Magnetic characterization of industrial dust from Gresik, East Java, Indonesia

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Abstract. Industrial dust has been known to be a potential health hazard and therefore need to be closely monitored. However, in heavily industrialized area such as Gresik in East Java, Indonesia identifying the source of particular dust or differentiating one type of dust to another might be complicated. In this study, industrial dust in the form of fly ash, cement dust and lime kiln dust from various industries in Gresik were analyzed for their magnetic properties. The measurements include magnetic susceptibility, magnetic susceptibility versus temperature as well as Anhysteretic Remanent Magnetization (ARM) decay curves. These samples were also subjected to Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF). The results, fly ash has the highest Fe content and therefore is the most magnetic. The predominant magnetic mineral is sphalerite-shaped magnetite. As magnetic methods are more straightforward than other type analyses, they are very prospective to be used as alternative methods for industrial dust pollution.

Keyword: industrial dust, fly ash, cement dust, lime kiln dust, magnetic parameter

1. Introduction
Industrial activities brought ever-increasing industrial dust that creates air pollution that might affect human health. Therefore, industrial dust has studied intensively [1-5]. There are many physical and chemical methods to study industrial dust, including environmental magnetic methods. These methods utilize characterization of magnetic minerals and their properties as parameters of the environmental issue. The environmental magnetic methods include among others, measurement of magnetic susceptibility as well as thermomagnetic, magnetic hysteresis, IRM (Isothermal Remanent Magnetization) and ARM (Anhysteretic Remanent Magnetization) analyses [6-7].

As industrial dust was produced using specific types of fuel, specific raw materials and specific processes, different types of industrial dust might have specific magnetic characters that could be identified through environmental magnetic methods. Such characterization of magnetic minerals could distinguish by anthropogenic magnetic minerals from the naturally occurring minerals [8-16]. One of the types of industrial dust that has been studied extensively is fly ash that was produced from coal combustion at very high temperatures. Fly ash has been known to contain magnetite as well as hematite. These magnetic minerals could be identified by their high magnetic susceptibility, distinctive Curie temperatures as well as by their specific visual forms [17-22].
In this study, industrial dust from various industries from Gresik, East Java, Indonesia are subjected to environmental magnetic methods to test whether industrial dust from each industry has specific magnetic characters that could be used as their identifiers. Gresik is an extensive and complex industrial area in East Java that house various industries ranging from the petrochemical plant, cement plant and all numerous small and medium enterprises.

2. Sample and Methodology

Samples were in the form of fly ash (FA) from PT Petrokimia Gresik, pozzolan Portland cement (PPC) dust from PT Semen Indonesia Tbk, and lime kiln (LK) dust from lime kiln home industry in Pongangan. All industries are in Gresik, East Java (see Figure 1). Once the samples arrived at the laboratory, they were heated in an oven at 100°C for 4 hours to eliminate any moisture or water content. The samples were then sieved using a 325-mesh size so that only clay-sized particles be used in this study. A portion of the sample is also mixed with double distilled water (DDW) and subjected to magnetic extraction processes.

The samples were first subjected to magnetic susceptibility measurements where measurements were carried out using a Bartington MS2B magnetic susceptibility system where low (0.46 kHz) and high (4.6 kHz) magnetic susceptibility were measured and termed respectively as $\chi_{LF}$ and $\chi_{HF}$. A derivative parameter termed $\chi_{fd}$ (%) or frequency dependent magnetic susceptibility was then calculated as $100\% \times (\chi_{LF} - \chi_{HF})/\chi_{LF}$ and $\chi_{HF}$. Later, the samples were also subjected to thermomagnetic analyses using a Bartington MS2B system equipped with furnace and water cooling system at Halu Oleo University.

SEM analyses were carried out using a JEOL JSM-636OLA Analytical Scanning Microscope at the Indonesian Geological Survey while the XRD analyses were carried out using a Philips Analytical PW 1710 at Institut Teknologi Bandung. Last, he XRF analyses were carried out using a PANalytical MiniPal 4 Spectrometer PW 4030/45B in Laboratory at Universitas Negeri Malang.

![Figure 1. Gresik, East Java, Indonesia](image-url)
3. Results
Table 1 shows the results of magnetic susceptibility measurements. FA samples have the highest $\chi_{LF}$ values inferring they have a much higher concentration of magnetic minerals. All samples have $\chi_{fd}$ (%) values of less about 2% or less implying that these samples have a low content of superparamagnetic grains. LK samples have smaller magnetic mineral content relative to that in FA samples but still higher the PPC samples.

| Samples | $\chi_{LF}$ ($\times 10^{-8}$ m$^3$kg$^{-1}$) | $\chi_{fd}$ (%) |
|---------|---------------------------------|-----------------|
| FA      | 4.286                           | 1.81            |
| LK      | 456                             | 2.87            |
| PPC     | 153                             | 0.74            |

Meanwhile, Figure 2a shows the thermomagnetic curves of magnetic susceptibility versus temperature for FA sample during heating and cooling. The heating and cooling curves are rather similar showing no alteration of magnetic minerals during these processes. Curie temperature of about 580°C implies that the predominant magnetic mineral is magnetite. Figure 2b shows the thermomagnetic curve for LK samples during heating and cooling. The curves are unstable implying some changes in magnetic minerals. The Curie temperature is higher than 600°C suggesting the presence of hematite. Figure 2c shows the thermomagnetic curves for PPC sample that are rather noisy due to the low values of magnetic susceptibility. The Curie temperature is a rather inconsistent showing more 600°C during heating and less than that cooling.

![Figure 2a](image)

Figure 2a. The Result of Magnetic Susceptibility Versus Temperature of FA
Figure 2b. The Result of Magnetic Susceptibility Versus Temperature of LK

Figure 2c. The Result of Magnetic Susceptibility Versus Temperature of PPC
Figure 3 shows the diffractograms of each sample showing that the samples have varying mineral contents. As expected, FA has a significant amount of magnetite apart from quartz. LK sample also shows the presence of quartz while PPC samples are dominated by calcite and calcium silicate minerals. Table 2 shows the results of XRF analyses significant variation in the major elements of the samples. Each industrial dust has different amounts of Al, Si, Ca and Fe elements. FA samples have the highest levels of Al, Si and Fe elements than that of LK and PPC. PPC, on the other hand, has the highest Ca content. These differences in major elements are to be expected as each industrial dust was derived from different industrial processes.

![Figure 3. The diffractogram of FA, LK and PPC. Q quartz; M magnetite; H hematite; Cal calcite; D dolomite ferroan; An anhydrite; CS calcium silicate.](image)

| Element | FA  | LK  | PPC |
|---------|-----|-----|-----|
| Si      | 19.800 | 3.00 | 7.250 |
| S       | -   | 0.300 | 0.700 |
| K       | 1.620 | 2.100 | 0.670 |
| Ca      | 16.200 | 75.980 | 77.090 |
| Ti      | 1.560 | 1.410 | 0.450 |
| V       | 0.007 | 0.045 | 0.030 |
| Cr      | 0.140 | 0.050 | -   |
| Mn      | 0.600 | 0.380 | 0.130 |
| Fe      | 46.700 | 8.640 | 7.740 |
| Ni      | 0.170 | 0.130 | 0.120 |
| Cu      | 0.110 | 0.086 | 0.094 |
| Zn      | 0.060 | 0.130 | 0.008 |
| Sr      | 0.740 | 0.770 | 0.230 |
| Mo      | 3.800 | 3.000 | 1.000 |
| In      | -   | 2.700 | 1.900 |
| Ba      | 0.330 | -   | 0.200 |
| Yb      | -   | 0.200 | 0.310 |
| Eu      | 0.610 | -   | 0.080 |
| Re      | 0.410 | 0.270 | 0.100 |
| Hg      | -   | -   | 0.100 |

Table 2. Element Content (%) of FA, LK and PPC
Figures 4a to 6b show the SEM images of magnetic grains in the industrial dust samples. Figure 4a and 4b show respectively the magnetic grains from non-extracted and extracted of FA sample. The images show magnetite spherules typical of industrial anthropogenic processes. Figures 5a and 5b show respectively the magnetic grain from non-extracted and extracted LK sample. Before extraction (Figure 5a) the image of the grains is random and only one grain of magnetic mineral is found. In contrast on extracted LK sample (Figure 5b) also show the presence of spherules magnetite mineral grains in the sample.

![Figure 4a. SEM-EDX of FA (500x).](image1)

![Figure 4b. SEM-EDX of Extraction FA (500x).](image2)

![Figure 5a. SEM-EDX of LK (500x).](image3)

![Figure 5b. SEM-EDX of Extraction LK (500x).](image4)

![Figure 6a. SEM-EDX of PPC (500x)](image5)

![Figure 6b. SEM-EDX of Extraction PPC (500x)](image6)

The SEM images of PPC samples before and after extraction were shown respectively in Figures 6a and 6b. Before extraction, the image showed that the grains in the PPC sample were very random and irregular where the presence of magnetite mineral grains could hardly be found. While the results of the SEM-EDX image on PPC samples that have been extracted visible presence of spherule magnetite mineral grains in varying sizes.
4. Discussion
In this study, FA samples have been shown to have the highest magnetic susceptibility value. Although 
FA is produced by coal combustion, apparently there were several Fe elements in coal including Fe 
carbonates such as ankerite and siderite, Fe sulfides and even sulfates [23]. During coal combustion at 
1400°C or higher, Fe is released and then oxidized in specific spherule forms. These iron oxide minerals 
have different morphology and grain size with magnetic minerals formed in natural processes [24-27].  
Meanwhile, LK samples were taken from lime kiln so that the dust could easily be hematite due to the 
repeated heating process. The presence of quartz in LK samples might be originated from the kiln 
wall that was made of clay. PPC samples have the lowest magnetic susceptibility as they were derived 
from cement. However, there is a trace of magnetic minerals in PPC samples. As fly ash is often added 
to PPC samples, the magnetic behaviors of PPC are likely due to the added fly ash.  

5. Conclusion
Different industrial dust from different types of industries in Gresik, East Java has been shown to have 
specific magnetic characters that potentially could be used as dust identifiers. FA samples have the 
highest magnetic susceptibility value and are dominated by spherule-shaped magnetite. LK sample 
contains agnetite and hematite mineral which contributed to magnetic susceptibility value. PPC samples 
have the lowest magnetic susceptibility indicating its low magnetic content.  

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