A CASE STUDY: INCREASING THE AERATION EFFICIENCY BY REDESIGNING THE AERATOR FOR A TERTIARY TREATMENT PLANT IN A NITROGENOUS FERTILIZER PLANT

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ABSTRACT:-

The main objective of this work is to redesign the aerator which is used for a tertiary treatment plant in a nitrogenous fertilizer plant. The existing aerator used in the fertilizer tertiary treatment plant is surface aerator. Totally there are 8 aerators used, each consuming 35HP power per day which was found non economical and least efficient because of higher power consumption. So a fine bubble aerator was proposed. In this fine bubble aerator the factors such as retention time, sludge age, BOD removal, and oxygen required were analyzed. The result shows that oxygen transfer efficiency is 50% and also it exhibits high aeration efficiency. Compared to coarse bubble aeration, fine bubble aeration can reduce power required to transfer oxygen by up to 50%. By this research work it was suggested that the existing 8 numbers of surface aerators which consumes 35HP per day can be replaced by 2 numbers of fine bubble aerators which consume 20HP each per day only.

Keywords:- Aerator, Surface aerator, Fine bubble aerator, Aeration efficiency, Tertiary treatment, Waste water treatment, Oxygen transfer.

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INTRODUCTION:-

Conventional wastewater treatment processes:-

Conventional wastewater treatment consists of a combination of physical, chemical, and biological processes and operations to remove solids, organic matter and, sometimes, nutrients from wastewater. General terms used to describe different degrees of treatment, in order of increasing treatment level, are preliminary, primary, secondary, and tertiary and/or advanced wastewater treatment. In some countries, disinfection to remove pathogens sometimes follows the last treatment step.

Preliminary treatment:-

The objective of preliminary treatment is the removal of coarse solids and other large materials often found in raw wastewater. Removal of these materials is necessary to enhance the operation and maintenance of subsequent treatment units. Preliminary treatment operations typically include coarse screening, grit removal and, in some cases, comminution of large objects. In grit chambers, the velocity of the water through the chamber is maintained sufficiently high, or air is used, so as to prevent the settling of most organic solids. Grit removal is not included as a preliminary treatment step in most small wastewater treatment plants. Comminutors are sometimes adopted to supplement coarse screening and serve to reduce the size of large particles so that they will be removed in the form of sludge in subsequent treatment processes. Flow measurement devices, often standing-wave flumes, are always included at the preliminary treatment stage.

Primary treatment:-

The objective of primary treatment is the removal of settleable organic and inorganic solids by sedimentation, and the removal of materials that will float (scum) by skimming. Approximately 25 to 50% of the incoming biochemical oxygen demand (BOD_5), 50 to 70% of the total suspended solids (SS), and 65% of the oil and grease are removed during primary treatment. Some organic nitrogen, organic phosphorus, and heavy metals associated with solids are also removed during primary sedimentation but colloidal and dissolved constituents are not affected. The effluent from primary sedimentation units is referred to as primary effluent.

Secondary Treatment:-

The objective of secondary treatment is the further treatment of the effluent from primary treatment to remove the residual organics and suspended solids. In most cases, secondary treatment follows primary treatment and involves the removal of biodegradable dissolved and colloidal organic matter using aerobic biological treatment processes. Aerobic biological treatment is performed in the presence of oxygen by aerobic microorganisms (principally bacteria) that metabolize the organic matter in the wastewater, thereby producing more microorganisms and inorganic end-products (principally CO_2, NH_3, and H_2O). Several aerobic biological processes are used for secondary treatment differing primarily in the manner in which oxygen is supplied to the microorganisms and in the rate at which organisms metabolize the organic matter.

High-rate biological processes are characterized by relatively small reactor volumes and high concentrations of microorganisms compared with low rate processes. Consequently, the growth rate of new organisms is much greater in high-rate systems because of the well controlled environment. The microorganisms must be separated from the treated wastewater by sedimentation to produce clarified secondary effluent. The sedimentation tanks used in secondary treatment, often referred to as secondary clarifiers, operate in the same basic manner as the primary clarifiers described previously. The biological solids removed during secondary sedimentation, called secondary or biological sludge, are normally combined with primary sludge for sludge processing. Common high-rate processes include the activated sludge processes, trickling filters or bio filters, oxidation ditches, and rotating biological contactors (RBC). A combination of two of these processes in series (e.g., bio filter followed by activated sludge) is sometimes used to treat municipal wastewater containing a high concentration of organic material from industrial sources.

Tertiary treatment:-

Tertiary treatment is the next wastewater treatment process after secondary treatment. This step removes stubborn contaminants that secondary treatment not able to clean up. Wastewater effluent becomes even cleaner in this treatment process through the use of stronger and more advanced treatment system. The purpose of tertiary treatment is to provide a final treatment stage to raise the effluent quality before it is discharged to the receiving environment (sea, river, lake, ground, etc.). More than one tertiary treatment process may be used at any treatment plant. If disinfection is practiced, it is always the final process. It is also called "effluent polishing."

Tertiary and/or advanced wastewater treatment is employed when specific wastewater constituents which cannot be removed by secondary treatment must be removed. The individual treatment processes are necessary to remove nitrogen, phosphorus, additional suspended solids, refractory organics, and heavy metals and dissolved solids. Because advanced treatment usually follows high-rate secondary treatment, it is sometimes referred to as tertiary treatment. However, advanced treatment processes are sometimes combined with primary or secondary treatment (e.g., chemical addition to primary clarifiers or aeration basins to remove phosphorus) or used in place of secondary treatment (e.g., overland flow treatment of primary effluent).

Biochemical Oxygen Demand (BOD):-

It is a measure of biodegradable fraction of the wastewater by monitoring the assimilation of the organic material by aerobic microorganisms over a set period of time under a strictly controlled condition. It is also defined as the amount of oxygen utilized by a mixed population of microorganisms under aerobic condition to stabilize the organic matter at 20°C for a period of 5 days.

Chemical Oxygen Demand (COD):-

It gives the value of the organics present in wastewater that can be digested by dichromate in 2 hours.

Total Oxygen Demand:-

It measures the oxygen demand of a sample rather than its carbon content.

Total Organic Carbon:-

It is a measure of all the carbon atoms present in wastewater at temperature greater than 95°C.

Types of Aerators:-

Aeration is the process of bringing water and air into close contact in order to remove dissolved gases, such as carbon dioxide, and to oxidize dissolved metals such as iron. It can also be used to remove volatile organic chemicals (VOC) in the water. Aeration is often the first major process at the treatment plant. During aeration, constituents are removed or modified before they can interfere with the treatment processes. Aeration is an important step in the treatment of sewage by bio oxidation and in much industrial fermentation. The three types of aerators normally used in the industries are surface aerators, diffused aerators, and jet aerators.

Surface Aerators:-

Mechanical aerators are the simplest type in the aeration system. They may be obtained in sizes from 0.75 to 75 kW. They consist of submerged or partially submerged impellers that are attached to motors that are mounted on floats or on fixed structures. The impellers are fabricated from steel, cast iron, non corrosive alloys and fiber glass-reinforced plastics are used to agitate the waste water vigorously, entraining air in the waste water and causing a rapid change in the air water interface to facilitate solution of air. Surface aerators may be classified according to the speed of rotation of the impeller as low and high speed. In low speed aerators, the impeller is driven through a reduction gear by electric motor.

The motor and gear box are usually mounted on a platform that is supported either by piers extending to the bottom of the tank or by piers extending to the bottom of the tank or by beams that span the tank. They have also been mounted on floats. These units where originally developed for use in ponds or lagoons where the water surface elevation fluctuates, or where a rigid support would be impractical. The Kessner brush aerators are an old device very popular in Europe, is used to provide both aeration & circulation in oxidation ditches. It is horizontally mounted just above the water surface and consists of a cylinder with bristles of steel protruding from in perimeter into the waste water. The drum is rotated rapidly by an electric motor drive, spraying wastewater across the tank by promoting circulation and entraining air in the wastewater.

Diffused Aerators:-

The Diffused Aeration System (DAS) comprising of rubber membrane and PVC pipe grid supported by RCC supports will be installed at the bottom of the aeration tank. Air from the blowers at the desired rate and having the required pressure will be diffused through the DAS. The diffuser consists of a porous membrane 1/0.5m in length made of polyurethane material. Each membrane diffused is fully supported over the full length and circumference with a 90mm PVC membrane support frame. The diffuser will be retained in place by two hose clips. Each diffuser will be provided with a removable cap to facilitate flushing of diffuser assembly so that cleaning becomes necessary. The Diffuser is fitted to the pipe lateral by a PVC and spectrum saddle arrangement. The pipe laterals are connected to a pipe header. The wetted parts of the systems are made of non-corrosive material. During shut down condition, membrane will contract and close around the PVC support frame to prevent any backflow. The diffuser is designed to ensure uniform permeability and to produce a flow of fine air bubbles approximately 2mm in diameter. The fine uniform pore size ensures minimum head loss across the diffuser.

Since the bubbles are of extremely small size the total surface area that interfaces with the liquid is large. The high contact area provided by the fine bubbles and the high contact time provided by the slow rise rate of the bubbles makes this system very efficient in terms of oxygen transfer efficiency. The slow upward movement of the fine bubbles keeps the bottom of the tank swept clears of any setting deposit and also provides gentle mixing. The gentle uniform diffusion of air also prevents flocs shear that means the setting time of the flocs are reduced. This results in the increased efficiency of the settling tank and higher sludge concentration.

Jet Aerators:-

Approach to jet aeration takes advantage of all the factors, which increase mass transfer rates while lowering operating costs. The jet aeration system is more effective than other aeration methods because the system utilizes multiple oxygen transfer zones. The jet system is ideal for gas/liquid contacting, blending, and solids suspension applications. Advantages of the Jet Aerators are,

- Ideal when liquid level fluctuates
- Control of mixing intensity
- No structural supports required
- No long shafts or submerged bearings
- Effective in both large tanks and deep tanks
- Corrosion resistant
- Installed close to the tank bottom where solids settle.

LITERATURE REVIEW:-

The objective of this work [2] is to design a high efficiency curved-blade-surface mechanical aerator for oxidation ditch, which is used to treat municipal and domestic sewage. Aeration experiments were conducted in oxidation ditch made up of mild steel sheets to study the design characteristics of curved blade surface mechanical aerator. The paper critically examines six different configurations of aerators, which were developed, fabricated and tested in the laboratory for its various dynamic parameters, such as diameter of aerators (D), speed (N) and immersion depth (h). Out of the different configurations tested, the curved blade rotor (CBR) emerged as a potential aerator with blade tip angle of 47°. The overall oxygen transfer coefficient (KLa) was observed to be as high as 10.33 h^{-1} and the optimum aerator efficiency was found to be 2.269 KgO /kW.h. The standard aeration efficiency (SAE) of CBR was observed to be higher as compared to other aerators used for oxidation ditch process. Dimensional analysis was used to develop equations that describe the aerator's behavior. Further, a CFD model is also developed for better understanding of the process that takes place inside the ditch. To prepare it 3D and steady flow, k-e turbulence model of flow was used and the simulation runs were carried out for one phase model to generate the data so as to compare it with experimentally observed values.

Oxygen transfer rate and the corresponding power requirement to operate the rotor are vital for design and scale-up of surface aerators. It has been demonstrated [1] that energy can be saved substantially if the aeration tanks are run at relatively higher input powers. It is also demonstrated that smaller sized tanks are more energy conservative and economical when compared to big sized tanks, while aerating the same volume of water, and at the same time by maintaining a constant input power in all the tanks irrespective of their size.

Oxygen transfer characteristics for three sizes of equipment, from 76 mm to 7.6 m in diameter and for liquid depths from 4 to 21 m, correlate well and permit scaling of fermentation systems in size were studied [8]. Nearly uniform bulk liquid composition and a linear decrease of gas phase composition with depth permit a proper, integrated value of the oxygen saturation driving force to be employed.

DESIGN OF AN EXISTING SURFACE AERATOR:-

There are 8 surface aerators used in the treatment plant. The different parameters used for the design of the aerators are given below. All the data's were taken from a private nitrogenous fertilizer plant. Two cases were analyzed for the fine bubble aerator.

Volumetric Loading Rate:-

It is defined as the retention time of wastewater in aeration tank. The hydraulic retention time is given by, = (V x 24) / Q

Where,

V = Volume of aeration tank (m^3)

Q = influent flow rate (m^3/day)

Sludge Age (θ_c):-

It is defined as the solids retention time in the aeration tank which is given by,

$$\theta_c = \theta / (1+R-(Xr/X))$$

Where,

θ = retention time in the aerator

R = solids recycle

X_r = recycle concentration

X = concentration in the aerator

The optimum value of sludge age is 3-14 days. If sludge age is less, then the biomass will not be dense enough to settle easily. If the sludge age is high, then the floc particles will be too small to settle rapidly and the fraction of living cells in the biomass will be low.

Mixed Liquor Suspended Solids (MLSS):-

Suspended matter of sludge's and aeration tank mixed liquor (MLSS) can be determined by gravimetric method. To determine the suspended matter, a membrane filter and Gooch crucible are required. The well-mixed sample is measured with a wide tip pipette or a volumetric flask. The sample is filtered through a weighed membrane filter or Gooch crucible, using suction. Leaving the suction on, it is washed with 10ml distilled water to remove soluble salts. The membrane filter or crucible and solids are dried at 103^0C for 1hr and are allowed to cool to room temperature in a desiccator's before weighing.

mg / lit of total suspended matter = mg of suspended solids x 1000 / ml

Sludge Volume Index:-

It is an empirical measurement used as an index of the settle ability of the sludge. It is denoted in ml/gm of dried solids and can be calculated by, $V / (V_0X)$

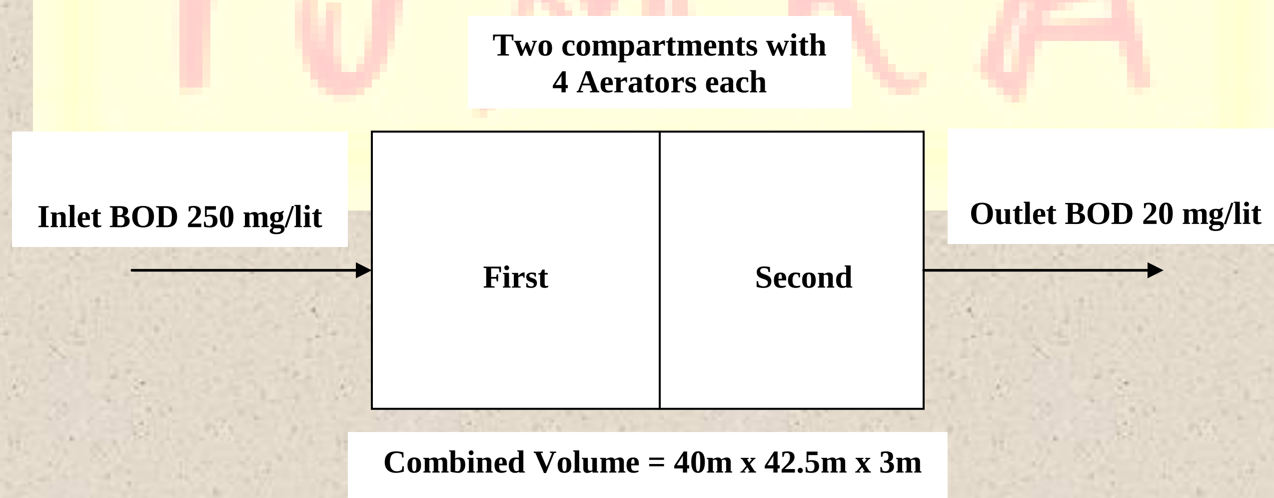
Where,

V = Volume of settled solids after 30 min (ml)

V_0 = initial volume of sludge tested (lit)

X = MLSS (mg/lit)

The optimum value of Sludge Volume Index is 35-100 ml/gm.



Data:

Inlet BOD, S_0	=	250 mg/lit
Outlet BOD, S	=	20 mg/lit
Aerator Volume, V	=	5100 m^3
Feed Rate, Q_0	=	666.67 m^3/hr = 16000 m^3/day
MLSS, X	=	2500 ppm
Y (growth constant)	=	0.6
K_d	=	2.5×10^{-3} hr^{-1}
(Decrease in biomass through cell death)		
Recycle ratio, R	=	30%
Oxygen Transfer efficiency	=	7% = 0.07

To Calculate Retention Time, $\theta = V/((1+R)\,Q_0)$

$= 5100/(1+0.3)\,666.67$

$= 5.88$ hrs

To Calculate Sludge Age, $\theta_c = X\theta/(Y(S_o\text{-}S) - XKd\theta)$

$= 2500 \times 5.88/(0.6 \times (230 – 2500) \times 2.5 \times 10^{-3} \times 5.88))$

$= 145.19$ hrs ≈ 6 days

To Calculate Total BOD removed, Total BOD removed = 230 mg/lit x Q_o

$= 230 \times 666.67 \times 10^{-3}$

$= 153.33$ kg/hr

To Calculate Oxygen Required,

O_2 required $= 1.47 \times Q_o \times (S_o\text{-}S) – 1.42 \times V \times X/\theta_c$

$= 1.47 \times 16000 \times (250\text{-}20) – 1.42 \times 5100 \times 2500/6$

$= 2392.13$ kg/day

$= 99.67$ kg/hr

Theoretical Oxygen required $= 99.67$ kg/hr

Actual Q_{air} $= 99.67/0.07$

$= 1423.85$ kg/hr

But Air contains only 21% Oxygen

Hence, Actual Q_{air} = 1423.85 x 0.21

= 299.0085 kg/hr

To Calculate Aerator HP required,

Oxygen Transfer Rate of existing Aerator is = 1.2 kg/hr per HP

Aerator HP required = Actual Q_{air} / 1.2

= 299.0085 / 1.2

= 249.174

HP per aerator = 249.174/8

= 31.147 HP

For 90% efficiency,

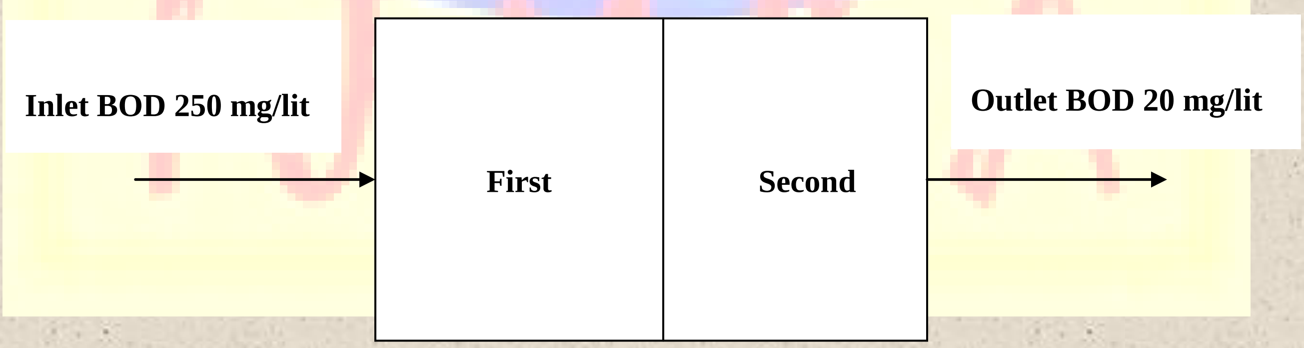
HP per aerator = 31.147/0.9

= 34.6 HP

Hence, 8 Aerators of ≈ 35 HP is required.

REDESIGN FOR FINE BUBBLE AERATOR – CASE-1:-

Two compartments of 1 Aerator each requiring 35 HP



Data:-

Inlet BOD, S_0, = 250 mg/lit

Outlet BOD, S = 20 mg/lit

Aerator Volume V = 5100 m^3

Feed Rate, Q_0 = 666.67 m^3/hr = 16000m^3/day

MLSS, X = 2500 ppm

Y (growth constant) = 0.6

K_d = 2.5 x 10^{-3} hr^{-1}

(Decrease in biomass through cell death)

Recycle ratio, R = 30%

Oxygen Transfer Efficiency = 50% = 0.5

To Calculate Retention Time, θ = V/ ((1+R) Q_o)

= 5100/ (1+0.3) 666.67)

= 5.88 hrs

To Calculate Sludge Age,

θ_c = $X\theta/ (Y (S_o\text{-}S) - XK_d\theta)$

= 2500 x 5.88/ (0.6 x 230 – 2500 x 2.5 x 10^{-3} x 5.88)

= 145.19 hrs ≈ 6 days

To Calculate Total BOD removed,

Total BOD removed = 230 mg/l x Q_o

= 230 x 666.67 x 10^{-3}

= 153.33 kg/hr

To Calculate Oxygen required,

O_2 required = 1.47 x Q_o x (S_o-S) – 1.42 x V x X/θc

= 1.47 x 16000 x (250-20) – 1.42 x 5100 x 2500/6

= 2392.13 kg/day

Theoretical Oxygen required = 99.67 kg/hr

Actual Q_{air} = 99.67/0.5

= 199.34 kg/hr

But Air contains only 21% Oxygen

Hence, Actual Q_{air} = 199.34 x 0.21

= 41.8614 kg/hr

To Calculate Aerator HP required,

Oxygen Transfer Rate of Existing Aerator = 1.2 kg/hr per HP

Aerator HP required = Actual Q_{air} / 1.2

= 41.8614/1.2

= 34.8845

For 90% efficiency,

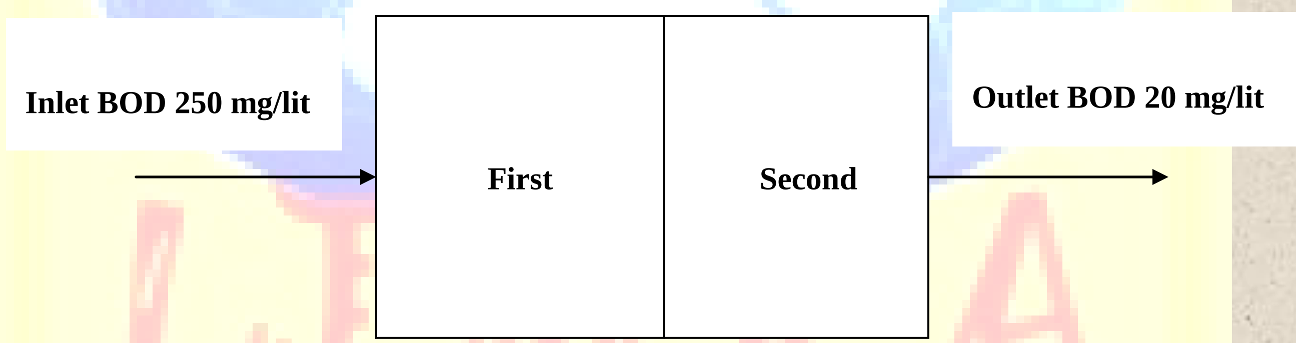
HP per aerator = 34.8845/0.9 = 38.46

For 35 HP Aerator,

Hence, 1Aerator of 35 HP are required

REDESIGN FOR FINE BUBBLE AERATOR – CASE-2:-

Two compartments of 1 Aerator each requiring 20 HP



Data:-

Inlet BOD, S_0, = 250 mg/l

Outlet BOD, S = 20 mg/l

Aerator Volume V = 5100 m^3

Feed Rate, Q_0 = 666.67 m^3/hr = 16000m^3/day

MLSS, X = 2500 ppm

Y (growth constant) = 0.6

K_d = 2.5 x 10^{-3} hr^{-1}

(Decrease in biomass through cell death)

Recycle ratio, R = 30%

Oxygen Transfer Efficiency = 50% = 0.5

To Calculate Retention Time,

θ = $V/ ((1+R)\, Q_o)$

= $5100/ (1+0.3)\, 666.67)$

= 5.88 hrs

To Calculate Sludge Age

θ_c = $X\theta/ (Y\, (S_o\text{-}S) - XK_d\theta)$

= $2500 \times 5.88/ (0.6 \times 230 – 2500 \times 2.5 \times 10^{-3} \times 5.88)$

= 145.19 hrs ≈ 6 days

To Calculate Total BOD removed,

Total BOD removed = 230 mg/l x Q_o

= $230 \times 666.67 \times 10^{-3}$

= 153.33 kg/hr

To Calculate Oxygen required,

O_2 required = $1.47 \times Q_o \times (S_o\text{-}S) – 1.42 \times V \times X/\theta c$

= 1.47 x 16000 x (250-20) – 1.42 x 5100 x 2500/6

= 2392.13 kg/day

Theoretical Oxygen required = 99.67 kg/hr

Actual Q_{air} = 99.67/0.5

= 199.34 kg/hr

But Air contains only 21% Oxygen

Hence, Actual Q_{air} = 199.34 x 0.21

= 41.8614 kg/hr

To Calculate Aerator HP required,

Oxygen Transfer Rate of Existing Aerator = 1.2 kg/hr per HP

Aerator HP required = Actual Q_{air} / 1.2

= 41.8614/1.2

= 34.8845

For 90% efficiency,

HP per aerator = 34.8845/0.9 = 38.46

For 20 HP Aerator,

Hence, 2 Aerators of 20 HP are required

DESIGN SUMMARY:-

Case1:-

1. Type of aerator used = Fine Bubble Aerator
2. Retention Time = 5.88 hrs
3. Sludge Age = 6 days
4. Aerator HP Required = 34.8845
5. Number of Aerators = 1

Case2:-

1. Type of aerator used = Fine Bubble Aerator
2. Retention Time = 5.88 hrs
3. Sludge Age = 6 days
4. Aerator HP Required = 34.8845
5. Number of Aerators = 2

CONCLUSION:-

The oxygen transfer efficiency of fine bubble aerator is 50%. The amount of oxygen that dissolves in sewage is increased when compared to coarse bubble aerator. Fine bubble aerators also exhibit high aeration efficiencies. Fine bubble aeration systems reduce the power required to transfer oxygen by 50% when compared to existing surface aeration system. Thus, it requires lesser power for its operation and hence it's very economical to use a fine bubble aerator. The calculations have also shown that it's economical to use fine bubble aerator. So, compared to coarse bubble aeration, fine bubble aeration can reduce power required to transfer oxygen by up to 50%. By this research work it was suggested that the existing 8 numbers of surface aerators which consumes 35HP per day can be replaced by 2 numbers of fine bubble aerators which consumes 20HP each per day only.

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