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Recycling of rare earth particle by mini-hydrocyclones

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ABSTRACT

Mini-hydrocyclones were applied to separate the fine rare earth particles from the suspensions. The effects of the flow rate, split ratio, and feed concentration on the total separation efficiency and grade separation efficiency were studied. The combined effects of the flow rate (1200–1600 L/h), split ratio (20–60%) and concentration (0.6–1.0 wt%) on the total separation efficiency in mini-hydrocyclones were investigated using a response surface methodology. The optimum operating parameters for a total separation efficiency of 92.5% were: feed flow rate = 1406 L/h, split ratio = 20%, and feed concentration = 1 wt%.

1. Introduction

Rare earth polishing powder is an important abrasive material used in chemical mechanical polishing, optical glass, and integrated circuit polishing. A Ceria-based polishing powder has a high polishing efficiency, good polishing quality, and moderate hardness compared to other polishing powders. The rare earth polishing power is valuable, but an enormous amount of the abrasive material is wasted during the polishing process. The abrasive particles are difficult to separate because of the fine particle size of the rare earths. To recycle the abrasive materials, an effective separation technology is needed. The recovered rare earth particles can be reused, which would reduce production costs.

The hydrocyclone separator system has been extensively investigated since the 1950s. Hydrocyclones are widely used for separation, classification, and thickening. Hydrocyclones are effective for oil-water separation, starch cleaning, protein cleaning, and submicro-particle recycling. The advantages of a hydrocyclone separator system over other separation technologies, such as membrane and centrifugation, include lower energy consumption, low maintenance requirements, and high operational reliability. A hydrocyclone with a diameter between 1 and 10 mm is called a mini-hydrocyclone. Mini-hydrocyclones are of interest because of their ability to separate fine particles. A smaller hydrocyclone diameter results in a greater difference in the centrifugal force, which makes it easier to separate fine particles (<10 μm). Recent developments suggest that improvements in separation may be achieved using hydrocyclone units with smaller diameters. Hydrocyclones with diameter ranging 10–15 mm have been widely applied in the separation of fine particles in recent years (Cilliers and Harrison, 1997; Pasquier and Cilliers, 2000). Neesse et al. (2015) used a 10 mm hydrocyclone to separate fine barite particles at pressures up to 40 bar and at 50 °C. This processing method revealed that the cut size can reach 0.5 μm at high feed pressure.

The complex hydrodynamic phenomena that occur within a hydrocyclone require attention to the process design and optimum operating conditions. The feed flow rate, split ratio and feed concentration have significant effects on the separation performance of mini-hydrocyclones. Abdollahzadeh et al. (2015) studied the influence of a particle's shape, the inlet velocity and the feed volume concentration on particle classification and the fishhook effect in a 15 mm diameter hydrocyclone. The cut size was decreased from 11 μm to 4 μm with the increase of inlet velocity. Yuan et al. (2015) found that the separation efficiency rises with increase in split ratio and remain at 86.5% until the split ratio reaches 0.47 and falls gradually when the split ratio increases continuously. Kuang et al. (2012) studied how the feed concentration affects the hydrocyclone performance when the feed volumetric concentration was varied from 1% to 25%. Their experimental results showed that the separation efficiency decreased with an increase in the feed solid concentration. The influence of the pressure drop and yeast concentration on the separation efficiency was evaluated by Bicalho et al. (2013).

Previous research has mainly focused on studying the effect of the individual operation parameters on the separation efficiency. The statistical experimental design techniques have already used in tests of the hydrocyclone separation. In recent years, the response surface methodology has drawn attention for the opti-

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Nomenclature

C_i	suspension concentration by weight (–)
d_{50}	cut size at 50% of particle curve (μm)
d_j	the particle grade used in the grade separation efficiency (μm)
d_p	particle size (μm)
D_c	cylinder diameter of hydrocyclone (mm)
D_o	overflow diameter of hydrocyclone (mm)
D_u	underflow diameter of hydrocyclone (mm)
E_t	total separation efficiency (–)
$f_i(d_j)$	mass percentages of feed particles with diameter in d_j (–)
$f_o(d_j)$	mass percentages of overflow particles with diameter in d_j (–)
$G(d_j)$	grade separation efficiency of the particles with size d_j (–)
h_i	the height of the inlet (mm)
L	length of the swirl chamber (mm)
m_i	the feed mass flow rate of the solids (kg/s)
$(m_i)d_j$	the inlet mass flow rate of the particle with a diameter of d_j (kg/s)
m_o	the overflow mass flow rate of the solids (kg/s)
$(m_o)d_j$	the overflow mass flow rate of the particle with a diameter of d_j (kg/s)
m_u	the underflow mass flow rate of the solids (kg/s)
$(m_u)d_j$	the underflow mass flow rate of the particle with a diameter of d_j (kg/s)
Q_i	total inlet volumetric flow rate (L/h)
Q_o	overflow volumetric flow rate (L/h)
Q_u	underflow volumetric flow rate (L/h)
P_i	feed pressure (Pa)
S	split ratio (–)
w_i	the width of the inlet (mm)
θ	included cone angle of the hydrocyclone (°)

mization of process parameters because it can provide clues as to whether an interaction exists among important parameters. Grommers et al. (2004) used a statistical central composite experimental design, and three experimental parameters (feed flow rate, feed density and split ratio) of the 10 mm hydrocyclone were changed to obtain the optimum process parameters.

Mognon et al. (2016) applied a response surface method to study the effect of the carboxymethyl cellulose concentration, solid concentration, and underflow conduit diameter on the total separation efficiency. Bicalho et al. (2012) used the response surface methodology to study the effect of the feed inlet diameter, overflow diameter, angle of hydrocyclone cone, and pressure drop on the total separation efficiency. The effects of the pressure drop and different geometic variables on the total separation efficiency were investigated. The total separation efficiency can be maximized by reducing the feed inlet diameter, the overflow diameter and the angle of the hydrocyclone cone in combination with an increase in the pressure drop of the equipment.

Lee (2014) investigated the separation performance of a low pressure (1.38–5.56 kPa) hydrocyclone with a cylinder diameter of 335 mm. The optimum operating parameters, such as the inflow rate, underflow ratio and feed concentration, were obtained using the response surface methodology. The cut size of the hydrocyclone in the experiments ranged from 30 to 200 μm. However, the operation parameters are not suitable for the separation of finer particles in mini-hydrocyclone.

Currently, studies on the optimization of the feed flow rate, split ratio, and feed concentration to maximize the separation efficiency of mini-hydrocyclone are seldom reported. The objective of this research was to demonstrate the separation performance of a newly designed mini-hydrocyclone for rare earth particles. The effects of three important operating variables, feed flow rate, split ratio, and feed concentration, on the total separation efficiency and grade separation efficiency were evaluated. The 'interaction' between the effects of the three parameter were investigated. The optimal operating variables based on the response surface technology are proposed.

2. Materials and methods

2.1. Materials

The particulate sample was polishing powder that was obtained from the Epson Precision Photoelectric Company (Wuxi, China). The polishing powder is the pure rare earth particles which are composed by CeO_2 and La_2O_3. The polishing slurry was mixed by the powder and the tap water according to the solid-liquid weight concentration. The density of the rare earth particles was 5130 kg/m^3. The size distribution of the samples was measured using a laser particle sizer (Marven 2000, UK), and the measurement accuracy is ±0.01 μm. The mean particle diameter was 2.45 μm, and the maximum particle size was 34.67 μm. The detailed size distribution of the particles is shown in Fig. 1. The feed was a solid suspension dispersed in water at different concentrations.

2.2. Design of the hydrocyclone

A newly designed mini-hydrocyclone with longer conical section length compared with similar hydrocyclones was used for this

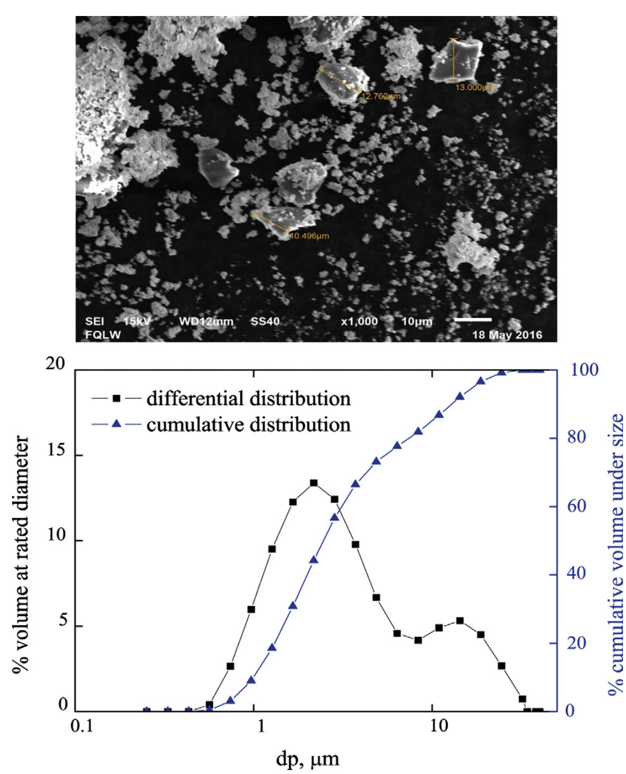

Fig. 1. Microphotograph and particle size distribution of the test powder.

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