

**STUDY ON REDUCTION OF METALS CONTENT Fe, Ni and Cu ON
SEPARATING LIQUID WASTE SYSTEM WITH HIGH GRADIENT
MAGNETIC SEPARATION (HGMS) USING ADSORBENT
NANOPARTICLES Fe₂O₄
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Abstract Research has been carried out to determine the effective level of artificial metals waste purification such as Cu, Ni and Fe using High Gradient Magnetic Separation (HGMS). Electromagnetic filter is made from Polyvinyl Chloride (PVC) pipe with 1-inch in diameter and coiled by wire (0,45 mm in diameter), small pipes as a filter with diameter of 500 μ m consisting of 1173 coil. Purification is done by varying the magnetic field strength i.e 2,3 Gs, 5,1 Gs and 7,7 Gs. In this investigation, three treatments are given by changing the magnetic field direction, i.e the directions of the magnetic field are parallel, antiparallel and perpendicular in respect to the sample flow. And then, purification samples were analyzed using Atomic Absorption Spectroscopy (AAS). The result showed that the percentage of Cu tends to decrease, Ni constant and Fe increase. Magnetic field with opposite direction to the sample flow, percentage of Cu (II) i.e 92.90% , 94.96% , 93.15% and perpendicular to the sample flow i.e 96.58% , 94.71% , 95.67%. Magnetic field with opposite direction to the sample flow, the percentage of Ni (II) i.e 99.16% , 99.11% , 99.20% and perpendicular to the sample flow i.e 99.32% , 99.38% , 99.30%. The percentage of Fe (II) maximally in the magnetic field with opposite to the sample flow i.e 100%, 100%, 100% and perpendicular to the sample flow i.e 100%, 100%, 100%. This result is caused by the Fe (II), a ferromagnetic material, which has a spontaneous magnetic moment and a little valence electrons paired compared to Cu (II) and Ni (II). So, when the magnetic field is applied to the artificial waste water, spin orientation in Fe (II) will easily tend to align and attach to small pipes in the HGMS system

Keywords HGMS, metals waste and AAS

1. INTRODUCTION

Water is a vital requirement for living, especially humans. All human activities in the household, industry and agriculture need water. Along with the increasing of human activities, the balance of aquatic ecosystems are beginning to fail so that they can pollute the environment. According to the Law of the Republic of Indonesia No. 23 of 1997 about Environmental Management, environmental pollution is the entry of living things, matter, energy and other components into the environment by human activities so that the quality decreases to a certain level that causes process in environmental to be unable to work in accordance with the

designation. Industrial waste water that contains heavy metals are not disposed immediately into rivers, reservoirs or the ocean because the presence of heavy metals are very dangerous to human life, animals and the environment. Heavy metals are pollutants that are dangerous to human health because it cannot decompose naturally but precipitate the residue.

Purification is the ability to clean up contaminants through chemical biological, and physical processes in the water. There are two methods usually used for purification: conventional purification and purification by using adsorbent. The adsorbent is a solid substance that can adsorb certain components of a fluid phase

(Carabante, 2012). There are two kinds of adsorbent: magnetic and non-magnetic. Fe₃O₄ magnetic adsorbent is chosen because it is easily magnetized so it can attract heavy metals and attach to the surface of Fe₃O₄. But, using Fe₃O₄ adsorbent cannot adsorb maximally so it must be repeated many times. Therefore, a new method is tried to perform in this study, namely High Gradient Magnetic Separation (HGMS) to reduce metal content such as Fe, Ni and Cu in artificial wastewater using adsorbent nanoparticles Fe₃O₄. HGMS is a separation technique based on magnetic force that allows the separation of weakly magnetic particles from non-magnetic which cannot be separated conventionally by a magnetic separator.

2. THEORY

2.1. Magnetic and superparamagnetic nanoparticle

The magnetic nanoparticles are magnetic materials that have only one magnetic domain (single domain). The study of magnetic nanoparticles generally has the size in the range of 1 to 100 nm. Superparamagnetic is a material that has a large magnetization in the present of external magnetic field, and the average value of magnetization is zero when there is no external magnetic field. Superparamagnetic material consists of a group of small-sized ferromagnetic, but if the grain size is very small, magnetic moment will be oriented randomly under thermal fluctuations. As a result, the overall material is not magnetized except under the influence of a magnetic field (Xu, 2009).

2.1. High Gradient Magnetic Separation (HGMS)

HGMS is a separation technique based on magnetic force and allows the separation of weakly magnetic particles from non-magnetic that cannot be separated by a conventional magnetic separator. As paramagnetic particles in suspension pass through the magnetic field there will be some force acting on it. A paramagnetic particle is a particle with a permanent magnetic dipole moment but without specific direction. The resulting style is:

$$\vec{F}_p = \vec{F}_m + \vec{F}_d + \vec{F}_g. \quad (2.1)$$

\vec{F}_m represent the magnetic force, \vec{F}_d drag force of the fluid and the \vec{F}_g buoyance force.

Magnetic force \vec{F}_m acting on a particle can be generally described as

$$\vec{F}_m = V_p \vec{M}_p \cdot (\nabla \vec{H}) \quad (2.2)$$

V_p is the volume and \vec{M}_p particle magnetization. \vec{H} is the magnetic field strength. The equation shows that \vec{F}_m increases with magnetic field gradients. Because of the non-permanent magnetization \vec{M}_p proportional to \vec{H} , the magnetic force is also proportional to the magnetic field. Drag force given by Stokes law :

$$\vec{F}_d = 6\pi\eta \frac{d}{2} \left[\vec{v}(\vec{r}) - \frac{d\vec{r}}{dt} \right] \quad (2.3)$$

is the viscosity of the fluid and dr/dt for speed. d is the particle diameter and $v(r)$

It shows that the drag force increases with viscosity, particle size and velocity difference between fluid and particle. Buoyant force depends on density, volume, and gravity. It means that the buoyant force depends on the particle and fluid density difference (Ottinger, 2009).

Particles will remain in the column, if greater than the force and . This will allow the separation of the particles, because they live in the column while the non-magnetic component flows. The degree to which dominating force F perpendicular style, determine the particle capture efficiency. This is shown in Figure 2.1.

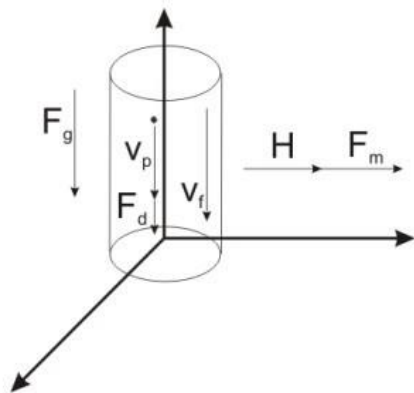


Fig. 2.1 Direction Force: This image shows how the force should be directed to have a possible setting for magnetic separation. (Ottinger, 2009)

There are three possible settings of the spatial arrangement of the wire, a magnetic to reach the high value of maximum field gradient. In general, all three are described as transverse direction (a), longitudinal (b) and axial (c) cases and is shown in Figure 2.2 (Ottinger, 2009).

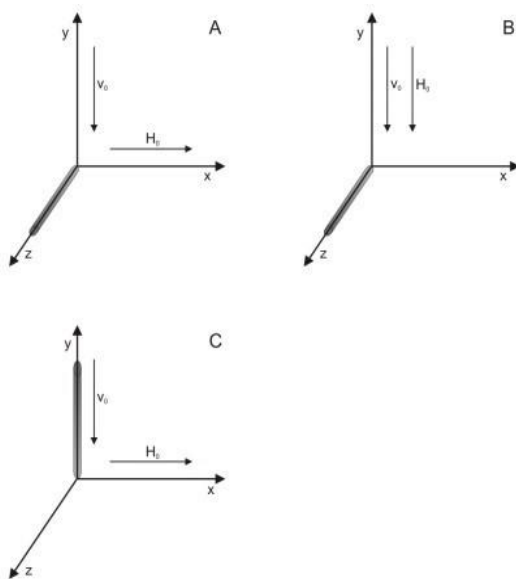


Fig. 2.2 Configuration for the geometric representation of magnetic separation. Of the three geometrical configurations: (A) shows the transverse, (B) longitudinal, and (C) axial configuration of wire in a magnetic field (Ottinger, 2009).

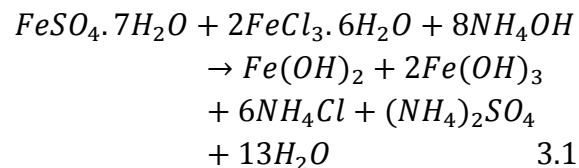
3. METHODS

3.1. Equipment

Equipment used in this research are spatula, magnetic stirrer, and pipette sterilized in the ultrasonic cleaner for 15 minutes. The sterilization is used to synthesize of super paramagnetic Iron Oxide nanoparticles (SPIONs) magnetite (Fe_3O_4), make artificial wastewater and sewage purification. While HGMS is cleaned by spraying with aquades and dryer.

3.2. Synthesis of Nanoparticles Fe_3O_4 coprecipitation method

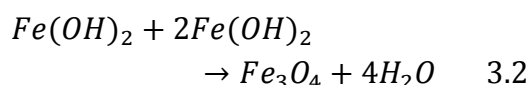
In this study synthesis of nanoparticles Fe_3O_4 refers to the previous research (Pauzan, 2013). Nanoparticle synthesis is carried out as follows: as much as 4.1703 g and as much as 8.109 g weighed with digital scales, then the two materials are mixed and dissolved with 30 ml of distilled water. The solution was stirred using a magnetic stirrer for 10 minutes to get homogeneous solution. After that, with a concentration of 10 % (60 ml) was added drop by drop and stirred at 60 until 90 min at the speed 450 rpm. At this stage, the chemical reaction which occurred is written in equation 3.1.



The next process after stirring the solution was the precipitation. A permanent magnet attached at the bottom of the beaker glass is used to accelerate the precipitation process. When the precipitation was completed, water in the beaker glass was removed and replaced with new water (distilled water).

The purpose of the process is to minimize the dissolved salts that react participated previously in order to obtain pure Fe₃O₄ sediment.

The precipitate was washed then poured into a hot plate and dried in the furnace at a temperature of 80 for 2 hours. Samples were dried and crushed to form a powder. At this stage, the chemical reaction is written in equation 3.2.



3.3. Artificial Wastewater of Fe, Ni and Cu

The process of making artificial waste water of Fe, Ni and Cu use basic precursors FeSO₄, 7H₂O, NiSO₄, 6H₂O Required of Preparation of 1.5 g of material with a ratio of 1 : 1 : 1 are required for manufacturing the test samples, dissolved in 1000 ml of distilled water and followed by adding 20 drops of HCl.

Method of making artificial metal waste Fe, Ni and Cu as follows: an amount 1.5 g of and were weighed using digital scales and 1000 ml of distilled water was poured. The solution was stirred using a magnetic stirrer at room temperature for 4 hours and this was followed by adding 20 drops of HCl. Once the manufacturing process was complete, artificial wastewater was put into containers.

3.4. Purification Experiment

Experiments which were conducted at the Laboratory of Materials Physics and Instrumentation, Department of Physics, Faculty of Mathematics and Natural Sciences Yogyakarta included filtering metals Fe, Ni and Cu. Purification was done

by varying the magnetic field of 2.3 Gs, 5.1 Gs, 7.7 Gs and magnetic field direction are the same, opposite and perpendicular to the sample flow. Step of filtration experiments are as follows:

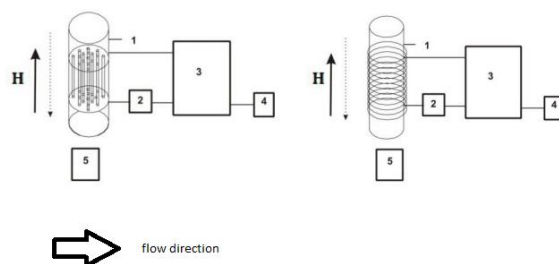
1. Regulators connected with a voltage source is turned on, the digital multimeter is installed at the position ON with the maximum current 10 A.
2. Currents are regulated by turning the switch on the regulator until the digital multimeter shows the value of 0.5 A, 1 A and 1.5 A.
3. Samples were poured into the pipe HGMS slowly.
4. Purification results are taken from the 2,3 Gs, 5,1 Gs, 7,7 Gs.
5. The experiment was repeated for different samples and currents with the field opposite direction to the sample flow.

3.5. Schematic Arrangement of Equipment

3.5.1. Magnetic field parallel columns

Table 3.2 Current and magnetic field used in the experiment

| No | Current (A) | Field (Gauss) |
|----|-------------|---------------|
| 1. | 0.5 | 2.3 |
| 2. | 1 | 5.1 |
| 3. | 1.5 | 7.7 |



Specification Figure 3.1 .

1. High Gradient Magnetic Separation (HGMS)
2. Digital Multimeter
3. Rectifier circuit
4. Regulator
5. Beaker glass

3.5.2. Magnetic field parallel columns

Table 3.3 Current and magnetic field used in the experiment

| No | Current (mA) | Field (Gauss) |
|----|--------------|---------------|
| 1. | 17.3 | 2.3 |
| 2. | 41.8 | 5.1 |
| 3. | 66 | 7.7 |

Arrangement of the equipment used in this study are presented in Figure 3.2 .

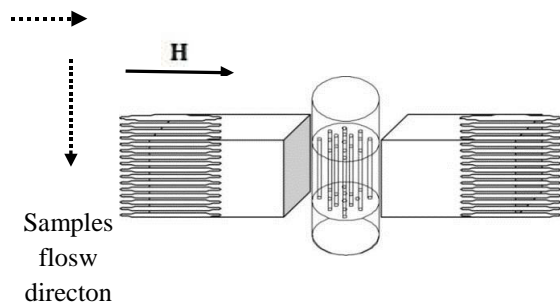


Fig. 3.2 Schematic arrangement of equipment HGMS in the magnetic field with perpendicular direction to the sample flow

4. RESULTS AND DISCUSSION

4.1. Results Synthesis of Nanoparticles Fe₃O₄

Nanoparticles Fe₃O₄ were formed immediately with black color after the solution was mixed with an alkaline solution

NH₄OH. The precipitate is then washed to neutralize the concentration of the solution. Furthermore, magnetic field was given to separate between Fe₃O₄ and the salts. Fe₃O₄ in the colloids form were dried by furnace at a temperature of 80 °C for 2 hours to obtain Fe₃O₄ powder, as shown in Figure 4.1.

Black color of the sample indicates that the nanoparticles produced from the synthesis process is dominated by Fe₃O₄ phase. Furthermore, Fe₃O₄ powders were characterized by XRD, TEM and VSM.

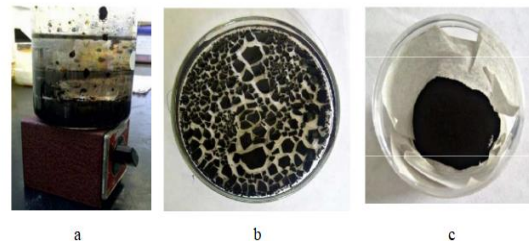


Fig 4.1. Nanoparticles Fe₃O₄ produced from the synthesis by coprecipitation method (a) nanoparticles Fe₃O₄ in a liquid medium on the magnetic field, (b) nanoparticle solid phase, and (c) powder nanoparticles Fe₃O₄.

4.1.1. Characterization of Fe₃O₄ using X-Ray Diffractometer (XRD)

XRD results were processed using Origin 8 software in order to obtain the graph shown in Figure 4.2

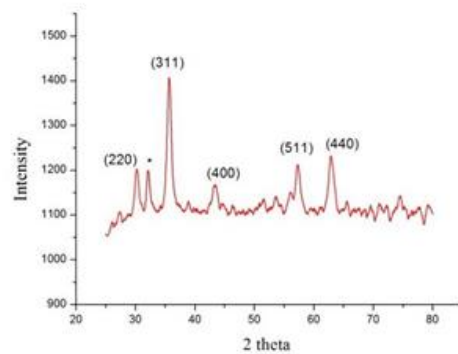


Fig. 4.2 XRD results of Fe₃O₄

Figure 4.2 shows the peaks that indicate

hkl of samples Fe_3O_4 indicating the formation of Fe_3O_4 phase in the sample. Indications based on the lattice parameter values estimated from the angle $2\theta = 35.68^\circ$ that the main peaks with indices (311) sample is 8.34 \AA closer Fe_3O_4 lattice parameter values in the bulk state (8.397 \AA) (Coey, 2009). In addition, it is also indicated by the emergence of several other diffraction peaks with Miller indices (220), (400), (511) and (440). Diffraction peaks with Miller indices is a typical index of cubic spinel structure of Fe_3O_4 which always appear in the XRD diffractogram Fe_3O_4 material (Loh et al., 2008). There are other diffraction peaks (marked *) in the angle position $2\theta = 32^\circ$ in the sample Fe_3O_4 which showed the presence of $\alpha\text{-Fe}_3\text{O}_4$ phase. $\alpha\text{-Fe}_3\text{O}_4$ is a modification of Fe_3O_4 crystals called hematite.

4.1.2. Characterization of Fe_3O_4 using Transmission Electron Microscopy (TEM)

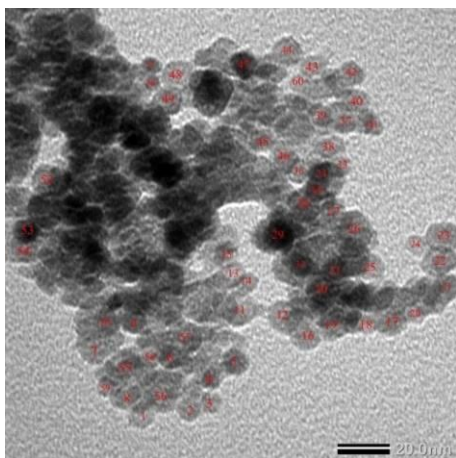


Fig. 4.3 TEM results of Fe_3O_4

As shown in Figure 4.3, most of Fe_3O_4 particles showed a spherical shape with a homogeneous particle distribution is quite dispersive although there are agglomeration in some places. Agglomeration is due to the

magnetic dipole interaction between the particles. Fe_3O_4 particles without any surface coating, has a hydrophobic surface with a surface area large enough. Hydrophobic interactions between the particles make the particles closer and form large clumps resulting in enlargement of the particle size. Attraction of strong magnetic dipole between these particles also shows a ferromagnetic behavior at the Fe_3O_4 samples. Fe_3O_4 nanoparticle size distribution is shown in histogram in Figure 4.4. From the TEM pattern calculation using ImageJ software, it is known that the highest Fe_3O_4 nanoparticle size distribution is at a size of 9 nm with an average diameter of grain particles is $9.2 \pm 1.6 \text{ nm}$.

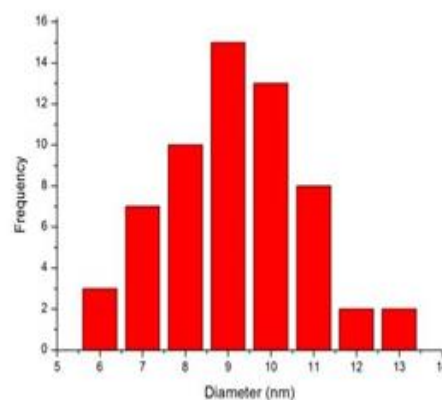


Fig. 4.4 Diameter distribution of Fe_3O_4 nanoparticles

4.1.3. Measurement of magnetic properties of Fe_3O_4 using Vibrating Sample Magnetometer (VSM)

Fe_3O_4 magnetic properties from VSM measurement results are shown in Figure 4.5. The Fe_3O_4 sample has a value of 45.7 oersted coercive field, remanent magnetization of 7.846 emu/g and saturation magnetization (M_s) of 77.16 emu/g . Saturation magnetization obtained is much smaller than the bulk material which has a

saturation magnetization
 $M_s \sim 98 \text{ emu/g}$ (Barlianti, 2009).

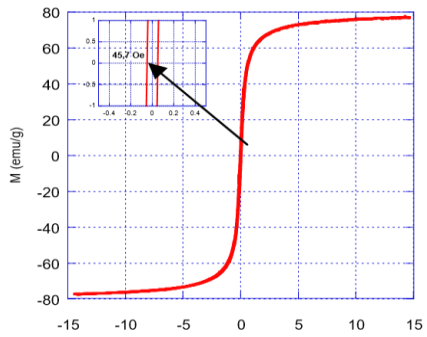


Fig. 4.5 Hysteresis curve Fe_3O_4

4.2. Metal Ion Adsorption Mechanism of Cu (II), Ni (II) and Fe (II) on the adsorbent surface Fe_3O_4

One indicator of successful adsorption process was also marked by a color change in the solution of artificial waste (adsorbate).

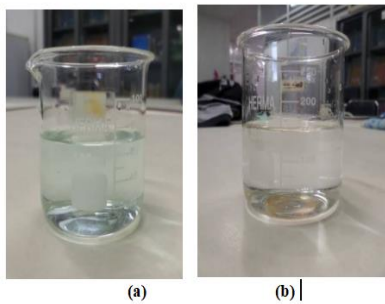
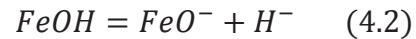


Fig. 4.6 (a) Waste before adsorbed and (b) waste after adsorbed

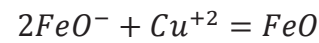
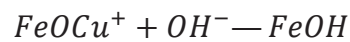
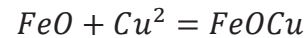
Color changes that occur both before and after adsorption indicates that the metal ions contained in the waste is absorbed by the surface of Fe_3O_4 adsorbent. Waste which was originally green turns into pure, as shown in Figure 4.6.

At the time of contact between magnetite with water, adsorbent surface (hydroxyl group) reacts via proton exchange with the water phase where protons exist. Surface charge that occurs on the surface of the adsorbent as a result of chemisorption of water split into H^+ and OH^- ions resulting in the

hydroxylate surface, is shown in the following equation.



Cation has the greatest tendency to be adsorbed by the surface of the metal oxide negative sites (FeO^-). So that the metal ions (cations) adsorbed by the surface of the negative metal oxide is indicated by equations 4.3 - 4.5.



The same adsorption mechanism also occurs in metals Ni (II) and Fe (II).

4.3. Purification Results of High Gradient Magnetic Separation (HGMS) System

4.3.1. Purification Results of HGMS in the magnetic field with the same direction to the sample flow

The percentage decrease in the levels of metal ions Cu (II) in the conventional method is 99.38%. While using HGMS the percentage tends to decline in the 97.19%, 98.12% and 98.09%.

Table 4.1 Purification Results of HGMS in the magnetic field with the same direction to the sample flow (Variation of the magnetic field with a pH of 9, 3 hours and stirring at room temperature)

| NO | Parameter | Raw material (ppm) | | Conventional | Magnetic field (Gauss) | | |
|----|-----------|-----------------------|--------------------------|--------------|------------------------|-----------|-----------|
| | | | | | 2,3 | 5,1 | 7,7 |
| 1. | Cu | 340,478 | Average | 2,115 ppm | 9,565 ppm | 6,403 ppm | 6,493 ppm |
| | | | Percentage reduction (%) | 99,38 % | 97,19 % | 98,12 % | 98,09 % |
| 2. | Ni | 374,488 | Average | 4,456 ppm | 4,947 ppm | 4,374 ppm | 4,333 ppm |
| | | | Percentage reduction (%) | 98,81 % | 98,68 % | 98,83 % | 98,84 % |
| 3. | Fe | 313,01 | Average | 0,72 ppm | 0,115 ppm | 0,134 ppm | 0,247 ppm |
| | | | Percentage reduction (%) | 99,77 % | 99,96 % | 99,95 % | 99,92 % |

Remarks: Signed = not detected / below the detection limit of SSA tool Detection limit $Fe = 0.02$ ppm Cu (II) is one of paramagnetic material which has positive magnetic susceptibility with a very small value. Where the magnetic moment oriented randomly and if external magnetic field is applied, the magnetic moments will align in the same direction with the field. However, the cause is a very significant reduction in the dissolution of a layer of small pipes in the HGMS identified from material Cu (II). So causing the ion content of Cu (II) to increase significantly.

The percentage for metal ions Ni (II) and Fe (II) in the conventional method are 98.81% and 99.77%. While using HGMS, the percentage remained constant at 98.68%, 98.83%, 98.84% and 99.96%, 99.95%, 99.92%. Metal Ni (II) and Fe (II) tends to a constant as including to the ferromagnetic materials have a spontaneous magnetic moment which arises even without an external magnetic field being given. However, because of magnetic field with same direction to the sample flow, it has no significant effect in decreasing the metal content. This is presumably because the magnetic field is not able to align the domains in the metallic Ni (II) and Fe (II)

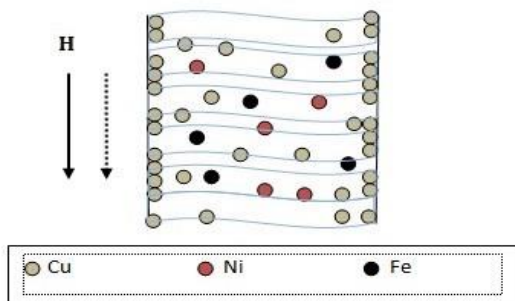


Fig. 4.7 Metal ions affected by the magnetic field with the same direction to the sample flow

Metal ions Fe (II) when viewed from the relationship between the magnetic force (\bar{F}_m) the direction of the buoyant force (\bar{F}_g) then the resultant force is maximal. Because of the maximum resultant force, it results in the greatest sample rate. HGMS attracts metal ions Fe (II) to be attached to the pipe wall with difficulty. More details can be seen in Figure 4.8.

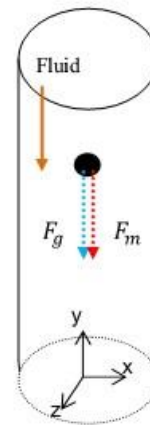


Fig. 4.8 Forces acting on the HGMS when the magnetic field is the same direction with the sample flow.

4.3.2. Purification Results of HGMS in the magnetic field with opposite direction to the sample flow

Purification of HGMS in magnetic field with opposite direction to the samples flow is shown in Table 4.2. The results showed that the percentage of metal ions Cu (II) uptake conventionally is 98.35%. While the percentage using HGMS tends to decrease to become 92.90%, 94.96% and 93.15%.

The percentage is likely to decline due to Cu (II) include paramagnetic material group. However, the significant reduction is caused by dissolution of a small layer of pipes in the HGMS identified from Cu (II) material. So that, the ion content of Cu (II) increases significantly.

The percentage for metal ions Ni (II) tends

to a constant and Fe (II) tends to increase, i.e., from the conventional method are 99.16% and 99.88%. While using HGMS the percentages are 99.16%, 99.11%, 99.20% and 100%, 100%, 100%. Those results are caused by the Ni (II) and Fe (II) that are included in the group of ferromagnetic material. Ni (II) tends to be constant and the Fe (II) tends to rise despite both being ferromagnetic because it has different valence electrons. So, if magnetic field is applied, Fe (II) spins will tend to align more easily than Ni (II) and easily attaches to the small pipes HGMS.

Based on the experimental results, in magnetic field with opposite direction to the sample flow, metal ions can be modeled in figure 4.9.

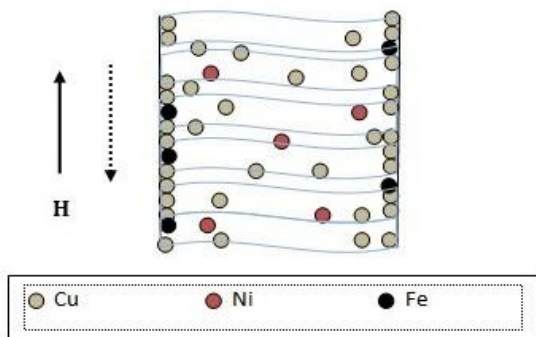


Fig. 4.9 Metal ions affected by the magnetic field in the opposite direction to the sample flow

| NO | Parameter | Raw material (ppm) | | Conventional | Magnetic field (Gauss) | | |
|----|-----------|--------------------|--------------------------|--------------|------------------------|------------|------------|
| | | | | | 2,3 | 5,1 | 7,7 |
| 1. | Cu | 338,365 | Average | 5,581 ppm | 24,091 ppm | 17,056 ppm | 23,187 ppm |
| | | | Percentage reduction (%) | 98,35 % | 92,90 % | 94,96 % | 93,15 % |
| 2. | Ni | 350,564 | Average | 2,93 ppm | 2,946 ppm | 3,119 ppm | 2,821 ppm |
| | | | Percentage reduction (%) | 99,16 % | 99,16 % | 99,11 % | 99,20 % |
| 3. | Fe | 276,728 | Average | 0,344 ppm | ttd | ttd | ttd |
| | | | Percentage reduction (%) | 99,88 % | 100 % | 100 % | 100 % |

Remarks: Signed = not detected / below the

detection limit of SSA tool Detection limit Fe = 0.02 ppm

As for the metal ions Fe (II) the percentage tends to rise when compared with the results of screening sample unidirectional magnetic field. This occurs because the direction of the magnetic field (\vec{F}_m) opposite to the direction of the buoyant force (\vec{F}_g) causes the value of the resultant force to be minimal. HGMS easily attracts the metal ions Fe (II) to be attached to the pipe wall. More detail can be seen in Figure 4.10.

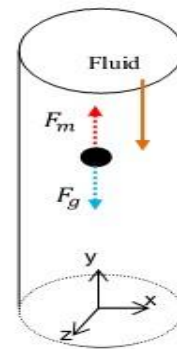


Fig. 4.10 Forces acting on the HGMS when the magnetic field is opposite direction to the sample flow.

4.3.3. Purification Results of HGMS System in the Magnetic Field with Opposite Direction to the Sample Flow and in the Variation of Time

Purification of HGMS in the magnetic field with opposite direction to the sample flow in the variation of time shown in Table 4.3. The results showed that the percentage of metal ions Cu (II) uptake conventionally is 98.83%. While using HGMS the percentage tends to decrease to 96.83%, 95.17% and 97.04%.

Table 4.3 Purification Results in the magnetic field with opposite direction to the sample flow (variation of time with a pH of 9, stirring 3 hours, 5.1 Gs magnetic field and room temperature)

| NO | Parameter | Raw material (ppm) | | Conventional | | | Time (S) | |
|----|-----------|--------------------|--------------------------|--------------|-----------|------------|------------|--|
| | | | | | | | | |
| | | | | | 423 | 925 | 1314 | |
| 1. | Cu | 338,365 | Average | 3,951 ppm | 10,74 ppm | 16,336 ppm | 10,017 ppm | |
| | | | Percentage reduction (%) | 98,83% | 96,83% | 95,17% | 97,04% | |
| 2. | Ni | 350,564 | Average | 2,954 ppm | 3,05 ppm | 2,594 ppm | 2,569 ppm | |
| | | | Percentage reduction (%) | 99,16% | 99,13% | 99,26% | 99,27% | |
| 3. | Fe | 276,728 | Average | 0,137 ppm | ttd | ttd | ttd | |
| | | | Percentage reduction (%) | 99,95% | 100 % | 100 % | 100 % | |

Remarks: Signed = not detected / below the detection limit of SSA tool Detection limit Fe = 0.02 ppm

The decrease in metal ion Cu (II) is caused by the paramagnetic nature of the material. In addition, it is also caused by the limitation of screening process to a certain time to get the best results caused by small pipes of Cu (II) HGMS which has reduced its ability to attract metal ions in the effluent because the overall surface of the pipe has been covered by metal ions and dissolution of Cu layer on small pipes in HGMS causing the metal ion content of Cu (II) to increases.

Percentage for metal ions Ni (II) tends to a constant and Fe (II) tends to increase the conventional manner by 99.16% and 99.95%. While using HGMS by 99.13%, 99.26%, 99.27% and 100%, 100%, 100%. This happens because the Ni (II) and Fe (II) are both ferromagnetic materials, however, having different valence electrons. So, if given the magnetic field of Fe (II) spins will tend to align more easily than Ni (II). It is also because a large adsorption, so that the adsorption of the metal ions Fe (II) is

maximum.

4.3.4. Purification Results of HGMS in the Magnetic Field with Perpendicular Direction to the Sample Flow

Purification of HGMS in the magnetic field with perpendicular direction to the sample flow is shown in Table 4.4. The results showed that the percentage of metal ions Cu (II) uptake conventionally is 98.23%. While using HGMS percentage tends to decrease by 96.58%, 94.71% and 95.67%.

Table 4.4 Purification Results of HGMS in the magnetic field with perpendicular direction to the sample flow (variation of magnetic field with a pH of 9, 3 hours and stirring at room temperature)

| NO | Parameter | Raw material (ppm) | | Conventional | | | Magnetic field (Gauss) | |
|----|-----------|--------------------|--------------------------|--------------|------------|------------|------------------------|--|
| | | | | | | | | |
| | | | | | 2,3 | 5,1 | 7,7 | |
| 1. | Cu | 359,231 | Average | 6,348 ppm | 12,292 ppm | 18,996 ppm | 15,544 ppm | |
| | | | Percentage reduction (%) | 98,23% | 96,58 % | 94,71% | 95,67 % | |
| 2. | Ni | 370,429 | Average | 2,252 ppm | 2,512 ppm | 2,289 ppm | 2,586 ppm | |
| | | | Percentage reduction (%) | 99,39% | 99,32 % | 99,38% | 99,30 % | |
| 3. | Fe | 284,739 | Average | 0,32 ppm | ttd | ttd | ttd | |
| | | | Percentage reduction (%) | 99,89% | 100% | 100% | 100% | |

Remarks: Signed = not detected / below the detection limit of SSA tool Detection limit Fe = 0.02 ppm

In accordance with previous data that the reduction of metal ions Cu (II) occurs because it includes paramagnetic material which has a positive magnetic susceptibility with a very small value. When the magnetic moment is oriented randomly and if external magnetic field is applied, the magnetic moments will align very large. However, a very significant reduction is caused by dissolution of a layer of small pipes in the HGMS identified by material Cu (II).

Causing the ion content of Cu (II) to increase significantly.

Percentage for metal ions Ni (II) tends to a constant and Fe (II) tends to increase in the conventional method by 99.39% and 99.89%. While using HGMS by 99.32%, 99.38%, 99.30% and 100%, 100%, 100%. This happens even though Ni (II) and Fe (II) are both ferromagnetic materials, however, having a different valence electrons. So, if given the magnetic field of Fe (II) spins will tend to align more easily than Ni (II).

Based on the experimental results, in the magnetic field with perpendicular direction to the sample flow, metal ions can be modeled in Figure 4.11.

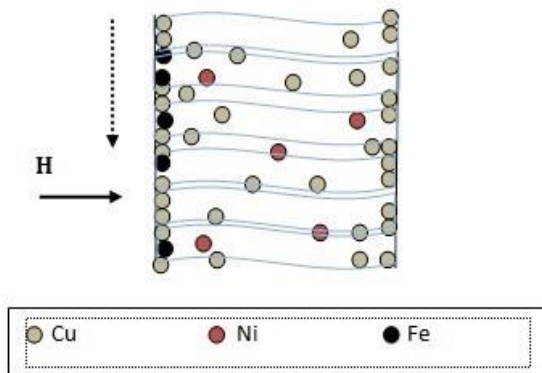


Figure 4.11 Metal ions affected by the magnetic field with perpendicular direction to the sample flow.

Besides that, when viewed from the magnetic force (\bar{F}_m) perpendicular to the direction of flow of the sample or the buoyant force (\bar{F}_g) it will produce a small resultant magnetic force compared to the resultant magnetic force on the magnetic field in the sample stream. So that the metal ions Fe (II) is attached to the pipe HGMS. More detail can be shown in Figure 4.12.

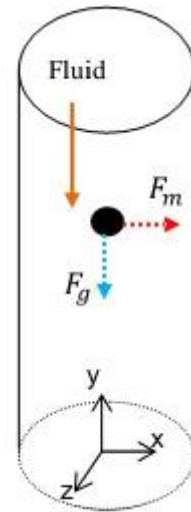


Figure 4.12 Forces acting on the HGMS when the magnetic field is perpendicular direction to the sample flow

4. CONCLUSION

High Gradient Magnetic Separation (HGMS) is effective in lowering the levels of the waste metals to the maximum for Fe (II) compared to Cu (II) and Ni (II) is the percentage to 100% with opposite magnetic field and perpendicular to the direction of the sample. The decline in the percentage levels of metal ions Fe (II), Ni (II) and Cu (II) is more effective for the metal ions Fe (II) using a magnetic field opposite to the direction of flow sample of 100%, 100% and 100% compared to the field direction unidirectional magnetic sample flow of 99.96%, 99.95% and 99.92%. The decline in the percentage levels of metal ions Fe (II), Ni (II) and Cu (II) by using a magnetic field perpendicular to the direction of the samples showed a maximum of 100% for the metal ions Fe (II).

4. REFERENCES

Barlianti, V., 2009, Fungsionalisasi Komposit Oksida Besi pada Silika untuk Proses Penyisihan PAH dalam

Air dan Uji Kinerjanya, Tesis, Fakultas Teknik, UI.

Carabante, I. 2012,. Arsenic (V) adsorption on Iron Oxide: Implification for soil remediation and water purification. Doctoral thesis. Universitetstryckreriet, Lulea.

Loh, K., Lee, Y.K., Musa, A., Salmah, A.A. dan Zamri, I., 2001, Use of Fe₃O₄ for enhancement of Biosensor Response to the Herbicide 2,4-Dichlorophenoxyacetic Acid, Sensor, 8, 5775-5791.

Ottinger, A., 2009, High Gradient Magnetic Separation (HGMS) of Erythrocytes Infected with Plasmodium Falciparum, Disertasi, Johannes GutenbergUniversity of Mainz.

Pauzan, M., 2013, Kajian Sifat Kemagnetan pada Superparamagnetic Iron Oxide Nanoparticles(SPIONs) menggunakan Kurva Loop Histerisis, Skripsi, Jurusan Fisika FMIPA UGM, Yogyakarta. Xu, C., 2009, Modification of Superparamagnetic Nanoparticles for Biomedical