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Magnetite-Activated Carbon Composite to Reduce Pollutant:Review

Muhammad Rafli[1], Reza Mega Wahyuni[2], Nilna Muna Zahiro[3], I Wayan Dasna[4*]

Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Jln. Semarang 5, Malang 65145, Indonesia

Corresponding Author: idasna@um.ac.id

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Abstract

Pollution is a serious environmental problem. One of the causes of pollution is the presence of heavy metals. Besides heavy metals, there are plastics that cause serious problems in the environment because they are difficult to decompose. These two problems appear an idea about synthesizing activated carbon-magnetite (Fe_3O_4) composite based on polyethylene that can absorb heavy metals. The method used literature review of relevant articles. This study examines the properties of magnetite both physical and chemical along with the applications and benefits of magnetite in daily life. This study can become a new perspective effort to reduce heavy metals pollution using plastic waste as a composite with Fe_3O_4.

Keywords: Plastic, pollution, magnetite composites, Fe_2O_3.

INTRODUCTION

Dependence on the use of fossil fuels in the transportation, industry, and energy sectors which reached 80% (EIA data for 2018) has an effect on increasing air pollution and decreasing human health. (Kumar et al., 2019). One of the characteristics of air pollution is the increased of heavy metals content such as Zn, Cd, Pb, and Hg (Wan et al., 2019). Small concentrations of heavy metals play a major role in metabolism and growth of plants and animals, but increasing concentrations can cause some toxic effects in humans (Purushotham et al., 2013). Apart from entering the environment naturally, heavy metals can enter through anthropogenic activities, such as mining, smelting, waste disposal, use of pesticides or inorganic fertilizers, and atmosphere deposition. (Haiyan & Stuanes, 2003). The most pollutants from the atmosphere are particulates measuring 2.5 μm (PM2.5) which are easily inhaled, causing several diseases such as damage to respiratory organs and nerve damage (Ma, Liu, Liu, & Bi, 2019; Sankhla, Sharma, & Kumar, 2017). Research on the prevention of air pollution which causes many diseases is needed by applying science and technology. One of the effective ways to reduce pollutants in the air is to adsorb pollutants using adsorbents.

The adsorption process has the advantage of being easy to use, economical, simple design, and high efficiency in absorbing pollutants (Al-Ghouti, Da'ana, Abu-Dieyeh, & Khraisheh, 2019; Maddah, Yavaripour, Ramedani, Hosseni, & Hasanzadeh, 2020). Activated carbon is one of the most widely used adsorbents for adsorption, so it can be used to absorb heavy metals in the air. Activated carbon is an adsorbent that is widely used to remove various kinds of organic and inorganic pollutants, polar and non-polar compounds in the liquid and gas phases(Ao et al., 2018). Activated carbon was first reported as a gas adsorbent in 1793 by Dr. D.M. Kehl used wood charcoal to reduce odors and in 1872 as a gas mask with a carbon filter was used in the chemical industry to prevent mercury vapor inhalation (González-García, 2018). Commercial activated carbon is usually made from wood, coal and lignite (S. Wong, Ngadi, Inuwa, & Hassan, 2018). The disadvantages of using these sources include: (1) these materials are not environmentally friendly, (2) require high production cost, and (3) if the carbon source comes from wood, it can cause damage ecosystem although it can still be used as an absorben. In this paper, in addition to a review, a new problem solving is also carried out, namely the manufacture of activated carbon using plastic waste as raw material which is a pollutant in soil and water.

The solutions presented have advantages including: (1) Reducing production costs due to available raw materials, (2) being an effort to overcome environmental problems due to plastic waste which is difficult to degrade, and (3) overcoming air pollution with pollutants so that it is very effective in solving water, soil and air pollution. As a heavy metal adsorbent, carbon has an active surface that is rich in functional groups that will interact chemically/ physically with heavy metals, the functional groups can be improved by modifying the surface of the carbon (X. Yang et al., 2019). To increase the negative charge on the surface of the activated carbon, a modification was made using magnetite nanoparticles. Magnetite nanoparticles were chosen because they have the advantages of having a high surface area ratio and can be modified, good magnetic properties, reusable, economical, non-toxic, and have an active side spreaded on the surface so it is very potential if it is combined with activated carbon as an absorbent for heavy metals (Alfe, Ammendola, Gargiulo, Raganati, & Chirone, 2015; Giraldo, Erto, & Moreno-Piraján, 2013a; Jain et al., 2018).

There are no studies that have made activated carbon composites from plastics-magnetite nanoparticles with applications as an absorber of heavy metals in air. Research on pollutant adsorbents using magnetite nanoparticles has been widely carried out to adsorb pollutants in water such as Pb(II), Cu(II), Zn(II), and Mn(II). Although composites have never been applied to absorb heavy metals in the air, they have the ability to absorb heavy metals. Beside on the structure, magnetite nanoparticles can be used as adsorbents because they have an active side in the form of O atoms on the surface so they can interact with molecules using Lewis acid-base interactions (Alfe et al., 2015).Therefore, in this paper we will review activated carbon from plastic-magnetite nanoparticles and their suitability as an adsorbent of heavy metals in air.

ACTIVATED CARBON AS AN ADSORBENT

The carbon material is mainly composed of carbon atoms which have several allotropes including diamond, graphite, and fullerenes with various derivatives such as nanotubes and nanofibers (Menéndez-Díaz & I. Martín-Gullón, 2006). Sources of carbon material can be obtained, including from plants, vegetable oils, and waste. In several previous studies, most of the carbon sources were taken from plants and vegetable oils, including from papaya peel waste (Abbaszadeh, 2016), oak nut shells (Esra Altıntıg, Altundag, Tuzen, & Sarı, 2017), olive fruit waste Palm oil (Cazetta, 2016), harmala peganum seeds (Fazlzadeh, 2017), guava seed (Pezoti, 2016), spruce sawdust (Kazemi, 2016), cocoa shells (Saucier, 2015), bagasse (Sharma, 2019), *Moringa Oleifera* seeds (Reck, 2018), *Babassu* Coconut (Reck, 2018), Pine tree waste (Tonucci, 2015), *Parthenium* plant (Kamaraj, 2020), Rice husk charcoal (Li, 2019), Cucumber skin (Mahmoodi, 2019), and orange peel (Lam, 2017). Plants can be used as carbon sources because they consist of compounds that contain many carbon atoms, one of which is cellulose (Suhas, 2016). In addition, other studies also use non-plant waste such as rubber tire waste (Saleh, 2017), fabric waste (Taís L. Silva et al., 2018), and coal (C. Yang, 2020). Carbon material has the ability as an adsorbent because it has layers and pores that allow a molecule or particulate to be adsorbed on the surface or insertion between layers and pores (Figure 1).

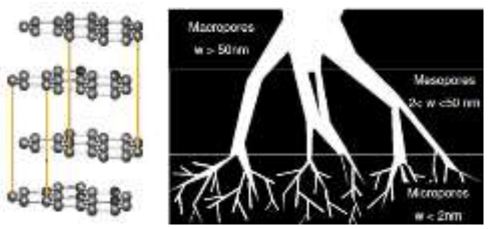


Figure 1. Carbon Structure. (a) Layer (Housecroft dan Sharpe, 2012) dan (b) Pore (Menéndez-Díaz dan I. Martín-Gullón, 2006)

To increase the adsorption capacity, carbon activation can be carried out both thermally (for example, pyrolysis is then oxidized) and chemically (for example using phosphoric acid) (Menéndez-Díaz dan I. Martín-Gullón, 2006). The activated carbon surface will have a functional group as shown in Figure 1(Moseley, Rand, Davidson, & Monahov, 2018) so that it can attract polar molecules (dipole-ion force) and nonpolar (induced dipole-dipole force) (Reucroft, Simpson, & Jonas, 1971). The carbon with the different sources and material morphology will produce activated carbon with different surface areas and pore specifications. As a result, the capacity of activated carbon will vary when adsorbing certain species (Asuquo, Martin, Nzerem, Siperstein, & Fan, 2017; Lam, 2017; Li, 2019). The weakness of carbon adsorbent is its limited capacity so it is necessary to combine with other materials to increase its adsorption capacity. Research conducted by (Esra Altıntıg, Altundag, Tuzen, & Sarı, 2017b) shows that using activated carbon only, the adsorption capacity is 303.0 mg/g. Whereas after being composite with magnetite the adsorption capacity becomes 357.1 mg/g.

MAGNETITE NANOPARTICLES AND THEIR MODIFICATIONS

Magnetite nanoparticles are magnetite materials which have the compound formula Fe_3O_4. Magnetite nanoparticles have an active side in the form of O and metal atoms on the surface so they can interact with molecules using Lewis acid-base interactions (Alfe et al., 2015), so that it can be used to absorb heavy metal particles in the air which are positively and neutral. Magnetite nanoparticles which have a magnetic field are often used as adsorbents because they have the advantage of being easily separated by external magnetic fields (Hadi Baseri & Tizro, 2017), The high specific surface area of the nanoparticles also leads to a high adsorption capacity (Bao, Fu, & Bao, 2013), and low toxicity (Z. F. Akl, El-Saeed, & Atta, 2016). Previous studies conducted the synthesis of magnetite nanoparticles using several methods, including coprecipitation and solvothermal. In the last 10 years, the majority of research on magnetite has been carried out by compositing it with other compounds to produce different characteristics, thereby increasing the adsorption capacity as research has been done by (Hadi Baseri & Tizro, 2017) and (Tanhaei, 2015). The disadvantage of magnetite nanoparticles when used as an adsorbent is that they tend to form aggregates, so it is necessary to modify them with other compounds (El-Dib, Mohamed, El-Shamy, & Mishrif, 2020).

CHARACTERIZATION STUDY OF ACTIVATED CARBON AND MAGNETITE-ACTIVATED CARBON NANOPARTICLE COMPOSITES

Activated carbon and activated carbon-magnetite nanoparticle composites that have been synthesized must be characterized using several instruments. To determine the success of activating carbon and activated carbon-nanoparticle magnetite composites, tests were carried out using the XRD technique.

Activated carbon that was successfully activated was then compared with JCPDS XRD data no. 7440-44-0, while the magnetite-activated carbon nanoparticle composite was compared with JPCDS 98-008-2450 (Figure 2c). One of the XRD results of the activated carbon is shown in Figure 3a above with a peak at 2ϴ about 25° dan 43° (Shamsuddin, Yusoff, & Sulaiman, 2016). These results show a peak at 2θ which is almost the same when compared to the results of our characterization of activated carbon that we have synthesized, namely the peaks of 25° and 44° (Figure 2a). The characterization results of the activated carbon-magnetite nanoparticle composites that we have synthesized compared to JPCDS 98-008-2450 also showed a peak at the same 2 which is at 31.73°; 35.19°; 43.01°; 53.56°; 57.02°; dan 62.56° (Figure 2c).

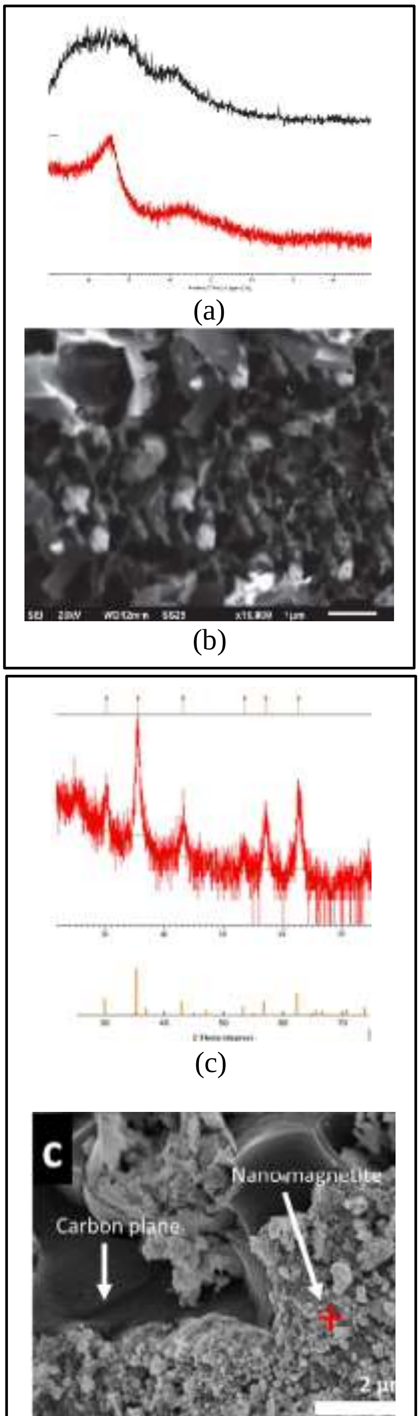
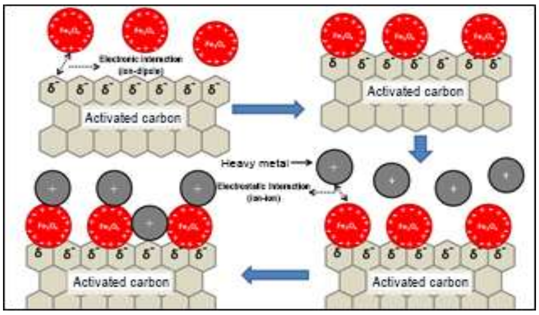


Figure 2. (a) Activated carbon XRD pattern (Shamsuddin et al., 2016), (b) SEM results of activated carbon (Yuliusman, Puspitasari, & Nafisah, 2019b), (c) XRD pattern of composite activated carbon-magnetite nanoparticles experimental results, (d) SEM results of activated carbon-magnetite nanoparticles composites (K. T. Wong et al., 2016).

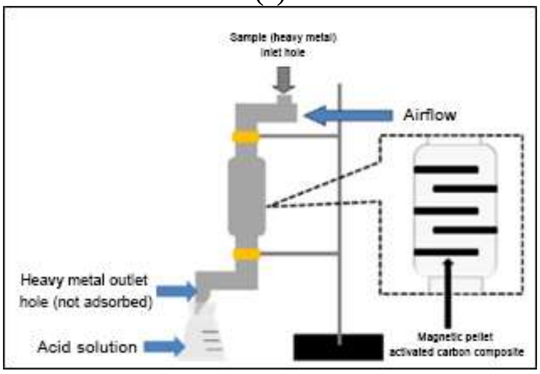
Characterization techniques to determine the microsutructure and surface morphology of activated carbon and magnetite-activated carbon-nanoparticle composites can be done using SEM. Research using a source of activated carbon from plastics was carried out by (Yuliusman, Puspitasari, & Nafisah, 2019), with SEM results shown in Figure 2b which shows a porous surface of activated carbon. The characterization of the activated carbon-magnetite nanoparticle composite is shown in Figure 2d. To test the specific surface area and pore character, the Brunaur, Emmett and Teller (BET) test was performed. Characterization using FTIR is used to determine the presence of functional groups on activated carbon and magnetite such as carboxyl, hydroxyl, and carbonyl which have specific wave numbers. The adsorption capacity of activated carbon and magnetite can be carried out using Freundlich and Langmuir isotherm models. The results of the characterization of activated carbon, magnetite, and their modification in several previous studies are shown in Tables 1 and 2.

COMPOSITE ACTIVATED CARBON-MAGNETITE NANOPARTICLES AS ADSORBENT OF HEAVY METALS IN AIR

Adsorption on activated carbon occurs in the presence of dipole ion interactions if the one bound is positively charged or induced dipole-dipole if the nonpolar compound is attached (Reucroft et al., 1971). The intermolecular forces that exist on adsorption using activated carbon are quite weak when compared to ion-ion interactions. Therefore, other useful compounds are needed to cause the surface of activated carbon to have a negative charge so that the electrostatic force becomes stronger, such as the addition of magnetite nanoparticles. Previous research on activated carbon composites-adsorbent magnetite nanoparticles has been carried out with different activated carbon sources such as oak nut shells (E. Altıntıg, 2017), Palm shells (Cazetta, 2016), and commercial activated carbon (Juang, 2018). Polyethylene plastic waste which has many C atoms can be used as a carbon source. The advantage of activated carbon from polyethylene plastic is that in addition to being able to carry out adsorption, it can also reduce plastic waste which is difficult to degrade. So, it can be used for reduce water and soil pollution. The resulting polyethylene plastic activated carbon is then composited with magnetite nanoparticles. The adsorption mechanism of heavy metal pollutants on the adsorbent and testing mechanism shown in Figure 3.



(a)



(b)

Figure 3. (a) The adsorption mechanism of heavy metal pollutants on the adsorbent, (b) Testing mechanism

Compared with activated carbon adsorbent only, the polyethylene-magnetite plastic activated carbon composite will increase the adsorption capacity of heavy metals in positively charged air because it has a more negative adsorbent surface in the presence of magnetite which has a negative charge on its surface. When a heavy metal is positively charged, it will be attracted to the composite due to the electrostatic force as shown in Figure 3a. Testing can be done by inserting a heavy metal sample into a device that has been fitted with an adsorbent with a certain thickness as shown in Figure 3b so that adsorption occurs. The metal that is not adsorbed will come out into the acid solution, then the metal that is not adsorbed will be tested using AAS.

Table 1. Characterization of activated carbon and its modification

Source	Modification	Adsorbed compound	Surface Area (m^2 g^{-1})	Total Pore Volume (cm^3 g^{-1})	Micropore Volume (cm^3 g^{-1})	Mesopore Volume (cm^3 g^{-1})	Average Pore Diameter (nm)	Adsorption Capacity (mg g^{-1})	Reference
Papaya skin waste	-	Lead (II)	15.26	0.0469	-	-	-	38.31	(Abbaszadeh, 2016)
Commercial	Modification with metal oxides	Acetaldehide	-	-	-	-	-	Increase 20% with La_2O_3	(Baur, 2015)
Oak shell seeds	-	Methylene blue	870.356	-	0.27	-	-	330.0	(E. Altıntıg, 2017)
Oak shell seeds	Magnetite	Methylene blue	940.132	-	0.23	-	-	357.1	(E. Altıntıg, 2017)
Olive fruit waste	-	Copper (II)	1194	0.56	0.552	0.009	2.072	8.832	(Bohli, 2015)
Olive fruit waste	-	Cadmium (II)	1194	0.56	0.552	0.009	2.072	34.173	(Bohli, 2015)
Olive fruit waste	-	Lead (II)	1194	0.56	0.552	0.009	2.072	84.33	(Bohli, 2015)
Palm shells	Magnetite	Sunset yellow dye	1:1 = 372 2:1 = 337 3:1 = 238	1:1 = 0.210 2:1 = 0.172 3:1 = 0.118	1:1 = 0.156 2:1 = 0.141 3:1 = 0.101	1:1 = 0.054 2:1 = 0.031 3:1 = 0.017	1:1 = 2.26 2:1 = 2.04 3:1 = 1.98	22.31	(Cazetta, 2016)
Harmala peganum seeds	Coated with ZnO nanoparticles	Chromium (VI)	442	0.233	-	-	2	74.67	(Fazlzadeh, 2017)
Guava seeds	-	Amoxicillin	2573.6	-	-	-	Mesopore :4.42 Micropore :1.96	570.48	(Pezoti, 2016)
Orange peel	-	Malachite green dye	1350	0.60	0.38	0.22	23	28.5	(Lam, 2017)
A mixture of plastic, paper and palm oil waste	-	Malathion	115.17	-	-	-	-	32.1	(Habila, 2015)
Waste paper	-	Methylene blue	1670	1.14	0.06	-	29.8	350	(Novais, 2018)
Cocoa shell	-	Sodium diclofenac	619	0.315	-	-	4.8	DFC = 63.47 NM = 74.81	(Saucier, 2015)

Continued

		(DFC) and nimesulide (NM)						
Rubber tire	Composite with magnetite, modified with polyethyleneimine	Uranium (VI) ion	303	-	-	-	62	115.31	(Saleh, 2017)
Moringa *Oleifera seeds*	-	Tartrazine	18.93	0.026	0.003	0.023	2.571	91.27	(Reck, 2018)
Babassu Coconut	-	Tartrazine	624.30	0.351	0.304	0.028	1.400	31.10	(Reck, 2018)
Fabric waste	-	Remazol Brilliant Blue R	1582	1.005	0.17	0.39	3.6	292	(T.L. Silva, 2018)

Table 2. Characterization of magnetite and its modification

Composites	Methode	Diameter (nm)	Adsorbed substance	Capacity (mg/g)	Reference
Hidroxyapatite	Coprecipitation	-	Pb(II)	598.8	(Dong, Zhu, Qiu, & Zhao, 2010)
Graphene Oxide	Solvothermal	9	Rhodamine B Malachite Green	13.15 22	(Sun, Cao, & Lu, 2011)
Dodecylbenzene sulfonate	Coprecipitation	53	-	-	(Eskandari & Shariati, 2011)
Montmorillonite (MMT) Polyethylenimine (PEI)	Coprecipitation	40	Cr (VI)	PEI 800 g/mol = 8.77 PEI 25000 g/mol = 7.69	(Larraza, López-Gónzalez, Corrales, & Marcelo, 2012)
Graphene Oxide	two-step reaction	13	Hg (II)	289.9	(Fu, 2013)
Zeolit	Precipitation	17			(Yamaura & Fungaro, 2013)
Graphene Oxide	-	-	SDZ STZ SDD	10 8 6	(Shi & Ye, 2014)
Chitosan		36, 30, dan 29	Methyl orange	417	(Tanhaei, 2015)

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Al_2O_3					
Maize tassel	Coprecipitation		Cd(II)	52.05	(Guyo, 2015)
Carbon	Coprecipitation		CO_2	20	(Alfe, 2015)
Acrylamido-amineamidoxime-co-2-acrylamido-2-methylpropane sulfonic acid (AO/AMPS)	-	-	U(VI)	476.190	(Z. Akl, 2016)
-	Coprecipitation		As(V) Cu (II)	-	(Iconaru, 2016)
Graphene Oxide	Solvothermal	10 dan 30	Methylene blue		(Sharif, 2017)
-	Coprecipitation	60±10	Ni (II)	46.513	(H. Baseri, 2017)
Graphene	Coprecipitation				(Musa, 2018)
cetyltrimethylammonium bromide (CTAB)	Coprecipitation	10-20	Congo red	93.46	(Saksornchai, 2018)
naturalbentonite	-	2-50	Cu (II)	46.94	(Mohammed, 2018)

Potential Development of Magnetite-Activated Carbon Nanoparticle Composites

In the future, the resulting composites can be added in factory chimneys and in the exhaust of motorized vehicles where the air is prone to containing heavy metals. The polyethylene-magnetite nanoparticle composite can be printed in the form of a plate and then arranged like an electric mosquito repellent plate as shown in Figure 4.

In addition, the activated carbon-nanoparticle magnetite composite can also be used as an antimicrobial when combined with other species such as Ag (Furlan et al., 2017) so it is necessary to be installed in central air conditioning. Based on this explanation, it is known that the polyethylene-magnetite nanoparticle composite is very potential to be researched and developed.

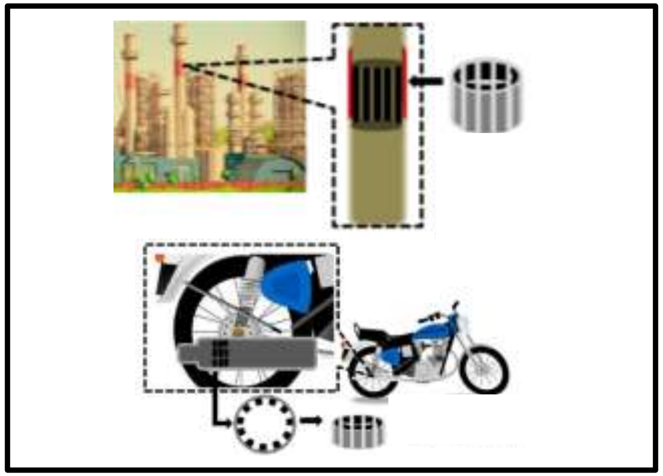

Figure 4. Application and arrangement of adsorbents in factory chimneys and motor vehicle exhausts

CONCLUSIONS

Activated carbon can be synthesized from polyethylene plastic waste which has many carbon atoms. To increase the adsorption capacity of the material, compost is carried out using magnetite which has a negative charge on its surface. The composites formed can adsorb heavy metals in the air by interacting with ions so that they can reduce air pollution.

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