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Analysis and comparison of particle tribochargers

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ABSTRACT

Triboelectric separation is a dry electrostatic particle processing technique. A 'tribocharger' is used to differentially charge particles of different materials by contact or friction. These are then separated by an electric field. There has been little analytical work done on tribocharger design, slowing the development of this promising technology. One problem is that the fundamental physics of bulk particulate tribocharging have hitherto been poorly understood. We have previously performed experimental and theoretical studies to characterise the charging of bulk particulates in dynamic contact with surfaces. Following from this, a number of tribocharger configurations (sliding trough, vibratory canister and pneumatic cyclone) have been studied and their charging performance and other key parameters compared. An overview of the important results so far is presented, and these are used to demonstrate a general approach to design of tribocharging devices.

1. Introduction

As pressure grows on water resources in many parts of the world, dry particle separation methods, including electrostatic techniques, become an increasingly attractive alternative for mineral beneficiation. A number of electrostatic separation methods, such as high-tension roll separators and inductive electrostatic plate separators, are long-established in, for instance, the mineral sands industry, e.g. Dance and Morrison (1992). Different electrostatic separation methods operate on the basis of different particle properties: for instance, high-tension roll separators separate conducting from non-conducting particles, whereas dielectrophoretic separators separate electrically polarisable particles from non-polarisable ones, and so on (Kelly and Spottiswood, 1989a,b). Triboelectric separation, which separates particles with different surface charge affinity (characterised by the electron work function), is probably the least developed of these, and thus the most ripe for development. Its applications thus far in minerals processing have been very limited, and include separation of coal from fly-ash by Kim et al. (2000), quartz from calcite or apatite by Pearse and Pope (1977) and quartz from feldspar or wollastonite by Manouchehri et al. (2001). Overall, the field has been hampered significantly by an almost complete lack of analytical work. In particular, study of the physical mechanisms involved in the operation of tribochargers is in its infancy. Part of the purpose of this work is to provide examples of the sort of information that tribocharger designers will require from physical studies.

Unlike corona or inductive charging, where the particles are charged by some external charge source, tribocharging simply involves the exchange of charge during contact or friction. This exchange of charge is driven by the difference in electrochemical potential between the surfaces of different materials, as experienced in many everyday situations (e.g. charge generated while putting on or removing clothing, when rubbing feet on carpet, etc.). In triboelectric separation, a 'tribocharger' is a device that encourages contact and charge exchange, either between the different particle species, or between the particles and itself. For example, according to Nicholson and Ireland (2010), when coal and silica are brought into contact, the coal tends to charge positively and the silica negatively. In addition, coal brought into contact with stainless steel tends to charge positively, whereas silicates tend to charge negatively under the same circumstances. A mixture of coal and silica particles can be either encouraged to collide with each other (e.g. in an air-fluidised bed), or made to collide with or rub against a third body (e.g. the inside of a pneumatic cyclone made of stainless steel). In both cases, the coal and silica particles are given a different magnitude (or in some cases, even sign) of charge, and can subsequently be separated by being passed through an electric field (Fig. 1), which deflects the different charged species by different amounts. We would expect greater charge magnitudes on the differentially-charged particle species in a mixture to produce greater differential deflection in an electric field, leading to better separation and a higher-grade product. This has been observed directly in beneficiation of coal, as shown in Fig. 2. In this case, a mixture of coal and silicates was charged in a vibratory canister (described later in this article) and passed through a parallel-plate separator as shown in Fig. 1. The different data were obtained by moving the splitter. A strong linear

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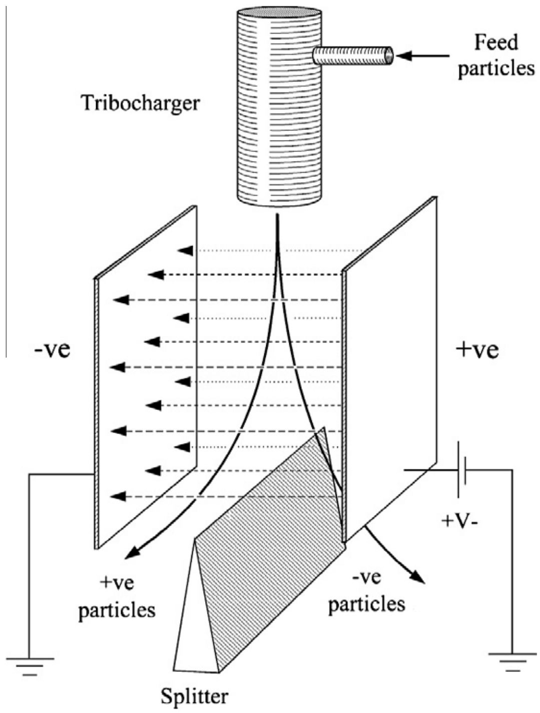

Fig. 1. Schematic of a typical free-fall triboelectric separator.

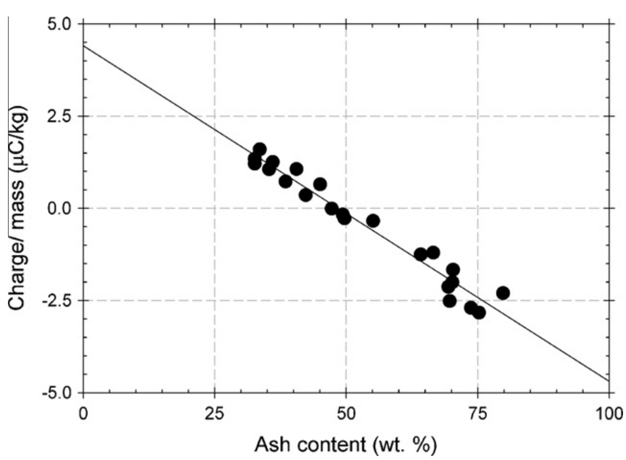

Fig. 2. Measured charge/mass ratio vs. ash content for a 50–50% weight mixture of coal and silica particles, charged in a vibratory canister and passed through a parallel-plate separator.

relationship between charge/mass ratio and ash content of the concentrate stream was observed. Full details of these experiments will be presented in forthcoming articles. Generally, more energetic contact results in a greater transferred charge magnitude (Bailey, 1993). Tribocharging devices are therefore usually designed to foster a very dynamic contact environment (as in both of the examples cited above). For mineral separation applications, it is usually an advantage if the charging and separation are continuous flow-through rather than batch processes. Those tribochargers that are able to impart large charge magnitudes at the same time as handling large continuous throughputs usually exploit particle–wall rather than particle–particle charging, so we concentrate on that type here.

The magnitude and sign of triboelectric charge are often determined by a complex set of factors whose effect is difficult to predict; some of these are discussed by Castle (1997). As a result, there are considerable difficulties inherent in analytic study of the triboelectrification of particulates, and systematic design of particle triboelectrification and separation systems. On the other hand, the very complexity of these systems means that relatively small changes to design or operating parameters can often result in very large gains in terms of charging and separation performance. The range of valuable/gangue mixtures that could be separated triboelectrically, under the right conditions, is potentially very large.

When a mature technology is to be incorporated into a processing plant, the designer can call upon an established body of data on both the performance of the device itself and its interaction with upstream and downstream processes. However, if the technology is in its infancy, as in the present case, it is necessary to establish whether under optimal conditions the unit is able to provide the required performance in isolation for the feed of interest. Once proof-of-concept has been achieved, the larger plant environment can be considered. The design strategy proposed in this paper is meant to provide a broad guide for the proof-of-concept stage – a simple way to compare the new technology with existing options, and decide whether it is competitive to a first approximation.

A frequent parameter used for broad comparison of dissimilar technologies is the throughput per unit plant floor area occupied. For mature technologies, the plant footprint will depend on the support infrastructure as well as the device itself. For technologies at the pre-pilot stage, where the details of the support infrastructure have not yet been established, one must make do with the device footprint in isolation. In the following discussion, it is assumed that the tribocharger or array of tribochargers is positioned above the separator stage, and that the footprint of the separator stage is smaller than that of the tribocharger/s. In that case, the footprint of the overall device can be equated with that of the tribocharger/s. Since in triboelectric separation the separator deflection, and thus product grade, are so strongly dependent on the difference in charge between particle species, the design requirement for a tribocharger can typically be expressed in the following terms: 'for a throughput of at least X kg per hour per unit floor space, a differential charge of at least Y C/kg is required'. Note that for a free-fall separator, it is the mass-specific charge that is important. To determine the best design and operation regimes for a given type of device, the key design and operational variables must be identified and their combined effect on the throughput and mass-specific charge must be determined. If the number of adjustable variables is relatively small, the second part of the process can sometimes be carried out empirically. However, where there are larger numbers of adjustable variables, or, where the exact design of the device has not yet been finalised (often these amount to the same thing), analytical or numerical models of the particle behaviour and charging are needed. A good example, which is dealt with in more detail later in this paper, is a pneumatic cyclone. Let us assume that the cyclone has a simple cylindrical barrel, a fixed length, a constant input pipe angle and diameter, and the feed is of a constant composition and size distribution. We also assume that the mass throughput of feed particles has a well-defined relationship to the input air flow rate, and that the cyclone material has been chosen to differentially charge the feed mixture. The main adjustable variables for design and operation of the device will therefore be the air flow rate and the barrel radius, and choice of the best parameter values will be relatively easy to carry out empirically. However, if changes are made to the basic design (e.g. a conical or shaped barrel, and angled input pipe, etc.), the number of adjustable variables and the complexity of their interaction will soon make the empirical approach untenable.

Whatever the design approach, the tribocharger can never be treated completely as a 'black box', giving a well-defined charge output for a given set of input variables. For one thing, the precise