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Bibliometrics Analysis and Future Study Trends in Anaerobic Biofilter Systems for Laundry Wastewater Treatment

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Abstract **- The rapid expansion of the laundry industry, particularly in residential areas, has led to significant environmental challenges due to the discharge of untreated wastewater containing high levels of pollutants, such as Chemical Oxygen Demand (COD) and phosphate (PO_4). This study aims to explore the effectiveness of anaerobic biofilter systems in reducing COD and PO_4 levels in laundry wastewater. A lab-scale anaerobic biofilter reactor was designed and operated at varying hydraulic retention times (HRTs) of 9, 11, and 13 hours to treat the wastewater. The results showed that the anaerobic biofilter system effectively reduced PO_4 levels, meeting Indonesian regulatory standards, with the highest removal efficiency observed at an HRT of 11 hours. However, while COD levels were reduced, they remained above the required quality standards, indicating the need for optimization of the treatment process. The study highlights the potential of anaerobic biofilters in laundry wastewater treatment and suggests further research into integrated treatment approaches for improved pollutant removal.**

Keywords: laundry wastewater, anaerobic biofilter, bibliometrics analysis, hydraulic retention time, pollutants

I. Introduction

The recent expansion of industries has undoubtedly contributed to economic growth in various regions and countries. However, it is crucial to acknowledge that industrial activities have harmful effects on the environment. These activities produce a lot of contaminants, including solid waste, organic compounds, and heavy metals, all of which threaten the sustainability of both human life and aquatic ecosystems. One industry that significantly contributes to pollution and environmental harm is the laundry industry. Laundry wastewater, generated from clothes-washing processes, contains various organic contaminants. When discharged into drainage systems, this wastewater is mixed with domestic sewage. The laundry industry, particularly in residential areas, has grown rapidly. Unfortunately, many laundry businesses lack wastewater treatment plants (WWTP), leading to the direct release of untreated wastewater into drainage channels, which eventually flows into natural water bodies [1].

Industrial laundries serve various sectors, including friendliness, hospitals, and pre-market clothes. In the European Union (EU), the corporate laundry sector processes approximately 2.7 billion kilograms of clothes annually (wet weight) and consumes 42 million cubic meters of water, ultimately discharged as wastewater into the sewage system. This wastewater may contain more than two thousand mg/L of Chemical Oxygen Demand (COD) and typically exhibits a basic pH, high turbidity, suspended solids, phosphorus compounds, and allergenic fragrance compounds, betwixt other contaminants [2], [3], [4]. These pollutants contribute to various forms of pollution, including COD, Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), Total Nitrogen (N-total), and phosphate (PO_4). In some cases, COD levels in laundry wastewater can exceed 20,000 mg/L, coupled with high pH and the presence of fragrance compounds that may trigger allergic reactions [5], [6]. The polyphosphate compounds found in detergents are a significant source of phosphate in laundry wastewater, contributing to increased environmental pollution [7], [8]. Elevated PO_4 levels in water can cause uncontrolled plant and algae growth (eutrophication), leading to reduced dissolved oxygen levels and disrupting ecosystems [9]. High COD levels in wastewater also promote the activity of anaerobic microorganisms, which decompose organic matter and lower oxygen levels, resulting in unpleasant odors, harm to aquatic life, aesthetic issues, and the potential spread of disease-causing organisms [1].

Conventional wastewater treatment facilities have been found to contain low levels of fragrance allergens, surfactants, and microfibers, which pose risks of environmental toxicity and can persist in water bodies for extended periods [10], [11], [12], [13]. Numerous studies have explored various methods for

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treating industrial laundry wastewater, such as biological, chemical, and advanced oxidation processes. In many cases, these techniques are combined to reach the target water quality. Earlier research has highlighted the effectiveness of moving-bed bioreactors (MBBR), catalytic ozonation, and Fenton processes in treating laundry wastewater, showing significant potential in achieving mineralization [14]. Considering the increasing contamination from the growth of the laundry industry, a novel approach is needed to address this challenge. Anaerobic biofilter technology has emerged as the most effective solution for treating heavily polluted laundry wastewater.

The reduction of pollutants in anaerobic biofilter systems primarily depends on the growth and proliferation of microorganisms capable of breaking down waste materials on the surface of the filter media. These microorganisms are essential for eliminating contaminants from laundry wastewater. The effectiveness of the anaerobic biofilter process is largely influenced by the type and structure of the medium, which provides an adequate surface area for bacterial and microorganism reproduction. This biofilter system offers multiple benefits, including the conversion of ammonia into nitrite and subsequently into nitrogen gas, removal of organic pollutants like BOD and COD, oxygenation in aerobic processes, elimination of excess nitrogen and other inert gases, reduction of turbidity, water clarification, and the removal of various organic compounds. The anaerobic biofilter process is specifically selected for its efficiency in treating wastewater with both high and low organic content [15], [16], [17], [18].

This study attendant consequential progress in wastewater treatment by specifically focusing on applying anaerobic biofilter systems for the operation of laundry wastewater, targeting the alleviation of COD and PO_4 levels. The study is novel in its approach as it not only explores the removal of COD but also emphasizes PO_4 removal—a pollutant often overlooked in previous studies related to laundry wastewater. This dual focus on COD and PO_4 is relatively uncommon in the literature, and the research identifies a gap in existing studies where no prior research has examined the use of anaerobic biofilters for PO_4 removal in this specific context. Additionally, the use of bioball media within the anaerobic biofilter system and the investigation of different hydraulic retention times (HRTs) provide new insights into optimizing these systems for better pollutant removal. These two pollutants were selected for several reasons: (1) to simplify the research process and sample analysis, (2) COD and PO_4, as organic pollutants, can serve as representative indicators for other organic contaminants, and (3) detergents, the main components of laundry products, tend to accumulate as surfactants or PO_4, making PO_4 an ideal choice for analyzing detergent pollution. Notably, no prior research has investigated the removal of PO_4 from laundry wastewater using anaerobic biofilter technology, according to searches conducted in Web of Science (WOS) and ScienceDirect.

II. METHOD

Research design

In this study, a lab-scale anaerobic biofilter reactor (Figure 1) was designed and constructed to treat laundry wastewater and assess the initial levels of COD and PO_4. All necessary tools and materials for the anaerobic biofilter system were prepared in advance. The reactor, made from 4 mm thick acrylic, had a total volume of 15,000 cm³ (15 × 40 × 25 cm) and was filled with biofilter media. Seeding and acclimatization were performed using laundry wastewater to allow the waste-degrading microorganisms to adapt. Once the microorganisms reached a steady-state condition, the laundry wastewater treatment process was initiated by incorporating predetermined variable variations.

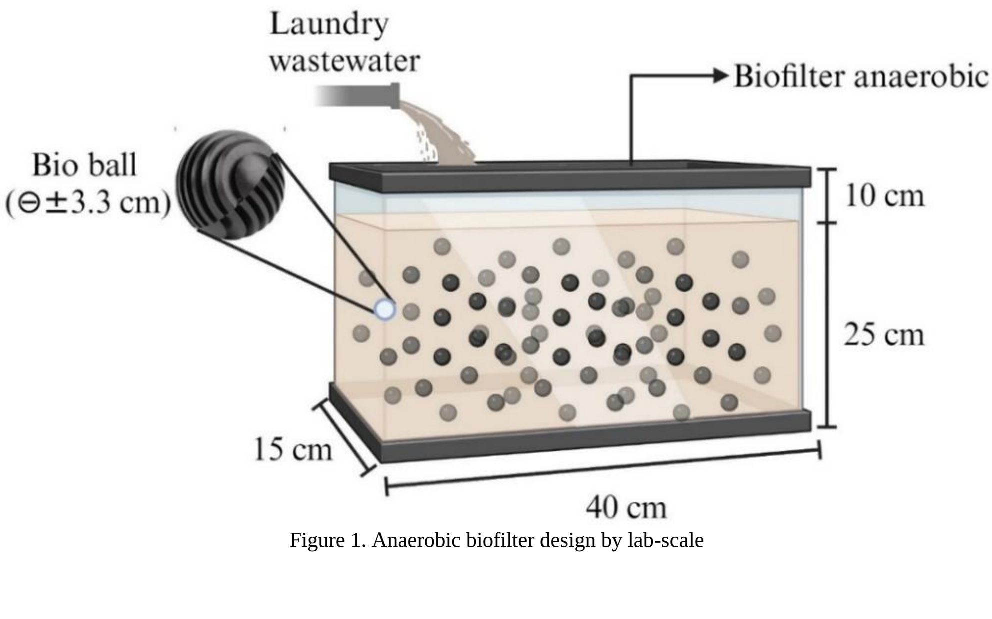

Figure 1. Anaerobic biofilter design by lab-scale

Operation of anaerobic biofilter reactor

The anaerobic biofilter reactor was operated in a batch system, according to the predetermined hydraulic retention times (HRT), to treat laundry wastewater containing COD and PO_4. The reactor consisted of three units, each operating at a specific HRT of 9, 11, and 13 hours. These HRT variations were designed to observe changes in pollutant levels and to provide optimal conditions for waste-degrading microorganisms to break down COD and PO_4 contaminants. Implementing HRT systems in lab-scale wastewater treatment has set the stage for large-scale sewage treatment applications. The HRT typically varies based on the technology used and the characteristics of the wastewater being treated. For highly polluted wastewater, combining multiple technologies and employing a longer HRT is recommended to achieve higher removal rates. In contrast, for medium or low-level wastewater, a single technology with a shorter HRT can deliver satisfactory results. Energy consumption and economic analysis are crucial factors when implementing HRT in wastewater treatment, as longer HRTs generally lead to higher energy usage and costs.

Data collection and analysis methods

The data collection process included both the seeding and acclimatization phases, as well as the treatment process. To make certain the correctness and reliability of the data, each HRT was closely monitored, allowing for the detection of any changes that occurred. The analysis of COD and PO_4 parameters adhered to the procedures specified in Standar Nasional Indonesia (SNI) 6989.72:2009 [19] and SNI 06-6989.31-2005 [20]. During the seeding and acclimatization phase, COD levels were monitored until a steady-state condition was achieved. The removal and efficiency of COD and PO_4 levels were calculated in terms of removal (mg/L) and efficiency (%) using Equations 1 and 2 (Eq. 1 and 2) [21].

$$\text{Removal (mg/L)} = C_0 - C \quad (1)$$

$$\text{Removal efficiency (\%) } \varepsilon = \frac{C_0 - c}{C_0} \times 100 \quad (2)$$

Where ε is the efficiency, C_0 is the initial concentration, and C is the final concentration.

III. RESULT AND DISCUSSION

Initial concentration laundry wastewater

The initial phase of this research involved the daily collection of 50 liters of laundry wastewater, which was gathered at the start of the seeding and acclimatization processes as well as during the treatment phase. The primary goal of this research is to treat laundry wastewater to reduce COD and PO_4 levels. The wastewater used for the initial analysis was sourced from a laundry business in Prambon Village, Prambon District, Sidoarjo Regency, and was collected directly from the washing machine drains. A preliminary analysis of the laundry wastewater is exhibited in Table 1.

TABLE 1.
THE RESULT OF THE INITIAL ANALYSIS OF LAUNDRY WASTEWATER

Parameter	Quality standard*	Result
COD (mg/l)	250	727,1
PO_4 (mg/l)	10	14.2
pH	6	7,25

*[22]

The data presented in Table 1 indicate that the studied parameters exceed the quality standards established by East Java Governor Regulation No. 72 of 2014 [22]. It is vital to note that none of the laundries in the area have wastewater treatment facilities, leading to the contamination of water bodies with high levels of COD, PO_4, and other pollutants. Therefore, developing an innovative solution to effectively treat laundry wastewater is crucial to preventing significant environmental degradation.

Seeding and acclimatization

Seeding involves cultivating microorganisms within the reactor media. In this study, seeding was carried out by submerging the bioball media in each reactor containing laundry wastewater until a biofilm layer formed on the media. The seeding process was monitored daily, and the results were recorded, as shown in Figure 2. Initially, the media appeared clean, with a thin biofilm layer forming by the third day. By the eighth day, the biofilm layer had thickened. After completing the seeding process, the acclimatization phase began. The primary objective of acclimatization was to allow microorganisms to adapt to the new

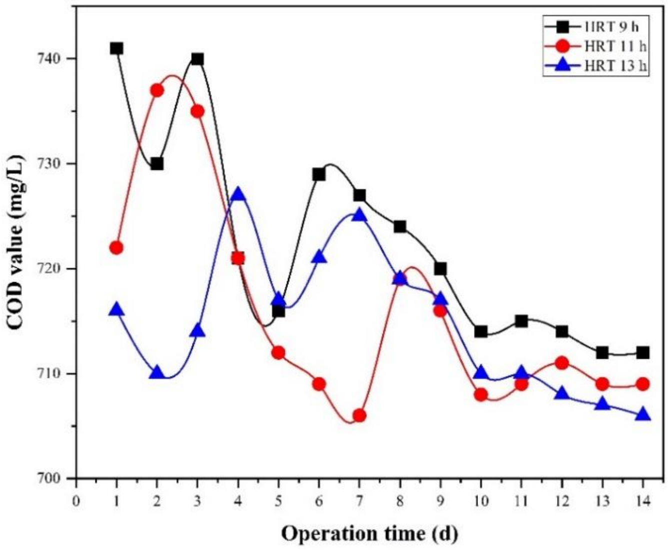

Figure 2. Seedings and acclimatization process

wastewater. In this study, acclimatization lasted for two weeks, with results analyzed based on COD test outcomes from the first to the fourteenth day of operation.

The results showed fluctuations across the three reactors, each represented by its respective HRT, indicating that the microorganisms in the media had not yet reached steady-state conditions. Steady-state conditions were observed starting from the tenth day, marked by relatively stable COD test results. Microorganisms are considered to have reached a steady state when the variation in COD reduction efficiency is ≤ 10% [23], [24]. A previous study by Nugroho et al. [25] achieved steady-state conditions in a biofilter system consisting of randomly arranged plastic and pottery fibers in laundry wastewater after twenty-one days. Another study found that it took at least twenty-seven days to achieve steady-state conditions when using anaerobic biofilters to treat wastewater from a chicken slaughterhouse [26].

COD removal rate efficiency

The use of anaerobic biofilters is a prospective approach to alleviating COD from laundry wastewater. Numerous studies have explored the efficiency of this technology in treating various pollutants. In this study, COD analysis was conducted to assess the reduction of organic matter and microbial growth within each anaerobic biofilter reactor. After treatment, based on the respective holding time rates (HRT), the average COD values for HRTs of 9, 11, and 13 hours were 328.33 mg/L, 295.77 mg/L, and 320.73 mg/L, respectively.

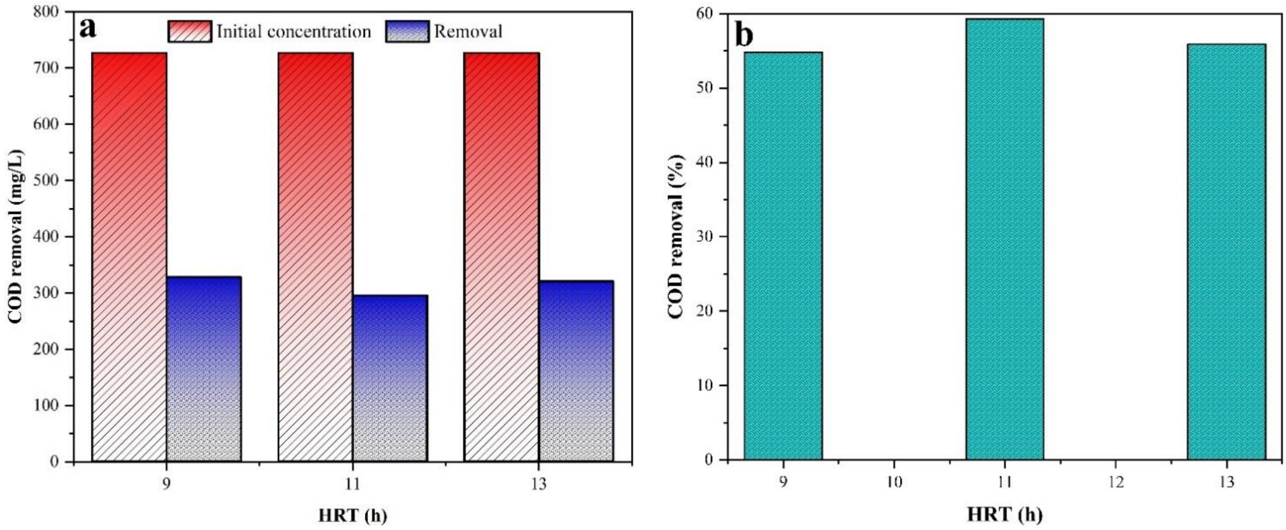

Figure 3. (a) COD before and after treatment, (b) removal efficiency after using anaerobic biofilter.

The minimal variation in COD reduction across different HRT durations is shown in Figure 3a. Among the three HRT durations tested, the 11-hour HRT achieved the most significant reduction, lowering the COD level to 295.77 mg/L. In a study involving the treatment of chicken slaughterhouse wastewater using an anaerobic biofilter system, the initial COD level of 2,603 mg/L was decreased to 130.15 mg/L after seven days of treatment [27]. Similarly, in a phytoremediation system using *Pistia Stratiotes L.* plants, the COD concentration in laundry wastewater decreased from 121 mg/L to 56.7 mg/L [28]. Under optimal conditions, microorganisms can efficiently degrade waste, leading to a greater reduction in pollutant levels [29]. However, at an HRT of 13 hours, there was a decline in COD alleviation efficiency, likely due to reduced microbial activity and the presence of complex compounds resistant to decomposition, which hindered the microorganisms' ability to treat the wastewater effectively.

An HRT of 11 hours demonstrated superior efficiency compared to the other HRTs. Overall, all three HRTs achieved COD removal efficiencies exceeding 50%, as illustrated in Figure 3b. The efficiency values were 54.8% for HRT 9 hours, 59.3% for HRT 11 hours, and 55.9% for HRT 13 hours. In a separate study by Susilawati et al. [30], using syringes as biofiltration media, a COD alleviation efficiency of 45.92% was achieved for laundry wastewater. Other studies have exposed that the use of natural coagulants can effectively reduce COD levels by over 80%. However, it is important to note that the resulting sludge may contain toxic residues from detergents [31], [32]. Despite achieving over 50% efficiency, it is important to recognize that the COD levels for all three HRTs still exceeded the predetermined quality standards. The exceptionally high initial COD levels in this study contributed to the persistent presence of COD above the established quality standards.

The efficiency of the decomposing microorganisms is not optimal, as evidenced by their inability to reduce COD levels below 250 mg/L during the seeding and acclimatization stages. Although the microorganisms have reached a stable state, their performance remains limited, even with an extended HRT. In simple terms, biological treatment using an anaerobic biofilter alone is insufficient to remove COD effectively. This challenge has also been observed in the operation of laundry wastewater in Spain using a biofilter system. Despite achieving a significant COD removal efficiency of up to 80%, the final treatment stage still resulted in a COD value of 450 mg/L, exceeding Spain's COD limit of 160 mg/L [6].

PO_4 removal rate efficiency

Anaerobic biofilter systems are effective at removing PO_4 from laundry wastewater. Factors such as reactor type, waste concentration, flow rate, and HRT can all influence the efficiency of PO_4 alleviation. As presented in Figure 4, the reduction in PO_4 levels after treatment with the anaerobic biofilter system is significant. The results indicate that the average PO_4 reduction for all three HRTs exceeds 5.4 mg/L, meeting Indonesian regulatory quality standards. The highest PO_4 reduction was observed at an HRT of 11 hours, with a reduction of 5.46 mg/L. Similarly, HRTs of 9 and 13 hours achieved reductions to 5.66 mg/L and 5.81 mg/L, respectively, starting from an initial PO_4 concentration of 14.2 mg/L (Figure 4a).

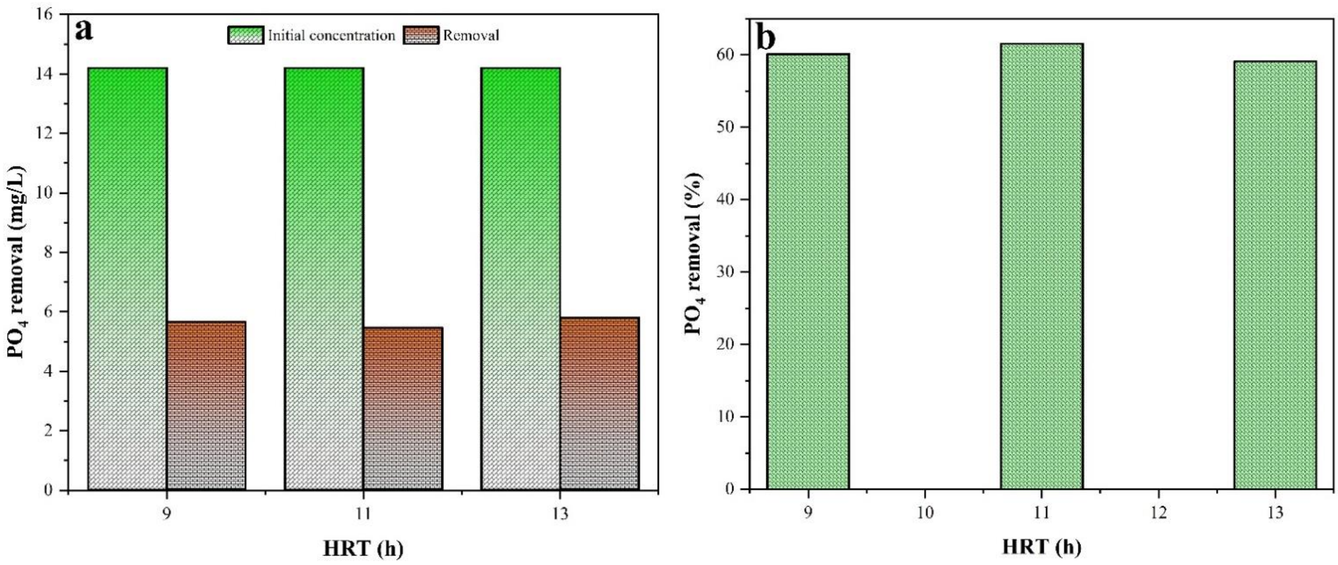

Figure 4. (a) PO_4 before and after treatment, (b) removal efficiency after using anaerobic biofilter

According to the PO_4 test, the highest efficiency was achieved with an HRT of 11 hours, resulting in a 61.5% reduction (Figure 4b). Among the three HRTs tested, there were no significant differences in PO_4 removal efficiency. While the overall PO_4 reduction met existing quality standards, further exploration of alternative technologies is recommended. For example, a phytoremediation system using *Pistia Stratiotes* L. plants can reduce PO_4 levels in laundry wastewater starting with 1.92 mg/L to 0.97 mg/L [33]. Additionally, bio-sand filters have shown the potential to achieve PO_4 reductions of up to 74.32% in laundry wastewater treatment [34]. Another study, which combined local filtration methods such as sand, biochar, and straw, demonstrated PO_4 removal efficiencies ranging from 22% to over 62% [35]. The decline in PO_4 levels can be attributed to the activity of waste-decomposing microorganisms within the anaerobic biofilter reactors, with the bioball media providing an optimal environment for their growth and proliferation.

Bibliometrics analysis and future study trends

The advancement of wastewater treatment technology has experienced substantial growth, especially in the treatment of laundry wastewater. As shown in Figure 5, numerous studies have focused on reducing COD and PO_4 levels in laundry wastewater. A detailed analysis of the data reveals that most research has explored various technologies for treating laundry wastewater, resulting in an expanded range of outcomes. However, it is essential to note that the use of anaerobic biofilter systems to reduce both COD and PO_4 levels in laundry wastewater is still relatively uncommon. In fact, most studies have primarily concentrated on reducing BOD and TSS levels rather than focusing on the removal of COD or PO_4, as illustrated in Figure 6.

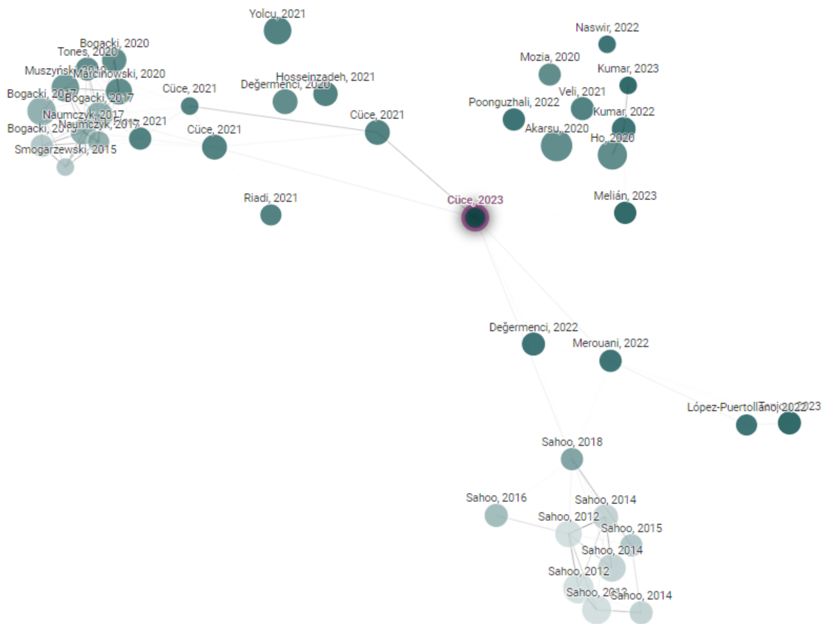

Figure 5. Data study regarding COD and PO_4 removal from laundry wastewater

The data shown in Figure 5 reveals a correlation among research topics. The bright blue circular markers indicate that scholarly articles on reducing COD or PO_4 in laundry wastewater treatment have been frequently cited. This trend is particularly evident in more recent research, represented by lighter blue hues, as opposed to earlier years. This suggests that research on laundry wastewater has gained significant attention in recent years, highlighting the need for further investigation and the adoption of more advanced technologies.

Based on the simulation results in Figure 5, it is clear that our research remains a topic of active discussion among researchers, particularly regarding alleviating COD and PO_4 levels in laundry wastewater. This is supported by the fact that most related articles have been published since 2020. Our research topic highlights emerging trends that warrant deeper exploration in the future. These findings will undoubtedly offer new insights and ideas for other researchers to pursue similar studies using different methods and variables, thereby enhancing the state-of-the-art and novelty of each research endeavor. We have focused this study on observing COD and PO_4 levels in laundry wastewater because these two parameters are critical in wastewater treatment and are often overlooked by other researchers. Additionally, the relatively short process of analyzing samples in the laboratory allows for quicker acquisition of COD and PO_4 data, thus saving time. Moreover, these two parameters can also serve as indicators of other pollutants present in laundry wastewater, such as BOD, TSS, SS, and more.

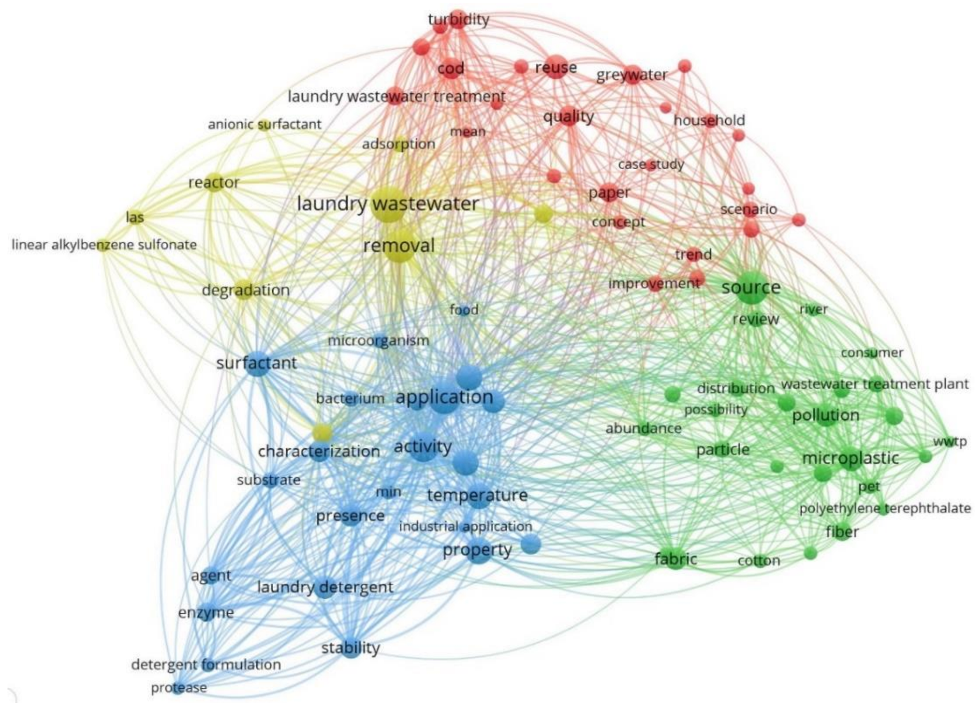

Figure 6. Development of research on laundry wastewater treatment

The observations in Figure 6 highlight a gap in the literature, as no studies have utilized a modeling system to assess pollutant loads in laundry wastewater, particularly for COD and PO_4. While some research has focused solely on reducing COD and PO_4 levels or has provided review papers, this gap underscores the need for further exploration of modeling systems to monitor pollutant levels in laundry wastewater, including COD and PO_4. Additionally, more research is needed to analyze PO_4 levels using alternative treatment systems. Although various treatment technologies, such as filtration, phytoremediation, electrocoagulation, membranes, and wetlands, have been extensively studied, the use of anaerobic or aerobic biofilters remains significantly underrepresented, especially on a pilot or large scale. Future efforts should prioritize the implementation of green manufacturing, which emphasizes profitability through environmentally friendly operational practices.

Future studies on laundry wastewater treatment using anaerobic biofilters are expected to focus on several key trends highlighted in the current literature. One notable trend is the exploration of integrated systems that combine anaerobic reactors with biofilters to enhance treatment efficiency. These integrated systems have shown promising results in treating numerous types of wastewater, including laundry effluents. Additionally, there is increasing interest in combining advanced oxidation processes with biological process methods to further enhance the quality of treated water. This combined approach not only enhances contaminant removal but also opens up the possibility of recycling water within the laundry process. Moreover, the use of biofilters to target specific contaminants in laundry wastewater, such as odors and volatile compounds, is gaining increasing attention.

Biofilters have proven effective in reducing odors and volatile compounds commonly found in wastewater treatment plants. Future research will likely focus on applying biofilters to remove specific pollutants, such as hydrogen sulfide and ammonia, in these facilities. Additionally, there is a growing interest in developing innovative biofilter designs tailored to specific wastewater characteristics and treatment needs. For instance, submerged biofilters offer a unique method of wastewater treatment by utilizing microorganisms in a continuous flow system. Furthermore, the integration of different treatment technologies, such as combining aerobic biofilters with granular adsorption and nano adsorption processes, is being explored to achieve more comprehensive wastewater treatment.

IV. Conclusion

This study highlights the potential of anaerobic biofilter systems in treating laundry wastewater, particularly in reducing COD and PO_4 levels. The research demonstrates that anaerobic biofilters, when operated with varying HRT, can achieve notable reductions in PO_4, with an HRT of 11 hours showing the highest removal efficiency. However, the results exhibited that while the biofilter system was effective in reducing PO_4 to meet quality standards, it was less successful in lowering COD levels to the required thresholds. The study underscores the importance of optimizing microbial activity within the biofilter system and suggests that a combination of treatment technologies may be necessary to achieve comprehensive wastewater purification. Future research should explore integrated approaches, combining biofilters with advanced oxidation processes or other innovative methods, to elevate the overall ability and sustainability of laundry wastewater treatment. This work contributes valuable insights into the expansion of eco-friendly and impressive wastewater treatment technologies, particularly in the context of the rapidly growing laundry industry.

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