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The Effect of HCl Activator on PET Adsorbent to Reduce Phosphate Content in Laundry Waste

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ABSTRACT. Plastic waste is waste that cannot be decomposed, so it causes serious environmental problems. The National Waste Management Information System (SIPSN) reported that in 2020 plastic waste was found to be 17.2% of the total waste collected. Several types of plastic can become porous charcoal through the heating process in a furnace so that it can be used as an adsorbent for liquid waste from the laundry industry. Laundry liquid waste containing excess phosphate will disrupt the environment, such as eutrophication. This research aims to determine the effect of HCl activator on carbon from polyethylene terephthalate (PET) plastic bottle waste to reduce phosphate levels in liquid laundry waste. This research uses varying concentrations of HCl as a carbon activator, namely 1 M, 5 M, and 10 M. The adsorbent is added to the liquid laundry waste and stirred at a speed of 100 rpm. Phosphate content analysis was carried out using a spectrophotometer in liquid laundry waste before and after the adsorption process and BET (Brunauer-Emmet-Teller) analysis on activated carbon with activator HCL 10 M. The most significant decrease in phosphate levels was 10 M HCL concentration of 52.87%, with a carbon surface area of 203.12 m^2/g and a particle size of 29.53 nm. The adsorption capacity of activated carbon with 10 M activator is 0.15 mg/g

1. INTRODUCTION

Plastic is waste that is not easy to decompose, in contrast to biomass waste, which is made from organic materials, so it is easy to decompose [1]. In today's era, plastic is used in various fields. Examples include using plastic for drink bottles. One of the types of plastic used is polyethylene terephthalate (PET). PET bottles were originally used to contain soft drinks, but their use in bottled water is gradually becoming more common. PET is a family of the polyester family and is a transparent plastic, durable, flexible, dimensionally stable, fire resistant, non-toxic, and permeable to gas and water. PET type plastic in everyday life can be found in mineral water bottles, soft drinks, syrup packaging, jam, cooking oil, etc. [2]. The non-degradable nature of PET means that PET plastic waste has increased over the years, causing environmental pollution. PET plastic is an inorganic waste that is difficult to decompose, if it can be decomposed, it will take a long time [3]. PET plastic waste is difficult to decompose, but there is another way, namely, PET waste is recycled. Utilization of plastic waste for other purposes [4].

One way in this research is to use PET waste as active carbon, which is applied to liquid laundry waste. Laundry liquid waste is wastewater resulting from washing clothes. The laundry service business continues to develop in line with the increase in waste from laundry activities. The liquid laundry waste produced contains various kinds of pollutants [5]. Laundry businesses use detergent as a clothes-washing agent. Detergent is an organic substance whose derivatives, if accumulated, cause an increase in the organic content. Apart from that, it also contains surfactants, builders, fillers and additives. Laundry waste produced from detergents contains high levels of phosphate derived from sodium tripolyphosphate. Phosphate functions as a builder, the second most important element after surfactants, because it deactivates hard minerals in water. If this laundry waste is thrown directly into the waters, it will have a negative impact on the waters themselves, such as eutrophication, oxygen levels are drastically reduced and cause water biota to experience degradation and can endanger human health if consumed or used directly [6]. Laundry waste produced from detergents contains high levels of phosphate derived from sodium tripolyphosphate (STTP). Phosphate functions as a builder which is the second most important element

after surfactants because of its ability to deactivate hardness minerals in water. Dissolved phosphate is a nutrient that stimulates the growth of algae and grass in lakes, estuaries and calm rivers. Based on previous research, the phosphate concentration found in laundry waste is shown in Table 1.

Table. 1 Phosphate concentration in laundry waste

Phosphate concentrations (mg/L)	References
2.67	[7]
4.98	[8]
59.60	[9]
7.79	[10]
9,80	[6]
9.90	[11]
19.10	[12]
14.15	[5]

Indonesia has wastewater quality standards regulated in the Regulation of the Minister of Environment and Forestry of the Republic of Indonesia Number 5 of 2014 concerning Waste Water Quality Standards, where the highest phosphate content is 2 mg/L [10].

Methods that can be used to reduce levels of anionic surfactants and phosphates in laundry waste include filtration, photocatalysis, coagulation and adsorption. If the phosphate content in laundry waste is higher, it can cause environmental problems, namely eutrophication [5]. In connection with this problem, PET plastic waste was used as an adsorbent in this research. An adsorbent is a solid substance that can absorb specific components or compounds from a fluid (liquid or gas) [9]. Carbon from PET plastic is heated using a furnace to become carbon and activated using a chemical activator. Chemical activation usually uses activating ingredients such as calcium chloride salt ($CaCl_2$), magnesium chloride ($MgCl_2$), zinc chloride ($ZnCl_2$), sodium hydroxide (NaOH), sodium carbonate (Na_2CO_3) and sodium chloride (NaCl) and hydrochloric acid (HCl)[13]. 1 M KOH activator and acetone were used to activate carbon from plastic to reduce phosphate levels by 45% [3]. Adsorption of hospital liquid waste with 1 M HCL activator can reduce phosphate levels by 48.77%[14]. Adsorbent activated carbon from polyethylene plastic with 10 M activator [9]. Adsorbent has a wider surface area, more pores and a high absorption capacity. In this study, the activator used was HCl with varying concentrations, which was applied to liquid laundry waste to reduce its phosphate levels. Activation in this study was carried out chemically using an HCl solution.

2. MATERIALS AND METHODS

2.1 Materials and Methods

The materials used in this research are liquid waste laundry, polyethylene terephthalate (PET) plastic bottle waste, 12M HCl, phenolphthaline indicator, litmus paper, H_2SO_4 5 N pro analysis, ammonium molybdate pro analysis Merck, ascorbic acid, potassium antimonyl tartate for analysis Merck, and KH_2PO_4 for analysis. The process of making adsorbent is carried out in three stages: dehydration, carbonization and activation. PET that has been cleaned and cut into smaller sizes, then dried in the sun to remove the water on the surface of the plastic. The raw materials were small pieces of PET plastic, then heated using a furnace at 450°C for 2 hours. The adsorbent formed in the grinding was hereupon sieved using a mechanical sieve of 200 mesh. Adsorbents were soaked in HCl solution with a concentration of 1 M, 5 M, and 10 M for 2 hours. The adsorbent was filtered using filter paper, and dried using an oven at 110^{o}C for 3 hours. The liquid laundry waste about 250 mL was put into a 1000 mL beaker. Adsorbent from polyethylene terephthalate (PET) plastic bottle waste was added to a liquid laundry of about 4 gram. The sample was stirred at 100 rpm for 120 minutes. Water and adsorbent were separated by using filter paper. Analysis was carried out using a spectrophotometer to determine the levels of phosphate contained. The adsorbent or activated carbon that reduced the highest phosphate was analyzed using BET (Brunauer-Emmet-Teller), which was carried out at the Serpong Advanced Characteristics Laboratory, Chemical Analysis Services Laboratory- BRIN with a Micromeritics Tristar II 3020 instrument.

2.2 Determination of phosphate content in laundry waste

This test method is used to determine phosphate levels using an AE Lab brand UV-Vis spectrophotometer using ascorbic acid in water and wastewater samples according to SNI 06-6989.31-2005.

2.2.1. Material Preparation

- Preparation of phosphate mother liquor 500 mg P/L
  Dissolve 2.195 g of KH_2PO_4 with 100 mL of distilled water in a 1000 mL measuring flask, then add distilled water until it reaches the mark and is homogenized.
- Preparation of 10 mg P/L phosphate standard solution
  Pipet 2 mL of 500 mg P/L phosphate stock solution and put it into a 100 mL measuring flask, then add distilled water until it reaches the mark and is homogenized.
- Preparation of phosphate working solution
  Pipette 0 mL, 5 mL, 10 mL; 20 mL and 25 mL of phosphate standard solution containing 10 mg P/L and put each into a 250 mL volumetric flask then distilled water is added until exactly at the mark, then homogenized to obtain a phosphate content of 0.0 mg P/L, 0.2 mg P/L, 0.4 mg P/L, 0.8 mg P/L and 1.0 mg P/L.
- 5N sulfuric acid (H_2SO_4) solution
  Carefully put 70 mL of concentrated sulfuric acid into a beaker containing 300 mL of distilled water and place it in an ice bath. Dilute the solution with distilled water to 500 mL and homogenize.
- Potassium antimonyl tartrate solution ($K(SbO)C_4H_4O6.½\ H_2O$)
  Dissolve 1.3715 g of potassium antimonyl tartrate with 400 mL of distilled water in a 500 mL volumetric flask. Then, add distilled water until it reaches the tera mark and is homogenized.
- Ammonium molybdate solution ($(NH_4)_6Mo_7O_{24}.4H_2O$)
  Dissolve 20 g of ammonium molybdate in 500 mL of distilled water and homogenize.
- Ascorbic acid solution, $C_6H_8O_6$ 0.1 M
  Dissolve 1.76 g of ascorbic acid in 100 mL of distilled water and homogenize.
- Mixed solution
  Mixed successively 50 mL of 5N H_2SO_4, 5 mL of potassium antimonyl tartrate solution, 15 mL of ammonium molybdate solution and 30 mL of ascorbic acid solution.

2.2.2. Determination of phosphate levels in laundry waste samples

2.2.2.1. create a calibration curve

1. Optimize the spectrophotometer according to the equipment instructions for testing phosphate levels;
2. Pipette 50 mL of working solution and put each into an Erlenmeyer.
3. Add 1 drop of phenolphthalein indicator. If pink color forms, add drop by drop H_2SO_4 5N until the color disappears;
4. Add 8 mL of the mixed solution and homogenize;
5. Put it in a cuvette on a spectrophotometer, read and record the absorption at a wavelength of 898 nm within 20 minutes;
6. Create a calibration curve from the data above and determine the straight-line equation.

2.2.2.2. The analysis procedure is carried out by:

1. Put a 50 mL sample of laundry wastewater in an Erlenmeyer flask.
2. Add one drop of phenolphthalein indicator to the sample, if pink color forms, then add 5 N H_2SO_4 drop by drop until the color disappears.
3. Add 8 mL of the mixed solution and homogenize.
4. The solution was left for 20 minutes.
5. Put ¾ of the cuvette volume into the solution and measure the absorbance using a UV-Vis spectrophotometer at a wavelength of 898 nm. Determination of phosphate levels was carried out on laundry waste samples before and after processing with PET plastic-activated carbon

2.3 Equations

Calculation of phosphate content can be calculated using equation 1 [15]

$$\text{Phosphate content } \frac{mg}{L} = Cx\ fp \quad (1)$$

Note :

C = concentration obtained from measurement results (mg/L);

fp = dilution factor.

Calculation of adsorption effectiveness using the Langmuir equation and the Freundlich equations the following equation:

$$Qe = K.\ Ce^{1/n} \quad (2)$$

For the linear form of the above equation it can be changed by taking the logarithmic form:

$$Log\ Qe = Log\ K + \frac{1}{n} Log\ Ce \quad (3)$$

Note :

Qe= Adsorption effectiveness (mg/g)

K= Maximum adsorption capacity (mg/g)

N= Adsorption constant

Ce= Equilibrium concentration (mg/L)

By creating a Ce/Qe curve relative to Ce, a linear equation is obtained with an intercept of 1/a and slope (b/a), so that the values of a and b can be calculated from the size of the values of a and b, indicating the adsorption capacity. A satisfactory adsorption isotherm approach was described by Freundlich law. According to Freundlich, if y is the weight of the solute per gram of adsorbent and c is the concentration of the solute in the solution [15].

3. RESULTS AND DISCUSSION

Making adsorbent is carried out through dehydration, carbonization and activation. Dehydration is reducing the air content contained in raw materials using sunlight. After being heated, PET plastic becomes a solid with the shape of a container or cup, is black in colour, and produces a yield of 24.62%. This heating process causes PET plastic to lose a lot of mass. This lost mass is a volatile component. PET consists of monomers that easily release their bonds. Activation is a treatment of carbon which aims to increase or expand the pore volume and enlarge the diameter of the pores that have been formed during the carbonization process so that it affects the adsorption capacity [13]. Activation in this research was carried out chemically using an HCl solution. The aim of using HCl as an activator is to remove metal oxides in the charcoal that cover the pores. Moreover, acid has destructive properties that can enlarge the pores to maximise the adsorption process. The result of the activation process is carbon which has a size of 200 mesh, powder form, shiny black color, and produces a product yield for a concentration of 1 M of 22.79%; 5 M concentration was 21.28%; and the concentration of 10 M was 21.02%. The final mass of carbon from PET plastic decreases again after activation using HCl because the impurities in the carbon dissolve together with the HCl solution, and as a result, the carbon that has been activated using HCl becomes more porous.

Wastewater samples were taken from the laundry industry around the Lampung State Polytechnic location to test the wastewater characteristics. The waste is then analyzed for phosphate content and pH. Phosphate content analysis was carried out using a spectrophotometer, and pH analysis was performed using litmus paper.

Table 2. Phosphate content in laundry waste before the adsorption process

Repetition	PO_4 (mg/L)	Average PO_4 (mg/L)
1	4.21	
2	5.16	4.54
3	4.26	

The phosphate content in laundry waste is 4.54 mg/L on average. Phosphate content analysis was carried out three times showed in Table 2. Based on Table 3, it is known that the parameters of laundry waste water do not comply with the quality standards stipulated in the Minister of Environment and Forestry Regulation No. 5 of 2014 on the phosphate parameter with a parameter value of 4.54 mg/L, this value exceeds the specified threshold government, in this research an adsorption process was carried out using polyethylene terephthalate (PET) plastic adsorbent to reduce the phosphate content according to quality standards.

Table 3. Laundry wastewater quality

Parameter	Maximum levels allowed*	This Research
pH	6-9	7
Phosphate (PO_4)	2 mg/L	4.54 mg/L

*Quality Standards Minister of Environment Regulation No. 05 of 2014

The phosphate content analysis process was carried out on laundry waste samples before and after adsorption using an AE Lab brand UV-Vis spectrophotometer at a maximum wavelength of 898 nm and an absorbance time of 20 minutes. Before the analysis of phosphate content is carried out, calibration is carried out by making a standard curve.

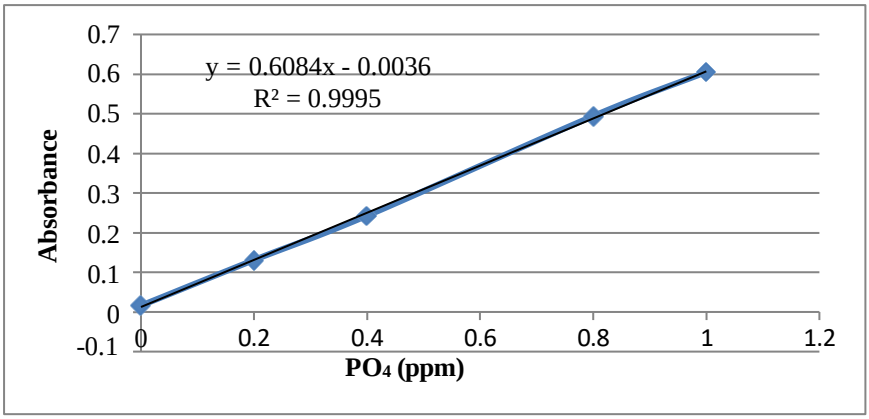

Figure. 1 Graph of the relationship between concentration and adsorption power of standard phosphate solutions

The analysis process was carried out in triplicate, and each sample was repeated three times. A dilution process is carried out to determine phosphate levels using a spectrophotometer. This refers to the book on the basics of UV-VIS spectrophotometry, which states that if the absorbance of the compound obtained is still too high, then the solution must be diluted [16]. In this study, dilution was carried out four times to obtain equation 1, and the result is shown in Table 4. Dilution is carried out on laundry waste samples before and after the adsorption process to make reading the absorbance value on a spectrophotometer easier. The results obtained for waste samples that have gone through the adsorption process can be seen in Table 4.

Table 4. Phosphate content in laundry waste after the adsorption process

Sample	Absorbance	Concentration (mg/L)	fp	PO_4 (mg/L)
C1P1	0.47	0.78	4	3.11
C1P2	0.47	0.78	4	3.13
C1P3	0.47	0.78	4	3.12
C2P1	0.38	0.64	4	2.56
C2P2	0.36	0.60	4	2.41
C2P3	0.35	0.58	4	2.32
C3P1	0.36	0.60	4	2.41
C3P2	0.29	0.48	4	1.90
C3P3	0.32	0.53	4	2.12
AP1	0.45	0.75	4	2.94
AP2	0.49	0.81	4	3.24
AP3	0.40	0.65	4	2.62

Note: C1 = 1M, P1 = first repetition, C2 = 5M, P2 = second repetitions, C3 = 10M, P3 = third 3 repetitions, A = Commercial Activated Carbon, fp = Diluent Factor

The results obtained in each repetition obtained the average value of the phosphate content analysis after the adsorption process, according to Table 5. After the adsorption process, the samples were sampled with concentrations of 1 M, 5 M, and 10 M and commercial activated carbon samples as a comparison. Commercial activated carbon is activated carbon purchased on the market in an active state with a 12x30 iodine number >900 specification. The aim of using activated carbon purchased on the market is to compare the results obtained with the adsorbent produced in this research.

Table 5. Average Phosphate Content After the Adsorption Process

Sample	PO_4 (mg/L)
C1	3.12
C2	2.43
C3	2.14
A	2.95

Note: C1 = 1M, C2 = 5M, C3 = 10M, A = Commercial Activated Carbon

The research results on plastic adsorbent with an HCl concentration of 1 M can reduce the phosphate content to 3.14 mg/L (27.75%). Based on previous research, the percentage reduction in phosphate levels using a 1M HCl solution concentration can be reduced by 45.45%. This can occur due to several factors, such as the type of plastic used, polyethylene, and the initial activation process where the carbon is soaked using acetone solution for 24 hours before being activated using 1 M HCl for 2 hours [16]. In this research, activating carbon from plastic with an HCl concentration of 5 M can reduce the phosphate content by 2.43 mg/L (46.47%). Activation of carbon from plastic with a concentration of 10 M HCl can reduce the phosphate content by 2.14 (52.86%). In the other research, the percentage reduction in phosphate levels in laundry waste was 89.46% using 10 M HCl activation solution [9]. This occurred because it was influenced by several factors, such as the use of a different type of plastic raw material, there are polyethylene and the presence of stirring during the carbon activation process, with a speed of 300 rpm, the stirring process during activation can affect effectiveness because there is continuous contact between the carbon and the activator solution so that the activation process is maximized.

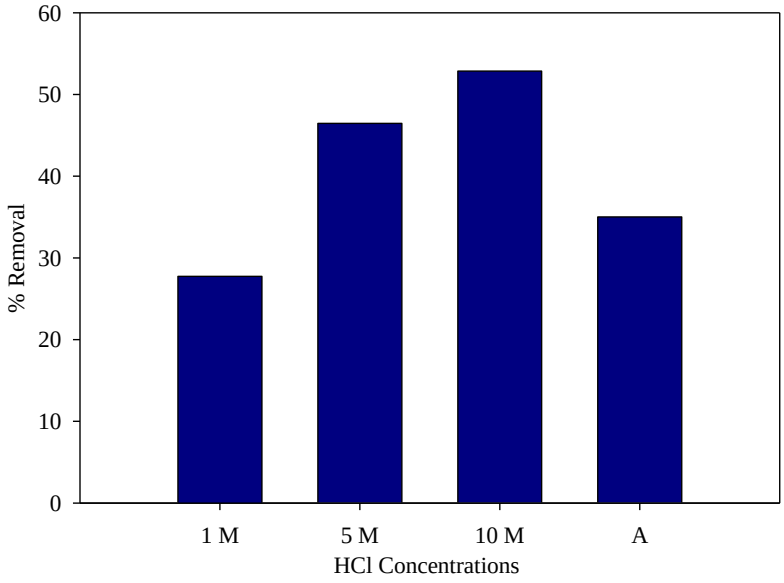

Figure 2. Percentage reduction in phosphate content

Determine the % removal by subtracting the initial phosphate content in laundry waste from the phosphate content after the adsorption process and then multiplying by 100% so that the results can be seen in Figure 1, it can be seen that the concentration of the activation solution greatly influences the effectiveness of reducing phosphate levels in laundry waste. Reduction effectiveness is the ability of the adsorbent to reduce phosphate levels in laundry waste. The value of reducing phosphate levels was not the same from each treatment, and the best conditions were obtained, namely by adding activated carbon activated with HCl at a concentration of 10 M because it could reduce the phosphate content by 2.14 mg/L. Commercial activated carbon (A) is activated carbon purchased on the market in an active state with a 12x30 iodine number >900 specification. The aim of using activated carbon purchased on the market is to compare the results obtained with the activated carbon produced in this study, reducing phosphate levels. Using commercial activated carbon of 35%. Activated carbon with 10 M HCL activation reduced phosphate content about 52.86%. Acidic pH will cause the adsorbent to be positively charged, and a positive charge will be formed on the adsorbent due to the entry of H+ ions on the surface of the adsorbent, which will form hydrogen bonds. Before adsorption, the H^+ ions on the surface bind with other anions. The presence of hydrogen bonds causes the surface of the adsorbent particles to become positively charged so that they can bind negatively charged phosphate ions (PO_4^{3-}). This allows bonding to occur with the adsorbent [16].

Important factors that can influence the quality of activated carbon as an adsorbent are surface area and particle size. The greater the surface area of carbon, the greater its adsorption power on molecules. The particle size factor determines whether or not a molecule can enter the pore. Suppose the available carbon pore size is smaller than the size of the molecule to be adsorbed. In that case, the adsorption process will not occur because the molecule cannot enter the activated carbon pore [13]. An analysis of the surface area and particle size of activated carbon can be carried out using the BET (Brunauer-Emmet-Teller) method. The sample was activated using a 10 M HCl solution. This sample was able to reduce phosphate levels by 52.87%.

Table 6. Adsorbent data with BET analysis

No.	Sample	Surface Area, m^2/g	Nanoparticle Size, nm
1.	C3	203,12	29,54

The previous researchers found that the surface area value of activated carbon produced from PET plastic waste is better done using physical activation because it produces a larger surface area value than the surface area results in this study. The following research states that the surface area produced in the chemical activation process is quite high, while the value for physical activation is high [14]. The test results using BET stated that the surface area of the activated carbon produced in this study was 203.12 m^2/g, which meets the characteristics requirements for active carbon, namely, between 200-2000 m^2/g [19]. Apart from the surface area value, there is also the particle size of the activated carbon, where the results obtained were 29.54 nm, this value shows that the type of activated carbon resulting from this research is classified as mesoporous, where the value for the mesopore size is 2-50 nm [13]. Based on Table 6. The adsorbent's surface area and particle size are 203.12 m^2/g and 29.54 nm. Several research studies on making active carbon from PET plastic waste have given different results. Adsorbent from PET plastic by physical activation using a CO_2 gas flow obtained a surface area value of 1591.72 m^2/g [4]. Adsorbent from PET plastic waste goes through a carbonization process at a temperature of 800°C for 60 minutes and physical activation using N_2 and CO_2 gas for 240 minutes to produce activated carbon, which has a surface area of 790 m^2/g [17]. Research on making adsorbent from PET plastic bottle waste with different activation treatments. Physical carbon activation is carried out using N_2 gas, while chemical activation uses an 85% KOH solution. Physically, adsorbent has a surface area value of 1235 m^2/g, while adsorbent produced through a chemical activation process produces a surface area value of 1002 m^2/g [18]. Determination of adsorption capacity is carried out to determine an adsorbent's ability to adsorbate. The results of the analysis of adsorbed phosphate levels at several concentrations can be seen in Table 7.

Table 7. Average phosphate content adsorbed using PET-activated carbon

Activator (M)	**Co (mg/L)**	**Ce (mg/L)**	**Co-Ce (mg/L)**	**Qe (mg/g)**
1	4.54	3.14	1.42	0.0873
5	4.54	2.43	2.11	0.1316
10	4.54	2.14	2.40	0.1499

Note:Co= Initial concentration of PO4 content, Ce = Final concentration of PO4 content, Qe = Adsorption Capacity

Based on Table 7, it can be seen that the average adsorbed phosphate content with the phosphate concentration used was 4.54 mg/L respectively, resulting in the highest adsorption capacity on activated carbon with 10 M activator, namely 0.1499 mg/g with the lowest adsorption capacity on 1 M concentration of activated carbon is only 0.0873 mg/g, which means that the concentration of active carbon is directly proportional to the ability of active carbon to adsorb phosphate levels in liquid waste from the laundry industry, this can be seen in Figure 2. Based on Figure 2, the adsorption capacity of activated carbon from PET plastic waste at phosphate levels increased up to an HCl activator concentration of 10M with adsorption capacity values respectively for activator concentrations of 1M, 5M and 10M, and there are 0.09 mg/g; 0.13 mg/g; and 0.15 mg/g. The limited adsorption capacity of activated carbon from PET plastic with an HCl activator concentration of 1 M, obtained an adsorption capacity of 0.15 mg/g [20]. Meanwhile, adsorption capacity of activated carbon from polyethylene plastic on the phosphate content in liquid laundry waste in Semarang with an active carbon activator concentration of 1M HCl obtained an adsorption capacity of 0.68 mg/g [16]. The adsorption process describes the relationship between the substance adsorbed by the adsorbent and the pressure or concentration at an equilibrium state at a fixed temperature, usually called the adsorption isotherm.

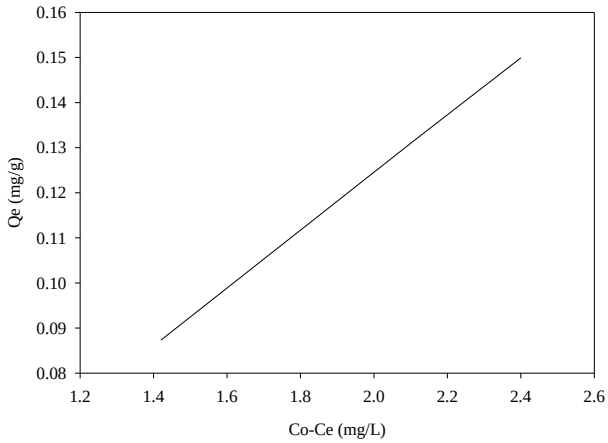

Figure 3. The relationship between PO_4 concentration and adsorption capacity

Langmuir adsorption isotherm occurs when a single layer is formed based on the assumption that the ability of particles does not depend on their proximity to each other. A good linearization graph proves testing of the Freundlich and Langmuir adsorption equations and has a coefficient of determination $R^2 > 0.9$ (close to 1). Figures 4 and 5 show that the adsorption equation for PET plastic-activated carbon towards reducing phosphate levels fulfills the Langmuir adsorption equation with an R^2 value of 0.98886.

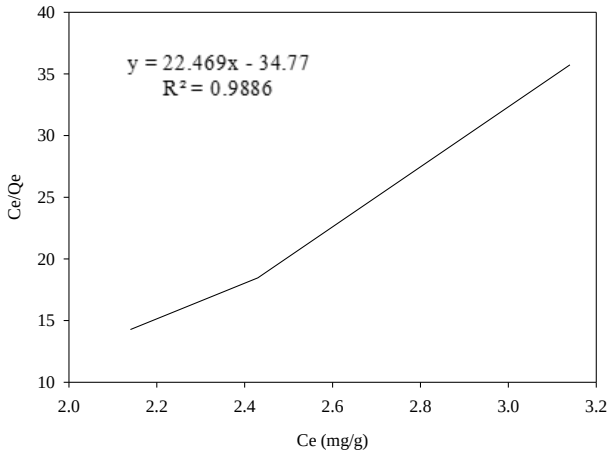

Figure 4. Langmuir isotherm graph for PER-activated carbon adsorption on decreasing phosphate levels

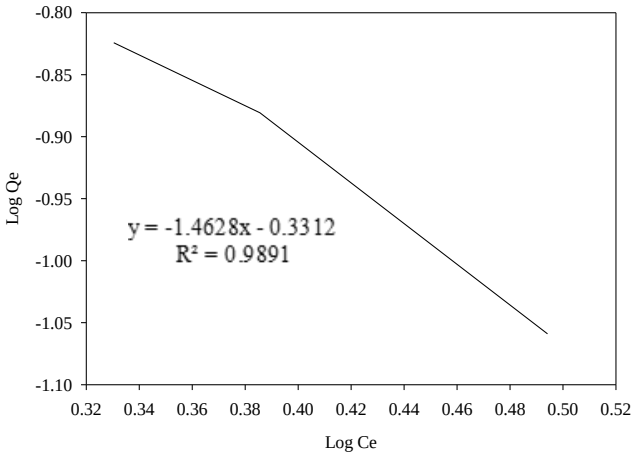

Figure 5. Freundlich isotherm graph for PET activated carbon adsorption against decreasing phosphate content

This shows that the adsorption of activated carbon from PET plastic waste towards phosphate reduction only takes place in one layer and the surface is homogeneous because each active site can only adsorb one molecule, besides being able to describe the equilibrium condition between the surface and the solution which can be reversible (reversible).

The maximum adsorption capacity of activated carbon in the phosphate absorption process was determined using the Langmuir adsorption equation. The results of data analysis show that the adsorption capacity of PET plastic active carbon for the Langmuir pattern is 34.77 mg/g, meaning that PET plastic active carbon per gram is able to absorb a maximum of 34.77 mg of phosphate content contained in liquid laundry waste.

4. CONCLUSION

The best efficiency for reducing phosphate content was obtained in activated carbon activated with 10 M HCl, namely 52.87%, with an initial waste content of 4.54 mg/L to 2.14 mg/L in liquid laundry waste after the adsorption process. The characteristics of activated carbon from PET plastic waste were carried out using the BET test on samples, namely on activated carbon samples that were activated using a 10 M HCl solution and the results obtained were for a surface area value of 203.12 m^2/g and a particle size value of 29.54 nm. The maximum capacity of activated carbon from PET plastic waste is 34.77 mg/g. This means that a PET adsorbent surface area of 203.12 m2/g is capable of adsorbing 34.77 mg/g of phosphate in laundry waste.

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