Utilizing industrial by-products as eco-friendly adsorbent for phosphate removal: An experimental approach

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Abstract. One of the widely present elements in the groundwater and surface water is phosphate due to two reasons; firstly, it is available at high concentrations in the soil, and secondly, it is widely available in wastewaters (industrial, agricultural and domestic wastewaters). Although phosphate causes many problems to the aquatic environment, eutrophication is the most severe problem due to its effects on water quality, economy, and health. Therefore, a number of studies have been made to evaluate the ability of different remedies to eliminate phosphates from wastewaters. Recently, phosphorus extraction may be achieved by filtering the contaminated solution. However, the cost of filtration materials is still high. Due to this reason, research to date has focused on employing inexpensive materials to reduce the cost of the filtering process. In this research, a by-product of steel manufacturing, kiln bottom ashes, was used to extract phosphates from polluted wastewater, considering the impacts of a number of operating parameters, such as to achieve the best possible extraction efficiency for the lowest possible cost. The findings of this study proved the excellent ability of the bottom ash in the extraction of phosphate from wastewater, where it removed more than 90% of 5 mg/L of phosphate after 40 minutes of treatment using 530 mg/L of bottom ash.

Keywords: By-products, phosphate; adsorption; wastewater.

1. Introduction
The increase in the global population led to a rapid expansion in urbanization and the global agricultural and industrial activity, which in turn drove a vast global demand for clean water that exhausts the available freshwater rapidly [1, 2]. This was badly reflected in the availability of freshwater [3-5], global warming [6, 7], and precipitations [8, 9]. The growing population increases the rate of sewage released into waterways, which has severe effects on consumers' health [10-12]. Furthermore, the increase in the population increased the dumping of solid wastes in landfills that pollute groundwater and then surface water [13-15]. Toxins must not be dumped directly into waterways, and all effluents, whether household or manufacturing, must be treated adequately to eliminate or limit the negative impacts of the contaminants. One of the types of impact of pollutants is algae flourishing which is due to phosphorous penetration into the water, which is harmful to the environment [16]. All types of sewage water contain phosphorus [17, 18] and nitrate [19, 20] beside other pollutants such as fluoride [21], heavy metals [22, 23], bacteria [24, 25], coloring pollutants [26-28] and organic matter [29-31]. Additionally, industrial and domestic wastewater [32-35] and atmospheric pollutants [36-38] are playing a role in increasing such pollutants in water bodies. The effluents of the construction industry [39-42], production plants [43-45] and food industry [32, 46].
Surface waters are depleted of oxygen due to algal blooms induced by phosphorus and nitrate contamination [12]. A large proportion of aquatic creatures and plants might die in a short period of time. As just a result of a substantial rise in organic matter content, the taste, smell, and structure of the water will be changed significantly [47-49]. A rise in algal development might have severe effects on health, industries, seafood, and agriculture [20, 50]. Many studies revealed that microalgal types could generate poisonous chemicals that cause a range of severe illnesses and, sometimes, fatalities. In drinkable water, the allowable concentration of phosphate is specified at 0.1 mg/L, whereas in streams and ponds, it is 0.05 mg/L [17, 18]. As far as the upper limit pollutant concentration in water is concerning, the Environmental Protection Agency has strict standards. It is therefore important to remove phosphates from contaminated water, depending on what has been said previously. When phosphate is removed via traditional methods, it generally requires a long and complicated procedure. As an instance, the normal filtering process [21], with some modifications, provides an effective approach for phosphate removal, according to the authors. However, the usage of expensive screens makes this approach uneconomical [46, 51]. It is possible to remove phosphate from the water bodies by converting it to a solid-state, which would be subsequently removed from the water via flotation or some other means. Thermal processing, lakes, anaerobic digestion, absorption, and other techniques are used to transform phosphorus [18]. As just a result of the typical operations of species of bacteria and microalgae, phosphate could be biologically processed. Depends on the kind of microbe, anaerobic or aerobic techniques could be used in these situations. The pH, starting dosage, etc. are all factors that affect the efficacy of the treatments. In regards to employing biological intervention to reduce the existence of phosphate, several disadvantages are discovered [17]. Soluble carbon, the fast development of microorganisms, and the pH level of the fluid are all factors to be considered. Phosphate particles can be converted by adding metallic compounds to water polluted with Phosphorus particles. Usually, sewer water encompassing phosphate is treated using chemical techniques. Calcium ion is amongst the most frequently utilized chemical additions for phosphorus removal for its availability, affordability, and convenience of usage. Especially in an acidic medium, aluminium hydroxide is believed to be highly successful in eliminating phosphate from wastewater. As a consequence of the usage of chemical substances, chemical treatment methods frequently lead to toxic sludge [20]. Due to the utilization use reagents, the technique is much more costly than many other procedures. Physically, phosphate extraction methods do not change the chemical composition of the phosphate, which is resulting in a change. After the removal of phosphate pollution using this approach, it is possible to separate these contaminants (phosphate contaminants) from the removal medium. For phosphate removal, filtering and screening technologies are frequently employed [17, 18]. Substances sensitive to pollutants are used in filtering. Water is then separated from pollutants using a variety of processes such as coagulation [10, 27], absorption [11, 52], and straining hybrid methods [19, 29]. To remove phosphates from water, several permeable mediums were employed. The general rule, the expense of filtering is determined based on the cost of the adsorbent materials employed. The phosphate removal capability of membranes has been demonstrated in previous studies. Several methods extract phosphates from water at low levels, but reverse osmosis is among the most popular. Polluted water is forced through a barrier with really limited porosity under high pressure. Assist in removing pollutants in water by means of high-pressured water. Membrane systems are rarely utilized due to their expensive running costs, difficulties in discarding them, and the requirement for specific equipment and expertise. Recently, studies have centred on the use of waste products or natural resources as economical and useful replacements for traditional materials. Fly ash is a standard manufacturing by-product used to remove phosphate from wastewater and is widely used in the construction industry [39, 53]. Water with an acidity level of 7 can be effectively treated with this substance. Due to the above, our research focused primarily on the possibility of using furnaces bottom ashes as an absorbent to extract the phosphates from polluted effluent.
2. Methods

According to the studies, furnace bottom ashes may be utilized as a convenient and efficient adsorbent for the removal of phosphate from the wastewater. Studying the grain size, permeability, porous structure, and relative density of the bottom ashes is essential. The particle size is highly essential because it is directly related to the adsorption surface. When sieve review is performed, sieve sizes of 4, 6, 10, 16, 30, and 50 are utilized, and the quantity of mass kept on each sieve is calculated by analyzing the distribution of particle size of the waste. This formula is used to determine the specific gravity test using the gas jar method:

$$\text{Specific Gravity} = \frac{L_2 - L_1}{(L_4 - L_1)(L_3 - L_2)}$$

(1)

Where

- $L_1$: Weight of jar + weight of plates
- $L_2$: The total weight of the sample, plate, and jar, including the plate and the jar itself.
- $L_3$: Water, dry sample, plate, and jar weight together.
- $L_4$: Weight of the jar plus water

Using an X-ray fluorescence analyzer, the chemical test is used to determine the structure of the ashes of the furnaces. It is performed to assess the effectiveness of extracting phosphates from the bottom ashes of the furnace since materials contain calcium, iron, and aluminum can be utilized for phosphate removal. To extract the phosphate in contaminated water, the bottom ashes were employed as a filter. The Box-Behnken design was utilized to improve the technique in terms of burner bottom ash dosage, duration of treatment, and temp. A potassium diphosphate solution in deionized water was used to modify the amounts of phosphate in synthetic water.

An experiment was conducted in which polluted water was combined for various lengths of time with the furnace's bottom ashes to determine the effect of duration. In such tests, the retention duration ranging from 10 to 70 min, while the burner ash dosages varied from 100 to 1000 mg/L. Calculations of phosphate levels are made with the use of a Hach Lange spectrophotometer. As a result of this study, the Box-Behnken Design was utilized to create an estimation model in order to obtain the highest water treatment. The response variable was phosphorus removal in this research. The determinants were the phosphorus content level, bottom ash dose, and the duration of treatment. In order to construct the estimation matrix, Minitab 20 was chosen. The ranges of predictor factors considered are shown in Table 1.

Table 1. Varying ranges of independent and dependent variables were examined.

| Factors                      | Code | Low | Moderate | High |
|------------------------------|------|-----|----------|------|
| Concentration of phosphate in water | CoP  | 5   | 10       | 15   |
| The dose of bottom ashes     | DoBA | 100 | 550      | 1000 |
| Time of the treatment        | ToT  | 10  | 40       | 70   |

A powerful determinant of linearity and relevance is the $\alpha$ value, which may be calculated using the formula below:

$$\alpha = (2X)^{1/4}$$

(2)

Where $X$ is the number of variables included in the model.

3. Results and Discussion

3.1. Properties of ashes from furnace bottoms

Based on empirical evidence, the majority of the bottom ash grains are maintained on sieves of lower diameters of less than 16. The results of the sieving tests show that the majority of the
bottom ash samples consisted of small particles within 1.180 mm and 4.750 mm in size. It was computed using the formulas 3 and 4:

\[
\text{Uniformity coefficient} = \frac{x_2^2}{x_1} \quad (3)
\]

\[
\text{The gradation coefficient} = \frac{x_3^2}{x_1 \times x_2} \quad (4)
\]

When plotting the passing rate with particle diameter, \(x_2\), \(x_3\), and \(x_1\) show the percentages of particles that pass through each size. Analysis indicated that \(x_2\), \(x_3\), and \(x_1\) the quantity of the first term were 3.06, 1.36, and 0.48, correspondingly. Furthermore, the uniformity coefficient is 6.21 and the gradation coefficient is 1.32. The specimens of bottom ash are judged to be of good quality. Because of this, it is unlikely that the bottom ashes would float, as their relative density is greater than those of the liquid. Permeability was 0.61 m²/g, while the total area was 6.81 m²/g. A wide surface, good permeability, and high relative density make the bottoms of the furnace excellent for phosphorus extraction. Chemists determined that the bottom ashes included aluminum, iron, and calcium oxide, magnesium in roughly 25% of the furnace’s ash. As a result, it may be argued that the bottom ash of a burner is suitable for removing phosphates.

3.2. Phosphate Removal

To investigate the effectiveness of burner ash in removing phosphorus compounds from wastewater, batch experiments were run. For each of the 15 tests, the experimental variables were modified, in order to identify the optimal experimental set for achieving high removal efficiency at low costs. The findings are shown in Table 2 below. As can be seen in Table 2, the Box-Behnken Design and the removal efficiency obtained are provided.

| test | DoBA | CoP | ToT | RE% |
|------|------|-----|-----|-----|
| 01   | 1    | 0   | 0   | 90.1 |
| 02   | 1    | 0   | 1   | 63.1 |
| 03   | 1    | -1  | 0   | 77.3 |
| 04   | 0    | 0   | 0   | 83.5 |
| 05   | 0    | 1   | 1   | 79.1 |
| 06   | -1   | 0   | -1  | 77.2 |
| 07   | 0    | 0   | 0   | 66.4 |
| 08   | 0    | -1  | -1  | 58.2 |
| 09   | 0    | 1   | -1  | 59.9 |
| 10   | 0    | -1  | 1   | 65.7 |
| 11   | -1   | 1   | 0   | 80.1 |
| 12   | 1    | 1   | 0   | 79.2 |
| 13   | -1   | 0   | 1   | 77.8 |
| 14   | -1   | -1  | 0   | 79.2 |
| 15   | 0    | 0   | 0   | 70.1 |

As a result of this investigation, it was shown that the removal efficiencies are proportional to the dose of furnace bottom ashes and the length of time intervals. Phosphorus removal, on the other hand, has an adverse correlation with starting phosphorus concentrations. This is because the accessible surface area of the adsorption is insufficient to collect the phosphorus from the liquid. As a result, there is more surface area accessible for phosphate adsorption from the contaminated water in the furnace bottom ash. It also enhances the interaction of phosphate and the adsorbent. 90.1% of the phosphate concentration in the contaminated water could be removed by using 530 mg/L of bottom ashes for 40 minutes, as shown in Figure 1.
Figure 1: Effects of the studied parameters on phosphate removal by the bottom ash, A) DoBA vs CoP, B) DoBA vs ToT, and C) ToT vs CoP.

To estimate the removal efficiency based on the employed parameters, Box-Behnken Design was used to construct Equation 5.

\[
RE\% = 73.33 - 0.44 \text{DoBA} + 2.24 \text{CoF} - 0.10 \text{ToT} + 8.61 \text{DoBA} \times \text{DoBA} - 2.99 \text{CoF} \times \text{CoF} - 4.62 \text{ToT} \times \text{ToT} + 0.25 \text{DoBA} \times \text{CoF} - 7.17 \text{DoBA} \times \text{ToT} + 2.93 \text{CoF} \times \text{ToT}
\]

(5)

It can be seen from the presented studies about the adsorption method, the depletion of the active sites results in a serious reduction in the adsorption process, therefore; the application of successful sensors (in the literature) helps the operators of the treatment plant to monitor the depletion process, two good examples of the sensors that widely used in the civil and water engineering are the microwave [54-56] and electromagnetic [57-60] sensors.

4. Conclusion

The present study experimentally explored the prospect of using furnace bottom ashes as a treatment method to remediate contaminated water by phosphate. Therefore, the chemical and physical properties of furnace bottom ashes were examined first to check the usability of this by-product for phosphate removal, and then it was experimentally applied for phosphate removal from solutions. It was found the bottom ashes removed more than 90 % of phosphate. Also, it was found that the dose of the bottom ashes and the detention time positively affect the percentage of phosphate removal from the polluted wastewater. With respect to phosphate
adsorption capacity, on the other hand, it is inversely correlated with the initial concentration of the pollutant.

Modelling the relationship between phosphate removal and essential parameters, such as furnace bottom ash dose, phosphate content, and treatment duration is recommended for future studies. To achieve this goal, many software and methods can be used, such as Box–Behnken design.

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