# TRIBO-ELECTROSTATIC BENEFICIATION OF LANDFILLED AND PONDED FLY ASH

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The American Coal Ash Association (ACAA) annual survey of production and use of coal fly ash reports that between 1966 and 2011, over 2.3 billion short tons of fly ash were produced by coal-fired utility boilers.[1] Of this amount, approximately 625 million tons have been beneficially used, mostly for cement and concrete production. However, the remaining 1.7+ billion tons are primarily found in landfills or filled ponded impoundments. While use rates for freshly generated fly ash have increased considerably over recent years, with current rates near 45%, approximately 40 million tons of fly ash continue to be disposed of annually. While use rates in Europe have been much higher than in the United States, considerable volumes of fly ash have also been stored in landfills and impoundments in some European countries.

Recently, interest in recovering this disposed material has increased, partially due to the demand for high-quality fly ash for concrete and cement production during a period of reduced production as coal-fired power generation has decreased in Europe and North America. Concerns about the long-term environmental impact of such landfills are also prompting utilities to find beneficial use applications for this stored ash.

## LANDFILLED ASH QUALITY AND REQUIRED BENEFICIATION

While some of this stored fly ash may be suitable for beneficial use as initially excavated, the vast majority will require some processing to meet quality standards for cement or concrete production. Because the material has been typically wetted to enable handling and compaction while avoiding airborne dust generation, drying and deagglomeration is a necessary requirement for use in concrete because concrete producers will want to continue the practice of batching fly ash as a dry, fine powder. However, assuring the chemical composition of the ash meets specifications—most notably the carbon content, measured as loss on ignition (LOI)—is a greater challenge. As fly ash use has increased in the last 20+ years, most "in-spec" ash has been beneficially used, and the off-quality ash disposed. Thus, LOI reduction will be a requirement for using the vast majority of fly ash recoverable from utility impoundments.

## LOI REDUCTION BY TRIBOELECTRIC SEPARATION

While other researchers have used combustion techniques and flotation processes for LOI reduction of recovered landfilled and ponded fly ash, ST Equipment and Technologies (STET) has found that its unique triboelectrostatic belt separation system, long used for beneficiation of freshly generated fly ash, is also effective on recovered ash after suitable drying and deagglomeration.

STET researchers have tested the triboelectrostatic separation behavior of dried landfilled ash from several fly ash landfills in the Americas and Europe. This recovered ash separated very similarly to freshly generated ash with one surprising difference: the particle charging was reversed from that of fresh ash, with the carbon charging negative in relation to the mineral.[2] Other researchers of electrostatic separation of fly ash carbon have also observed this phenomenon.[3-5] The polarity of the STET triboelectrostatic separator can easily be adjusted to allow rejection of negatively charged carbon from dried landfilled fly ash sources. No special modifications to the separator design or controls are necessary to accommodate this phenomena.

## TECHNOLOGY OVERVIEW—FLY ASH CARBON SEPARATION

In the STET carbon separator (Fig. 1), material is fed into the thin gap between two parallel planar electrodes. The particles are triboelectrically charged by interparticle contact. The positively charged carbon and the negatively charged mineral (in freshly generated ash that has not been wetted and dried) are attracted to opposite electrodes. The particles are then swept up by a continuous moving belt and conveyed in opposite directions. The belt moves the particles adjacent to each electrode toward opposite ends of the separator. The high belt speed also enables very high throughputs up to 36 tons per hour on a single separator. The small gap, high-voltage field, counter—current flow, vigorous particle-particle agitation, and self-cleaning action of the belt on the electrodes are the critical features of the STET separator. By controlling various process parameters, such as belt speed, feed point, and feed rate, the STET process produces low LOI fly ash at carbon contents of less than 1.5 to 4.5% from feed fly ashes ranging in LOI from 4% to over 25%.

The separator design is relatively simple and compact. A machine designed to process 40 tons per hour is approximately 30 ft (9 m) long, 5 ft (1.5 m) wide, and 9 ft (2.75 m) tall. The belt and associated rollers are the only moving parts. The electrodes are stationary and composed of an appropriately durable material. The belt is made of nonconductive plastic. The separator's power consumption is about 1 kilowatt-hour per ton of material processed with most of the power consumed by two motors driving the belt.

The process is entirely dry, requires no additional materials other than the fly ash, and produces no waste water or air emissions. The recovered materials consist of fly ash reduced in carbon content to levels suitable for use as a pozzolanic admixture in concrete, and a high-carbon fraction useful as fuel. Use of both product streams provides a 100% solution to fly ash disposal problems.

## PROASH RECOVERED FROM LANDFILLS

Four sources of ash were obtained from landfills: Sample A from a power plant located in the United Kingdom and Samples B, C, and D from the United States. All these samples consisted of ash from the combustion of bituminous coal by large utility boilers. Due to the intermingling of material in the landfills, no further information is available concerning specific coal source or combustion conditions.

The samples as received by STET contained between 15 and 27% water, as is typical for landfilled material. The samples also contained varying amounts of large >1/8 in. (3 mm) material. To prepare the samples for carbon separation, the large debris was removed by screening and the samples then dried and deagglomerated prior to carbon beneficiation. Several methods for drying/deagglomeration have been evaluated at the pilot scale to optimize the overall process. STET has selected an industrially proven feed processing system that offers simultaneous drying and deagglomeration necessary for effective electrostatic separation. A general process flowchart is presented in Fig. 2.

The properties of the prepared samples were well within the range of fly ash obtained directly from normal utility boilers. The most relevant properties for both the separator feeds and products are summarized in Table 2, along with recovered product.

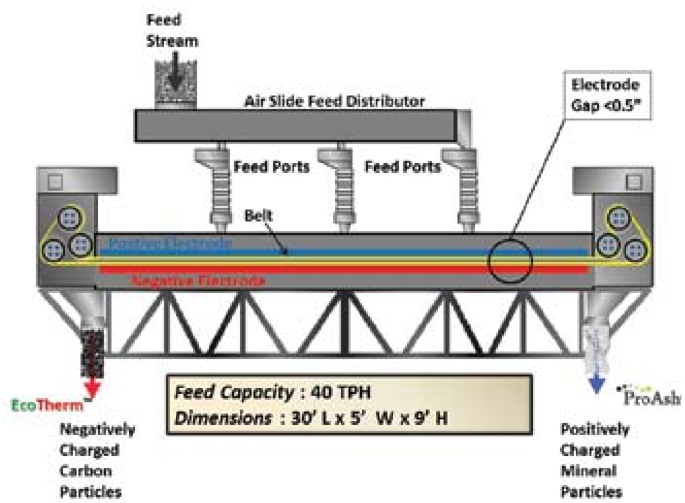


**Fig. 1: STET separator processing dried, landfilled fly ash**

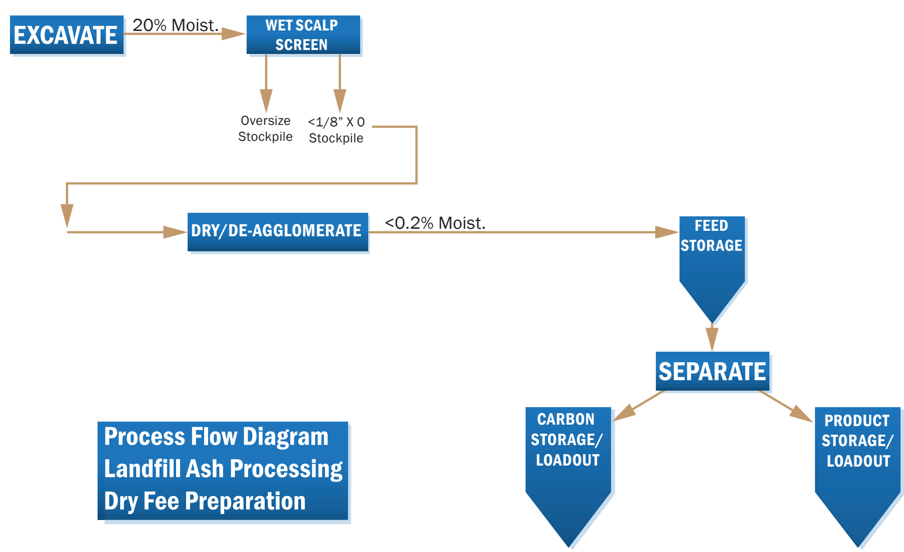


**Fig. 2: Process flow diagram**

## CARBON SEPARATION

Carbon reduction trials using the STET triboelectric belt separator resulted in very good recovery of low-LOI products from all four landfill fly ash sources. The reverse charging of the carbon as discussed previously did not degrade the separation in any way as compared to processing fresh ash.

The properties of the low-LOI fly ash recovered using the STET process for both freshly collected ash from the boiler and ash recovered from the landfill is summarized in Table 1. The results show that the product quality for ProAsh® produced from landfilled material is equivalent to product produced from fresh fly ash sources.

## PERFORMANCE IN CONCRETE

The properties of the ProAsh generated from the reclaimed landfill material were compared to that of ProAsh produced from fresh fly ash generated by the utility boilers from the same location. The processed reclaimed ash meets all the specifications of ASTM C618 and AASHTO M 250 standards. Table 2 summarizes the chemistry for samples from two of the sources showing the insignificant difference between the fresh and reclaimed material.

Strength development of a 20% substitution of the low-LOI fly ash in a mortar containing 600 lb/yd$^3$ cementitious material (see Table 3) showed the ProAsh product derived from landfilled ash yielded mortars with strength comparable to mortars produced using ProAsh from fresh fly ash produced at the same location. The end product of the beneficiated reclaimed ash would support high-end uses in the concrete industry consistent with the highly valuable position ProAsh enjoys in the markets it currently serves.

## PROCESS ECONOMICS

The availability of low-cost natural gas in the United States greatly enhances the economics of drying processes, including the drying of wetted fly ash from landfills. Table 4 summarizes the fuel costs for operations in the United States for 15% and 20% moisture contents. Typical inefficiencies of drying are included in the calculated values. Costs are based on the mass of material after drying. The incremental costs for drying fly ash for STET triboelectrostatic separation processing are relatively low.

Even with the addition of feed drying costs, the STET separation process offers a low-cost, industrially proven process for LOI reduction of landfilled fly ash. The STET process for reclaimed fly ash is one-third to one-half of the capital cost compared to combustion-based systems. The STET process for reclaimed fly ash also has significantly lower emissions to the environment compared to combustion or flotation-based systems. Because the only additional air emission source to the standard STET process installation is a natural gas-fired dryer, permitting it would be relatively simple.

## RECOVERED FUEL VALUE OF HIGH-CARBON FLY ASH

In addition to the low-carbon product for use in concrete—brand-named ProAsh—the STET separation process also

## TABLE 1: PROPERTIES OF FEED AND RECOVERED PROASH

| Feed sample to separator | LOI, % | ProAsh LOI, % | ProAsh fineness, % +325 mesh | ProAsh mass yield, % |
|---|---|---|---|---|
| Fresh A | 10.2 | 3.6 | 23 | 84 |
| Landfilled A | 11.1 | 3.6 | 20 | 80 |
| Fresh B | 5.3 | 2.0 | 13 | 86 |
| Landfilled B | 7.1 | 2.0 | 15 | 65 |
| Fresh C | 4.7 | 2.6 | 16 | 82 |
| Landfilled C | 5.7 | 2.5 | 23 | 72 |
| Landfilled D | 10.8 | 3.0 | 25 | 80 |

## TABLE 2: ASH CHEMISTRY OF LOW-LOI ASH

| Material source | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $K_2O$ | $Na_2O$ | $SO_3$ |
|---|---|---|---|---|---|---|---|---|
| Fresh B | 51.60 | 24.70 | 9.9 | 2.22 | 0.85 | 2.19 | 0.28 | 0.09 |
| Landfilled B | 50.40 | 25.00 | 9.3 | 3.04 | 0.85 | 2.41 | 0.21 | 0.11 |
| Fresh C | 47.7 | 23.4 | 10.8 | 5.6 | 1.0 | 1.9 | 1.1 | 0.03 |
| Landfilled C | 48.5 | 26.5 | 11.5 | 1.8 | 0.86 | 2.39 | 0.18 | 0.02 |

## TABLE 3: COMPRESSIVE STRENGTH OF MORTAR CYLINDERS

| | 7-day compressive strength, % of fresh ash control | 28-day compressive strength, % of fresh ash control |
|---|---|---|
| Fresh B | 100 | 100 |
| Landfilled B | 107 | 113 |
| Fresh C | 100 | 100 |
| Landfilled C | 97 | 99 |

## TABLE 4: DRYING COSTS ON BASIS OF DRIED MASS

| Moisture content, % | Heat requirement KWhr/T wet basis | Drying cost/T dry basis (natural gas cost $3.45/mmBtu) |
|---|---|---|
| 15 | 165 | $ 2.28 |
| 20 | 217 | $ 3.19 |

recovers otherwise wasted unburned carbon in the form of carbon-rich fly ash, branded EcoTherm™. EcoTherm has significant fuel value and can easily be returned to the electric power plant using the STET EcoTherm Return system to reduce the coal use at the plant. When EcoTherm is burned in the utility boiler, the energy from combustion is converted to high-pressure/high-temperature steam and then to electricity at the same efficiency as coal, typically 35%. The conversion of the recovered thermal energy to electricity in the STET EcoTherm Return system is two to three times higher than that of the competitive technology where the energy is recovered as low-grade heat in the form of hot water, which is circulated to the boiler feed water system. EcoTherm is also used as a source of alumina in cement kilns, displacing the more expensive bauxite, which is usually transported long distances. Using the high-carbon EcoTherm ash either at a power plant or a cement kiln maximizes the energy recovery from the delivered coal, reducing the need to mine and transport additional fuel to the facilities.

STET's Talen Energy Brandon Shores, SMEPA R.D. Morrow, NBP Belledune, RWEnpower Didcot, EDF Energy West Burton, RWEnpower Aberthaw, and the Korea South-East Power fly ash plants all include EcoTherm Return systems.

## STET ASH PROCESSING FACILITIES

STET's separation process has been used commercially since 1995 for fly ash beneficiation and has generated over 20 million tons of high-quality fly ash for concrete production. Controlled low-LOI ProAsh is currently produced with STET's technology at 12 power stations throughout the United States, Canada, the United Kingdom, Poland, and the Republic of Korea. ProAsh fly ash has been approved for use by more than 20 state highway authorities, as well as many other specification agencies. ProAsh has also been certified under the Canadian Standards Association and EN 450:2005 quality standards in Europe. Ash processing facilities using STET technology are listed in Table 5.

## CONCLUSIONS

After suitable scalping of large material, drying, and deagglomeration, fly ash recovered from utility plant landfills can be reduced in carbon content using the commercialized STET triboelectric belt separator. The quality of the fly ash product, ProAsh, using the STET system on reclaimed landfill material, is equivalent to ProAsh produced from fresh feed fly ash. The ProAsh product is very well-suited and proven in concrete production. The recovery and beneficiation of landfilled ash will provide a continuing supply of high-quality ash for concrete producers in spite of the reduced production of "fresh" ash as coal-fired utilities reduce generation. Additionally, power plants that need to remove ash from landfills to meet changing environmental regulations will be able to use the process to alter a waste product liability into a valuable raw material for concrete producers. The STET separation process with feed preprocessing equipment for drying and deagglomerating landfilled fly ash is an attractive option for ash beneficiation with significantly lower cost and lower emissions compared to other combustion- and flotation-based systems. ❖

## REFERENCES


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## TABLE 5: FLY ASH PROCESSING FACILITIES USING STET SEPARATION TECHNOLOGY

| Utility and power station | Location | Start of commercial operations | Facility details |
|---|---|---|---|
| Duke Energy—Roxboro Station | North Carolina | Sept. 1997 | 2 separators |
| Talen Energy—Brandon Shores Station | Maryland | Apr. 1999 | 2 separators<br>35,000 ton storage dome<br>Ecotherm Return 2008 |
| ScotAsh (Lafarge / Scottish Power Joint Venture)—Longannet Station | Scotland, UK | Oct. 2002 | 1 separator |
| Jacksonville Electric Authority—St. John's River Power Park, FL | Florida | May 2003 | 2 separators<br>Coal/petcoke blends<br>Ammonia removal |
| South Mississippi Electric Power Authority R.D. Morrow Station | Mississippi | Jan. 2005 | 1 separator<br>Ecotherm return |
| New Brunswick Power Company<br>Belledune Station | New Brunswick, Canada | Apr. 2005 | 1 separator<br>Coal/petcoke blends<br>Ecotherm return |
| RWE npower<br>Didcot Station | England, UK | Aug. 2005 | 1 separator<br>Ecotherm return |
| Talen Energy Brunner Island Station | Pennsylvania | Dec. 2006 | 2 separators<br>40,000 ton storage dome |
| Tampa Electric Co.<br>Big Bend Station | Florida | Apr. 2008 | 3 separators, double pass<br>25,000 ton storage dome<br>Ammonia removal |
| RWE npower<br>Aberthaw Station (Lafarge Cement UK) | Wales, UK | Sept. 2008 | 1 separator<br>Ammonia removal<br>Ecotherm return |
| EDF Energy West Burton Station<br>(Lafarge Cement UK, Cemex) | England, UK | Oct. 2008 | 1 separator<br>Ecotherm return |
| ZGP (Lafarge Cement Poland / Ciech Janikosoda JV) | Poland | Mar. 2010 | 1 separator |
| Korea South-East Power<br>Yeongheung Units 5&6 | South Korea | Sept. 2014 | 1 separator<br>Ecotherm return |
| PGNiG Termika-Siekierki | Poland | Scheduled 2016 | 1 separator<br>Ecotherm return |
| To Be Announced | Poland | Scheduled 2016 | 1 separator<br>Ecotherm return |