Advanced Powder Technology 26 (2015) 119–125

Contents lists available at ScienceDirect

Advanced Powder Technology

journal homepage: www.elsevier.com/locate/apt

Original Research Paper

Upgrading of positively buoyant particles using an Inverted Reflux Classifier

A. Kiani *, J. Zhou, K.P. Galvin

Centre for Advanced Particle Processing and Transport, School of Engineering, The University of Newcastle, University Drive, Callaghan, NSW 2308, Australia

ARTICLE INFO

Article history:
Received 8 January 2014
Received in revised form 9 August 2014
Accepted 24 August 2014
Available online 4 September 2014

Keywords:
Buoyant
Cenosphere
Fly ash
Reflux Classifier
Fluidization

ABSTRACT

This paper is concerned with the separation of cenosphere particles from fly ash. Cenospheres are hollow alumina silicate micro-shells found in fly ash. They are positively buoyant in water, thus allowing gravity-separation to be used to achieve separation from negatively buoyant fly ash particles. In this study an Inverted Reflux Classifier, a combination of parallel inclined channels and a vertical fluidized bed, was used for the first time to recover and concentrate cenospheres from a real fly ash feed obtained from a coal fired power station. The effects of different operating parameters such as the feed rate, product rate, and fluidization rate were investigated. The device was fed at a solids flux of about 2600 kg/(m^2 h). A product grade of 76% was achieved from a feed with a grade of only 0.51%, corresponding to an upgrade of 149. Here, the recovery of the cenospheres was 42%. By increasing the overflow product rate, a significantly higher recovery of 64% was achieved, but at a reduced upgrade of 33. In both cases most of the losses were attributed to the relatively fine cenosphere particles being entrained to the underflow.

1. Introduction

It is estimated that in Australia alone about 18 million tonnes of fly ash are generated from coal fired power stations every year. While there has been extensive research undertaken to explore new options for utilizing this waste, more than 60% of the fly ash continues to be discarded in reservoirs that surround the power stations [1]. This waste is not only a blight on the landscape, but a potential environmental hazard [2–4]. Moreover, some sites are running out of available land. Clearly, if more value can be secured from the components of the fly ash it is likely the material will be seen as a resource, thereby solving this long-standing problem.

This research is focused on new methods of classification aimed at separating the fly ash into more valuable components. The most valuable component of fly ash is cenospheres, hollow alumina-silicate spheres, typically less than 150 μm in diameter. The low density of these particles, typically 300–800 kg/m^3, is attractive in many applications ranging from building materials to drilling fluids, and hence a value in excess of $1000 per tonne is typical. The grade of the cenospheres is given by the ratio of the mass of the cenospheres to the total mass of solids, expressed as a percentage. In a typical fly ash the grade of the cenospheres is of the order of 1% by mass, and therefore a method of recovery and concentration is required.

Often relatively coarse cenospheres are recovered by scooping from the surface of ponds, but material gathered in this way still contains significant portions of ultrafine fly ash of much higher density. Relatively fine cenospheres may fail to rise in time and hence their recovery, defined by the ratio of the cenosphere product rate to the cenosphere feed rate, will be poor. The grade of the cenospheres from many coal fired power stations has been decreasing due to changes in the combustion process aimed at reducing the NOx emissions [5] hence the traditional method of recovery via an open pond has become ineffective.

It is clear that new methods are needed to recover and concentrate cenospheres from fly ash. Dry separation is ineffective given the significant densities of the cenospheres and the fly ash relative to that of air. Flotation is also ineffective given the similar surface properties of the cenospheres and fly ash. Separation in water is therefore the most effective option since the cenospheres are positively buoyant and the fly ash negatively buoyant. However ultrafine fly ash will tend to split with the water, and hence significant contamination of the rising cenospheres is a problem. Moreover, the rising velocities of the fine cenospheres are very low.

Boycott [6] was the first to report that the settling rate of particles in a tube increases significantly by inclining the system. This observation led to the development of the lamella thickener,

* Corresponding author. Tel.: +61 (2) 4033 9251.
E-mail address: Ali.Kiani@uon.edu.au (A. Kiani).

http://dx.doi.org/10.1016/j.apt.2014.08.014

used in solid–liquid separation. The high potential of inclined settlers in the separation of particles was then investigated [7]. Of course there remained a problem in scaling-up the system to insure the delivery of a uniform feed to multiple inclined channels, essential for achieving a sharp overall separation. The Reflux Classifier, which incorporates a fluidized bed system, and overflow weirs across each channel, addressed this problem [8]. More recently, the Reflux Classifier has been used to enhance the gravity separation of coal and dense minerals [9], utilizing relatively narrow channels in order to promote laminar flow and shear induced lift of lower density particles.

The system of inclined channels increases the rate of segregation, leading to a throughput advantage over conventional fluidized beds. This advantage is defined by the ratio of the fluid velocity, U, passing upwards through an inclined channel, to the terminal velocity, u_t, of a target particle (of size d and density ρ_p) which has a 50–50 probability of reporting to the overflow. In conventional fluidization the throughput advantage, U/u_t, is limited to a maximum of 1, given the system cannot be fluidized at a velocity higher than the terminal velocity of the so-called target particle. Laskovski et al. [10] showed that the throughput advantage of the Reflux Classifier approached the asymptotic result,

$$U/u_t = 7.5\, Re_t^{-0.33} \tag{1}$$

where Re_t is the particle Reynolds number, which depends on the fluid properties, the particle diameter, d, and the terminal velocity, u_t. This asymptotic result is achieved using a significantly large channel aspect ratio, involving long channels, and a narrow channel spacing. For a cenosphere particle, 50 μm in diameter, and 800 kg/m^3 in density, the particle Reynolds number is calculated to be 0.014 using the equation proposed by Zigrang and Sylvester [11], and hence the throughput advantage is $U/u_t = 31$. Thus the Reflux Classifier has the potential to permit a feed rate some 31 times greater than for a conventional fluidized bed, for the same separation.

The Inverted Reflux Classifier offers additional advantages over the Reflux Classifier and conventional fluidized bed in separating positively buoyant cenospheres from fly ash. Fig. 1 provides a schematic representation of the Inverted Reflux Classifier with a system of inclined channels located below the fluidized bed. In the Reflux Classifier or conventional fluidized bed there will be a strong tendency for ultrafine, high density, silica to report to the overflow with the cenospheres. However, in the Inverted Reflux Classifier, fluidization water entering through the top distributor washes these silica particles downwards, increasing the cenosphere grade. This inverted fluidization has the tendency also to entrain the low density cenospheres downwards; however, within the inclined channels, the cenospheres segregate strongly from the flow, returning to the upper fluidized bed zone and ultimately to the product overflow. Thus the Inverted Reflux Classifier can be used to both recover and to concentrate the cenospheres. The purpose of this study was to investigate the potential of this novel device, the Inverted Reflux Classifier, in recovering and concentrating cenospheres from fly ash.

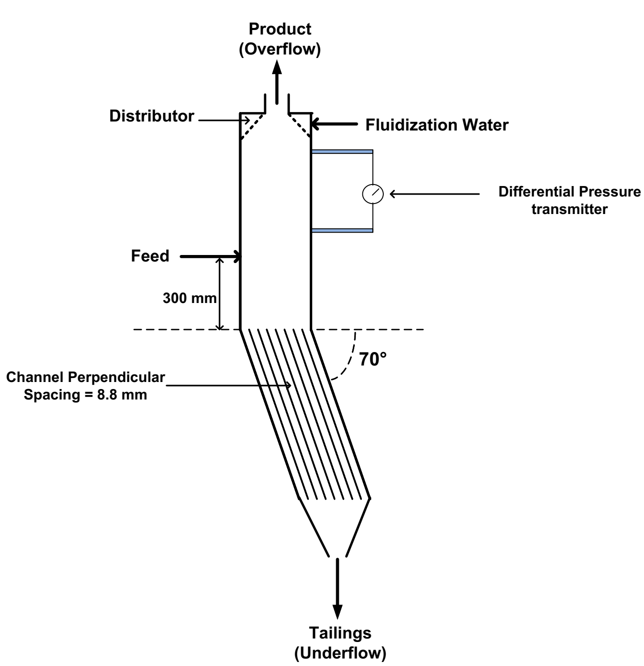

Fig. 1. A schematic representation of the Inverted Reflux Classifier used in this study.

2. Experimental

As shown in Fig. 1, the Inverted Reflux Classifier consists of a 1 m long vertical zone with a wash-water distributor and discharge port at the top. The inclined section, which is also 1 m long, has an angle of 70° with respect to the horizontal, with 8 channels of perpendicular spacing of 8.8 mm. The feed enters 300 mm above the junction between the vertical and inclined zones. The rates of the feed, overflow product, underflow tailings, and fluidization water are all controlled by specific peristaltic pumps. A vent tube located at the tailings discharge, and extended to a level above the device, is used to insure any discrepancy between these flows can be accommodated, so that the system remains full.

In the preliminary work, a model feed consisting of a mixture of silica flour (Sibelco, 400 G) and the 7040S grade of Q-Cell commercial cenospheres (Potters industries) was used. The concentration of the cenospheres in the model feed was 0.51% and the feed solids content of the slurry was about 8.3% by mass. In the main part of the study, a real fly ash feed was examined. The feed fly ash was sourced from an Australian coal-fired power plant. The grade of the cenospheres in the feed was nominally 0.53% by mass and typically 30% of the cenospheres were finer than 50 μm. For this work, 350 kg of dry solid fly ash was mixed with 650 kg of water in a mixing tank, forming slurry with a solid content of 35% by mass. The feed slurry was withdrawn via a vertical tube located near the inner wall of the tank, with its entrance elevated 100 mm off the base of the tank. This approach was essential given the strong tendency for the fly ash to sediment and pack tightly causing blockages when the flow or mixing ceased.

Two pressure transducers were fitted to the fluidized bed section of the Inverted Reflux Classifier above the feed inlet as shown in Fig. 1, and used to measure the suspension density, providing information relevant to the control of the system. After reaching the steady state condition, samples of the overflow product, underflow tailings, and the feed were taken and analyzed.

A relatively quick and accurate method was used to quantify the separation performance. The samples were dried and the particles placed in a gas pycnometer in order to measure the average density of the solids. Assuming values for the densities of the dense fly ash component and the cenospheres allowed the portion of each component in each sample, and hence the grade and the recovery, to be calculated. In practice this approach carries uncertainty because the density of each component varies with the separation; the density of the fly ash that appears in the overflow is typically lower than the density of the fly ash that appears in the underflow, especially when the portion of the fly ash in the overflow is relatively small. A sensitivity analysis was therefore applied, using different fly ash densities, to quantify this uncertainty.