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Performance of pozzolan in trickling filter for secondary treatment of urban wastewater in Tlemcen, Algeria

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Abstract: The research aims to study the purification performance of a local and natural material as an input or as a biological filter for treating urban domestic wastewater. For this purpose, pozzolan was used as the biofiltration support that was provided from Beni Saf located in the North-West of Algeria. Tests were carried out with a specially modified pilot unit (TE900) for wastewater treatment over a period of four months.

To assess the efficiency of the treatment, two main parameters have been focused on – the height of the sprinkler filter (40 cm and 80 cm) and the flow rate (10, 16, and 25 $dm^3 \cdot h^{-1}$). Physicochemical and bacteriological analyses were carried out on raw wastewater and treated water. The obtained results show that the Beni Saf pozzolan-filled trickling filter eliminates a large fraction of the studied pollutants. The purification yields obtained are fairly encouraging; 98% for turbidity, 88% for suspended solids (*SS*), 94% for chemical oxygen demand (*COD*), and 98% for biological oxygen demand (BOD_5). As for bacterial indicators, the formation of biofilms has significantly reduced bacterial activity with a percentage of over 80%.

It can be concluded that the reduction of pollutant parameters clearly indicates the effectiveness of the treatment by this ecological process. Therefore, the use of local and natural materials for wastewater treatment can be a promising alternative based on sustainable environmental technologies and development.

Keywords: physicochemical parameters, pollution, pozzolan, trickling filter, wastewater treatment

INTRODUCTION

The problem of environmental protection is really important to modern communities, it whereas has been known for a long time [Soloviy *et al.* 2021]. Wastewater treatment has become a major environmental concern on a global scale, encouraging the development of processes for improving the quality of water discharged into the natural environment. The treatment of these discharges is essential in order to reduce their harmful and toxic effects. Different treatment techniques are used, such as biological (natural or aerated lagooning, activated sludge or trickling filters), physicochemical (coagulation-flocculation, precipitation or oxidation), or membrane (reverse osmosis, nanofiltration, or electrodialysis) [Degremont 2005; Edeline 1997].

Wastewater treatment is therefore the only way to mitigate environmental problems; many natural and inexpensive technologies could be used in rural areas, such as lagoons, macrophytes, sand filters, and trickling filters [Bdouri *et al.* 2009]. Owing to the lack of natural sources of water, the treatment of wastewater is considered a major priority. Organic wastes are causing serious problems for wastewater; so different methods are used to purify the wastewater from pollutants it contains [Omri *et al.* 2013; Ouadi *et al.* 2020].

In the world and in Algeria in particular, the most commonly used wastewater treatment process is activated sludge, which requires a significant investment, high technicality, a variety of equipment, and significant energy consumption (for aerators, brewers, compressors, recirculation screws, etc.). The search for alternative processes that are simple, easy to implement, and energy-efficient is necessary; among these processes in urban wastewater purification, we cite the trickling filters that are easy to use and effective. This process is interesting in secondary or tertiary purification and may justify its use [Ferchichi *et al.* 1994].

The use of natural material filters for treating urban wastewater has been used for a long time. It was already practiced in Massachusetts (USA) in the late 1800s [Bernier *et al.* 2001; Liénard, Racault 2003]. Wastewater treatment using filtration on granular natural media, such as sand filters, could be an effective method to meet water quality requirements for reuse applications [Al-Jlil *et al.* 2009; Kauppinen *et al.* 2014], those media allow the retention of particles, and the fixation of the biomass developed on the granular material, but also, the biodegradation of phosphorus and organic pollutants as well as physical filtration [Hua *et al.* 2003; Zidane *et al.* 2006]. The microorganisms are immobilised on the filling material in the form of a biofilm. The polluting substances are then transferred from the moving liquid phase to the fixed biofilm, which constitutes the immobile solid phase. These polluting substances are then degraded by the microorganisms constituting the biofilm [Dumont *et al.* 2008].

There are many advantages of using biofilm in wastewater treatment systems in comparison with suspended growth systems, such as smaller space demand, flexible procedures, higher biomass retaining period, improved recalcitrant substance degradation as well as a decreased rate of microbial proliferation [Shahot *et al.* 2014]. The quality of the composition of the support on which biofilm is fixed on static platforms, such as granular carriers, distinguished the application of moving and fixed bed processes [Ouadi *et al.* 2020].

Among the most common materials used for the elimination of microorganisms in wastewater are pozzolan, sand, brick, granular activated carbon, sponge, plastic profiles, granular carriers or membranes, which provide a high degree of biological contaminants removal. Among many authors who use different materials, Ouadi *et al.* [2020] studied the efficiency of sawdust and pozzolan as biofilters for wastewater treatment and found high yields for *COD* and BOD_5.

Fylypchuk *et al.* [2017] used an expanded polystyrene filter for the treatment of domestic waste effluent and found that this filter is potentially an adequate robust option for small sites.

According to the research of Jóźwiakowski [2017], who studied the efficiency of organic substance removal in the hybrid sand filter, it was concluded that sand filters with a horizontal flow do not guarantee high performance in wastewater treatment.

Soloviy *et al.* [2021] observed that the effectiveness of the use of natural materials such as bentonite (clay) for wastewater treatment is confirmed by regeneration and reusability.

In this perspective, we propose in this study the use of classic trickling filters filled with local material which is the natural pozzolan of Beni Saf for the purification of urban wastewater. Algeria has an appreciable quantity of pozzolanic materials of volcanic rock origin extracted from the Bouhamidi deposit located at 2.5 km from Beni Saf, in western Algeria and which extends along 160 km between the Algerian-Moroccan border and the Oran Sahel. This deposit is in the form of a conical mountain called El Kalcoul whose absolute height is 236 m [Belaribi *et al.* 2003].

The objective of this study is to test the effectiveness of a trickling filter system filled with the pozzolan to purify domestic wastewater from the wastewater treatment plant (WWTP) of Ain El Houtz located in the city of Tlemcen, Algeria on a laboratory scale, and to study the purification performance of this process. To carry out this work, the wastewater was provided from Ain El Houtz WWTP, which treats the domestic wastewater of the city of Tlemcen, Algeria by the process of activated sludge. The wastewater for the experiment was collected before the biological treatment (by activated sludge), which we passed through the purification pilot TE 900 [DELTALAB 1993], which consists of a pozzolan filter column, and then the filtered water settles on a settling tank. To assess our research, physicochemical parameters have been taken as a reference, such as suspended solids (*SS*), turbidity, dissolved oxygen (*DO*), pH, temperature (*T*), chemical oxygen demand (*COD*), and biological oxygen demand after five days (BOD_5), that have been daily analysed at the inlet and outlet of the trickling filter for sixteen weeks. As for the microbiological parameters, we have focused on faecal and total coliforms, and faecal streptococci. After evaluating the results of the analysis, it can be then possible to state whether or not the purification system has been effective for the purification of urban wastewater, and also if the analysis matches with the norms of reuse in irrigation.

MATERIALS AND METHODS

PILOT DESCRIPTION

The pilot that we have used to study the efficiency of pozzolan as support for bacteria on the trickling filter to treat urban wastewater, is the pilot TE 900 (Fig. 1) provided by the wastewater treatment and purification laboratory of Abou Bekr Belkaid University, Faculty of Technology, Tlemcen, Algeria.

The pilot TE900 is composed of a cylindrical transparent PVC feed tank (A) (300 dm^3) with a drain valve and a suspension feed pump, a borosilicate glass filter cartridge playing a role of a filter column with a length of 1 m, a diameter of 10 cm and

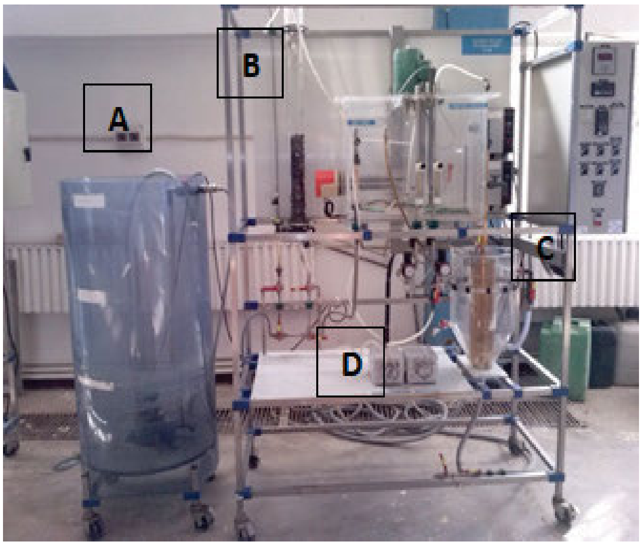

Fig. 1. The pilot TE 900; A = cylindrical transparent PVC feed tank, B = borosilicate glass filter cartridge, C = cylindrical-conical borosilicate glass static settling tank or clarifier, D = discharge valve for the clarified water, and a recirculation circuit from the clarifier to the feed tank; source: own elaboration

a volume of 5 dm^3 (B), a cylindrical-conical borosilicate glass static settling tank or clarifier with a diameter of 28 cm and a length of 55 cm and a capacity of 25 dm^3 (C), a discharge valve for the clarified water, and a recirculation circuit from the clarifier to the feed tank (D). Figure 2 illustrates the diagram of the pilot unit which operated continuously during our tests.

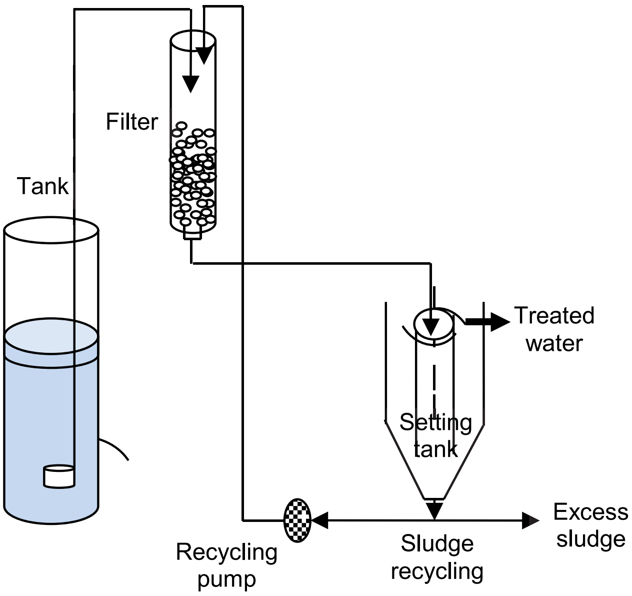

Fig. 2. Diagram of the pilot; source: own elaboration

RAW WATER

The raw wastewater used in our study was provided every week from Ain El Houtz WWTP of Tlemcen. For each experiment, 300 dm^3 were taken after the pretreatment (after the screening, grit removal, oil removal, and degreasing) to fill the pilot feed tank, and 5 dm^3 of fresh sludge was introduced into the filter cartridge in order to accelerate the biological degradation process and to maintain an adequate rate of active microorganisms.

THE EXPERIMENT PROCEDURE AND SAMPLING METHOD

The experiment consisted of filling the cartridge with the support material, then pumping raw wastewater from the feed tank to the cartridge and keeping them in contact, allowing the wastewater containing micro-organisms to settle onto the porous or cavernous materials which serve as a support for microorganisms (bacteria) that will degrade the pollution and purify the raw wastewater. The whole system is left in rotation in a closed circle for 24/24 h to provide oxygen to bacteria.

Before taking the samples of treated wastewater to be analysed, we had to make sure that the bacterial plating on the trickling filter has been effectively done.

Water samples have been taken under aseptic conditions, on a glass vial, and analysed within a maximum of four hours. The samples of raw wastewater and purified water were taken daily, and each experiment is considered completed when the *COD* of the purified water is stable. The experiment lasted for four months: from December 2016 to March 2017.

NATURE AND CHARACTERISTICS OF THE BIOMASS SUPPORT MATERIAL

The material is first rinsed to remove impurities and then dried at 105°C in an oven before being characterised. The determination of the physical and chemical characteristics of natural pozzolan was carried out at the civil engineering laboratory (Faculty of Technology, University of Tlemcen), and in collaboration with the West Public Works Laboratory (Fr.: Laboratoire des Travaux Publics de l'Ouest – LTPO), in the Geo-Resources Laboratory (GRL) in Tunisia, and at National Centre for Research and Study on Water and Energy (Fr.: Centre National d'Etudes et de Recherches sur l'Eau et l'Energie – CNEREE) in Morocco within a short internship for chemical composition and X-ray diffraction (RXD) (Fig. 3). The results of these analyses are reported in the Tables 1–3. The characteristics and properties of pozzolan are regrouped in Table 1. The mineral composition was measured applying the X-ray diffraction method. The results of the quantitative chemical analysis of pozzolan are presented in Tables 2 and 3.

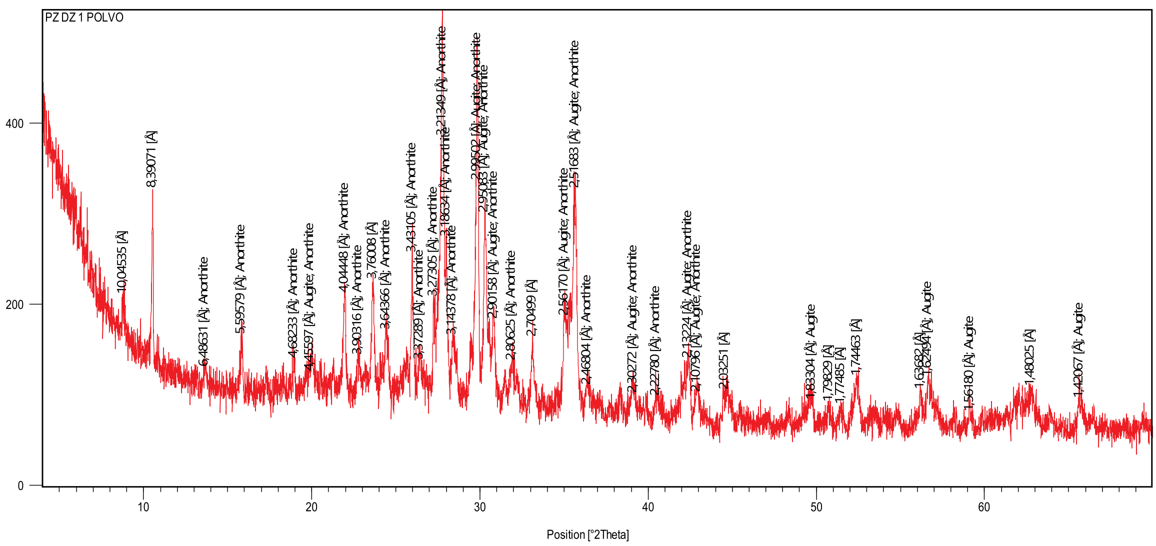

Fig. 3. X-ray diffraction spectrum of pozzolan (RXD); source: own study

Table 1. Different characteristic properties of pozzolan

Main characteristics	Value
Absolute density (g·cm^{-3})	1.25
Apparent density (g·cm^{-3})	4.66
Blaine specific surface of powder (cm^2·g^{-1})	2567
Coefficient of absorption (%)	19.65
Specific gravity (–)	1.43
Porosity (%)	59
Pozzolanicity (%)	85
Humidity (%)	2.5
pH	5.6–7.0
d_{10}	10.5
d_{60}	15.5
C_c	1.038
C_u	1.47

Explanations: d_{10} = mesh diameter allowing 10% of the sand mass to pass through (mm), d_{60} = grain diameter (mm) at 60% passing, C_u = coefficient of uniformity: ratio d_{60}/d_{10}, C_c = curvature coefficient [Arias *et al.* 2001; Degremont 2005].
Source: own study.

Table 2. Content of chemical elements of pozzolan

Chemical element	Percentage
Na_2O	3.41
MgO	5.84
Al_2O_3	17.01
SiO_2	45.66
P_2O_5	0.74
K_2O	2.17
CaO	10.09
TiO_2	2.62
MnO	0.17
Fe_2O_3	9.73
LOI	2.43
Total	99.86

Explanation: *LOI* = loss on ignition.
Source: own study.

Pozzolan is characterised by a high content of carbon, oxygen and hydrogen as well as chlorine and calcium.

ANALYSIS METHOD

In order to purify raw wastewater, our experiments were carried out by adjusting the height of the pozzolan in the filtration cartridge, the inlet flow (feed), and the recycling flow.

Physicochemical parameters were measured for the inlet water and at the level of the settling tank to assess and evaluate the effectiveness of the treatment:

Table 3. Mineral composition of the media

Composition	Value
Light element (%)	87.55
Cl (%)	8.72
Ca (%)	2.47
Si (mg·dm^{-3})	5220
Al (mg·dm^{-3})	2083
Ti (mg·dm^{-3})	1686
P (mg·dm^{-3})	1356
K (mg·dm^{-3})	1154
S (mg·dm^{-3})	543
Fe (mg·dm^{-3})	285
Cd (mg·dm^{-3})	72
Zn (mg·dm^{-3})	49
Ag (mg·dm^{-3})	37
Th (mg·dm^{-3})	36
Sr (mg·dm^{-3})	18
Mo (mg·dm^{-3})	15
Zr (mg·dm^{-3})	4
Y (mg·dm^{-3})	3

Source: own study

a) granulometry of 10/25 mm over a height of 40 cm: for feed flow rates of 10, 16, and 25 dm^3·h^{-1};

b) granulometry of 10/25 mm over a height of 80 cm: for feed flow rates of 10, 16, and 25 dm^3·h^{-1}.

The physicochemical and bacteriological parameters are determined from daily samples taken from the supply tank and the clarifier, i.e. raw water and purified water [AFNOR 1997; Baird *et al.* (eds.) 2005; Rodier 2009]. Samples of wastewater are collected in polyethylene bottles of 0.5 dm^3 or glass vials, two samples were taken per day.

The main parameters that have been used to assess the performance of pozzolan filters are *T*, pH, turbidity, *DO*, *SS*, *COD*, and BOD_5:
- the temperature was measured using a thermometer;
- the pH was measured using a pH meter, type PHM 220;
- the turbidity was measured by a turbidity meter, HI88703;
- the dissolved oxygen was measured by an Oxymeter;
- the *SS* were determined by the membrane filtration method; it is the filtration of a volume of effluent through a 0.47 μm porosity glass fiber filter;
- the *COD* was determined by oxidation with potassium dichromate;
- the determination of the BOD_5 is done by the manometric method [Baird *et al.* (eds.) 2005; Rodier 2009].

As for bacteriological analyses, we did just at the end of the experiment for a height of 40 cm and 80 cm; in our studies faecal and total coliforms, streptococci are sought.

The enumeration of bacteria indicative of faecal pollution in purified water was carried out by the filtration method on a filter membrane with a porosity of 0.45 μm. The volume of filtered water is 100 cm^3, and also according to the indirect method of multiple tube fermentation in lactose broth, the number was then statistically deduced using the most probable number method [Rodier 2009].

The culture of total coliforms (TC) was carried out on the agar medium with incubation at 37°C for 24 h. The culture of faecal coliforms (FC) was also carried out on the agar medium with triphenyl tetrazolium chloride (TTC), but the incubation was carried out at 4°C for 24 h. Enumeration of faecal streptococci was performed on Slanetz and Bartley medium after incubation at 37°C for 24 h.

RESULTS AND DISCUSSIONS

PHYSICOCHEMICAL CHARACTERISTICS OF WATERS

The results of the obtained analyses are presented in the following figures and tables for the various pollution parameters; the graphs show the evolution of the physicochemical parameters at the outlet of the trickling filter. All the results show that the concentration of different parameters analysed decreased from the inlet to the outlet of the biological filter.

Temperature and pH

The concentrations of pH and temperature in the influent for different height and flow rates are shown in Figures 4 and 5. The temperature and pH are factors, strongly influenced by the environmental conditions related to the geographical location of the locality [Nasra, Zahran 2014]. Alkaline pH values were detected at the inlet and outlet of the trickling filter system for all flow rates. The pH values of the influent are always higher than those of the effluent.

According to the graphs (Fig. 4), the passage of urban wastewater through the media shows an increase in pH from 7.25 to 7.31, 7.31 to 7.43, and from 7.07 to 7.7 respectively at the flow rate of 10, 16, and 25 $dm^3 \cdot h^{-1}$ for the height of 40 cm (Fig. 4a), and for the height of 80 cm (Fig. 4b), an increase in pH has been observed from 7.3 to 7.61, 7.78 to 8, and from 7.2 to 7.5 respectively at the flow rate of 10, 16, and 25 $dm^3 \cdot h^{-1}$.

This change in pH values in the treatment with biofiltration materials is related to the process of nitrification and denitrification inside the pilot [Luanmanee *et al.* 2002]. This increase could be explained by the dissolution of certain existing salts or the presence of alkaline salts during the flow of the effluent, leading to chemical reactions inside the trickling filters [Gherairi *et al.* 2015]. According to Adouani *et al.* [2015], the increase in pH could be due to the elimination of CO_2 by aeration (stripping) or to the denitrification that could occur in the biofilm, especially when its thickness increases during adaptations.

According to the results obtained (Fig. 5), the temperature of the different samples is very close. It varies from 20 to 29°C at the inlet of the filter and between 16 and 21°C for the treated water for the height of 40 cm for different flow rates (Fig. 5a), and between 16 and 22°C for the height of 80 cm (Fig. 5b). According to Sevrin-Reyssac *et al.* [1995], an alkaline pH and a moderate temperature constitute ideal environmental conditions for the

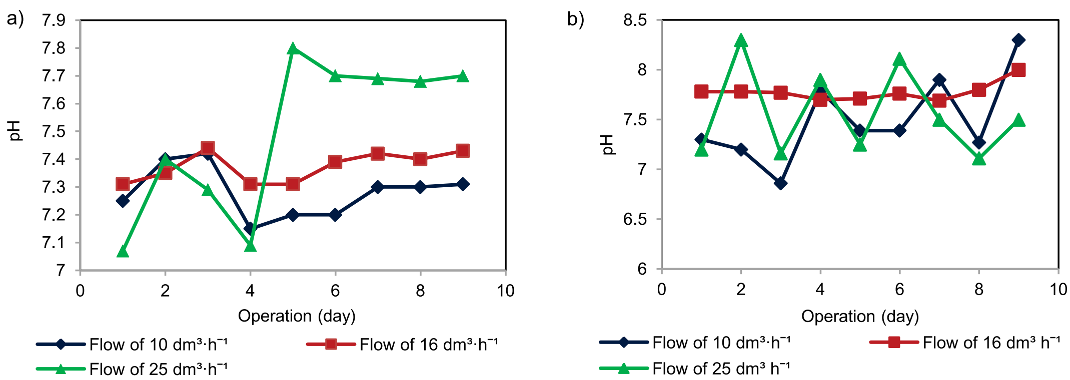

Fig. 4. Variation of pH during the experiment for different feed rates (10, 16, and 25 $dm^3 \cdot h^{-1}$); a) for a height of 40 cm, b) for a height of 80 cm of pozzolan; source: own study

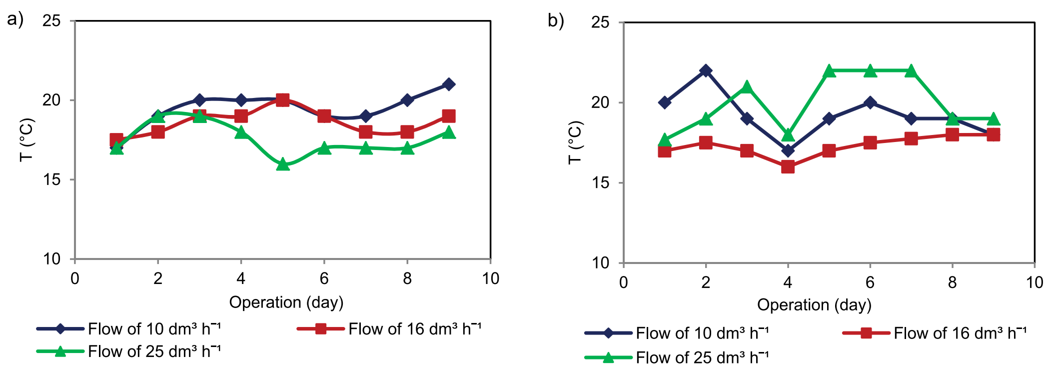

Fig. 5. Variation of temperature during the experiment for different feed rates (10, 16, and 25 $dm^3 \cdot h^{-1}$); a) for a height of 40 cm, b) for a height of 80 cm of pozzolan; source: own study

multiplication of microorganisms which establish a perfect biological balance and allow the degradation of organic matter leading to the water decontamination.

Suspended solids, turbidity and dissolved oxygen

The concentrations of suspended solids (*SS*), turbidity, and dissolved oxygen (*DO*) for the influent are shown in Figures 6, 7, and 8. During filtration on the pozzolan, we have observed a high capacity of organic particles removal (Fig. 6) with a decrease of *SS* of 84, 85, and 82% respectively for the flow rate of 10, 16, and 25 $dm^3 \cdot h^{-1}$ for the height of 40 cm (Fig. 6a), and the mean removal percentages for the height of 80 cm were 86, 85, and 88% respectively for 10, 16, and 25 $dm^3 \cdot h^{-1}$ (Fig. 6b).

This reduction is due mainly to the physical processes of sedimentation and filtration, and sieving in the filtering media [Achak *et al.* 2011]. The elimination of *SS* was mainly realised by the mechanism of filtration on the material. The organic matter, after being retained on the media, has been reduced by a biological degradation by the microorganisms (biofilm) found in the porous media under oxygenated conditions [An *et al.* 2016]. It has been found that the flow rate of 10 $dm^3 \cdot h^{-1}$ with the height of 80 cm (Fig. 6b) achieved the highest *SS* removal; this may reflect that pozzolan needs a longer time to form the biofilm responsible for the purification efficiency. When the trickling filter is running with the flow rate of 10 $dm^3 \cdot h^{-1}$, it allows the organic particles to percolate slowly on the media, consequently, the microorganisms formed within the biofilm have more time to degrade the organic matter compared with the flow rate of 16 and 25 $dm^3 \cdot h^{-1}$. Since the bed of 80 cm is deeper than of 40 cm, the biofilm formed on

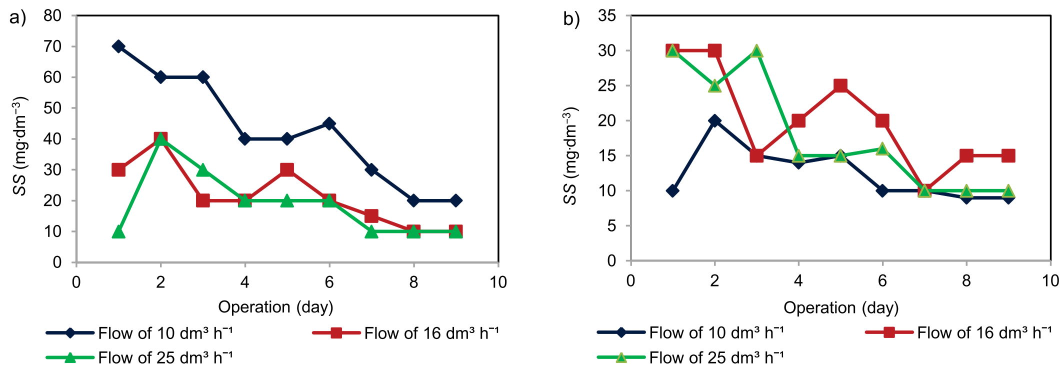

Fig. 6. Variation of suspended solids (*SS*) during the experiment for different feed rates (10, 16, and 25 $dm^3 \cdot h^{-1}$); a) for a height of 40 cm, b) for a height of 80 cm of pozzolan; source: own study

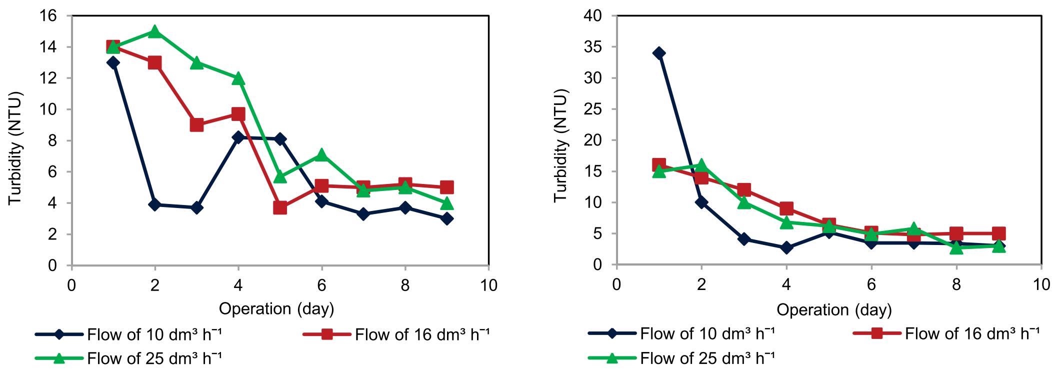

Fig. 7. Variation of turbidity during the experiment for different feed rates (10, 16, and 25 $dm^3 \cdot h^{-1}$); a) for a height of 40 cm, b) for a height of 80 cm of pozzolan; NTU = nephelometric turbidity unit; source: own study

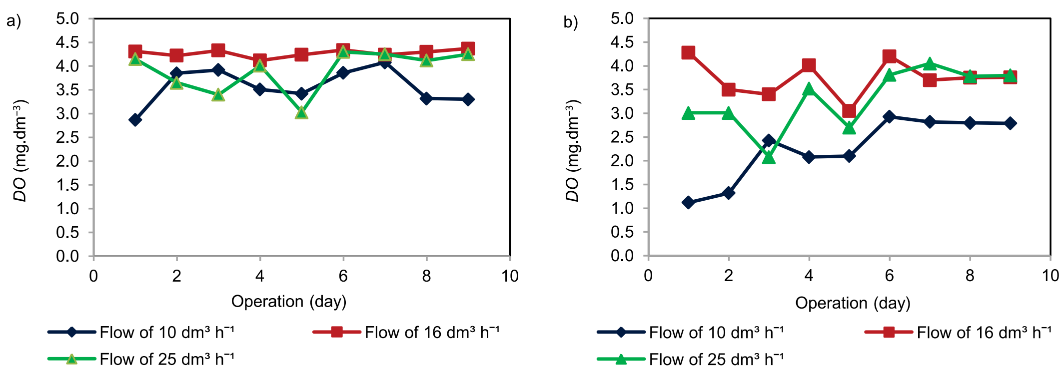

Fig. 8. Variation of dissolved oxygen (*DO*) during the experiment for different feed rates (10, 16, and 25 $dm^3 \cdot h^{-1}$); a) for a height of 40 cm, b) for a height of 80 cm of pozzolan; source: own study

the deepest one is more important and will be more efficient for organic matter degradation.

HEISTAD *et al.* [2009] have demonstrated the role of biofilms for effective wastewater treatment in infiltration material systems, which take place after the maturation of the filter media by the formation of the biofilm that degrades the organic matter, consequently reducing the suspended solids.

Turbidity is one of the parameters of particulate pollution and it represents the amount of fine material responsible for the cloudiness of the sample [LIPTÁK 2003]. The turbidity of water is a measure that takes into account all the particles, either insoluble or colloidal, of organic or mineral origin [THAYER *et al.* 2007]. The turbidity values, recorded in the wastewater before treatment, vary from 80 to 300 NTU; depending on the daily load at the inlet of the WWTP and the nature of the water to be treated, there is a decrease in the turbidity from 13 to 3 NTU, 14 to 5 NTU and 14 to 4 NTU respectively for 10, 16 and 25 $dm^3 \cdot h^{-1}$ for the height of 40 cm (Fig. 7a). For the height of 80 cm, there is also a decrease from 34 to 3 NTU, 16 to 5 NTU and 15 to 3 NTU respectively for 10, 16 and 25 $dm^3 \cdot h^{-1}$ (Fig. 7b), this reduction is due to the degradation of the organic matter. The consistency of material performance has improved during the running of the filter due to the gradual clogging, where pore sizes became smaller leading to an increase in tension in the top layer of the filter, which reduces the size of the pores of the media and therefore improves the elimination of turbidity [DAVIES, WHEATLEY 2012]. This tendency may be consistent with the maturation of the granular material, which helps to enhance the removal efficiency over time, and through the interaction of the contaminants with the biofilm, composed mainly of bacteria, and other life forms in the biological filter which is considered as the main turbidity reduction [LI *et al.* 2010]. As water passes through the biofilm, suspended and organic matter can be trapped in the material and get dissolved, then adsorbed and metabolised by the microorganisms [WU *et al.* 2011].

The result of dissolved oxygen in the raw sewage from the WWTP of Ain El Houtz is approximately 0.78 $mg \cdot dm^{-3}$ (Tab. 4). In our experience the dissolved oxygen value varies between 0.59 and 2.77 $mg \cdot dm^{-3}$ before the purification by the pozzolan, and after filtration, the dissolved oxygen value shows an increase from 2.87 to 4.25 $mg \cdot dm^{-3}$ on average and from 1.12 to 3.8 $mg \cdot dm^{-3}$ respectively for the height of 40 cm (Fig. 8a) and 80 cm (Fig. 8b) of pozzolan for the different flow rate. The increase of dissolved oxygen could be due to the improvement of oxygen transfer due to the progressive elimination of organic matter and consequently, the decrease in viscosity and also this increase is renewed by introducing atmospheric air through the infiltration surface filter medium of the trickling filter [FAN *et al.* 2016; LATRACH *et al.* 2017]. The vertical flow in wastewater treatment systems, such as trickling filters, supply high oxygenation conditions than the systems based on the horizontal flow [JÓŹWIAKOWSKI 2017; STEPHANAKIS, TSIHRINTZIS 2012].

Chemical oxygen demand and biological oxygen demand

COD is an important indicator of organic load in urban wastewater; it is also an indication of the quantities of organic substances present in water that are chemically oxidisable [BLIEFERT *et al.* 2001]. Note that the *COD* values of raw water vary depending on weeks and the pollution load of raw water at the inlet of the WWTP, they range between 115 and 489 $mg \cdot dm^{-3}$ (Tab. 4). Concerning the treated water, the recorded values of the *COD* vary between 9.6 and 48 $mg \cdot dm^{-3}$ for all flow rates and for the height of 40 cm (Fig. 9a) and 80 cm (Fig. 9b) respectively. The obtained results indicated high removal percentage of *COD*, the mean removal efficiencies for the height of 40 cm and 80 cm were 92% (Fig. 10a) and 98% (Fig. 10b) respectively. This removal can be explained by the probable formation of biofilm, especially on the superficial layer of the filter and good bacterial assimilation takes place in the pozzolan, which favours the adsorption and retention of the organic matter and consequently its degradation by the microorganisms [KHENGAOUI *et al.* 2015; RILEY *et al.* 2018]. Our results are higher compared to those observed by OUADI *et al.* [2020] for the use of pozzolan in wastewater treatment systems, who found an average *COD* removal efficiency of 88%. In another study with the use of filter material in Morocco, CHAKRI *et al.* [2019] found that the efficiency is higher with the filter with crashed pozzolan compared with the filters of gravel, with an abatement rate of 78% for *COD*, which is lower compared to our study (92%). Whereas the variations in the BOD_5 contents during our monitoring of the parameters of organic pollution, along the treatment process are represented in Figure 10a. The average value of the pollutant load received by the trickling filter varies between 50 $mg \cdot dm^{-3}$ and 290 $mg \cdot dm^{-3}$ depending on the week (Tab. 4). The BOD_5 contents of the filtered water are between 4 and 40 $mg \cdot dm^{-3}$ for the height of 40 cm (Fig. 11a) and 80 cm (Fig. 11b), with an average reduction of 92% (Fig. 10a), and 97% (Fig. 10b) respectively.

Table 4. Characteristics of the raw domestic wastewater from Ain El Houtz wastewater treatment plant after pretreatment (2017)

Parameter	Unit	Values range	Average values
T	°C	16–19.5	18
pH	–	7.71–7.87	7.83
DO	$mg \cdot dm^{-3}$	0.41–0.92	0.78
SS	$mg \cdot dm^{-3}$	102–288	152
EC	$\mu s \cdot cm^{-1}$	1062–1291	1082
Turbidity	NTU	159–288	162
COD	$mg \cdot dm^{-3}$	231–383	383
BOD_5	$mg \cdot dm^{-3}$	210–290	290
NH_4	$mg \cdot dm^{-3}$	29.62–38.05	36.1
N-NO_2	$mg \cdot dm^{-3}$	0.22–1.8	0.22
N-NO_3	$mg \cdot dm^{-3}$	2.1–4.5	2.1
TP	$mg \cdot dm^{-3}$	4.2–6.2	6.2

Explanations: *T* = temperature, *DO* = dissolved oxygen, *SS* = suspended solids, *EC* = electrical conductivity, NTU = nephelometric turbidity unit, *COD* = chemical oxygen demand, BOD_5 = biological oxygen demand (after 5 days), *TP* = total phosphorus.
Source: own study.

A decrease in the improvement of the filter has been observed during the last four days of each feed rate, this decrease is accompanied by a “fatigue” of the filters indicating the beginning of their puncture [DJEDIDI, HASSEN 1991]. Additionally, OUADI *et al.* [2020] reported a similar removal percentage between 93 and 97% for BOD_5 using pozzolan as a bio filter system. According to BAGUNDOL *et al.* [2013], the mechanism of BOD_5

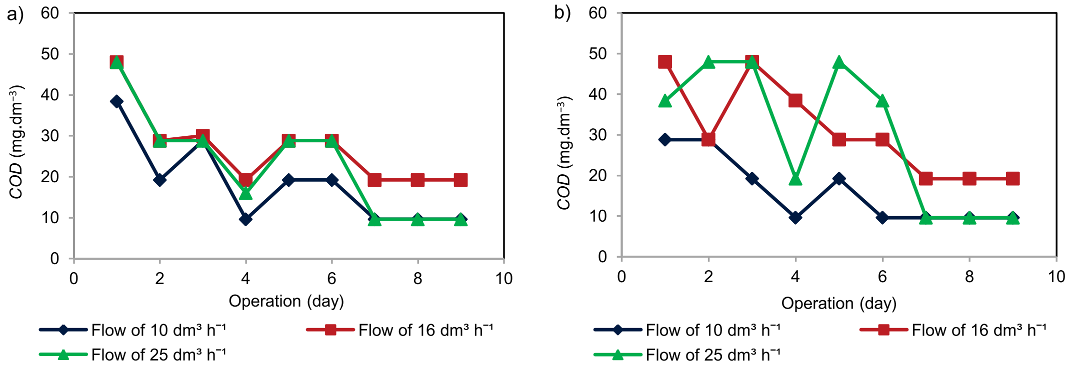

Fig. 9. Variation of chemical oxygen demand (*COD*) during the experiment for different feed rates (10, 16, and 25 $dm^3 \cdot h^{-1}$); a) for a height of 40 cm, b) for a height of 80 cm of pozzolan; source: own study

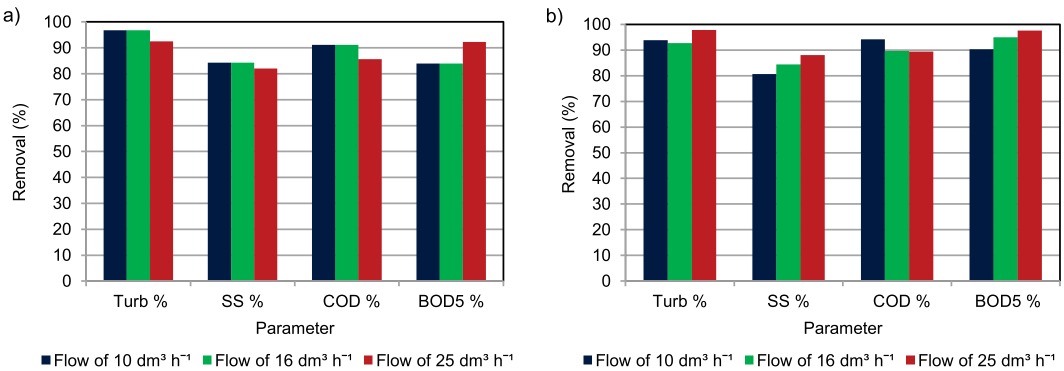

Fig. 10. Purification yield; a) for a height of 40 cm, b) for a height of 80 cm; Turb = turbidity, *SS* = suspended solids, *COD* = chemical oxygen demand, BOD_5 = biological oxygen demand (after 5 days); source: own study

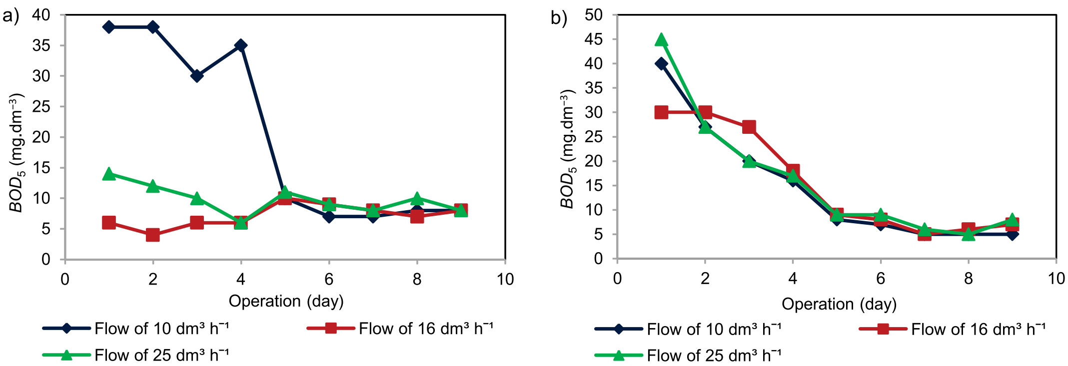

Fig. 11. Variation of biological oxygen demand (BOD_5) during the experiment for different feed rates (10, 16, and 25 $dm^3 \cdot h^{-1}$); a) for a height of 40 cm, b) for a height of 80 cm of pozzolan; source: own study

reduction may be the mechanical adsorption and entrapment of organic and inorganic particles.

As the materials have not been washed during the experiment, it can be considered that a mature filter allows the adsorption to be dominated by the flocs captured in the filters. However, the texture of the support and the possibility of more or less adhesion of microorganisms is probably not the only one responsible for the observed differences in performance [Williams *et al.* 2007].

RESULTS OF MICROBIOLOGICAL ANALYSES

The search for pathogenic organisms in specific ways and on a daily basis is expensive and random, which is why we were interested in the concentrations of indicator germs (total and faecal coliforms, streptococci) for only two samples for the first height of 40 cm, and another for the second height of 80 cm (Tab. 5).

The average concentration of total coliforms in wastewater before treatment with the filter material is 6.55 log unit, and after treatment by the pozzolan it was reduced by 1.65 log unit for the height of 40 cm, and from 6.6 log unit to 5.5 log unit for the height of 80 cm. For faecal coliform, the mean log removal by the material was 1.1 and 1.2 for the height of 40 and 80 cm respectively. Regarding the removal efficiencies of faecal streptococci, the log removal values are around 1.2 and 1.26 for the height of 40 and 80 cm respectively, which conforms with the Algerian norms (Tab. 6). These rates of elimination of bacterial indicators can be explained by the nature of the material used which is characterised by its shape that contains several pores.

Table 5. Concentration of microbiological parameters of raw and filtered water for the two heights

Parameters	Height of 40 cm		Height of 80 cm	
	wastewater	treated water	wastewater	treated water
	log CFU·(100 cm^3)$^{-1}$			
Total coliforms	6.55	4.9	6.6	5.5
Faecal coliforms	6.1	5.5	5.4	4.5
Faecal streptococci	5.3	4.4	5.8	4.6

Source: own study.

Bacterial reduction in filter medium is normally allocated to diverse mechanisms besides the filtration, such as microbial death and adsorption of bacteria [Torrens *et al.* 2009]. According to Latrach *et al.* [2014], adsorption and filtration are the first mechanisms of bacterial removal, followed by other elimination mechanisms such as the natural death of bacteria and microbial degradation. It is in these areas that bacteria can then diffuse and get trapped in addition to constriction areas where pores are too small to allow passage of cells [Johnson *et al.* 2007].

PURIFICATION PERFORMANCE OF THE EXPERIMENTAL PILOT

Figures 6, 7, 9 and 11 indicate that abatement of *SS*, turbidity, *COD* and BOD_5 is very high for a height of 80 cm, where the yields are greater than that of the height of 40 cm.

If we compare the results found in our experiment (using pozzolan) with the treated wastewater (after activated sludge) from the WWTP of Ain El Houtz, we can say that pozzolan gave higher efficiency in removing *COD* and BOD_5 with 98% and 97% compared to 92% and 95% respectively with activated sludge. However, the activated sludge gave higher *SS* removal with 93% compared to 88% with pozzolan.

Using a trickling filter as a secondary treatment instead of activated sludge is more interesting because it requires less space, less energy, cheap and natural material that are locally found, and it is also adequate in rural areas.

The performances of the pilot were satisfactory and no significant clogging was observed (Tab. 7). The microporous

Table 6. Algerian standards for wastewater reuse in irrigation

Parameter	Unit	Maximum tolerable value
pH	–	6.5–8.5
SS	mg·dm^{-3}	30
EC	dS·m^{-1}	3
Turbidity	NTU	5
BOD_5	mg·dm^{-3}	30
COD	mg·dm^{-3}	90
Nitrogen (N-NO_3)	mg·dm^{-3}	30
Aluminum	mg·dm^{-3}	20
Arsenic	mg·dm^{-3}	2.0
Beryllium	mg·dm^{-3}	0.5
Boron	mg·dm^{-3}	2.0
Cadmium	mg·dm^{-3}	0.05
Chrome	mg·dm^{-3}	1.0
Cobalt	mg·dm^{-3}	5.0
Copper	mg·dm^{-3}	5.0
Cyanides	mg·dm^{-3}	0.5
Fluorine	mg·dm^{-3}	15
Iron	mg·dm^{-3}	20
Phenols	mg·dm^{-3}	0.002
Lead	mg·dm^{-3}	10.0
Lithium	mg·dm^{-3}	2.5
Manganese	mg·dm^{-3}	10.0
Mercury	mg·dm^{-3}	0.01
Molybdenum	mg·dm^{-3}	0.05
Nickel	mg·dm^{-3}	2.0
Selenium	mg·dm^{-3}	0.02
Vanadium	mg·dm^{-3}	1.0
Zinc	mg·dm^{-3}	10.0
Total coliforms	CFU·(100 cm^3)$^{-1}$	<120
Faecal coliforms	CFU·(100 cm^3)$^{-1}$	<100
Faecal streptococcus	CFU·(100 cm^3)$^{-1}$	<100

Explanations: *SS* = suspended solids, *EC* = electrical conductivity, NTU = nephelometric turbidity unit, *COD* = chemical oxygen demand, BOD_5 = biological oxygen demand (after 5 days), CFU = colony-forming unit.
Source: own elaboration based on Arrêté interministériel ... [2012].

Table 7. Performances of purification by pozzolan on the physicochemical parameters.

Parameters	Influent	Effluent					
		height of 40 cm			height of 80 cm		
		flow rate *Q* (dm^3·h^{-1})					
		10	16	25	10	16	25
pH	7.53	7.49	7.36	7.43	7.51	7.74	7.59
T (°C)	17.5–29.0	19	18	17	20	19	22
DO (mg·dm^{-3})	1.97	3.60	4.27	3.67	2.20	3.73	3.25
Turbidity (NTU)	120	10 (91%)	8 (93%)	5.4 (95%)	6.8 (94%)	6.4 (95%)	4.1 (96%)
SS (mg·dm^{-3})	154.02	28.75 (82%)	24.29 (85%)	21.43 (87%)	17.38 (89%)	21.43 (87%)	16.88 (90%)
COD (mg·dm^{-3})	289.07	27.60 (91%)	26.06 (91%)	26 (91%)	24 (92%)	24.64 (92%)	23 (92%)
BOD_5 (mg·dm^{-3})	149.97	12.5 (92%)	6.86 (95%)	10 (94%)	16 (89%)	6.71 (95%)	6.25 (96%)

Explanations as in Tab. 4. Source: own study.

texture of pozzolan would facilitate the development of the biofilm and limit its detachment; this would partly explain the better overall performance of the pozzolan filter [Menoret 2001]. The structure of pozzolanic material with its adsorption rate, density, and porosity allowed to ensure the easy diffusion of atmospheric oxygen, so the oxygen dissolved in water is an important factor for a good purification of effluent [Abissy, Mandi 1999; Chakri *et al.* 2019].

CONCLUSIONS

1. The results obtained in the experiment show the efficiency of the different stages of treatment by this process and the purification performance of natural pozzolan from Beni Saf for the treatment of urban wastewater. The operation of this pilot is reliable and allows a significant reduction of *SS*, BOD_5, *COD*, and turbidity and thus for the microbiological parameters.
2. The removal yield obtained is higher for the *COD* and BOD_5 than those found in the process of activated sludge of Ain El Houtz WWTP in the city of Tlemcen.
3. All the results found conform to the discharge norms and quality standards for water intended for irrigation in Algeria.
4. The performance of the parameters of this study by using pozzolan as a biofilter depends on many parameters which are the feed flow rate, the height of the trickling filter, and other parameters also such as the quality of the water to be purified.
5. Good performances are derived from the use of this natural material for the purification of water from the urban origin with about 96% for turbidity, 85% for *SS*, 92% for *COD*, and 94% for BOD_5 for a trickling filter height of 40 cm, and about 97, 90, 98 and 97% for turbidity, *SS*, *COD*, and BOD_5 respectively, for a trickling filter height of 80 cm.
6. Trickling filter using pozzolan is an interesting alternative for treating wastewater because it requires materials that are natural, local, abundant in large quantities, and of low energy consumption. In terms of performance achieved, the application of the local materials use method, provides an effective option for purification and reuse of domestic wastewater in small isolated communities. However, more research into the long-term pollution removal performance of this system with the use of other materials is needed.

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