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# Advanced wastewater treatment with autoclaved aerated concrete particles in biological aerated filters

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## ABSTRACT

Autoclaved aerated concrete particles (AACP) were tested as biofilter carriers in biological aerated filters (BAF) to solve the disposal problems of construction wastes. AACP were characterized using X-ray diffraction, X-ray fluorescence, scanning electron microscopy, and porosimetry analysis. Results showed that the main crystalline phases of $SiO_2$, $Ca_5Si_6O_{18}H_2$, CaO, and $Al_2O_3$ were the major oxides and hydrous silicates in AACP. In addition, AACP had a high total porosity of 89.21% and a high specific surface area of 81 $m^2/g$. Different from commercially available ceramsite (CAC), AACP had an open macroporous structure that was suitable for immobilizing microorganisms. AACP and CAC were loaded into two identical BAFs to compare the efficiency of their microbial treatment of wastewater. AACP BAF was more efficient than CAC BAF in terms of TOC, $NH_3$-N, TN, and $PO_4^{3-}$ removal. Therefore, AACP, as a novel product of recycling construction waste, provide a promising way to utilize construction waste.

## 1. Introduction

As a backbone of economy, constructional work has rapidly developed in many countries, but the corresponding construction waste materials has also quickly increased. In China, statistics show that construction waste materials such as waste concrete block, waste crushed stone, waste mortar, and waste autoclaved aerated concrete claim 30–40% of the whole city garbage in the last few years. Furthermore, these waste materials greatly contribute to city pollution [1,2].

Autoclaved aerated concrete particles (AACP) are good energy-saving construction materials that possess light weight and high compressive strength. AACP minimize the deadweight of a building. Given their properties, building blocks of AACP are usually used as a frame structure of support walls and are seldom utilized as bearing walls. The treatment of waste AACP currently remains in traditional simple backfill and pile-up stage, which have partly realized the utilization of construction waste materials but failed to realize the effective and rational utilization of resources [2,3]. Therefore, finding a sustainable way to balance the environment and economy is challenging. Phosphate has been removed from wastewater through several techniques, including chemical, biological, and adsorption; among these techniques, the latter is the most useful and economical. Phosphate adsorption through fly ash has been extensively researched in the past years because AACP are enriched with aluminum, iron, and calcium oxides that can strongly adsorb or precipitate phosphates [4–6].

Recent studies have focused on the roles of phosphorous and nitrogen in eutrophying surface waters. Significant sources of phosphorous and nitrogen that enter freshwaters include drainage from agricultural land and diffuse urban drainage [7,8]. Five Chinese lakes, namely, Tai Lake, Chao Lake, Dianchi Lake, Poyang Lake, and Dongting Lake, have been severely contaminated and subjected to diverse eutrophication conditions in recent years. Several fish and aquatics are fast disappearing because of severe pollution [9].

Biological aerated filter (BAF) is a flexible, and effective bioreactor that provides a small footprint process option at various stages of advanced wastewater treatment. BAFs usually treat settled sewages by removing chemical oxygen demand (COD) and ammonia ($NH_3$-N). BAFs are fixed-film reactors that use biofilter

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carriers with a high specific surface area and high total porosity for wastewater treatment [10]. In recently years, many researchers have been focusing on $NH_3$-N, TNT, $Mn^{2+}$contained wastewater treatment by using the BAF. Hasan et al. showed an effective method of the simultaneous removal of $NH_3$-N and $Mn^{2+}$, using a BAF [11]. Wu et al. reported the development and application of a catalytic-ceramic-filler in the catalytic micro-electrolysis coupled with BAF for TNT manufacturing wastewater treatment [12]. Feng et al. reported that red mud particle electrodes were prepared using waste material and used in a BAF coupled with a three dimensional particle electrode reactor for use in municipal wastewater treatment with regard to the removal of organic matter and ammonia nitrogen [13]. These materials achieved good results for $NH_3$-N, TNT, $Mn^{2+}$ removal, but only few focus on phosphorus removal. There is a need to investigate the simultaneous removal of nitrogen and phosphorus (SNP). Waste materials such as ceramsite and polyethylene plastic have been successfully utilized as filter media for BAF. This finding suggests a new approach for waste AACP disposal that involves treating wastes with wastes. Commercially available ceramsite (CAC) are widely used as building materials and filter media of wastewater treatment plants in China. However, the principal raw material used for CAC production is farmland clay. This raw material is a valuable agricultural resource, and its loss may threaten the sustainable development of agriculture in the long run [4,9]. Therefore, finding an appropriate substitute for clay is highly significant. Given their similar mineral contents to clay, AACP were selected to replace a part of CAC in the present study. AACP have a lower density and higher total porosity than CAC, indicating that the formation of interior porosity improves microbial growth in AACP. Furthermore, in recent years AACP have received considerable attention as a potential adsorption material for phosphate removal because of their high availability and cost effectiveness [5]. Therefore, AACP can be considered a suitable novel material for the SNP in BAF.

## 2. Materials and method

### 2.1. AACP preparation

As shown in Fig. S1(A) and S1(B), CAC and AACP samples were obtained from Ma an Shan and He Fei in An Hui, China, respectively. AAC was manufactured by steam curing raw materials consisting of fly ash (70 wt%), cement (13.8 wt%), lime (13.8 wt%), and gypsum (2.30 wt%) as binders; pore-generating aluminum powder (0.10 wt%); and water. The chemical reaction caused by adding aluminum expanded the mixture to about twice its volume and produced a highly porous structure. Approximately 80% of the volume of the hardened material is composed of pores, among which 50% and 30% are air pores and micropores, respectively, which participate in capillary moisture transport. The microstructure of the solid matrix mainly comprises microcrystalline platelets of $Ca_5Si_6O_{18}H_2$ that form the pore walls [14,15].

### 2.2. Physical characterization of AACP and CAC

The chemical compositions of AACP and CAC were measured using Shimadzu XRF-1800 with Rh radiation. X-ray diffraction (XRD) was performed using a Rigaku powder diffractometer with Cu K$\alpha$ radiation [9]. Biological structure analysis showed that the selected AACP and CAC were gilt with pores. Surface morphology was examined using an environmental scanning electron microscope (Philips XL30 ESEM). The physical characteristics of AACP were measured in accordance with the sandstone pore structure method of image analysis [16,17]. The development of protozoan and metazoan populations was microscopically observed using a U-RFL-T Olympus biological microscope (Japan). Protozoan and metazoan populations were characterized as described by Zou and Xu [18].

**Table 1**
Regulatory levels of ceramsite in AACP and CAC.

| Item | CAC | AACP |
|---|---|---|
| Grain diameter, d/mm | 4–6 | 5–9 |
| Silt carrying capacity, $C_s$/% | $\leq 1$ | 3.34 |
| Void fraction, $\upsilon$/% | $\geq 42$ | 69.10 |
| Specific surface area, $S_w/cm^2/g$ | $\geq 2 \times 10^4$ | $8.1 \times 10^5$ |
| Piled density, $\rho_p/g/cm^3$ | $\leq 1.0$ | 0.53 |
| Apparent density, $\rho_{ap}/g/cm^3$ | 1.4–1.8 | 1.71 |
| Compression strength,/N | $\geq 87$ | 35–43 |
| Porosity, P/% | – | 89.21% |

### 2.3. BAF setup and wastewater quality analysis

Two lab-scale biofilter columns were constructed from polyvinylchloride pipes 6 cm in diameter with a depth capable of holding 150 cm of biofilter carrier. The set-ups are shown in Fig. S2. Two BAFs were present, one of which was packed with AACP and the other with CAC. The two BAFs were monitored for 4 months after the initiation of biofiltration. The test was divided into four stages. During each test stage, the operating conditions of the two BAFs were identical (Table 2). The air–water ratio (A/W) was 3:1 (DO > 4.00 mg/L), whereas the hydraulic retention time (HRT) ranged from 0.5 h to 7 h. City wastewater samples were collected from the inlet and outlet pipes of the two BAFs. Chinese EPA standard methods were used for chemical determinations [19]. The total organic carbon (TOC) and total nitrogen (TN) were measured using a TOC/TN (Jena Multi N/C 2100) analyzer, and ammonia nitrogen ($NH_3$-N) and phosphorous ($PO_4{}^{3-}$) were analyzed via colorimetry [19].

## 3. Results and discussion

### 3.1. Evaluation of AACP and CAC characteristics

As BAFs are applied, the selection of filter media plays an important role in maintaining a high amount of active biomass and a variety of microbial populations. Filter media are required to obtain a high specific surface area and high total porosity in wastewater treatment; filter media can also be used at various stages of wastewater treatment [9,13]. As shown in Fig. S1 and Table. 1, both filter media (CAC and AACP) had a mean diameter of 4–9 mm. The characteristics of CAC and AACP are shown in Table 1. AACP showed higher porosity, larger total surface area, lower bulk, and apparent density than CAC, indicating that AACP are a suitable filter medium for support media [20].

### 3.2. X-ray diffraction (XRD) and X-ray fluorescence (XRF)

Fig. 1 and Table. 3 illustrate the XRD and XRF patterns of AACP and CAC, respectively. The main mineral components were $SiO_2$, $Ca_5Si_6O_{18}H_2$, $Al_2O_3$, and CaO in AACP. Fig. 1(II) shows the XRD patterns of CAC. The strong reflections of CAC at $2\theta = 26^\circ$ were identified as quartz when compared with the standard (JCPDS 89-6538). The main mineral components were hematite and quartz in CAC (Table 3). The chemical composition of AACP determined through XRF was as follows: 44.88 wt% $SiO_2$, 24.98 wt% CaO, 16.06 wt% $Al_2O_3$, 4.16 wt% $Fe_2O_3$, and small amounts of $K_2O$, $SiO_3$, $TiO_2$, MgO, $Na_2O$, and $Cr_2O_3$. CAC consisted of 60.24 wt% $SiO_2$, 17.94 wt% $Al_2O_3$, and 13.16 wt% $Fe_2O_3$. In addition to transitional metals ($Cr_2O_3$ and MnO), small amounts of co-existing alkali and alkaline-earth metal oxides, including CaO, MgO, $K_2O$, and $Na_2O$ (4.5 wt% in total), were