Phosphate removal from wastewater by furnace bottom ash

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Abstract. Orthophosphate is a natural chemical found in large quantities in the Earth's crust, and its inclusion in water causes eutrophication. As a result, several experiments have been conducted to investigate the potential of various treatment systems to remove phosphate from wastewater. According to recent research, filtration methods are useful for phosphate removal, with one drawback being the expensive cost of the filtration materials. Therefore, new research has focused on reducing the cost of filtration method using cheap replacements. The current research focuses on the efficacy of using iron industry wastes which the blast furnace bottom ashes to remove phosphates from contaminated wastewater. Some operating conditions, like phosphates level, treating periods and blast furnace bottom ashes dosages, have investigated in order to find a suitable set for achieving the highest probable removal rate at a fair charge. The findings showed that the bottom ashes are an effective phosphate removal substitute. The highest removal of phosphate was 91.2% at 37.5 minutes treatment period, using initial concentration of 5 ppm, and a dose of the bottom ashes of 575 ppm. The findings have been used to build a production model with a high level of reliability.

Keyword: Blast furnace bottom ashes, phosphate; wastewater.

1. Introduction
The demand for fresh potable water is growing all over the world as a result of the rapid growth of population growth and dwindling clean water supplies [1-3]. Since the discharged wastewater volume is measured in strict proportion to the population, the increasing population increases the quantity of wastewater disposed to waterbodies and turn the negative consequences on the environment and human [1, 3-5]. As a result, overt discharge of toxins into freshwater should be banned, and drainage should be properly handled, whether residential, industrial, and agricultural effluents, in order to remove or reduce the harmful effects of the pollutants [6, 7]. Algae flourishing is caused by phosphorus infiltration of water, which harms water. Phosphate is considered an important source of nutrients and, therefore, is considered a common pollutant in all kinds of wastewater effluents [8-11]. The biggest problem produced by the pollution of phosphate is the rapid growth of algae which absorbing sunshine and depleting the oxygen in water bodies. This could result in the death of a significant number of water animals and plants in a brief period [12-14]. Because of the dramatic increase in organic matter concentration, the water's flavour, odour, and composition will be greatly affected. Algal growth at an increased rate could have devastating consequences for human health,
Many researchers discovered that phytoplankton species can produce toxic materials that cause a variety of harmful diseases and, in some cases, death [15-21]. The Environmental Protection Agency has specific guidelines when it comes to the maximum permissible pollutant concentrations in water. The permissible phosphate concentration in drinking water is set to be 0.1 ppm, while it is 0.05 ppm in lakes and rivers, according to the Environmental Protection Agency. Based on the above, it is essential to remove the phosphate from polluted water. However, using conventional procedures to remove phosphate usually necessitates an expensive and time-consuming treatment process [12, 22]. To give an example, the standard filtration process, with certain improvements, provide a promising method for phosphate. However, this method is considered a non-economical method due to the use of costly filters. Therefore, the focus of this research was on the potential to use furnaces bottom ashes as industrial waste as a low-cost adsorbent to remove phosphate from polluted wastewater.

2. Review of literature
Phosphorus elimination from the aquatic environment is accomplished by changing the format of the element to a solid format, which is then removed from the solution through flocculation or other methods [12, 23]. Phosphate is converted using a variety of methods, including chemical treatment, ponds, biological treatment, adsorption, etc.

The biological treatment of phosphate can be performed by using the normal actions of various microorganisms such as microalgae and bacteria. These methods can be anaerobic or aerobic, based on the type of microorganism. The treatment effectiveness is depending on various aspects like pH, initial concentration etc.[24-30]. Many drawbacks are found in terms of using biological treatment to eliminate the presence of phosphate. This includes the presence of ample biodegradable carbon, the rapid growth of microorganism, and the pH level of the solution as pH changes could destroy the bacteria [31-38]. Chemical techniques involve adding metallic salts to phosphate contaminated water to convert phosphate ions. Chemical methods are commonly used for the treatment of wastewater containing phosphate [39-43]. Because of its obtainability, cheapness, and ease of use, calcium ion is regarded as one of the most used chemical additives for phosphate treatment. The aluminium hydroxide is considered very efficient in removing phosphate from contaminated water, particularly in an acidic environment. Chemical treatment processes often result in poisonous sludge because of the use of chemical materials. An additional consideration is that the procedure is more expensive than most processes due to the use of chemicals [44, 45]. Physical phosphate removal techniques do not alter the chemical structure of the phosphate which are usually reversible. Based on this method the removed phosphorus pollutants may be isolated from the removing media. Membrane and filtration and membrane methods are widely used physical techniques for phosphate elimination [46, 47].

Filtration is an extraction technique that employs permeable media to remove many contaminants. Following that, various techniques like precipitation, flocculation, impaction, adsorption, and straining are used to separate contaminants from water. To eliminate phosphate from water, the filtration process used various permeable media [5, 48-51]. Overall, filtration cost is dictated by the cost of used adsorption materials, which are typically expensive particularly for industrial materials. Earlier experiments on membrane approaches revealed that membrane methods are a strong capacity to remove phosphate. Reverse osmosis is one of the wildly adopted methods to remove low phosphate concentrations (below 0.008 mg/L) [3, 52, 53]. Reverse osmosis is based on the pressure-driven way of contaminated solution in a membrane with very low permeability. The member helps to remove the contaminants from water by pressure. But, because of the high operating energy and costs, the difficulty of disposing of the membrane concentrators, and the need for specialized apparatus and skills, membrane system is uncommonly used. As a result, recent research has centred on the adoption of industrial waste or environmental resources as efficient and functional substitutes. Fly ash is a common expel of industrial waste in phosphate removal from water. Research showed that this material is effective in removing the phosphate from wastewater that has pH level of 7 [20, 21, 30].

3. Research methods
As stated earlier, the current research aimed to see whether blast furnace bottom ashes could be used as cheap and adsorbent to remove phosphate from. It's crucial to study the physical properties of the bottom ashes like size distribution, porosity, surface areas and specific gravity. It is very important to conduct the particle size distribution since it is linked to the area available for adsorption. Sieve numbers of 4,6,10,16,30, and 50 are used conducted using sieve analysis, and the quantity of materials retained on every mesh is determined to examine the particle size distribution of the waste. Besides, the following equation is used to find the specific gravity (SG) test using the gas jar technique:

\[
SG = \frac{Y_2 - Y_3}{(Y_4 - Y_1) - (Y_5 - Y_2)}
\]

Where

\(Y_1\): Jar weight + plate weight
\(Y_2\): The combined weight of the sample, plate, and jar.
\(Y_3\): The combined weight of the water, dray sample, plate, and jar.
\(Y_4\): Jar weight + water

Following this, a chemical test was performed to see the composition of the furnaces bottom ashes using an X-ray fluorescence analyzer. The chemical composition test is done to determine the removing efficiency of the furnaces bottom ashes because it has been discovered that compounds containing calcium, iron, and aluminium, can be used for phosphate treatment. The bottom ashes were used to eliminate the presence of phosphate in polluted water samples. In terms of furnaces bottom ashes dose, treatment period and temperature, the central composite configuration was used to optimize the method. The test implemented various concentrations of phosphate, which were modified and regulated by combining potassium diphosphate within deionized water.

To investigate the impact of the time, the contaminated water was mixed with the furnaces bottom ashes were kept mixed for varying amounts of time in one bottle. In these experiments, the detention period was 10 to 65 minutes, the furnaces bottom ashes doses ranged from 150 to 750 mg/L, and the concentration of the phosphate ranged from 5 to 15 mg/L. Hach Lange spectrophotometer is adopted to calculate the concentrations of the phosphate.

The central composite design has been used in this research to build the production model in order to attain the best water treatment as this technique is an effective and largely adopted method. Phosphate elimination was the response variable in this study. Phosphate concentration level, furnaces bottom ashes dosage, and treatment duration were the predictors. Minitab 19 has been adopted to create the production matrix. Table 1 shows the independent variable ranges that were used.

Table 1. The independent and dependent variable ranges that were investigated.

| Independent variables       | units | Code   | Level  |
|-----------------------------|-------|--------|--------|
| Phosphate concentration level| mg/L  | PCL    | Low    |
|                            |       |        | 5.0    |
|                            |       |        | 10.0   |
|                            |       |        | 15.0   |
| Furnaces bottom ashes dosage| mg/L  | FBADs  | Moderate|
|                            |       |        | 575.0  |
|                            |       |        | 1000.0 |
| Treatment duration          | Minutes| TD     | Elevated|
|                            |       |        | 37.5   |
|                            |       |        | 65.0   |

Following this, the \( \alpha \) value, which creates a useful predictor of linearity and indicated significance is determined using the following equation:

\[
\alpha = \frac{4}{\sqrt{2a}}
\]

Where \( a \) represents the number of used predictors.

4. Results
4.1. Furnaces bottom ashes properties

Most of the bottom ashes particles are retained on sieves of smaller sizes (sieves 4 to 16) based on the experimental results. The outcome of the sieves analyses suggests that small particles sizes between 1.180mm and 4.750 mm made up the bulk of the bottom ashes sample. The level of gradation was calculated using the below equations (3, and 4):

Uniformity coefficient \[ \frac{D_{60}}{D_{10}} \] (3)

The gradation coefficient \[ \frac{D_{20}}{D_{10} \times D_{80}} \] (4)

Where \( D_{60}, D_{50}, \) and \( D_{10} \) represents the percentage of particles passing on each noted size while were found for the plot of the passing rate with particle size. The results of the analyses showed that the \( D_{60}, D_{50}, \) and \( D_{10} \) values were 3.08 1.40, and 0.50, respectively. In addition, the gradation coefficient is 1.27 and the uniformity coefficient is 6.16. The bottom ashes samples are deemed well-graded. Besides, the specific gravity of the bottom ashes was found to be 1.25 which means that the ashes will not float as it has specific gravity is larger than water specific gravity. Additionally, the permeability of the ashes was found to be 0.58 m²/g, and the surface area was 6.2 m²/g, based on these results the furnaces bottom ashes can be considered ideal for phosphate removal from water, as they have a large area, proper permeability, and higher specific gravity.

On the other hand, based on the chemical tests, it was found that about 20% of the furnaces bottom ashes is calcium oxides, magnesium, iron, and aluminium. Thereby, it can be said that the furnace bottom ashes, is ideal for phosphate removal.

4.2. Phosphate treatment

In this research batch tests were used to assess the removal of the phosphate from water using furnace bottom ashes. 20 trials where experimental variables were changed in each trial to determine the best experimental set to achieve high removal efficiency of low costs. Table 2 displays the results. The central composite design and removal efficiency achieved is presented in Table 2.

Table 2. Central composite design for phosphate removal in a batch flow experiment.

| Trail | PCL | FBADs | TD | Removal % |
|-------|-----|-------|----|-----------|
| 01    | -1  | -1    | -1 | 72.1      |
| 02    | 1   | -1    | -1 | 83.5      |
| 03    | -1  | 1     | -1 | 77.2      |
| 04    | 1   | 1     | -1 | 65.7      |
| 05    | -1  | -1    | 1  | 63.1      |
| 06    | 1   | -1    | 1  | 58.2      |
| 07    | -1  | 1     | 1  | 75.2      |
| 08    | 1   | 1     | 1  | 79.1      |
| 09    | -1.682 | 0   | 0  | 59.9      |
| 10    | 1.682 | 0    | 0  | 80.1      |
| 11    | 0   | -1.682 | 0  | 56.2      |
| 12    | 0   | 1.682 | 0  | 77.3      |
| 13    | 0   | 0     | -1.682 | 91.2   |
| 14    | 0   | 0     | 1.682 | 66.4     |
| 15    | 0   | 0     | 0   | 70.1      |
| 16    | 0   | 0     | 0   | 79.2      |
| 17    | 0   | 0     | 0   | 78.1      |
| 18    | 0   | 0     | 0   | 79.2      |
| 19    | 0   | 0     | 0   | 77.8      |
| 20    | 0   | 0     | 0   | 78.1      |

The findings of this research study revealed that the treatment efficiency is related to the dosage of the furnace’s bottom ashes and treatment duration. However, phosphate treatment has a negative relationship with the initial concentration the phosphate. The available surface area of the adsorbent is not sufficient to absorb the phosphate from the water, resulting in a decreased treatment performance. Implementing a higher concentration of furnace’s bottom ashes increases the available area for adsorption of the phosphate from polluted water. The increased treatment tie increases the contact between the adsorbent and the phosphate. Using 75 mg/L of furnace’s bottom ashes for 37.5 minutes were appropriate to remove 91.2 of the phosphate concentration in the polluted water as presented in Figure 1.
Figure 1: surface plots of the removal performance of phosphate vs experimental parameters

Equation 5 were developed using the central composite design method to estimate the removal efficiency based on the used parameters.

\[
\text{Removal \%} = 77.08 + 2.41 \text{PCL} + 4.08 \text{FBADs} - 4.73 \text{TD} - 2.46 \text{PCL} \times \text{PCL} - 3.60 \text{FBADs} \times \text{FBADs} + 0.66 \text{TD} \times \text{TD} - 1.76 \text{PCL} \times \text{FBADs} - 0.11 \text{PCL} \times \text{TD} + 5.71 \text{FBADs} \times \text{TD}
\] (5)

5. Conclusion
The potential to use furnaces bottom ashes to treat the presences of phosphate from polluted was investigated in order to determine the best operating considerations. Research findings showed that furnaces bottom ashes chemical and physical characteristics are necessary to remove phosphate from polluted water. The performance of the furnaces bottom ashes is like previous research finding of around 90% per cent removal. The treatment percentage is proportional to the dosage of the furnace’s bottom ashes and treatment duration. On the other hand, the removal efficiency is negatively connected to phosphate removal. In addition, the developed central composite model can predict the change in the removal efficiency of the phosphate-based on the dose of the furnace’s bottom ashes, the concentration of the phosphate and the treatment time.

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