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Separation of Pozzolonic Material from Lignitic Fly Ash of Tuncbilek Power Station

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ABSTRACT

Fly ash is an excellent source of pozzolanic material. Pozzolans are siliceous or siliceous/aluminous materials and when mixed with lime and water, form cementitious compounds. The spherical shape of fly ash particles and their extreme fineness have a beneficial effect on the workability of concrete. The carbon content of fly ash, however, creates problems as it adsorbs the chemicals used to make the concrete. In order to make a valuable cement additive, the carbon content of fly ash must be less than 3%. The objective of this study is to characterize fly ash, and develop a flow sheet through which fly ash by products can be efficiently separated. For this purpose, physical, chemical and mineralogical characterization of the fly ash is made. Separation tests, including gravity and magnetic on Tuncbilek power station fly ash, have been carried out to reduce the carbon in fly ash.

INTRODUCTION

More than half of the electricity in Turkey is produced from lignite-fired power plants. This energy production has resulted in the formation of voluminous fly ash waste. Despite annual production of over 13 million tons of fly ash in Turkey, unfortunately, only 1 % of this amount is utilized in the cement and brick industry.

Today, fly ash is an accepted beneficial ingredient in the construction industry and widely used in blended cements [1, 2]. In addition, it provides a major source of revenue to power plants. Physically, fly ash is very fine, powdery material, predominantly silica, with particles almost spherical in shape and excellent source of pozzolanic material. The properties of fly ash make it a good binding agent and a good substitute for natural pozzolan in the amelioration of clinker [3]. In addition to the natural materials, the industrial wastes (for example fly ash, slag blast furnace, and silica-fume) are also used [4]. Rice hull, wheat straw, and hazel nut shell, though not common, have been also used as binding agents [5]. Fly ash with higher amount of CaO is found to exhibit much better properties and to favorably contribute to the quality of concrete [6].

In 1992, over 367 million tonnes of fly ash, resulting from burning of coal at power stations were produced worldwide [7]. However, only around one third of this production was utilized in cement industry [8]. One of the reasons for not using fly ash directly is the carbon content of fly ash. In some uses carbon is simply an undesirable mineral, which must be lower than 3% [9]. The presence of carbon in fly ash inducing common faults include; adding unwanted color (black), adsorbing process or product materials (e.g. water and chemicals), carrying unwanted chemicals into process (e.g. ammonina). Since fly ash is mostly used in concrete products, and carbon can cause an increase in the consumption of water and air entraining agents in concrete, the focus of most beneficiation methods has been to minimize the negative effects that carbon have in normal-strenght concrete [10]. These carbon particles are generally of lower density than inorganic matter in the fly ash [11]. The carbon content of fly ash is also very important in ceramics industry as it leads to undesirable properties such as gas evolution, high porosity, and high water absorbance [12]. For this reason, especially, removal of unburned carbon from fly ash has been studied by a number of researchers [13]. Recently, application of a dry tribo electrostatic process has been considered for the separation of unburned carbon from fly ash into economically valuable products [(13-14)]. Apart from these methods, froth flotation and air classification are also used for the separation of unburned carbon from fly ash [(15-16)]. Removal of unburned carbon from Soma fly ash of Turkey was investigated by flotation [17]. Some studies show that unburned carbon can be recovered with oil agglomeration process [18]. A new separator was recently tried to classify and reduce the unburned carbon of fly ash [19]. Gravity and magnetic separation were also used for removing not only unburned carbon but also magnetic material as well [(12-20)].

The objective of this study is to investigate the extent of separating unburned carbon from fly ash using various dry and wet beneficiation techniques.

EXPERIMENTAL

Materials

Fly ash used in this study was obtained from the electrostatic filter bag house of Tunçbilek Power Station in Kütahya. A representative sample of 20 kg was used for chemical and physical characterization and separation studies. Chemical analysis of fly ash sample given in Table 1 show that the fly ash mainly consists of oxides of silica, aluminum and iron with lesser amounts of calcium, magnesium and potasium oxides. Since Tunçbilek fly ash is a by-product of a lignitic coal and SAF ($SiO_2 + Al_2O_3 + Fe_2O_3$) value is over 50, it is classified as a C type fly ash according to the ASTM C 618 [21].

Table 1. Chemical analysis of the Tunçbilek power station fly ash

Compound	% by weight
SiO_2	55.38
Al_2O_3	18.76
Fe_2O_3	9.94
S+A+F	84.08
CaO	2.95
MgO	5.38
K_2O	1.47
Na_2O	0.12
TiO_2	0.72
SO_3	0.28

Wet screen analysis was made to determine the size distribution of fly ash. The screen analyses given in Table 2 show that the D_{80} and D_{50} values for fly ash are respectively 180 and 90 μm. The results in Table 2 show that while the carbon content of fly ash decreases with a decrease in particle size, a significant proportion of unburned carbon remains in the coarse sizes. As seen from the table, the unburned carbon content of fly ash is over 3 % at plus-210 micron size fraction. Therefore, a simple sieving at 210 micron can be effective for producing fly ash of suitable quality for the cement industry. Bulk density is an important property of fly ash, and thus used in cement industry as an indicator of lightweight material for construction equipment. Table 2 also shows that the bulk density of fly ash increases with a decrease in particle size indicating that light materials like unburned carbon and cenosphere accumulate at coarse sizes, whereas heavy materials like magnetic particles and pozzolan typically collect at fine sizes. Table 2 shows the correlation between LOI and carbon content in the fly ash. Evidently, the difference is approximately 10%. Therefore, in the majority of analyses, the LOI values were used for carbon.

Table 2. Size analysis, carbon content, loss on ignition and bulk density results of fly ash sample

Particle Size (mm)	Weight (%)	Cumulative undersize (%)	Carbon Content (%)	LOI (%)	Bulk Density (g/cm^3)	Fe content (%)
+ 0.210	11.28	100.00	3.69	3.79	0.69	10.25
-0.210+0.150	15.53	88.72	1.81	2.05	0.76	10.29
-0.150+0.106	16.24	73.19	0.85	1.01	0.81	10.46
-0.106+0.075	14.53	56.95	0.81	0.96	0.87	11.09
-0.075+0.053	10.76	42.42	0.79	0.95	0.94	11.66
-0.053+0.038	6.75	31.66	0.63	0.88	0.96	12.60
-0.038	24.91	24.91	0.96	1.46	1.01	12.42
Feed	100.00		1.32	1.57	0.87	11.26

Figure 2 shows an optical microscope view of fly ash particles.

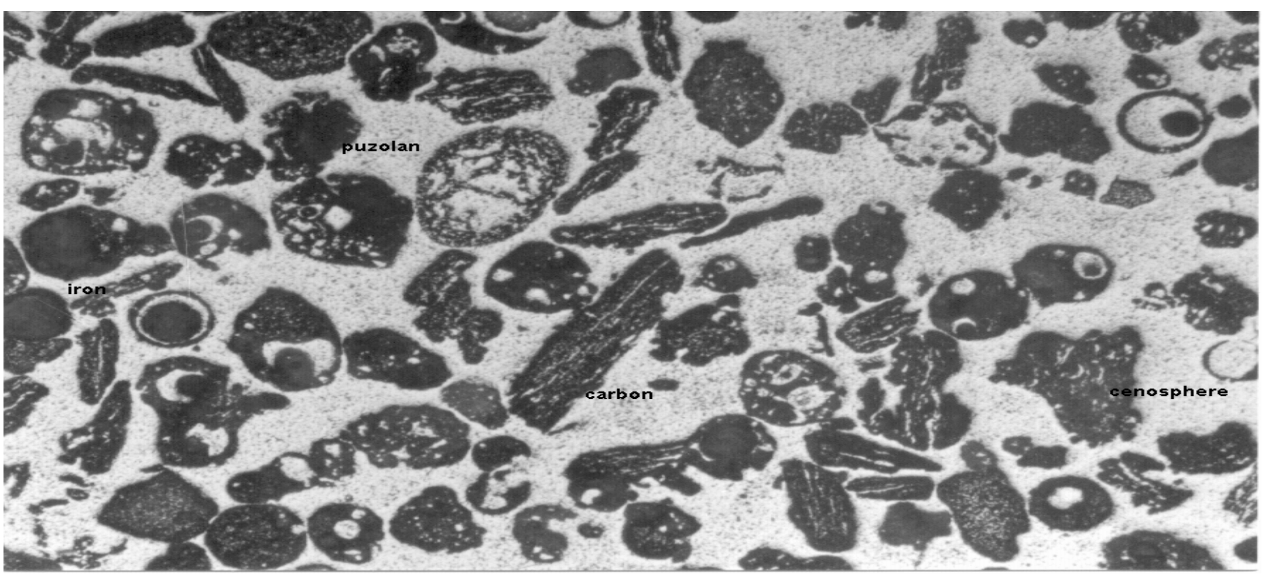

Fig 1. A typical view of fly ash by-products.

The carbonaceous material in fly ash is composed of angular particles and appears to be incompletely combusted.. Fly ash particles exhibit varying quantities of iron oxide minerals including magnetite and hematite, as black spherical particles. Fly ash also contains particles having irregular shape and gray in color. Fly ash has spherical particles with cream color called cenospheres.

Methods

There are sufficient density differences between unburned carbon and pozzolan. Therefore, gravity methods will be essential for separating unburned carbon from pozzolan. Fly ash sample of lignitic origin is found to contain magnetic particles mostly those of hematite. For this reason, magnetic separation was carried out to recover the magnetic particles from fly ash. Roll type Rare Earth Magnetic separator (REMS) as dry and Crocket magnetic separators as wet devices were used for this purpose. The float-sink experiments were carried out at various density fractions to identify the mineralogical composition of float and sink fractions. These experiments were conducted in a float-sink cell with a volume of 100 cc using an appropriate mixture of bromoform, carbon tetrachloride and acetone to adjust the density of liquid between 1 and 2.4 g/cm^3.

RESULTS AND DISCUSSION

Gravity Separation Tests

Different methods were tested for recovering fly ash by-products by various separation techniques. The gravity methods were particularly tried owing to large density differences among the fly ash particles. For this purpose, Mozley Table was used to remove heavy particles, typically of pozzolanic matter from light particles of unburned carbon. The aim was to divide by-products into two groups. Interestingly, if the fly ash were sieved from 210 microns, a direct product suitable for cement industry was obtained. Carbon content lower than 3 % C is the limit value to be used in the cement industry.

Float-Sink Experiments

Float-sink test presented elsewhere indicated that particular materials in the fly ash are found to accumulate in certain density fractions [22]. The magnetic particles in the fly ash remained at the 2.4 g/cm^3, puzzolanic material at the 1.3-2 g/cm^3, the unburned carbon at the 1-1.3 g/cm^3 and cenosphere at the 1-1.2 gr/cm^3 density intervals. The results show that unburned carbon could be easily separated from pozzolan by some type of gravity separation including heavy medium.

Mozley Table Experiments

Separation tests conducted on Mozley Table are given in Table 3 for different products together with the respective carbon contents. The carbon content of 1.41 % C in the feed is decreased to 1.02 % C in the heavy product. Meanwhile, a product containing 2.16 % C by weight with a recovery of 51.8 % is obtained. The results show that fly ash having relatively high carbon content can be separated from unburned carbon by using gravity methods. However, this product can be only used in the cement industry, but not in the brick industry because of high Fe content.

While carbon is collected in the light product, magnetic particles are also collected with pozzolons in the heavy product. Therefore, if magnetic separation is applied on the heavy product, this pozzolonic product of lower Fe content can be also utilized in ceramics industry.

Table 3. Experimental results on Mozley Table

Product	Weight (%)	Carbon (%)	C Recovery (%)	Fe Content (%)
Heavy	66.62	1.02	48.2	12,35
Light	33.38	2.16	51,8	8.39
Feed	100.00	1.41	100.0	11.03

Magnetic separation followed by Mozley Table on Non-magnetic Products

Fly ash contains iron compounds typically of hematite, and the use of fly ash in ceramic industry depends on its iron content, i.e. it must be lower than 2 %. Therefore, magnetic separation was carried out for the removal of magnetic particles from fly ash. As seen in Table 2, the Fe_2O_3 content of the fly ash changes marginally with a decrease in particle size. Since particle size range is relatively broad, the fly ash sample is divided into two sizes; above and below 106 microns. This scheme increased the recovery and hindered the formation of flocs between fine and coarse particles. For this purpose, magnetic separation was performed on two size ranges and the results were combined. Table 4 shows the results of magnetic separation. The non-magnetic product with this Fe content cannot be used in ceramics industry but, if conditions optimized, the Fe content can be reduced to below 2 %.

Table 4. Upgrading of +106 micron ve –106 micron size fractions

By magnetic separation

Size (micron)	Weight (%)	Products	Weight (%)	Fe (%)
+ 106	43.05	Magnetic I	4.61	35.71
		Middling I	8.46	13.92
		Non magnetic I	29.98	6.00
- 106	56.95	Magnetic II	9.14	34.89
		Middling II	5.75	16.57
		Non magnetic II	42.06	6.63
Total	100.00		100.00	11.55

The non-magnetic product collected from the products in Table 4 was subjected to a series of Mozley Table testing with the final aim of separating light unburned carbon from pozzolonic material. The combined results in two sizes are presented in Table 5.

Table 6 shows the combined results of magnetic separation tests on two size fractions following Mozley Table. As seen from the data, a magnetic product with Fe content of 35,17 % and a non-magnetic product with Fe content of 6.36 % Fe are obtained. Meanwhile, a pozzolonic material with the carbon content of 1.17 % C with 54.20 % by weight in the heavy product and another product with carbon content of 3.33 % C and 42.1 % recovery in the light product are obtained.

Table 5. Combined results of Mozley Table on +106 and –106 micron non-magnetic products

Size (micron)	Product	Weight (%)	Carbon (%)	C Recovery (%)
+106	Heavy I	83.3	1.64	59.1
	Light I	16.7	5.64	40.9
	Feed I	100.00	2.31	100.0
-106	Heavy II	69.5	0.77	42.5
	Light II	30.5	2.37	57.5
	Feed II	100.00	1.26	100.0
	Total		1.71	

Table 6. Combined results of magnetic separation and Mozley Table products

Product	Weight (%)	Carbon (%)	C Recovery (%)	Fe (%)
Heavy(I+II)	54.20	1.17	45.0	6.36
Light (I+II)	17.84	3.33	42.1	
Magnetic(I+II)	13.75	0.65	12.9	35.17
Middling(I+II)	14.21			14.99
Feed	100.00	1.41	100.0	11.55

Design of an Optimum Flowsheet

An optimum flow sheet was developed by which the recovery of by-products in the fly ash is possible. A set of experiments was made to construct this flow sheet at two size fractions. Figure 2 shows a simplified flowsheet for these separation. The products in slime sizes are concentrated by hdrocyclone. All the combined results are shown in Table 7. If Underflow I, II and Middling are joined, a product assaying 1.11 % C with 64.85 % by weight, and Overflow I, II and the screening product are joined, a product assaying 3.32 % C with 48.3 % recovery is obtained. Also, a magnetic product with 30.49 % Fe is obtained.

Table 7. Results for an optimum flowsheet

Products	Weight (%)	Carbon (%)	Carbon Recovery (%)	Fe (%)
Puzolan	58.12	1.07	44.5	
Carbon	27.2	2.85	55.0	
Magnetic	14.68	0.05	0.5	30.49
Total	100.00	1.41	100.0	11,26

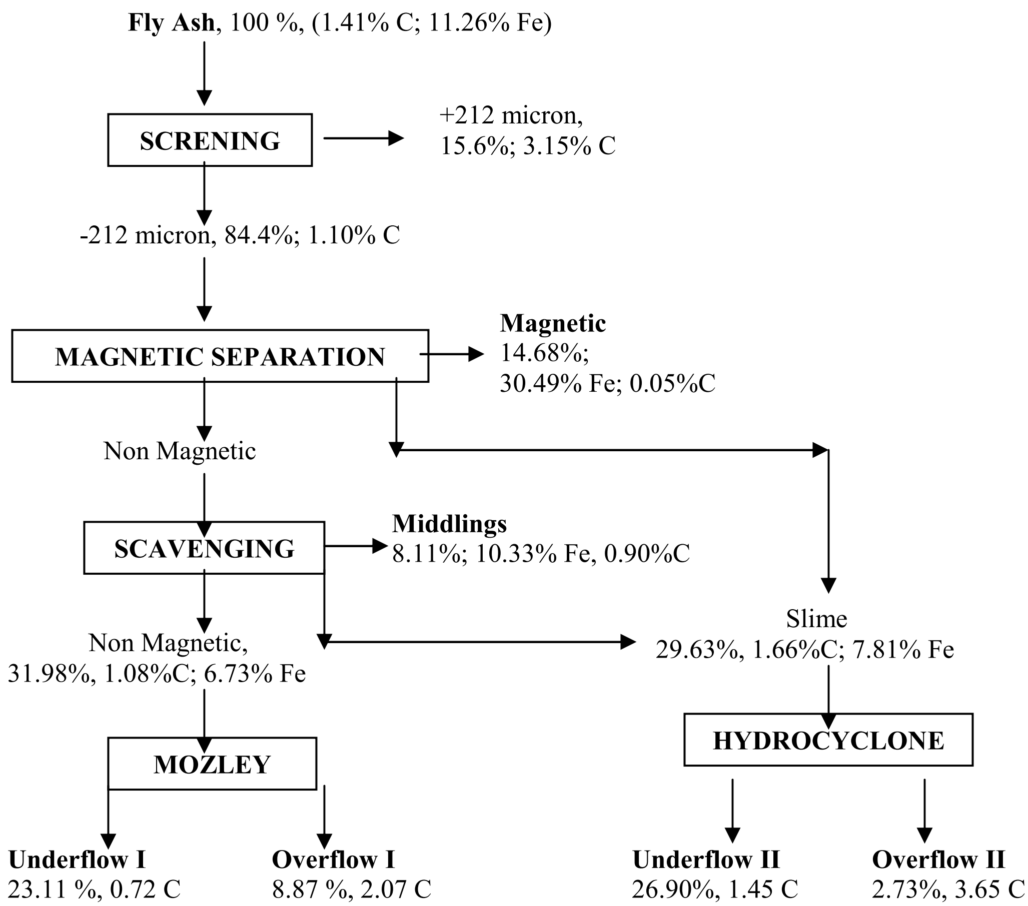

Fig. 2. Optimum flowsheet for separation of fly ash by-products.

CONCLUSIONS

- Characterization studies including chemical analysis, bulk density, and float-sink tests reveal that gravity and magnetic separation methods can be conveniently used to separate pozzolonic material from fly ash.
- An optimum flowsheet to recover by-products of fly ash at two size fractions has been developed. Pozzolonic matter containing 1.11 % C with 64.85 % by weight, and a second product containing 3.32 % C with 48.3 % recovery is obtained. A magnetic product with 30.49 % Fe is also obtained.
- These results show that while the unburned carbon can be used in power plants as a fuel source, the magnetic material can be used in heavy medium plants. Gravity separation methods are capable of producing materials with low carbon content for use in the cement industry. This study also reveals that fly ash unsuitable for use in ceramic industry due to its high iron content can be made suitable upon magnetic separation.

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