
Natural Charcoal in Water Treatment Through Metal Bed Filters Fe⁰/S/Pz/C: The Concept of Wood-Energy-Sanitation

Dipita Kolye Ernest Yves Herliche, Suzanne Makota S. N. *, Mbarga Landry Valère, Mintang Fongang Ulrich Armel, Dika Manga Joseph Marchand, Nassi Achille

Department of Chemistry, Faculty of Sciences, University of Douala, Douala, Cameroon

Email address:

s.makota@laposte.net (Suzanne M. S. N.), kolyedipita@yahoo.fr (Dipita K. E. Y. H.), lamervy223@yahoo.fr (Mbarga L. V.), armelulrichmintangfongang@yahoo.fr (Mintang F. U. A.), chendodemanga@gmail.com (Dika M. J. M.), achillen@yahoo.fr (Nassi A.)

*Corresponding author

To cite this article:

Dipita Kolye Ernest Yves Herliche, Suzanne Makota S. N., Mbarga Landry Valère, Mintang Fongang Ulrich Armel, Dika Manga Joseph Marchand, Nassi Achille. Natural Charcoal in Water Treatment Through Metal Bed Filters Fe⁰/S/Pz/C: The Concept of Wood-Energy-Sanitation. *American Journal of Applied Chemistry*. Vol. 10, No. 1, 2022, pp. 28-37. doi: 10.11648/j.ajac.20221001.14

Received: February 1, 2022; **Accepted:** February 16, 2022; **Published:** February 28, 2022

Abstract: The concept of the W.E.S (Wood-Energy-Sanitation) for raising awareness among populations far from the distribution networks of drinking water is established. The process of decontaminating filter columns made up of natural charcoal (NC) as porous non-expansive absorbent/adsorbent materials such as pozzolan (Pz) is experienced. The contribution of the NC to the filtering power of the Fe⁰-based filters, whose decontamination involves the electrochemical oxidation processes of Fe⁰, and corrosion products (CPs) that can cause a blockage of the reactive surface is studied. To do this, seven systems were tested with reactive zones (RZ) respectively consisting of (1) C (pure NC), (2) Pz (pure Pozzolan), (3) Fe⁰/C (iron/NC), (4) Fe⁰/Pz (iron/Pozzolan), (5) Fe⁰/S/C (Iron/Sand/NC), (6) Fe⁰/S/Pz (Iron/Sand/Pozzolan), (7) Fe⁰/S/Pz/C (Iron/Sand/Pozzolan/NC). OM (orange methyl) of 2 mg/L concentration was used as operative indicator. The experiments lasted 40 days per device. Performance parameters such as pH, residual iron, OM discoloration and flow rate were measured. As a result, it appears that the NC alone or associated in the Fe⁰/C, Fe⁰/S/C devices has a better filtering power than the Pz. The combination of NC and Pz in the same Fe⁰/S/Pz/C device improves strikingly the results, such as Fe⁰/S/Pz/C > Fe⁰/S/C > Fe⁰/S/Pz > Fe⁰/C > Fe⁰/Pz > C > Pz. Combining two non-expansive porous materials in the RZ stabilizes the Fe⁰/S/Pz/C-filter and improves its lifespan.

Keywords: Aqueous Corrosion, Fe⁰-bed Filters, Natural Charcoal, Orange Methyl, Pozzolan, Sand, Zero-valent Iron

1. Introduction

Wood is the main source of energy for cooking food for people in southern countries, particularly in sub-Saharan Africa. The product of its partial combustion provides natural coal (NC), a source of energy for households for whom other forms of energy are expensive. The concept of W.E. (Wood-Energy) [1] is the use of wood as an energy source, although it causes significant degradation and major environmental risks. However, this concept can be extended to that of the W.E.S. (Wood-Energy-Sanitation) in order to provide drinking water to populations while valuing wood waste. The W.E.S. needs to raise awareness of the ecology and recovery of waste, as NC production worldwide is increasing

by 3.7% per year [2]. In 2002, diarrhoeal diseases and malaria resulted in an infant mortality rate equivalent to 21% in developing countries where access to safe drinking water remains limited [3-5]. However, various sanitation techniques have been proven, including Fe⁰-based filters. The 100% Fe⁰-filters are subject to rapid clogging and should not exceed 60% in the filtering device. The best-performing devices are 25% in Fe⁰-filters [6-9]. The combination of Fe⁰ and Sand (S) is a way to limit rapid clogging and to remedy the problem of chemical compaction of the iron bed due to corrosion products (CPs) [10-15]. The limitations of binary filters, i.e., the not insignificant concentrations of residual iron, have shown the need to associate with Fe⁰/S devices, a porous, non-expansive material such as pozzolan (Pz), capable of collecting Fe⁰CPs and de-cluttering the reactive surface [16]. Thanks to its varied

physicochemical characteristics, Pz, with neutral pH, has an average chemical composition of 45% of SiO₂, 15% Al₂O₃, 15% Fe₂O₃ and other minor oxides [11, 17]. It is a low-density, high porosity material with water absorption capacity and odor, and a large specific area [18-20]. The work of Makota et al. have shown that the proportions of materials that make up the Fe^o/S/Pz ternary devices for good discoloration in orange methyl (OM), a good pH correction, and a net mitigation of residual iron would be 25% ≤ Fe ≤ 60%, 25% ≤ S ≤ 50%, 25% ≤ Pz ≤ 50% [21]. However, access to the Pz remains difficult for many households. The NC could be an alternative to the Pz, and a means of enacting the concept of W.E.S. and valuing the NC initially considered only as an energy source (W.E.). NC, by its porous structure, can capture and fix many toxic molecules in water. It can also house microbial life capable of contributing to the clean-up of water according to wood quality [22]. NC is mainly composed of 75-80% carbon, mineral materials and residual volatile compounds 20-25%. The study of its physicochemical characteristics reveals a high porosity, a low density, a capacity to absorb water and odors. Its absorbent and adsorbent properties give it great application for filtration and water purification [22-25]. So, pure C, Fe^o/C, Fe^o/S/C, have been tested to find out if the NC could be an alternative for Pz in Fe^o-filters. This work consists of determining through the OM as operative indicator, the NC's contribution to the performance of Fe^o-based filters, and the ability to replace, or support Pz's responsiveness through a

quaternary Fe^o/S/Pz/C filter. Performance parameters such as pH, [Fe], discoloration, and flow were measured by 100% C, 100% Pz, 25%/75% Fe^o/C, 25%/75% Fe^o/Pz, 25%/50%/25% Fe^o/S/C, 25%/50%/25% Fe^o/S/Pz, 25%/25%/25%/25% Fe^o/S/Pz/C.

2. Materials and Methods

2.1. Solutions

OM is used in acid-base dosages as a coloured indicator. Its cornering zone is between [3.1-4.4] and allows to mark the presence of an acid medium, it turns red, or a basic medium, it turns yellow. It naturally has a great affinity for solid surfaces of opposite loads such as certain Fe^o-CPs [29, 30]. The OM comes from KEM LIGHT PVT Laboratories. LTD, Mumbai, India. The solution used has a concentration of 2.0 mg/L; the pH value is 5.2, this concentration is chosen to be close to natural pollution conditions [31]. A standard iron solution, 990 µg/mL from Aldrich Chemical Company, Inc. (Milwaukee, WI, USA) was used to calibrate the spectrophotometer. The L (+) -ascorbic acid from E. MERCK, Darmstadt. 90% ethanol; sodium acetate from ANALAR; 1.10 o-phenanthroline from NORMAPUR used as a reagent for Fe²⁺ complexation require for spectrophotometric reading, 0.2 g/L concentration [32-34].

Four (4) materials were used to carry out our work, Table 1.

Table 1. Granulometry, source, Symbol and nature of the materials used, ¹North Region, ²South West Region, ³Littoral Region, ⁴Communal Market in Cameroon.

N°	Materials	Symbol	Granulometry	Source	Nature
1	Sand	S	1 mm	Collected (NR ¹)	Adsorbent
2	Pozzolan	Pz	2 mm	Collected (SWR ²)	Porous Absorbent/Adsorbent
3	Coal	C	2 mm	Collected (LR ³)	Porous Absorbent/Adsorbent
4	Fe ^o	Fe ^o	≤ 1 mm	Collected (CM ⁴)	Adsorbent Generator

2.2. Solid Materials

2.2.1. Metal Iron

The iron used in this work is iron wool made by the steel mills of Cameroon (Douala, Cameroon) and marketed in the various local markets; its granulometry is less than 1 mm. This material has shown its effectiveness in discoloring methylene blue [26]. It is used without treatment. The X-ray fluorescence analysis reveals: 0.62% Mn, 0.52% Si, 0.23% Cu, 0.2% Cr, and 0.09% Ni.

2.2.2. Sand

The sand (S) used is a natural material taken in the Vina River (Cameroon), washed and rinsed with water boiled at 100°C for 3 hours and then dried at 110°C for 4 hours, it constitutes the different layers L₁ (upper), L₂ (intermediate or RZ) and finally L₃ (lower). For its availability and mixing agent, sand was used in Fe^o/H₂O systems (Anderson, 1886; Devonshire, 1890). The average chemical composition per X-ray diffraction reveals: 81.5% SiO₂, 5.60% Al₂O₃, 4.71% Fe₂O₃, 3.86% CaO, 1.75% TiO₂, 0.91% K₂O, 0.48% P₂O₅, 0.26% SO₃, 0.32% MnO, 0.08% SrO, 0.03% V₂O₅.

2.2.3. Pozzolan

The pozzolan (Pz) used comes from Idenau (Southwest, Cameroon) and has undergone the same pre-treatment as sand. It is L₂ layer (RZ). Pozzolan has a porosity of 60% which serves as a reservoir for Fe^oCPs (Dron 1975; Kofa et al., 2015; Ndé-Tchoupé et al., 2018) and has adsorption and absorption properties. The average chemical composition per X-ray diffraction is: 81.18% SiO₂, 10.00% Al₂O₃, 2.19% Fe₂O₃, 0.59% CaO, 0.46% TiO₂, 3.60% K₂O, 0.05% MnO, 0.02% SrO, 0.02% ZrO₂.

2.2.4. Natural Charcoal

Charcoal is the result of carbonization; it comes from the coal stoves of Ndogbong (Douala, Cameroon), it has undergone the same pre-treatment as the S and the Pz. It is the L₂ layer (RZ). Its adsorption capacity has been known for a long time and has been used in many areas such as water purification, and well sanitation [22]. The wood is made up of three (3) main constituents: cellulose, lignin and water. Cellulose and lignin, plus other substances, are strongly linked to form the material called wood. The first step in carbonization is drying at 100°C until the anhydrous state. The

temperature of the dry wood is then raised to about 280°C, a temperature at which the dry wood begins to decompose spontaneously to give charcoal. At 500°C, the carbon content is 85%, and 10% of volatile elements. The carbonization was carried out in the coal mines of the local market, with temperature regulators. The resulting coals were calibrated as mentioned in Table 1 and have undergone the same pre-treatment (washed and dried) as the S and the Pz. It is the L₂ layer (RZ). Adsorption tests were performed on all samples outside the filters. However, only the performance of the RZs is taken into account in this manuscript Table 2 below. The adsorption tests performed are used to assess the amount of adsorbed.

$$Q_e = \left(\frac{C_o - C_r}{m} \right) \times V$$

Q_e is the amount adsorbed per gram of coal in mg/g. C_r is

Table 2. Composition of the reactive zone (RZ) of each filtering device. The masses of materials are expressed in gram (g) and percentage (%)

N°	Devices	Fe° (g)	Fe° (%)	S (g)	S (%)	Pz (g)	Pz (%)	C (g)	C (%)
1	C	00	00	00	00	00	00	40	100
2	Pz	00	00	00	00	40	100	00	00
3	Fe°/Pz	10	25	00	00	30	75	00	00
4	Fe°/C	10	25	00	00	00	00	30	75
5	Fe°/S/Pz	10	25	20	50	10	25	00	00
6	Fe°/S/C	10	25	20	50	00	00	10	25
7	Fe°/S/Pz/C	10	25	10	25	10	25	10	25

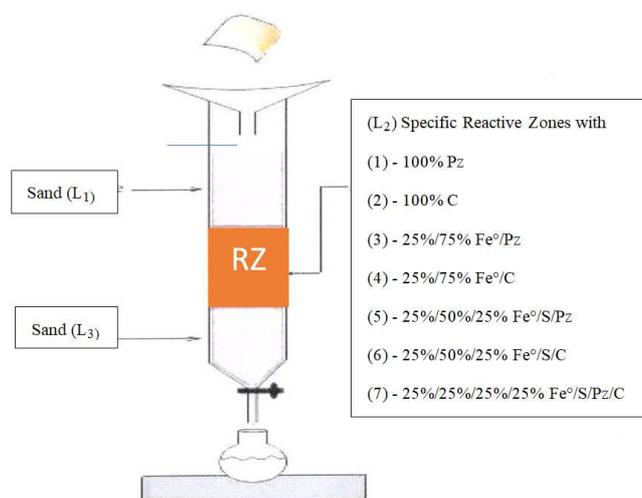


Figure 1. The seven (7) experimental filtering devices, with specific Reactive Zones.

L₁ ensures a distribution of raw water over the entire filtering device, decreases the energy or strength of the incoming contaminated water that can disturb the reactive layer, ensures the constant height of the polluted water; L₃, however avoids the phenomenon of air bubbles under the RZ, regularize or improve the flow [35].

2.4. Analytical Methods

The [Fe] and OM were determined by Sigma-Aldrich Inc.'s Spectront pharo 300 UV-Vis spectrophotometer (St. Louis,

the concentration of the species in solution at the moment t in mg. C_o is the initial concentration of the solution in mg/L. V is the volume of the solution initially introduced in L. Mass (m) of the adsorbent in g [22, 23, 50-58].

The chemical composition is determined by the contribution of MIPROMALO (Mission for the Promotion of Local Materials) in Yaounde- Cameroon.

2.3. Procedure

We experimented with seven (7) filter devices including two (2) 100% material devices, two (2) binary devices, two (2) ternary devices and one (1) quaternary device. The column is made of polyethylene and each filter has a total material mass of 220 g, including the top layer L₁ (m = 60 g of sand), intermediate layer L₂ (m = 40 g RZ) and lower layer L₃ (m = 120 g of sand). All devices are equal in total mass of materials.

MO, USA). The wavelength for the OM is 461 nm and for the iron solution is 510 nm, the tanks used are 1.0 cm. The determination of [Fe] was made by the 1.10-Orthophenanthroline method [32-36]. The PH values are obtained by an electrode pH (WTW Co, Weilheim, Germany).

2.5. Introducing Experimental Results

The OM content in the filter is determined by UV-visible spectrophotometer at $\lambda = 461\text{nm}$ Ling type 9100-9400 whose spectral range extends over a range ranging from 320-1100 nm. The effectiveness in discoloring the initial OM filter (c_o) depending on the residual OM content, the effectiveness (E) to discoloration is given by the relationship:

$$E(\%) = \left(1 - \frac{c_e}{c_o} \right) \times 100.$$

Residual iron is determined according to the 1.10 Orthophenanthroline protocol [36]. The UV-Vis spectrophotometer is read at $\lambda = 510\text{nm}$.

3. Results and Discussion

3.1. Filtering Power and Performance of NC

Figures 2, 3, 4, and 5 successively represent the rates of OM discoloration (2 mg/L) for single-material devices in the RZ, 100% C and 100% Pz, binary devices 25%/75% Fe°/Pz and 25%/75% Fe°/C, ternary devices 25%/50%/25% Fe°/S/C, 25%/50%/25% Fe°/S/Pz, and finally a quaternary device consisting of a 25%/25%/25%/25% Fe°/S/Pz/C RZ.

The columns 100% Pz, 25%/75% Fe⁰/Pz, 25%/50%/25% Fe⁰/S/Pz confirm the ability of the Pz to eliminate OM [21], as well as methylene blue [16]. The performance of the 100% C, 25%/75% Fe⁰/C devices, 25%/50%/25% Fe⁰/S/C that involve NC are superior to those of the Pz and Fe⁰-Pz. We also observe for the six (6) devices a net and progressive loss of efficiency beyond the thirty (30) days; this failure decreases with the number of materials associated with Fe⁰ in the RZ. As a result, the 25%/25%/25%/25% Fe⁰-system with a RZ (Fe⁰, S, Pz, C) with four (4) materials of which two (2) porous (Pz, C) is perfectly stable during the forty-five (45) days of experimentation, with a decontamination rate of 98-100%. The OM decontamination rates for the seven (7) devices evolve as follows: 25%/25%/25%/25% Fe⁰/S/Pz/C > 25%/50%/25% Fe⁰/S/C > 25%/50%/25% Fe⁰/S/Pz > 25%/75% Fe⁰/C > 25%/75% Fe⁰/Pz > 100% C > 100% Pz.

Indeed, the process of decontamination of Fe⁰-filters is already proven [5-9, 16, 21]. The reactivity of the Fe⁰ involves electrochemical reactions of the wet corrosion of iron; CPs such as Fe₂O₃, Fe₃O₄, Fe(OH)₂, Fe(OH)₃, FeOOH ([13, 37] are contaminant collectors because of their absorbent properties for a wide range of soluble species [38-42]. The reactivity of the Fe⁰-based filters to the contaminants is related to the affinity of the oxide layer to the present species and not with passivated iron ([31, 43-44]. But since 100% Fe⁰-filters are prone to rapid clogging ([45-47], the combination of a porous material Pz, or at best the NC, seems to support the reactivity of Fe⁰-filters. Pz [11, 17-25] are porous non-expansive absorbent/adsorbent materials. The presence of the SiO₂ in the Pz could explain the inferiority of the performance of the Pz compared to the NC. Indeed, the SiO₂, whose reactivity depends heavily on Si-OH silanol groups, has negative surface loads favourable to the fixation of opposite load species; this would explain possible repulsion phenomena from anionic coloring OM to pH studied [15]. The 25%/25%/25%/25% Fe⁰/S/Pz/C device with the lowest SiO₂ content is the best performing. The concomitant reactivity of two porous materials within the RZ appears to stabilize the Fe⁰-based filters for a long time, and the loss of porosity is further delayed. This is an excellent result, and a great way to prevent water-borne diseases in the countryside with a protocol within reach of all fellowships.

These results can be improved thanks to the introduction into the RZ of natural wood species with variable absorption/adsorption capacities, Since the use of NC as an energy source is part of the daily lives of many African households, it is available [22, 23, 50-52, 87]. The study of its physicochemical characteristics reveals high porosity and absorption capacity [22, 23]. Wood is a cellular, hygroscopic, anisotropic and compact, more or less hard material that makes up the trunk, branches, and roots of trees and shrubs; it is biodegradable [50]. Some species are abundant in tropical forests, such as Ayous, Moabi, Movingui, Padouk and Tali varieties [51]. Ayous, or *triplochiton scleroxylon*, from the Sterculiaceae family, is a light wood that dries quickly in the air [52]. Movingui or *Distemonanthus benthamianus* of the

leguminosae family is a hardwood used as firewood and for coal production [53]. Padouk or *Pterocarpus soyauxii*, is a strong and hard wood [54].

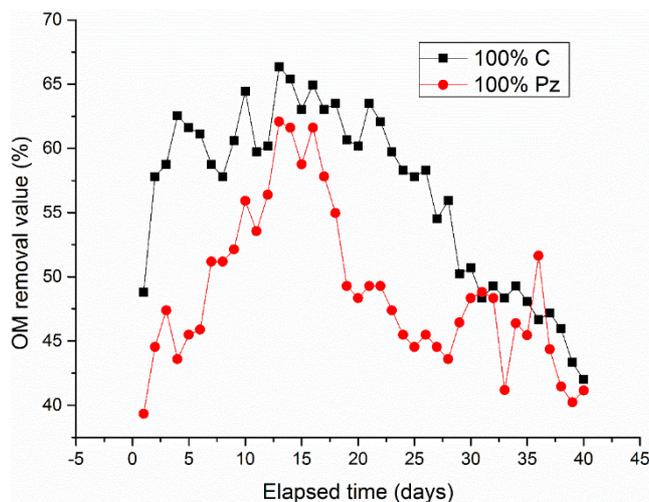


Figure 2. OM removal values, one-material RZs with pure C and pure Pz.

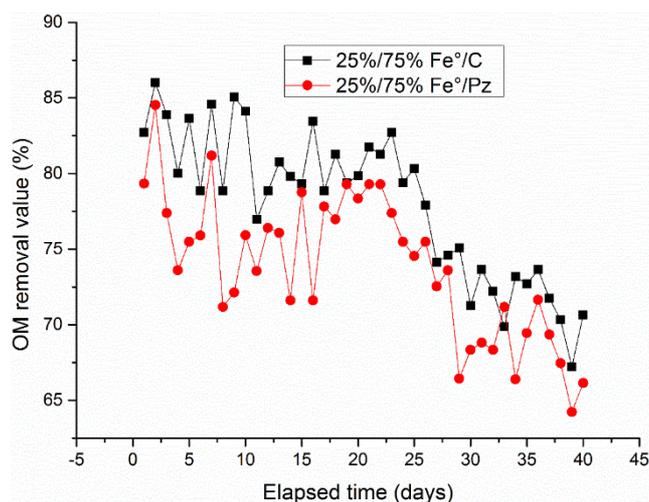


Figure 3. OM removal values, binary RZs with Fe⁰/C and Fe⁰/Pz

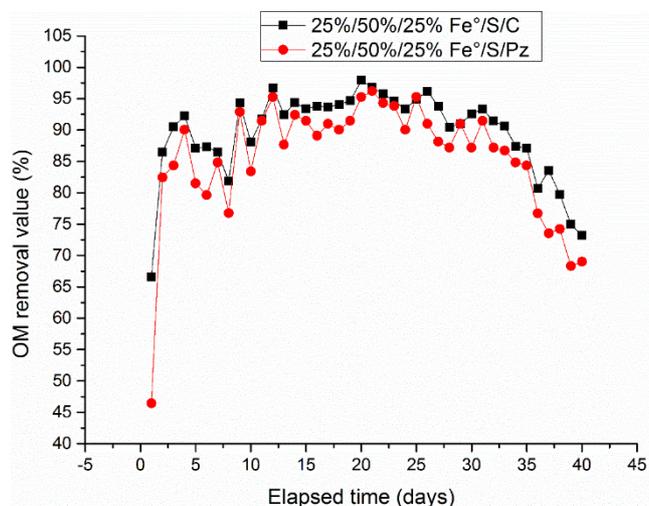


Figure 4. OM removal values, ternary RZs with Fe⁰/S/C and Fe⁰/S/Pz

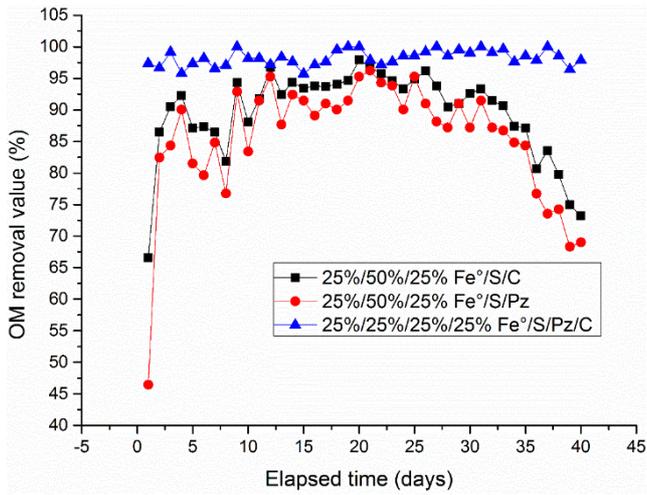


Figure 5. Performance of the quaternary device 25%/25%/25%/25% $Fe^{\circ}/S/Pz/C$ for OM discoloration

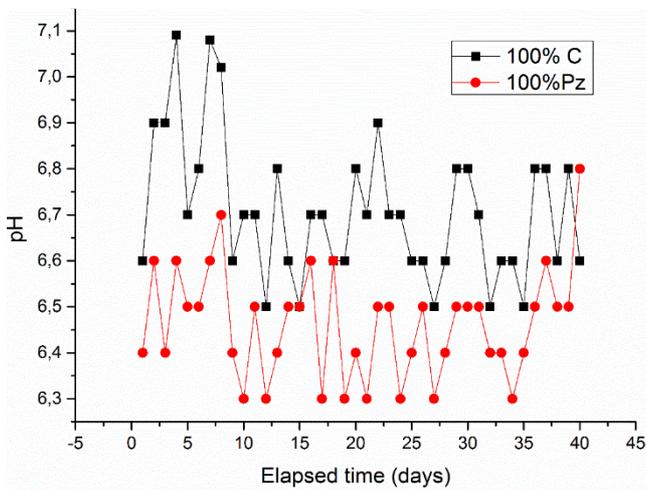


Figure 6. pH studies, one-material RZs with pure C and pure Pz

3.2. pH and Performance of NC

Figures 6, 7, 8 and 9 represent the pH measured for forty-five (45) days from the seven (7) experimental devices in the presence of OM (2 mg/L). RZs are specific, 100% C, 100% Pz, 25%/75% Fe°/C , 25%/75% Fe°/Pz , 25%/50%/25% $Fe^{\circ}/S/C$, 25%/50%/25% $Fe^{\circ}/S/Pz$, and 25%/25%/25%/25% $Fe^{\circ}/S/Pz/C$. The initial pH of contaminated water is 5.2. We observe a pH increase in filters collected for the seven (7) devices. They range from [6.3-6.6] 100% C, [6.5-7.1] 100% Pz, [6.3-6.6] 25%/75% Fe°/C , [6.5-6.9] 25%/75% Fe°/Pz , [6.4-7.0] 25%/50%/25% $Fe^{\circ}/S/C$, [6.3-7.4] 25%/50%/25% $Fe^{\circ}/S/Pz$ and [6.5-7.1] 25%/25%/25%/25% $Fe^{\circ}/S/Pz/C$. Thus, pH correction is effective for all devices, values are included in the intervals recommended by WHO [3, 33].

The elimination of OM results in increased pH, a process in which the reactivity of Fe° is ensured by CPs; the consumption of H-ions induces an increase in pH. [5-9, 13, 16, 21, 31, 38-43]; S's reactivity is ensured by surface phenomena of silanol groups that have an affinity for opposite-load species such as protons, and vice versa by repulsion [45-47]. Pz reacts both by surface phenomena by adsorption, and by

absorption phenomena due to its very high porosity ([11, 17-20]; finally, the NC reacts by its porosity [22-25]. Such a result comforts us in the choice of NC as materials for water sanitation since it rivals perfectly with the Pz and remains so easy to access because it is present in many households.

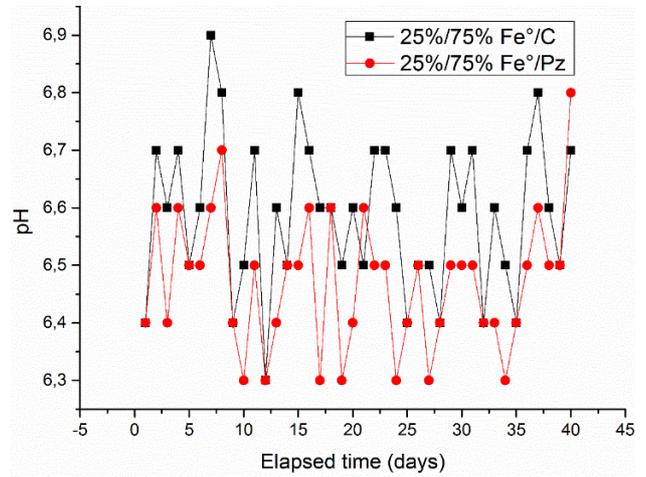


Figure 7. pH studies, binary RZs with Fe°/C and Fe°/Pz

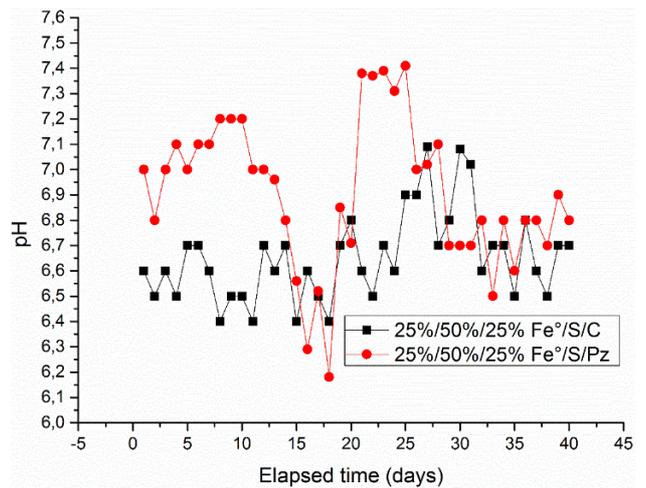


Figure 8. pH studies, ternary RZs with $Fe^{\circ}/S/C$ and $Fe^{\circ}/S/Pz$

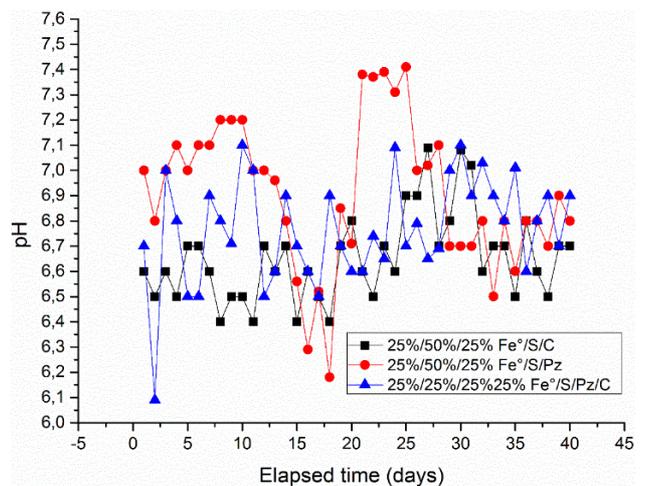


Figure 9. Performance of the quaternary device 25%/25%/25%/25% $Fe^{\circ}/S/Pz/C$ for pH correction

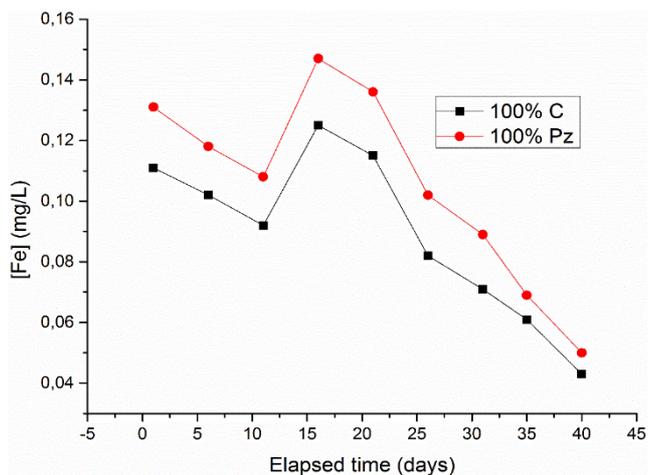


Figure 10. [Fe], one-material RZs with pure C and pure Pz.

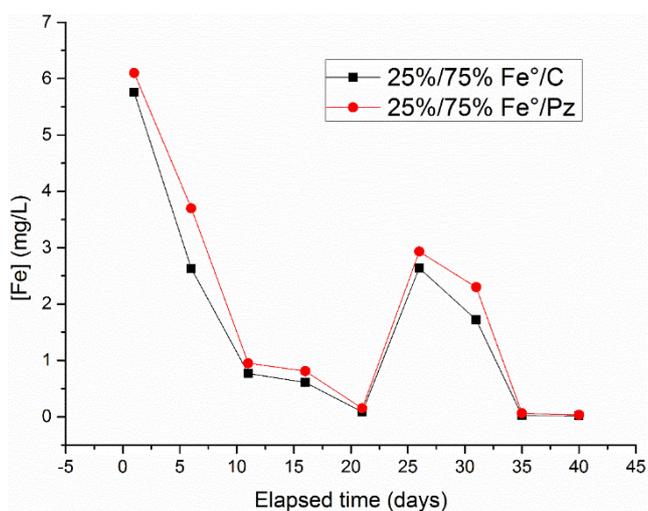


Figure 11. [Fe], binary RZs with Fe°/C and Fe°/Pz.

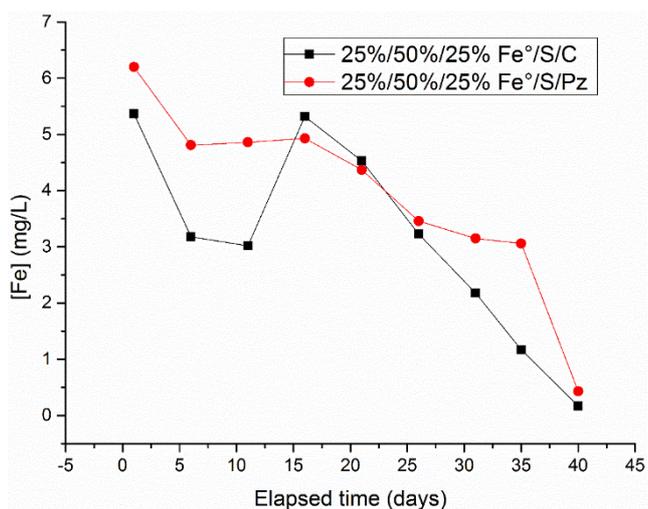


Figure 12. [Fe], ternary RZs with Fe°/S/C and Fe°/S/Pz.

3.3. [Fe] in the Collected Water

Figures 9, 10, 11, and 12 depict the released iron in the collected water during the forty-five (45) days of experimentation with the seven (7) filter devices and the

respective ZRs below: 100% C, 100% Pz, 25%/75% Fe/C, 25%/75% Fe/Pz, 25%/50%/25% Fe/S/C, 25%/50%/25% Fe/S/Pz, and 25%/25%/25%/25% Fe/S/Pz/C. We observe that all devices involving C have lower residual iron levels than their counterparts with Pz. So, we observed the increasing order of released iron in the collected water as followed: $[Fe]_{100\% C} < [Fe]_{100\% Pz}$, $[Fe]_{25\%/75\% Fe/C} < [Fe]_{25\%/75\% Fe/Pz}$, $[Fe]_{25\%/50\%/25\% Fe/S/C} < [Fe]_{25\%/50\%/25\% Fe/S/Pz}$. 100% C and 25%/25%/25%/25% Fe°/S/Pz/C have the lowest residual iron levels, and the proportions $25\% \leq Fe \leq 60\%$, $25\% \leq S \leq 50\%$, $25\% \leq Pz \leq 50\%$ are respected [21].

This could be explained by the fact that for 100% C, the residual iron comes from L₁ and L₃, because of the low levels of iron oxides in the sand. For the 100% Pz, it comes from L₁, L₂, and L₃ for the same reasons. For binary and ternary filters, the presence of 25% Fe° in the RZ (L₂) is responsible for the increase in [Fe], even if it also comes from layers L₁ and L₃. It therefore seems wise through these results, that the NC is a good porous material that does not contribute to the increase of dissolved iron neither in the RZ nor in the filtered water. When associated with Fe° in 25%/75% Fe°/C and 25%/50%/25% Fe°/S/C, it collects more pollutants in its pores than Pz as shown in Figures 3 and 4; it is therefore possible that once saturated, they regurgitate dissolved iron. The combination of two porous absorbent and non-expansive materials increases the porous surface in the RZ and validates this hypothesis since [Fe] is almost zero for the device 25%/25%/25%/25% Fe°/S/Pz/C [7-9, 13, 37-42, 45-49, -62-87]. This is an excellent result.

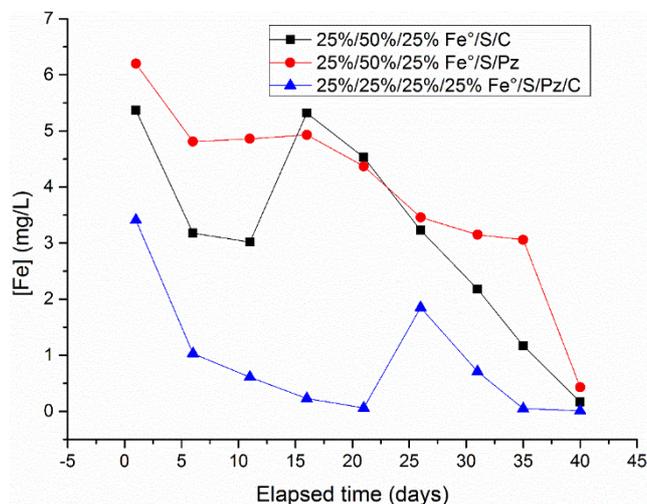


Figure 13. Performance of the quaternary device 25%/25%/25%/25% Fe°/S/Pz/C for removal of dissolved iron.

3.4. Flow Rate and Performance

Figures 14, 15, 16 and 17 depict variations in the flow of the seven (7) devices. Specific RZs are 100% C, 100% Pz, 25%/75% Fe/C, 25%/75% Fe/Pz, 25%/50%/25% Fe/S/C, 25%/50%/25% Fe/S/Pz, and 25%/25%/25%/25% Fe/S/Pz/C. We observed the decreasing order of flow rates as followed: $Flow_{(100\% Pz)} > Flow_{(100\% C)} > Flow_{(25\%/75\% Fe/Pz)} > Flow_{(25\%/75\% Fe/C)} > Flow_{(25\%/25\%/25\%/25\% Fe/S/Pz/C)} > Flow_{(25\%/50\%/25\% Fe/S/Pz)}$

$Fe^{\circ}/S/Pz$ *Flow (25%/50% Fe°/C). The decrease of flow is attributed to the progressive clogging due to accumulation of OM in the initial pores and interstices systems, since the best adsorbents/adsorbents have the lowest flows. It is now agreed that pure Fe° systems are efficient but not sustainable [81-82]. The replacement of a fraction of Fe° by a non-expansive porous material was therefore found as alternative approach [16, 21, 60-61, 87].

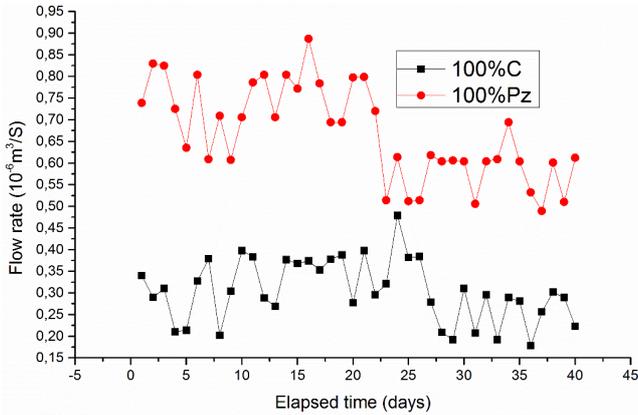


Figure 14. Flow rate studies, one-material RZs with pure C and pure Pz.

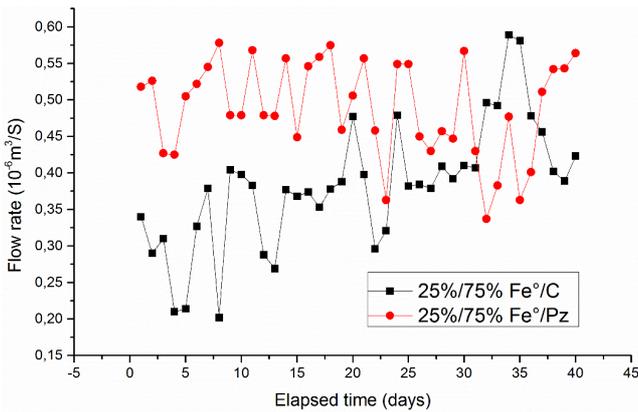


Figure 15. Flow rate studies, binary RZs with Fe°/C and Fe°/Pz .

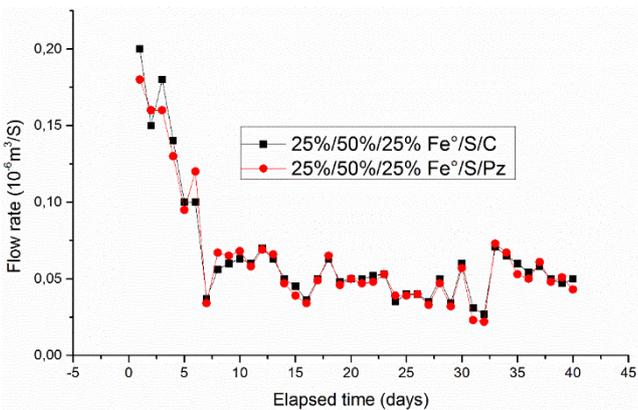


Figure 16. Flow rate studies, ternary RZs with $Fe^{\circ}/S/C$ and $Fe^{\circ}/S/Pz$.

As a result, ternary devices have the worst flow, while they are good OM collectors; the flow improves with the combination of C and Pz in the RZ, for the device

25%/25%/25%/25% $Fe^{\circ}/S/Pz/C$. The flow of C is explained by the fact that, the best discoloration necessary induces the worst flow, for the reasons already explained above (Figures 14, 15, 16 and 17). This is why the association of NC and Pz in the RZ has a beneficial effect on flow, hence the resurgence of reactivity (figure 5), and the improvement of the flow of the quaternary compared to the ternary (figure 17).

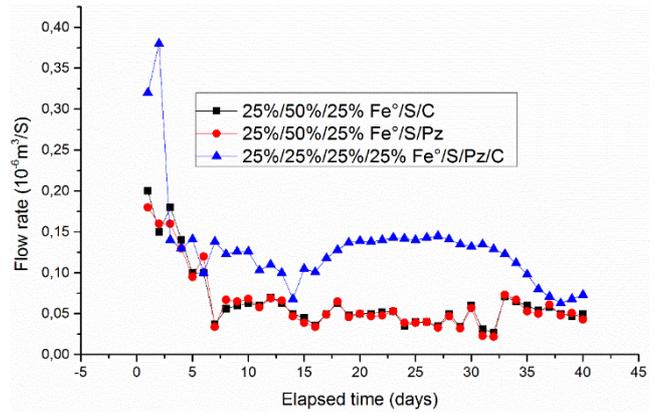


Figure 17. Performance of the quaternary device 25%/25%/25%/25% $Fe^{\circ}/S/Pz/C$ on throughput improvement

4. Conclusion and Recommendations

This work involved enacting and consolidating the concept of the W.E.S. through the enhancement of local multifunctional materials, accessible to populations far from the distribution networks of drinking water. To do this, we introduced the NC into the RZ of a metal bed device and observed its performance compared to the Pz whose performance is already proven in our previous work. As a result, the devices 100% C, 100% Pz, 25%/75% Fe°/C , 25%/75% Fe°/Pz , 25%/50%/25% $Fe^{\circ}/S/C$, 25%/50%/25% $Fe^{\circ}/S/Pz$, 25%/25%/25%/25% $Fe^{\circ}/S/Pz/C$ were experienced with OM. The results show that NC is an excellent pollutant collector. Pure (100%C) in the RZ, it has a higher decontamination rate than the Pz for an acceptable flow rate. Associated with the Fe° , we observe the order below; 25%/25%/25%/25% $Fe^{\circ}/S/Pz/C$ > 25%/50%/25% $Fe^{\circ}/S/C$ > 25%/50%/25% $Fe^{\circ}/S/Pz$ > 25%/75% Fe°/C > 25%/75% Fe°/Pz > 100% C > 100% Pz. The NC contributes to pH correction as recommended by WHO. This non-expansive porous material is a good pollutant collector that does not bring additional iron into the Fe° -bed filter. The association C and Pz, makes the device 25%/25%/25%/25% $Fe^{\circ}/S/Pz/C$ a good sanitation tool with 98-100% efficiency. NC can be an alternative to Pz for households, in this case populations that are often poor in sub-Saharan Africa. It gives a boost of activity and stability to Fe° -bed filters with a RZ with four (4) materials. The NC can have a triple use Of Wood-Energy-Sanitation (W.E.S.). This recovery of household waste gives it a second life.

Acknowledgements

Our thanks to the Department of Chemistry of the Faculty of Science, University of Douala, to the Department of

Chemistry of the Faculty of Medicine, University of Douala, and finally to the Department of Applied Geology, University of Göttingen for their unwavering support at all times. Thanks to MIPROMALO-Cameroon for the characterization of materials.

References

- [1] Schure, J., Mariem, J. L., de Wasseige, C., Drigo, R., Salbitano, F., Dirou, S., & Nkoua, M. (2012). Contribution of Wood-Energy to meeting the energy needs of people of Central Africa: Perspectives for sustainable management of the available resources. Chap. 5 p. 109. <http://doi.org/10.2788/48830>
- [2] FAO (2008). Les forêts et *Energie* (<http://www.fao.org/docrep/010/i0139f/i0139f00.htm>)
- [3] WHO (2006). Environment factors cause 24% of diseases, <http://www.futura-sciences.com>
- [4] Mpakam, H. G., Kamgang Kabeyne, B. V., Kouam Kenmogne, G. R., Tamo Tatietsé, & Ekodeck, G. E. (2006). Access to drinking water and sanitation in cities in developing countries: the case of Bafoussam (Cameroon), *Vertigo-la revue électronique des sciences de l'environnement*, 7, p. 2 <http://doi.org/10.4000/vertigo.2377>
- [5] Noubactep, C., Makota, S., Nanséu-Njiki, C. P., Ebelle, T. C., Nassi, A., Tchatchueng, J. B., Benguella, B. L., Wofo, P., & Njau, K. N. (2018). Affordable safe drinking water for the whole world: A coming reality. *Researchgate*, on 01 February. <http://www.researchgate.net/publication/322855761>
- [6] Rahman, M. A., Karmakar, S., Salama, H., Gactha-Bandjun, N., Btatkeu-K, B. D., & Noubactep, C. (2013). Optimising the design of Fe⁰-based filtration systems for water treatment: The suitability of porous iron composites. *J. Appl. Solut. Chem. Model.* 2: 165–177.
- [7] Ebelle, T. C., Makota, S., Tepong-Tsindé, R., Nassi, A., & Noubactep, C. (August 2016). Metallic iron and the dialogue of the deaf. *Fres. Environ. Bull.* 28 (11A): 8331-8340. <http://www.researchgate.net/publication/305986624>
- [8] Makota, S., Ndé-Tchoupé, A. I., Mwakabona, H. T., Tepong-Tsindé, R., Noubactep, C., Nassi, A., & Njau, K. N. (2017). Metallic iron for water treatment: leaving the valley of confusion. *Appl. Water Sci.* 7: 4177-4196. <http://doi.org/10.1007/s13201-017-0601-x>
- [9] Noubactep, C., Makota, S., & Randyopadhyay, A. (2017). Rescuing Fe⁰ remediation research from its systemic flaws. *Res. Rev. Insights.* 1 (4): 1-8. <http://doi:10.15761/RRI.1000119>
- [10] Mitchell, G., Poole, P., & Segrove, H. (1955). Adsorption of Methylene Blue by High-Silica Sands. *Nature* 176, 1025-1026.
- [11] Iler, R. (1979). *The Chemistry of Silica* Wiley Intersci. Public. 35 pp. New York, USA.
- [12] Wilkin, R., Puls, R., & Sewell, G. (2003). Long-term performance of permeable reactive barriers using zero-valent iron: geochemical and microbiological effects, *Ground Water* 41, 493-503. <https://doi.org/10.1111/j.17456584.2003.tb02383.x>
- [13] Henderson, A. D., & Demond, A. H. (2007). Long-term performance of zero-valent iron permeable reactive barriers: a critical review. *Environ. Eng. Sci.* 24: 401-423 <https://doi.org/10.1089/ees.2006.0071>
- [14] Miyajima, K., & Noubactep, C. (2012). Effects of Mixing Granular Iron with Sand on the Efficiency of Methylene Blue Discoloration. *Chem. Eng. J.* 433–438.
- [15] Btatkeu, K., Miyajima, K., Noubactep, C., & Caré, S. (2013). Testing the suitability of metallic iron for environmental remediation: discoloration of methylene blue in column studies. *Chem. Eng. J.* 215-216, 959–968. <https://dx.doi.org/10.1016/j.cej.2012.11.072>
- [16] Ndé-Tchoupé, A. I., Makota, S., Nassi, A., Rui, H., & Noubactep, C. (2018). The suitability of pozzolan as admixing aggregate for Fe⁰-Based Filters. *Water.* 10: 417. DOI: 10.3390/w10040417.
- [17] Dron, R., (1975). Les pouzzolanes et la pouzzolanité. *Revue des matériaux de construction* n° 692, 27-30 (In French).
- [18] Sieliechi, J. M., Lartiges, B. S., Ndi, S. K. Kamga, R., & Kayem, G. J. (2012). Mobilization of heavy metal from natural pozzolan by humic acid: implications for water and environment, *Int. J Environ.* 2: 11-15.
- [19] Billong, N., Chinje Melo, U., Njopwouo, D., Louvet, F., & Bonnet, J. P. (2013). Physicochemical characteristics of some Cameroonian pozzolans for use in sustainable cement like materials. *Materials Sci. Appl.* 4: 14–21. <http://doi.10.4236/msa.2013.41003>
- [20] Kofa, G. P., NdiKoungou, S., Kayem, G. J., & Kamga, R. (2015). Adsorption of arsenic by natural pozzolan in a fixed bed: determination of operating conditions and modeling. *J. Water Process Eng.* 6: 166–173 <https://doi.org/10.1016/j.jwpe.2015.04.006>
- [21] Suzanne Makota, S. N, Nguemo Wekam, E., Dipita Kolye, E. Y. H., & Nassi, A. (2022). Ranges and fitting ratios of natural aggregates for a sustainable and effective Fe⁰/Sand/Pozzolan ternary device using orange methyl. *American Journal of Applied Chemistry* Submit.
- [22] Dejong, E., & Rotschild, J. (1894). 3^e édition p. 63- 64.
- [23] Wigmans, T. (1989). *Carbon*, 27 (1), 13-22 [http://doi.org/10.1016/0008.6223\(89\)90152.8](http://doi.org/10.1016/0008.6223(89)90152.8).
- [24] Louppe, D. (2014). CIRAD UPR BSEP http://ur-bsep.cirad.fr/Campus_international_de_Baillarguet_34398_Montpellier_Cedex_5_France_dominiquelouppe@cirad.fr
- [25] LaSIE (Laboratoire des Sciences de l'Ingénieur pour L'environnement) (2014). Pôle Sciences et Technologie Avenue Michel Crépeau 17042 LA ROCHELLE CEDEX (In French).
- [26] Noubactep, C. (2009). Characterizing the discoloration of methylene blue in Fe⁰/H₂O systems. *J. Hazard. Mater.* 166, 79–87.
- [27] Anderson, W. (1886). On the purification of water by agitation with iron and by sand filtration. *Journal of the Society for Arts* 35 (1775), 29–38.
- [28] Devonshire, E. (1890). The purification of water by means of metallic iron. *Journal of the Franklin Institute* 129, 449-461.

- [29] Al-heetimi, D., Dawood, A., Khalaf, Q., & Himdan, T. (2012). Removal of methyl orange from aqueous solutions by Iraqi bentonite adsorbent. *Ibn Al-Haitham J. for Pure and Appl. Sci.* 1, Vol. 25.
- [30] Phukan, M. (2015). Characterizing the Fe⁰/sand system by the extent of dye discoloration. *Freiberg Online Geosci.* 40: 70. <https://doi.org/10.1016/j.cej.2014.08.013>
- [31] Miyajima, K. (2012). Optimizing the design of metallic iron filters for water treatment. *Freiberg Online Geosci.* 32: 107.
- [32] Norme NF T 90-017 (1982). Dosage du fer, Méthode Spectrométrique à la phénanthroline-1,10, AFNOR Paris (In French).
- [33] Rejsek, F. (2002). Analyse des eaux – Aspects réglementaires et techniques p. 66 (In French).
- [34] Standard Methods for the examination of water, 19th edition, sheet 3-68.
- [35] Centre International de l'eau et de l'assainissement IRC/ (1991). la filtration lente sur sable pour approvisionnement en eau potable (In French).
- [36] Fortune, W. B., & Mellon, M. G. (Ed. 1938). Determination of iron with o-phenanthroline: A spectrophotometric study. *Ind. Eng. Chem. Anal.* 10: 60-64.
- [37] Comba, S., Di Molfetta, A., & Sethi, R. (2011). A comparison between field applications of nano-, micro-, and millimetric zero-valent iron for the remediation of contaminated aquifers. *Water Air Soil Pollut.* 215: 595-607.
- [38] Pilling, N. B., & Bedworth, R. E. (1923). The oxidation of metals at high temperatures. *J. Inst. Metals.* 29: 529, 591.
- [39] Schwertmann, U. (1991). Solubility and dissolution of iron oxides. *Plants and Soil.* 130: 1-25.
- [40] Crawford, R. J., Harding, I. H., & Mainwaring, D. E. (1993a). Adsorption and coprecipitation of single heavy metal ions onto the hydrated oxides of iron and chromium. *Langmuir.* 9: 3050-3056.
- [41] Brown Jr., G. E., Henrich, V. E., Casey, W. H., Clark, D. L., Eggleston, C., Felmy, A., Googman, D. W., Grätzel, M., Maciel, G., McCarthy, M. I., Nealson, K. H., Sverjensky, D. A., Toney, M. F., & Zachara, J. M. (1999). Metal oxide surfaces and their interactions with aqueous solutions and microbial organisms. *Chem. Rev.* 99: 77-174.
- [42] Casentini, B., Falcione, F. T., Amalfitano, S., Fazi, S., & Rossetti, S. (2016). Arsenic removal by discontinuous ZVI two steps system for drinking water production at household scale. *Water Res.* 106: 135-145. <https://doi.org/10.1016/j.waters.2016.09.057>
- [43] Noubactep, C. (2013a) Relevant reducing agents in remediation Fe⁰/H₂O systems *Clean-Soil Air Water.* 41: 493-502. <https://doi.org/10.1002/clen.201200406>
- [44] Gatcha-Bandjun, N., Noubactep, C., & Loura Mbenguela, B. (2017). Mitigation of contamination in effluents by metallic iron: The role of iron corrosion products. *Environ. Technol. Innov.* 8: 71-83. <https://doi.org/10.1016/j.eli.2017.05.002>
- [45] Detay, M. (1993). Le forage de l'eau. *Ingénierie de l'environnement* p. 231-242, (Eds) Masson (In French).
- [46] Nestic, S. (2007). Key issues related to modeling of internal corrosion of oil and gas pipelines –A review: *Corros. Sci.* 49: 4308-4338. DOI: 10.1016/j.corsci.2007.06.006.
- [47] Lazzari, L. (2008). General aspects of corrosion. Chapter 9.1: vol. V. *Encyclopedia of hydrocarbons*, Istituto Enciclopedia Italiana, Rome, Italy.
- [48] Crawford, R. J., Harding, I. H., & Mainwaring, D. E. (1993a). Adsorption and co precipitation of multiple heavy metal ions onto the hydrated oxides of iron and chromium. *Langmuir* 9: 3057-3062.
- [49] Detay, M. (1993). Le forage de l'eau. *Ingénierie de l'environnement* p. 250-259, (Eds) Masson (In French).
- [50] Nguila, I. G., Petrissans, M., Lambert, J., Ehrhardt, J. J., & Gérardin, P. (2006). XPS characterization of wood chemical composition after heat-treatment. *Surface and Interface Analysis* 38 (10) 1336-1342.
- [51] Saha Tchinda, J. B. (2015). Wood and fiber Science. PhD thesis. University of Lorraine French (In French) pp 20-56.
- [52] Wageningen, (2008). Medicinal plants 1, Prota Foundation, resources from tropical Africa Backhuys publishers/CTA, Pays-Bas, 11 (1): 276-281.
- [53] Nguielefack, P. M. E., Ngu, B. K., Atchade, A., Dimo, T., Tsabang, N., & Mbafor, T. J. (2005). Phytochemical composition and in vitro effect of ethyl acetate bark extract of *Distemonanthus benthamianus* Baillon (Caesalpiniaceae) on *Staphylococcus aureus* and *Streptococcus agalactiae*. *Cameroon Journal of Experimental Biology* 1 (1): 50-53.
- [54] Jansen, P. C. M., (2005). *Pterocarpus soyauxii* Taub. In: Louppe, D., Oteng-Amoako, A. A. & Brink, M. (Ed.) *Prota 7 (1): Timbers / Bois d'oeuvre 1*. PROTA, Wageningen, Pays Bas.
- [55] Gbamele, K. S., Atheba, G. P., Dongui, B. K., Drogui, P., Robert, D., Kra, D. O., Konan, S., De Bouanzi, G. G. M., & Trokourey, A. (2016). Contribution à l'étude de quatre charbons activés à partir des coques des noix coco. *Afrique SCIENCE* 12 (5) 229-245.
- [56] Sjoström Eero, (1993). *Wood Chemistry-Fundamentals and Applications*. San Diego, USA, Academic Press. 2nd Ed., pp 51-108.
- [57] Mellouk, A. (2007). Extraction of volatile compounds from wood by Instant Controlled Relaxation (ICR): Industrial recovery of solid extracts and residues. PhD thesis Specialization: Genie of processes University of La Rochelle French. (In French) pp 152.
- [58] Mounquengui, W. S. (2008). HPLC characterization of markers to predict the evolution of certain macroscopic properties of wood during different degradation processes. PhD thesis University of Henri Poincaré, Nancy-I French (In French). pp 229.
- [59] Visscher, J. T., Paramasivam, R., Raman, A., & Heijnen, H. A. (1991). (IRC) International Water and Sanitation Center / Slow filtration on sand for drinking water supply (In French) pp 51.
- [60] Noubactep, C., & Caré, S. (2010). Dimensioning metallic iron beds for efficient contaminant removal. *Chem. Eng. J.* 163: 454-460.
- [61] Noubactep, C., Caré, S., Togue-Kamga, F., Schöner, A., & Wofo, P. (2010). Extending service life of household water filters by mixing metallic iron with sand. *Clean – Soil, Air, Water* 38: 951-959.

- [62] Li, S., Heijman, S., Verberk, J., & Van Dijk, J. (2009). An innovative treatment concept for future drinking water production: Fluidized ion exchange – Ultrafiltration nanofiltration – Granular activated carbon filtration, *Drink. Water Eng. Sci.* 2, 41–47.
- [63] Nasser, E., Ndé-Tchoupé, A. I., Mwakabona, H. T., Nansu-Njiki, C. P., Noubactep, C., Njau, K. N., Wydra, K. D. (2017). Making Fe⁰-based filters a universal solution for safe drinking water provision. *Sustainability*, 9, 1224.
- [64] Noubactep, C. (2009). An analysis of the evolution of reactive species in Fe⁰/H₂O systems. *J. Hazard Mater.*, 168, 1626-1631.
- [65] Kumar, R., Sinha, A. (2017). Biphasic reduction model for predicting the impacts of dye-bath constituents on the reduction of tris - azo dye Direct Green-1 by zero-valent (Fe⁰). *J. Environ. Sci. (China)*, 52, 160-169.
- [66] Guan, X., Sun, Y., Qin, H., Li, J., Lo, I. M. C., He, D., & Dong, H. (2015). The limitations of applying zero-valent iron technology in contaminants sequestration and the corresponding countermeasures: The development in zero-valent iron technology in the last two decades (1994-2014). *Water Res.*, 75, 224-248.
- [67] O'Hannesin, S. F., & Gillham, R. W. (1998). Long-term performance of an in situ "iron wall" for remediation of VOCs. *Ground Water*, 36, 164-170.
- [68] Diao, M., & Yao, M. (2009). Use of zero-valent iron nanoparticles in inactivating microbes. *Water Res.*, 43, 5243–5251.
- [69] Gheju, M. (2011). Hexavalent chromium reduction with zero-valent iron (ZVI) in aquatic systems *Water, Air Soil Pollut.*, 222, 103-148.
- [70] Noubactep, C. (2010a). The fundamental mechanism of aqueous contaminant removal by metallic iron. *Water SA*, 36, 663-670.
- [71] Lamoureux, J-J. (2000). Précis de corrosion. Sciences des matériaux, p. 1-78, (2^e Eds) Masson (In French).
- [72] Noubactep, C. (2006). Contaminant reduction at the surface of elemental iron: The end of a myth. *Wissenschaftliche Mitteilungen Freiberg*, 31, 173-179.
- [73] Noubactep, C. (2007). Processes of contaminant removal in "Fe⁰-H₂O" systems revisited: The importance of co-precipitation. *Open Environ. Sci.*, 1, 9-13.
- [74] Noubactep, C. (2008). Processes of contaminant removal in "Fe⁰-H₂O" systems revisited: The importance of co-precipitation. *Open Environ. Sci.*, 1, 9-13.
- [75] Odziemkowski, M. S., & Simpraga, R. P. (2004). Distribution of oxides on iron materials used for remediation of organic groundwater contaminants-Implications for hydrogen evolution reactions. *Can. J. Chem.*, 82, 1495-1506.
- [76] Baker, M. (1934). Sketch of the history of water treatment. *Journal American Water Works Association*, 26, 902-938.
- [77] Noubactep, C. (2016b). Designing metallic iron packed-beds for water treatment: A critical review. *Clean- Soil, Air, Water*, 44, 411-421.
- [78] Ghanch, A. (2015). Iron-based metallic systems: An excellent choice for sustainable water treatment. *Freiberg Online Geosci.*, 38, p. 80.
- [79] Keenan, C., & Salad, D. L. (2008). Factors affecting the yield of oxidants from the reaction of nanoparticulate zero-valent iron and oxygen. *Environ. Sci. Technol.*, 42, 1262-1267.
- [80] Ngai, T. K. K., Murcott, S., Shrestha, R. R., Dangol, B., & Maharjan, M. (2006). Development and dissemination of Kanchan™ arsenic filter in rural Nepal. *Water Sci. Technol. Water Supply*, 6, 137-146.
- [81] Hussam, A., & Munir, A. K. M. (2007). A simple and effective arsenic filter based on Composite iron matrix: Development and deployment studies for groundwater of Bangladesh. *J. Environ. Sci. Health*, 42, 1869-1878.
- [82] Hussam, A. (2009). contending with a development disaster: SONO filters remove arsenic from well water in Bangladesh. *Innovations 4*: 89-102.
- [83] Makenzie PDI, Horney DP and Sivavec TM (1999). Mineral precipitation and porosity losses in granular iron columns. *J Hazard Mater.* 68: 1-17.
- [84] Li, L., & Benson, C. H. (2010). Evaluation of five strategies to limit the impact of fouling in permeable reactive barriers. *J. Hazard Mater.* 181: 170180. <https://doi.org/10.1016/j.jhazmat.2010.04.113>
- [85] Ngai, T. K. K., Shrestha, R. R., Dangol, B., Maharjan, M., & Murcott, S. E. (2007). Design for sustainable development - Household drinking water filter for Arsenic and pathogen treatment in Nepal. *J. Environ. Sci. Health*, 42, 1879-1888.
- [86] Btatkeu-K, B. D., Olvera-Vargas, H., Tchatchueng, J. B. Noubactep, C., & Caré, S. (2014). Determining the optimum Fe⁰ ratio for sustainable granular Fe⁰/sand water filters. *Chem. Eng. J.* 247, 265–274. <https://doi.org/10.1016/j.cej.2014.03.008>
- [87] Suzanne Makota S. N., & Dipita Kolye, E. Y. H. (2021). Natural Coal Aggregates to the Rescue of Fe⁰-Bed Filters in Quaternary Reactive Zones Fe⁰/S/Pz/C_x to Repel Clogging and Boost Reactivity. *American Journal of Applied Chemistry*. Vol. 9, No. 3, pp. 74-82. Doi: 10.11648/j.ajac.20210903.13 ISSN: 2330-8753 (Print); ISSN: 2330-8745 (Online).