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Particle de-agglomeration with an in-line rotor-stator mixer at different solids loadings and viscosities

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ABSTRACT

Rotor-stator mixers are commonly used in energy intensive processes but there is relatively little published information on which to base process design. This study investigated the de-agglomeration of nanoparticle clusters in a liquid to determine the effects of solids loading (up to 15%wt) and continuous phase viscosity (up to 100 mPa s) on the mechanisms and kinetics of breakup and dispersion fineness in an in-line rotor-stator. A Silverson 150/250MS rotor-stator was used in the recirculation loop of a stirred tank. It was shown that the power number values previously obtained at Reynolds numbers greater than 200,000 are constant at Reynolds numbers as low as 2400.

It was found that the breakup kinetics were not significantly affected by the solids loading, within the range covered in this study. On the other hand, when the viscosity of the continuous phase was increased, the de-agglomeration became slower even though the solids concentration was low (1%wt) and the flow through the rotor-stator was still turbulent. This indicates that it is the flow conditions around the particle and not the bulk rheology of the dispersion that determines the kinetics of the de-agglomeration process. Breakup mechanism was found to be erosion and the dispersion fineness was determined by the size of aggregates.

1. Introduction

In-line rotor-stators are the preferred equipment for many high intensity large-scale applications in the chemicals, personal and health care, cosmetics, agricultural and food processing industries (Atiemo-Obeng and Calabrese, 2004). Despite their widespread use, the design and scale up of processes involving rotor-stator mixers are still highly empirical. It is on account of both the design – narrow gap between the rotor and stator, teeth, or the presence of holes – and the high operating speeds (thousands of rpm), that the rotor-stator mixers produce high levels of local energy dissipation and liquid velocities in the mixer head. Therefore, they are used in applications that require high levels of local energy dissipation, such as liquid–liquid dispersions (Carrillo De Hert and Rodgers, 2017; Håkansson et al., 2016; Jasińska and Bałdyga, 2017; O'Sullivan et al., 2018), de-agglomeration of particles (Bałdyga et al., 2008a; Özcan-Taşkın et al., 2016; Padron et al., 2008), chemical reactions (Bałdyga et al., 2007; Jasińska et al.,2016). These devices have attracted more attention in the recent decades with more focus on the flow field in the mixer head and/or solid–liquid and liquid–liquid dispersion processes through both experimental (Hall et al., 2013; O'Sullivan et al., 2017; Özcan-Taşkin et al., 2011) and numerical studies (Bałdyga et al., 2008b; Håkansson and Innings, 2017; Özcan-Taşkin et al., 2011; Zhang et al., 2017).

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Nomenclature

C	Impeller's off-bottom clearance (m)
d_{32}	Sauter mean diameter (μm)
$d_{32,t=0}$	initial Sauter mean diameter (μm)
D	rotor diameter (m)
D_I	impeller diameter (m)
E_M	Energy per unit mass of solids (MJ/kg)
F	volume fraction of fines (–)
L	bob length (m)
L_e	end effect equivalent length (m)
m_S	mass of solids (kg)
N	rotor speed (s^{-1} or rpm)
N_T	number of tank turnovers (–)
P	power (W)
Po_1	power number 1 constant (–)
Po_2	power number 2 constant (–)
Q	flow rate (l/s or m^3/s)
R_b	bob or vane radius (m)
R_c	cup radius (m)
t	time, s
T	tank diameter (m)
T_o	Torque (Nm)
v_{tip}	rotor tip velocity (m/s)
V	volume of dispersion (m^3)
Z	volume fraction of fines produced per turnover (–)

Greek letters

β	ratio of cup radius to bob or vane radius (–)
$\dot{\gamma}$	shear rate in rheometer (s^{-1})
$\dot{\gamma}_g$	shear rate based on the rotor-stator gap (s^{-1})
$\dot{\gamma}_K$	Kolmogorov shear rate (s^{-1})
δ	rotor-stator gap (mm)
ε	energy dissipation rate (m^2/s^3)
η_K	Kolmogorov microscale (m)
$\mu_{(a)}$	(apparent) dynamic viscosity (mPa s)
μ_C	continuous phase dynamic viscosity (mPa s)
ν_C	continuous phase kinematic viscosity (m^2/s)
ρ	density (kg/m^3)
τ	shear stress (Pa)
Ω	angular velocity (rad/s)

Dimensionless numbers

Po	Power number (Eq. (4))
Fl	Flow number (Eq. (5))
Re	Reynolds number (Eq. (6))

This study was performed to investigate the effects of solids loading and continuous phase viscosity on the deagglomeration of nanoparticle clusters using an in-line rotor-stator. It also included the determination of power consumption with the in-line rotor-stator to extend the previously covered Reynolds number range ($Re > 200{,}000$) to lower values ($Re > 2400$). An estimate of the power dissipation is essential in both correlating results from different processes and also to assess the process performance.

The deagglomeration of nanoscale silica particle clusters was reported in a comparative study using three rotor-stator head designs for a dilute system: 1%wt Aerosil® 200 V in water (Özcan-Taşkın et al., 2016). As higher solid concentrations are of more interest in industrial practice due to the advantages of preparing a master batch, or the products may have a higher viscosity continuous phase, this study has been conducted to establish the effects of solids loading (up to 15%wt) in water and continuous phase viscosity (up to 100 mPa s) for 1%wt particle concentration.

The specific objectives of this study were to determine the effects of increasing either the solids concentration (up to 15%wt in water) or continuous phase viscosity (up to 100 mPa s for 1%wt solids concentration) on the mechanisms and kinetics of deagglomeration process using a given type of in-line rotor-stator.

2. Experimental set up and conditions

2.1. Equipment

The experimental rig consisted of an in-line Silverson 150/250MS rotor-stator mixer installed in the recycle loop of a Perspex stirred tank with a diameter (*T*) of 0.61 m. The tank was equipped with a down-pumping stainless steel 45° pitched blade turbine (PBT). The PBT had a diameter (D_I) of 0.42*T*, was mounted at a clearance (*C*) of *T*/4 and operated at 155 rpm (corresponding to a tip speed of 2.1 m/s). Fig. 1 shows a schematic representation of the rig. A mesh was installed at the exit of the tank to ensure that no large debris could come into contact with the high-speed rotor-stator. On leaving the rotor-stator, it passed through a flow meter and a valve was used to control the flow rate. The total volume of dispersion in the system was 100 l in all experiments.

Fig. 2 shows the stators and rotor used in the study. The stator used for the silica break up experiments was a dual stage Emulsor (EMSC) screen, with both stages consisting of 7 rows of 1 mm diameter round holes. The rotor also has two stages, the inner rotor consists of four blades and has a diameter of 38.2 mm and the outer rotor is comprised of eight teeth and has an external diameter of 63.5 mm. The width of the rotor-stator gap in both stages is 0.15 mm. The calorimetry tests were performed using the GPDH + SQHS stator, which consists of eight 10 mm diameter round holes (General Purpose Disintegrating Head) and the outer stator consisting of three rows of 2.4 × 2.4 mm square holes (Square Hole High Shear Screen).

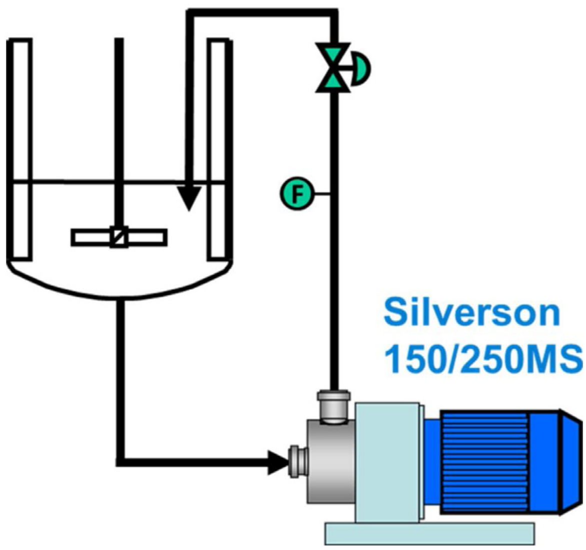

Fig. 1 – Experimental rig configuration.

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