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Exploring The Versatility of PVA Gel Beads as a Biomass Carrier in Domestic Wastewater Treatment

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Abstract - Water pollution arises from the discharge of domestic waste, which comprises residential, industrial, commercial, and agricultural wastewater. Traditional water treatment techniques involving aerobic/anaerobic processes may exacerbate the emission of greenhouse gases. To address this issue, a microbial-based approach utilizing polyvinyl alcohol biofilm supporting media has been introduced as a viable alternative. There is a pressing need for technologies that ensure low excess sludge yield rates and highly efficient biological treatment methods for domestic sewage. The moving-bed biofilm reactor shows significant potential in meeting these requirements. This study aims to estimate the bacterial diversity in polyvinyl alcohol (PVA) gel beads and proposes a method to mitigate excess sludge yield rates while treating domestic sewage through a moving-bed biofilm reactor system employing PVA gel beads as a biomass carrier.

The findings of the research demonstrate the efficiency of treating domestic wastewater across various parameters, including pH levels, biological oxygen demand, chemical oxygen demand, nitrate, ammonia, phosphorus, and total suspended and dissolve solids. Consequently, the use of polyvinyl alcohol (PVA) beads in domestic wastewater treatment proves effectiveness, reducing the necessity for constructing sewage treatment plants and eliminating the need for non-recyclable materials like synthetics and plastics.

Key Words: PVA gel beads, Moving Bed Biofilm Reactor (MBBR), biofilm process, Domestic wastewater treatment, sewage effluent, PVA Bio mass carrier, water recycling

1. INTRODUCTION

Water is the Substance that All living things, from small bacteria to giant blue whales need water to survive. Life as we know it would not exist if there were no water, and life exists wherever there is water. Covering about 71% of the earth's surface. Water is an odorless, tasteless, and nearly colorless chemical substance with the chemical formula H_2O. A molecule is formed by bonding two hydrogen atoms with one oxygen atom. It exists in three primary states: liquid, solid (ice), and gas (water vapor), and its unique properties make it essential for various physical, chemical, and biological processes. Water is known as a universal solvent, have the ability to dissolve a large range of chemicals. This property enables vital biological processes, from nutrient transport in organisms to the erosion of rock formations over millions of years.

Water is the essence of life; its unique properties make it vital for all known forms of life. Not only does water support us by quenching our thirst, but it also plays a vital part in different biological processes, from digestion to temperature control. Furthermore, its capacity to break down a wide extend of substances makes it a great solvent, facilitating chemical reactions essential for life. Water could be a primary ingredient in cooking and food preparation. It is utilized for boiling, steaming, washing, and rehydrating dried foods. Numerous cooking processes would be impossible if there were no water. The human body is composed of around 60% water, and keeping up appropriate hydration levels is crucial for overall wellbeing. Water is fundamental for substantial functions such as circulation, absorption, absorption of nutrients, and the regulation of body temperature. Water is fundamental for the right digestion of food and the absorption of nutrients within the digestive tract. It helps break down food particles, helps within the development of nutrients over cell membranes, and encourages the disposal of waste products.

Wastewater refers to any liquid waste originated from a community generally conveyed by a sewer is called as wastewater. it consists of wastewater from kitchen, washbasin, urinals, WC, bathrooms from public and private buildings; it also includes water from industrial processes, commercial activities, and agricultural practices and stormwater runoff and has become contaminated or altered in quality as a result, rendering it unsuitable for its original purpose. Domestic wastewater refers to water contaminated by human daily consumption. Domestic wastewater is the most polluting source of natural water bodies in India. According to reports, COD, BOD, and ammoniacal-nitrogen were among the pollutants that polluted more than 25% of India's river basin. Commonly, Domestic sewage contains a low concentration of organic pollutants, a high content of suspended solids, and numerous pathogenic bacteria and worms. If it is directly discharged into bodies of water or groundwater, it will pollute the water and cause eutrophication of lakes and river. Wastewater typically contains a variety of pollutants, including organic and inorganic substances, pathogens, chemicals, heavy metals, nutrients (such as nitrogen and phosphorus), and suspended solids. These contaminants can pose significant risks to human health and the environment if not properly treated. Proper treatment of wastewater is essential to remove these contaminants before it can be safely released back into the environment or reused for purposes such as irrigation or industrial processes.

Access to clean water and sanitation is essential for public health, economic development, and quality of life. Wastewater treatment plays a critical role in providing safe water for drinking, agriculture, industry, and recreation, contributing to the overall well-being and prosperity of communities. Waste water treatment involves converting wastewater, which is no longer suitable for use, into drain water that can be discharged back into fresh water source. The goal of its treatment is to decrease contaminants to acceptable levels, ensuring that the water is safe to be released back into the environment.

The main objective of wastewater treatment is to permit household, commercial & industrial effluent, to be dispose in a proper manner without risking a human health. Improper management of wastewater will contribute an environmental pollution, besides transmissible disease will easy to spread due to presence of pathogenic organism in waste water. Wastewater treatment is crucial for several reasons like, Untreated wastewater can contain harmful pollutants and pathogens that can harm aquatic ecosystems, wildlife, and human health. Treatment removes or reduces these contaminants before the water is discharged back into the environment, helping to protect water quality and biodiversity. Wastewater often contains disease-causing pathogens such as microbes, viruses, and parasites. Treating wastewater expels these pathogens, decreasing the hazard of waterborne diseases and securing public wellbeing. Treating wastewater allows for the recovery and reuse of valuable resources such as water, nutrients (like nitrogen and phosphorus), and energy. Recycling treated wastewater for irrigation, industrial processes, or even drinking water reduces the strain on freshwater resources and helps to preserve water. Numerous countries have regulations and guidelines in place to ensure that wastewater is treated before being released into the environment. Compliance with these regulations helps to avoid contamination and ensures that water bodies stay secure for human use and biological health.

1.1 Wastewater treatment

Excessive waste water released to land can result in the area becoming contaminated and gives emitting unpleasant odors, leading to a dirty and unhygienic environment. In addition, if a significant amount of wastewater is introduced into waters source, it can render the water septic and unsuitable for any other purpose. Hence, wastewater treatment is essential to decrease its strength and ensure its safe application on land or discharge into natural water source. A wastewater treatment system is a combination of many operations, which employ physical treatment methods, and unit processes, which utilize biological and chemical treatment methods, all aimed at reducing contaminants to a standard level.

1. **Physical treatment**

Physical treatment includes the separation of impurities from wastewater through basic physical mechanisms, such as screening, filtration and sedimentation. These processes primarily target the removal of suspended solids.

2. **Chemical treatment**

Chemical treatment involves the application of chemicals to facilitate the transformation or elimination of contaminants via chemical reactions. Examples include coagulation-flocculation for solids removal, disinfection for pathogen destruction, and chemical precipitation for phosphorus elimination.

3. **Biological treatment**

Biological treatment employs microorganisms to convert or break down contaminants. Municipal wastewater treatment plants utilize microorganisms naturally found in wastewater for biological treatment processes. Examples include the activated sludge process, Moving bed bio-reactor (MBBR), membrane bioreactor, and trickling filter. The main objective of biological treatment is to reduce biodegradable organic matter in wastewater to meet regulatory standards. Additionally, biological treatment aids in the removal of nutrients like nitrogen and phosphorus from wastewater.

2. MATERIALS

2.1 PVA Gel Beads

PVA, a synthetic polymer component, is utilized in PVA (polyvinyl alcohol) gel, which serves as a permeable hydrogel ideal for immobilizing microorganisms crucial for environmental pollutant degradation. These PVA hydrogel beads boast have exceptional surface permeability and maintain a water content ranging from 95% to 98%. With an average diameter of 150-400 µm (1.5 to 4 mm) and a specific gravity of 1.025 ± 0.01, PVA gel beads exhibit high fluidity in water and can be easily suspended due to their similar specific gravity to water. Furthermore, PVA gel beads are non-biodegradable and insoluble in water.

The extensive porosity of PVA gel beads, with a network of Minutes pores about 20 microns in diameter tunnelling throughout each bead. Beneficial bacteria can be entered in a great amount in the central protective core of the beads, hence reducing sloughing of biomass more effectively while maintaing stable treatment efficiencies. PVA gel treatment results in a reduced generation of excess sludge compared to traditional biological methods. The considerable porosity of PVA gel beads enables a high-water content, promoting favorable oxygen and nutrient permeability to the bacteria colonized within the beads. Polymerized PVA gel beads are fundamentally insoluble in water and are not recognized for their biodegradability. Also, pva gel beads finds application in both nitrification and denitrification processes, along with treating a wide range of industrial pollutants. PVA gel beads have high efficiency treatment capability using PVA gel beads can be enriched about five times over that of activated sludge. As per research findings, the surface color of PVA gel beads transitioned from white to yellow within 30 days of operation, progressing to a red-brown hue after 85 days, indicating maturation.

In PVA gel bead treatment, there is reduced sludge production, low construction and maintenance costs, and minimal space requirements for the treatment plant. The treatment employs a moving bed reactor, where bacterial cultures colonize the gel bead surfaces, creating miniature bioreactors for pollutant elimination. This method is effective under both aerobic and anaerobic conditions, with high biomass concentration being removed in the sludge. The aeration phase requires more time than the settling phase, resulting in higher removal rates for COD, BOD, TSS, VSS, TN, ammonia, nitrate, and heavy metals such as sulfate.

Fig-1: Appearance of PVA Gel Beads

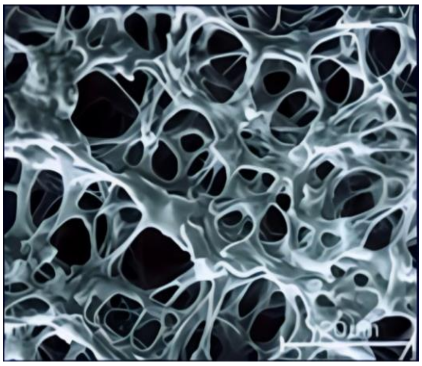


Fig -2: Microscopic Appearance of Pores of PVA Gel Bead

3. OBSERVATION OF TH EPVA GEL BEADS

The analysis of microorganisms in the PVA process involved observing the transformation of PVA-gel beads and the enrichment of microorganisms. Initially the color of PVA gel bead is white, the surface of the PVA-gel beads turned yellow after 30 days of operation, progressing to a red-brown tone after 85 days. The presence of red-brown strains on the bead surface after 85 days indicates an increase in the quantity of microorganisms adhering to the PVA-gel beads over time. At this time, the removal efficiency of NH_4 reached 96%. Previous research has noted a similar color change to red-brown when treating ammonia nitrogen sewage with PVA-gel beads.

Fig -3: Observation of the PVA Gel Beads

4. ADVANTAGES

a) PVA Gel beads with a specific gravity of 1.025±0.01, exhibit near to water specific gravity, enabling effortless mixing with less energy consumption.

b) The extensive porosity of PVA gel beads, with a network of Minutes pores about 20 microns in diameter tunnelling throughout each bead. Beneficial bacteria can be entered in a great amount in the central protective core of the beads, hence reducing sloughing of biomass more effectively while maintain stable treatment efficiencies.

c) PVA gel beads biological treatment has less production of sludge as compared to conventional biological treatment method.

d) The considerable porosity of PVA gel beads enables a high water content, promoting favourable oxygen and nutrient permeability to the bacteria colonized within the beads.

e) PVA gel is essentially insoluble in water which increases life span of beads.

f) PVA gel beads finds application in both nitrification and denitrification processes, along with treating a wide range of industrial pollutants.

5. LIMITATIONS

a) **Limited Specificity:** Hydrogel beads may not have high selectivity for specific pollutants, leading to the potential removal of beneficial ions or compounds alongside contaminants.
b) **Saturation:** The adsorption capacity of hydrogel beads is finite, and they become saturated after a certain point, requiring regeneration or replacement.
c) **Physical Stability:** Over time, hydrogel beads can degrade or break down, releasing adsorbed pollutants back into the water and reducing their effectiveness.
d) **Initial Investment:** Incorporating hydrogel bead systems might require an initial investment in terms of equipment, materials, and process optimization.
e) **Disposal Considerations:** Proper disposal of hydrogel beads after use, especially if they've captured hazardous pollutants, can raise environmental concerns.

6. APPLICATIONS

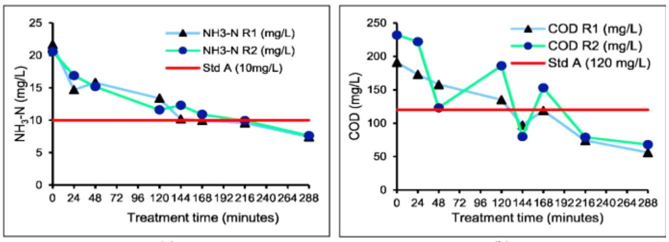
a) **Wastewater treatment:** PVA gel beads are employed in wastewater treatment as adsorbents or absorbents for the removal of various pollutants, including heavy metals, organic contaminants and dyes. These beads can allow the microorganism to colonize on the surface of the bead and within the bead for the digestion of organic matters in wastewater. PVA gel beads are useful in moving bed bioreactor for wastewater treatment process.
b) **Environmental Protection:** PVA gel beads are a vital component in enhancing biological wastewater treatment processes by facilitating the breakdown of environmental pollutants, thereby contributing significantly to environmental preservation. Their utilization boosts the effectiveness of wastewater treatment systems, aiding in the reduction of harmful substances in water bodies and promoting environmental sustainability.
c) **Control release of agricultural chemical:** PVA gel beads are employed in agriculture for the control release of chemicals such as fertilizers, pesticides and herbicides. These beads can encapsulate the active ingredients of agricultural chemicals, allowing for a gradual and sustained release over time. By controlling the releasing rate, PVA gel beads help optimize the use of chemicals, reducing waste and environmental impact while improving crop efficiency and minimizing adverse effect on soil and water quality.
d) **Biotechnology:** PVA hydrogel beads find widespread use in various applications such as enzyme immobilization, cell encapsulation, and bioreactors. These beads act as a supportive matrix for enzymes and cells, contributing to enhanced stability and activity levels.

7. SCOPE

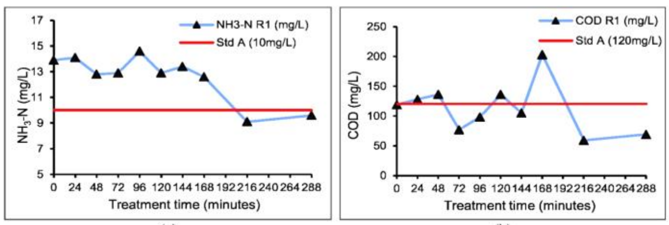
a) **Enhanced Selectivity:** Advancements in material science could lead to the development of hydrogel beads with higher selectivity for specific pollutants, minimizing the removal of beneficial ions and compounds.
b) **Hybrid Systems:** Combining hydrogel beads with other water treatment technologies, such as membranes, could lead to hybrid systems that offer complementary benefits and higher overall efficiency.
c) **Application in Remote Areas:** Hydrogel beads could play a vital role in providing clean water solutions to remote and underserved areas where traditional treatment methods might be impractical.

8. REVIEW OF RELATED LITERATURE

In their 2023 study, Nordin Sabil and Norzarina Zakaria, assessed the efficiency of polyvinyl alcohol (PVA) gel beads as carriers for immobilized biofilms to enhance the reduction of Ammonia-Nitrogen (NH_3-N) and Chemical Oxygen Demand (COD) in domestic wastewater. They created a laboratory-scale reactor to measure the reduction levels of ammonia-nitrogen and COD with and without PVA gel beads under both optimal and non-optimal treatment conditions. Utilizing an activated sludge sequencing batch reactor with a treatment cycle duration of 288 minutes, they observed that the non-optimal treatment mode achieved a more effective reduction in ammonia-nitrogen, ranging from 62.96% to 65.71%, compared to the optimal treatment mode, which attained a reduction rate of 30.94%. Additionally, treatment without PVA gel beads (in both optimal and non-optimal settings) yielded reduced rates ranging from 32.41% to 47.85%. Remarkably, incorporating PVA gel beads in the non-optimal treatment mode notably boosted the ammonia-nitrogen reduction rate from 17.86% to 18.82%, meeting the required parameter of 10mg/L for ammonia-nitrogen reduction.

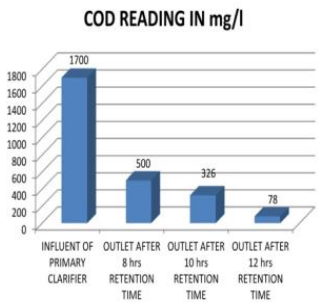


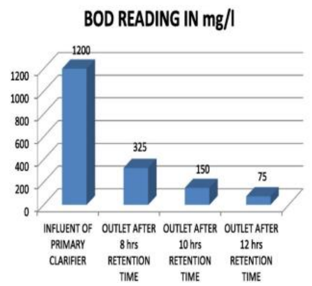
(a) (b)



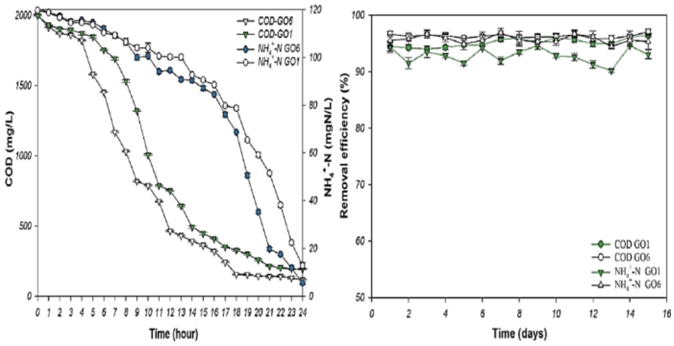
(a) (b)

In their 2015 study, Pawan G. Ramteke and Omkar P. Gurav, examined the application of PVA Hydro-Gel as a Moving Bed Bio-Mass Carrier for treating dairy wastewater. Given the global expansion of the dairy industry, the study aimed to evaluate the efficacy of a laboratory-scale biological treatment unit utilizing PVA-Gel. The initial phase involved pre-treating the PVA-Gel to facilitate the attachment and growth of biomass present in the wastewater within the gel over a 30-day period. Subsequently, a Bio-Reactor, constructed from fiberglass and measuring 25cm in height, 15cm in width, 30cm in length, with an 11-liter capacity, was employed in the second phase. The Bio-Reactor received one liter of pre-treated gel and 10 liters of wastewater from the primary clarifier, undergoing thorough mixing and aeration via a diffuser. Employing a batch process, samples were analyzed at retention times of 8, 10, and 12 hours, demonstrating a decline in BOD and COD levels. BOD decreased from 1200mg/lit to 325, 150, and 75 mg/lit, while COD decreased from 1700mg/lit to 500, 326, and 78 mg/lit, respectively. Additionally, a reduction in biological treatment time with decreased sludge volume production was observed.

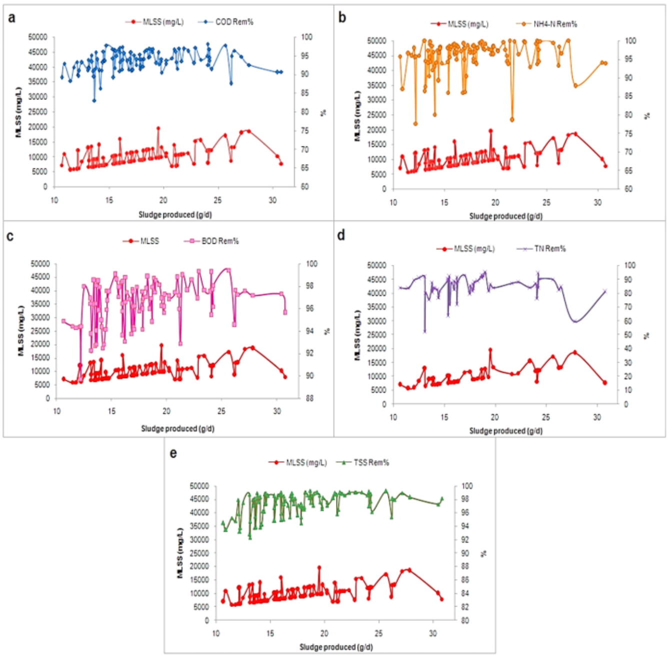




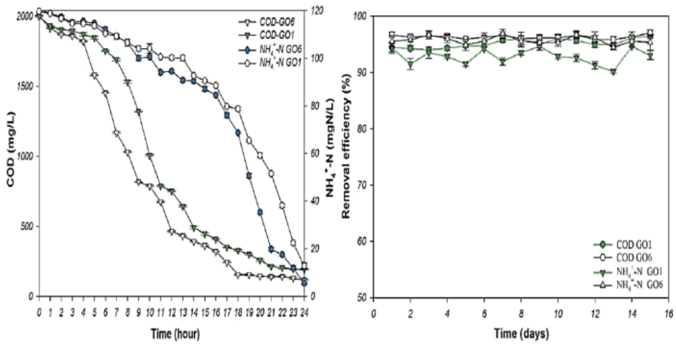
*In their 2017 research, Y*ibo Wang and Yonghong Liu, investigated the treatment of household wastewater utilizing a moving bed biofilm reactor system incorporating PVA gel beads as a biomass carrier. Analysis conducted via scanning electron microscopy identified the presence of sphalerite, filamentous bacteria, and bacillus on both the surface and internal structure of the PVA-gel beads. The study underscored the pivotal role of active sludge tanks in reducing excess sludge. The experimental setup included a PVA reactor, two active sludge reactors, a sedimentation tank, and an ultraviolet disinfection device, with aeration and heating systems strategically positioned at the base of the PVA and active sludge reactors. Initially, 2.5 L of 4 mm diameter PVA-gel beads and 20 L of activated sludge were introduced into the PVA reactor. Despite the absence of activated sludge initially, most of it eventually migrated to the first and second sludge tanks over time. Dissolved oxygen (DO) levels were maintained at 4–5 mg/L in the PVA reactor and 2–3 mg/L in the two sludge tanks. The process demonstrated effective sludge reduction, with an excess sludge yield rate of approximately 0.10 g SS/g COD removed. This novel technology holds promise for improving the CAS process without requiring extensive new infrastructure.



In their 2021 study, Ghazal Srivastav and Ankur Rajpal, addressed the pressing issue of sludge production in wastewater treatment operations and maintenance. She advocated for mitigating sludge production in the liquid treatment stream as a key management approach. By investigating a polyvinyl alcohol (PVA) gel-based oxic-anoxic-oxic process, the study aimed to evaluate wastewater treatment performance and minimize sludge generation. The initial reactor setup comprised three reaction tanks, each with a capacity of 10 L, along with a settler with a capacity of 5 L. Throughout the experimental period, the influent flow rate remained constant at 120 L/d, with 80% directed to the PVA-gel reactor and 20% diverted to an anoxic reactor to supplement carbon sources for denitrification. The return activated sludge (RAS) flow rate was maintained at 60 L/d, representing 50% of the inflow. Domestic wastewater sourced from a nearby sewage pumping station was utilized for the study. The influent wastewater characteristics during the study period were as follows: TSS: 272 ± 69 mg/L, BOD: 234 ± 71 mg/L, COD: 453 ± 104 mg/L, Ammonia-N: 35 ± 10 mg/L, and TN: 42 ± 9 mg/L. Results and comparative evaluations demonstrated that the treatment process effectively reduced sludge production while achieving satisfactory wastewater treatment performance. The pilot-scale plant generated high-quality effluent water that met stringent standards, making it suitable for reuse within a circular economy framework. This approach holds promise as a sustainable solution applicable to developing countries with varying temperature conditions.



In their 2023 study, Tuyen-Nguyen Van and Daehee Ahn, investigated the enhancement of polyvinyl alcohol/sodium alginate (PVA/SA) gel beads immobilizing aerobic sludge with graphene oxide (GO) as a nanofiller. They utilized various concentrations of GO (ranging from 0.02 to 200 mg/L) to produce different types of beads. Batch experiments were carried out in two 3L reactors, each containing 30% of the beads, over a 15-day period, with four steps: fill, aeration, settle, and withdraw, and a 50% exchange ratio between the reactors. Peristaltic pumps facilitated wastewater filling and treated water withdrawal, while dissolved oxygen for aeration was provided by an air compressor and diffuser at the reactor bottoms. Sensors for DO, pH, and temperature monitored reactor parameters, controlled via an electric control box. Results revealed that PVA/SA/GO gel carriers displayed superior reinforcement properties compared to non-GO gel carriers, with similar sphericity factor and methylene blue absorption. The strongest carrier, GO6, containing 200 mg/L GO, exhibited the highest COD and NH_4^+-N removal efficiencies of 97% and 96.67%, respectively, outperforming a non-GO PVA/SA (GO1) gel carrier.



9. CONCLUSIONS

From the above study the PVA gel beads as a biomass carrier have a great potential to treat contaminated domestic wastewater from different origins. With careful designing and planning a PVA gel beads can efficiently remove variety of organic, inorganic and biological contaminants from the domestic wastewater. The yield of activated sludge production from the treatment of PVA gel beads as a biomass carrier is comparatively low than conventional wastewater treatment. The construction and maintenance cost of treatment plant using PVA gel beads is low as compared to conventional wastewater treatment plant. Also, this treatment can enhance the efficiency of wastewater treatment process. Although these paper deals with the study of mechanism of several contaminants removal in domestic wastewater but still a long-term investigation will be required. This treatment can prove best alternative over the conventional wastewater treatment process. The present study may help to cheque the feasibility criteria for using PVA gel beads as a biomass carrier for domestic wastewater treatment. The study carried out on the PVA gel beads will be beneficial for the BOD, COD and TSS removal from the influent domestic wastewater. The performance of PVA gel beads in combination with attach growth system and moving bed bio-reactor system will give promising results. This study can definitely be helpful to achieve the standards required for discharging back wastewater into the environment.

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REFERENCES

[1] Kuraray Co. Ltd.

[2] Nordin Sabli and Norzarina Zakaria "Ammonia-Nitogen reduction in low strength domestic wastewater by polyvinyl alcohol (PVA) gel beads", Pertanika Journal, Volume 31, January 2023

[3] Pawan G. Ramteke, Karan N Khirde and Omkar P. Gurav "treatment of dairy wastewater using PVA hydro-gel", Research Publish Journal, Volume 3

[4] Yibo Wang, Minquan Feng, Yonghong Liu and Lina Wang "Study of the treatment of domestic sewage using PVA gel beads as a biomass carrier", IWA publishing, March 2017, pages 340-349

[5] Ghazal Srivastava, Jasdeep Singh, Khalid Muzamil Gani, Ankur Rajpal, Faizal Bux & Absar Ahmad Kazmi, "Reduced sludge production in a polyvinyl alcohol gel-based oxic-anoxic-oxic configured pilot-scale plant", ScienceDirect, Volume 4, December 2021, 100136

[6] Tuyen-Nguyen van, Trung-Do Quang, tuan-Hoang Van, Thuan-Tran Hung, Quang-chu Xuan, Hyungu Kim and Daehee Ahn "Enhancing mechanical properties of polyvinyl alcohol/sodium alginate gel beads by graphene oxide for the aerobic sludge immobilization in wastewater treatment", Environmental Engineering Research, Volume 28, January 2023

[7] Aparna Dutta and Sudipa Sarkar "Treatment on the mining impacted water using novel polyvinyl (PVA) gel beads bioreactor", EGU, Volume 21, EGU2019-16144, June 2019

[8] Zhang Li-sheng, WU Wei-Zhong and Wang Jian-long "Immobilization of activated sludge using improved polyvinyl alcohol (PVA) gel", ScienceDirect, Volume 19, Issue 11, pages 1293-1297

[9] Meta Levstek, Joseph D. Rouse and Igor Plazl, "Estimation of the specific surface area for a porous carrier. In this study, they estimated the effective surface area for a spherical", Research gate, 57(1):45-51, March 2010

[10] Himanshu Chaturvedi and Priyanka Kaushal "Process optimization of tertiary biological treatment of MSW leachate by innovative PVA gel technology", Journal of Emerging Technologies and Innovative Research, Volume 11, February 2024, page 56-64

[11] Muhammad Faidsyafiq Othman, Hassimi Abu Hasan, Mohd Hafizuddin Muhamad and Badiea S. Babaqi "Biopolishing of Domestic Wastewater Using Polyvinyl Alcohol supported Biofilm of Bacterial Strain Bacillus velezensis isolate JB7", Journal of Ecological Engineering, Volume 24, Issue 8, pages 33-42