

Performance of sand and wood fibres in tertiary treatment of effluent discharged by lagoons

ABSTRACT

In Burkina Faso, as in most developing countries, access to water and sanitation remains a challenge. This justifies the reuse of wastewater to provide additional quantities of water for different uses to reduce water deficits. In this context, the wastewater from the city of Ouagadougou is treated by lagoons for its reuse on gardening plots downstream the station. Since several years these plots have been disaffected and abandoned due to the quality of the discharged water. This work aims at experimenting complementary treatments to improve water quality for agricultural reuse. Indeed, pilots of infiltration-percolation on sand and on wood fibres have been implemented during 3 months in the Institute of Research in Applied Sciences and Technologies. A comparative analysis of the treated waters according to the ISO and AFNOR standards indicated that the various filters gave satisfactory purification efficiencies which are in agreement with the quality objectives imposed by the national standards for parameters such as Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD₅), nitrogen and faecal coliforms. The respective removals of COD by the sand filter (FS) and the wood fibres filter (FC) were 94% and 91%, while BOD₅ was eliminated with efficiencies of 84% and 64% respectively. Regarding nutrients such as ammonium and nitrate, the station gave the effluents contents conform to the discharge standards but the filters have made it possible to improve their quality. FS and FC gave satisfactory efficiencies of 97% and 92% for the faecal coliforms removal. Concerning faecal streptococci and *Bacillus cereus*, it is noted non-negligible with respective efficiencies of 84 and 93% with the wood fibres while the sand allowed efficiencies of 79 and 88% for the same parameters. In general, the additional treatment by the pilots has made it possible to improve the quality of the water coming from the station.

Keywords: Sewage, lagoons, sand, wood fibres, infiltration-percolation, COD, faecal coliforms.

1. INTRODUCTION

Context and problematic :In a context of significant population growth and climate change, with its consequences in terms of drought and / or flooding, developing countries are struggling to meet the needs of their population in terms of sanitation and water supply for domestic, industrial and agricultural use. Growing and urgent food needs justify the reuse of raw or partly treated wastewater in peri-urban agriculture for the production of various vegetables, source of substantial incomes for farmers, even though the population are exposed to risk of infection by pathogenic germs and heavy metals [1] [2].. However, this practice is not without its health consequences since the level of contamination of these waters by pathogenic germs, heavy metals and hydrocarbons is important [2]. Burkina Faso, like other sub-Saharan countries, is no exception. Indeed, with an annual increase of 3.1%, the rapid population growth especially in urban areas, induces a strong pressure on natural resources in general and water resources coupled with a serious lack of adequate sanitation systems [3]. The strategic plan to clean up the cities of Burkina Faso, has been an opportunity for the city of Ouagadougou to get sewerage networks that drains the domestic wastewater from the city and those from the industrial area to a lagoon treatment plant which has been operational since 2004. However, the purification report on wastewater quality at the outlet of the station remains unsatisfactory regarding the quality objectives assigned to the receiving environment. That explains why the gardeners gave up the site. Indeed, the effluents from the station present a strong reddish coloration, high concentrations of suspended solid and especially loads in faecal coliforms higher than WHO standards for irrigation. In addition, wastewater mainly from industrial sources is characterized by high sodium contents, high alkalizing power with high contents of carbonate and bicarbonate ions. This explains why the experiment seems not to be conclusive since the gardeners settled on the plots downstream the station has all given up the site since the quality of the water is not compatible with their crops [1] To improve the quality of the wastewater various technologies exist including the filtration on mineral or organic granular media. Various vegetal media have been used in the

treatment of water (surface or groundwater) to eliminate different types of pollutants. Bio based nanofibres are increasingly considered in purification technologies due to their high mechanical properties, their high specific surface area, and their natural abundance. For example, the copper adsorption capacity of the nanofibers can be improved due to the oxidization treatment [4].

Moreover, among various water treatment methods, adsorption is considered as the best one due to its low cost, its universal nature and its smooth operation; some of the methods can remove various organic pollutants ranging from 80 to 99.9% [5].

This is confirmed by Sud et al. who think that cellulosic agricultural waste materials are an abundant source for significant metal biosorption. Thanks to the presence of some functional groups, their major advantages over conventional treatment methods are: low cost, high efficiency, minimization of chemical or biological sludge, regeneration of biosorbents and possibility of metal recovery. The mechanism of biosorption process includes chemisorption, complexation, adsorption on surface, diffusion through pores and ion exchange, etc. [6].

Thus, Riahia et al. conducted an experimentation on the tertiary treatment of domestic wastewater by date-palm fibres to remove turbidity, phosphorus, COD and helminth from an activated sludge treatment process. The results indicate that diameter of the fibres had the most significant factor affecting the removal of targeted matter [7].

Ahmad and Hameed study concerns the use of activated carbon prepared from bamboo waste, as an adsorbent for the removal of chemical oxygen demand (COD) and the colour of cotton textile mill wastewater. It results that the efficiency depends on the temperature, the activation time and the chemical impregnation [8]. In addition, many studies have focused on the removal of heavy metals. The work of Asadi and co-workers on the rice hull and wood fibres used as adsorbents to remove Pb (II), Cd (II), Zn (II), Cu (II) and Ni (II) can be listed. To modify their adsorption characteristics, the samples were treated with HCl, NaOH and heat. It appears that the adsorption capacity of the rice hull was greater than that of the wood fibres [9].

Polycyclic aromatic hydrocarbons (PAHs) are also successfully removed by the use of organic media. The works of Boving and Zhangde confirm it through the demonstration of the ability of wood fibres to remove dissolved PAHs under laboratory conditions. Their experiments concern the uptake of naphthalene, fluorene, anthracene, and pyrene, which required up to 12.5 days to reach equilibrium [10]. As for the work of Acharyaa et al., the adsorption of chromium (VI) was studied on activated carbon from Tamarind wood with zinc chloride activation. The results indicate that the Tamarind wood activated could be the solution for chromium (VI) sorption from aqueous solutions [11].

In the case of Chen et al., who worked on the adsorption of Polycyclic aromatic Hydrocarbons (PAHs) on wood chips, ryegrass roots, and pine needles, it emerged from this study that adsorption of PAHs on these selected biosorbents has a correlation with their structures [12].

In view of the great possibilities offered by organic media in the treatment of wastewater, this study focuses on the use of wood fibres in the polishing of water from a lagoon station compared with the performance of sand. While sand is well known as a filter medium for wastewater treatment, raw wood fibres have been used very little in this area [4] [13]. But this material is well appreciated in the paper industry or as insulation in the construction industry [5]. As noted above, it can also be processed chemically to be converted into activated carbon. In this form, it is used in the treatment of drinking water to remove dyes or micro pollutants such as pesticides and heavy metals [8] [15] [16].

Objective: The objective of this study is to experiment additional treatment by biological processes to improve the quality of the water discharged by the station.
Treatment materials: For the treatment of this type of wastewater, several alternatives exist, such as infiltration-percolation on granular media. To ensure the additional treatment of the water from the station wood fibres and sand were used in infiltration-percolation to compare their performances in terms of improving the quality of the treated water.

The sand used: Depending on the need, it is necessary to know the characteristics of the sand to make the best choice regarding the application for which it is intended. In this study, a river sand with medium size particle was used with an actual size D_{10} of 0.30 mm while the D_{60} is 0.80 mm. The fines which constitute the particles with a diameter less than or equal to 80 μm represent 0.6% and the uniformity coefficient $U = D_{60}/D_{10} = 2.66$.

The wood fibres: Wood is a natural composite material made up of fibres with complex structure. Generally, wood is a building material whose industrial processing generates wood fibres which can be recovered for other use, such as energy recovery like fuel and a clean, natural and low cost adsorbent. The structural characteristics of wood and the presence of longitudinal cavities present an interest in the treatment of wastewater by fixing various undesirable elements on the walls and pores of the material. Wood from various species of trees, naturally or chemically treated, have been the subject of several studies about their ability to fix various pollutants in wastewater [4] [5]. The ability of wood fibres to fix adsorbents such as pollutants can be greatly improved by chemical treatment. But in the current study sawdust of white wood was used in its raw state without prior chemical treatment.

2. EQUIPMENTS AND METHODS

2.1 Equipment

All packing and storage sampling equipment is recorded in the table 1 below.

Table 1. Equipment used

Equipment	Use
Drums	Pilots
Sand, medium size gravel, coarse gravel, wood fibres	Media for infiltration
Plastic bottle (physical and chemical analyses)	Sampling
Sterilized glass vials (bacteriological analyses)	
Cooler	Transportation to the laboratory
Refrigerator (at a maximum temperature of 4 °C)	Storage

2.2 Conception of pilots

2.2.1 The experimental devices

The experimental devices consist of two cylindrical drums with a capacity of 160 litres each with a height of 75 cm for an inner diameter of 52 cm. The bottom of each drum was perforated over the entire surface with holes of 5 mm of diameter to ensure the gravity evacuation of the treated water by infiltration-percolation. The first pilot was used as a sand filter called FS and the second was wood fibres filter named FC.

2.2.2 Pilot plant setup

The pilots indicated by Figures 1 and 2 were installed in the Institute of Research in Applied Sciences and Technologies located in Ouagadougou. From bottom to top, the heights of the filtration beds after cleaning are as indicated by Table 2.

Table 2. Filtration media characteristics

Pilots	Drainage layer	Transitional layer	Filtration layer
Sand Pilot (FS)	15.5 cm of coarse gravel ($\emptyset$ 10 mm/25 mm)	10 cm of fine gravel ($\emptyset$ 3 mm/8 mm)	20 cm of medium size sand
Wood fibres Pilot (FC)	15.5 cm of coarse gravel ($\emptyset$ 10 mm/25 mm)	10 cm fine gravel ($\emptyset$ 3 mm/8 mm)	20 cm of wood fibres

Before feeding the pilots with wastewater, the beds were washed with clean water for four consecutive days to rid them of fine sand and waste.



Fig. 1. Top view of sand filter and wood fibres filter before feeding

re of the system

2.2.3. The technology investment cost estimate

The evaluation of the investment costs was carried out on the experimental treatment corresponding to a capacity of 100 litres / m² / day (Table 3).

Table 3: Evaluation of the investment costs

N°	Designation	Unit	Quantity	Unit Cost (USD)	Amount(USD)/pilot (160 dm ³)
1	Gravel	m ³	0.054	35	1.89
2	Sand or wood fibres	m ³	0.042	25	1.05
3	Containers		1	14	14
4	Funnel		2	1	2
5	Buckets		2	5	10
6	Gloves		2	1.25	2.5
7	Protective glasses		1	5	5
8	Masks		1	1	1
9	Boots		1	15	15
10	Workforce		1	50	50
					102.44

Amount for 1 m³ = Amount for pilote x1000 dm³/160 dm³

After the assessment of this technologie, it may cost 640.25 USD for 1 m³

The overall costs are implementation costs referring strictly to pilots of 1m³ with an area of 1 m². For extrapolation to a real scale of a wastewater treatment plant, taking into account the sizing rules, it is necessary to take into consideration all material requirements, but also the acquisition of the land, ancillary works, cost of implementation, civil engineering...

Nevertheless, studies by some authors indicate that investment costs decrease with the size of the station. Thus, when we move from 400 EH to 1000 EH, the cost of investment per inhabitant is divided by 2, 3 or even more depending on the technology [17] [18].

2.3 Methodological approach

2.3.1 Water Sampling at the Kossodo lagoons station

It is a natural lagoons purification station of 20 hectares located in Kossodo (Ouagadougou) with a treatment capacity of 240 000 equivalents-inhabitants, with an average expected daily discharge of 11 600 m³. It is made up of eight ponds as shown in the Figure 3. They receive domestic and industrial composite wastewater. The average time of stay of process water is about 30 days. Downstream the station there is a layout of 11 hectares for the reuse of purified water for agricultural activities.

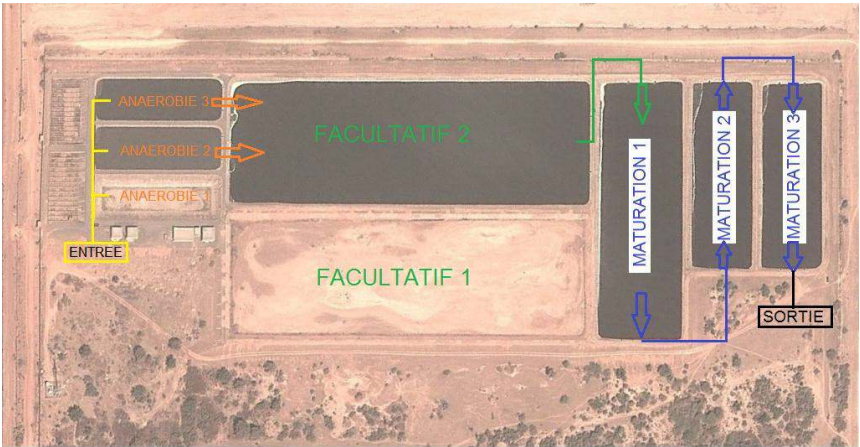


Fig. 3. Satellite view of the station of Kossodo with its eight ponds (source Google map)

2.3.2. The characteristic of inlet wastewater

Wastewater at the inlet of the lagoon station is heavily loaded with organic matter, TSS and nutrients with average contents of 2500 mg / l COD, 1500 mg / L BOD₅, 450 mg / l TSS as indicated in the Table 4 below. Koné found similar average contents with 2643 mg.l⁻¹ COD, 1758 mg BOD₅ and 487 mg.l⁻¹ of TSS [3]. Although the treatment by lagoons can significantly reduce pollution, it is however not negligible at the outlet of the station as demonstrated by the values recorded in Table 4 which shows the average values of various parameters concerning treated water discharged by the lagoons.

Table 4. The characteristics of Treated water discharged by the lagoons

Location	T (°C)	pH	Dissolved Oxygen (mg/l)	Electrical Conductivity (µS/cm)	TSS (mg/l)	NH ₄ (mg/l)	NO ₃ (mg/l)	PO ₄ (mg/l)	BOD ₅ (mg/l)	COD (mg/l)	Total Coliform (UFC/100 ml)	Faecal coliform (UFC/100 ml)	<i>Bacillus cereus</i> (UFC/100 ml)	<i>Streptococcus</i> (UFC/100 ml)
Inlet of lagoons	30	10.11	0.80	1680	450	34	14	13	1500	2500		7.10 ⁸		
Outlet of lagoons	28.31	8.72	2.81	1282	240	0.85	6.6	4.8	250	1264	38750	9750	38500	64500
National standards	18-40	6.5-9		2700	150 (for lagoons)	1	11.29	5	40	150	2000	2000	2000	2000

2.3.3. Operational procedure

The feeding effluent is taken from the final maturation tank of the lagoon for feeding the pilots. The choice of applied hydraulic loads is very important because it determines the quality of the treatment and the correct functioning of the system. The applied hydraulic regime affects the hydrodynamic characteristics of the filtration equipment. It is chosen according to the type of wastewater and the quality objectives required for the receiving environment.

This work lasted 3 months. The first month to allow the installation of the bacterial biomass and analyses were conducted the following two months. A starting hydraulic loading rates (HLR) was 100 l/m^2 (10 cm) which was conducted two times with two days of feeding and two days of rest. After two weeks of feeding, the FS showed a beginning of clogging inducing difficulties of filtration. Then a review of the hydraulic load was done, and the rate of 50 l/m^2 ($10.5 \text{ l/0.21 m}^2/\text{d}$) meaning that a height of 5 cm twice a day was adopted. In others words, the daily hydraulic load was $100 \text{ l/m}^2/\text{d}$ corresponding to organic loading rate (OLR) of $250\text{-}300 \text{ g COD m}^{-2} \text{ d}^{-1}$.

To simulate the daily peaks of wastewater production, feeding is done at 8 AM and at 3 PM. The pace of two days feeding followed by two days of rest favours a good airing of the beds and avoids the clogging of the system.

2.3.4. Start-up and acclimatization

The microorganisms contained in the wastewater were used to colonize the filter media. In bacterial growth there are a number of phases with different growth rates including a phase of latency or acclimatization of the bacteria at medium conditions with a low growth rate. For that reason, in the current study, a one-month period was observed in which the pilots were fed with wastewater without analysis in order to ensure a gradual colonization of the filters by organic biomass. In addition, the feeding frequency adopted (2 days of feeding / 2 days of rest) allows the combination of acclimatization of bacteria and performance of the treatment thanks to periods of recharge of oxygen and mineralization [3].

2.3.5. Wastewater sampling and analysis

The sampling began when a regular hydraulic regime was observed, from August to October 2016. To compare the effectiveness of the treatment, analyses were carried out on wastewater used for feeding the second day and on average samplings after 24 hours of treatment in each pilot, the morning of the first day of rest. Physical and chemical parameters such as temperature, pH, dissolved oxygen and electrical conductivity are recorded during the sampling in order to avoid any changes. Finally, the samples are stored in the freezer for the analysis of the other parameters the following days. For the bacteriological parameters, the samples are transported to the laboratory for seeding the same day to avoid any change of the bacterial flora.

2.3.6 Chemicals and instrumentation.

Temperature, pH, Electrical Conductivity and Dissolved Oxygen

HACH HQ40d Multi Parameters from HACH Company (USA) is used with digital IntelliCAL™ probes to measure temperature, pH, Electrical Conductivity and Dissolved Oxygen of water *in situ*. The meter recognizes the type of probe that is connected for measure.

The pH C28101 electrode is a refillable low ionic strength (LIS) with a built-in temperature sensor. The method is in accordance with the French standard AFNOR 90-008.

The LDO10101 standard probe provides measurement of the dissolved oxygen concentration in water (range 0.1 to 20.0 mg/L).

The CDC40101 standard conductivity probe provides measurement of electrical conductivity in wastewater. The reading is done after stabilizing the display. The determination of the Suspended Solids (SS) was carried out by gravimetric method after vacuum filtration with a GF/C glass microfiber filter and oven drying at $105 \pm 2 \text{ }^\circ\text{C}$, according to French standard NF 90-105.

The Chemical Oxygen Demand (COD) was determined by oxidization with an excess of potassium dichromate in an acid medium at $150 \text{ }^\circ\text{C}$ in the presence of silver sulphate as catalyst and mercury sulphate intended to avoid interference of chloride ions according to French standard AFNOR T-90-

101. The reading of the value is done by HACH DR / 2400 spectrophotometer at the appropriate wavelength. The five-day Biochemical Oxygen Demand (BOD₅) was determined by the incubation method for five days in the dark and at 20 °C using a "Lovibond OxiDirect" Apparatus according to French standard NF 90-103.

Ammonia nitrogen (NH₄⁺), nitrates (NO₃⁻) were determined by the colorimetric method with a Palintest 7100 spectrophotometer at the appropriate wavelengths according to Palintest Ltd methods (England).

Concerning bacteriological parameters, the analyses were carried out following well-defined steps according to standards required for each microorganism, according to the methods indicated in the Table 4 below. The handling protocol is the same for all germs but the culture medium used, the incubation temperatures and the applied standards that are specific to each microorganism change. The samples were analysed immediately the sampling day.

For that reason, sample preparation begins with the parent suspension and decimal dilution performed according to ISO 6887-1 (1999) standard. 10 g of samples was weighed in a Stomacher sterile rubber bag in which sterile thinner is added until getting a total weight of 100 grams. The whole goes through the Stomacher for 2 min. From this mother suspension, a series of successive decimal dilutions is conducted. The method of inoculation in the mass was used for culturing. For that matter 1 ml of each dilution chosen is put in a can of sterile dough in which is added the culture medium in super cooling at a temperature between 37°C and 47° C. The cans are left to solidify on a plane surface at ambient temperature before being incubated in the incubator at the various temperatures and conditions specific to each group of microorganism.

The cans selected for the enumeration of the colonies were those having 04 to 300 colonies for the enumeration of microorganisms.

The number of colony forming units (CFU) is determined by using cans of two successive dilutions with the formula below (equation 1):

$$N = \frac{\sum C}{(n1 + 0,1n2). d. v} \quad (1)$$

N = Number of microorganism (CFU) per gram or millilitre of product indicated by a number between 1.0 and 9.9 multiplied by 10^x.

ΣC: Sum of colonies numbered on selected cans of the two successive dilutions

n1: Number of cans selected for first dilution

n2: Number of cans selected for second dilution

d: First selected dilution

v: sampled volume

If the number of colonies in the parent suspension is between 01 and 03, the results are as follows :

- Less than 4×d⁻¹org /g, where d is the dilution of the mother suspension;
- If there is no colony on the cans of the parent suspension, the result is less than 1×d⁻¹μorg /g (d: the dilution of the parent suspension).

Table 5. Methods of microbiological analysis

Microorganisms	Culture medium	Incubation temperature	Standard	Incubation duration
Total coliforms	Violet Red Bile Lactose Agar (VRBL)	37°C	International Standard ISO 4832 (2006)	24H
Faecal	Purple Red Bile Lactose	44°C	Standard AFNOR	24H

coliforms	Agar (VRBL)	NF V 08-060 (2009)	
Bacillus cereus	Selective agar for 30°C <i>Bacillus cereus</i> (Base according to Mossel)	International Standard 7932 (1993)	ISO 48H
Streptococci	Streptococcus Isolation 37°C Agar	International Standard 4832 (2006)	ISO 48-72H

2.3.7. Statistical analysis.

The data collected were analysed with Excel and STATISTICA version 7.1

Statistica version 7.1. The non parametric test was used on the basis of the comparison of two matched samples through the Wilcoxon test for matched samples, with a significance level $p < 0.05$. In addition, boxes with whiskers of all variables allowed to make a graphical representation of the average contents and the spread of the values around the average through the standard errors and standard discrepancies.

The average is given by the formula (2) below:

$$\text{Average} = (\sum x_i) / n \quad (2)$$

n is the sample size.

Standard error of the Average is given by the following formula (3):

$$s_x\text{-barre} = (\sigma^2/n)^{1/2} \quad (3)$$

The standard error of the average is the theoretical standard discrepancy of all the sample averages with sample size n taken from a population and it depends on the variation of the population σ (sigma) and the size of the sample (n) as indicated below:

Standard discrepancy

The standard discrepancy is a measure of the spread frequently used. The standard discrepancy of a population of values is calculated according to formula (4):

$$\sigma = [\sum (x_i - \mu)^2 / N]^{1/2} \quad (4)$$

μ is the average population

N is the size of the population

3. RESULTS AND DISCUSSION

3.1 Characteristic of the effluent at the outlet of the lagoon station

The station receives composite wastewater made of domestic and industrial wastewaters with concentration in DOB_5 reaching 1500 mg/l whereas at the outlet of the station DOB_5 levels are on average 250 mg/l (Table 4). This corresponds to a removal efficiency of more than 80% which remains insufficient to make the effluent from the station conform to the national standard which requires 40 mg/l. The suspended solid contents record a reduction of 47%. But the average content of 210 mg/l remains important compared to the standard of 150 mg/l. This is due to the evaporation of water but also to the proliferation of algae. The electrical conductivity records an increase from the inlet to the outlet of the station mainly related to the mineralization of substances but also to high evaporation of water which highly reduces the hydraulic flow rejected. The contents in nutrients

(nitrate and orthophosphate) remain below the limit values required by law but the concentrations in pathogens are much higher than national standards required for the release in the environment or for reuse in agriculture. Overall, the effluents from the station require a finishing treatment.

3.2 The characteristics of the water discharged after treatment by the pilots

The Table 6 gives the characteristics of the water discharged by the two pilots. The average parameters such as conductivity, dissolved oxygen, suspended solids and pH indicate a global decrease of the values recorded on the effluents from the wastewater treatment plan (WWTP). The same applies to the nutrients even though these were not presenting environmental risks before their treatment by the pilots. The COD and the BOD₅ recorded a very significant reduction after the treatment by the two biological reactors. For pathogens like faecal coliforms, faecal streptococcus and *bacillus cereus*, high efficiencies were observed as indicated below.

Table 6. Average values of physicochemical parameters and bacteriological parameters

	Sand filter (FS)	Wood fibres Filter (FC)	Sampling number	FS/Removal Efficiency	FC/Removal Efficiency
Temperature (°C)	28,32	28,51	10		
pH	8,35	8,17	10		
Dissolved Oxygen (mg/l)	4,95	4,3	10		
Electrical Conductivity (µS/cm)	1056	1131	10	15	10
TSS (mg/l)	50	69	10	84	72
Ammonium (mg/l)	0,67	2,71	10	17	-262
Nitrates (mg/l)	5,16	4,37	10	21	36
BOD ₅ (mg/l)	39	90	10	84	63
COD (mg/l)	75	110	10	94	91
Total Coliform (CFU/100 ml)	605	7275	10	98	82
Faecal coliforms (CFU/100 ml)	305	5075	10	97	46
<i>Bacillus cereus</i> (CFU/100 ml)	4400	2750	10	88	93
<i>Streptococcus</i> (CFU/100 ml)	12500	9450	10	79	84

3.2.1. Physical and chemical parameters

3.2.1.1 The hydrogen potential (pH)

It characterizes many physical and chemical equilibrium and depends on multiple factors, including the origin of the water. The pH variations are related to the photosynthetic activity of the medium. The consumption of CO₂ by the aquatic flora during the photosynthesis reactions tends to displace the carbonic balance in the direction of its production and thus to raise the pH. Thus, a low pH may be indicative of low productivity due to absence or excess of algae. Generally, bacteria grow well at pH between 5 and 9. Then domestic wastewater (with pH between 6.5 and 8) is favourable to the development of the microorganisms scrubbing, in both the anaerobic and aerobic phenomena [19]. It

is also important to notice that the biological purification is strongly disturbed for values of pH <4.5 or pH > 9. The average pH values of wastewater and filtrates are within the range allowed by national regulations (between 6.5 and 9.5). The pH decreases during the treatment for the two pilots, although these pH remain alkaline (Figure 4). Indeed, the raw water has an average pH of 8.72 while the values obtained at the pilot FS range from 6.72 to 9.01 with an average of 8.30 while those of FC vary between 6.31 and 9 with an average of 8.16. Thus, FS has higher pH values compared to FC. However, the statistical analysis of the results by the Wilcoxon test for matched samples indicates a p level of significance at the threshold of 0.13. This indicates that there is no significant difference between the behaviours of the two pilots with respect to pH variation. Moreover, there is no significant difference between the results at the outlet of the station and the results achieved by FS and FC with respective p-significance indices of 0.24 and 0.07.

According to some research results, the alkalinity of the water coming from the lagoons is due to the fact that it mainly receives brewery wastewater which discharges strongly basic waters rich in ions (Na^+ , OH^- , Ca^{2+} , CO_3^{2-} , and HCO_3^- ...)[20].

With the treatment by sand and organic medium, which is wood fibres, there is a downward trend, which could be explained by factors such as the accumulation of H^+ following the activity of nitrifying bacteria, and accumulation of CO_2 due to the bio-degradation of organic matters by heterotrophic bacteria [20]. The most pronounced trend of wood fibres suggests that this material could be used if the desire is to get a pH close to acid.

The temperature also influences the kinetics of reactions. But during this study, its recorded values (28.31 to 28.51) are well below the limit set by the national standard, which is 40 °C.

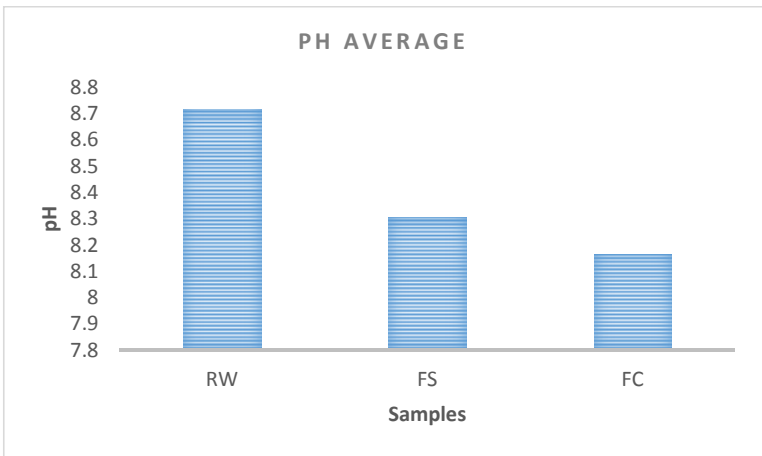


Fig. 4. Evolution of pH

3.2.1.2. Electrical conductivity

Electrical conductivity measures the ability of water to conduct electricity. It is the conductance of a column of water between two metal electrodes with a surface area of 1 cm² and at distance of 1 cm from each other. Electrical conductivity is a quick and convenient way to evaluate the mineralization or salinity of water, although the relationship is linear only for weak conductivities ($C < 100 \mu\text{S/cm}$) and deviates from it more when the mineralization is high. Most of the dissolved matter in water is in the form of cations Ca^{2+} , Mg^{2+} , K^+ , Na^+ ... and anions SO_4^{2-} , Cl^- , HCO_3^- , PO_4^{3-} , NO_3^- ... The conductivity depends also on the temperature of the water: it is more important when the temperature increases and vice versa. The variation of conductivity makes it possible to show the presence of pollutions because of mixing or infiltration. Its measurement may lead to the detection of an anomaly indicating the probable presence of pollution, by comparison to measured value expected. The conductivity of a natural water is between 50 and 1500 $\mu\text{S/cm}$.

Figure 5 shows the conductivity values of FS and FC lower than those of the wastewater from the station. indeed, the average conductivity of the raw water is 1282 $\mu\text{S/cm}$ while the filtrates of FS and

FC gave 1056 $\mu\text{S}/\text{cm}$ and 1131 $\mu\text{S}/\text{cm}$ respectively. In general, there is a slight decrease in conductivity which results in a reduction of the salt dissolved in the water. The result obtained shows that sand reduces the conductivity more than wood fibres. This result is contrary to what other authors had observed namely a greater elimination of salts by an organic medium such as coconut fibres compared to sand [3].

It is important to note that despite the relative good performance of the sand, the statistical analysis by the Wilcoxon test for matched samples gives a p level of significance of 0.20 which is above the set threshold of 0.05. This means that the two reactors have undifferentiated behaviours. In other words, the two reactors FS and FC are equivalent and the nature of the filtration medium has not significantly affected the results.

In sum, the wastewater treated by the two media always indicated high salinity levels so that their agricultural reuse could present a toxicity to the crops due to the accumulation of certain ions which prove to be a stress for the plants and which could result in reduction of crop efficiency [1] [21].. In addition, the excessive presence of salt in irrigation water is a source of soil clogging [3]. Bedbabis et al also noted the change of the characteristics of soil after several years when using treated wastewater for agricultural needs, it involves a significant decrease of pH and infiltration rate or a significant increase of organic matter, SAR and EC [22].

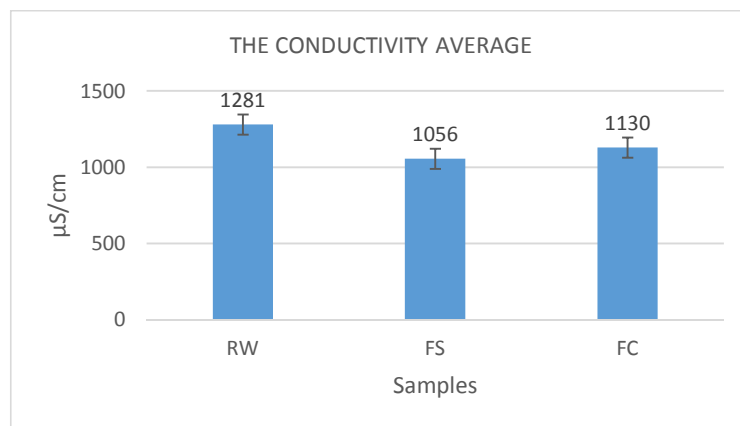


Fig. 5. Variation of Electrical Conductivity

3.2.1.3. The ammonium ions (NH_4^+)

Organic nitrogen is converted to ammonium (NH_4^+) by the action of anaerobic microorganisms. The presence of NH_4^+ in water is indicative of organic pollution due to agricultural, domestic or industrial activities. Ammonium represents a lesser danger, but depending on the characteristics of certain soils, its presence may lead to nitrogen enrichment or acidification with the disappearance of aquatic fauna and flora. Analysis of the ammonium ions shows a decrease of NH_4^+ concentration concerning sand filter and an increase for the wood fibres filter compared to the wastewater as shown in Figure 6. Thus, at the station outlet, the NH_4^+ value of the wastewater is 1.09 mg/l compared to 0.86 and 3.48 mg/l respectively for the sand and wood fibres filters. The sand filter gives treated water with NH_4^+ levels in accordance with the standard (1 mg/l), contrasting wood fibres values which are more than twice the permissible limit. Indeed, the p level of statistic test which is 0.003, far below the threshold of 0.05 is significant and it indicates differentiated behaviours of FS and FC in terms of efficiency of treatment when they are compared. The reduction of ammonium ions concentrations by the sand filter is due to an aerobic degradation process with nitrification. As for the increase of the NH_4^+ content in the filtrate resulting from the wood fibres filter, this could be explained by the fact that the organic fibres are rich in nitrogen, so that the organic nitrogen is firstly transformed into NH_4^+ before the nitrification step occurs if the conditions are favourable. The initial leaching carried out on the organic medium for four days was therefore not sufficient to eliminate the nitrogenous compounds (the polyphenols) of the wood. It is important to remember, however, that the presence of nitrogen in its ammonia form in the environment is a public health problem because it evolves towards nitrates which are sources of

eutrophication in conjunction with orthophosphates [23]. So, the use of wastewater with high levels of nitrogen in agriculture causes an imbalance in the availability of nutrients for plants. That will affect negatively crop efficiencies by increasing their fragility to stress. Nevertheless, it should be noted that in the present case, the water coming from the lagoons is conform to the discharge standards concerning ammonium level.

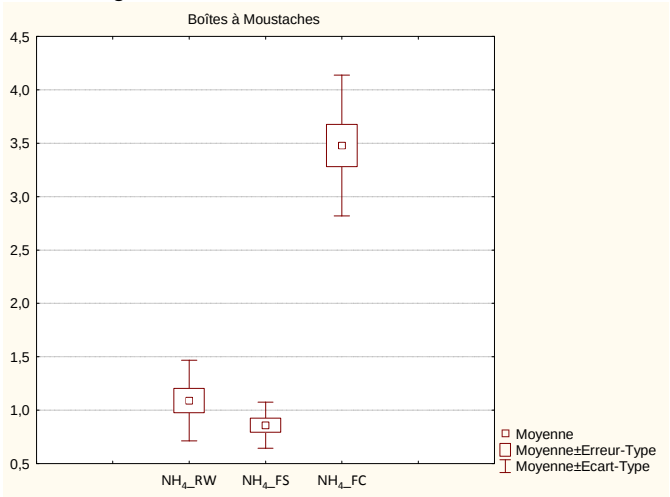


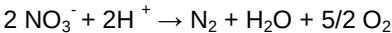
Fig. 6. Variation of NH₄⁺ concentrations

3.2.1.4. The nitrates (NO₃⁻)

Nitrates are naturally present in water but in small amounts. Nitrates and orthophosphates are nutrients for plants, which partly justifies the reuse of wastewater in agriculture. The presence of nitrates in the natural environment is due to anthropogenic activities such as the use of fertilizers, manure, domestic and industrial wastewater but also to the decomposition of living organisms (animals and plants) [6] [23]. Their massive presence has adverse consequences on the environment especially aquatic and on human health because of their association with orthophosphates, which can conduct to an eutrophication of surface waters. Orthophosphates are the predominant dissolved mineral form of phosphorus. They come from human metabolism and from laundry and cleaning products. However, they may also come from natural sources (rocks). Orthophosphates are implicated in the phenomena of eutrophication in aquatic environments.

Moreover, they are very soluble in water and can easily contaminate the ground water. They would be responsible of infant's methemoglobinemia by consumption of water rich in nitrate. It is also believed that they could be potentially carcinogenic by the formation of nitrosamines resulting from the reaction between nitrites and amines or amides although no studies have established certain causal relation. Besides, in acid medium, nitrates can turn into nitrites that turn out to be toxic.

The nitrate concentrations obtained during this study are very low compared to the limit of the national standard which is 50 mg of NO₃⁻/l, corresponding to 11.39 mg of N /l. The respective average values of 6.6, 5.16 and 4.37 mg of N /l were recorded for the lagoons, the sand filter and the wood fibres filter. In general, there is a much more remarkable decrease with the wood fibres filter. However, the statistical analysis of the results of the two pilots indicates similar behaviours with a non-significant p-index of 0.26. Nevertheless, the small decrease observed with the two pilots could be explained by evaporation of NH₃ or by the process of denitrification where the nitrates turn into atmospheric nitrogen (nitrogen diazote N₂) under the action of denitrifying bacteria according to the following equation:



Nitrate does not occur as would have been expected because of the very low concentration of ammonium in wastewater at the WWTP exit. It can be noted that the nitrate contents of the water coming from the pilots are low compared to that of water coming from the station. This confirms that

there is really no nitrification (Figure 7). Moreover, the previous Figure indicates an increase in ammonium at the outlet of the wood fibres filter; this suggests an elimination of nitrogen by this filtration medium by volatilization thanks the action of specific denitrifying bacteria which could transformed nitrate into atmospheric nitrogen [3].

Concerning orthophosphates, the average content measured at the outlet of the station is 2.9 mg/l of P. This value below the discharge standard (5 mg/l), did not present a risk to the environment.

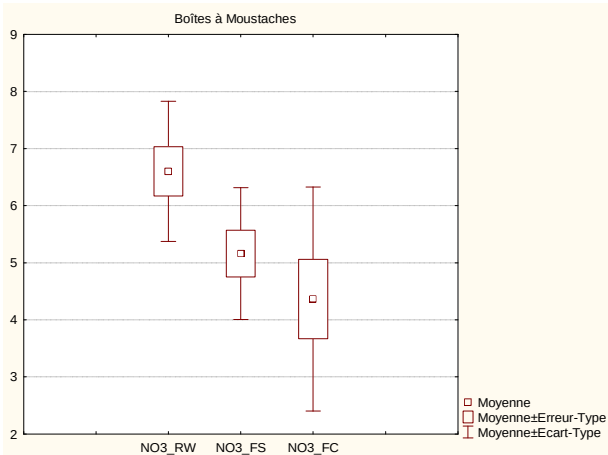


Fig. 7. Evolution of NO₃⁻ concentrations

3.2.1.5. Total suspended solid (TSS)

TSS are solids contained in wastewater and are separable by filtration or centrifugation. They include all inorganic or organic materials which are not soluble in water. They constitute an important parameter which clearly indicates the degree of pollution of an effluent. The TSS is responsible for the organic clogging of the pores of filters during the infiltration of wastewater [24]. However, a mineralized deposit on the surface of a filter can improve the purification performance of the filter because it increases the depth of the filter. This part is well aerated and it serves as a support for the scrubbing microorganisms [3]. The assessment of the suspended solids concentration during the study revealed a significant decrease regarding the levels observed with the treated water from the lagoons. For this purpose the national standards authorized 150 mg/l for natural lagoons discharged water and 60 mg/l for another treatment technologies. Indeed, the average of total suspended solids content at the station exit is 240 mg/l, which is well above the norm as shown by the Figure 8. On the other hand, after filtering with sand and wood fibres, the average of TSS contents are respectively 50 and 68 mg/l, corresponding to 79% and 71% elimination efficiencies. Indeed, the very low level of p (0.007) indicates a significant difference between the performances of the two pilots. We can deduce therefore that FS has a better performance than FC in eliminating the suspended solid, even though its efficiency of 71% is not negligible either. In general, this reduction could be due to the purifying power of the materials used. Considering the similarity of the structure of the wood fibres and the coconut substrate, it could be hypothesized that the higher TSS contents of the water from the wood fibres filters are due to the high porosity and the low level of compaction of this material contrary to the sand which is best compacted in the presence of water and offers smaller inter-granular spaces [3] [14]. Thus, for this parameter, the sand retains the greatest purifying power. The high TSS levels of treated water discharged by the lagoons can be one of the causes of the departure of gardeners. In fact, the TSS are responsible for the clogging which make the soil compact and which do not allow the infiltration of water [24]. This phenomenon results in the impoverishment and degradation of the soils producing very low efficiencies of production.

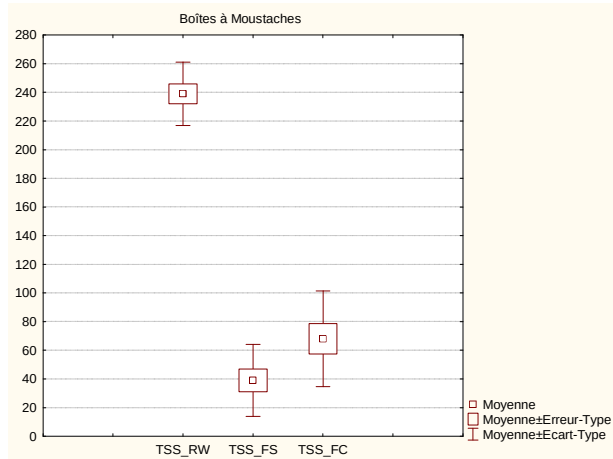


Fig. 8. Evolution of TSS levels

3.2.1.6. Chemical oxygen demand (COD)

The Chemical Oxygen Demand expresses the amount of dissolved oxygen required to chemically oxidize all oxidizable substances contained in an effluent (oxidizable mineral salts, biodegradable or non-biodegradable organic compounds, ...). The Chemical Oxygen Demand is an indicator of organic pollution. Its measurement makes it possible to evaluate the effectiveness of wastewater treatment and to predict the impact of these waters on the environment concerning the risk of asphyxia through the determination of oxygen consumption during the oxidization reactions.

For the current study, the Figure 9 below shows averages of 69 and 110 mg/l respectively for FS and FC with little dispersion of values around the average while the p level of significance indicates a very low threshold of 0.007 indicating a significant difference between the performance of the two pilots. COD values for raw water coming from lagoons are higher than the national standard that sets the limit value at 150 mg/l. However, after treatment with FS and FC, the removal efficiencies of 94% and 91% are noted respectively. This decrease of COD values is the result of the degradation of pollutants, but it is also due to the considerable reduction of TSS by retention within the filters [20]. The higher values of COD from FC compared to the sand filter could be explained by the structure of the wood fibres which are more porous and less compact than sand as noted previously; this fact is corroborated by its greater value of TSS content. This porous structure of the wood fibres favours a more rapid percolation of the effluent while the reactor is in a progressive phase of biofilm installation. Its hydraulic retention time (HRT) is short comparing to sand filter. So, the wood fibres filter did not provide sufficient contact time between the wastewater and the biofilm on the medium because of its texture and its high porosity. However, it is the biofilm which ensures the elimination of biodegradable pollution [3]. Despite its performance compared to sand, wood fibres are nevertheless a good material of oxidizable carbon elimination (biodegradable and non-biodegradable).

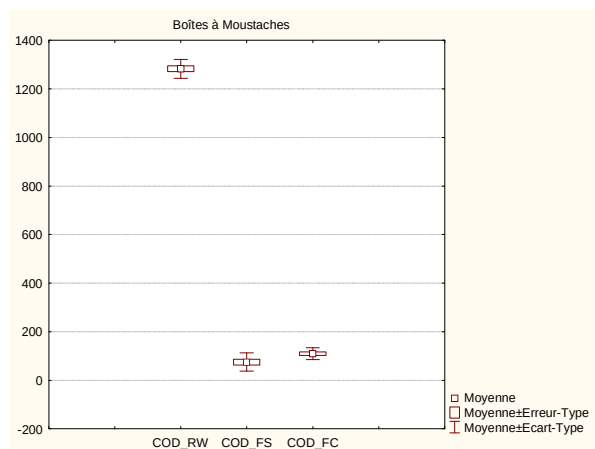


Fig.9. COD removal

3.2.1.7. Biochemical Oxygen Demand (BOD)

BOD₅ represents the amount of oxygen used by aerobic microorganisms for the destruction of biodegradable organic matter at a temperature of 20 °C in the dark during five days. It is used to assess the biodegradable organic content of water. It is therefore an indirect measure of the degree of biodegradable organic matter pollutants.

As revealed by Figure 10, the respective mean concentrations measured for BOD₅ were 250 mg/l for treated water by lagoons, 39 mg/l for sand filtrate and 90 mg/l for wood fibres filtrates whereas the quality objective imposed by the national regulation is 40 mg/l at most.

The Wilcoxon test revealed a significant difference between the two filters with a p level of 0.005 much lower than the set threshold of 0.05. In other words, the two materials occur different behaviours regarding the BOD₅ removal.

It is found that the filtrates from the sand reactor is conform to the standard whereas the removal efficiencies of the BOD₅ are 84% and 64% respectively for sand and wood fibres. The lower efficiency of the wood fibres reactor could be explained by a low capacity of the wood fibres to ensure the biodegradation of the organic pollution considering the very porous structure of the material which favours a more percolation regarding its short hydraulic retention time (HRT) compared to the sand.

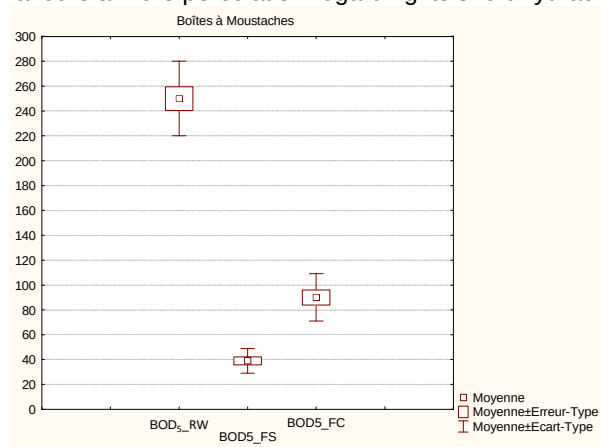


Fig. 10. Evolution of BOD₅

3.2.2 Evolution of bacteriological parameters

3.2.2.1 Faecal coliforms and total coliforms

The wastewater is charged with microorganisms depending on their origin [25]. They contain the microorganisms excreted with faecal matter. This normal enteric flora is accompanied by pathogenic organisms, causing water-borne diseases [21]. These microorganisms can be classified into four major groups: bacteria, viruses, protozoa and helminths. Bacteria are the most commonly encountered microorganisms in wastewater [1]. It would be difficult to identify all microorganisms for characterizing the effectiveness of wastewater treatment; therefore, it is common to identify faecal indicator bacteria to assess the efficacy of water treatment and to estimate the health risks in wastewater reuse. The coliform of bacteria is used such as faecal coliforms or *Escherichia coli* (*E. coli*), which are much more representative [19]. The average content of faecal coliforms and total coliforms at the end of the treatment by the two pilots. The mean values of the treated water collected at the lagoons exit are well above the limit value imposed by the standard which is 2000 CFU/100 ml [21].

Figure 11 representing the average faecal coliform values, the dispersion of the values and the standard deviations indicates average values of 305 and 5076 CFU/100 ml for the sand filter and the wood fibres filter corresponding to the respective efficiencies of 97 and 46%. The greatest performance of the sand filter is confirmed by the Wilcoxon test with a very significant p-index at the 0.005 threshold. Then the sand filter shows a greater ability to remove faecal coliforms.

Concerning total coliforms values, statistical analysis indicates a significant p-index of 0.007 and respective efficiencies of 98 and 82% for FS and FC. The sand filter has a best capacity to remove total coliforms comparing to wood fibres filter [26]. Nevertheless, it is important to note that the 82% removal capacity of the wood fibres reactor is not negligible, indicating that this material also has characteristics that allows it to reduce faecal pollution.

In conclusion, despite the observed efficiencies, the two filters failed to meet the discharge standards for these two parameters because of very high levels of these pollutants in raw water.

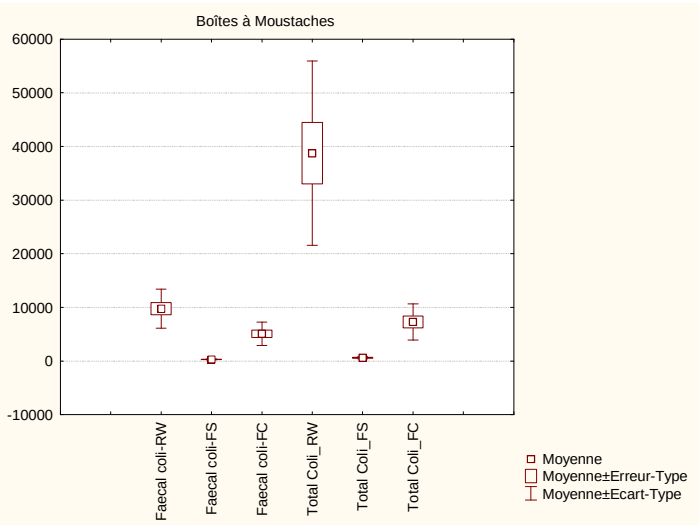


Fig. 11. Total coliforms and faecal coliforms average

3.2.2.2. Faecal streptococci

These bacteria belong to the family *Streptococcaceae*. These germs colonize the intestines of humans and warm-blooded animals. Their presence in the water environment proves faecal pollution of the water [25]. However, faecal streptococci can also be found in soil, plants and insects.

In the present study, the analysis of faecal streptococci removal efficiencies gave values that are higher than national standards even after treatment with the filter materials as shown in Figure 12 below. Indeed, the statistical analysis indicates average values of 12500 and 9450 CFU/100 ml

corresponding to removal efficiencies of 79 and 85%. In any case, despite the non-conformity with the standard, the streptococcal contents are considerably reduced after the treatment with the two pilots as shown in the figure below. The Wilcoxon test applied to FS and FC indicates a very significant p level of 0.0076 indicating a very clear difference between the performances of the two reactors. The wood fibres filter removes better faecal streptococci.

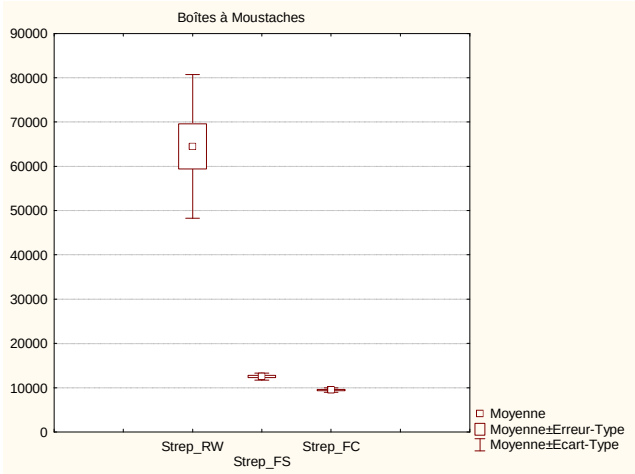


Fig. 7. faecal streptococci removal

3.2.2.3. *Bacillus cereus*

The genus *Bacillus* is composed of a set of bacteria belonging to the family *Bacillaceae*. They are Gram-positive, heterotrophic, aerobic or anaerobic bacilli, getting their energy from breathing or fermentation. These bacteria can produce endospores allowing them to resist to adverse environmental conditions [1].

As shown in Figure 13 *Bacillus cereus* average found are 38500 CFU/100 ml, 4400 CFU/100 ml and 2750 CFU/100 ml respectively for raw water, treated water from FS and FC. The corresponding efficiencies are 88% and 93% respectively. In addition, the statistical analysis by the Wilcoxon test for matched samples indicates a p-value of significance at the threshold of 0.006. That confirms differentiated performance of both pilots with an advantage for the wood fibres pilot. The analysis reveals that wood fibres better eliminate *Bacillus Cereus* than sand. Despite these efficiencies, the decreasing mean concentrations recorded are still well above the acceptable standard limit because of high level of this parameter before treatment by the pilots.

So, it can be noted that wood fibres have an appreciable ability to eliminate *Bacillus Cereus* which may warrant further investigation in subsequent work.

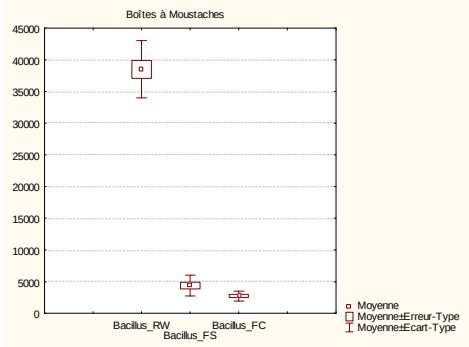


Fig. 13. Evolution of Bacillus Cereus

4. CONCLUSION

The treatment of effluents from the lagoons station by using a sand filter and a wood fibres filter made it possible to improve the quality of these waters in general by reducing the concentrations of the various parameters. In general, there is a decrease of the concentrations for all the parameters after the treatment on sand and on wood fibres. For parameters, such as electrical conductivity, TSS, BOD₅, COD, the sand has a greater purifying power. FS and FC gave respective efficiencies of 97 and 46% concerning bacteriological pollutants, such as faecal coliform. But about faecal streptococci and *Bacillus Cereus* with respective removal efficiencies of 79 and 85% in the one hand and 88% and 93% in the other hand for FS and FC, wood fibres ensure best abatements with remarkable purification efficiencies. Consequently, this medium deserves further investigations in wastewater treatment domain.

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