Coal Ash Beneficiation and Utilization in Coal Separation Process

Maoming Fan[1,2], Qingru Chen[2], Yuemin Zhao[2], Daniel Tao[1], Zhenfu Luo[2], Xiuxiang Tao[2], Yufen Yang[3], Xingkai Jiang[1], Jinbo Zhu[4]

[1] University of Kentucky, Department of Mining Engineering, 230 Mining and Mineral Resources Building, Lexington, KY 40506; [2] China University of Mining and Technology, School of Chemical Engineering and Technology, Xuzhou 221008, Jiangsu, P. R. China; [3]Tsinghua University Department of Materials Science and Engineering, Beijing 100084, China; [4]Anhui University of Science and Technology, Department of Material science and Technology, Huainan 232001, Anhui, P.R. China

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ABSTRACT

In recent years, coal production and consumption increased dramatically, especially in China. So, more and more attentions have been paid to coal preparation and coal ash utilization with the growing concern about the pollution by fly ash. The unburned carbon in fly ash significantly affects its utilization in many fields, especially in concrete production industry. Technologies such as flotation, triboelectrostatic separation and carbon burnout have been developed to remove carbon from coal ash. This paper introduces chemical compositions of a typical coal ash and a dry beneficiation method. For some kinds of fly ash, magnetically stabilized fluidized bed was studied to recover magnetic pearls from fly ash. The magnetic pearls are mainly composed of Fe_3O_2 and Fe_3O_4 and are mostly hollow spheres. The size distributions of three kinds of magnetic pearls are from 300 to 25 μm. A magnetic pearls fluidized bed and a magnetically stabilized magnetic pearls fluidized bed for coal dry separation are studied in the paper.

[1] Corresponding author: Tel. +1 859 257 4124; Fax: (859)323-1962; E-mail address: fmaoming@yahoo.com

INTRODUCTION

Over 70% of primary energy consumption is derived from coal combustion in China. As a by-product of coal power plants during coal combustion, a large amount of coal fly ash is produced in China as in the world. However, only a small percentage of coal ash is utilized, mainly in the cement industry, in bricks plants, and road construction etc, with most of the coal ash being directly discharged as solid waste, which is causing many environment problems. In order to make full use of coal ash, it is very important to separate the species in coal ash to get different products for meeting specific usages. For example, the unburned carbon in fly ash affects its utilization in concrete production industry. Based on the composition of the coal fly ash, it would be possible to produce many useful materials such as magnetic pearls and glass materials. So, one of our main research goals is to separate coal fly ash into different products and make full use of each product according to their physical and chemical properties. The magnetic pearls can be use as a separation medium to beneficiate coal and reduce the total amount of coal ash and waste gas such as SO_x and NO_x produced during coal combustion.

Because two thirds of China's coal is located in arid areas, dry separation provides an alternative approach. Of the dry coal separation methods, air dense-medium (magnetic pearls from coal ash) fluidized beds have been used to separate 50~6mm coal efficiently. Magnetically stabilized fluidized beds also with magnetic pearls can avoid excessive bubbling and back mixing of the separated solids in the air-dense media fluidized bed and decrease the lower size limit of 6mm to 0.5 mm.

COAL ASH COMPOSITION AND DRY SEPARATION

The particle size and chemical components distributions of coal ash depend on the pulverized coal particle size distribution, mineral composition and the kinds of coal burned, the types of burner used and the combustion. Figure 1 shows the particle size and LOI (Loss On Ignition: dried and treated at 1000°C for 1 h in air to completely remove the organic compounds) distributions of a typical coal fly ash obtained from a power station and used in this experiment. The bulk density of this coal fly ash is about 1.6 g/cm^3 and the coal fly ash has near spheroid morphology with mean particle sizes about 80 microns.

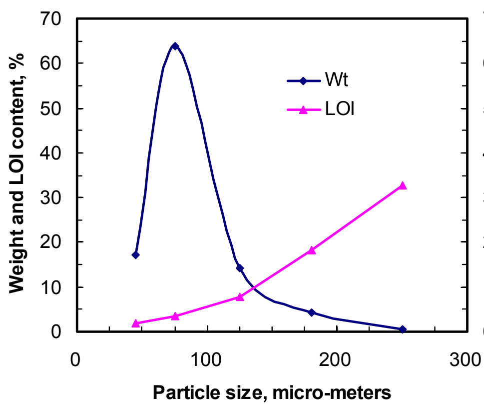

Figure.1 Particle size and LOI distributions of a coal ash

Table 1 shows the main chemical components of the coal fly ash. The coal fly ash mainly composes of SiO_2, Al_2O_3 and Fe_2O_3. The SiO_2 and Al_2O_3 can be utilized as main glass network formers. The magnetic pearls (Fe_2O_3) also can be used as a separation medium for coal beneficiation.

Table 1 Main chemical components of the coal fly ash

Components	Wt,%	Components	Wt, %
LOI	4.57	MgO	1.14
SiO_2	52.30	K_2O	1.02
Al_2O_3	27.45	Na_2O	0.63
Fe_2O_3	9.76	SO_3	0.37
CaO	2.51	ZnO	0.25

Magnetic separation technology can be used to recovery the magnetic pearls (Fe_2O_3) from coal ash. We studied a kind of air coal-ash fluidized bed to separate the LOI from the ash. The fluidization method remove the unburned carbon from the fly ash by utilizing a suitable air velocity due to the density difference between unburned carbon and other compositions in fly ash. With superficial air velocity of 20 cm/s and air pressure 0.18 kg/cm^2, the fluidization beds can efficiently separate 250~75 µm fly ash with 11% LOI into three products: the high LOI content product with 60% LOI; the middling with 26 % LOI and the low LOI content product with 5%.

CHARACTERISTICS OF THE MAGNETIC PEARLS

Magnetic pearls are recovered from the waste of coal power plant. The magnetic pearls mainly consist of Fe_3O_2 and Fe_3O_4. The shape of the magnetic pearls is hollow ball or near hollow ball as shown in Figure 2.

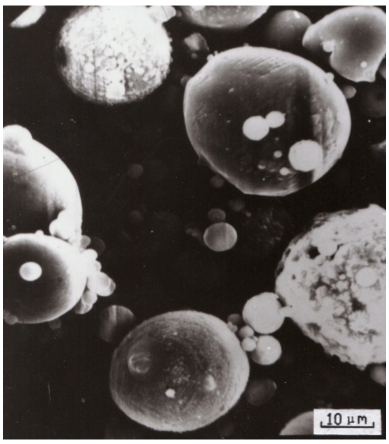

Figure 2. Microgram of magnetic pearls

The particle size distributions of three kinds of magnetic pearls range from +300µm to -25µm as shown in Table 2. We can learn from Table 2 that the size distributions of the three magnetic pearls are different, but the main size ranges of the three magnetic pearls are all less than 98 μm.

Table 2 Particle size distribution of magnetic pearls

Item	Producing area		
	Zouxian	Shiliquan	Fushun
Size range (μm)	Mass (%)	Mass (%)	Mass (%)
+300	0.39	0.75	0.68
300~200	0.67	1.38	1.03
200~150	4.21	2.16	3.56
150~125	7.98	4.22	5.98
125~98	5.59	5.74	6.43
98~74	20.42	9.15	15.67
74~43	18.24	25.10	21.88
43~25	22.65	30.14	24.64
-25	19.85	21.36	20.13
Total	100.00	100.00	100.00

The real density and bulk density of magnetic pearls are shown in Table 3. The magnetic pearls real density is mainly depended on the mineral composition and hollow degree. The magnetic pearls bulk density is decided by the magnetic pearls real density, accumulation state and porosity.

Table 3 Real density and bulk density of magnetic pearls from three locations

Density (kg/m^3)	Zouxian	Shiliquan	Fushun
Real density	3650	3680	3720
Bulk density	1780	1800	1840

The magnetic characteristic of the magnetic pearls is important for magnetic stabilized fluidized bed and medium recovery. The specific magnetization susceptibility (X) of the magnetic pearls is more than 6.3×10^{-6} m^3/kg. So, the magnetic pearls are strength magnetic matter.

MAGNETIC PEARLS FLUIDIZATION BED FOR COARSE COAL SEPARATION

The so-called beneficiation with air magnetic pearls fluidized bed is that applies the pseudofluid properties of gas-solid fluidized bed to form a uniform and stable gas-solid suspended substance in fluidized bed with density ρ_f:

$$\rho_f=(1-\varepsilon)\rho_s$$

where ρ_f is density of the fluidized bed, kg/m^3; ρ_s is density of solid particles in the fluidized bed,

kg/m^3; ε is porosity in the fluidized bed. The active forces of the feedstock in the fluidized bed are gravitational force of itself, frictional force and pressure difference given by upward gas flow, buoyant force of gas and drag force given by the medium solid particles with relative motion to the feedstock. The acceleration of feedstock in the fluidized bed is

$$a = \frac{\rho_f - \rho}{\rho} g + \frac{C_D \rho_f}{d\rho} |u_s - u| (u_s - u)$$

where ρ is density of the feedstock, kg/m^3; g is gravity acceleration, m/sec^2; C_D is drag coefficient; d is grain size of the feedstock, m; u_s is velocity of the medium solid particles, m/s; u is velocity of feedstock, m/s. In the above formula, $\frac{\rho_f - \rho}{\rho} g$ is buoyant force; $\frac{C_D \rho_f}{d\rho} |u_s - u| (u_s - u)$ is drag force.

When u_s=u, $a = \frac{\rho_f - \rho}{\rho} g$, the light and heavy feedstock are separated strictly by density in fluidized bed (That is separated according to Archimedes' Principle). When u_s=u, ρ_f =ρ, $a = \frac{C_D \rho_f}{d\rho} |u_s - u| (u_s - u)$, the motion tendency of the feedstock is entirely determined by medium solid particles and their density. The buoyant force has nothing to do with the motion tendency. When $(u_s-u)(\rho_f-\rho)>0$, the drag force will enforce buoyant force effect and will be conducive to material's separation by density. When $(u_s-u)(\rho_f-\rho)<0$,the drag force will weaken buoyant force effect and will be detrimental to material's separation by density.

In the practical air magnetic pearls fluidized bed, the beneficiation of feedstock is affected not only by the density, but also by viscous misplaced effect of the fluidized bed and motional misplaced effect of the magnetic pearls particles. This makes the misplacement of the higher density material and the lower density material. The viscous misplaced effect and the motional misplaced effect are enforced as the grain size of the feedstock decreases. So, the separation of fine material is affected in the common air magnetic pearls fluidized bed.

The separation efficiency of coal in magnetic pearls fluidized bed is decided directly by the uniformity and stability of bed[1]. In order to investigate the distribution of bed density, 15 pressure measuring points are arranged uniformly in the three dimensions of magnetic pearls fluidized bed (1000 mm wide, 1000 long and 400 high). According to the results of exploration experiments, the bed density is uniform and stable under appropriate technical and operating conditions with small bubbles and weak back mixing of medium solids. The maximum of relative errors between mean density of bed and different density measuring value is 2% at gas velocity of 0.06 m/s and bed height of 400 mm. Therefore, the air magnetic pearls fluidized bed possesses excellent fluidizing performance, and provides a good basis for the dry separation of coarse coal with high efficiency.

The feedstock is the raw coal of 50~6mm size with ash of 21.48%. The feed coal was separated into a clean coal float product and a refuse sink product in the magnetic pearls fluidized bed. The experimental result shows that the air magnetic pearls fluidized bed has a good separation performance for the coal of 50~6mm size with a clean coal ash of 9.8%, a refuse ash of 79.0%, and a probable error (Ep value) of 0.05. The light (which density is lower than magnetic pearls fluidized bed density) in refuse product is 1 %, and the heavy (which density is higher than magnetic pearls fluidized bed density) content in clean coal product is 0.06% only. Therefore, the clean coal recovery and separation efficiency were good. The result also shows that the lower the density of materials in feed, the higher the recovery of it in clean coal.

Figure 3 shows the apparatus of coarse coal dry beneficiation with air magnetic pearls fluidized bed. The separator with air magnetic pearls fluidized bed consists of an air-chamber, an air distributor, a separation vessel, a scraper, as well as equipment of magnetic pearls recovering. The feed's separating process in the separator is the screened 6~50mm coal and dense medium are fed into the separator, the compressed air from an air buffer is provided to the air-chamber, and then to the distributor uniformly . It makes the magnetic pearls fluidized. The comparative stable and uniform air-solid suspension that makes a certain density is formed under certain technical conditions. The feedstock is stratified and separated according to its density. The separated materials are transported in counter flow. The floated light product such as clean coal is discharged to the left, and the sink heavy product such as refuse to the right.

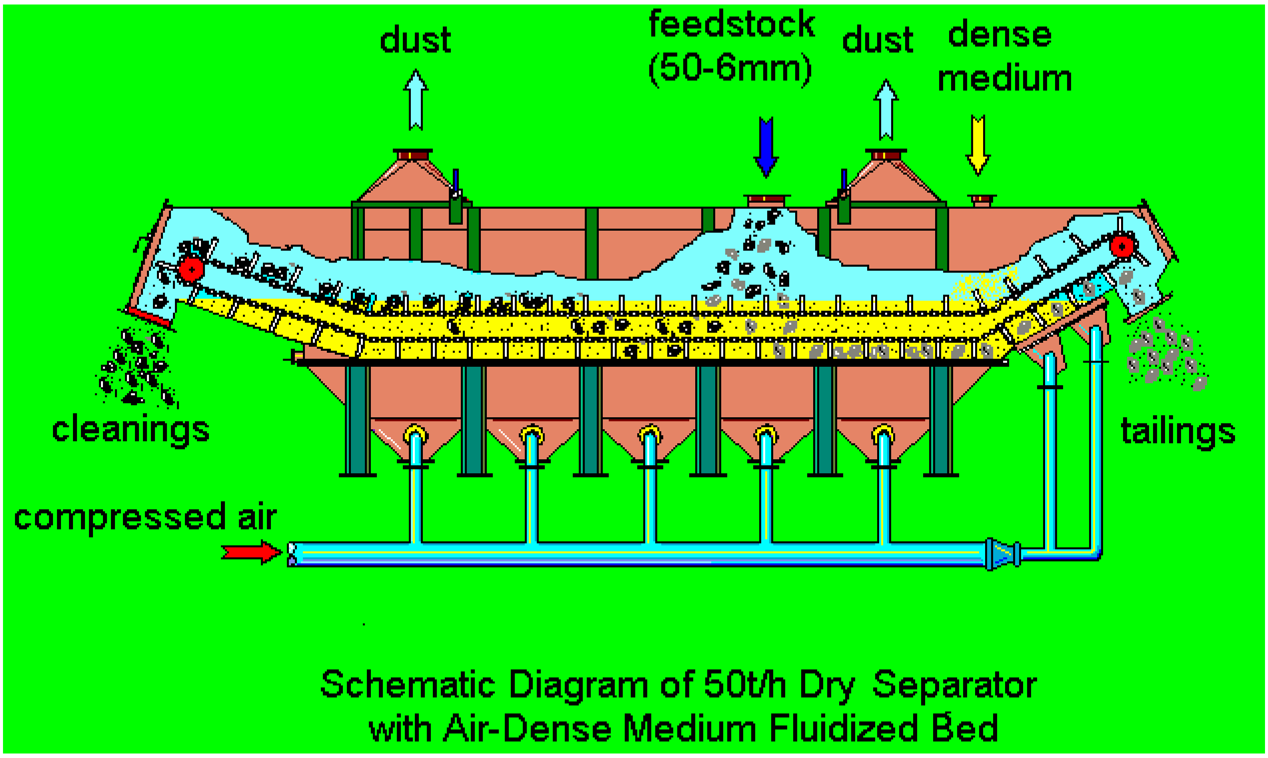

Figure 3. The 50t/h dry separation apparatus

Figure 4 shows the flowsheet of the coal dry beneficiation system with air magnetic pearls fluidized bed. It consists of raw coal preparation, coal separation, magnetic pearls recovery and purification system, air supply and dust removal system, etc.

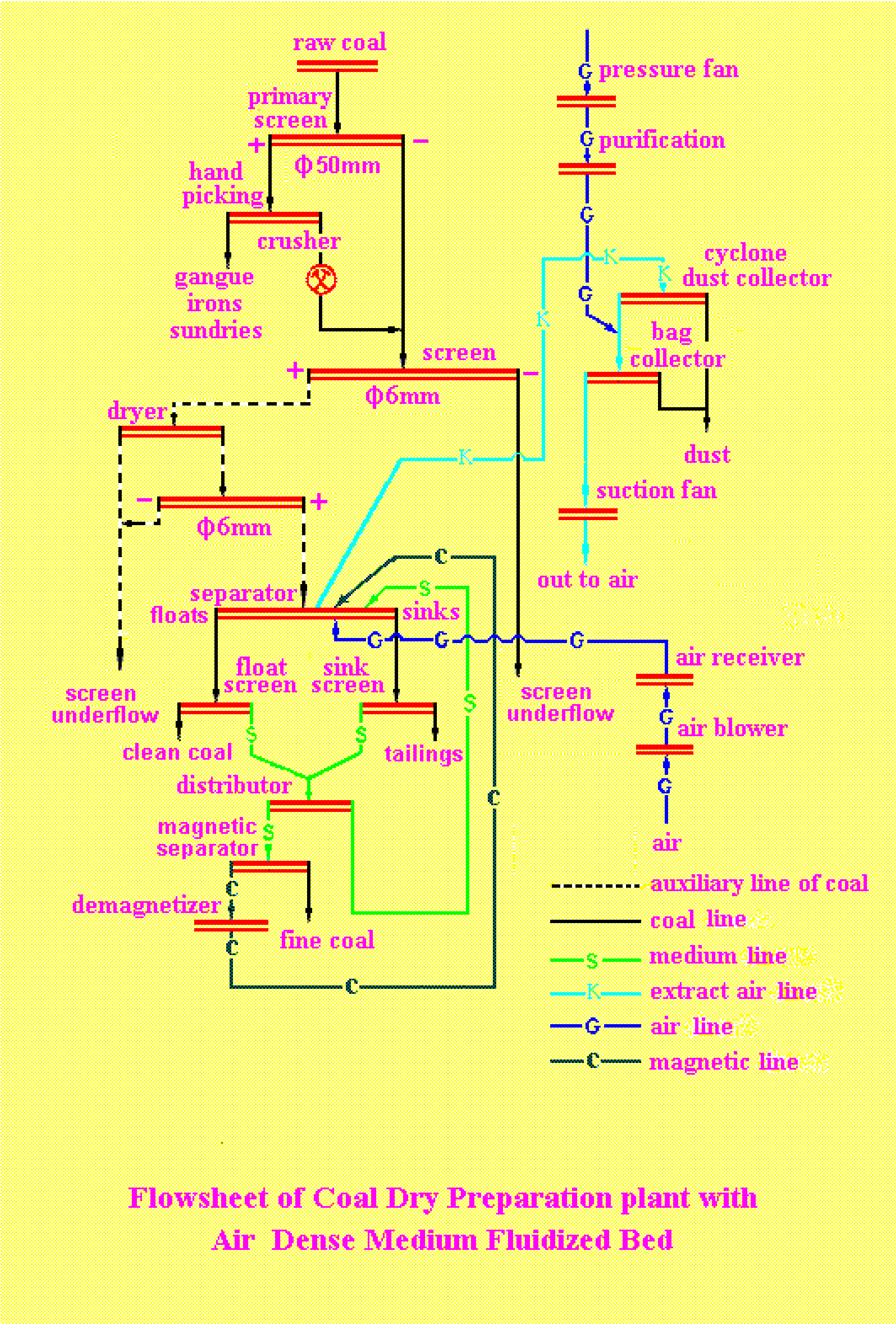

Figure 4. The coal dry beneficiation system with air magnetic pearls fluidized bed

The industrial test results of the 50t/h dry beneficiation apparatus with air magnetic pearls fluidized bed has high separation precision with Ep value range from 0.051 to 0.053. For the very rebellions coal to be separated, the organic efficiency can be higher than 90%. The sink-and-float composition and distribution coefficients of product are analysized and the distribution coefficients curves are shown in Figure 5.

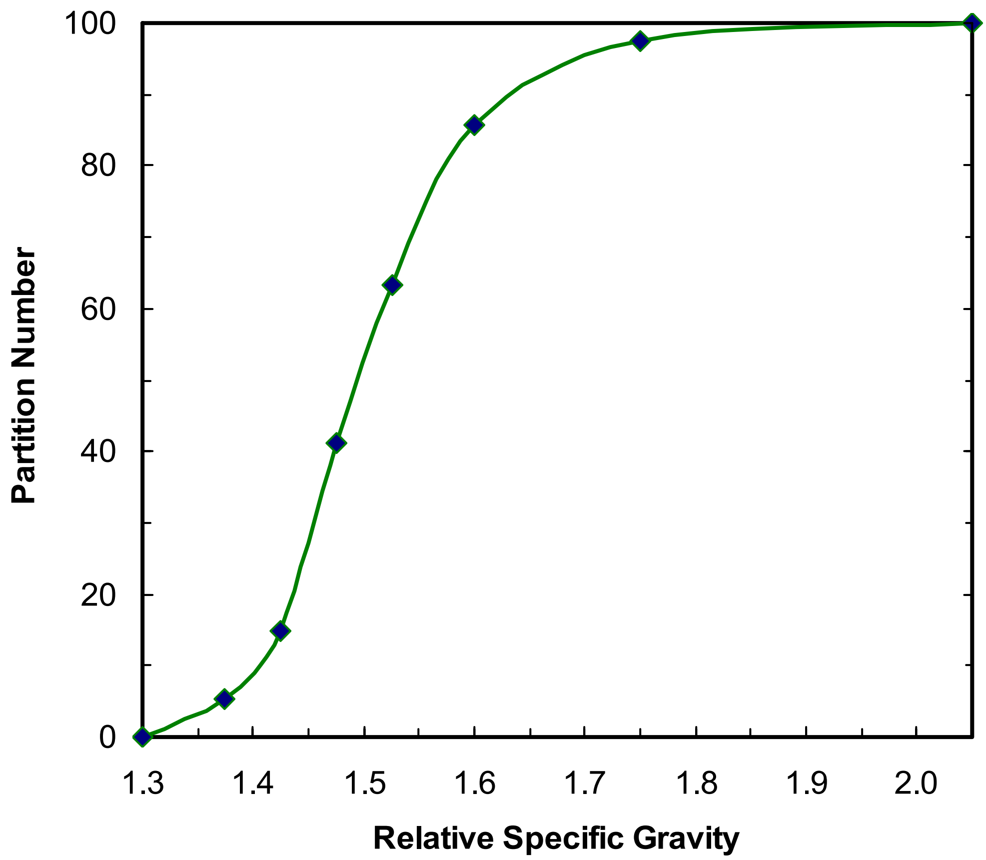

Figure 5. Partition curve of dry coal separation

MAGNETICALLY STABILIZED MAGNETIC PEARLS FLUIDIZATION BED FOR FINE COAL SEPARATION

The MSFB has good fluidization characteristics[2~11]. We studied magnetically stabilized fluidized beds (MSFB) with magnetic pearls for fine coal dry preparation and is especially suitable for 0.5~6mm coal separation[12~13]. The experimental system, shown in Figure 6, is composed of two flow regulating valves (1), an air flowmeter (2), a manometer (3), a DC power supply (4), a fluidized bed (5), and a set of electromagnet coils (6).

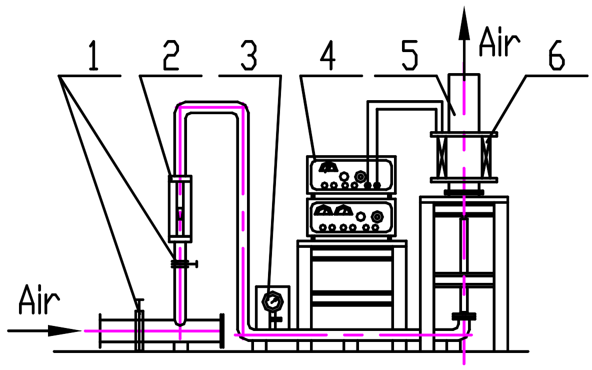

Figure 6. Experimental setup

Fluidization was carried out in a vessel made of non-magnetic materials, including the interconnecting pipes, screws and nuts. The fluidization vessel had an inner diameter of 100mm, an effective height of 300 mm, and was fitted with a stainless steel sintered distributor plate. The electromagnet coils were wound with 1.5 mm diameter insulated wire, each 100mm in height, 180 mm i.d., and 210 mm o.d. The magnetic field intensity could be adjusted by regulating both the quantities of the electromagnet coils in operation and the electric current.

Many experiments have been conducted to separate 0.5~6mm coal by density difference in magnetically stabilized bed. We chose the size range of 0.5~6 mm, because 50~6 mm coal can be efficiently separated in common air magnetic pearls fluidized bed, and 0~1 mm coal can be separated by electric separation technology. The authors have done development work in the above three dry separation technologies.

We chose Zouxian magnetic pearls (size range shown in Table 2) as fluidization medium. The magnetic field intensity was 30 Oersted and the gas velocity was 12.3 mm per second. In this condition, the bulk density of the magnetic pearls magnetically stabilized fluidized bed was maintained at 1520 kg/m^3. The 0.5~6 mm size range coal to be separated was introduced into the magnetically stabilized fluidized bed by dropping it from a standard height of 30 mm above the bed top surface. We found that the coal particles floated on the top surface of the magnetically stabilized fluidized bed, while the gangue particles always sank into the magnetically stabilized fluidized bed. After forty seconds of the separation time, we shut down the fluidizing gas flow and removed the magnetic field. Then we took the samples of the float product from the top bed stratum and the sink product from the bottom bed stratum. The two samples' sink-and-float composition in product and partition coefficient is shown in Table 4. The separation efficiency is high with Ep=0.066.

Table 4 Coal-shale separation evaluation

Density fraction g/cm^3	Floats, wt. %	Sinks, wt. %	Floats in feed %	Sinks in feed %	Partition Number
-1.350	19.03	0.80	11.67	0.31	2.60
1.35-1.4	38.12	1.92	23.37	0.74	3.18
1.4-1.5	32.93	4.69	20.19	1.82	8.25
1.5-1.6	5.27	13.49	3.23	5.22	61.75
1.6-1.7	2.40	15.99	1.47	6.19	80.81
1.7-1.8	0.96	14.47	0.59	5.60	90.50
1.8-1.9	0.56	15.01	0.34	5.81	94.38
1.9-2.0	0.42	16.39	0.25	6.34	96.07
+2.0	0.31	17.24	0.19	6.67	97.23
Totals	100.00	100.00	61.30	38.70	100.00

CONCLUSIONS

The magnetic pearls are a kind of cheap and good heavy medium suitable for dry coal separation. The magnetic pearls fluidized bed and magnetic pearls magnetically stabilized fluidized bed can be used for the dry separation of 50~6mm coarse coal and 6~0.5 mm fine coal according to density difference respectively. The experimental results reported here show that the separation efficiency is high.

As proved by the industrial tests , the technology of coal dry beneficiation with air magnetic pearls fluidized bed is a highly effective dry beneficiation method, which can be used to effectively beneficiate coal of 50~6 mm grain size with a Ep value within 0.05~0.07.

Since this technology greatly simplifies the coal beneficiation process and leaves out the coal-water-mud processing system, which is very complicated and costly, it's engineering investment and production cost can greatly reduced and is thus much lower than the wet cleaning process. As a result, a new and profitable method is opened for beneficiating the easily muddied coal in the vast areas of China, where are characterized by water deficiency and severe cold.

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