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Performance Evaluation of Laboratory Scale RBC to Treat Wastewater from Hostels

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Abstract—In different parts of India, most wastewaters from small communities like institute hostels, private hostels, small colonies, etc. having lesser hydraulic loading and may or may not contain high organic content, are directly disposed of into the surface or subsurface water bodies without any treatment. Thereby, it becomes the prime cause of many nuisances such as waterborne epidemic which may toll many lives, eutrophication, hardness of water, acidity of water, etc., to the downstream dwellers. Therefore, an attempt has been made in this paper to design a laboratory scale Rotating Biological Contactor (RBC) to treat these water before being disposed of into the surface or subsurface water bodies. In order to evaluate the performance of the designed RBC, sewage effluent from hostels of NERIST (North Eastern Regional Institute of Science and Technology), Arunachal Pradesh) has been used as an standard sewage, An attempt has also been taken for development of economical self-sustaining of RBC, in which the inflow of sewage itself could be used in rotating the discs, thereby, replacing the electricity driven rotor such as electric motor, thus may save the expenses related to power supply.

Keywords—Rotating Biological Contactor, Domestic Wastewater, Organic Loading, Hydraulic Loading, Self-sustaining RBC

I. INTRODUCTION

All the wastes from food preparation, dishwashing, garbage-grinding, toilets, baths, showers, and sinks are the domestic wastewater. Therefore, the domestic wastewater, also called sewage, is the effluent from residential, institutional, and commercial. However, the municipal sewage is a complex mixture of liquid wastes flushed down sewers by residential, commercial, institutional and industrial sources. It contains human wastes and bathroom tissues, which arrive at the treatment facility largely in the form of dissolved organic matter and suspended fibrous material, and which contribute large loadings of nitrogen, phosphorus and pathogens. These are the substances that municipal sewage treatment plants (STPs) are chiefly designed to treat.

The effluent from the primary sedimentation tank of the STP contains about 60 to 80% of the unstable organic matter originally present in sewage. This colloidal and dissolved organic matter, which passes the primary clarifiers, without settling there, has to be removed further by biological treatment. This further treatment of sewage, called secondary or biological treatment, is carried out by changing the characteristics of the organic matter, and thus converting it into stable form (like nitrates, sulphates, etc.) by oxidation and nitrification.

The domestic wastewater/sewage can be treated either using attached growth process or suspended growth process. These processes help in changing the unstable organic matter into stable forms, and thus ensuring their removal, when the effluent from these units is settled in secondary sedimentation tanks.

A. Attached Growth Processes

Attached growth biological system employed for the wastewater treatment essentially consists of a reactor with some kind of medium to support the growth of biomass on it. In this case, the microorganisms in the reactor remain attached to some inert packing material or

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medium. The media may be inert material of any type or even biological sludge itself [1]. For inert media, the specific surface area and void space are important parameters to increase the biomass growth on the media. The secondary clarifier to separate the excess suspended solids of effluent is part of the system. Attached growth process can be operated as aerobic or anaerobic process.

Depending upon the types of media used the attached growth processes are of following types:

1. Trickling filters (or percolating filters),
2. Rotating biological contactor,
3. Submerged media beds (down flow, up flow), and
4. Land treatment and infiltration systems; constructed wetlands, etc.

B. Rotating Biological Contactor

A Rotating Biological Contactor (RBC) is an attached growth biological treatment process in which the microorganisms (generally bacteria) responsible for biodegradation of organic matter are attached to the rotating media which is in the form of assembly of discs mounted on a common shaft with specific spacing between the successive discs (Fig. 1.1). It is an aerobic biological treatment system based on bio-absorption principle. It uses captive biological slimes to remove substances from the liquid wastewater by physical and Biological means. RBC treatment design criteria are still in the development stage and have been based generally on hydraulic loading [2]. However, except for some studies, the importance of organic loading in system design or in evaluating the performance of the RBC process has been overlooked. The organic loading could be expressed better in weight per unit time per unit disk surface area [2]. Earlier investigation indicated that the percentage removal for carbon removal followed the first-order relationship with respect to substance, justifying the use of hydraulic loading [2].

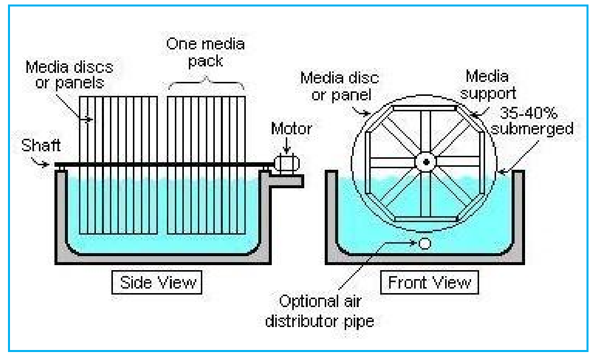

Fig. 1 Rotating Biological Contactor

C. Removal Mechanism in RBC

As the shaft rotates, the surface of rotating discs alternately comes in contact with the microorganisms and organic content of wastewater and atmosphere. During the rotation, the microorganisms get attached to the discs, and oxygen needed to maintain aerobic conditions in the system is transferred into wastewater from the atmosphere. In due course of time, the microorganisms adhered to discs grow in the form of a biological film on the surfaces by consuming (oxidizing) organic content of wastewaters on the disc surface. After some time as the bio-film thickens, an aerobic condition develops nearer to the disc surface and the thickened bio-film, known as slime layer, gets sheared off (called sloughing) by incoming wastewater flow. The soughed bio-film is ultimately removed in the secondary clarifier before the final disposal of treated effluent [3]. The removal mechanism in RBC is depicted in Fig. 2.

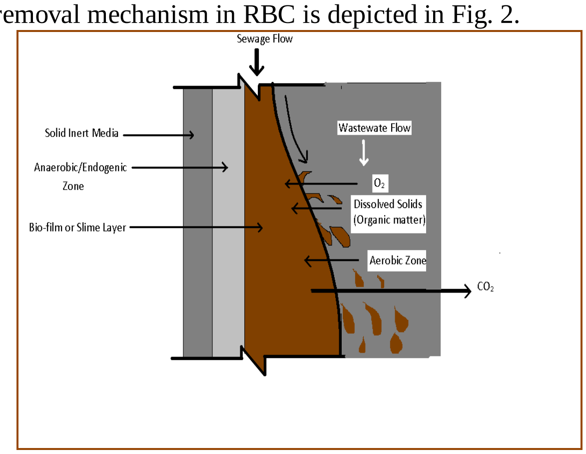

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Fig. 2 Schematic diagram of removal mechanism inRBC

D. Advantages of RBC

Treatment of wastewater using RBC has following advantages in comparative to other treatment methods.

- RBCs are capable of handling wide range of flows.
- Sloughed biomass generally has good settling characteristics and can easily be separated from the waste stream.
- Lower power requirements.
- Operating costs are low as no skill supervisor is required for plant's operation.
- Short contact period is required because of large active surface.
- Elimination of the channelling to which conventional percolators are susceptible.
- Low sludge production and excellent process control.
- Self-cleaning of biofilm occurs by shearing-off of it by inflow of sewage. The hydraulic loading is responsible for shearing-off of biofilm.

However, there are few limitations associated with operating an RBC. These include

- Dissolved oxygen transfer efficiency through this type of system is not especially efficient. If high oxygen is needed due to high organic loadings, additional dissolved oxygen cannot easily be provided to the microorganisms.
- Since all microorganisms used for stabilising the wastewater, known as the biomass, are attached to the media in the RBC, incoming wastewater that contains a toxic substance can potentially wipe out the entire biological population when it enters the RBC.
- Lack of flexibility becomes a problem because of the absence of provisions for recirculation. Recirculation of secondary clarifier effluent is necessary to maintain constant flow through the RBC to keep the biofilm submerged for a sufficient period of time.
- Requirement for covering RBC units in northern climates to protect against freezing.
- Shaft, bearings, and mechanical drive units require frequent maintenance.

II. METHODOLOGY USED

The important parameters such as hydraulic loading, organic loading, sewage discharge, and detention time are necessary for designing an RBC. The designing the RBC using these values has been done in following sections.

A. Organic Loading Used

The sewage from NERIST hostels has been used for the treatment by RBC. The necessary parameters such as organic loading, hydraulic loading, pH and BOD_5 of the same has been tested according to Standard Methods [4]and recorded as tabulated below.

Table 1 Average value of different parameter of Sewage

pH	Discharge of sewage (m^3/d)	DO (mg/l)	BOD_5 (mg/l)	Organic loading (g $BOD/m^2/d$)	Hydraulic Loading ($m^3/d/m^2$)
7.8	0.754	1.1	55	6.73	0.122

B. Design Parameters of RBC

In order to design the RBC, following parameters has been assumed. The accuracy of design are checked by finding the value of other parameters using following calculated results and check to ensure that this value is within the permissible range of design criteria [3].

Assumed Parameters

1. Size: Pilot Model
2. Diameter of discs : 350 mm (200 to 600 mm) (1:10 of this of original prototype)
3. Thickness of discs: 4 mm (up to 10 mm)
4. Disc spacing: 20 mm (20 to 40 mm)
5. Hydraulic retention time: 2 hours (0.5 to 4.0 h)

Sludge production: 0.6 kg/kg of BOD_5 removed (0.5 to 0.8 kg/kg of BOD5 removed).

a. <u>Calculation of No. of Discs Required:</u>

Hydraulic loading from kitchen

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$= 0.122\ m^3/m^2/d$

Average discharge from the kitchen,

$Q = 0.754\ m^3/d$

∴ Total surface area required to carry the above discharge

$$= \frac{Q}{\text{Hydraulic loading}}$$

$= 6.18\ m^2$

Let N be the no. of discs required per module to carry above loading

Using assumed disc diameter as 350 mm, the total surface area of each disc

$$= 2\times\frac{\pi\times0.35^2}{4} = 0.192\ m^2$$

$$\therefore\ N = \frac{\text{Total surface area required}}{\text{total surface area of each discs}}$$

$= 32$

b. Calculation for width of each stage and length of shaft to be used:

Thickness of each disc = 4 mm

Spacing between two discs = 20 mm

Hence, width of each stage, L can be calculated as

$L = (32\times4) + (32+1)\times20$

$\therefore\ = 788\ mm \approx 80\ cm$

And, length of the shaft

= width of each stage + provision for fittings

$= 80 + 10 \approx 90\ cm$

c. Check for organic loading:

ThicknessTotal BOD_5 loading per day to be treated

= discharge × BOD_5 loading per litre

= 41.47 g of BOD_5/day

$$\therefore\text{Organic loading} = \frac{\text{Total BOD5 loading}}{\text{Total area of discs}}$$

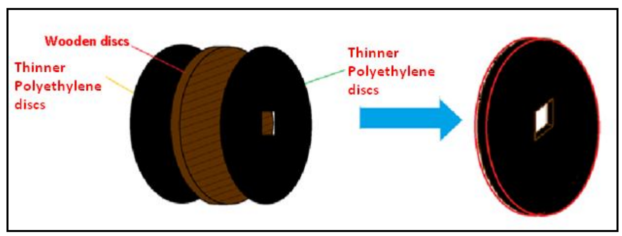
= 6.71 g of $BOD_5/d/m^2$ of disc surface area, which is within the acceptable range of organic loading of RBC (3 to 10 g of BOD_5/m^2/day).

C. Design of Parts of RBC

Using the above calculated values, different parts of the RBC has been constructed as follow.

a. Discs

High-density polyethylene is the material used most commonly for the manufacture of RBC discs [5]. However, the plywood has used to make the circular discs. In order to protect the plywood discs from being biodegraded, it has been sandwiched between two circular thin polyethylene sheets by the use of adhesive materials. Fig. 3 shows the procedure pictorially. The diameter and thickness of the discs used is mentioned in the section II-B.



(a) Plywood sandwiching between two thin polyethylene discs (b) Final disc

Fig. 3 Procedure of making discs

b. Shaft

The shaft supports and rotates the plastic discs. The length of the shaft is as calculated in section II-B (b). The square shaft of 4 cm ×4 cm has been used. The shaft was fitted with bearings at either ends to reduce the friction, as shown in Fig. 4.

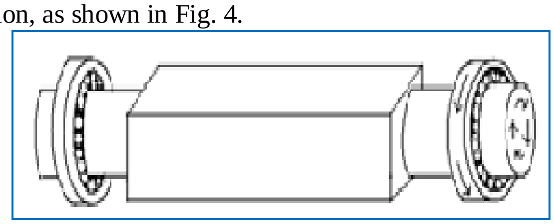


Fig. 4 Fitting of Bearings

c. Cylinder

A semi-circular cylindrical tank made up of thick tin sheet has been used. Waste water is to be allowed to retain in the tank for the duration equal to hydraulic retention time (HRT), and circular discs assembly rotates in it. The design of tank is as follow.

Tank

Referring section ,II-B,

The length of the main tank (width of each module)

=80 cm

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Assuming diameter of cylinder
= 50 cm (dia. Of discs + 10 cm clearance)
Depth of the sewage in the cylinder
= 40% of the total diameter of the cylinder
= 0.4×50=20 cm

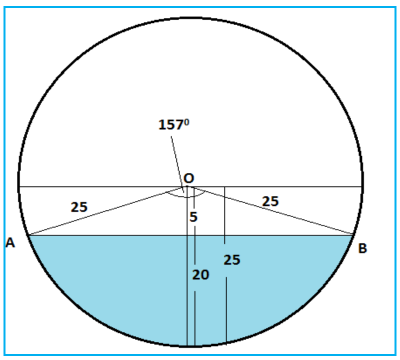
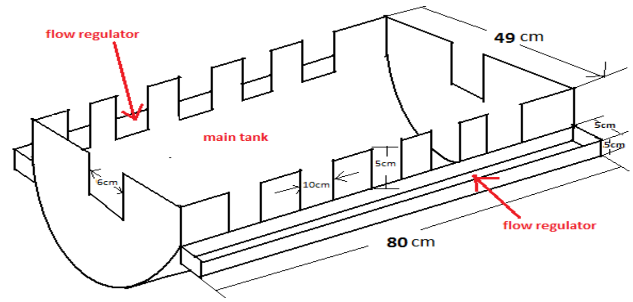


Fig. 5 Cross-section of Cylinder

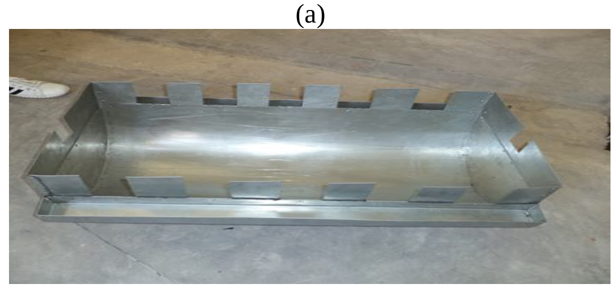
From fig.2.3, central angle, ∠AOB or ϴ
=157°= 0.872π
Length of arch AB of end face = r × ϴ
=0.685 m
Area of minor segment
= area of the sector AOB – area of the triangle AOB
= 0.0734 m^2
∴ Volume of sewage to be stored until detention time
= area of segment × length of the cylinder
= 0.0587 m^3

The sides of the tank are raised by extra portion of 5 cm height for the provision of gates. As many as possible nos. of gates of uniform shape and size are provided on both side of the tank as an access for uniform inflow or outflow of wastewater. Fig. 6. may be adopted as a pictorial procedure.

Two flow regulators, called inlet and outlet flow regulators, which are small tank which is provided on both sides of the tank hanging where water retains for some time before flowing into and out of the tank such that uniform discharge in both cases is ensured. Details about flow regulator are explained in Fig. 6 (a) and (b).



(a)



(b)

Fig. 6 Cylinder – (a) Isometric view of tank with flow regulator on its sides, (b) constructed tank

d. Storage System

As the model is a laboratory model, the wastewater to be treated is been brought to the laboratory and stored.Given volume of sewage has to stay in the cylinder at least for detention period. Referring section II-B, the detention period of the sewage in the cylinder is to be 2 hours. Each batch of water has to be replaced after every detention period. Therefore continuous supply of sewage is necessary. Thus the volume of the storage tank should be such that it should at least be able to hold the volume of water flowed for detention period so that at least one batch of treated water leaves the RBC on which all the tests can be performed.Referring table1, the discharge required
= 754 l/d
= 62.83 l/2h
Thus at least approximately 100 litres capacity primary tank is necessary to give continuous supply for 2 hours. Water storage sintax having capacity of 200 litres best serves the purpose.

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Storage system consists of two tanks called primary and secondary tank. Primary tank is larger tank which is for storage of sewage before it is allowed to flow into the cylinder for treatment. And secondary tank is smaller tank as compare to primary tank from where sewage issupplied into the cylinder in required discharge.

As per hydrostatic law of pressure, pressure at any point is given by$P = \rho gh$.

Above equation shows the proportionality of pressure at any point inside the tank to the depth of water in the tank. Since there is no continuous supply of wastewater into primary tank, the depth of water in the primary tank decreases with time. Hence pressure required at the outlet of the primary tank does change with time, or discharge from the primary tank is not constant. In order to get constant desire discharge, a secondary tank is provided. The capacity of the secondary tank should be such that its depth is not being affected by the change in the depth of the water level in the primary tank. Therefore the secondary tank is made as self-regulatory that when it is full, the inflow from primary tank is stopped automatically. The secondary tank is connected to the inflow regulator of the tank through hose pipe. Fig. 7 shows the arrangement of primary and secondary storage tank.

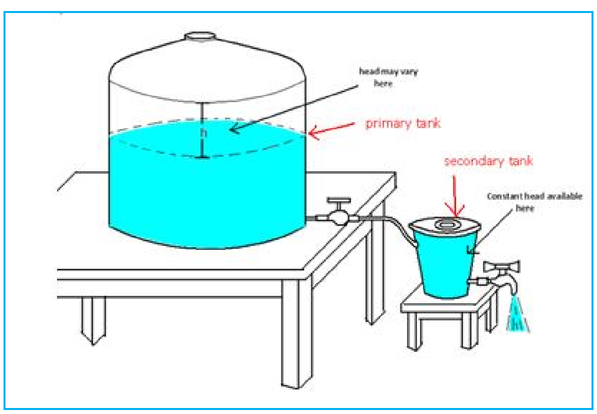

Fig. 7 Arrangement of Primary and Secondary storage tank to prevent variation in discharge

e. Driving Units or Rotors

Microorganisms from sewage attached to the disc surface need oxygen for further degradation of organic matter. Therefore, the microorganisms are to be alternatively exposed to the atmosphere by rotating the discs. The rotation of the discs is done by employing wind vane and blower system as enumerated in the following section.

i. Wind Vane and Blower System

In this system the wind force has been used to rotate the shaft of the RBC fitted with wind vane. For this mechanism following materials are required.

1. Blower: Table fan
2. Vane: CGI sheets

Wind vane is made up of plywood, as shown in Fig. 8, fitted at end of the shaft of RBC. When the table fan blow air on the vane, it will rotate, as a result the shaft will also move. In order to get maximum wind force, the vanes of wind vane are made curved. To achieve desire revolution of the shaft, the table fan can be brought to and pro relative to the wind vane.

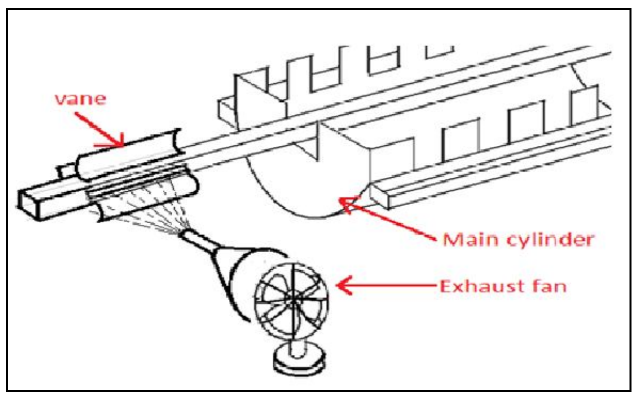

Fig. 8 Wind Vane and Wind Blower Set up

ii. System Self-Sustaining RBC

RBC can also be made self-sustaining using inflow wastewater to be treated to drive the discs. If the inflow of sewage to be treated is utilized in such a way that it rotates the shaft of an RBC, then the necessity of complicate arrangements of driving units, explained above, can be fulfilled, which may make the RBC self-sustaining and more economical. Self-sustaining RBC can be achieved by fixing numbers of buckets on rotating arms fixed on the shaft, which rotates around the shaft, and then wastewater to be treated is allowed to fill the buckets. The rotation of the bucket is based on the principle that when the bucket of one arm gets filled, due

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to its weight it tries to fall. As the rotating arms are fixed to the shaft, the bucket takes the circular motion. When a bucket of one arm gets filled and falls due to its weight, the bucket of opposite arm rises, and thereby adjacent following bucket takes the position of first bucket and gets filled and falls. This successive filling and falling leads to continuous rotation of the arms and thereby rotates the shaft containing discs. This continuous filling and falling of buckets are known as falling bucket method. The circular motion of buckets has property of self-emptying itself. The raising buckets are generally in bottom-up position, as it cannot move itself about arms; the content inside the bucket falls completely out and gets emptied.

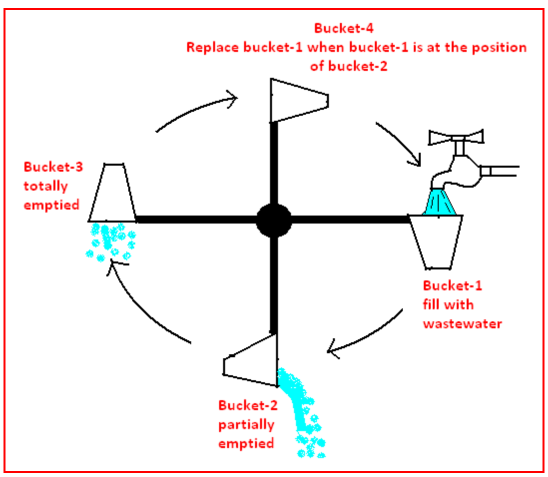

Fig. 9 Falling buckets system used as a driving unit

As shown in Fig. 9 above, bucket-1 after getting filled falls due to its weight and takes the position of the bucket-2. At the position of bucket-2, bucket-1 partially gets emptied. During this moment, bucket-4 takes the position of bucket-1 and gets filled and falls. This lead bucket-1 to takes the position of bucket-3 where its position becomes bottom-up and contents inside it completely gets emptied, and eventually returns to its initial position and completes the cycle. Therefore, the shaft of an RBC fitted with such a mechanism can rotate continuously. Additionally the rotational speed of the shaft can be control by varying the number of buckets and influent discharge of the wastewater. To decrease rotation, the number of arms or buckets has to be decreased and influent discharge has to be decreased. This makes this mechanism simple and flexible comparatively.

III. Results and Discussion

The content of different parameters such as nitrates, nitrites, sulphates, BOD, etc. present in the wastewater can be influence by the RBC. The treated sample from above RBC has been collected and tested for some parameters and results have been compared to properties of untreated wastewater. The efficiency of change in concentration of above parameters has also been evaluated as shown in table below.

Table 2 Tests results of treated wastewater properties and comparing them with untreated wastewater properties.

Sl. No.	Parameter	Before Treatment	After treatment	Efficiency (%)	Remarks
1	BOD_5 mg/L	125.37	60.50	52	BOD_5 decreased
2	Nitrites (NO_2^-) mg/L	0.06	0.01	83.3	Nitrites decreased
3	Nitrates (NO_3^-) mg/L	42.1	55.1	30.9	Nitrates increased
4	Sulphate (SO_4^{--}) mg/L	5.0	25	400	Sulphate increased by four times

The test results in table 3.1 shows that some parameters content increases after treatment, however other parameters content decreases. The nitrites are the intermediate product of nitrogen cycle and are unstable toxic products. All the nitrogenous substances present in the wastewater before being converted into more stable product i.e. nitrates, they form nitrites. Nitrites then convert into nitrates by oxidation or reduction. The tests results also conform that nitrites content are decreasing which shows that nitrites are keeping on converting into nitrates. As explained, all the nitrites get convert to nitrates. Thus the nitrates content increases according to the test results as comply with the general rule. The nitrates remain in the wastewater until it is consumed by plants as plant's protein. Biochemical Oxygen Demand (BOD) is the amount of oxygen required by microorganisms to decompose the biodegradable organic matter. The BOD content in wastewater indicates the amount of biodegradable organic matter. According to the results of tests the BOD content decreases after treatment. Although the efficiency of reduction in content is less, which is supposed to be 70% normally, addition of more such models connected in series can ensure greater BOD removal. Similarly, since the sulphate is the stable end product of sulphur cycle, its content must increase after treatment. Conforming to this, the results of tests on sulphate content show that the sulphates content increases after treatment to four times the original sulphate before treatment. Sulphates remain in the wastewater until it being used by the plants as plant's protein.

Finally, assuming sludge production to be 0.6 kg/kg of BOD_5 removed, the sludge produced perlitre of treated sample taken = 0.6 × BOD_5 removed from the per litre of sample

= 0.6 × (125.37-60.50)

= 38.92 mg/l

And, daily sludge production

= Q × sludge produce per litre of wastewater

= 754 × 38.92

= 29.34 g/day

IV. CONCLUSION

The BOD removal efficiency of 52% has been achieved from above RBC as compare to that of 70% for standard RBC. Therefore, little modification in components and its design may improve the efficiency considerably. However, for exceptional cases such as lack of locally available materials, the results i.e. BOD_5, sulphate, nitrites, and nitrates removal efficiency of table 3.1 are quite satisfactory.

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