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How Can A Cost-Effective Method for Industrial Wastewater Treatment Be Developed in India?

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ABSTRACT

Wastewater treatment and repurposing will be pivotal for growing economies as demand for water increases. A sustainable approach toward economic development in India would be treating industrial wastewater for agricultural applications, reducing overall water consumption, and feeding one sector of the Indian economy with effluent from another. To achieve this, a cost-effective and sustainable treatment process needs to be developed. This paper provides a comprehensive analysis of the available methods and equipment for wastewater treatment through a brief literature review. A four-stage treatment was considered, including pretreatment, primary and secondary chemical treatment, and post treatment. The overall process features screening, oil skimming, coagulation, flocculation, sedimentation, aeration, and gravel filter. The most important specifications suitable for India include using spent poly-aluminum chloride as a coagulant and flocculant (CPCB, 2022) and using vertical shaft aerators (Drewnoski, et. al., 2019) and high-efficiency blowers (Bell, et. al., 2011) in the aeration process.

1. Introduction

Billions of liters of industrial wastewater are discharged without treatment in India every day. According to a United Nations country report on Wastewater production treatment and use in India (Kaur, Wani, Singh, Lal), only 60% of industrial wastewater is treated properly. (Most of the industrial wastewater is sent to common effluent treatment plants (CETPs), which as of now, don't re-use the treated water and discharge in water bodies.

On the other hand, India needs to sustain its growing population with a large agriculture sector, which needs to be supported by irrigation methods. The food security of India depends on the supply of irrigation water and the quality of that irrigation water (UNEP, 2023) The United Nations Sustainable Development Goals (SDGs) outline the importance of working towards a world with zero hunger (SDG 2) and access to clean water (SDG 6). Clean irrigation water is key for humanity to accomplish SDG 2. According to (Ringler, Cline, Rosegrant, 2009), India has achieved an improvement in agricultural output due to improved water supply. Apart from irrigation, procurement of fertilizers is also key for agriculture in India: this additional cost raises the price of any crop-based food in Indian markets.

The paper aims to solve SDG 6, by ensuring the supply of water to the agriculture sector in India despite exponential growth in water consumption in India due to the expansion of industry. The paper compiles all the newest developments in water treatment methods and presents an optimized, cost-effective, step-by-step treatment process. The paper presents a 4 stage approach incorporating the following processes: Stage 1 (screening, oil skimming); Stage 2 (coagulation, flocculation, sedimentation); Stage 3 (aeration); and Stage 4 (passing through gravel filter).

2. Methodology

2.1. Forming the Research Question

The research question was selected because of the impact wastewater management will have on the country, especially taking into consideration India's high ceiling for industrial growth. Repurposing the wastewater into the Agriculture sector would help millions of farmers across the country, who all rely on irrigation water supply to produce food for the country (Brar, 2009.) The research question was deemed fit to investigate due to the potential socio-economic benefits addressing such a problem may have on the country.

2.2. Literature Search Strategy

A wide range of Databases, such as JSTOR, PubMed, and Google Scholar were used to find the literature required to present for analysis and review. An AI-driven research tool, Elicit was used to streamline search efforts and find specific papers on some of the nuances of wastewater treatment Newer articles, published in the last ten years, were favored, however, older articles were thoroughly considered and reviewed as well. Work present in peer-reviewed journals was prioritized wherever possible and documents issued by large organizations such as the UN and Central Pollution Control Board of India were extensively referred to.

2.3. Data Extraction and Analysis

A wide range of both qualitative and quantitative secondary data was used from multiple sources when providing information to address the research question. The focus was on the main findings of reference literature, and trying to find secondary data to provide readers of this paper a clear answer and explanation to the research question. Any qualitative data was always checked in terms of its relativity to the research question. Analysis of existing data was then checked by an expert in the field: Mr. A.L. Garg, a Chemical Engineer who has been in the Indian Pigment industry for 30+ years. His expertise was key in making decisions revolving around the selection of certain equipment and methods to best address the need for a cost-effective wastewater treatment strategy.

3. Literature Review

3.1. Stage 1- Pretreatment

Screening is a form of primary treatment of wastewater and is a simple physical separation of wastewater and the largest particles (eg polyethylene bags) floating in it. The finest screening processes that can remove hair, seeds, etc. from wastewater only constitute up to 3% of the total operating cost of an effluent treatment plant (Côté et. al., 2006.) Multiple types of screens can be constructed to remove large pollutants from wastewater. These include a vibrating screen, brush screen, and rotary drum screen, (Côté et. al., 2006) all of which have moving parts to increase the flow rate of wastewater in the screening process. When trying to tackle large amounts of wastewater usage, a high flow rate through the filter is essential for the effective operation of the treatment plant.

Oil skimming is another form of primary treatment relying on flotation. The lower-density oil eventually settles on top of the wastewater, from where it can be removed from the wastewater.

3.2. Stage 2- Primary Chemical Treatment

Wastewater contains a large number of suspended solids (SS) that need to be removed before the main treatment can take place. The methods of primary treatment discussed below in this paper are coagulation, flocculation, and sedimentation.

3.2.1. Coagulation

Coagulation is a process in which the SS present in wastewater are gathered together to form large clumps called flocs (Jiang, 2015). Coagulants like ferric chloride, aluminum chloride, and aluminum sulfate are employed to trigger the chemical reaction. The positively charged metal ions neutralize the negatively charged suspended contaminants, which causes them to bind together and form the flocs (Campbell, 2022). The most commonly used coagulants are aluminum sulfate, ferric sulfate, ferric chloride, and sodium aluminate (Campbell, 2022) all of which are purchased as salts by the wastewater treatment plant. In India, it would be far more cost-effective to use poly-aluminum chloride (PAC), which is found in the wastewater of CPC (copper phthalocyanine) green pigment factories. The majority of the CPC green factories are located in the industrial zones of Gujarat and Maharashtra, where PAC-rich wastewater can feed into established common effluent treatment plants (CETPs).

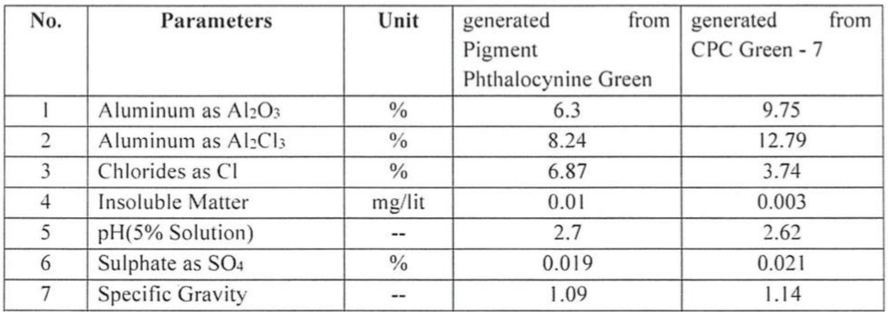
Left- Figure 1: PAC Pump brought in for a field trial

Right- Figure 2: Addition of PAC as a coagulant in the coagulation chamber

The images above (all three self-clicked and self-uploaded) depict a temporary system designed for the trial of spent PAC as a coagulant in a CETP. In this trial, PAC (in the form of CPC green effluent) was administered using a pump with a controlled flow rate and input into the flash mixer where coagulation happens.

The table below (Central Pollution Control Board, 2022) shows why the wastewater from the CPC green industry may be deemed fit as an effective coagulant.

Table 1- Overview of the coagulant and pollutant content in the wastewater from pigment phthalocyanine green (4th column) and CPC green - 7 (5th column) (Central Pollution Control Board, 2022)



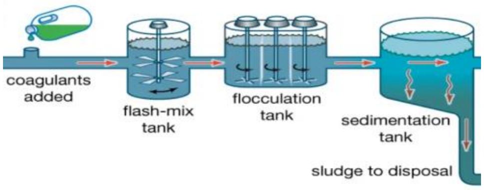
No.	Parameters	Unit	generated from Pigment Phthalocynine Green	generated from CPC Green - 7
1	Aluminum as Al_2O_3	%	6.3	9.75
2	Aluminum as Al_2Cl_3	%	8.24	12.79
3	Chlorides as Cl	%	6.87	3.74
4	Insoluble Matter	mg/lit	0.01	0.003
5	pH(5% Solution)	--	2.7	2.62
6	Sulphate as SO_4	%	0.019	0.021
7	Specific Gravity	--	1.09	1.14

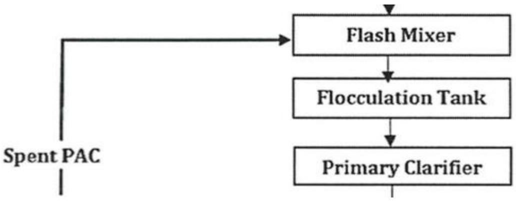
8	Sodium	mg/lit	10443	17647
9	TOC	mg/lit	260	210
10	COD	mg/lit	1080	810
Heavy Metals				
11	Cyanides	mg/lit	ND*	ND*
12	Arsenic	mg/lit	ND*	ND*
13	Total Chromium	mg/lit	2.53	0.36
14	Hexavalent Chromium	mg/lit	< 0.02	< 0.02
15	Copper	mg/lit	28.6	1.04
16	Lead	mg/lit	ND*	0.39
17	Mercury	mg/lit	ND*	ND*
18	Nickel	mg/lit	0.56	1.04
19	Zinc	mg/lit	1.42	9.62
20	Cadmium	mg/lit	ND*	0.021
21	Selenium	mg/lit	ND*	ND*

*ND = Not Detected

The data above indicates that wastewater from CPC green - 7 and phthalocyanine green plants are rich in aluminum salts, which can act as coagulants, as well as chlorides that may form coagulants by reacting with the Al_2O_3 present. This makes the effluent from these plants fit to act as coagulants which are effective enough to trigger the coagulation reaction. Furthermore, the effluent has a manageable level of COD (chemical oxygen demand) and TOC (total organic content) which can be easily removed using primary and secondary treatments. The effluent also has minimal or no amounts of heavy metals except copper in phthalocyanine green and zinc in CPC green - 7. The Zinc present is capable of reacting with chlorine to form a zinc-based coagulant that can perform on par with traditional iron or aluminum-based coagulants (Jarvis, et. al., 2012.) Copper can also perform as a coagulant similar to the way zinc would (Aqilah, et. al., 2021) but its effectiveness may be hindered by its lower reactivity. The most toxic heavy metals like Arsenic have not been detected in the effluent, making it suitable to ultimately be put into the agriculture sector. Effluent also has low levels of insoluble matter which makes it easy to employ in an ETP (effluent treatment plant). To summarize, the high coagulant dose and low contribution to the overall toxicity of the wastewater make the wastewater from CPC green and pigment phthalocyanine green industries capable of acting as coagulant and replacing traditional coagulants currently in use in the majority of India's CETPs.

The Central Pollution Control Board of India (CPCB) found this vital resource and accordingly published a guideline on the use of spent PAC in wastewater treatment. The guideline (Central Pollution Control Board, 2022) recommends that spent PAC be added to the wastewater in a flash mixer, which will act as the site for the coagulation reaction. The guideline then advises undergoing flocculation in a separate tank and then moving the water with the formed flocs into a primary clarifier, in this case, a sedimentation tank, as shown in this snippet from a diagram made by Britannica and a flowchart (Central Pollution Control Board, 2022.)





Left- Figure 3: Diagram overview of the coagulation, flocculation, and sedimentation process (Britannica, YEAR)

Right: Figure 4: Flowchart of the coagulation, flocculation, and sedimentation process (CPCB, 2022)

3.2.2 Flocculation

Flocculation is a process in which all the SS and colloidal particles are included within the larger flocs. The objective is to obtain flocs large enough that they can be easily separated through sedimentation. Many methods have been proposed for increasing the efficiency of the flocculation process by either manipulating the properties of flocs such as pH, temperature, flocculant used, and dosage of flocculant (Zaki, et. al., 2023,) or by altering the design of the flocculator itself.

The ideal flocculant for this system would be any sort of poly-electrolyte. Spent PAC can potentially be used as a flocculant again (Jie, 2008,) however it may not work in this system since PAC was already the coagulant. PAC as a flocculant was paired with a silicon-based substance to be efficient (Jie, 2008.) Other poly-electrolytes such as Al_2SO_4 (Radoiu, et. al., 2004) and a variety of organic options have been proven efficient but they will have to be bought, increasing the cost of the water treatment method. Instead, a mixed approach of using the available spent PAC coupled with a smaller quantity of another polyelectrolyte which can be purchased based on the market price and availability.

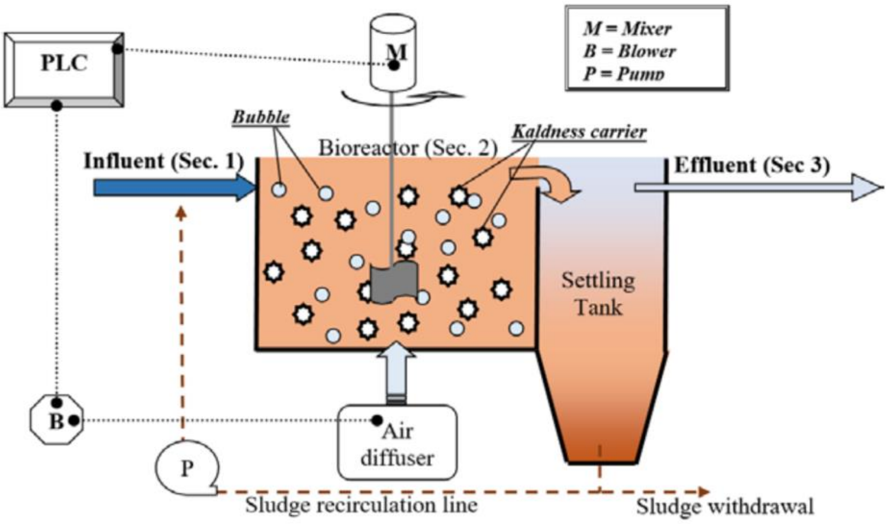
3.2.3. Sedimentation

Sedimentation occurs in a large tank, where erstwhile flocs sink to the bottom of the effluent and can be discharged as sludge (Sontheimer, 1978.) Water near the top and middle areas of the tank can be deemed clean enough for the next stage of treatment and be removed through a separate channel installed higher up in the tank.

3.3 Stage 3- Secondary Chemical Treatment

Aeration is a chemical process in which microorganisms consume the COD and BOD of wastewater through aerobic respiration (Alam, et. al., 2002.) Aeration is a treatment where the wastewater is in a very large volume and has a relatively low concentration of pollutants (Fonade, et. al., 2001,) meaning that it is conventionally carried out in large manmade lagoons (Uggetti, et. al., 2016) or tanks (Bella, et al., 2020.) The aeration process involves the creation of an activated sludge (Bella, et al., 2020,) consisting of aerobic bacteria which can consume the COD of the wastewater. The bacteria is supplied oxygen by blowing bubbles of air through the wastewater, typically having the bubbles input from the bottom of the tank (Drewnowski, et. al., 2019.) The air supply ensures that the respiration is aerobic (no oxygen deficiency) in nature.

Figure 5: Aerator (Bella, et al., 2020)



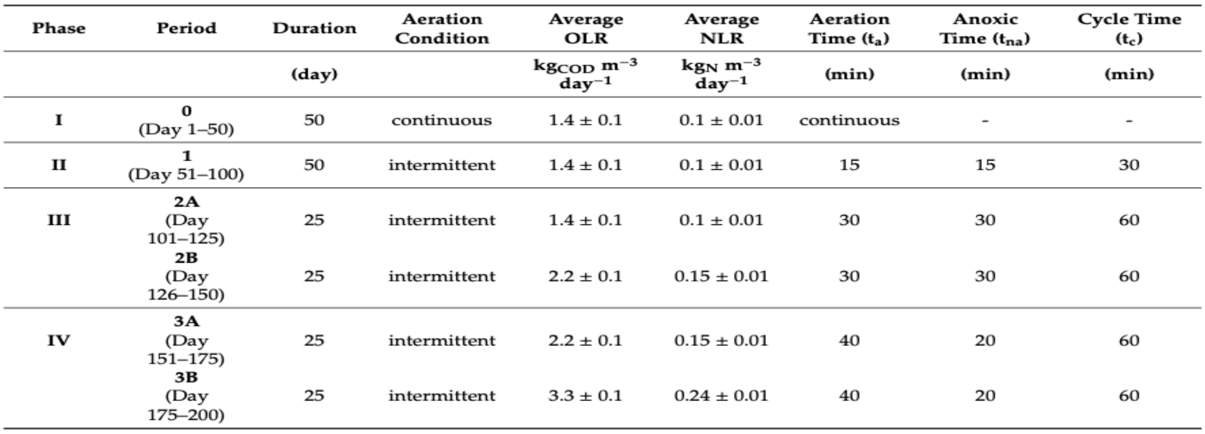
The diagram of an aerator (Bella, et al., 2020) above shows all the basic parts that constitute a functioning aerator. The influent pours into a reactor where the activated sludge (biofilm) is present on Kaldness Biofilm Carriers. These small polyethylene contraptions help evenly distribute the biofilm (and henceforth, the bacteria) across the aerator (Aygun, et. al., 2014.) Air is bubbled through the bottom of the chamber using a diffuser to shape the bubbles (Drewnowski, et. al., 2019) and a blower to provide air at a pressure high enough for bubbles to form at that depth. The reaction is sped up using a mixer, and once complete the water is put into a settling tank. This is where the majority of the sludge settles and separates from the effluent.

The following section describes modifications to the conventional aeration process which are capable of saving energy and hence cutting down operating costs. The modifications are intermittent aeration process, diffuser selection, and blower selection.

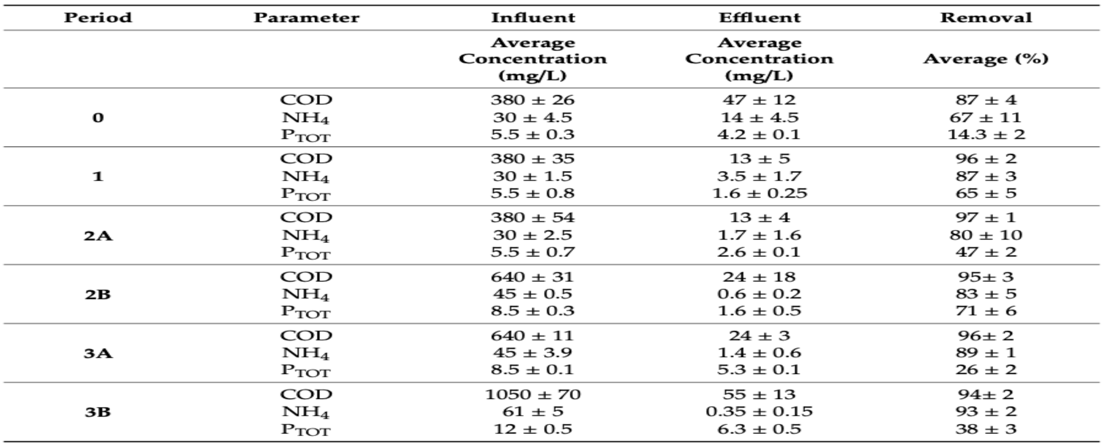
3.3.1. Intermittent Aeration Process

Conventional aeration requires the blower and diffuser to be in action for the entire duration of the aeration process, ensuring that completely aerobic aeration takes place. However, newer methods (Uggetti, et. al., 2016) propose intermittent aeration which combines aerobic and anoxic (constant oxygen deficiency) respiration. The reaction takes place in a cycle, where the blower and diffusers are turned on/off to alternate between aerobic and anoxic respiration. Not only is this process capable of saving energy (Uggetti, et. al., 2016) but also it may yield a higher COD and pollutant removal than the conventional method (Bella, et al., 2020.)

Tables 2 and 3: Overview of pollutant removal capabilities of several intermittent aeration strategies (Bella, et al., 2020)



Phase	Period	Duration	Aeration Condition	Average OLR	Average NLR	Aeration Time (t_a)	Anoxic Time (t_{na})	Cycle Time (t_c)
		(day)		kg_{COD} m^{-3} day^{-1}	kg_N m^{-3} day^{-1}	(min)	(min)	(min)
I	**0** (Day 1–50)	50	continuous	1.4 ± 0.1	0.1 ± 0.01	continuous	-	-
II	**1** (Day 51–100)	50	intermittent	1.4 ± 0.1	0.1 ± 0.01	15	15	30
III	**2A** (Day 101–125)	25	intermittent	1.4 ± 0.1	0.1 ± 0.01	30	30	60
	2B (Day 126–150)	25	intermittent	2.2 ± 0.1	0.15 ± 0.01	30	30	60
IV	**3A** (Day 151–175)	25	intermittent	2.2 ± 0.1	0.15 ± 0.01	40	20	60
	3B (Day 175–200)	25	intermittent	3.3 ± 0.1	0.24 ± 0.01	40	20	60



Period	Parameter	Influent	Effluent	Removal
		Average Concentration (mg/L)	Average Concentration (mg/L)	Average (%)
0	COD	380 ± 26	47 ± 12	87 ± 4
	NH_4	30 ± 4.5	14 ± 4.5	67 ± 11
	P_{TOT}	5.5 ± 0.3	4.2 ± 0.1	14.3 ± 2
1	COD	380 ± 35	13 ± 5	96 ± 2
	NH_4	30 ± 1.5	3.5 ± 1.7	87 ± 3
	P_{TOT}	5.5 ± 0.8	1.6 ± 0.25	65 ± 5
2A	COD	380 ± 54	13 ± 4	97 ± 1
	NH_4	30 ± 2.5	1.7 ± 1.6	80 ± 10
	P_{TOT}	5.5 ± 0.7	2.6 ± 0.1	47 ± 2
2B	COD	640 ± 31	24 ± 18	95± 3
	NH_4	45 ± 0.5	0.6 ± 0.2	83 ± 5
	P_{TOT}	8.5 ± 0.3	1.6 ± 0.5	71 ± 6
3A	COD	640 ± 11	24 ± 3	96± 2
	NH_4	45 ± 3.9	1.4 ± 0.6	89 ± 1
	P_{TOT}	8.5 ± 0.1	5.3 ± 0.1	26 ± 2
3B	COD	1050 ± 70	55 ± 13	94± 2
	NH_4	61 ± 5	0.35 ± 0.15	93 ± 2
	P_{TOT}	12 ± 0.5	6.3 ± 0.5	38 ± 3

The data above shows the effectiveness of using the intermittent aeration method. Phase 0, (conventional aeration, fully aerobic) shows an estimated removal of 87% COD and 14.3% total pollutants. Phase 1 involves 30-minute cycles of alternating aerobic and anoxic respiration. It shows far more effective results than stage 0, with 96% COD and 65% total pollutant removal. Switching to 60-minute cycles reduces the system's efficiency, consuming equal energy but yielding worse results: the removal of COD is the same as phase 1 but with a far lower total pollutant removal. Increasing aeration time as shown in stage 3 yields similar results to stage 2. Hence the data above (Bella, et al., 2020) presents the idea that stage 1, 30-minute alternating cycles between aerobic and anoxic respiration is the optimal strategy for intermittent aeration.

The use of intermittent aeration also reduces the costs of operating a wastewater treatment plant. The conventional aeration method is responsible for 55% (Dotro et. al., 2011) of the total energy consumption in a wastewater treatment plant. Aeration is energy intensive because the blower needs to provide a constant supply of high-pressure air (Drewnowski, et. al., 2019) for elongated periods. Instead, the intermittent aeration method reduces energy consumption by reducing the total time the blower is active. The data by Bella, et al., 2020 suggests the idea of reducing the total time the blower is active by half can be a feasible strategy in terms of pollutant removal effectiveness. The operating costs, especially energy consumption are a key factor when fine-tuning the aeration process to develop a wastewater treatment system in India.

Intermittent aeration has clear advantages over the conventional method, however, there are a few downsides to this practice. During the anoxic process, the bacteria perform incomplete nitrification (Dotro et. al., 2011,) converting the nitrogen present in pollutant ammonia to nitrite (NO_2) ions. Meanwhile, fully aerobic aeration is known to produce nitrate (NO_3) ions. Nitrite ions are rendered far less desirable than nitrate ions because they produce nitrogen dioxide gas, which is harmful to the environment. Nitrogen dioxide gas is a more effective greenhouse gas than carbon dioxide, meaning smaller concentrations may also harm the environment in the long run (Dotro et. al., 2011.) It is safe to say that the environmental impact of the anoxic process cannot be underplayed when deciding on a new system for wastewater treatment in India.

3.3.2. Diffuser Selection

Diffusers are instruments responsible for creating air bubbles at the bottom of the aeration vessel to ensure the supply of oxygen gas to the bacteria. In industry, there are two main types of diffusers available: fine-pore and coarse-pore diffusers (Rosso, et. al., 2008.) Fine pore diffusers are the most commonly used diffusers due to their high oxygen transfer efficiency of 2.0 to 2.5 kg of O_2 per kWh of energy consumed (Drewnowski, et. al., 2019.) These diffusers also produce small bubbles, which can better dissociate oxygen to the bacteria than larger bubbles. The use of many small bubbles ensures that the air is well spread throughout the aeration vessel so that all of the bacteria have the air supply necessary to perform aerobic respiration. However, the fine-pore diffusers are very prone to fouling and scaling, leading to high maintenance costs and a reduction in O_2 transfer efficiency if left unchecked. Maintaining a diffuser system fixed to the bottom of the aeration vessel will also be an arduous task. To fix an individual diffuser, the whole tank needs to be emptied (Rosso, et. al., 2008.) After emptying, fouling (formation of slime and algae) can be fixed by washing with clean water and cleaning the diffusers. Scaling (deposits of silica, calcium carbonate, gypsium, etc.) (Rosso, et. al., 2008) can be solved by washing with 10% to 15% HCl solution. The maintenance of fine-pore diffusers will become a very frequent task, leading to the aeration vessel being emptied and re-filled regularly, stopping the treatment process for intervals of time. On the other hand, if fine-pore diffusers are left unmaintained, their O_2 transfer efficiency will drop, removing the advantage

. Hence, anyone adopting fine-pore diffusers for large-scale wastewater treatment in India will face the paradox of either regularly shutting down the aeration process or suffering from a sub-optimal level of O_2 transfer efficiency.

Coarse-pore diffusers have a lower transfer efficiency than the fine-pore versions, at only 0.8 to 1.2 kgO_2/kWh (Drewnowski, et. al., 2019.) They produce large air bubbles, not only much more difficult to form at high pressure due to the overhead wastewater but also much worse at distributing oxygen throughout the activated sludge. The blower would have to operate at a much higher flow rate of air, substantially increasing the energy costs. While the coarse-pore diffusers are far less susceptible to fouling and scaling, the two will still take a toll on diffusers over a long period. For maintenance, the vessel will have to be emptied and diffusers cleaned in the same way as fine-pore diffusers (Rosso, et. al., 2008.) While a coarse-pore diffuser-based aeration process will not be brought to a halt as frequently as the fine-pore version, the high operating costs of the blower will discourage the use of coarse-pore diffusers for large-scale wastewater treatment in India.

The use of shaft aerators should be considered due to their easier maintenance. Vertical and horizontal shaft aerators can have an O_2 transfer efficiency of up to 2.0 kgO_2/kWh (Drewnowski, et. al., 2019.) The horizontal shaft aerator can be accessed and maintained easily and is capable of rotating and hence distributing O_2 efficiently to all the sludge. It is conventionally installed very close to the surface level, requiring airflow at a lower pressure and saving on blower operating costs. However, a wastewater management project where the depth of the aeration tank is minimal might be a problem due to the large amounts of land needed to build such an aeration plant. When dealing with large volumes of wastewater, deep tanks need to be constructed to have the aeration plant fit in an affordable plot of land. Furthermore, the horizontal shaft aerator is known to be more prone to damage induced by cold weather (Drewnowski, et. al., 2019,) although this should not be an issue taking into consideration the warm climate of India's industrial regions.

The vertical shaft aerator has the same O_2 transfer efficiency as the horizontal (Drewnowski, et. al., 2019) and it can reach deeper points in an aeration tank. They can be maintained as floating or suspended sets of devices (Drewnowski, et. al., 2019,) designed to be removable from the aeration tank for maintenance. The vertical shaft aerator can, however, cause mechanical disruption of the flocs in the activated sludge unless a small diameter is maintained while building the shaft aerators (Drewnowski, et. al., 2019.) While the small diameter and need for mechanized floatation or suspension systems would make these instruments difficult and expensive to produce, the long-run cost efficiency that this system promises should make up the higher initial investment required.

3.3.3. Blower Selection

The blower is responsible for providing air at high pressure to the diffusers so that bubbles can be formed deep within the aeration tank. It is the instrument responsible for the most significant amount of electricity consumption in the whole wastewater treatment process (Bell, et. al., 2011.) An efficient blower, even if it requires a higher initial investment, would provide long-run cost efficiency and would cut down the daily operating costs of a wastewater treatment plant significantly. Direct-drive turbo blowers are capable of providing air at high speed and are the ideal replacement for conventional blowers (Pöyry, et. al., 2020.) Direct-drive turbo blowers have an energy efficiency of 70% to 85% and can save up to 35% on blower operating costs (Bell, et. al., 2011.) Installing them on new, large-scale aeration facilities is the ideal situation for their use (Pöyry, et. al., 2020) and is possible if the project, given its socioeconomic importance, is allocated a large enough budget to fit the costs of purchasing these machines.

3.3.4. Kaldness Carriers

Kaldness biofilm carriers are small polyethylene contraptions that can be utilized to disperse the biofilm across the aeration tank (Aygun, et. al., 2014.) They are kept suspended in the wastewater and activated sludge/biofilm (Aygun et. al., 2014) and remain inert in the vessel because the aeration bacteria are not capable of breaking down polyethylene. The carriers have a low cost and disperse the activated sludge/biofilm across the aeration tank, however, one must consider the possibility that it may lead to mechanical disruption of any mechanisms present within the tank.

3.4 Stage 4- Post-Treatment

A gravel filter separates the treated wastewater from the sludge that forms during aeration. It falls into the category of post-treatment.

4. Discussion

This section entails the proposed solution to develop a new, cost-effective, and efficient wastewater treatment system in India. The first step in this process is a pre-treatment, consisting of a screening of garbage by having the water flow through a coarse filter. This will separate large objects (leaves, polyethylene bags, etc.) which may damage machinery further down the treatment process if left unchecked. Vibrating screens (Côté et. al., 2006) need to be employed because they can increase the flow rate of the wastewater without the moving parts occupying large amounts of space. Next, the water will settle in a tank where oils are allowed to float to the top. The top layer of oil is to be removed using an oil skimmer.

The primary chemical treatment is the poly-aluminum chloride (PAC) assisted coagulation (CPCB, 2022) and flocculation (Jie, 2008) processes, as suggested by the Indian Central Control Board. PAC will be present in a quantity large enough to be an effective coagulant (CPCB, 2022) in the wastewater of CPC green and pigment phthalocyanine green plants. The same wastewater will also be used as a flocculant. While no major site trials have been done, any polyelectrolyte (PAC included) can work after PAC-based coagulation (CPCB, 2022) and PAC is capable of being an effective flocculant (Jie 2008.)

The secondary chemical treatment is the aeration method. Although the intermittent aeration approach should be followed due to the significant power savings (Bella, et. al., 2020), the 40-minute aerobic and 20-minute anoxic cycle is a more environmentally friendly approach than the 30-30-minute cycle, which results in higher pollutant removal per unit energy consumed. The former process also leads to good results in terms of COD removal (Bella, et. al., 2020) and is much safer for the environment, due to lower amounts of nitrogen dioxide gas produced during the anoxic process (Dotro, et. al., 2011,) which is why it fits the objectives of the wastewater treatment process best. The ideal diffuser system is a series of vertical shaft aerators. Not only are they energy-efficient in terms of oxygen transfer, but also they can also be removed from a tank full of wastewater, cleaned/repaired, and put back in (Drewnowski, et. al., 2020) making the maintenance/repair process easier. Each vertical shaft aerator should be suspended using a tensile and non-corrosive rope or chain, allowing individual removal for maintenance and repair. This allows the diffuser system to continue working at a high energy efficiency even if a few individual units require maintenance or repair. To increase the energy efficiency of the aeration process, direct-drive turbo blowers are to be used (Bell, et. al., 2011) so that energy costs can be cut down by up to 35%. The initial investment for both the blowers and the removal mechanisms in the diffuser system will increase the seed cost of the project, however, given its socioeconomic importance, a budget large enough may be present to fit the cost of purchasing these machines. Kaldness carriers are not present because of the risk of them interfering with the many mechanical parts present in the suspended diffuser system.

Gravel filters are employed for the post-treatment due to low operating costs and simple functioning. Ideally, the filter should be cleaned with an acidic, basic, and water washing if and when the quality of the outlet water is worse.

METHODOLOGY

Forming the Research Question

The research question was selected because of the impact wastewater management will have on the country, especially taking into consideration India's high ceiling for industrial growth. Repurposing the wastewater into the Agriculture sector would help millions of farmers across the country, who all rely on irrigation water supply to produce food for the country (Brar, 2009.) The research question was deemed fit to investigate due to the potential socio-economic benefits addressing such a problem may have on the country.

Literature Search Strategy

A wide range of Databases, such as JSTOR, PubMed, and Google Scholar were used to find the literature required to present for analysis and review. An AI-driven research tool, Elicit was used to streamline search efforts and find specific papers on some of the nuances of wastewater treatment Newer articles, published in the last ten years, were favored, however, older articles were thoroughly considered and reviewed as well. Work present in peer-reviewed journals was prioritized wherever possible and documents issued by large organizations such as the UN and Central Pollution Control Board of India were extensively referred to.

Data Extraction and Analysis

A wide range of both qualitative and quantitative secondary data was used from multiple sources when providing information to address the research question. The focus was on the main findings of reference literature, and trying to find secondary data to provide readers of this paper a clear answer and explanation to the research question. Any qualitative data was always checked in terms of its relativity to the research question. Analysis of existing data was then checked by an expert in the field: Mr. A.L. Garg, a Chemical Engineer who has been in the Indian Pigment industry for 30+ years. His expertise was key in making decisions revolving around the selection of certain equipment and methods to best address the need for a cost-effective wastewater treatment strategy.

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