Treatment of Simulated Acid Mine Drainage with Fly Ash-Doped Porous Concrete

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***Abstract*—The aim of this paper was to demonstrate the technical feasibility of AMD treatment using fly ash-doped porous concrete (FAPC). The FAPC were prepared through adding the fly ash into the ordinary porous concretes (PC), and the acid mine drainage (AMD) was treated by FAPC in this paper. The results show that: At influent pH of 2.9-3.4 and 24 h hydraulic retention time, the acidity of AMD was improved significant by FAPC, and which the pH of effluent was maintained at 8-9. The average removal rate of turbidity, COD and TP of AMD were 69.7%, 75.4% and 91.9%, respectively. Compared to none fly ash-doped porous concrete that the FAPC improved the AMD purification effect, for turbidity, COD and TP the average removal rate were increased of 13.6%, 10.0% and 1.9%, respectively. The experimental results also show that, the porosity of all FAPC was decreased after the AMD treated, but all in less than 10% and which does not affect the use of FAPC in AMD treatment. In view of the purification effect of FAPC, it provides a new way of AMD treatment and resources.**

***Index Terms*—porous concrete, fly ash, acid mine drainage, pH.**

I. INTRODUCTION

Acid mine drainage (AMD) is produced from the oxidation of sulfide minerals as a result of exposure to both oxygen and water during the mining and processing of metal sulfides and coal [1][2][3]. High content of toxic metals (manganese, copper, lead, aluminum, Calcium, etc.) and high acidity is the main features of AMD, which adversely affects surface water, groundwater and soil. Others environmental impacts of AMD are the reduction of species diversity and total biomass in contaminated water bodies in addition to limiting the possible uses of these resources. AMD can persist for hundreds of years after the end of mining operations, posing significant environmental liabilities [3][4][5][6]. Therefore, AMD release into the environment is a chief concern both for the mine industry and environmental agencies [7], the quality of AMD needs to be monitored and suitable treatment methods need to be developed.

Because AMD has different chemistries, There are many types use various physical, chemical and biological methods to treat the AMD [5]. Since metal solubility is reduced as pH increases, Most metal elements of AMD can be removed by just increasing drainage pH, which is achieved usually by lime addition. So the current most widely used method for the treatment of AMD is based on chemical neutralization by the addition of lime (CaO) and hydrated lime ($Ca(OH)_2$), which increase the pH and precipitate metals as hydroxides and sulfates [8][9]. Another effect treatment for AMD is sulfate-reducing bacteria (SRB), which based on processes conducted by microorganisms [2]. These methods, however, is expensive and generates wastes that must be discharged and landfilled[3][10][11][12]. Finding an economically feasible alternatives for AMD treatment is becoming more and more important.

One solution for the task comes from environment-friendly concrete, so-called porous concrete (PC), which can reduce the environmental load and contribute to the harmonious coexistence of humankind and nature [13]. PC was developed as an environmentally friendly material in Japan in the 1980s [14][15]. Compare to conventional concrete, PC has a large volume of air voids. Due to the water-permeating, water-draining, and water retaining performances of the PC, it has been utilized in road pavements, sidewalks, parks, and infiltration beds for water purification [16][17]. Fly ash-doped porous concrete (FAPC) is prepared based on conventional PC, which by adding certain proportion of fly ash into PC prepare material, and hope to improve the wastewater treatment effect. Fly ash is a waste material generated from electric power plants [18]. Approximately 500 million tons of fly ash is discharged per year throughout the world [19]. This material has pozzolanic properties and therefore is valuable and desirable raw material [20]. For example, due to the highly alkaline nature and Adsorption capacity of fly ash, it can be used during the adsorption of heavy metal cations(Cd, Cu and As) [21][22][23], as well as phosphorus [24].

The main objective of this paper was to investigate the neturalization and contaminants removal effect of AMD synthetic solution by FAPC. Laboratory experiments were conducted to evaluate treatment efficacy by monitoring pH, Total phosphorus (TP), Chemical oxygen demand (COD) and Turbidity. And the FAPC porosity prior to and after the experiment was measured for the FAPC performance evaluation.

II. MATERIALS AND METHODS

A. Fly ash-doped porous concre preparation

The raw materials of FAPC include cement (P.O42.5, density of 2.8g/cm^3), gravel (particle size of 5-15mm, density of 1.57g/cm^3), fly ash ($SiO_2$51.94%, $Fe_2O_3$13.10%, $Al_2O_3$24.06%, CaO3.74%, MgO0.93%, $TiO_2$0.96%, $SO_3$3.00%, K_2O1.52%, Na_2O0.32%, $P_2O_5$0.09%) and tap water. The materials were admixture with certain proportion used to fabricate each FAPC columu (Φ10cm×10 cm). The compressive strength and porosity of these concretes (age 25d) were 2.54-3.87Mpa and 21.8-30.1%. The FAPC raw mixture ratio shown in Table I.

TABLE I. MIX RATIO FOR FAPC

FAPC Number	W/C	Cement /g	Fly ash /g	Gravel /g	Water /g
1	0.45	100.0	0.0	855.0	45.0
2	0.45	100.0	20.0	835.0	45.0
3	0.45	100.0	40.0	815.0	45.0
4	0.45	100.0	60.0	795.0	45.0
5	0.45	100.0	80.0	775.0	45.0

a. W/C, Water-cement ration.

B. Acid mine drainage

Based on the concentration of contaminants in the real AMD sample, a AMD synthetic solution with similar properties was prepared. The corresponding salts ($FeSO_4.7H_2O$, $ZnCl_2$, $CaCl_2$, NH_4Cl, $MgSO_4.7H_2O$, Soluble starch, $K_2HPO_4.3H_2O$, NaH_2PO_4) were weighed and dissolved in deionized water. The synthetic solution with pH, NH_4^+, Turbidity, COD and TP of 2.9-3.4, 51.5-69.7mg/L, 652.6-699.3mg/L and 20.5-22.7mg/L, respectively.

C. Experimental procedures

The laboratory scale experimental was carried out in 5 plastic cylindrical reactors, each have a 4.5L capacity (high 25cm and inner diameter 15cm), at room temperature (Fig. 1). Two FAPC overlap into the bucket central, and the blank fill up with the white plastic foam. The AMD synthetic solution was inlet from the bottom and outlet from the top of the bucket using peristaltic pump (BT100-2J, China) with 24 hours hydraulic retention time. The pH, TP, COD and Turbidity of the inlet and outlet of he AMD was analyzed to evaluate treatment efficiency, and Test the FAPC porosity prior to and after the experiment to evaluate the system clogging.

D. Analytical procedures

The COD, TP and Turbidity analyses were performed following the methods described by the Monitoring and analysis methods of Water and Wastewater (China's Ministry of Environmental Protection, Fourth Edition 2002). pH was measured using a pH-meter (Model, PHSJ-3F, Shanghai, China). The compressive strength was mesured by Computer hydraulic universal testing machine (Model, CHT4106, Ningbo, China).

The porosity was determined by testing the volume of water displaced by samples (FAPC) [15]. An porosity percentage of FAPC then expressed as a percentage as Eq. 1.

$$P_e = (V_b - V_d)/V_b \times 100\% \quad (1)$$

Where P_e is the FAPC porosity, V_d is the volume of water repelled by the sample, V_b is sample bulk volume. The analysis was made in triplicates.

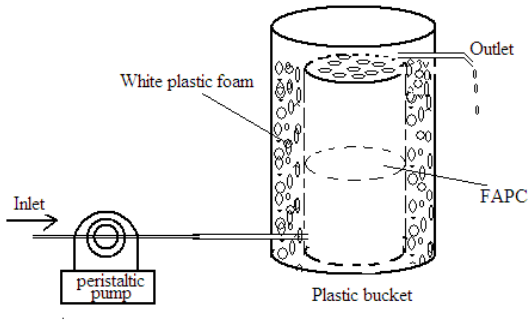

Fig. 1. Schematic diagram of experimental device

III. RESULTS AND DISCUSSIONS

A. The neutralization effect of FAPC

Increase the pH and reduce its corrosive is the primary problem of the AMD treatment, and the current most widely used and reliable method is using alkaline addition, like lime (CaO) or hydrated lime ($Ca(OH)_2$) [8][9]. This method, however, is expensive and generates wastes that must be discharged and landfilled [3]. In this paper, After the treatment of FAPC the AMD pH changes was expected as shown in Fig. 2.

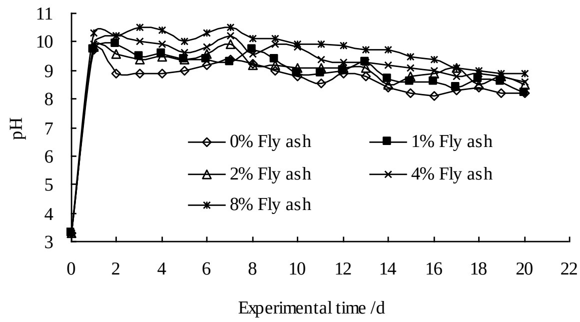

Fig. 2. pH changes after FAPC treatment

Figure 2 shows that the pH of each treatment was increased to of 9.7-10.3, an average of 9.9, indicated that FAPC could generate a large amount of the alkaline substance and has a good effect on AMD neutralization. The cement is one of the raw materials of FAPC ,and CaO is the main composition of Cement (contains approximately of 65% CaO), and then when the FAPC immersion into water that $Ca(OH)_2$ was generated [25]. During the experiment the effluent pH showed a slightly decreased trend, but overall performance was relatively stable, that is maintained at between of 8.0-9.0, and it compliance with Emission Standard for Pollutants from Coal industry (GB 20426-2006).

The alkaline nature of fly ash makes it a good neutralising agent [19], A natural pH (10–10.50) imposed by fly ash was discovered by M. Ahmaruzzaman. So, with the increase of fly ash, Fig. 2 also shows that the effluent pH of each treatment has a corresponding increase.

B. Turbidity removal effect of FAPC

The Turibidity removal from AMD by FAPC is shown in Fig. 3. It was shows that the average removal efficiency of Turibidity was of a 69.7%, and the effluent turbidity reached between 6.7-10.2 NTU. Fly ash has strong adsorption capacity in which played a positive role. When the fly ash doped dosage less than 4%, turbidity removal efficiency increased with the increasing of fly ash. When the fly ash doped dosage were 4% and 8%, both turbidity removal efficiency were not obivous different, which may relate to the Etching phenomenon during the fly ash water immersion, and this resulting in increased effluent turbidity.

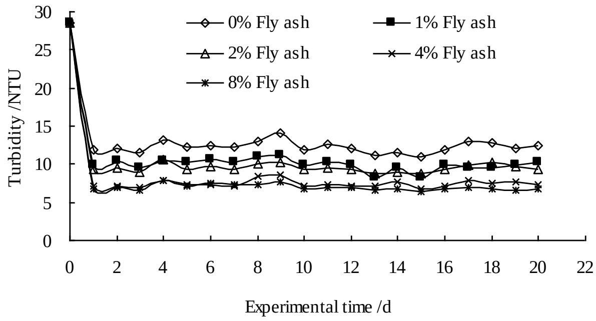

Fig. 3. Turbidity changes after FAPC treatment

C. COD removal effect of FAPC

In fact, the ordinary porous concrete has a high COD removal rate that the aveage of 50%-70%, while the fly ash can effectively reduce the COD content too. Therefore, the PC in incorporation with fly ash is expected to enchance the COD removal efficiency.

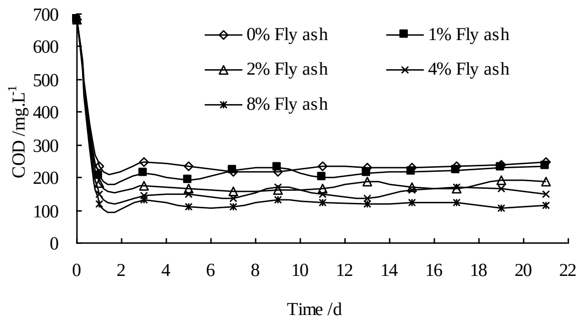

Fig. 4. COD changes after FAPC treatment

In this test, the COD average content of AMD was 676.0mg/L and dropped to 166.1mg/L after treated by FAPC, the average removal reached to 75.4%. For PC, the COD removal efficiency was of 65.4% with the effluent COD was of 233.6mg/L. So the fly ash addition can significantly improved the COD removal rate. The experimental results also showed that the fly ash doped dosage has a great impact on COD removal (Fig. 4), when the fly ash doped dosage were 1%, 2%, 4% and 8%, the COD removal were 67.9%, 74.2%, 77.3% and 82.3%, respectively.

D. TP removal effect of FAPC

The TP removal from AMD by FAPC is shown in Fig. 5. The inlet TP was of 21.6mg/L and effluent TP was dropped to 1.2 mg/L-2.5mg/L, the average removal reached to 91.9%. From the Fig. 5 we can see that the TP removal rate was gradually increased with the increasing of fly ash dosage, which increased from 88.4% to 94.5%. In addition to adsorption, the dissolved precipitated $Ca(OH)_2$ to react with the phosphate ions to generate precipitate of magnesium hydrogen phosphate, both are the reasons of TP removal by FAPC.

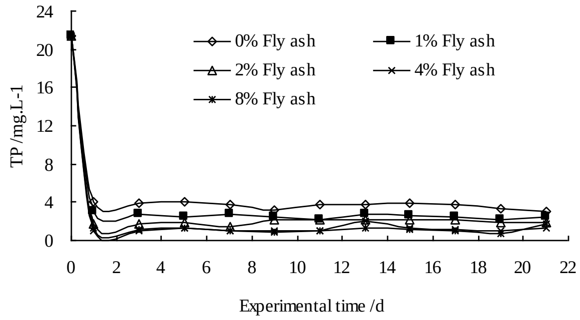

Fig. 5. TP changes after FAPC treatment

E. The porosity changes of FAPC

How to prevent and mitigate the clogging during the sewage purification process has been an important issue in the development and application of porous concrete. In this paper the porosity changes of FAPC was shown in Tab. Ⅱ. The Tab. Ⅱ showed that all FAPC porosity reduced after the acidic water treatment, and the porosity decreased with the increasing of fly ash dosage. The porosity of no fly ash doped porous concrete reduced most, up to of 9.6%. The FAPC with 8% fly ash dosage porosity reduced least, was of 4%. According to the analysis it concluded that it related to FAPC sorption enhancement and neutralization weaken after the fly ash doped. And it also related to the FAPC porosity prior to acidic water treatment, the more bigger porosity the more difficult to clog. Due to the short time of the test, about the FAPC porosity changing and its clogging mechanism remains to be further research and exploration.

TABLE II. THE POROSITY CHANGES OF FAPC

Items	*FAPC Number*				
	1	**2**	**3**	**4**	**5**
Prior to treatment (%)	21.8	19.3	23.4	26.8	30.1
After treatment (%)	19.7	17.6	21.5	24.7	28.9
Porosity changes (%)	9.6	8.8	8.1	7.8	4.0

IV. CONCLUSIONS

The fly ash-doped porous concrete was prepared and its applied to treatment of AMD, the results showed as following:

1) At influent pH of 2.9-3.4 and 24 h hydraulic retention time, the acidity of AMD was improved significant by FAPC, and which the pH of effluent was maintained at 8-9.

2) The average removal rate of turbidity, COD and TP of AMD were 69.7%, 75.4% and 91.9%, respectively.

3) The porosity of all FAPC was decreased after the AMD treated, but all in less than 10% and which does not affect the use of FAPC in AMD treatment.

4) In view of the purification effect of FAPC, it provides a new way of AMD treatment and resources.

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