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Effects of magnetic field on fluidization properties of magnetic pearls

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Abstract

An experimental study of the influence of external magnetic field on the fluidization behavior of magnetic pearls was carried out. Magnetic pearls are a magnetic form of iron oxide that mainly consists of Fe_2O_3 which are recovered from a high-volume power plant fly ash from pulverized coal combustion. Due to its abundance, low price and particular physical and chemical properties, magnetic pearls can be used as a heavy medium for minerals or solid waste dry separation based on density difference. This paper introduces the properties of magnetic pearls and compares the performance of magnetic pearls fluidised bed operation with or without an external magnetic field. Experimental results show that an external magnetic field significantly improves the fluidization performance of magnetic pearls such as uniformity and stability.

Keywords: Magnetic pearls; Magnetic field; Fluidization properties; Gravity separation

1. Introduction

Fly ash from coal combustion is a fine-grained dusty material that is primarily composed of silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3) as well as unburned carbon. China and the United States are two main coal burning countries, each producing approximately 300 million metric tons of fly ash per year. Recently, as coal production and consumption increase dramatically with rising oil price, fly ash producers are anxious to identify practical uses for fly ash other than disposal as landfills at significant cost and with growing concern about pollution or, in somewhat limited amounts, as a filler for plastics and other polymers.

There is a promising potential for recovering the magnetic pearls from fly ash for use as a heavy-medium material for dry beneficiation of coal, which is less costly and more efficient for reducing SO_2 pollution. Such approach involves dry separation of coal from its heavier gangue in an air-dense medium fluidized bed (of magnetic pearls), by virtue of density difference (Luo, Zhao, Chen, Tao, & Fan, 2004a). This technology is especially suitable for coal preparation in arid and cold regions (Zhao & Wei, 2000). Efforts have been made to improve the fluidization of magnetic particles in a magnetic field (Filippov, 1961; Rosensweig, 1978; Rosensweig, Lee, & Siegell, 1987; Tuthill, 1969; Wu, Smith, & Saxena, 1997), especially by using very fine particles (Zhu & Li, 1996). In the past decade, Hristov (1996, 1998, 1999, 2002, 2006) contributed greatly to the investigation of magnetic field stabilized fluidized beds (MFSFB), especially in aerosol filtration (Cohen & Tien, 1991) and particles separation (Fan et al., 2002; Harel, Resnick, & Zimmels, 1990; Lochmuller & Wigman, 1987; Luo, Zhao, Chen, Tao, & Fan, 2004b; Shao & Kwauk, 1991). This paper reports on the fluidization properties of magnetic pearls in the absence and in the presence of an external magnetic field.

2. Materials and methods

The particle size distribution, density, particle shape and magnetic characteristics of magnetic pearls were first studied.

2.1. Particle size, density and shape

Fig. 1 shows the particle size distributions of the magnetic pearls obtained from a coal power plant and used in the following experiments. About 98% of the magnetic pearls are finer than

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Nomenclature

d_p	particle size (μm)
H	magnetic field intensity (Oe)
Δp	pressure drop (Pa)
u_L	superficial gas velocity (mm/s)
u_{mf}	minimum fluidization velocity (mm/s)
U_b	minimum bubbling velocity (mm/s)

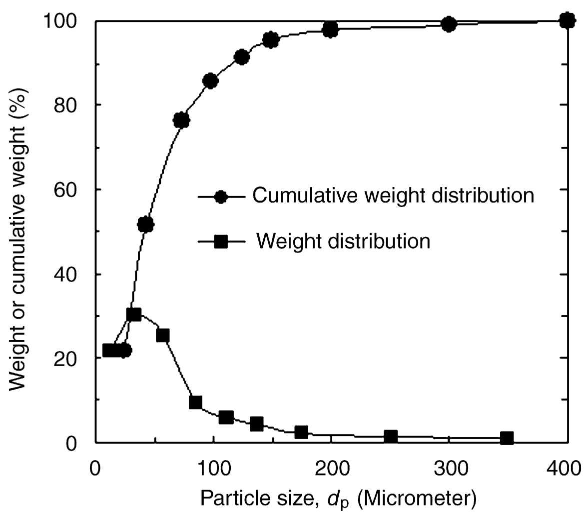

Fig. 1. Particle size distribution of magnetic pearls.

75 μm, with the most frequently occurring size of about 40 μm. The cumulative weight distribution curve in Fig. 1 depicts the median of the magnetic pearls sample as the 50% size, about 42 μm.

Particle density of magnetic pearls varies from 3.5 to 4.0 g/cm^3, while the real density of magnetic pearls is about 3.7 g/cm^3 and the bulk density of magnetic pearls is about 1.8 g/cm^3.

Fig. 2 is a scanning electron micrograph of the magnetic pearls, essentially spheroidal particles, some of which are hollow ball or near-hollow balls.

2.2. Magnetic characteristics and recovery method

The mass magnetic susceptibility of the magnetic pearls is more than 6.3×10^{-6} m^3/kg. Magnetic pearls (Fe_2O_3) can be recovered from coal fly ash using magnetic separators, such as the permanent-magnet rotary separator or the Roto-flux magnetic separator which uses the rotation of magnetic particles to provide agitation to shake loose the adhering nonmagnetic particles thus improving separation.

3. Experimental facilities

Fig. 3 shows the experimental system used in the present study. The fluidized bed and its accessories are made of non-magnetic materials. The fluidized bed has an inner diameter of 100 mm and an effective height of 300 mm. The electromagnetic

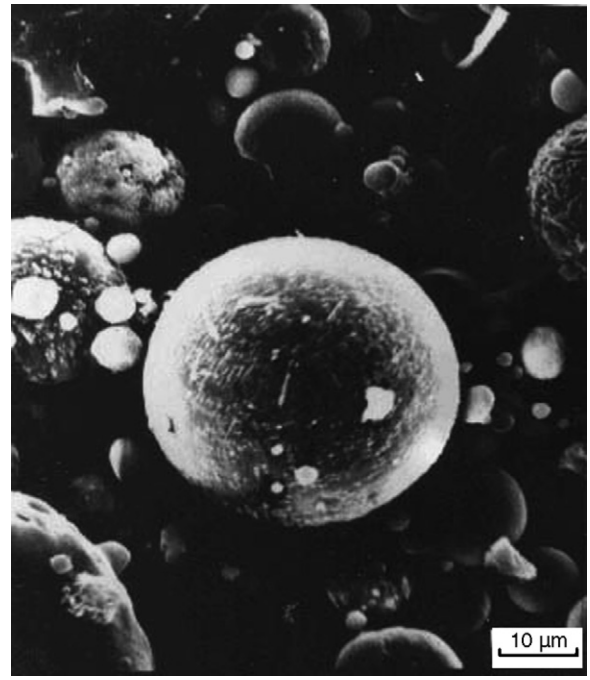

Fig. 2. SEM image of magnetic pearls.

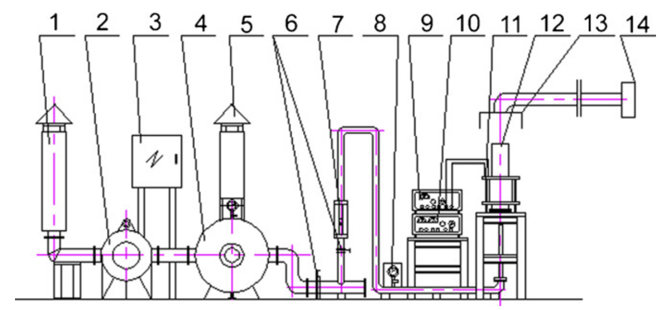

Fig. 3. Experimental equipment for fluidization characterization, consisting of air filter (1), air blower (2), distribution box (3), air buffer (4), attenuator (5), flow regulating valve (6), effusion meter (7), manometer (8), dc source (9), ac supply (10), electromagnetic coils (11), fluidized bed (12), dust collecting cover (13) and air suction fan (14).

coils are 180 mm i.d. and 210 mm o.d. The effects of external magnetic field on the magnetic pearls fluidization performance such as fluidization gas velocity, pressure fluctuation and density were investigated. Considering that magnetic pearls are not transparent materials, a specially designed two-dimensional Plexiglas vessel of 20 mm × 120 mm × 400 mm was used for the study of the transition from the ordinary fluidized bed to magnetically stabilized fluidized bed. In such a fluidized bed, the picture of bubble in the fluidized bed with magnetic field and without magnetic field can be taken.

4. Results and discussion

A series of tests were performed on the effects of the external magnetic field on the critical fluidization gas velocities of the magnetic pearls fluidized bed, the density, uniformity and stability of the fluidized magnetic pearls and the tran-