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Influence of geometry and slurry properties on fine particles suspension at high loadings in a stirred vessel

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ABSTRACT

Particle size, solids loading and impeller clearance from the base were all found to have significant effects on the just-suspension of fine particles in a stirred tank. At the higher end of particles size studied, where there is greater difference in settling velocities between particle sizes, the smaller the particles the less specific energy, ε_{js} is required for just-suspension. But at the low end of particle size range, changes in the settling velocity are small while continued reduction in particle size corresponds to substantial increase in total particle surface area, leading to increased ε_{js} possibly due to particles interactions. Just-suspension of PMMA particles of diameter 195.5 μm required higher ε_{js} than for 75.3 μm particles, whereas ε_{js} for 75.3 μm particles was lower than that for 18.0 μm diameter particles. Experiments were conducted in water in a 15.5 cm cylindrical tank at an aspect ratio of 1:1 over a range of loadings from 5 to 40% by weight. The HR100 and HS604 SUPERMIX® impellers manufactured by SATAKE, generally showed better efficiencies compared to the conventional 4 pitched-blade turbine and 3-blade propeller, in addition to being less affected by changes in operational parameters. The HS604 performance proved that a radial impeller can be comparable to or better than a downward axial impeller in solid–liquid suspension if used at very low clearance. S factor values under different experimental conditions are presented.

Keywords: Fine particles; SUPERMIX® impellers; High solids loading; Particle size; Impeller clearance; Just-suspension

1. Introduction

The suspension of solids in stirred tanks is governed by various parameters, namely the impeller-to-tank configuration, solids loading and solid/liquid properties. Changes in these variables will affect the speed and energy required to achieve the desired level of suspension; and there are multitude possible combinations of these parameters.

Zwietering's (1958) pioneering work to obtain an empirical correlation relating the just-suspension speed, N_{js} to other variables, is arguably the most highly cited literature on the subject. Subsequent studies using glass beads (Nienow, 1968; Ibrahim and Nienow, 1996), quartz (Rao et al., 1988), bronze particles (Machado et al., 2012), ion exchange resins (Ayranci and Kresta, 2011), lead shots and the neutrally buoyant Cytodex microcarrier particles (Ibrahim and Nienow, 1996,2004) have shown the range over which Zwietering's correlation can be applied; and alternative correlations have also been proposed.

In scaling up or changing from one system to another, the power or specific energy at just-suspension, ε_{js} has been commonly used to compare the efficiencies of different systems. Nienow and Miles (1977) reported that specific power for just suspension was always less in larger vessels of geometrically similar impeller to tank configuration. Ochieng and Lewis (2006) stressed that while bulk fluid flow represented by impeller tip speed may cause particles suspension at low solids loadings, turbulence intensity is what governs the particles suspension at high loadings, thus the use of power per unit volume as a scale up factor is recommended.

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Nomenclature

c_w	solids loading (%)
N_{js}	just-suspension speed
ε_{js}	power per unit mass of slurry (W/kg)
N_p	power number
b_w	baffle width
wt%	weight percent
vol%	volumetric percent
ρ_s	solid density ($kg\,m^{-3}$)
ρ_l	liquid density ($kg\,m^{-3}$)
C	off-bottom clearance
D	impeller diameter (cm)
H	mixing height (cm)
S	Zwietering's N_{js} coefficient
T	tank diameter (cm)
V_y	terminal velocity ($m\,s^{-1}$)
d_p	particle diameter (μm)
$d_{18.0}$	solid particles with diameter 18.0 μm
$d_{75.3}$	solid particles with diameter 75.3 μm
$d_{195.5}$	solid particles with diameter 195.5 μm

Bubbico et al. (1998) explained that particles gain kinetic energy as they are moved by stirring, and this energy is dissipated in particle–liquid friction and particle–particle or particle–equipment collisions; causing either attrition of the particles or elastic deformation that will release heat energy when the particles recover their shape. Ayranci and Kresta (2011) explained that hard particles can transfer momentum through collisions, while introducing a second solid phase in the system would significantly affect the suspension, especially in mixtures above 20 wt% solids as the particle–particle interactions becomes important. For bimodal solids in liquid Ayranci et al. (2012) proposed a new power model to predict N_{js} for solid particles of different physical properties with experiments up to 27 wt%, when the Zwietering correlation could only give accurate prediction up to 10%. In ultra-high solids loading (50 vol%), Wang et al. (2012) reported that similar amount of specific energy is required to suspend 70 μm and 120 μm particles.

On the effect of geometry, Nienow and Miles (1977) found with the radial Rushton and 2-flat blade paddles, that larger impellers and lower clearances were more efficient for suspension. And the 45° pitched-blade impellers were better than the radial impellers. Armenante and Nagamine (1998) stated that axial and mixed-flow impellers are more energy efficient to suspend particles as compared to radial-flow impellers. But Wu et al. (2002) found that at high solids loading it was more efficient to use radial flow impellers, particularly with unbaffled tanks. Chapple et al., 2002 reported the pitched blade geometry having strong interactions with the tank walls, such that changes in the impeller position can have a significant impact on the power number, as opposed to a radial impeller for which form drag dominates the power consumption, hence the impeller details are important.

Kumaresan and Joshi (2006) using hydrofoils, pitched blade and disc turbines, reported how the flow patterns generated from varying the impeller design, impeller diameter, number of blades, blade angle, blade width, blade twist, and pumping direction can have impact on suspension; and suggested tailoring the flow pattern to enhance mixing. Jirout and Rieger (2011) reported that all hydrofoils have similar efficiency when compared at optimum clearance, and they are more efficient than the standard 45° pitched-blade impellers which are more sensitive to changes in impeller clearance. They also found that the pitch angle for pitched-blade impellers has minimum effect on the suspension efficiency in the region of relatively fine particles. Ayranci et al. (2012), employing two Lightnin A310 impellers of diameters of T/3 and T/2 discovered that turbulence is dominant for suspending solids with the T/3 impeller while for the T/2 impeller some combination of turbulence and mean flow is required; and the former is more efficient in solids suspension.

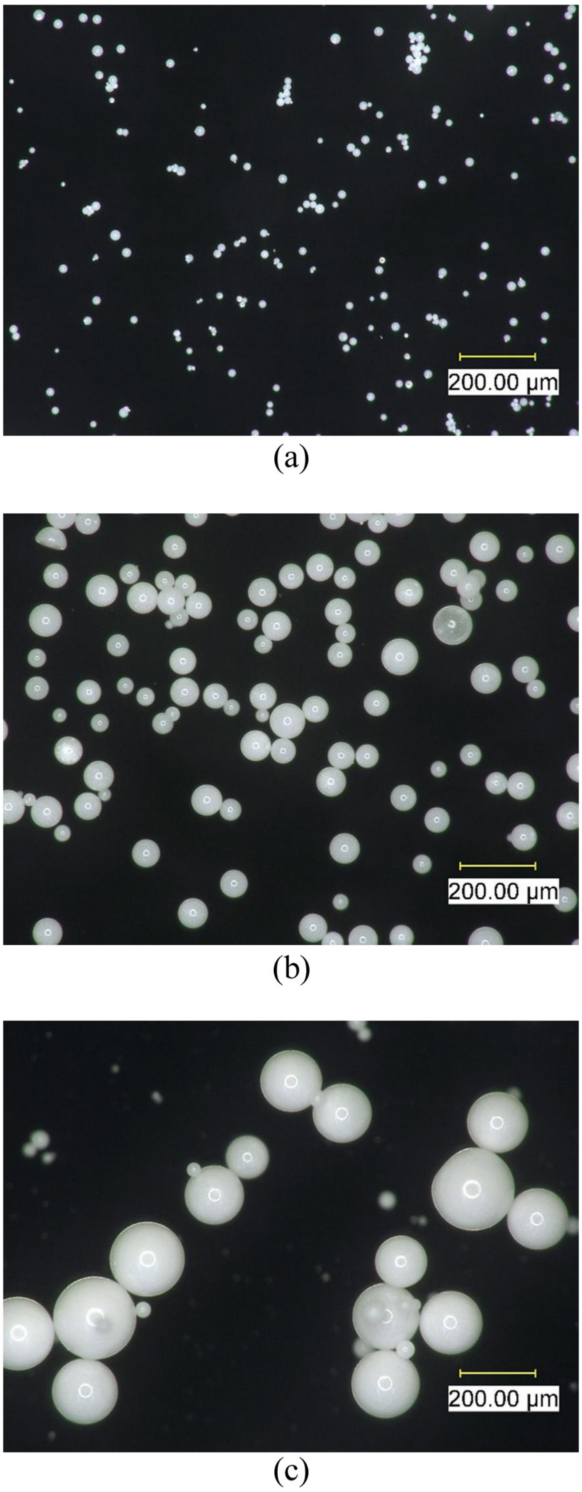

Fig. 1 – Microscopic images of PMMA particles (a) 18.0 μm; (b) 75.3 μm; (c) 195.5 μm.
Provided by SATAKE