

Study of The Maximum Uptake Capacity on Various Sizes of Electric Arc Furnace Slag in Phosphorus Aqueous Solutions

W M W Afnizan¹, R Hamdan² and N Othman³

^{1,3} Faculty of Civil and Environmental Engineering Universiti Tun Hussein Onn Malaysia (UTHM), 86400 Parit Raja, Batu Pahat, Johor, Malaysia.

² Department of Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM), 86400 Parit Raja, Batu Pahat, Johor.

E-mail: afnizan@uthm.edu.my

Abstract. The high content of uncontrolled phosphorus concentration in wastewater has emerged as a major problem recently. The excessive amount of phosphorus that is originated from domestic waste, improper treated waste from septic tanks, as well as agricultural activities have led to the eutrophication problem. Therefore, a laboratory experiment was initiated to evaluate the potential of the Electric Arc Furnace Slag (EAFS), a by-product waste from steel making industry in removing phosphorus concentrations in aqueous solutions. In this work several particle sizes ranging from (9.5-12.4 mm, 12.5-15.9 mm, 16.0-19.9 mm, 20.0-24.9 mm, 25-37.4 mm) with a known weight (20 ± 0.28 g, 40 ± 0.27 g, 60 ± 0.30 g, 80 ± 0.29 g and 100 ± 0.38 g) were used to study the effect of different particle sizes towards phosphorus removal. Each particle size of EAFS was shaken in synthetic phosphorus solutions (10 mg/l, 20 mg/l, 30 mg/l, 40 mg/l and 50 mg/l) at a contact time of 2 hours. Final concentrations of phosphorus were sampled and the measurement was made using WESTCO Discrete Analyzer equipment. Results showed that the highest of the maximum uptake capacity of each EAFS particle size distribution achieved at 0.287, 0.313, 0.266, 0.241 and 0.25 mg/g as particle size range was varied from 9.5-12.4 mm to 25-37.4 mm. In conclusion, the maximum uptake capacity of each EAFS mostly was determined to occur at adsorbent weight of 20 to 40 g in most conditions.

Keywords: Steel slag, phosphorus concentration, particle size.

1. Introduction

The excessive of phosphorus in the aquatic environment create a serious hazard to the environment and negative health effects. According to Camargo et al. [1] phosphorus pollution in aquatic environments can be attributed to three major sources: industry, agriculture and wastewater treatment works. Wastewater from industrial, commercial, municipal, and individual households and runoff from residential, agricultural, and municipal are contributors to the phosphorous loading issue. Besides that, phosphates used in food processing, detergents and agriculture have resulted in the depletion of the essential plant nutrient. The presence of phosphorus in industrial wastes and its persistence in wastewater treatment plant effluents have led to the increase concentrations into water bodies and eventually has resulted a widespread concern over its environmental impact.

Recently several materials have been investigated due to their potential use as a filter media in a wastewater for phosphorus removal treatment system which include piles of natural, industrial by-products and man-made materials. The use of industrial by-products for phosphorus removal was



started in Japan in late 1980s [2]. Among the industrial by-product material tested, steel slag appeared as an excellent adsorbent for phosphorus removal study. The most thoroughly investigated steel slag for their potential use in removing phosphorus were blast furnace slag (BFS) [1,2,3,4], electric arc steel furnace slag and melter slag [5,6,7]. Amongst the investigated slag, BFS has undergone the most numerous study for its phosphorus adsorption properties, with the result demonstrate that almost 60 % removal achieved in the field in case of both filter boxes and Constructed Wetland System (CWS). Therefore, a motivation arises for the author to further studies on the Electric Arc Furnace Slag (EAFS) particularly on the effect of various sizes towards the maximum uptake capacity of the adsorbent..

2. Materials and methods

2.1 Media preparation

The collected Electric Arc Furnace Slag (EAFS) media from Perwaja Steel Sdn. Bhd., located in Telok Kelong Industrial Area, Kemaman, Terengganu, Malaysia were sieved using test sieve shaker Endecotts Lombard Rd. London, model Sw193BR, England with British Standard sieve BS410/1986 into a uniform size of 9.5-12.4 mm, 12.5-15.9 mm, 16.0-19.9 mm, 20.0-24.9 mm, 25-37.4 mm for a period of 15 minutes. The retained EAFS media on each sieve were collected and washed with tap water twice followed by distilled water once. This process was done in order to remove any dirt or particulate that adheres to the media before being used for batch study. The washed media were oven dried at 105 °C for 24 hours and kept in a heavy duty air-tight plastic bag.

2.2 Synthetic phosphorus solutions

Phosphorus concentration in synthetic solutions was measured in the dissolved reactive inorganic phosphorus (orthophosphate) form. This species is one of the major biologically-available nutrient that is responsible in contributing and accelerating eutrophication process [8].

Synthetic stock phosphorus solution was prepared by dissolving 0.4394 g of potassium phosphate monobasic, KH_2PO_4 which was oven dried previously inside the electrical oven at 105 °C for 1 hour and cooled down inside dessicator. The above amount KH_2PO_4 was then dissolved in 900 mL of reagent water and diluted to 1 L and this procedure gave phosphorus stock solution of 100 mg/L. The preparation of other diluted solutions were using ultrapure laboratory water. The desired synthetic phosphorus concentrations of 10, 20, 30, 40 and 50 mg P/L were prepared through the following relationship (Equation1)

$$C_1V_1 = C_2V_2 \quad (1)$$

which;

C1 is the phosphorus concentration of stock solution (mg/L) before dilution,

C2 is the desired phosphorus concentration (mg/L) to be prepared after dilution,

V1 is the stock solution volume taken from the volumetric flask (mL) before dilution, and

V2 is the filled volume of ultrapure laboratory water (UPW) (mL)

to the mark of the diluted volumetric flask after a known volume V_1 was added into it. For example, 10 mg P/L of the desired concentration can be prepared inside 1 L of the diluted volumetric flask by taking 10 mL of stock solution from 1 L volumetric flask (before dilution) and placed it inside 1 L of another empty volumetric flask and diluted with UPW until reached the mark. The same procedures were implemented to prepare the other desired solutions used for the synthetic wastewater.

Moreover the maximum uptake capacity of EAFS was calculated using Equation 2.

$$q_e = \frac{C_o - C_e}{W} x V \quad (2)$$

which;

q_e is the uptake capacity of P adsorbed by EAFS (mg P/g),

C_o is the initial concentration of phosphorus (mg/l),

C_e is the final concentration of phosphorus (mg/l),

W is the weight of EAFS (g) and

V is the solution volume (l).

Meanwhile removal of phosphorus concentration was observed using EAFS at particle size range from 9.5 – 37.4 mm and the result was expressed in percentage of removal based on Equation 3.

$$RP = \frac{C_o - C_e}{C_o} \times 100 \quad (3)$$

which;

RP is the removal percentage of phosphorus taken up by EAFS adsorbent.

2.3 Study condition design

All experiment conditions that were set during the study is summarized in Table-1.

Table 1. Study conditions on the maximum uptake capacity of EAFS adsorbent.

Parameter	Value
Particle size (mm)	9.5-12.4, 12.5-15.9, 16.0-19.9, 20.0-24.9, 25-37.4
Initial concentration (mg P/L)	10, 20, 30, 40, 50
Contact time (hours)	2
Adsorbent dosage (g)	20, 40, 60, 80, 100
pH	Original (4 – 6)
Temperature (°C)	Room (22 – 27)
Solution volume (ml)	200
Shaking speed (rpm)	150

According to Table-1, laboratory experimental work was conducted using five different particle size distributions with the aim to determine the maximum uptake capacity of EAFS for each size that could offer towards phosphorus removal study.

Meanwhile, initial phosphorus concentration was selected between 10 - 50 mg/L based on the typical residential untreated wastewater for total phosphorus concentration (5 - 20 mg/L). The maximum value of phosphorus concentration for this study was set up to 50 mg/L to make sure that when equilibrium state is achieved there should be solute concentration is remaining in solution after the adsorption takes place. If this is not happened the adsorption maximum uptake capacity could not be established because the sites on matrix surfaces is still not saturated with the attach adsorbate and consequently the equilibrium state is not attained. Such condition will occur when running the experiment at low concentration with more adsorbent dosage added to the solution.

Furthermore, the required volume of phosphorus solution for this study was determined at 200 mL (using 500 mL conical flask) since the largest particle size range (25.0 - 37.4 mm) in average diameter of both adsorbents will be completely submerged at this volume when it is added to the solution. This is very crucial because during shaking process, the whole surface of adsorbent should be covered by the solution so that the phosphate ions can attach to it and hence achieve the actual of the maximum uptake capacity state.

3.0 Result and Discussion

Maximum uptake capacity of EAFS and removal efficiency of phosphorus concentration Figure-1 to Figure-6 show the relationship of different EAFS weight on the maximum P uptake capacity (q_e) and P removal percentage (RP) efficiency. In general, it was observed that as the weight of EAFS adsorbent increases, the maximum P uptake capacity decreases. Similar trend was shown for all initial concentrations (10 – 50 mg/l) and all EAFS particle sizes (9.5 – 12.4 mm to 25.0 – 37.4 mm) – Figure-1, Figure-3, and Figure-5. According to Figure-1, as EAFS adsorbents were shaken in 2 hours contact time, the highest q_e were recorded at 0.016 to 0.287 mg/g when initial concentrations were adjusted from 20 – 50 mg/l.

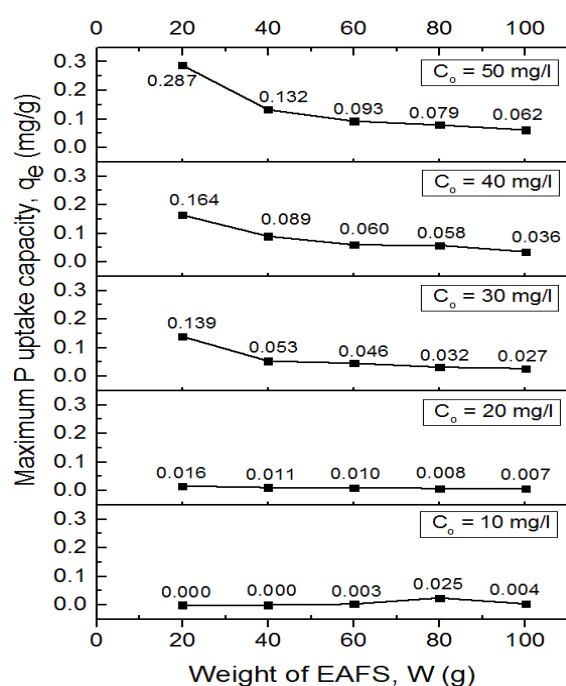


Figure 1. The effect of initial phosphorus concentrations on the maximum P uptake capacity (EAFS particle size: 9.5 – 12.4 mm, C_o = 10 – 50 mg/l).

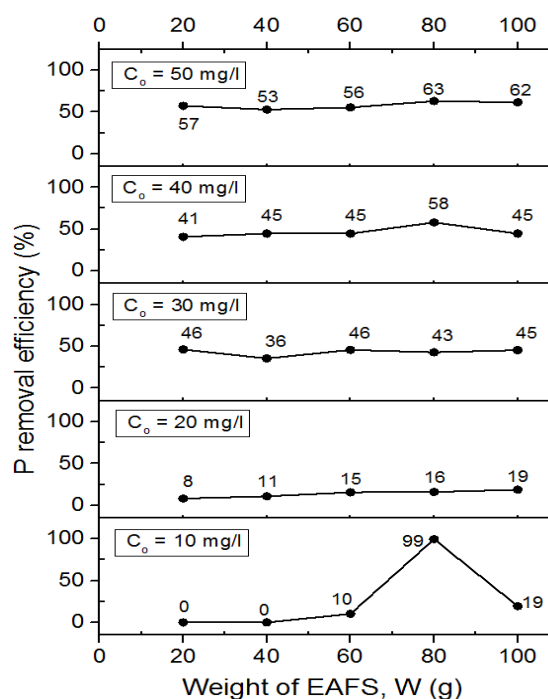


Figure 2. The percentage of P removal efficiency on various initial phosphorus concentrations (EAFS particle size: 9.5 – 12.4 mm, C_o = 10 – 50 mg/l).

The highest RP of phosphorus concentrations were found to occur as the weight of EAFS adsorbents used increases (Figure-2). Value of RP appeared higher at lower initial P concentration (10 mg/l) with the RP achieved almost 100%. However, the pattern for other initial concentrations (30, 40 and 50 mg/l) demonstrated that the RP values did not much different when the adsorbent weight increases up to 100 g. As such 20 g of EAFS adsorbent is adequate to remove about 45% - 60% of initial phosphorus concentrations from the solutions for 2 hours contact time.

Similar result was also obtained for particle size of 16.0 – 19.9 mm. Values of q_e were found to decrease as the weight of EAFS adsorbent increases. The highest values of q_e were occurred at lower adsorbent weight (20g) with 0.060, 0.117, 0.204 and 0.266 mg/g as the initial concentration of P was elevated from 20 – 50 mg/l.

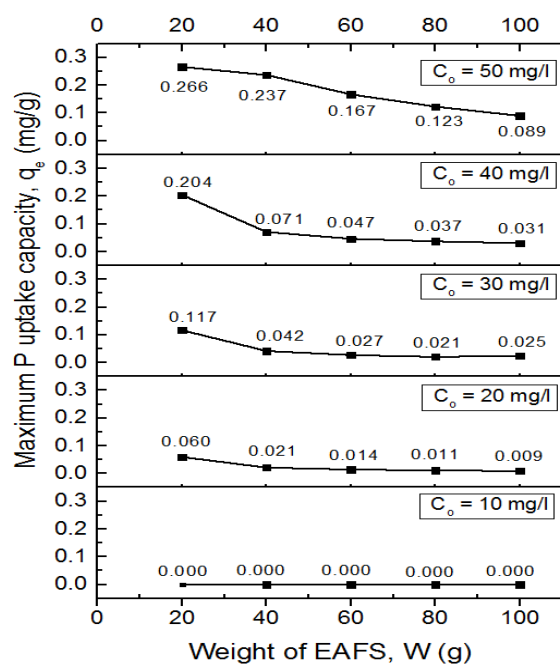


Figure 3. The effect of initial phosphorus concentrations on the maximum P uptake capacity (EAFS particle size: 16.0 – 19.9 mm, C_o = 10 – 50 mg/l).

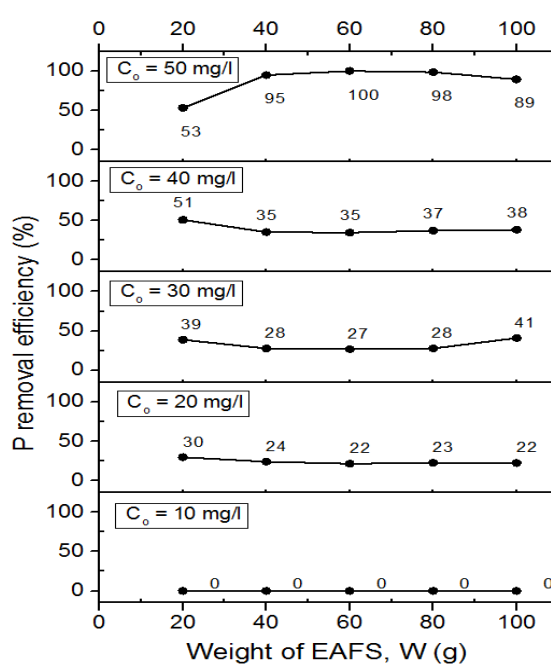


Figure 4. The percentage of P removal efficiency on various initial phosphorus concentrations (EAFS particle size: 16.0 – 19.9 mm, C_o = 10 – 50 mg/l).

However, it was noted that bigger particle sizes produce higher RP of phosphorus tremendously especially at the highest initial concentration (50 mg/l). An amount of 40 g EAFS was enough to produce RP close to 100% at 2 hours contact time.

Experiment was also conducted at the biggest selected particle size range (25.0 – 37.4 mm) under the same control condition. Weight of 20 g was not obtained in this set of experiment because on average, a single of EAFS adsorbent for this size range produce the weight of more than 25 g. Again, the same pattern was observed when more adsorbent weight was shaken inside the initial phosphorus solution (Figure-5 and Figure-6). Values of q_e was reached at its peak when lower weight of adsorbent was used. An amount of 40 g gave the highest value of q_e (0.073, 0.079 and 0.250 mg/g) for each initial concentrations (30, 40 and 50 mg/l). Furthermore, an amount of 40 g was found capable to produce completely RP of phosphorus (100%) particularly at the highest initial concentration (50 mg/l). Nevertheless, the lowest concentration (10 mg/l) was revealed to produce a very poor removal of P which was zero removal (0%).

A comparison of the percentage removal between the present study and that of Bird and Drizo (2010) shows that EAFS was significantly capable in removing the dissolved reactive phosphorus (DRB). In the researcher's work, two different particle sizes of EAFS (5 –10 mm and 10 – 20 mm) were utilized where the latter size was used at the inlet of the filter as a purpose to reduce clogging problem. These sizes were employed inside two 0.242 m³ polypropylene drums which connected in series. They found that the use of the above mentioned sizes were capable to provide removal efficiency up to 70%. Compared with the present study it was found that bigger size range (25.0 – 37.4 mm) was determined could provide higher removal efficiency (almost 100%) at a high phosphorus concentration (50 mg/l).

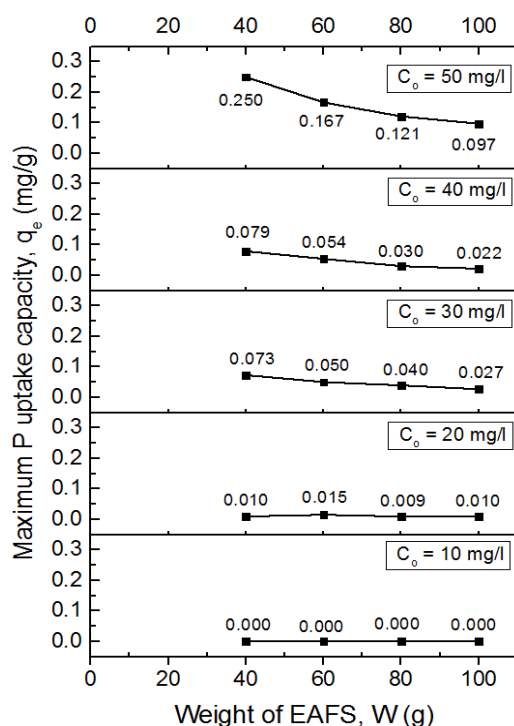


Figure 5. The effect of initial phosphorus concentrations on the maximum P uptake capacity (EAFS particle size: 25.0 – 37.4 mm, $C_o = 10 - 50$ mg/l).

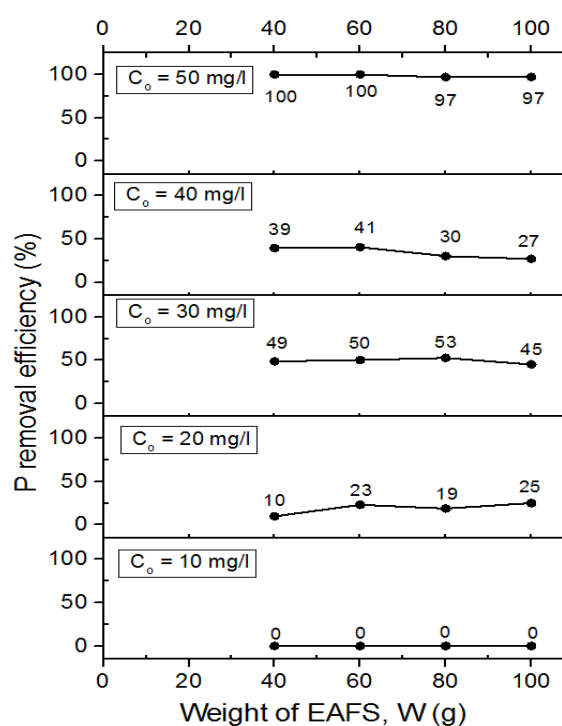


Figure 6. The percentage of P removal efficiency on various initial phosphorus concentrations (EAFS particle size: 25.0 – 37.4 mm, $C_o = 10 - 50$ mg/l).

3.1 The highest of the maximum uptake capacity of EAFS and removal efficiency of phosphorus concentration

The optimum weight of EAFS that produce the highest of the maximum uptake capacity and RP efficiency for each initial concentration were then analyzed and shown in Figure-7 and Figure-8. Apparently, with an amount of 20 – 40 g of EAFS utilized, the q_e value was increased as the initial phosphorus concentrations were raised from 10 – 50 mg/l. Values of q_e were found at the highest when $C_o = 50$ mg/l was used for all particle sizes distribution (9.5-12.4 mm, 12.5-15.9 mm, 16.0-19.9 mm, 20.0-24.9 mm, 25-37.4 mm) and reported as 0.287, 0.313, 0.266, 0.241 and 0.25 mg/g respectively (Figure-7).

The highest RP efficiency of phosphorus was determined to increase as the particle size increases, however, on contrary for smaller size (9.5 – 12.5 mm) the efficiency portrayed a fluctuating value. This could be attributed to the adsorbent was saturated with phosphate ion when it was in contact with high phosphorus concentration thus creating the potential of desorption to occur. Particle size distribution of 25 – 37 mm demonstrated the best removal efficiency (100%) of phosphorus concentration especially at higher phosphorus concentration (50 mg/l) (Figure-8).

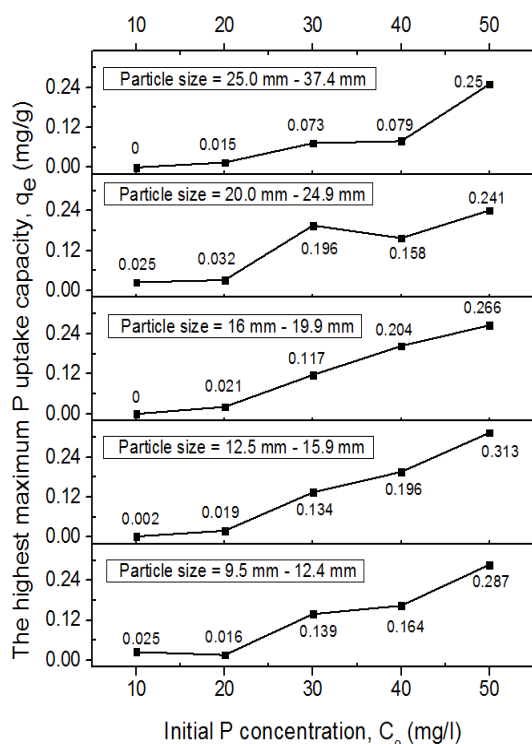


Figure 7. The highest of the maximum P uptake capacity on various particle sizes of EAFS (EAFS particle size: 9.5 – 12.4 mm to 25.0 – 37.4 mm).

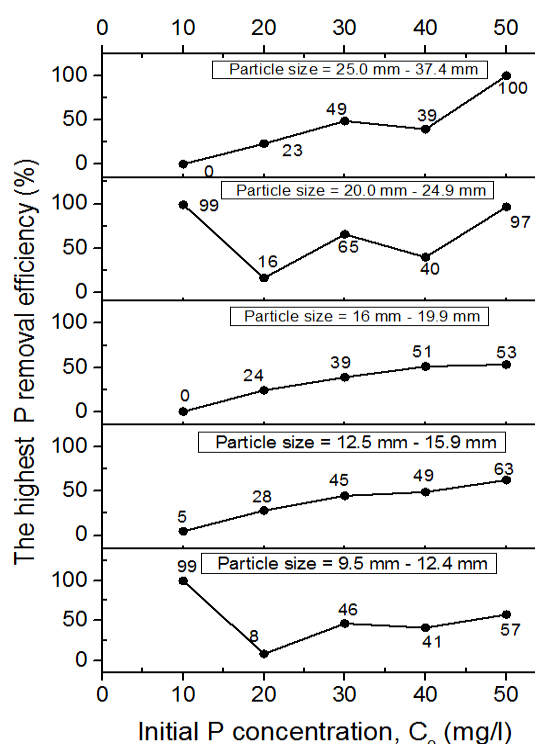


Figure 8. The highest percentage of P removal efficiency on various particle sizes of EAF (EAFS particle size: 9.5 – 12.4 mm to 25.0 – 37.4 mm).

4.0 Conclusions

In conclusion, the maximum uptake capacity of EAFS was excellent at lower adsorbent weight. Moreover, bigger particle sizes showed a tremendous phosphorus removal as initial concentration increases. It is suggested that future study should be conducted on the equilibrium state of the adsorbate. This is vital because equilibrium studies on adsorption provide information about the capacity of the sorbent or the amount required to remove a unit mass of pollution.

Acknowledgment

We are extremely indebted to all our funders: especially to Malaysian Ministry of Education under Exploratory Research Grant Scheme (Vot. E031), Universiti Tun Hussein Onn Malaysia and Perwaja Steel Sdn. Bhd. for providing us Electric Arc Furnace Slag (EAFS) samples during this research

References

- [1] Camargo Valero, M. A., Johnson, M. L., Mather, T. and Mara, D.D. (2009). Enhanced Phosphorus Removal In a WSP System With Blast Furnace Slag Filters. *Desalination and Water Treatment* 4, pp.122–127.
- [2] Yamada, H., Kayama, M., Saito, K. and Hara, M. (1986). A fundamental research on phosphate removal by using slag. *Water research*, 20(5), pp.547 – 557.
- [3] Mann, R. A. (1997). Phosphorus adsorption and desorption characteristics of constructed wetland gravels and steelworks by-products. *Australian Journal of Soil Research* 35, pp.375–384.
- [4] Agyeia, N. M., Strydomb, C. A. and Potgieter J.H. (2002). The removal of phosphate ions from aqueous solution by fly ash, slag, ordinary Portland cement and related blends. *Cement and Concrete Research* 7 32(12), pp.1889-189.

- [5] Drizo, A., Forget, C., Chapuis, R.P. and Comeau, Y. (2002). Phosphorus removal by EAF steel slag - A parameter for the estimation of the longevity of constructed wetland systems. *Environmental Science and Technology* 36, pp.4642-4648.
- [6] Lu, S., Bai, S. and Sahn, H. (2008). Mechanisms of phosphate removal from aqueous solution by blast furnace slag and steel furnace slag. *Journal of Zhejiang University – Science A* 9 (1), pp.125–132.
- [7] Bird, S. C. and Drizo, A. (2010). EAF Steel Slag Filters for Phosphorus Removal from Milk Parlor Effluent: The Effects of Solids Loading, Alternate Feeding Regimes and In-Series Design. *Water* 2, pp.484-499.
- [8] Reynolds, C.S. and Davies, P.S. (2001). Sources and bioavailability of phosphorus fraction in freshwaters : A British perspective. *Biol. Rev.*, 76, pp.27 - 64.