /\ (25\ m3/m2.day) = 60\ m2$$

$$\mathbf{The\ area\ of\ clarifier} = \mathbf{60\ m2} = \pi r2, \mathbf{The\ area\ of\ clarifier} = \mathbf{60\ m2} = \pi r2$$
$$= 3.14 * r2,\quad r2 = 60/3.14 = 19.10\ m2$$

- Now r = square root of $19.10 = 4.37$, $\mathbf{Dia} = \mathbf{2r} = \mathbf{8.74}$, $\mathbf{Volume} == \pi r2 *$ depth $= 59.97 * 3 = \mathbf{179.9\ m3\ say\ 180\ m3}$

Results and Discussion: The wastewater feed from bottom of UASBR is key consideration to prevent the channeling of wastewater feed and equal distribution in bottom which will move upwards through sludge zone inside the UASBR. The volume of UASBR calculated 1875m^3/day, with dia of 19.9 meters and 6 meters of liquid height. Biogas generation will be 4805 m^3/day for the wastewater flow of 1500 m^3/day with designed COD value of 7500mg/l with COD removal efficiency 90% in UASBR. Once the dimension of reactor calculated the focus area becomes design, fabrication and erection of Gas Liquid Solid Separation Unit (GLSS). Deflectors installed immediately below the aperture to the GLS separator; to enable the separation of the biogas and to allow only liquid and solids pass through the settling compartment. These deflectors avoid the presence of biogas bubbles (which trigger turbulence and bad sedimentation of solids) in the settling zone of the GLS separator. Slope of the separator bottom from 45° to 60°. Free surface in the aperture between the gas collectors: 15 – 20% of reactor area. Height of separator from 1.5 – 2 m. The baffles to be installed beneath the gas domes should overlap the edge of the domes over a distance from 10 – 20 cm **[13,15,25].**

The UASBR design which will reduce 90% of organic load in terms of COD will reduce and ultimately reduce this organic load on the ASP so oxygen requirement is 90% reduced which will reduce electricity requirement to surface aerators. The estimated biogas can be used directly to boiler after H_2S scrubbing by relacing or eliminating the biogas or can use directly for electricity production by biogas to electricity converter. The activated sludge process is designed based on the outlet parameters of UASBR. The standard values are taken from table 1 and table 2 **[24].** The volume of Aeration tank is calculated as 800m^3 with HRT of 12.8 hrs. The volume of secondary clarifiers is calculated 180 m^3.

Conclusion: The design of UASBR followed by ASP reflects that biogas production from UASBR can be utilized as fuel to boiler after sulfur scrubbing for replacement of PNG or to reduce the PNG requirement for Boiler and this will help to reduce the CO_2 emissions under scope 1. As described above under head of "Energy from Biogas and CO_2 emission reduction by replacement or reduction of PNG and Electricity" reflects 4805 m^3 of biogas of 6000kCal/ m^3 will replace to 3203 SCM of PNG. The expected CO_2 emissions reduction under scope 1 will be equivalent to 5631.91kg CO_2 emissions per day by using biogas in boiler instead of PNG.

The 9000 kg/day of organic load in terms of COD to be removed in UASBR as per design, If this was supposed to treat in ASP then 9000kg COD/day removal will require theoretically 9000kg excluding the load of amonical `nitrogen. The HP of aerator requirement to meet the oxygen demand of 9000 kg of COD will be 9000/24*1.05 = 357.14 HP =266.32kwh so per day kwh load will be 6391.714kwh/day. The CO2 emissions from electricity is 0.71kg CO_2 / kwh so proactively CO2 emissions prevented by using UASBR will be 6391.714*0.71 = 4538.11 kg CO2 emissions / day under scope 2.

The use of biogas will make costs competitive by reducing the product cost. Hence wastewater treatment through UASBR will help in reducing CO_2 emissions under scope 1 and scope 2 both with concept of waste to energy, waste to economy for sustainable development.

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