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# Utilization of autoclaved aerated concrete solid waste as a bio-carrier in immobilized bioreactor for municipal wastewater treatment

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## ABSTRACT

Autoclaved aerated concrete waste (AACW) resulted from construction and demolition was used as a bio-carrier in a passively aerated biological filter (PABF) treating municipal wastewater. Physical, chemical and morphological characterization of AACW were carried out in terms of X-ray diffraction, surface area, porosity, scanning electron microscopy and energy-dispersive X-ray. Results showed that the main crystalline phases in AACW are mainly oxides of $SiO_2$, CaO and $Al_2O_3$ beside hydrous silicates ($Ca_5Si_6O_{18}H_2$). In addition, AACW has a rough surface with a high specific surface area of 42.8 $m^2/g$. Different from commercially available bio-carriers, AACW has an open macro-porous structure that is suitable for immobilizing microorganisms. The use of AACW as a bio-carrier in a pilot scale PABF reactor improved greatly the removal of organic and inorganic pollutants. Average removal values of chemical oxygen demand, biochemical oxygen demand and total suspended solids were 90%, 92% and 89% with corresponding average residual values of 36.4, 17.2, 11.3 and 3.3 mg/L. Results indicated that the potential of using AACW as a bio-carrier in a PABF is recommended and it provides a promising approach to utilize construction and demolition solid waste.

*Keywords:* Passive aeration; Attached growth; Bio-carrier; Recycling; Concrete solid waste; Municipal wastewater

## 1. Introduction

The water scarcity and energy crisis are a growing global problem which challenging the sustainable development especially in developing countries. In addition to water scarcity, the fresh water courses suffer from the discharge of untreated municipal wastewater especially in small communities and rural areas and it causes the contamination of available fresh water resources [1]. Also, it affects public health due to the presence of contaminants such as pathogenic microorganisms and chemical of variable toxicity [2]. One of the promising options to overcome the water scarcity is the treatment of wastewater to a level suitable for reuse. Decentralized treatment technologies could be the most suitable solutions to be applied in rural areas and small communities. These technologies are varied between anaerobic treatment such as up-flow anaerobic sludge blanket [3], aerobic treatment like biological aerated filter (BAF) [4] and passive or natural aeration treatment systems such as down flow hanging sponge [5], constructed wetlands [6,7] and passively aerated biological filter (PABF) [8,9]. Selection of such technologies in small communities is usually depending on many factors such as investment costs, energy consumption, ease of operation and maintenance [10].

PABF is a promising biological technology for full scale application due to its cost and energy effectiveness. The passive aeration process combines the advantages of the vertical flow constructed wetland concept (minimal energy input,

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low operational costs, low maintenance and high reliability) with the high loading rates typically associated with trickling filters [9]. The process is based on convective aeration of a vertical flow bed in which the wastewater was evenly distributed on the top of the bed, trickles through the unsaturated media and settles at the bed's bottom. PABF is usually packed with a bio-carrier which the biofilm grows on its surface and wastewater is infiltrated through it while aeration occurred due to trickle down of wastewater over the media [8]. The characteristics of bio-carrier are one of the most important factors which affect the performance and success of PABF [11]. Many kinds of commercial carriers have been used in bioreactor for wastewater treatment [12] such as quartz, artificial gravel, zeolite, sand and synthetic inorganic chemicals such as pyrolysis cinder, activated carbon, crushed glass, lightweight alloy body, geotextile, ceramics and others [13]. Several carriers such as the porous recycled products (less expensive and more environmentally friendly) are under development to enhance the biodegradation capability of bio-filters and to reduce the capital expenditure [14]. One of these products is the autoclaved aerated concrete (AAC). AAC is a good energy-saving construction material that possesses high compressive strength and light weight. AAC minimize the deadweight of a building is usually used as a frame structure of support walls. The material of AAC is a concrete-like with very light weight, obtained by uniformly distributed closed air bubbles. AAC is a non-permeable porous material that allows water only under pressure to pass slowly through it [15]. The manufacturing process of AAC produced about 5% crushed waste as a residual unusable slice resulted from shaping process. Utilization of this solid waste in a sustainable way to balance the environment and economy should be concerned. There are few studies investigated the reuse of concrete solid waste as a bio-carrier in laboratory scale wastewater treatment system. Le et al. [16] studied the use of concrete solid waste for ammonia removal from sewage in 3 L BAF reactor. Also, Renman et al. [17] investigated the use of crushed autoclaved aerated concrete (CAAC) as a filter media in a bench scale conventional aeration system for phosphorus removal from wastewater. They recommended a high retention time up to 24 h for acceptable removal of phosphorus. However, no pilot scale study has been recorded for the use of autoclaved aerated concrete waste (AACW) as a bio-carrier in attached growth treatment systems such as PABF. From this prospective, the aim of this study was to investigate and evaluate the effectiveness of utilizing AACW material as a bio-carrier in a pilot scale PABF for municipal wastewater treatment.

## 2. Materials and methods

### 2.1. Description of the PABF system

The pilot scale PABF reactor used in this study was similar to that used and tested by Abou-Elela et al. [9], except for the packing material. AACW was used as a bio-carrier in the reactor. The PABF was located in a wastewater treatment plant and fed with setteled municipal wastewater from inclined plate settler (IPS) throgh a spray nozzle fixed at the top of the reactor. The PABF has a highet of 250 cm and consists of four cuboid compartments where each onewas packed with AACW at a height of 30 cm. Details of the design parameters and operating conditions are shown in Table 1, while Fig. 1 shows a schematic diagram of the PABF.

### 2.2. Preparation of AACW bio-carrier

Solid waste of AACW was obtained from the local Delta Block Co. (Quesna Industrial Zone, Menoufia Governerate Egypt) for manufacturing white light bricks and it was obtained in the form of slim boards with dimensions of 60 cm length, 20 cm width and thickness of 10 cm. Each wasted board was cut and shaped into small cubes (2.5 cm × 2.5 cm × 2.5 cm). The cubes were placed randomly in each compartment of the PABF reactor at 30 cm height which represents about 4500 AACW cubes.

### 2.3. Physical and chemical characterization of AACW

Physical and chemical characterization of AACW covered X-ray diffraction (XRD), surface area, porosity, scanning

Table 1
Operating conditions and design parameters of PABF

| Parameters | Value |
|---|---|
| PABF total volume($m^3$) | 0.72 |
| Packing media volume ($m^3$) | 0.432 |
| Compartment dimensions(cm) | 60 × 60 × 50 |
| Total media surface area ($m^2/m^3$) | 155.5 |
| Media depth per compartment (cm) | 30 |
| Total media depth (cm) | 120 |
| Temperature range (°C) | 29–32 |
| Hydraulic retention time (h) | 2.59 |
| Average organic loading rate (Kg BOD/$m^3$ d) | 2.18 |
| Hydraulic loading rate ($m^3/m^2$ d) | 11.11 |

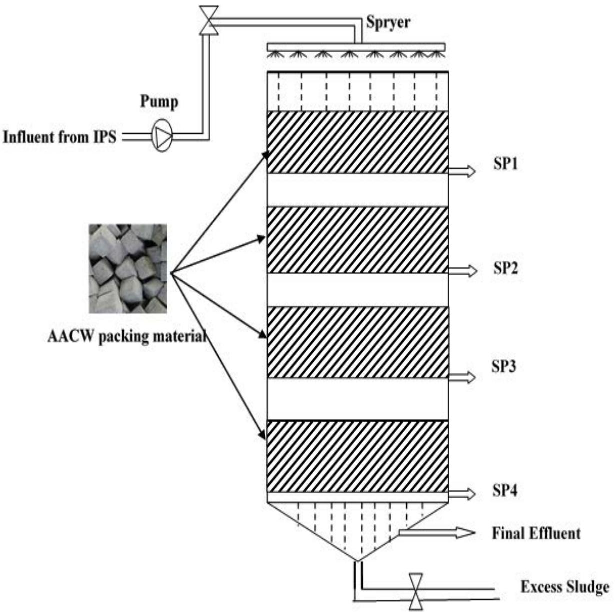


Fig. 1. Schematic diagram of PABF reactor.

electron microscopy (SEM) and energy-dispersive X-ray analyses (EDX). PANalytical XPert PRO (UK), was used for XRD analysis using Cu-target with Ni-filtered radiation (l = 1.542 Å). The surface area and porosity of AACW were measured using Brunauer–Emmett–Teller (BET) analyzer model SA-9600. The specific surface area was calculated from the BET equation in its normal range of applicability. The morphology of AACW before inoculation was studied via cross-section images and with a scanning electron microscope and EDX using JEOL JSM model 6510LV (Tokyo, Japan), with resolution of $1pA^0$–$11A^0$ and at a beam energy of 30 kV [18]. At the end of the study, one piece of immobilized AACW was collected from each compartment and prepared for SEM examination. Drying process was completed by incubating the samples for 2 h at 50°C prior to SEM investigation.

### *2.4. Start up of PABF reactor*

The PABF reactor was initially seeded with activated sludge containing mixed liquor suspended solids concentration of 4.5 g/L. To reach the steady state, the reactor was fed with constant flow of 1 $m^3$/d then it was gradually increased from 1 to 4 $m^3$/d. The steady state was achieved after 45 d.

### *2.5. Wastewater sampling and analyses*

Physico-chemical and biological analyses were carried out for influent, effluents from each compartment and the final treated effluent. During a period of 120 d, 105 samples were analyzed according to standard methods for the examination of water and wastewater [19]. Analyses included: total chemical oxygen demand ($COD_{tot}$), soluble chemical oxygen demand ($COD_{sol}$), biological oxygen demand (BOD), total suspended solids (TSS), volatile suspended solids (VSS), total Kjeldahl nitrogen (TKN), ammonium ($NH_4^+$–N), nitrite ($NO_2^-$–N), nitrate ($NO_3^-$–N) and fecal coliform (FC).

### *2.6. Determination of total and volatile solids retained in the AACW and the excess sludge*

Five AACW cubes were collected from each compartment and washed with distilled water until they were completely cleaned. Total solids (TS), volatile solids (VS) and biofilm density (g/$m^3$) (biomass weight (g) per occupied volume of AACW in each compartment ($m^3$)) were analyzed in the eluted biomass. The sludge yield coefficient was calculated as the concentration of kg TS or VS per kg COD removed according to Eq. (1):

$$\text{Sludge yield coefficient} = \frac{\text{TS or VS}\left(\text{kg}\right)}{\text{COD}_{\text{influent}} - \text{COD}_{\text{effluent}}\left(\text{kg}\right)} \quad (1)$$

The settled excess sludge was discharged bi-weekly from the settler located at the bottom of the PABF reactor and was analyzed for TS and VS.

### *2.7. Statistical analysis*

Microsoft Excel 2013 was used for statistical analysis of the collected data. The percentage removal was calculated according to Eq. (2):

$$\%R = \left(C_i \times Q_i\right) - \frac{\left(C_e \times Q_e\right)}{C_i \times Q_i \times 100} \quad (2)$$

where $C_i$ is the influent concentration in kg/$m^3$; $C_e$ the effluent concentration in kg/$m^3$; $Q_i$ the inflow in $m^3$/d; and $Q_e$ is the outflow in $m^3$/d.

## 3. Results and discussion

### *3.1. Wastewater characteristics*

The physico-chemical characteristics of raw and primary settled wastewater indicated the stability of raw wastewater's strength. The average concentration of $COD_{tot}$ was 362 ± 26.4 mg/L, while the $COD_{sol}$ was 183 ± 18 mg/L which indicated that about 50% of the COD value existed in the soluble form. Average concentration of BOD was 172.6 ± 29 mg/L and BOD/COD ratio was 0.46 which means that the organic matters are highly biodegradable. TSS ranged from 69 to 210 mg/L, while the average TKN and ammonia concentrations were 27.9 and 17.9 mg/L. The use of IPS was very efficient as a primary treatment system. It was operated at a surface loading rate of 6.9 $m^3/m^2$/d and hydraulic retention time (HRT) of 2 h. In terms of residual COD and BOD, the IPS effluent percentage removal was 42% and 37%. The average residual concentrations of $COD_{tot}$, $COD_{sol}$ and BOD were 207 ± 23.7, 129.7 ± 15 and 107.6 ± 23 mg/L. The IPS removed about 35% of TSS and the average residual value was 100.5 ± 16.7 mg/L. The inclined surfaces in IPS increases the effective surface area available for settlement and consequently increases its efficiency.

### *3.2. Characterization of AACW*

#### *3.2.1. Surface area and porosity*

The specific surface area was measured using BET equation in its normal range of applicability. The textural properties were determined from the $N_2$ adsorption-desorption isotherms. Fig. 2 shows the adsorption isotherm in terms of volume of $N_2$ adsorbed ($cm^3$/g) versus the equilibrium relative pressure $P/P_0$, where $P$ is the equilibrium pressure and $P_0$ is the saturated vapor pressure of nitrogen. The results indicated that the specific surface area of AACW was 42.8 $m^2$/g and the average pores volume was 0.08 $cm^3$/g, while the average pore size was 7.92 nm.

#### *3.2.2. XRD, SEM and EDX analysis*

Fig. 3a illustrates the XRD patterns of AACW. Its chemical composition was determined through XRD as follows: 45% $SiO_2$, 25% CaO, 17% $Al_2O_3$, and small amounts of sodium, potassium, and magnesium as sulfur oxides. SEM examination of AACW (Fig. 3b) shows that there are some big smooth pores and other small spherical pores on the surface of AACW. These findings indicated the roughness and porosity of open AACW surface which is suitable for microorganism's

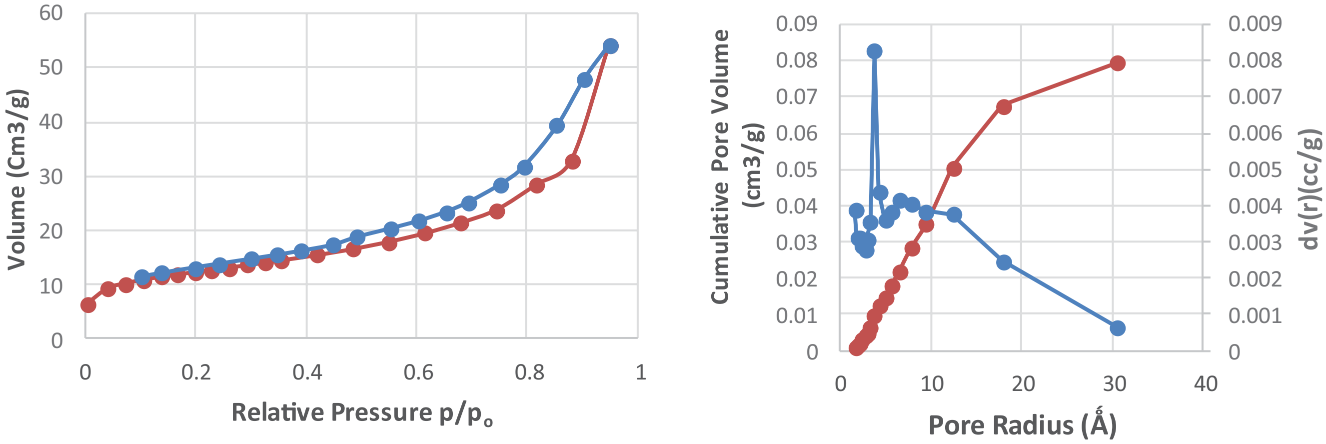


Fig. 2. Adsorption and porosity isotherms of the AACW.

propagation. Also, EDX analysis (Fig. 3c) indicated that 52.9% of AACW content is oxygen, while silica, calcium, aluminum and carbon contents are 13.6%, 25.3%, 3.3% and 4.9%, respectively.

### *3.3. Performance of PABF for pollutants removal*

#### *3.3.1. Organic matters and suspended solids removal*

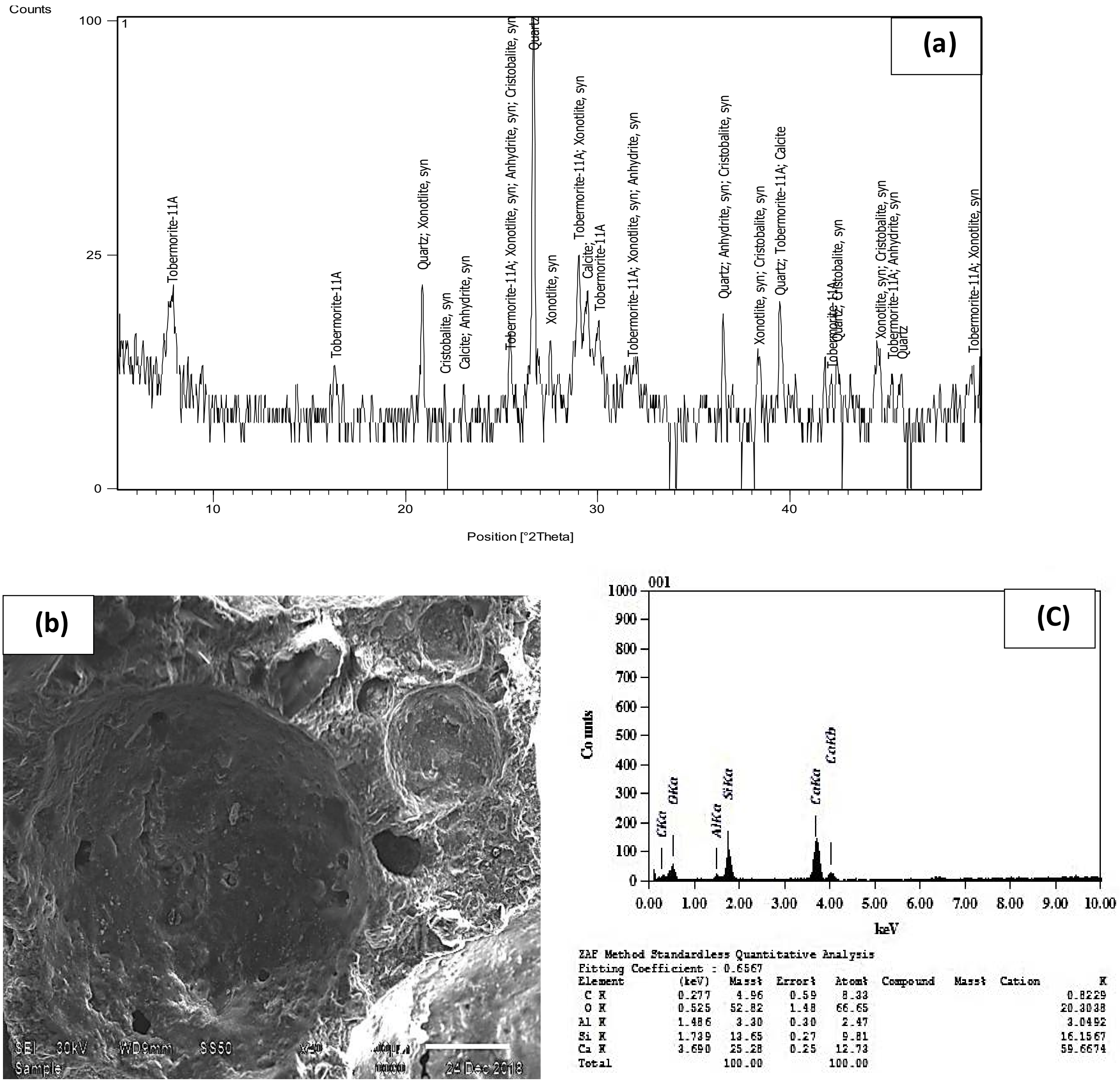
The average removal of $COD_{tot}$, $COD_{sol}$, BOD and TSS, in the PABF effluents from each compartment and the final effluent is shown in Fig. 4. Results indicated that the use of AACW in PABF reactor achieved a final effluent with an overall average percentage removal value of $COD_{tot}$, $COD_{sol}$, BOD, and TSS of 90.48%, 89.8%, 90.04% and 92%. Their corresponding residual values were 34.5, 17.6, 19.5 and 11.2 mg/L. Removal of TSS can be explained by the physical filtration and biological degradation of organic contents along the reactor. Organic matter removal in terms of COD and BOD occurred due to good passive aeration in the PABF. Hellal et al. [8] stated that PABF reactor with appropriate design can produce a very high-quality effluent through natural ventilation as the dissolved oxygen (DO) concentration increases gradually along the reactor and improves the soluble organics adsorption onto the organisms, which speeds up organic matters removal by transporting them from wastewater to the biofilm. Patel et al. [20] reported that the driving forces of bio-sorption are electrostatic or hydrophobic interactions, which are different from the metabolically driving bioaccumulation and are greatly affected by the organic matter characteristics and mass transfer efficiencies. Also, the rough surface of AACW and its internal pores structure are uniform and well distributed so that tiny suspended particles, soluble organic matter and nutrient substances can reach the shallow holes of the surface which resulted in the enhancement of bulk transfer efficiencies of these matters.

Several studies stated that natural ventilation system can afford DO concentration for aerobic process up to 7 mg/L [9,21]. Fig. 5 shows PABF profile analyses for the percentage removal of COD, BOD and TSS at different compartments. At the first compartment (SP1), the depth of AACW bio-carrier was 30 cm with a surface area of 16.8 $m^2$ and HRT 38 min. The average DO concentration was 2.5 which is not enough for creating good aerobic environment for microorganisms. The average removal efficiencies of COD, BOD and TSS were 52%, 48% and 54% with corresponding average residual values of 100.1, 56.25 and 67 mg/L. Physical filtration of some of the solids containing organic matter was the main removal mechanism at this compartment. In the second compartment (SP2), the media height was increased to 60 cm which the mean surface area intensification was 33.6 $m^2$ and the HRT increased to 1.29 h. This resulted in the improvement of microorganism's growth on the surface of AACW, accordingly causes slight improvement in the removal efficiencies of COD, BOD and TSS to 62%, 66% and 67%.

The total AACW depth in the 3rd compartment (SP3) was 90 cm with a surface area of 50.4 $m^2$, consequently increasing the HRT to 1.94 h which enabled the growth of microbial communities on the surface and pores of AACW for degradation of organic contents and capture of suspended solids which escaped from the 2nd compartment. Also, DO measurement indicated the incremental increase of oxygen concentration as it reached 4.5 mg/L. Accordingly, the percentage removal of COD, BOD, and TSS increased to 74%, 79%, and 76%. The 4th compartment (SP4) received lower residual values of COD, BOD and TSS which achieved better removal of the concerned pollutants at a total media depth of 120 cm, DO 5.4 mg/L and HRT of 2.59 h. The percentage removal of COD, BOD and TSS reached 88%, 87% and 86%. As the DO concentration increased, the population of microorganisms in the outer layer of the biofilm and suspension increased and the organic substance in the wastewater could be completely degraded [8]. Also, the AACW exhibited high organics removal due to its rough surface with a large BET surface area (42.8 $m^2/g$), which promoted biofilm growth densely on the AACW surface.

#### *3.3.2. Nitrogen life cycle assessment in PABF*

Fig. 6 shows average concentrations of TKN, $NH_4^+$–N, $NO_2^-$–N and $NO_3^-$–N in the effluents from SP1 to SP4 and the final settled effluent from PABF. Results indicated that the use of AACW as a bio-carrier resulted in 80% and 89%



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ZAF Method Standardless Quantitative Analysis
Fitting Coefficient : 0.6567
Element        (keV)   Mass%  Error%   Atom%  Compound   Mass%  Cation          K
 C K           0.277    4.96    0.59    8.33                                0.8229
 O K           0.525   52.82    1.48   66.65                               20.3038
Al K           1.486    3.30    0.30    2.47                                3.0492
Si K           1.739   13.65    0.27    9.81                               16.1567
Ca K           3.690   25.28    0.25   12.73                               59.6674
Total                 100.00          100.00
```

Fig. 3. Physical characterization of AACW (a) XRD, (b) SEM and (c) EDX.

reductions of TKN and $NH_4^+$–N with average residual values of 7.1 and 3.3 mg N/L. These results are better than those obtained by Ismail and Tawfik [22] who reported 80% reduction of $NH_4^+$–N concentration using passive aerated immobilized biomass reactor. Abou-Elela et al. [9] stated that the removal of $NH_4^+$–N in PABF reactor was due to nitrification process which includes the oxidation of ammonia into nitrite then nitrate. The data in Fig. 6 shows that $NH_4^+$–N in the PABF was gradually decreased along the reactor versus increase of $NO_3^-$ and $NO_2^-$–N concentrations.

The important key parameters that affect the $NH_4^+$–N removal through nitrification process are concentrations of DO, organic matter and biodegradability represented by VSS/TSS ratio. The DO concentration was enough to the conservation of nitrifiers and nitrification process in the compartments of the PABF system. The presence of organic matter inhibited the nitrification process, as the concentration of COD increases, large amounts of $O_2$ (as the electron acceptor) are consumed by increasing heterotrophic microorganisms, which results in the inhibition of growth-rate and biological-activity of nitrifying bacteria. It is well known that the potential of $NH_4^+$–N removal is greatly affected by the number of nitrifiers and the microorganism's activity [23]. Thus, the increase of COD/$NH_4^+$–N ratios is inevitably decreasing the $NH_4^+$–N removal efficiencies in the bio-filters. It should be noted that when COD concentration increases, heterotrophic bacteria breed rapidly and thickness of the biofilm increases, which is not beneficial for organics to enter

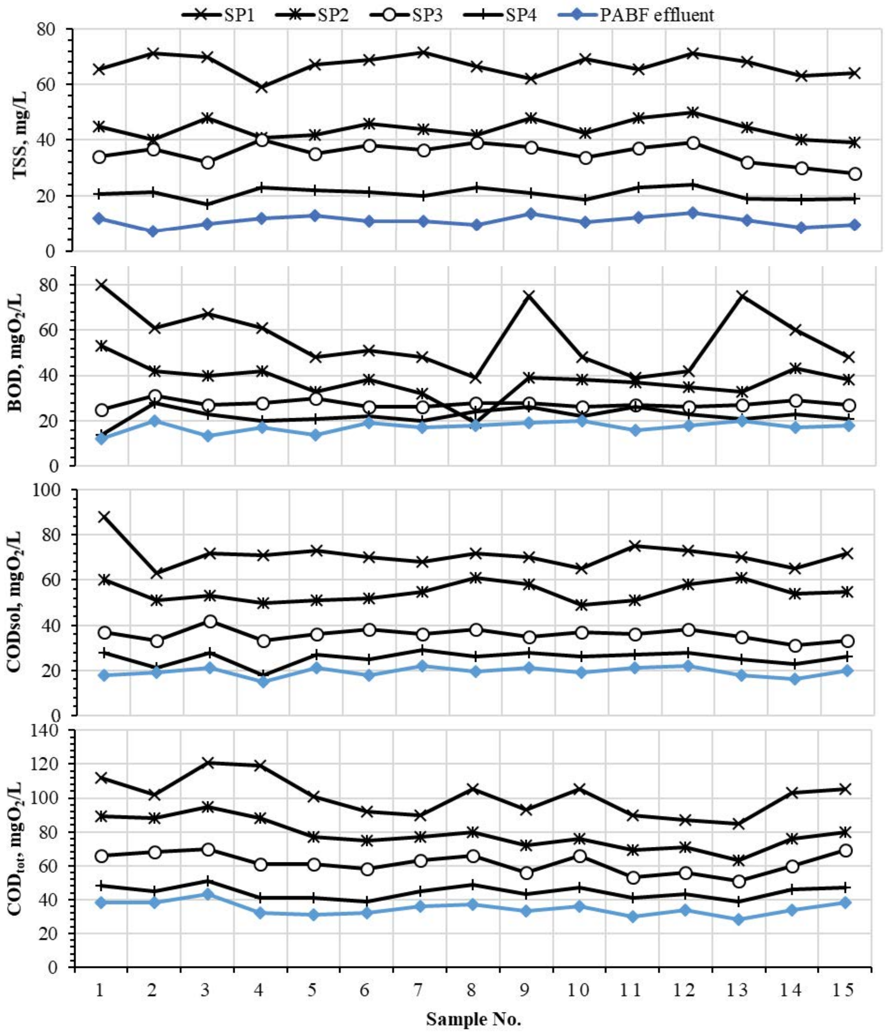

Fig. 4. Concentrations of COD, BOD and TSS in influent to PABF, effluents from each compartment and the final effluent.

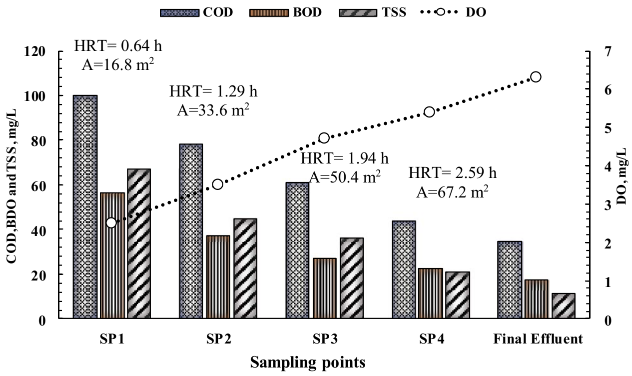

Fig. 5. Profile analyses of COD, BOD, and TSS at different media depths.

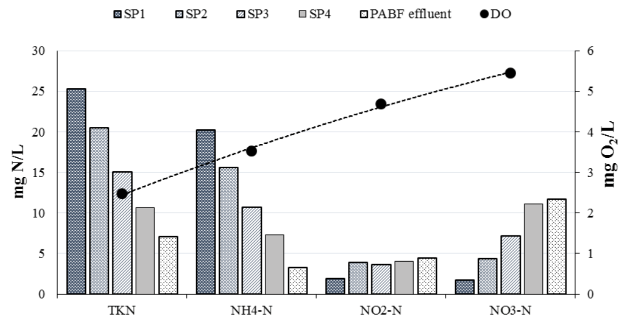

Fig. 6. Average concentrations of TKN, $NH_4^+$–N, $NO_2^-$–N and $NO_3^-$–N in effluents from SP1 to SP4 and final effluent from PABF.

the carriers. Therefore, carbon source inside the carriers is not always increased as COD/$NH_4^+$–N increased, so the number and activity of nitrifying bacteria may be decreased and then the removal efficiencies may be decreased. This phenomenon was observed in our study during the follow up of $NH_4^+$–N removal in different compartments of PABF (Fig. 7). In the first compartment, the COD/$NH_4^+$–N ratio reached the highest value (8) and the concentration of $NO_2^-$–N and $NO_3^-$–N was very low. The COD/$NH_4^+$–N ratio decreased gradually along the PABF reactor and its value reached 4 at the fourth compartment and resulted in the increase of nitrification.

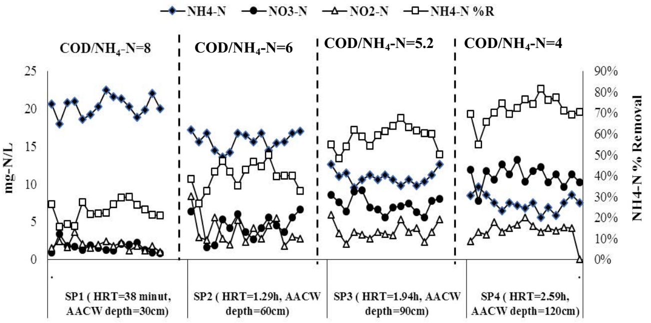

Fig. 7. Removal performance of $NH_4^+$–N at different COD/$NH_4$–N ratios.

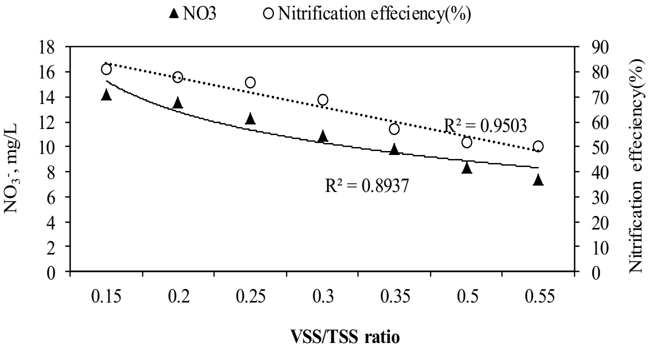

Fig. 8. Effect of VSS/TSS ratio on the nitrification efficiency.

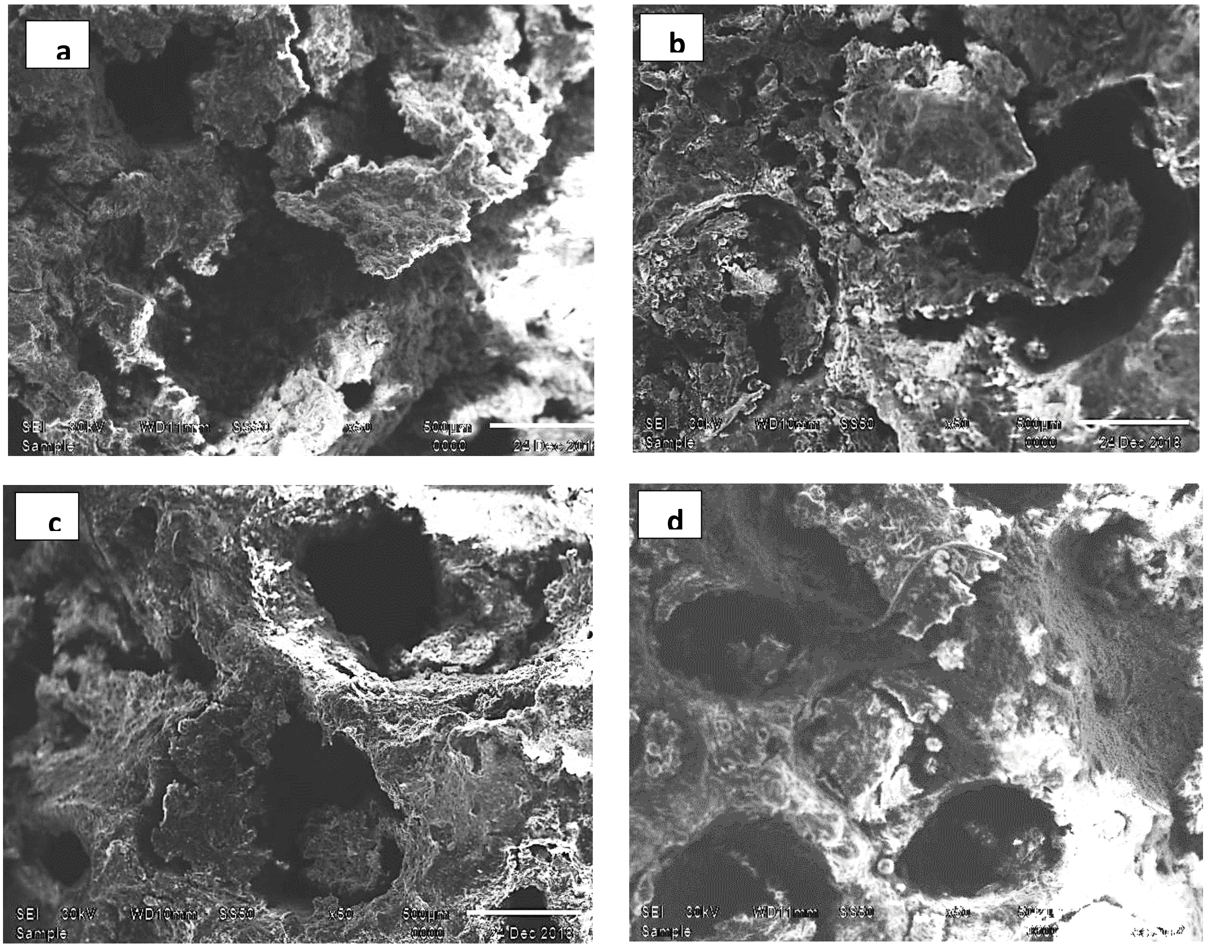

Fig. 9. SEM images of external surfaces in AACW after microbial inoculation, (a) 1st compartment, (b) 2nd compartment, (c) 3rd compartment and (d) 4th compartment.

The ratio of $NO_3^-$–N/$NO_2^-$–N was more than 3:1 indicating that nitrification was successful during the short contact time (2.59 h). Similar observation was recorded by Long et al. [24] and Ismail and Tawfik [25]. They reported that, the ammonia removal reached its maximum value when the COD/$NH_4^+$–N ratio was about 4.

The biodegradability expressed as VSS/TSS ratio was another parameter affecting nitrification in the PABF reactor (Fig. 8). The nitrification efficiency and nitrate production decreased from 81% to 49% and from 14.2 to 6.5 mg/L when the VSS/TSS ratio was increased from 0.15 to 0.6. However, higher concentration of $NO_3^-$–N is accumulated in the effluent, which means that the absence of denitrification process that cannot keep up with the nitrification rate in the PABF. By realizing this point, one of the hypothetical reasons for the denitrification restriction can be attributed to low concentrations of COD which is essential for denitrification process [26].

### *3.3.3. Efficiency of PABF for the removal of bacterial indicator of pollution*

The geometric mean of the bacterial indicator counts in terms of FC in the final effluent from PABF was 1.7 × $10^4$ MPN/100 ml. The use of AACW succeeded to remove about 2.07 log10 orders of magnitude of FC. Gradual increase in the removal of FC was achieved from compartment 1 to 4. A very small amount of FC (0.68 log10) was removed in the first compartment because of only adsorption of the microbial cells on the surface of the AACW. The average residual counts of FC in the effluent from the second and the third compartments were 1.9 × $10^5$ and 5.4 × $10^4$ MPN/100 ml, while it reached 1.4 × $10^4$ MPN/100 ml in the fourth compartment. The removal of FC significantly improved along the PABF reactor as the concentration of the COD fractions has become very low and DO has increased from 2.5 to 5.4 mg/L. Stevik et al [27] found that adsorption of microbial cells to the porous media is influenced by the content of organic matters, degree of biofilm development and electrostatic attraction due to ion strength of the solution or electrostatic charges of cell and particle surface. The PABF reactor packed with AACW achieved a final effluent with a very satisfactory removal rates for organic and inorganic pollutants but the geometric mean of the FC exceeds the limits for reuse in restricted irrigation purposes (1,000 MPN/100 ml) [28]. To ensure safe reuse for irrigation, the treated effluent should be disinfected.

### *3.3.4. Excess and retained sludge in AACW*

Characteristics of the excess sludge of the PABF reactor showed that the TS produced was 350 mL/d which means 0.087 L/$m^3$ and the average sludge volume was 120 ml/L. The average TS and VS concentrations were 1.89 and 1.12 g/L. The sludge yield coefficient from PABF reached 0.23 kg TS/kg COD removed per day. This can be attributed to the higher degree of sludge mineralization in which organic matters were converted to carbon dioxide. These results are comparable to those recorded by Tandukar et al. [5] who found that the sludge yield coefficient was 0.2 kg SS/kg COD in down flow hanging sludge system (DHS) treating anaerobically pretreated sewage. The attached biomass on the AACW at different compartments showed that the biomass concentration was gradually decreased from 1st compartment until the 4th compartment. The TS concentrations were 21.2, 18.6, 13.5 and 10.6 g/L, while VS were 13.2, 10.9, 7.8 and 6.5 g VS/L at 1st, 2nd, 3rd and 4th compartments. Hellal et al. [8] stated that in the upper portion of the PABF, the OLR was higher resulting in a higher organic removal rate and more entrapment of most of suspended solids. These results were confirmed by SEM photographs of biomass immobilization on AACW in the four compartments of PABF (Figs. 9a–d). AACW has a rough surface which is characterized by a netted texture and a porous structure that provide shelter for biofilm overlay on the surface of the AACW. In Figs. 9a and b which represents the first and second compartments, the biofilm was clearly observed on the surface of internal pores after the growth of bacterial populations and the surface of AACW seems to be almost covered. There are still few pores available for more accumulation of microorganisms. Fig. 9c which represents the third compartment, illustrated a slim layer of biofilm on the rough surface of AACW which indicated that it can accommodates more biofilm on its surface and in the internal pores. The microstructure in Fig. 9d which represents the fourth compartment shows that a small number of microorganisms were immobilized on the inner and outer surfaces of AACW.

## 4. Conclusion

- This study proved the success of utilizing autoclaved aerated concrete solid waste (AACW) as a low-cost biocarrier in PABF treating municipal wastewater.
- Physical and chemical characteristics (BET, XRD, EDX and SEM) indicated that AACW has a rough surface with a total surface area around 42.8 $m^2/g$, a low bulk and apparent density. These characteristics are propitious to develop many microbial communities and to improve the capacity of biofilm's layer for pollutant's removal.
- The bio-carrier characteristics has a noticeable effect on the COD and TN percentage removal in immobilized bio-reactor as they determine the mass transfer of wastewater constituents, the permeable capacity of biofilm and the extent of contact reactions.
- The use of AACW as a bio-carrier enhanced the performance of the PABF bio-reactor and minimize the solid wastes coming from construction and demolition.
- The effluent quality from the treatment system complies with National Regulatory Standards for either discharge into surface water and/or reuse in irrigation after disinfection.
- The extensive characterization and performance data of AACW as a bio carrier in biological filter proved to be a promising and reliable technology for municipal wastewater treatment where water and energy are scarce. It will offer a large opportunity in future for the utilization of AACW solid waste as a bio-carrier in biological reactors.

## Acknowledgement

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