Magnetization of Metal Mesh for Fine Dust Capture

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ABSTRACT

This study investigated the magnetic capture of fine dust containing iron compounds using a metal mesh. Test filters were prepared by magnetizing stainless woven mesh with permanent magnetic bars. The iron content of the test dust was 8.66%, 25.24%, and 12% for fly ash from a coal-fired power plant, effluent dust from a metro subway, and particulate matter from an urban integrated power plant boiler, respectively. Based on experimental results focusing on TSP, PM1.0, PM2.5, and PM3.5, the intensity of the source magnets is directly related to the dust capturing efficiency, and 7.41% of additional subway dust can be collected with a source magnet of 3,000 gauss for structure of the dust was more effective for magnetic capture than the elemental iron composition. It was also found that the magnetized mesh filters contributed synergistically to improve the fine dust capture with low pressure resistance.

Keywords: Magnetic filter; Fine dust; Metal mesh; Pressure drop; Filtration.

INTRODUCTION

Particulate matter is an important index used to determine the urban air quality. The atmospheric fine dust level depends on various artificial emission sources as well as natural factors or long distance migration in Korea. Many epidemiologic studies have revealed a certain causal relationship between very fine dust suspended in the air and human health (Seo and Chang, 2012; Ni et al., 2017). In particular, fine particulate matters (PM10 and PM2.5) smaller than 10 μm and 2.5 μm respectively may penetrate the human bronchium and lungs, and chronic exposure for long time may lead to death (Liu et al., 2015; Choung et al., 2016). The government has initiated a control limit on the atmospheric level of PM2.5 to a 24-hour mean of 50 μg m⁻³ since 2015, and is now carrying forward to lower the level up to 35 μg m⁻³.

Major emission sources of fine dust include coal-fired power plants as well as mobile sources such as automobiles and subway trains. Since coal-fired power plants provide 44.7% of domestic electricity, the concern regarding fine dust emission is increasing (Suh and Maeng, 2015). A major public transportation in Seoul, as in other world cities, the metro-subway generates a variety of PMs from attrition of iron rails and wheels, and discharges huge amount of fine dust through ceil duct lines without any trapping devices (Kwon et al., 2011; Sim et al., 2017).

Fine dust can be captured mostly by filtration devices through diffusional mechanisms such as electrostatic or magnetic forces (Lee et al., 2009; Park et al., 2012). Jung et al. (2012) confirmed the possibility of the use of magnet for collection of subway dust and coal-fired power plant dust by peer examination of their chemical properties. Park et al. (2015) verified the effectiveness of magnetic separation of fly ash from a power plant in a certain regime of magnetic intensity. A magnetically stabilized bed (MSB) and magnetically stabilized fluidized bed (MSFB) have been designed for the separation of magnetic particles (Rincon, 1991; Hristove, 2007; Wang et al., 2008). However, the use of external power to form a magnetic field in these studies has been a limit to prevent from wide applications for field dust control processes.

Thus, this work attempted to utilize permanent magnets for the formation of a magnetic field in the open space of the metal mesh. In our previous numerical simulation, Huang et al. (2015a) ascertained the magnetic collection of 0.1 to 0.5 μm iron component particles by metal porous nets with the assumptions of spherical, uniform size of target particles, and no other collection mechanism. Huang et al. (2015b) also numerically analyzed the fine particle behavior in a magnetized rectangular flow channel as a function of magnetic field strength and particle collection. Thus, this work applied magnetic collection to a few typical field dust arisen from coal-fired power plant, metro-subway and urban energy generation plant.

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THEORETICAL BACKGROUND

Based on Newton’s second law, the fluid dynamics of solid particles in the magnetic field is determined $F_g$ (gravitational force), $F_d$ (drag force), $F_B$ (Brownian force) and $F_m$ (magnetic force). It was denoted as follows (Li et al., 2007a).

$$m \frac{dv}{dt} = F_g + F_d + F_B + F_m$$

(1)

In order to understand the effect of the magnetic force on dust collection, $F_m$ firstly was defined as Eq. (2) (Zadra vec et al., 2014);

$$F_m = \mu \cdot V_p \left( \mathbf{M}_p \cdot \nabla \right) H_a$$

(2)

where $\mu$ is magnetic permeability indicating the extent to which the material is magnetized in response to an external magnetic field. It is determined depending on the magnetic material such as ferromagnetic element, paramagnetic element, or semi-magnetic element. Amongst them, ferromagnetism refers to a material in which strong magnetization is formed in the direction corresponding to the magnetic field from the outside. Magnetized elements provide magnetic force fields when the external magnetic field disappears, and $F_g$ represents magnetic particle volume. With the assumptions of spherical and uniform size of target particles and no other collection mechanism, iron compounds such as $\text{Fe}_3\text{O}_4$, $\text{Fe}_2\text{O}_3$ and maghemite ($\text{Fe}_3\text{O}_4$) have favorable properties for magnetic attraction, suggested in Eq. (3). The greater the content of the following compounds, the greater the efficiency of collection by the magnetic.

Therefore, we decided to test the samples generated from three sources with various iron contents through the following theoretical formula.

$\mathbf{M}_p$ is a vector value determining the magnetic property of an object.

$$\mathbf{M}_p = f(H_a)H_a$$

(3)

$$H \propto 1/\mu_o$$

(4)

$H_a$ is the magnetic field strength across the center of the particle in unit of A/m which is proportional to the magnetic flux density. The magnetic flux density is proportional to the total number of lines of magnetic force passing vertically. For magnetic filter studies, this value represents the intensity at which the filter is magnetized by external magnetic sources. The former study magnetized the filter using only attractive force (Huang et al., 2015a, b; Park et al., 2015), but this work provided the equilibrium interaction condition between attractive and repulsive forces. It was found that the repulsive force of permanent magnets could enforce the magnetic force into the mesh because the magnetic intensity at the mesh net center, which was far from the source magnets, was very low.

EXPERIMENTAL METHOD

Test Dust

Test dust was coal fly ash, subway dust and boiler dust from an integrated power plant burning liquefied natural gas (LNG). Dust particles were first classified and collected under a Tyler standard sieve (38 $\mu$m, ASTM-E11 No. 400), and were observed using scanning electron microscope (SEM, Stresscan 440, Leica Cambridge, UK) with a magnification of 15,000 times. True density of each dust particle was measured using a gas pycnometer (Accupyc 1330, Micromeritics, USA). X-ray diffraction analysis (XRD; D8 Advance, Bruker, US) was performed to understand the chemical structure of iron components in test dust.

Preparation of Magnetic Filters

The filter system seen in Fig. 1 was composed of a stainless mesh with permanent rectangular magnets according to a previous study (Park et al., 2015). The open aperture of stainless wire mesh was 100 $\mu$m (Tyler No. 150) of which wire diameter was approximately 100 $\mu$m according to observation by an optical microscope. The intensity of rectangular permanent magnets, 10 mm in width and 40 mm in length, was determined by varying the thickness of 2, 3 and 4 mm for 1,750, 2,500, and 3,000 gauss respectively. Fig. 1 presents a view of the upper side (b) and a side view (c). Mesh net filter was designed to capture the dust particles mainly by the magnetized metal mesh filters. Flat rectangular magnets with the same intensity were placed on both sides to form strong magnetic fields on the mesh filter. The magnetic intensity of the magnetic field space was measured every 0.5 cm from the center of mesh filter using a gauss meter (5180 gauss meter, F.W. Bell, USA).

Magnetic Filtration Test

A schematic diagram of the test apparatus is depicted in Fig. 1(a). Amount of feed dust was 1.5 g for each test. Dry air of an air compressor was injected at a flow rate of 0.5 m s$^{-1}$. Test dust was pneumatically conveyed from the bottom of cylinder chamber. The magnetic metal meshes were placed at the center of the vertical duct of cylinder chamber. Detailed geometry and configurations are summarized in Table 1.

Dust particles were weighed from the upflow and downflow of mesh filter unit in order to evaluate the total collection efficiency ($\varepsilon$) according to Eq. (5). Grade efficiency $\varepsilon(x)$ for individual particles, as defined in Eq. (6), was calculated from the measurement of size distribution using a particle sizer in a dry phase (Malvern Mastersizer 2000, Malvern, UK), as follows:

$$\varepsilon(\%) = \frac{W_{\text{capture}}}{W_{\text{feed}}} \times 100$$

(5)

$$\varepsilon(x)(\%) = \frac{W_{\text{capture}} \times V(x)_{\text{capture}}}{W_{\text{feed}} \times V(x)_{\text{feed}}} \times 100$$

(6)
**Table 1.** Specification of permanent magnet filtration system.

| Parameters          | Values            |
|---------------------|-------------------|
| **Test dust**       |                   |
| Sample weight (g)   | 1.5               |
| Maximum sample size (μm) | 38               |
| **Mesh**            |                   |
| Mesh aperture size (μm) | 100             |
| **Magnet**          |                   |
| Magnet intensity (kG) | 1.75, 2.5, 3     |
| **Cylinder chamber**|                   |
| Height (cm)         | 66                |
| Collecting point (cm)| 33               |
| Inner diameter (cm) | 5                 |
| Velocity^a (m s⁻¹)  | 0.5               |

Velocity^a: Superficial velocity at the collecting point.

where \( W_{\text{feed}} \) and \( W_{\text{capture}} \) represent the weight of fed and collected dust, respectively. And the ratio of \( V(x)/V \) for each flow could be obtained by the particle sizer, and \( x \) denote each size of particles.

**RESULTS AND DISCUSSION**

Since the present work focused on the magnetic effect on dust capture by metal woven mesh with the least pressure drop, it was made an effort to form mono-layer than multi-layer of which may have an influence of inertial force. In accordance, dust collection by direct capture on the surface of permanent magnets and filtration by accumulated layers of collected dust were excluded as the magnets were installed at the outside of the mesh filter.

**Characterization of Test Dust**

Fig. 2 shows the size distribution of test dust, indicating mostly under 40 μm. Volume proportion of test dust under 1 μm was approximately 23%, 12% and 3% of fly ash, boiler dust and subway dust, respectively. At the emission sources, coarse dust is relatively simple to capture, but it is difficult to capture fine particles particularly smaller than 1 μm due to the lower effect of inertial or diffusional forces.

Fig. 3 displays the SEM images of test dust. Most fly ashes are spherical, because they have experienced high temperature combustion over 800°C (Park et al., 2015). Integrated power stations, which commonly are located in urban areas, use LNG for operation of gas turbines and steam turbines generating electricity. Large amount of scales composed mainly of particulate impurities and rust debris due to corrosion is often accumulated at the inner surface of pipelines. These particulate contaminants are occasionally exhausted to the outside by strong flushing for periodical cleanings or refreshing of pipelines. Such cleaning works bring about significant dust pollution around the plant, since integrated power stations do not have dust control devices in general. The boiler dust procured for this study consisted mainly of metallic lumps as seen in Fig. 3(b).

Despite the various generation sources of subway dust, the dust containing iron components mainly arises from friction of railway tracks and wheels (Jung et al., 2012). As seen in Fig. 3(c), the microscopic appearance of the subway dust implies various chemical composition as well as irregularity in size and chemical forms. It involves fabrics and some components arising from soil or base concrete in addition to iron compounds (Jung et al., 2010; Lu et al., 2015). Passengers are exposed to such heterogeneous dust inside subway stations including on platforms and in train cabins. First of all, ventilation ducts of metro-subways lead the dust to the outside without any dedusting facilities. Thus, they are significant emission sources for atmospheric fine dust in crowded downtown areas (Son et al., 2014).
While large particles could fall on the duct bottom due to gravity before escaping the ceiling vent exit, most fine dust flows out of the horizontal and vertical duct lines by frequent train winds.

Density and iron contents are summarized in Table 2. Despite the high content of iron elements analyzed using an energy dispersive spectrometer (EDX), the average density of subway dust was only 2.44 g cm$^{-3}$ probably due to multi-complexity of organic and inorganic origins. Fly ash contained 8.66% iron at 2.59 g cm$^{-3}$, and boiler dust 12% Fe at a density of 2.71 g cm$^{-3}$. The magnetic intensity of dust particles did not directly relate to the iron content, but depended more on the type of magnetic compounds (Perișanoğlu et al., 2016). For this reason, it was necessary to perform XRD analysis to identify iron compounds in more details. While maghemite ($\gamma$-Fe$_2$O$_3$) or $\varepsilon$-Fe$_2$O$_3$ and magnetite (FeO) are classified into ferromagnetic substances, hematite ($\alpha$-Fe$_2$O$_3$) has been known to be a diamagnetic substance among the various iron compounds (Park et al., 2015). Therefore, XRD analysis enabled to predict the potential possibility of magnetic capture.

As shown from the X-ray diffraqtograms of fly ash in Fig. 4(a), the peaks indicating ferromagnetic substances appeared clearly in addition to the main peaks of quartz. Similar chemical composition could be seen in other dust in Figs. 4(b) and 4(c). The main peak of boiler dust represented butlerite (Fe(SO$_4$)(OH)∙2H$_2$O) according to a standard database of JCPDS card, and subway dust revealed quartz as a main compound. Since hematite was detected in all samples, the actual test dust contained a little less amount of magnetic components than the contents expected by EDX analysis.

In this study, we attempted to investigate the inertial effects of relative density on dust filtration across the mesh filter, but it could not be clearly compared due to the fact that the densities of test particles were not significantly different from one another. Different dispersion rates could merely result in the difference in the dust concentration passing the magnetic filter unit of the present apparatus with
upward flow. Thus, the dust feeding rate was controlled as closely as possibly by observing with the naked eye, even though it was impossible to measure precisely.

**Characteristics of the Magnetized Mesh Filter**

The magnetized filter was expected to increase the selective filtration efficiency through additional magnetic attraction in addition to capture by the metal mesh filter (Zeng et al., 2013). In practice, magnetized filters using permanent magnets are advantageous in cost without exothermic operation. Fig. 5 shows the magnetic field intensity profiles, which were formed by attaching the magnets on both sides of the woven metal mesh. Fig. 5(a) shows the field intensity formed by repulsive magnetic forces and Fig. 5(b) shows the attractive forces by placing two magnets with opposite poles in the same direction. In order to prevent potential interactions between two magnetic sources, the distance between the magnets was maintained at 5 cm. Since the intensity of magnetic fields decreased with increasing distance from the source magnet, the attractive force decreased steeply as the distance increased (–2 and 2 cm to 0), with it finally approaching zero at the center of the mesh filter. However, the enforcement of repulsive force generated the center intensity of 73, 110 and 242 gauss for the test magnets of 1,750, 2,500 and 3,000 gauss respectively. In the case of a confronting position between the same poles, the enhanced magnetic field at each point could be formed by combining the field from two magnets, because the magnetic field forms from north pole to south pole. Facing the opposite pole decreases the magnetic force, thereby
minimizing the magnetic intensity at the center of the mesh filter. In accordance with this, we attempted to utilize the repulsive design in this study.

The maximum intensity was found as 1,635 gauss at the position (2 cm) closest to the magnet, and the intensity of the magnetic field decreased in proportion to the square of distance, which finally showed a minimum value at the mesh center. In accordance, it was expected that more dust could be collected in the vicinity of the mesh edge.

**Filtration Efficiency by Mesh Filters**

The test metal mesh filter without magnetization was first investigated focusing on dust capture alone. The metal mesh consisted of a single layer, which varied from fibrous filters composed of multiple layers. Since the mesh aperture of 100 µm was larger than the dust particle size (≤ 38 µm), it was estimated that interception, which is an external capturing effect, was not significant. In accordance, the overall collection efficiency of fine dust by the mesh filter could be obviously less than that of general fabric filters.

As seen in Fig. 6, the collection efficiencies of the metal mesh filter for total suspended particulate matters (TSP) were 18.58%, 19.69% and 3.09% for fly ash, subway dust and boiler dust, respectively. The highest efficiency was seen in subway dust of which apparent density was relatively low. The lowest efficiency was seen for 1 to 10 µm dust. It was determined that the spherical shape of fly ash decreased external enforcement based on bilateral interactions between particles and mesh wire (Li et al., 2007b). In other words, the particle number concentration decreased as the size increased to over 10 µm. Therefore, the collection efficiency was higher for smaller particles.

Despite the high density of boiler dust, the grade efficiency was lower than that of the other dust. The capturing efficiency was under 5% throughout the sizes up to 38 µm. There was a tendency toward low efficiency for a small number of large particles over 10 µm, although many tests were repeated. Since the present woven mesh filter is composed of a similar design of enlarged nuclo pore filters with the porosity of more than 90%. In accordance, direct capture or inertial collection even for large particles must be very low unless particles are larger than the uniform mesh aperture. Extreme fine dust can preferably be trapped by diffusional force of wire strings. Thus this work attempted to improve the effect of diffusion by adding magnetic force field. Those experimental examples are shown in many open literatures (Gooding and Felder, 1981; Li et al., 2007a, b; Cheng et al., 2014; Son et al., 2014). In particular, low drag force in irregular shaped particles may deviate from the conventional mechanisms (Lapple and Shepehred, 1940). This work focused on fine dust collection by adding magnetic force field, so that settlement of some upward large particles due to gravity was not significantly traced in the present vertical duct design. Dust from the subway and fly ash showed a similar level of collection efficiency except for large particles.
Dust Capture by Magnetized Mesh Filters

Fly Ash
The collection efficiency for fly ash particles in terms of the intensity of the source magnet is summarized in Fig. 7, and an obvious effect of magnetization appeared throughout the overall size distribution. High intensity with a 3,000-gauss magnet led to high efficiency based on the formation of a strong magnetic field on the woven metal mesh. According to a previous study of numerical simulation by Huang et al. (2015b), inertial force dominates the dust collection for greater than 1 m s\(^{-1}\) of spatial flow velocity across the filtration unit. The diffusion and magnetic force were more significant in velocity zones lower than 1 m s\(^{-1}\). Thus, the maximum efficiency of fine dust smaller than 0.2 µm was 50% with magnetization by 3,000 gauss.

Fig. 8 displays the individual collection efficiency for the size band of dust with magnetic intensity. An increase of 6% by magnetic enforcement appeared in TSP and the other sizes also showed a proportional trend with the magnetic intensity. The increase in the absolute efficiency was more obvious in PM\(_1\) and PM\(_{10}\) than in large particles. We concluded that magnetization of metal mesh to a certain degree contributed to the collection enhancement of coal-fired power plant fly ash.

Boiler Dust Collection by Magnetic Force
The very irregularly shaped dust particles that arise from integrated power station boilers limit the comprehensive application of theoretical particle dynamic behavior to the filtration mechanism through porous filter units. As can be seen in Fig. 9, lower efficiency was found for boiler dust than in the other dust. The heavy particles were less dispersed through the filter unit than the low density dust for the same sample weight. This may have caused the low apparent efficiency based on the particle number, although coincident dispersion of numerous dust particles caused temporal clogging of pores and interception effects. In the case of boiler dust, a consistent tendency of collection was found regardless of magnetic intensity, which implied an even distribution of magnetic constituents regardless of size. However, the grade efficiency decreased with particle size over 10 µm. Large particles tended to pass through mesh openings, of which the aperture was 100 µm, mostly by strong inertial force at an instantaneous high velocity. Nevertheless, high magnetic intensity also aided the collection of particles.

Fig. 10 indicates a similar increasing rate of collection efficiency with magnetic intensity. Rust of iron oxides or other sulfuric compounds from anti-rust additives are formed from the corrosion of metal pipelines when boiling water flows through the inside. Warmed gas travels along the surface of many tube bundles in a heat exchanger. The iron content was 12% for dust less than 38 µm, 9.31% for 38–56 µm, 23.68% for 56–106 µm and 39.22% for particles over 106 µm. Although large particles contained more iron components, the collection efficiency by magnetic force was higher in the size range of 2.5–10 µm. Particles larger than 56 µm were not moved up to the filter unit by the upward pulse jet pressure. Therefore, the absolute number of large particles reaching the magnetized mesh filter was very low, so that arithmetic evaluation revealed low values of number efficiency. In addition to very fine dust smaller than 0.1 µm, a significant number of large particles of a few microns could be collected. Magnetization of the metal mesh filter improved collection capacity for fine dust in the case of boiler dust.

Subway Dust
The dust samples collected from mechanical ventilation & air control (MVAC) filters of the metro subway contained a high quantity of iron compounds, which implied that it was an appropriate use for a magnetic filter system. Thus, studies of subway dust collection utilizing magnetic properties have occasionally been performed. For example, Kang et al. (2008) found more iron elements in small particles and Jung et al. (2012) reported various phases of iron oxides in PM\(_{2.5}\). Huang et al. (2015a) verified that, while low flow velocity was effective for small particles less than 1 µm in theoretical simulation, for large particles
Fig. 7. Collection efficiency of fly ash according to particle size.

Fig. 8. Collection efficiency of fly ash according to TSP, PM$_1$, PM$_{2.5}$ and PM$_{2.5-10}$.

Fig. 9. Collection efficiency of boiler dust according to particle size.
over 2.5 μm, high efficiency was achieved at a high velocity. Son et al. (2014) carried out field testing at a metro station in Seoul using a set of permanent magnets as filter units in a ventilation duct. That study varied from the present study using a magnetized mesh filter, but both experiments revealed the same tendency, indicating a dependency on magnetic field intensity.

Unlike the other test dusts, the subway dust in Fig. 11 was not evident by the strength of the magnets. At 2,500 gauss, the collection efficiency of particles in the range of 1–10 μm showed the greatest increase rate. This result implies that the magnet force is greater than the other external forces received by the subway dust when the magnet intensity is over than 2,500 gauss. Figs. 11 and 12 show similar capture efficiencies for fine dust from 20 to 25% for all sizes. Stronger magnets improved the collection effect by up to 8%, particularly for PM$_1$ with 3,000 gauss. PM$_{2.5}$ also showed obvious effects at 2,500 gauss and 3,000 gauss. Therefore, a partial fraction of tiny-sized effluent subway dust could be captured by the magnetic force field, and indirect application of the magnetic force to the filter net played an additional role in dust control without any complicated devices or energy source.

**Capturing Mechanism of Magnetized Mesh Filters**

Fig. 13 presents the collection efficiency with only magnetization and the mesh net itself. On the whole, fly ash and subway dust were more influenced by mesh magnetization than boiler dust. High efficiency was seen even at a relatively low external force of 1,750 gauss for fly ash in all size bands. The magnetic effects of other dust were rather obvious at 2,500 gauss. Despite the low iron content, the effects of magnetization were the most significant in fly ash. Subway dust also had a remarkable dependency on magnet intensity for magnetic capture.

In the case of PM$_1$, subway dust achieved quite a decent effect with an increment of 7.41% at 3,000 gauss. Differing from the EDX analysis, most iron phases in dust particles

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**Fig. 10.** Collection efficiency of boiler dust for TSP, PM$_1$, PM$_{2.5}$ and PM$_{2.5-10}$.

**Fig. 11.** Collection efficiency of subway dust according to particle size.
were not pure elements, but compounds instead. They consisted of ferromagnetic or paramagnetic substances. Ferromagnetic oxides, such as Fe$_2$O$_3$ and Fe$_3$O$_4$, might be widely distributed in PM$_1$ of subway dust. Thus, such fine iron dust could be attached to the magnetized wire surface when entering the magnetic field in mesh interstices. The magnetic enforcement of 3,000 gauss increased the capture efficiency of fly ash. In conclusion, the magnetization of a porous metal mesh filter would be helpful for control of environmental fine dust, particularly PM$_{10}$.
CONCLUSIONS

An auxiliary device consisting of a magnetized metal mesh filter, as a concept of preliminary collection prior to ultimate capture, was applied to field dust procured from three different emission sources: a coal-fired power plant, a metro-subway, and an urban power plant firing liquefied natural gas. The use of permanent magnets and metal mesh provided several advantages, such as requiring no external power source and selectively capturing iron containing particles. This work presents certain possibilities for fine dust collection, as noted below:

1. The dust particles used for testing were fly ash, boiler dust, and subway dust, which contained 8.66%, 12.01%, and 25.24% of iron compounds with densities of 2.59, 2.71, and 2.44 g cm\(^{-3}\), respectively.
2. The magnetization of a wire mesh filter by permanent magnets formed both attractive and repulsive field forces. The center of the mesh filter had the lowest magnetic field intensity, 73–242 gauss, which increased to a maximum of 1,632 gauss, depending on the source magnet intensity as it approached the exterior surface of the filter.
3. The magnetized mesh filters were particularly useful for improving the overall efficiency in collecting fly ash, and the most effective collection was found for subway dust smaller than 1 µm (7.41% of additional capture).

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NOMENCLATURES

- \( F_{Br} \): Brownian force, N.
- \( F_d \): drag force, N.
- \( F_g \): gravitational force, N.
- \( F_m \): magnetic force, N.
- \( H \): magnetic field intensity, A m\(^{-1}\).
- \( H_a \): magnetic field intensity on the particle, A m\(^{-1}\).
- \( M_p \): magnetization of particle, A m\(^{-1}\).
- \( V_{feed} \): volume of entering dust, m\(^3\).
- \( V_{capture} \): volume of collected dust, m\(^3\).
- \( V_p \): magnetic particle volume, m\(^3\).
- \( W_{feed} \): weight of entering dust, g.
- \( W_{capture} \): weight of collected dust, g.

Greek Letters

- \( \rho \): dust density, g cm\(^{-3}\).
- \( \mu \): magnetic permeability, H m\(^{-1}\).
- \( \mu_0 \): magnetic permeability in vacuum, H m\(^{-1}\).

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