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Enhancement of tapioca starch separation with a hydrocyclone: effects of apex diameter, feed concentration, and pressure drop on tapioca starch separation with a hydrocyclone

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ABSTRACT

This research aims to develop a new approach replacing a centrifugal separator with a hydrocyclone in a tapioca starch production process. The studied hydrocyclone was designed on the basis of Bradley's geometry, which is suitable for starch–water separation according to a small density difference and small diameters of starch particles. Three factors, i.e., pressure drop across the hydrocyclone (ΔP), feed concentration $[C]$, and apex diameter (D_u), were varied into three levels at 2, 4 and 6 kg/cm^2; 3, 7, and 11% weight by volume; and 1.5, 2.1, and 4.0 mm, respectively. The hydrocyclone's performance indices (i.e., % solid recovery (%R), % split (%R_v), reduced efficiency (E')) and cut size diameter (d_{50}) were determined. The experimental results were used to construct empirical models predicting hydrocyclone efficiencies from the pressure drop, feed concentration, and apex diameter. The models for three indices were: $\%R = 70.71(\Delta P)^{0.15} \cdot [C]^{-0.09} \cdot D_u^{0.17}$, $\%R_v = 30.69(\Delta P)^{-0.09} \cdot [C]^0 \cdot D_u^{0.47}$, and $E' = 54.95(\Delta P)^{0.31} \cdot [C]^{-0.17} \cdot D_u^{0.19}$.

1. Introduction

Thailand produces approximately 2 million tons of tapioca starch per year with a domestic demand of 35% and an export demand of 65% [1]. In tapioca starch production process, most factories use centrifugal separators to increase the concentration of starch slurry as well as to remove fruit water and protein before drying [2]. However, the centrifugal separator has several disadvantages, e.g., having moving part and abrasion from solid particles, reducing separation efficiency.

Hydrocyclone, a well-known separation equipment in mineral processing industry, utilizes centrifugal force to separate solid from liquid streams [3]. It has advantages of no moving parts, simple operation, less space requirement, and less expensive device. Fig. 1 shows a cross-section of a conventional hydrocyclone design. It consists of a cylindrical upper body joined to a conical lower body. The suspension of particles in a liquid is injected tangentially through the inlet opening in the upper part of the cylindrical section, and, as a result of the tangential entry, a strong swirling motion is developed within the hydrocyclone. A portion of the liquid containing the fine fraction of particles is discharged through a cylindrical tube fixed in the centre of the top; the outlet tube is called the overflow pipe or vortex finder. The remaining liquid and the coarse fraction of the material leave through a circular opening at the apex of the cone, called the underflow orifice or spigot.

For the solid–liquid separation, a particle at any point within the flow in a hydrocyclone is basically subjected to two forces: one from the external and internal field of accelerations (i.e., gravity and centrifugal forces) and the other from the drag exerted on the particle by the flow. The gravity effect is normally neglected in hydrocyclone, so that only centrifugal and drag forces are taken into account. If the centrifugal force acting on a particle exceeds the drag, the particle moves radically outwards, and if the drag is grater, the particle is carried inwards (Fig. 2). The centrifugal force developed accelerates the settling rate of the particles, thereby separating particles according to size and specific gravity. Faster settling particles move to the wall of the hydrocyclone, where the velocity is lowest, and migrate to the apex opening. The centrifugal force is shown in the following equation [3].

$$F_c = \frac{\pi D_p^3}{6} \frac{(\rho_p - \rho_l)}{r} v_t^2 \quad (1)$$

where F_c is centrifugal force, D_p is particle diameter, ρ_p is density of particle, and ρ_l is density of liquid. Because of the drag force,

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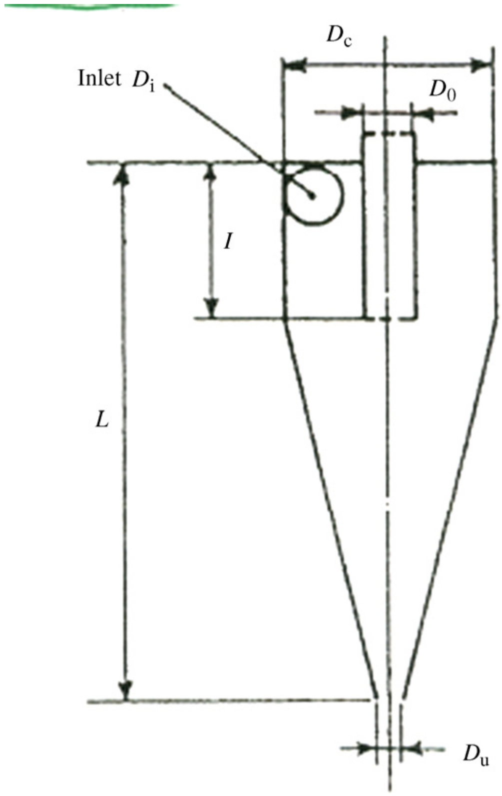

Fig. 1. Schematic diagram of a typical hydrocyclone.

the slower settling particles move toward the zone of low pressure along the axis and are carried upward through the vortex finder to the overflow. The drag force is expressed by

$$F_d = 3\pi D_p \mu v_r \quad (2)$$

Many researchers have tried to improve a hydrocyclone efficiency for solid–liquid separation [4–13]. However, hydrocyclones are often designed for partial capacity only to match the cut size requirements or the hydrocyclone is constructed to reach the desired capacity. A few researchers were conducted to obtain the hydrocyclone's design concept for both the capacity and cut size simultaneously, especially in the starch–water separation [14–16].

The simplest and most obvious way to calculate mass efficiency of a hydrocyclone is to relate it to the mass flow rates of fine and coarse fractions. The relative amounts of material in different products can be defined as a total efficiency. In the fine fraction, the total fine efficiency is

$$E_o = \frac{M_o}{M_f} \quad (3)$$

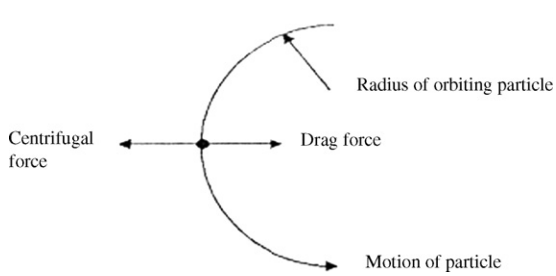

Fig. 2. Forces acting on an orbiting particle in the hydrocyclone.

and in the coarse fraction, the total coarse efficiency is

$$E_u = \frac{M_u}{M_f} \quad (4)$$

where M_o, M_u and M_f are mass flow rate of overflow, underflow, and feed, respectively.

Other than the total coarse efficiency or solid recovery (%R), the performance indices used to predict experimental hydrocyclone efficiencies are the water recovery or split (%R_v), the reduced efficiency (E'), and the cut size diameter (d_{50}).

Total coarse efficiency or solid recovery (%R) is the ratio of the solid rate in the underflow stream to the solid rate in the feed or equal to Eq. (4) as described by

$$\%R = \frac{Q_u C_u}{Q_f C_f} \quad (5)$$

where Q_u, Q_f are the volumetric flow rate at the underflow stream and feed, and C_u, C_f are the solid concentration of underflow stream and feed, respectively.

Water recovery, %R_v, is the ratio of the flow rate of water in the underflow to the feed, and can be calculated by

$$\%R_v = \frac{Q_u(1 - C_u/\rho_p)}{Q_f(1 - C_f/\rho_p)} \quad (6)$$

where ρ_p is the particle density. Suitable hydrocyclones should have both high solid recovery (i.e., high %R) and high solid content (i.e., low %R_v) in the underflow.

Reduced efficiency, E', is better to define than other mass efficiency definitions as it is zero only when bypass occurs, and it is unity for complete separation. It is the recovery of material to underflow due to separation action subtracting dead flux as described by

$$E' = \frac{\%R - R_f}{1 - R_f} \quad (7)$$

where R_f is the coarse fraction dead flux that can be corrected to the ratio of the pulp flow rate of the underflow to the feed.

The d_{50} is defined as the point on the partition curve for half of particles in feed of that size discharged to the underflow, meaning that particles with the cut size have an equal chance of going either with the overflow or the underflow.

This research aimed to enhance our understanding on the hydrocyclone's design concept for the starch–water separation for future development of the mini-hydrocyclone network in the tapioca starch production. The specific objectives of this research were (1) to study the effects of apex diameter of the Bradley's hydrocyclone for increasing tapioca starch concentration in a separation unit and (2) to develop the empirical equations for predicting the hydrocyclone efficiency and performance.

2. Materials and method

2.1. Design of hydrocyclone

This research studied a separation unit for increasing tapioca starch concentration using a hydrocyclone instead of a centrifugal separator. A Bradley's geometry was used in designing the hydrocyclone [17]. The geometry provides high starch slurry separation efficiency and is suitable for fine particles, e.g., tapioca starch particles.

The calculation of hydrocyclone dimension starts with defining a cut size diameter (i.e., 8.5 μm for tapioca starch particle). Then,