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# A Pilot Scale Study of Cenosphere Recovery and Concentration using the Inverted Reflux Classifier

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ABSTRACT

Cenospheres are hollow spherical particles formed as part of the fly ash waste of coal-fired power stations. In a previous paper Kiani et al. (2015) investigated the recovery and the concentration of these particles using an Inverted Reflux Classifier (IRC) at a laboratory scale, of cross-section 0.100 m × 0.086 m, achieving a throughput advantage over a conventional fluidized bed by a factor of 54. The present paper investigated the potential to achieve scale-up, utilizing a pilot scale device with cross-section 0.3 m × 0.3 m. The product grade and recovery were examined as a function of the solids yield by varying the product volumetric rate relative to the feed volumetric rate. The performance data were compared directly with those obtained at the smaller laboratory scale. Agreement was excellent. The performance was also examined as a function of the feed slurry flux, with good agreement again evident at the laboratory and pilot scales. Overall, the separation performance was excellent, with a cenosphere recovery of about 80% achievable at a high upgrade of 19 while a recovery of 75% was achieved at an upgrade of 38. Here the feed solids flux was 4.2 t/($m^2$ h). It is noted that much higher upgrade was achieved at a recovery of about 80% in the former study by operating at a lower solids feed flux. This paper provides the necessary basis for proceeding with a full scale implementation of this technology.



## 1. Introduction

Fly ash waste, produced from coal-fired power plants, has often been dumped in the lands surrounding the power stations. The fly ash is hazardous to the environment and to human health, thus efforts have focussed on finding added value applications of the material. One high value portion of the waste, typically at less than 2% by mass, is cenospheres. Typically 20–200 μm in diameter, these particles are hollow, with a density in the range of 400–900 kg/$m^3$. Their low density is ideal in many applications, including light weight building products, drilling fluids, and explosives, and hence cenospheres may be sold at about $2000 per tonne.

Traditional fine particle beneficiation by flotation is not an option given the similar alumina silicate surface properties of the fly ash and cenospheres. Rather, wet gravity separation is the most appropriate method for recovering and concentrating the cenospheres from the fly ash, exploiting the density difference between the particles and water. The cenospheres are very fine, with a density close to that of water, hence their rise velocity in water is very low and thus conventional methods of wet gravity separation are very inefficient. Kiani et al. (2015) exploited two approaches for promoting gravity separation, one utilizing inclined settling (Acrivos and Herbolzheimer, 1979; Boycott, 1920; Davis and Gecol, 1996; Galvin and Liu, 2011; Galvin et al., 2009; Laskovski et al., 2006; Probstein and Hicks, 1978), and the other a novel phenomenon based on combining positively and negatively buoyant particles at sufficiently high concentrations (Batchelor and Van Rensburg, 1986).

These two approaches were exploited by Kiani et al. (2015) following their earlier work (Kiani et al., 2014; Li et al., 2014). Their preliminary work was focussed on the Inverted Reflux Classifier shown schematically in Fig. 1. The initial work involved a model feed consisting of very low density commercial cenospheres at a high grade. These were processed in a laboratory IRC achieving high throughput, and a very high grade product. In a separate study these cenospheres were combined with silica flour and processed in a pilot scale IRC in closed loop, again demonstrating a high throughput, recovery and upgrade. Most recently, fly ash feed sourced from an Australian coal fired power station, was processed in a laboratory IRC, achieving a performance significantly higher than in the previous studies. In this work the grade of the cenospheres was higher at 1% by weight, and the overall fly ash feed pulp density was varied across a broad range. A strong optimum was identified at a feed pulp density of 38% solids, with the solids

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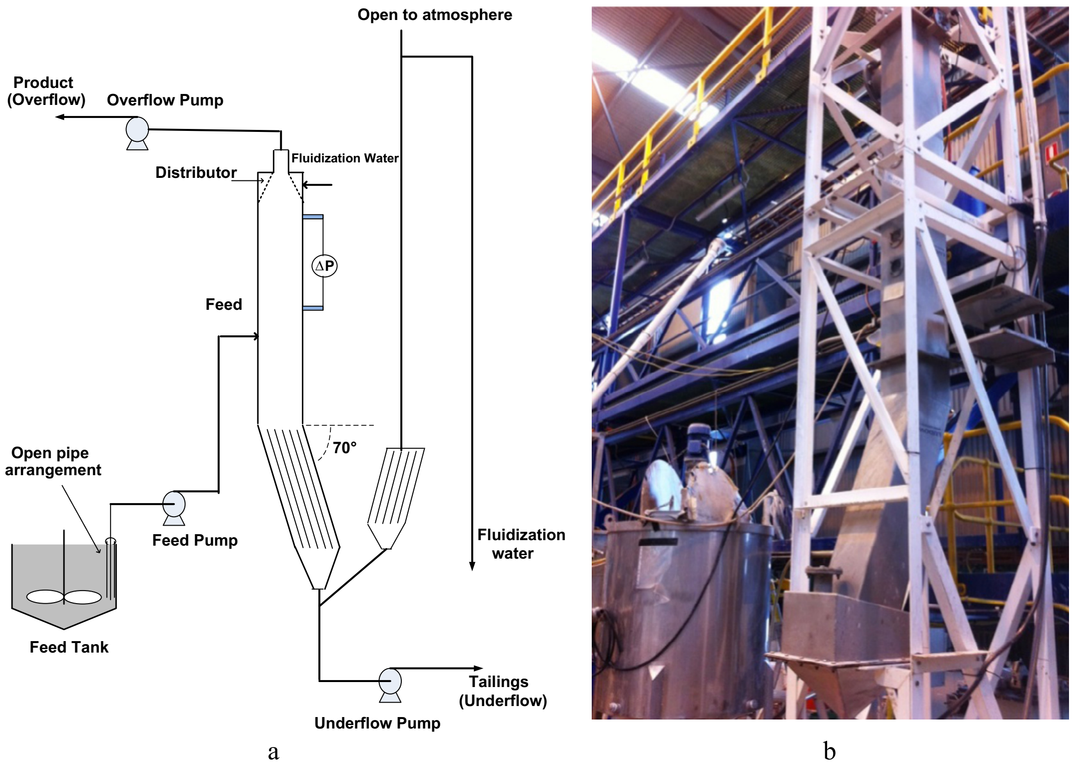


**Fig. 1.** (a) A schematic representation and (b) a photo of the experimental set up.

mass flux throughput at 3.1 t/($m^2$ h), a recovery of 89.9%, and an upgrade of 58.6. The system throughput was found to be 54 times higher than estimated for a conventional fluidized bed, with a factor of 18 attributed to the inclined system geometry and factor of 3 attributed to the interaction between the positively and negatively buoyant species.

While the previous laboratory scale study demonstrated remarkable separation performance, industrial application demands assessment at progressively larger scale. There are no guarantees of success when the scale of operation is increased. There are compromises that are introduced when a system is scaled-up, for example, in reducing the number of fluidization nozzles located at the top of the system for fluidizing and hence washing the cenospheres. Success with a ten-fold scale-up provides a positive basis for proceeding to the full scale industrial assessment. The present paper reports on the research findings at a larger pilot scale focussed around the optimal conditions identified from the earlier laboratory scale study. The research is based on the recovery and concentration of the cenospheres from actual fly ash.

## 2. Materials and methods

### 2.1. Pilot scale Inverted Reflux Classifier

A pilot scale Inverted Reflux Classifier (IRC), consisting of a series of parallel inclined channels below an inverted fluidized bed, was applied to the separation of the cenospheres from the fly ash. The inclined section consisted of 1.2 m long inclined channels. A system with 38 channels was formed from 37 plates with a perpendicular spacing of 6 mm. A 2.7 m long inverted fluidized bed with cross sectional area of about 0.300 m × 0.300 m was located above the inclined section. Two pressure sensors were used to measure the suspension density down the vertical fluidized bed section, providing a basis for controlling the discharge rate of product to the overflow, and information on the quality of the product. A fluidization water chamber was installed above the fluidized bed section, distributing the water used to suspend the bed of cenospheres and for washing the entrained ultrafine fly ash particles from the cenosphere product.

In order to re-use the feed it was necessary to remove significant quantity of water from the tailings stream. This was done using a small lamellae thickener containing 24 channels with a perpendicular spacing of 2.6 mm. Water was drawn from the tailings stream at a rate sufficient to match the rate of water addition to the fluidized bed distributor, significantly less than the actual tailings rate. This arrangement, which is shown in Fig. 1, was also connected to a vented tube extended up to 1 m above the device, thus insuring a positive pressure within the IRC during the experiments. A schematic and photo of the experimental set up are shown in Fig. 1a and b, respectively.

### 2.2. Experimental procedure

A sample of about 1300 kg of actual fly ash solids from an Australian coal-fired power station was supplied in two 1 $m^3$ containers for use in this study. The concentration of cenospheres in the solid fly ash was measured to be approximately 0.9 wt% using sink–float tests. The sample was mixed with 1950 L of water to produce a feed of about 40% solids. This feed solids concentration was found to be the optimum in the recent laboratory scale study involving the IRC (Kiani et al., 2015).

Two large mixing tanks with volumes of 1200 L and 1500 L were used to keep the feed slurry uniform during the experiments. Before each experiment, the contents of both tanks were kept the same by pumping the slurry between the tanks for several hours. A sample was taken from each tank on the day prior to a run to ensure the feed pulp density and the cenospheres grade were the same in both tanks. The samples were firstly poured into two volumetric flasks, allowing the cenosphere concentrations to be compared via the thickness of the cenosphere layer in each flask. Both