The oxygenic photogranule for wastewater treatment process

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Abstract. Wastewater treatment is an energy-intensive process. During secondary wastewater treatment, unwanted characteristics like Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD) etc. are reduced to permissible levels with the help of bacteria as this is a microbe driven process. A novel method of cultivating Oxygenic Photo Granules (OPGs) which are natural aggregates predominantly consisting of cyanobacteria from the activated sludge and using it to treat the wastewater in the secondary treatment is under development. After the primary treatment, OPGs help to substitute the high energy-consuming aeration equipment which deems the secondary process more sustainable. Cultivation of OPGs is influenced by many factors including the intensity of light used during cultivation, the concentration of sludge etc. Manipulating these factors, we can cultivate OPGs in the most efficient way possible. The objective of this work is the optimization of the time constraints for developing OPG samples, then analyze the energy saving of this process at a pilot scale. OPGs substitute the aeration equipment in the secondary treatment process, and they are mix evenly with the wastewater to be treated in a sequential batch reactor. Upon continuous stirring followed by settling and decanting, the wastewater is treated and analyzed. Utilization of OPGs in wastewater treatment not only saves energy but is also efficient than the conventional method, thereby making this process a more economical option.

1. Introduction
For the past few years, the generation of wastewater has been rapidly increasing with population growth, urbanization and industrialization. Most of the wastewater treatment methods are energy-intensive and have some disadvantages like high surplus biomass production, low flexibility with respect to fluctuating loading rates. So biological treatment methods are given more importance as it is environmentally friendly, resulting in less chemical use and energy input. Microbial granulation can be used as an alternative method to attain high treatment efficiency. In aquatic environments, algae and bacteria play a crucial role in nutrient cycling and contaminants removal by biosynthesis and biological metabolic process. A combined system of algae and bacteria has been extensively studied for application in wastewater treatment. These aggregates are often called as granules. Their specific gravity allows them to settle in the aqueous environment rapidly. Granules used in biotechnology have so far mostly involved non-phototrophic biomass. Only recently, in the wastewater treatment context, the development of oxygenic photo granules (OPG) has been described as a promising novelty[2]. OPGs are the most recent addition to the family of bio-granules for biotechnological
applications. OPGs generate oxygen from photosynthesis and may push the diversity of microorganisms to an extreme by providing a steep redox gradient across the granule diameter as demonstrated for microbial mats. That makes combined nitrification or denitrification activities or phosphorous removal in single-stage biomass. In addition, oxygen that is produced by the photo granules could reduce or entirely eliminate costly mechanical aeration of activated sludge in wastewater treatment. At the same time, autotrophic CO2 fixation in photo granules produces biomass that could serve as a renewable energy source. Much successful OPGs cultivation has been performed under a variety of conditions and from a variety of municipal waste streams around the world[7]. It is an algal sludge granule wastewater treatment process based on photo granulation of activated sludge into OPGs. During maturation, granules increase their net density via compaction. OPGs are dense, spherical and easily settleable granules that work without external aeration and consume more carbon dioxide, reducing the greenhouse gas emissions. Thus it has the potential to reduce the municipal wastewater treatment cost.

2. Experiments and methods

2.1. OPG cultivation
Activated sludge samples were collected from the aeration basin of the Sewage Treatment Plant, Golden Jubilee Hostel, TKMC Hostels, Kollam. The experimental procedure involves filling of the glass vials (15mL) with 7 mL sludge. The vials are placed in an incubator which is provided with illumination. Granulation takes place within the vials in the incubator. During granulation, the vials are kept undisturbed. The incubator is illuminated with LED lights of 18W, throughout the day at room temperature. The vials are illuminated for 12 hours using sunlight and 12 hours using LED bulbs within the incubator. The biomass in one vial yields precisely one photogranule that is typically situated at the bottom of the vial. The vials are observed at regular intervals to check on the progression of OPG growth. To determine the success of granulation, the shake test was performed by using three firm vertical shakes and then observing the vial contents. When a granule remained without particulates in the bulk liquid, granulation was considered as successful.

2.2. OPG characteristics

2.2.1. Settling velocity. Settling velocity of OPG is determined by dropping the granule into a 1 L capacity measuring cylinder filled the water up to 800ml mark. The time taken by the OPG to reach the bottom of the cylinder or to a predetermined mark is noted. Also, note the distance travelled by the granule. Settling Velocity is calculated using the following equation:

\[
\text{Settling velocity} = \frac{\text{Distance}}{\text{Time}} = \frac{D}{t}
\]  

(2.1)

2.2.2. Density. For the determination of the density of granules, the weight of granule is noted. The volume of the granule is determined by placing the granule inside a container which was filled with water completely. The amount of water displaced from the container due to the granule will provide the volume. The density of granule was calculated using the equation:

\[
\text{Density} = \frac{\text{Mass of granule}}{\text{Volume of granule}} = \frac{M}{V}
\]  

(2.2)

2.3. Wastewater collection
The wastewater used in this study was obtained from the collection tank of the sewage treatment plant, Golden Jubilee Hostel, TKMC Hostels, Kollam. The standard method for examination of water and wastewater was conducted in Cashew Export Promotion Council of India (CEPCI) Laboratory Kollam.

2.4. Reactor setup
Sequencing Batch Reactor was used in the experiment, and it has a working volume of 1 L. The reactor was installed in the ambient room temperature that has no temperature regulatory facility. The
reactor is seeded with precultured mature OPGs, and a stirrer is provided to prevent the settling of the granules.

2.5. Chemical analysis
The standard method for the examination of water and wastewater was conducted at Cashew Export Promotion Council of India (CEPCI) Laboratory Kollam.

3. Results and discussion

3.1. Initial characteristics of sludge used for OPG’s synthesis
The OPG synthesizing sludge’s initial characteristics are studied. The table shows the initial characteristics of sludge collected from the Sewage Treatment Plant, Golden Jubilee Hostel, TKMC Hostels Kollam.

| Sl. No. | Sludge No. | Total Suspended Solids (mg/L) | Fixed Solids (mg/L) | Power Rating (W) |
|---------|------------|-------------------------------|---------------------|------------------|
| 1       | Sludge 1   | 125000                        | 1000                | 9                |
| 2       | Sludge 2   | 52000                         | 450                 | 9                |
| 3       | Sludge 3   | 125000                        | 1000                | 18               |
| 4       | Sludge 4   | 52000                         | 450                 | 18               |
| 5       | Sludge 5   | 125000                        | 1000                | 27               |
| 6       | Sludge 6   | 52000                         | 450                 | 27               |

3.2. Photogranulation progression
From the sludge samples given above in the Table 1 characteristics of sludge3, were favourable for successful granulation while the other five samples failed at some point of time of granulation and due to the low TSS and FS contraction in Sludge 4 it dies not to give successful granules. From the above result, we can conclude that OPG formation is not successful at a higher or lower intensity of light, but they require an optimal intensity for their growth. The granules were formed by the end of the 34th day and was confirmed successful by performing the vertical shake test. It was found that under a batch static condition with light, typical activated sludge mixed liquor changes to a dense spherical aggregate of algae-sludge biomass. Unlike the flocs or aggregates in activated sludge, seed OPGs formed were dense, pellet-like aggregates with a diameter of 4-10 mm. OPGs generation in the reactor was a consistent and gradual process which was checked out through many stages of developing and maturation that was identified by the change in the shape, structure and sphericity of OPG besides the increase in OPG numbers, diameters and TSS concentration. Figure 1 shows the progress of photogranulation process.
3.3. Characteristics of oxygenic photogranules

3.3.1. Properties of Oxygenic Photogranules. Table 2 shows the properties of OPG developed from sludge under the static condition with light. Properties of OPG were determined by performing various experiments in the laboratory.

Table 2. Properties of Oxygenic Photogranules

| Sl. No. | Characteristics       | Value     |
|---------|-----------------------|-----------|
| 1       | Size (mm)             | 4 to 10   |
| 2       | Settling velocity (m/hr) | 36        |
| 3       | Density (kg/m$^3$)    | 1250      |

3.4. Comparative assessment - activated sludge process & oxygenic photogranule process

The results obtained after treating real wastewater using OPGs without aeration and Activated Sludge Process with external aeration are
Table 3. Parameters of sewage after ASP

| Parameter     | Initial Value | ASP |
|---------------|---------------|-----|
| COD (mg/L)    | 103           | 51.6|
| TSS (mg/L)    | 39            | 28  |
| Nitrate (mg/L)| 6.0           | 1.2 |
| Phosphate (mg/L) | 76.4      | 11.8|
| BOD (mg/L)    | 25            | 12.0|

Table 4. Parameters of sewage after OPG Process

| Parameter     | Initial Value | OPG Process |
|---------------|---------------|-------------|
| COD (mg/L)    | 124           | 50          |
| TSS (mg/L)    | 42            | 22          |
| Nitrate (mg/L)| 8.0           | 1.0         |
| Phosphate (mg/L) | 75.2     | 11.0        |
| BOD (mg/L)    | 28            | 10          |

Table 3 and Table 4, shows that oxygenic photogranule process is better than activated sludge process for treating wastewater, especially for the removal of chemical oxygen demand and nutrients such as nitrate and phosphate. Sludge produced after treatment can be used for generating bioenergy feedstock, e.g. biodiesel, fertilizer, bioethanol and biomass that can be burned to produce heat and electricity. Activated sludge process requires external aeration for treating sewage. Hence it consumes a large amount of energy in the form of electricity. But OPG treats sewage effectively without external aeration. Therefore, OPG process is a cost-effective method for the treatment of sewage. Table 5 shows the efficiency of ASP and OPG process in treating sewage.

Table 5. Efficiency of ASP & OPG Process in sewage

| Parameter     | COD (mg/L) | TSS (mg/L) | Nitrate (mg/L) | Phosphate (mg/L) | BOD (mg/L) |
|---------------|------------|------------|----------------|------------------|------------|
| ASP Initial value | 103        | 39         | 6.0            | 76.4             | 25         |
| Final value   | 51.6       | 28         | 1.2            | 11.8             | 12.0       |
| OPG Process   | 124        | 42         | 8.0            | 75.2             | 28         |
| Initial value | 50         | 22         | 1.0            | 11.0             | 10         |
| Efficiency of ASP (%) | 49.90 | 28.20 | 80.00 | 84.55 | 52.00 |
| Efficiency of OPG Process (%) | 59.68 | 47.62 | 87.50 | 85.37 | 64.29 |

Table 5 shows that OPG process is better than activated sludge process for wastewater treatment. OPG obtain better COD and nutrients removal without external aeration as compared to the activated sludge process. Figure 2 shows the bar diagram for the efficiency of ASP and OPG process in treating sewage.
3.5. **Energy comparison - activated sludge process & oxygenic photogranule process**

3.5.1. **Energy Consumption by OPGs Method.** Total energy consumption per day is calculated as follows:

Based on 65000 L wastewater treatment per day

OPG synthesis energy consumption:

For 1 L we need 5 OPG

The volume of reactor = \( \frac{65000}{6} \) (Presently treatment done as six equal time shifts) = 10833 L

No. of OPG required = 10833*5 = 54165

For 150 OPGs we require 216 Wh (18 W LED light for 12 hrs. and remaining 12 hrs. sunlight is used)

Energy required for synthesis 54165 OPGs = \( \frac{216}{150} \) * 54165 = 77998 Wh

OPG life span is approximately two months, (After day 74 the hydraulic retention time reduces and COD, Nitrogen removal does not take place effectively[4])

I.e., the energy consumption of OPG synthesis = \( \frac{77998}{2} \) = 38.998 kWh

**Table 6. Energy consumption per day by OPGs Method**

| Sl. No. | Process Description                                      | Type of Equipment | Power | Hours | Energy Consumption (kWh) |
|--------|----------------------------------------------------------|-------------------|-------|-------|--------------------------|
| 1      | For pumping the wastewater from equalizer to reactor     | Pump              | 1 HP  | 9     | 6.714                    |
| 2      | Wastewater mixing in equalizer                           | Stirrer           | \( \frac{1}{2} \) HP | 24    | 8.952                    |
| 3      | Mixing done in reactor                                   | Stirrer           | \( \frac{1}{2} \) HP | 24    | 8.952                    |
| 4      | For Multi-Grade(Sand) Filtration                         | Pump              | 2 HP  | 9     | 13.428                   |
| 5      | For Activated Carbon Filtration                          | Pump              | 2 HP  | 9     | 13.428                   |
| 6      | Pumping after treatment                                  | Pump              | 3 HP  | 9     | 20.142                   |
| 7      | OPG’s Synthesis                                          |                   |       |       |                          |
|        | TOTAL                                                    |                   |       |       | 38.998                   |

**Figure 2.** Efficiency of ASP & OPG Process in treating sewage.
3.5.2. Energy consumption by aeration method. Total energy consumption per day is calculated as follows

**Table 7. Energy consumption per day by Aeration Method**

| Sl. No. | Process                                           | Type of Equipment | Power | Hours | Energy Consumption(kWh) |
|--------|--------------------------------------------------|-------------------|-------|-------|--------------------------|
| 1      | For pumping the wastewater from equalizer to reactor | Pump              | 1 HP  | 9     | 6.714                    |
| 2      | For Aeration                                     | Blower            | 5 HP  | 24    | 89.520                   |
| 3      | For Multi-Grade(Sand) Filtration                 | Pump              | 2 HP  | 9     | 13.428                   |
| 4      | For Activated Carbon Filtration                  | Pump              | 2 HP  | 9     | 13.428                   |
| 5      | Pumping after treatment                          | Pump              | 3 HP  | 9     | 20.142                   |
|        | **TOTAL**                                        |                   |       |       | **143.232**              |

3.5.3. Energy comparison.

3.5.3.1. Wastewater treatment process. From Table 6 and Table 7, it is clear that the energy consumption for aeration method is high as compared to OPG method.

Energy consumption per day by Aeration Method =143.232 kWh

Energy consumption per day by OPG Method =110.612 kWh

Energy saving =143.232-110.612

=32.62 kWh

% Energy saving = (32.62/143.232)*100

=22.77%

3.5.3.2. Secondary treatment process. Energy consumption per day for Secondary Treatment Process by Aeration Method (Aeration only) =89.520 kWh

Energy consumption per day for Secondary Treatment Process by OPG Method (OPG Synthesis, mixing in equalizer and reactor) =38.998+8.952+8.952 kWh

=56.902 kWh

Energy saving =89.520-56.902

=32.618 kWh

% Energy saving = (32.618/89.520)*100

=36.44%

4. Conclusion

Domestic, municipal, & industrial wastewater treatment is very important and required great attention before the discharge of water into the water resource. The novel method of treatment of wastewater using Oxygenic Photo Granules (OPGs) shows promising results. As the technologies are moving towards sustainability, the energy-efficient treatment process using OPGs is very significant. In this work, the energy-intensive aeration process is substituted by OPGs. Result obtained from this work gives a clear indication that wastewater treatment using OPGs are efficient process compared to the conventional activated sludge process. OPGs allow the recovery of chemical energy from wastewater in the form of bioenergy feedstock. There is a considerable reduction in waste sludge generation and energy cost. The treatment of wastewater using OPGs is currently being done on a pilot-scale which upon scaling up will lead us one step towards sustainability.
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