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Improving the efficiency of aerobic biological treatment of domestic wastewater by using fixed culture media

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ABSTRACT

This study investigates the use of pozzolan, a volcanic slag, as a packing material in a fixed culture system for biological wastewater treatment. Experimental work was conducted to evaluate the performance of pozzolan in terms of removal of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD) and NH_4^+ under different substrate concentrations and bed heights. The results reveal that pozzolan achieved BOD_5 removal efficiencies of up to80% at a concentration of 1g/L with a 20 cm bed height, while COD degradation rates demonstrated a kinetic constant K of 0.080 min^{-1} under the same conditions. At higher concentrations (1.5 g/L) and a 40 cm bed height, the performance was slightly reduced, with COD degradation exhibiting K = 0.040 min^{-1}, likely due to substrate saturation effects. Comparatively, scoria showed lower efficiency, with kinetic constants ranging from 0.018 to 0.065 min^{-1}, highlighting the superior performance of pozzolan as a packing medium, NH_4^+.

Keywords: wastewater, aerobic biological treatment, biofilm, fixed culture systems, pozzolan, scoria, synthetic effluent, BOD_5, COD, NH_4^+, kinetic, biodegradation.

INTRODUCTION

Wastewater is all water from domestic, agricultural and industrial activities, loaded with toxic substances and entering the sewers. Wastewater also includes rainwater and its pollutant load, which causes all kinds of pollution and nuisances in the receiving environment (Dugniolle, 1980; Glanic and Benneton, 1989).

These discharges can contain numerous substances, in solid or dissolved form, as well as numerous pathogenic microorganisms, threatening the quality of the environment.

Wastewater is an extremely complex environment, altered by human activities following domestic, industrial, artisanal, agricultural, or other uses. It is considered polluted and must therefore be treated before any reuse or injection into the natural receiving environments. Therefore, in an effort to respect these various natural receiving environments, pollutant abatement or elimination treatments are carried out on all urban and industrial effluents. These treatments can be carried out collectively in a wastewater treatment plant or individually using intensive or extensive processes (Paulsrud and Haraldsen, 1993).

However, even when treated wastewater from wastewater treatment plants is not recycled, these effluents often have nitrogen and phosphorus loads exceeding the required standards, as many of these plants have limitations in the retention of phosphate and nitrate ions during secondary treatment. However, the direct discharge of these nutrients into receiving environments is not without risk. As mineral nitrogen enrichment associated with phosphorus in aquatic environments is detrimental to theto the environment and public health, complementary or tertiary treatments are necessary to better protect receiving ecosystems (Marsalek et al., 2001).

Among the techniques for reducing these two nutrients, soil-plant systems, lagooning, activated sludge, and mixed biological and physicochemical systems have been extensively studied by (Liu et al., 1997). In particular, they allow for the elimination of over 70% of nitrogen and phosphorus from secondary wastewater (Lazarova et al., 2003; Bendida et al., 2021; Kendouci et al., 2023).

The biomasses responsible for nitrification have an autotrophic (Schmidt et al., 2002) and strictly aerobic (Shin et al., 2005). They are found in several natural ecosystems, including wastewater, aquatic environments, soils, and rocks (Mansch et al., 1998; Bothe et al., 2000).

Wastewater treatment is therefore the only way to avoid environmental problems. Several natural and inexpensive technologies could be used in rural areas, such as lagoons, macrophytes, trickling filters, and sand filters (Bdouri et al., 2009).

The search for simple, easy-to-implement, and energy-efficient alternative processes is necessary; processes that are somewhat overlooked in urban wastewater treatment, such as trickling filters, are indeed interesting because their ease of use and performance in secondary or tertiary treatment can justify their use (Ferchichi et al., 1994).

The use of material filters to treat domestic wastewater has been known for a very long time. It was already practiced in Massachusetts (USA) towards the end of the 1800s [Bernier et al., 2001]. Wastewater treatment using granular media filtration, such as sand filters, could be an effective method to meet water quality requirements for reuse applications and has long been widely practiced in the field of wastewater treatment (Kauppinen et al., 2014). Algeria has a significant amount of pozzolanic materials of volcanic origin, extending over 160 km between the Algerian-Moroccan border and the Sahel region of Oran (Belaribi et al., 2003).

Biological treatment processes are a cornerstone of secondary wastewater treatment, particularly for the removal of soluble organic carbon compounds like sugars, fats, and proteins. These methods, relying on the action of microorganisms, are more cost-effective and adaptable for large-scale applications than physicochemical alternatives. In aerobic biological processes, heterotrophic microorganisms play a dual role: converting organic matter into gases (COD in aerobic conditions or biogas in anaerobic conditions) and producing biomass, which canbe separated from the liquid phase (Bendida et al., 2024). Additionally, advanced biological processes can achieve nutrient removal, such as nitrogen and phosphorus, when combined with tailored process steps (Smith et al., 2022).

The performance of biological treatments is assessed using key parameters like the five-day biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD), which measure organic pollutant loads. These pollutants deplete dissolved oxygen in aquatic environments, causing hypoxia or anoxia, which severely impacts aquatic ecosystems. Thus, reducing BOD_5 and COD is essential for preserving water quality and protecting biodiversity (Bendida et al., 2013).

One promising biological treatment method involves fixed cultures, as utilized in bacterial bed filtration systems. In these systems, purifying microorganisms are immobilized on porous or cavernous materials that provide a stable environment for microbial growth. The wastewater flows through the filler material, facilitating microbial activity that degrades pollutants. Materials such as pumice, volcanic rocks, metallurgical coke, and plastics are commonly used as supports due to their high porosity, which enhances microbial attachment and treatment efficiency (Mebarki et al., 2024; Hassan et al., 2021).

This study explores the potential of traditional bacterial beds using pozzolan, a volcanic slag, as a local and cost-effective packing material for domestic wastewater treatment. By evaluating the performance of this biofiltration system in terms of pollutant removal, this research aims to contribute to the development of sustainable and efficient wastewater treatment technologies (Bendida et al., 2024).

MATERIALS AND METHODS

Experimental protocol

This section outlines the experimental setup, materials, and procedures used to evaluate the performance of a fixed-bed biofiltration system for wastewater treatment. The study employs pozzolan as the packing material within a laboratory-scale trickling filter reactor. Synthetic wastewater was used to simulate domestic effluent characteristics, and a controlled flow rate was maintained using a peristaltic pump. Key parameters such as BOD_5 COD, NH_4^+ and microbial biofilm development were monitored to assess treatment efficiency. The methodology ensures reproducibility and provides a detailed framework for evaluating the effectiveness of pozzolan as a support medium.

The following flowchart (Figure 1) illustrates the experimental protocol, detailing the sequential steps for the preparation of synthetic effluent, biofilm development, bacterial bed setup, and the monitoring of key parameters to evaluate treatment performance.

The Figure 2 shows a laboratory-scale experimental setup used for the treatment of synthetic wastewater in a fixed-bed biofiltration system (Touafek, 2015).

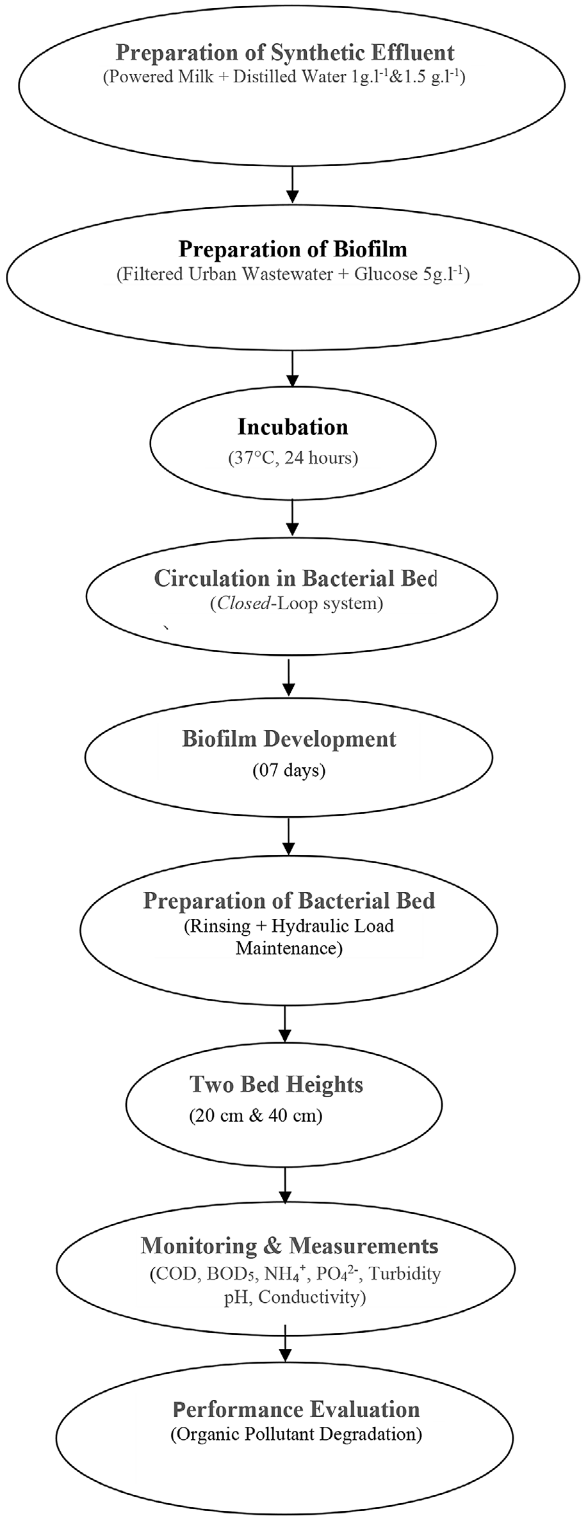

Figure 1. Experimental protocol

Preparation of synthesis effluent and biofilm

The synthesis effluent is prepared daily from powdered milk in order to obtain different concentrations 0.5 $g.l^{-1}$ and 1$g.l^{-1}$ and they are mixed in one liter of distilled water.

To prepare our biofilm, we used urban wastewater collected and brought back from the El-Kerma wastewater treatment plant in the city of Oran. After filtration, we enriched the medium with glucose at a rate of 5 $g.l^{-1}$. We prepared two liters which we placed in an oven at 37 °C for 2 hours.

The water is then pumped into the bacterial bed in a closed circuit using a peristaltic pump at a variable flow rate. The biofilm was apparent after a week of culture (Figure 3).

The bacterial bed being ready, we rinsed it with distilled water and a constant height of water is ensured to keep an invariable hydraulic load above our bacterial bed.

Two bacterial bed heights were chosen: 20 and 40 cm. The degradation efficiency of the organic effluent was monitored by measuring COD, BOD_5 and NH_4^+.

Materials

In this study, two primary filling materials were utilized: pozzolan and scoria, both volcanic rocks with distinct physical and chemical characteristics that make them ideal substrates for fixed-film biological processes (Table 1 and Table 2).

Presentation of the El Kerma-Oran wastewater treatment plant

The site of the Oran urban area wastewater treatment plant is located 12 km from the city of Oran, on the northeastern edge of the Greater Sebkha between the railway line and

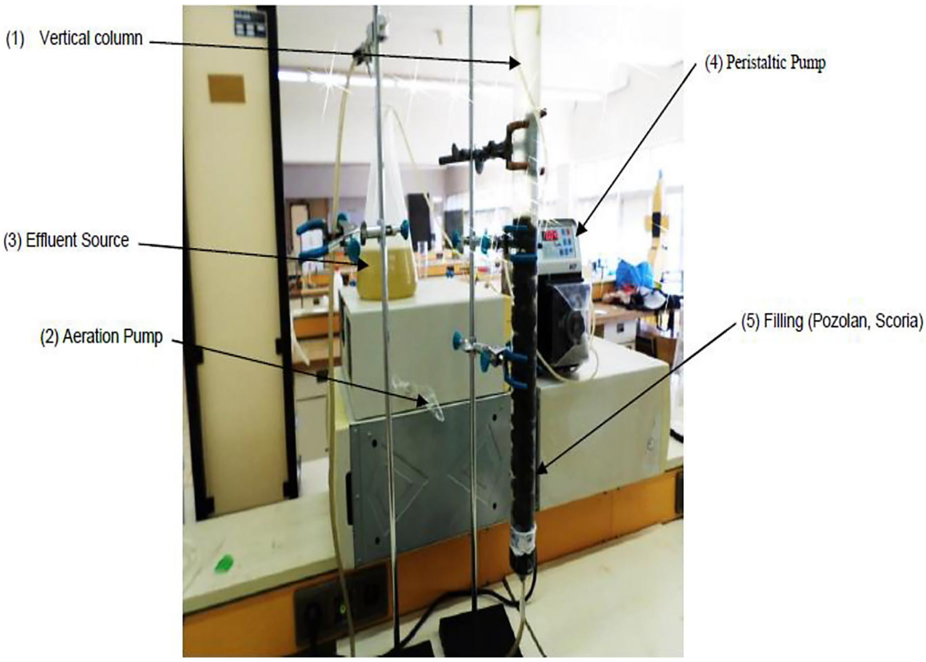

Figure 2. Laboratory-scale experimental setup for fixed-bed biofiltration system

Figure 3. The synthesis effluent and biofilm apparent

the national road. The EL Kerma Wastewater Treatment Plant was designed for a population of 1,526,000 EQH with a capacity of 270,100 $m^3 \cdot day^{-1}$. The towns are connected to the STEP Oran and Bir El Djir.

Objective of the El Kerma-Oran water treatment plant

Water treatment is a set of techniques that consist of purifying water either to recycle wastewater into the natural environment or to transform natural water into drinking water. The WWTP is an installation that is used to decontaminate wastewater to avoid the total destruction of aquatic and natural ecosystems due to polluted effluents (Kendouci et al., 2019). Therefore, a wastewater treatment plant has several objectives:

- Protection of public health;
- Protection of natural sources of drinking water;
- Protection of aquatic systems;
- Protection of adjacent land.

Table 1. Physico-mechanical characteristics of filling materials used

Property	Density ($kg \cdot m^{-3}$)	Porosity (%)	Mechanical strength (granules) ($kg \cdot m^{-2}$)
Pozzolan	1.02	64–83	33.2
Scoria	0.96	70	27.6

Table 2. Chemical composition of filling materials used

Compound	Percentage (%)	
	Pozzolan	Scoria
SiO_2	46.10	10-19
Al_2O_3	17.5	01-03
Fe_2O_3	10.5	10.5
CaO	10.5	40-52
MgO	3.8	05-10
Na_2O	3.4	<01
K_2O	1.50	<01

Basic data of the El Kerma-Oran wastewater treatment plant

The treatment line of the WWTP was designed and sized with the aim of ensuring a quality of treated effluent meeting the values expressed in the Table 3.

These limit values are given in the technical specifications of the management contract. The capacity of the connected population was estimated at approximately 1,500,000 population equivalents. This gives the following main allocations for the urban part in Table 4.

ANALYTICAL APPROACHES TO BIODEGRADATION KINETICS

The rate of removal of organic matter depends on the phase of the biological growth curve. BOD_5 theory assumes a first order reaction and although some reactions are thought to be first order there is evidence, sometimes conflicting, that other reactions are zero order (independent of concentration) or second order. The situation becomes more complex when dealing with wastes such as sewage, which contain many different compounds (Tebbutt, 1977).

Biodegradation kinetics can therefore be modeled using various mathematical expressions, depending on the interaction between substrate concentration and biomass density. With a given mass of microorganisms, the rate of disappearance of a substrate S over time can take different forms. It is common to use S as the concentration of the solution in the growth-limiting substrate.

When the organic concentration has been reduced to some limiting value, the rate of removal becomes concentration dependent:

$$-\left(\frac{ds}{dt}\right) = k \times S^n \qquad (1)$$

where: n – order of reaction.

The kinetic modeling of biodegradation using the first-order model allows us to study the evolution of chemical oxygen demand and biochemical oxygen demand over time (Table 5). This approach is particularly relevant for analyzing the

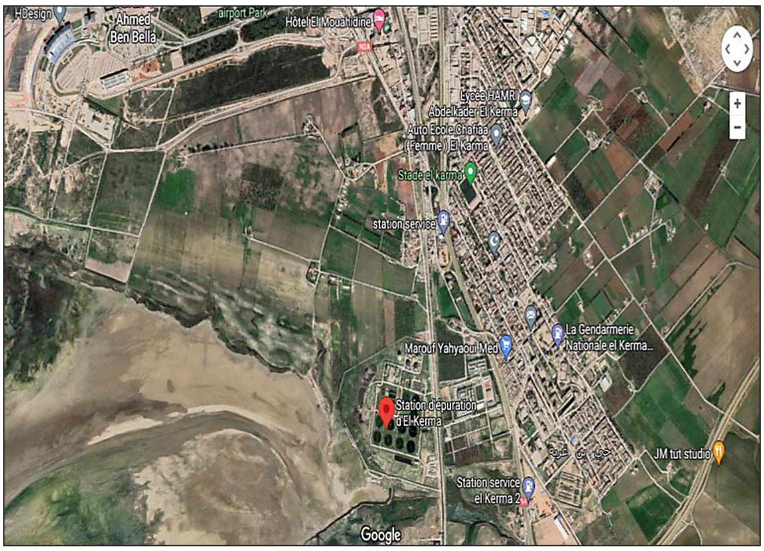

Figure 4. Location map of the El Kerma wastewater treatment plant (Algeria, Oran)

Table 3. Average value of pollutants in dry weather

Average in dry weather (24-h)	
Parameter	Value (mg.dm^{-3})
BOD_5	25
COD	125
MES	35

Table 4. Characteristics and capacity of the El Karma wastewater treatment plant

Settings	Unit	Value
Equivalent resident	E.H	1.526.000
Average daily flow rate	m^3.d^{-1}	270.096
Average hourly flow rate – dry weather	m^3. h^{-1}	11 254
Average hourly nighttime flow rate	m^3.h^{-1}	3 751
Hourly peak flow – dry weather	m^3.h^{-1}	16 200
Peak flow – biological input	m^3.h^{-1}	15400

exponential degradation phase until the system reaches saturation. The first-order model is expressed by the following equation:

$$\log(DCOe - DCOt) = \log(DCOe) - \left(\frac{k}{2.303}\right).t \quad (2)$$

where: *CODe* – COD at saturation (mg.dm^{-3}), *CODt* – COD at time *t* (mg.dm^{-3}), *k* – Constant of biodegradation process, *t* – Time of experiment (min).

RESULTS AND DISCUSSIONS

The variation curves of COD, BOD_5, and NH_4^+ over time show a similar trend, where a saturation point is observed. The exponential increase in COD, BOD_5, and NH_4^+ concentrations can be explained by the establishment of conditions favorable for the degradation of organic matter by microorganisms.

COD results (Figure 4) suggest that pozzolan initially performs better at a higher bed height but experiences saturation effects over time. Conversely, scoria demonstrates more consistent performance, which appears to better balance efficiency and stability.

BOD_5 results (Figure 5) highlight that while higher bed heights (40 cm) initially provide better BOD removal efficiency, their performance decreases rapidly due to possible saturation or oxygen limitations. On the other hand, the 20 cm bed height for both materials maintains more stable efficiency over time, making it a better option for sustained biological treatment at higher pollutant concentrations (1.5 g.dm^{-3}).

We observe a partial denitrification of ammoniacal nitrogen NH_4^+ (Figure 6). The observed trends differ slightly. Scoria occasionally exhibits a higher removal capacity than pozzolan, particularly at a bed height of 20 cm and a concentration of 1.5 g.dm^{-3}. This may be attributed to its chemical composition, which appears to favor ammonium adsorption (Figure 7).

Phosphorus (PO_4^{-2}) is naturally present in water (Figure 8). It exists in various forms. At high concentrations in water, it causes eutrophication. Protecting aquatic environments involves reducing phosphorus levels.

Variation in turbidity (Figure 9) during purification for the different time (2h, 4h, 6h, 8h) for a height of 20 cm, and for a height of 40 cm for pozzolan and Scoria. Consistency of material performance improved during operation of the filter due to progressive clogging; where the pore size became smaller leading to an increase

Table 5. Different models of biodegradation kinetics (Buttersby, 1990)

Models	$-\frac{[dS]}{dt}$	Speed constans	Unit
Ordre 1	$k[S]$	$k = \mu max.\frac{x_0}{K_1}$	h^{-1}
Michaelis and Menten	$k\frac{[S]}{k_1 + [S]}$	$K = \mu max.X_0$	$mg.l^{-1}.h^{-1}$
Ordre 0	K	$K = \mu max.X_0$	$mg.l^{-1}.h^{-1}$
Logistics	$K[S]([S_0] + X_0 - [S])$	$k = \frac{\mu max}{k}$	$l.mg^{-1}.h^{-1}$
Monod	$\frac{K[S]([S_1] + X^0 - [S])}{k_1 + [S]}$	$k = \mu max$	h^{-1}
Logarithmic	$K([S_0] + X_0 - [S]$	$k = \mu max$	h^{-1}

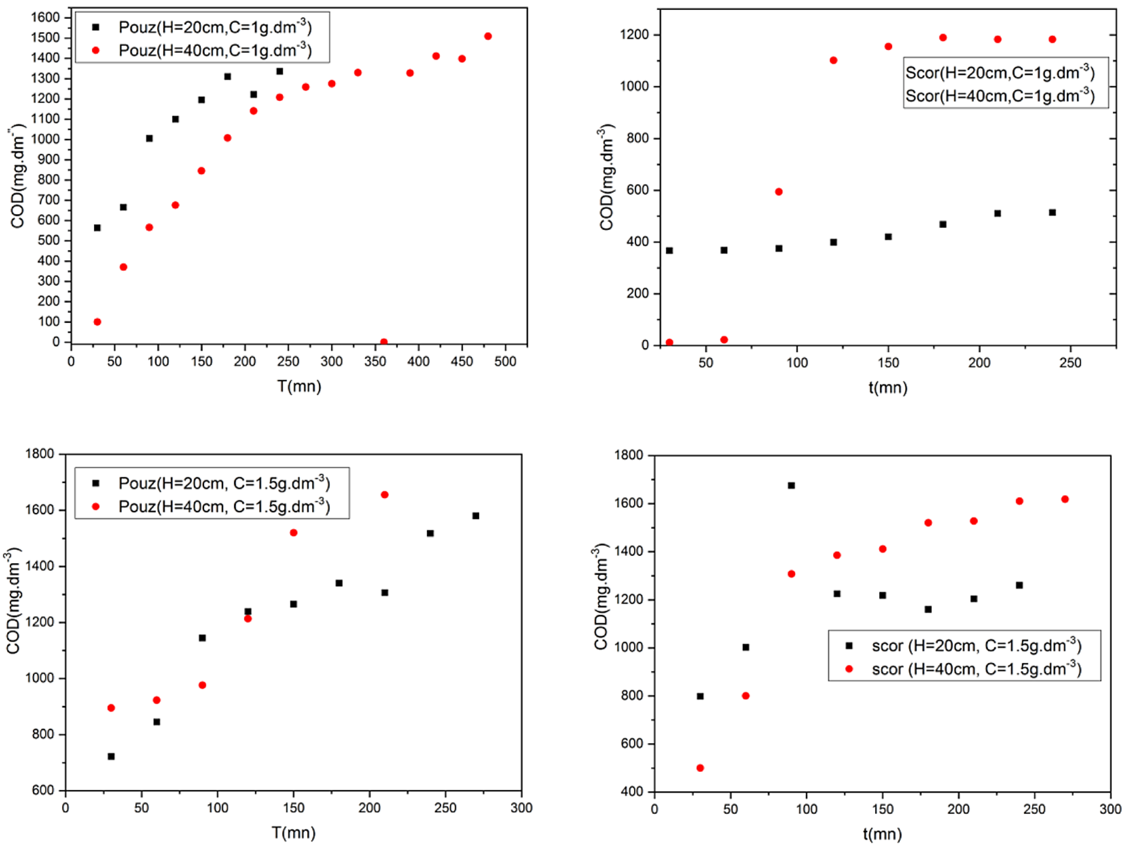

Figure 5. COD removal efficiency

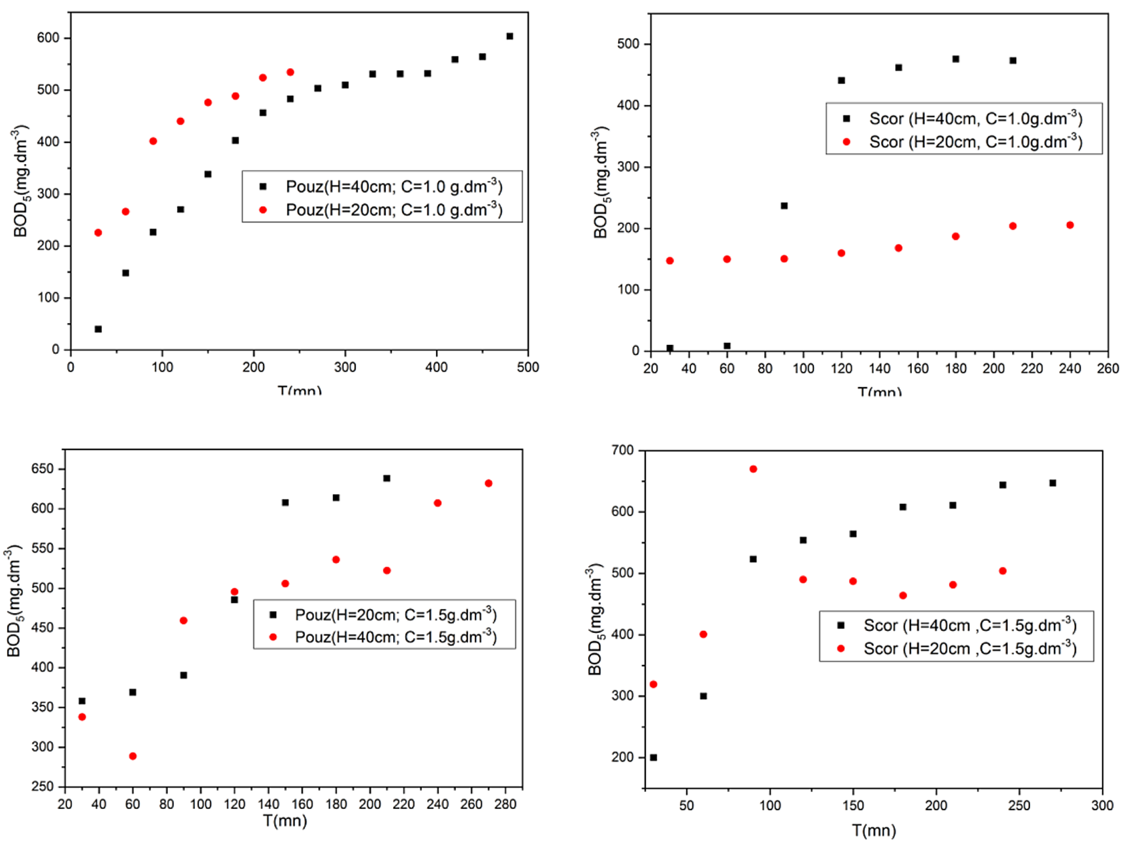

Figure 6. BOD_5 removal efficiency

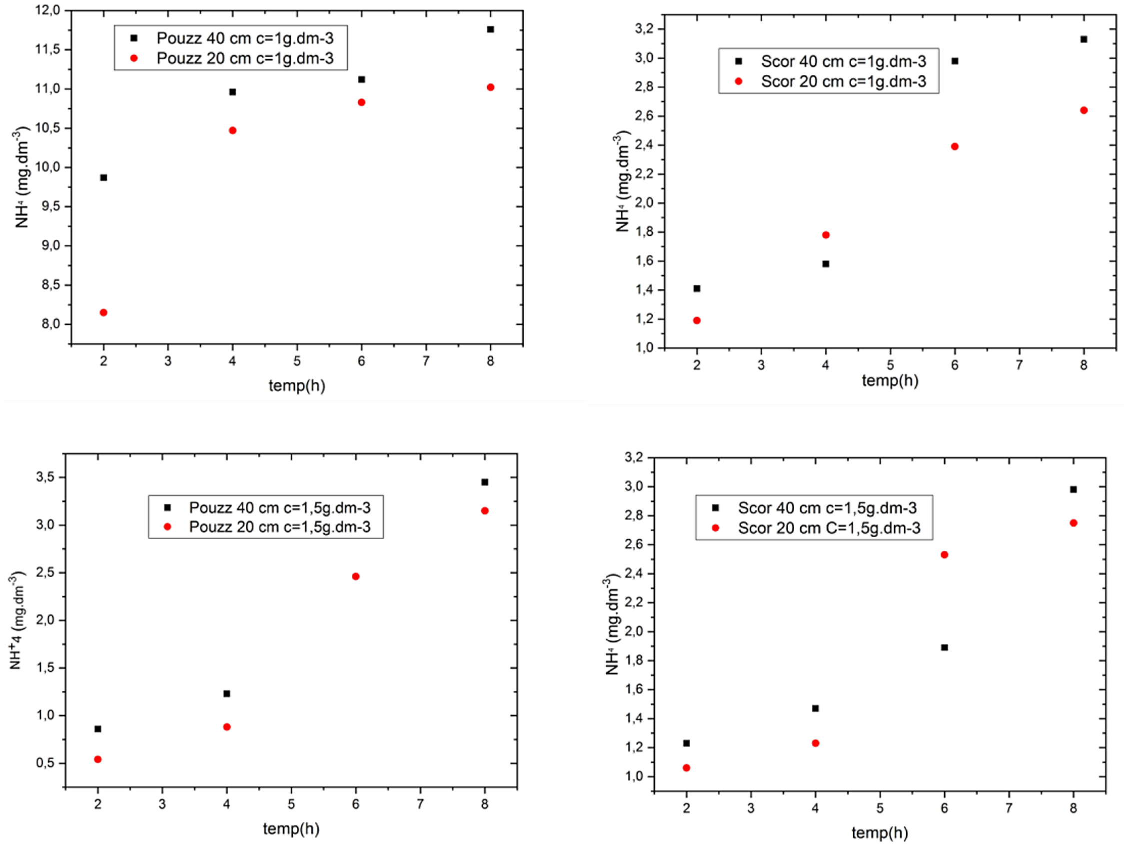

Figure 7. NH_4^+ removal efficiency

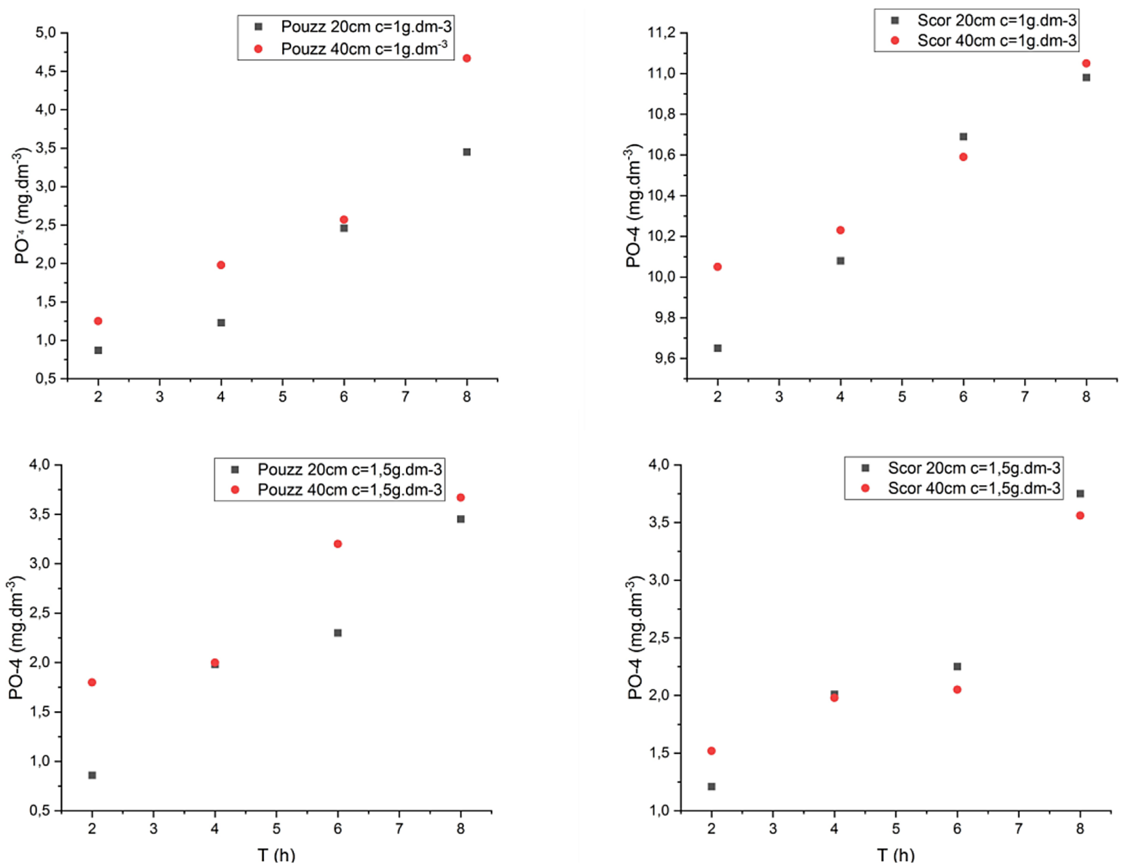

Figure 8. PO_4^{-2} removal efficiency

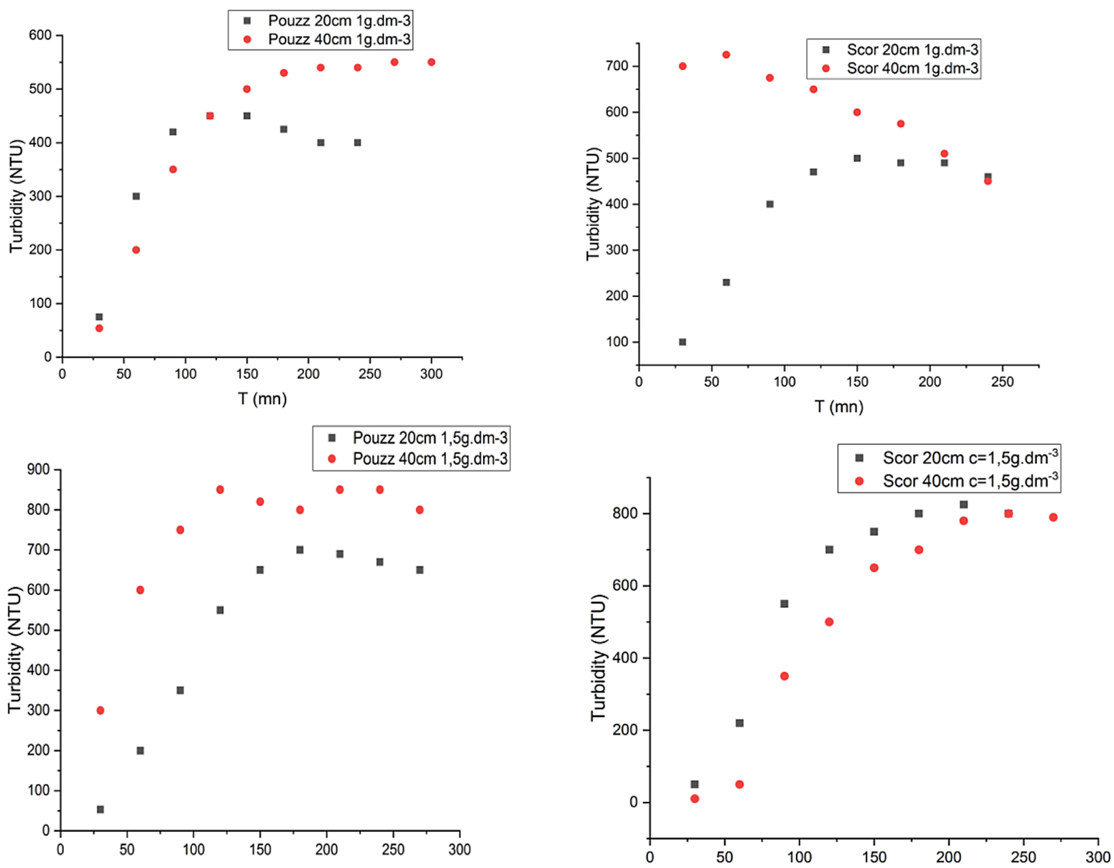

Figure 9. Turbidity removal efficiency

in voltage in the upper layer of the filter, thereby improving the elimination of turbidity by reducing the pore size of the media and therefore the retention of more particles (Davies et al., 2012). This trend may be consistent with maturation of the filter, which helps to improve the elimination efficiency over time and through the interaction contaminants with the biofilm composed mainly of protozoa, bacteria and other life forms in the filter bed which is considered the main reduction of the turbidity (Liu et al., 2010; Mebarki et al., 2021).

According to the graphs in Figure 10, the passage of domestic sewage through the pilot and filtration material shows a slight decrease in pH from 7.2 to 6.74 for the height of 20 cm. and for the second height 40 cm; a decrease in pH from 7.73 to 7.35 for the purified water concerning the first material. This variation in pH cannot be explained only by probable reactions during treatment that we cannot identify. Values of pH are between 6.40 and 6.10 in this experiment. This change in pH values in the treatment by biofiltration materials is linked to the nitrification process and denitrification (Luanmanee et al., 2002). Figure 11 shows an increase in conductivity, indicating water mineralization due to the dissolution of mineral salts contained in the rocky filtering materials during the filtration process.

The results of the kinetic modeling for the COD biodegradation using the first-order model. The goal is to analyze the decrease in COD concentrations over time and determine the kinetic constant (k), which characterizes the rate of pollutant degradation. By plotting log (DCOe−DCOt) as a function of time, linear trends are identified (Figure 12 and Figure 13), enabling the calculation of k. Comparisons are made between bed heights (20 cm and 40 cm) and materials (pozzolan and scoria) to evaluate their influence on the COD removal kinetics and system performance.

The kinetics of biodegradation through bacterial beds conforms to first order model with an explained variance (r^2) varying between 0.74 and 0.96. The kinetic constant k reaches 0.08 for pozzolan and 0.020 for scoria. Which is equivalent to a bacterial enzymatic mechanism.

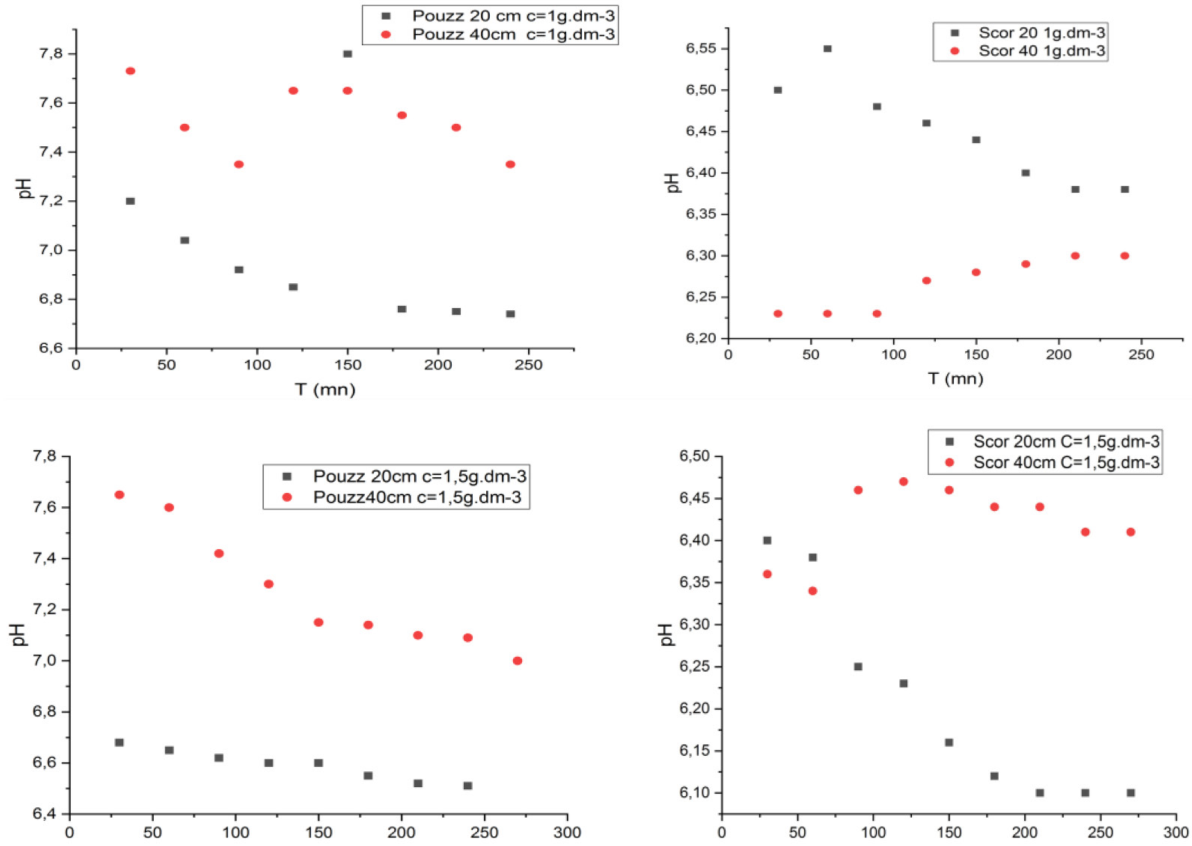

Figure 10. pH variation during biofiltration

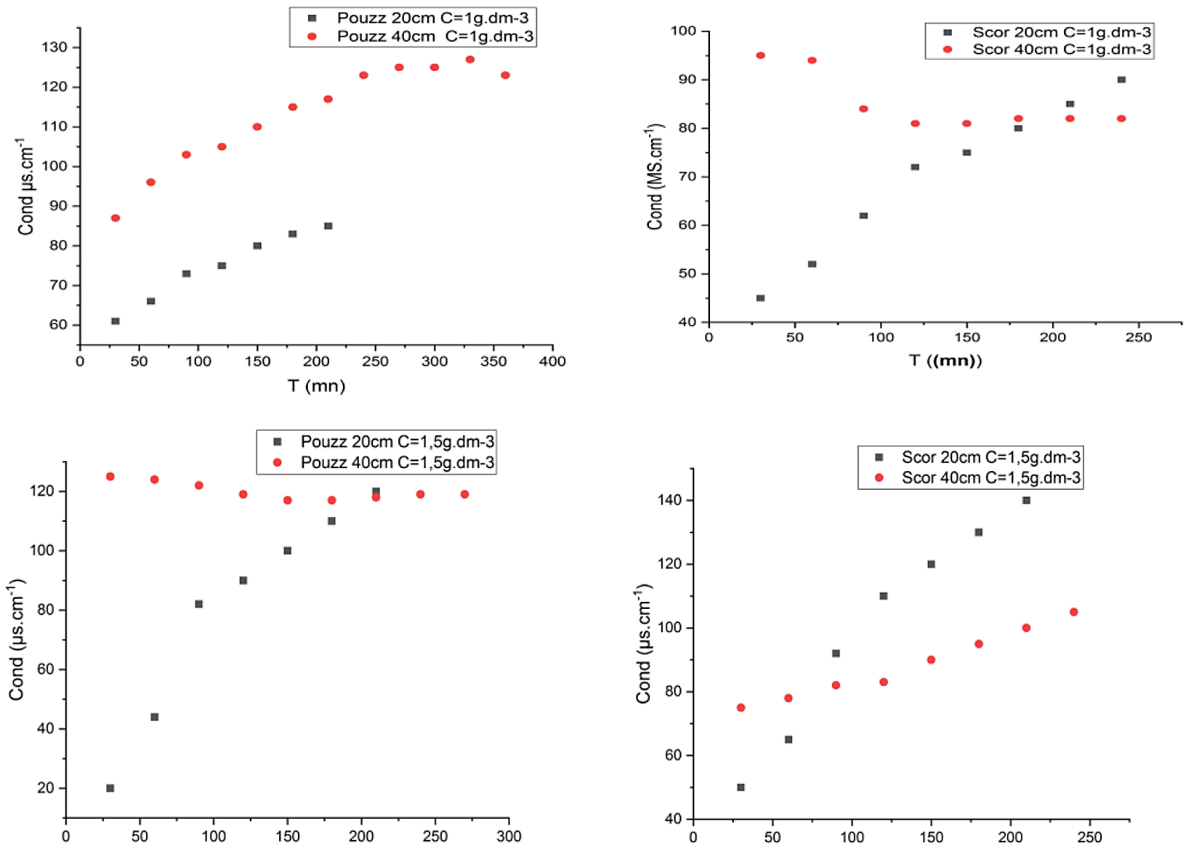

Figure 11. Conductivity variation during biofiltration

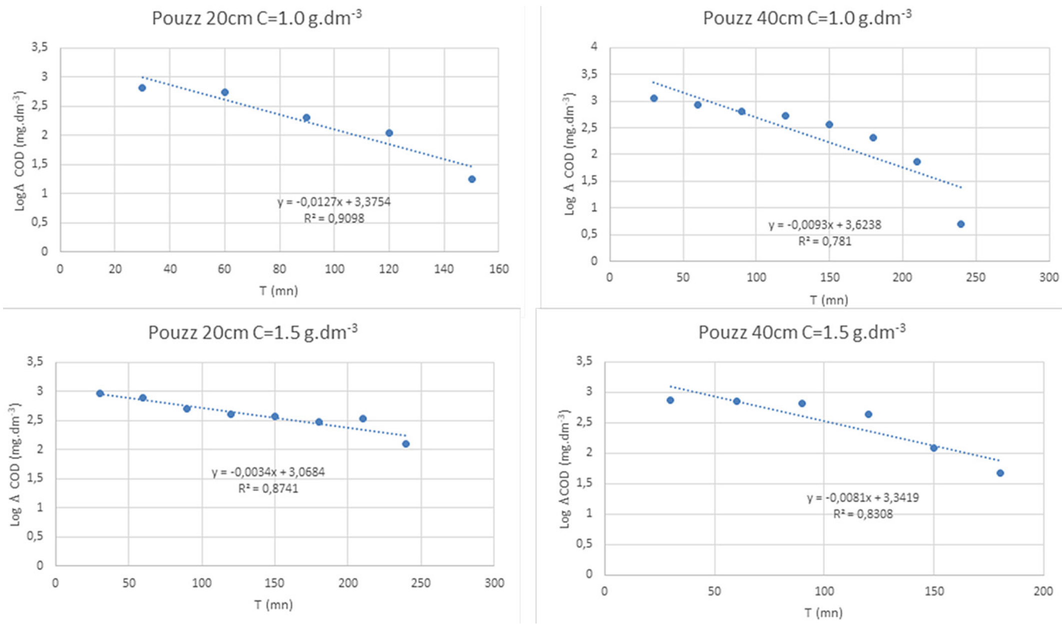

Figure 12. COD removal kinetics of pozzolan

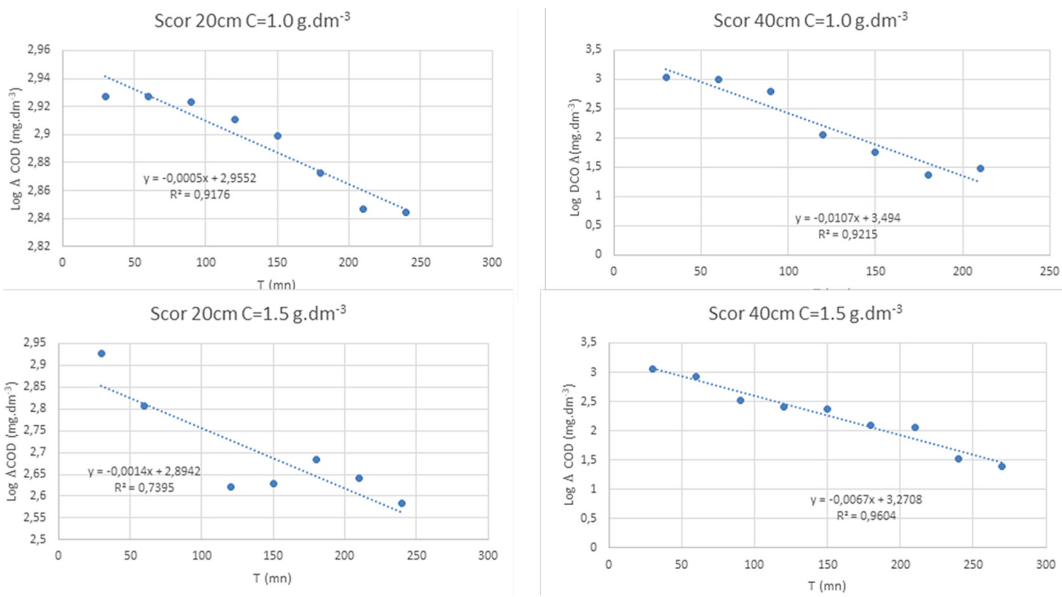

Figure 13. COD removal kinetics of scoria

CONCLUSIONS

This study highlights the significant role of material type, bed height, and substrate concentration in influencing COD removal efficiency in biofilm-based treatment systems. Pozzolan consistently outperformed scoria across all experimental conditions, attributed to its higher porosity and larger surface area, which enhance microbial attachment and activity. The 20 cm bed height proved more effective than the 40 cm bed, likely due to improved oxygen transfer and substrate accessibility, providing optimal conditions for biodegradation. Additionally, lower substrate concentrations (1 g.dm^{-3}) resulted in higher kinetic constants (K), indicating faster COD removal, whereas higher concentrations (1.5 g.dm^{-3}) slowed degradation due to substrate saturation effects. Overall, the most efficient condition was observed with pozzolan at 20 cm bed height and 1 g.dm^{-3} concentration, achieving the highest kinetic constant (K = 0.080). These findings emphasize the importance of material selection, optimal bed height, and controlled substrate concentration in improving biological treatment system performance. Future research should focus on further optimizing operational parameters, such as flow rate and oxygen availability, and analyzing microbial community dynamics to enhance system efficiency further. The denitrification rate of ammoniacal nitrogen NH_4^+ reaches 19% for pozzolan and 18% for scoria.

REFERENCES

1. Bdouri, A.N., Hamdi M.R., Tarawneh Z. (2009). Perspectives on sustainable wastewater treatment technologies and reuse options in the urban areas of the Mediterranean region. *Desalination, 237*, 162–174. https://doi.org/10.1016/j.desal.2007.12.030
2. Belaribi, N., Chemsa, M., Laouifi, L. (2003). Influence of Beni-saf pozzolan on the mechanical characteristics of concrete. *Canadian Journal of Civil Engineering*. https://doi.org/10.1139/l03-029
3. Bendida, A., Kendouci, M. A., Mebarki, S., Tidjani, A. E. B. (2024). Wastewater purification and recycling using plants in an arid environment for agricultural purposes: case of the Algerian Sahara. *Applied Water Science 14*(6): 123. https://doi.org/10.1007/s13201-024-02148-9.
4. Bendida, A., Kendouci, M. A., Tidjani, A. E. B. (2021). Characterization of Algerian Sahara groundwater for irrigation and water supply: Adrar region study case. *Journal of Water and Land Development 49*: 235–243. https://doi.org/10.24425/jwld.2021.137117
5. Bendida A., Tidjani A. E.-B.,Kendouci M.A.,Nabou M.(2013). Treatment of domestic wastewater from the town of Bechar by a sand filter (sand of Beni Abbes Bechar Algeria). Energy Procedia. 36, 825–833. https://doi.org/10.1016/j.egypro.2013.07.095
6. Bothe, H. M., Wardb, B., Witzel, K. (2000). Molecular analysis of ammonia oxidation and denitrification in natural environments. FEMS Microbial. *Rev, 24*, 673–690. https://doi.org/10.1111/j.1574-6976.2000.tb00566.x
7. Buttersby, N.S. (1990). A review of biodegradation kinetics in the aquatic environment, *Chemosphere, 21*, 1243–1284. https://doi.org/10.1016/0045-6535(90)90144-I
8. Dugniolle, H.(1980). The sanitation of domestic wastewater, Safety code for construction work, CSTC, Review n° 3- September, 44–52.
9. Ferchichi, A., Abdelhamid, N. M., Jean, D. (1994). Prospection caryologique de la famille des Poaceae en Tunisie steppique. *Acta Botanica Gallica*. https://doi.org/10.1080/12538078.1994.10515166
10. Glanic R., Benneton J-P. (1989). Characterization of individual sanitation effluents and testing of autonomous sanitation equipment - TSM - Water - 84 year - N 11 –573–584.
11. Hosseinzadeh, A., Zhou, J.L., Navidpour, A.H., Altaee, A. (2021). Progress in osmotic membrane bioreactors research: Contaminant removal, microbial community and bioenergy production in wastewater, *Bioresource Technology, 330*: 124998. https://doi.org/10.1016/j.biortech.2021.124998
12. Kendouci M.A., Mebarki S., Kharroubi B. (2023). Investigation of overexploitation groundwater in arid areas: the case of the lower Jurassic aquifer, Bechar province Southwest of Algeria. *Applied Water Science. 13*:102. https://doi.org/10.1007/s13201-019-1081-y
13. Kendouci M.A., Bendida A., Mebarki S., Kharroubi B. (2019). Study of the management efficiency of the drinking water supply in arid areas: case of Bechar city (southwest of Algeria). *Applied Water Science. 9*, 192. https://doi.org/10.1007/s13201-019-1081-y
14. Lazarova, V., Gaid, A., Rodriguez, J., Alday, J. (2003). The benefits of reusing wastewater: analysis of global examples, *Techniques, Sciences and Methods, 9*, 64–85.
15. Lefevre, F. (1988). *Urban wastewater treatment by infiltration-percolation: experimental study and process definition.* Doctoral thesis from Languedoc University, Montpellier, France.
16. Liu, F., Mitchell, C.C., Odom, J.W., Hill, D.T., Rochester, W. (1997). Swine lagoon effluent disposal by overland flow: effects on forage production and uptake of nitrogen and phosphorus. *Agronomy Journal, 89*, 900–904. https://doi.org/10.2134/agronj1997.00021962008900060009x
17. Luanmanee, S., Boonsook, P., Attanandana, T., Saitthiti, B., Panichajakul, C., Wakatsuki, T. (2002). Effect of intermittent aeration regulation of a multi-soil-layering system on municipal wastewater treatment in Tailand. *Ecological Engineering, 18*(4), 415–428. https://doi.org/10.1016/S0925-8574(01)00103-3
18. Mansh, R., Bock, E. (1998). Biodeterioration of natural stone with special reference to nitrifying bacteria. Biodegradation. *National Institutes of Health (NIH). N 9*, 47–64. https://doi.org/10.1023/a:1008381525192
19. Marsalek, J., Schefer, K., Exall, K., Brannen, K., Aidun, B. (2001). Water reuse and recycling. Canadian Council of Ministers of the Environment, Winnipeg, Manitoba. *CCME Water Science and Policy Workshop Series, Proceedings 3*, 46 http://doi.org/10.4296/cwrj195
20. Mebarki, S., Kharroubi, B., Kendouci, M.A. (2021). Physicochemical evolution and evaluation of groundwater quality in Mougheul area (Southwest of Algeria). *Appl Water Sci, 11*, 40. https://doi.org/10.1007/s13201-021-01368-7

21. Mebarki, S., Kendouci, M A. and Bendida, A. (2024). Monitoring the spatial evolution of groundwater quality during its diversion in the drinking water supply network in arid areas, case of Bechar city (Algeria Sahara), *Applied Water Science, 14*, 118. https://doi.org/10.1007/s13201-024-02157-8
22. Paulscrud, B., Haraldsen, S. (1993). Experiences with the Norvegian approval system for small waste water treatment plants. *Wat. Sc. Techn., 28*(10), 25–32.
23. Peter, B., Hannele, K.R. (2014). Culinary-gastronomic tourism: a search for local food experiences. *Nutrition and Food Science, 4*, 294–309. https://doi.org/10.1108/NFS-12-2013-0142
24. Rice, R.C. (1974). Soil clogging during infiltration of secondary effluents. *J.W.P.C.F. 46*(4), 708–716. https://www.jstor.org/stable/25038184
25. Richard, D., Gillian, R., Simon, M., Jennifer, M., Steinar, H., Leo, N. (2012). Hydraulic fractures: How far can they go. https://doi.org/10.1016/j.marpetgeo.2013.02.001
26. Schmitt A. (1989). *Modeling of infiltration purification. Thesis in Mechanics, Mechanical Engineering and Civil Engineering.* Languedoc University of Sciences, Montpellier II, 261. https://theses.fr/1989MON20174
27. Shin, J.H., Sang, B.I., Chung, Y.C., Choung, Y.K. (2005). The removal nitrogen using an autotrophic hybrid hollow-fiber membrane biofilm reactor. *Desalination, N 83*, 447–454. https://doi.org/10.1016/j.desal.2005.03.045
28. Smith, J.S., Cheng, D.L.. Castorani, C.N. (2022). Meta-analysis of ecosystem services associated with oyster restoration, *Conservation Biology*. https://doi.org/10.1111/cobi.13966
29. Tebbutt, T.H.Y. (1977). *Principles of water quality control,* University Birmingham, England, 2nd edition.
30. Touafek A. (2015). *Experimental study of the purification of effluents by fixed culture processes*. Magister thesis, Department of Hydraulic, University of Sciences and technology of Oran, Mohamed Boudiaf, Algeria.