Contents lists available at SciVerse ScienceDirect

Chemical Engineering Research and Design

journal homepage: www.elsevier.com/locate/cherd

Prediction of just suspended speed for mixed slurries at high solids loadings

Inci Ayranci[a,*], *Theodore Ng*[a], *Arthur W. Etchells III*[b], *Suzanne M. Kresta*[a]

[a] *Department of Chemical and Materials Engineering, University of Alberta, Edmonton, Canada T6G 2V4*
[b] *Rowan University, Glassboro, NJ, United States*

ABSTRACT

One design heuristic used to determine the just suspended speed, N_{js}, for mixed slurries assumes that the mixture N_{js} is dominated by the particle phase with the maximum N_{js}. This approach does not incorporate the effect of the second solid phase. Two new models are proposed to predict the mixture N_{js}: the power model and the momentum model. These models determine the mixture N_{js} using the sum of the power or the sum of the momentum required to suspend the individual solid phases. The models were tested using experimental data for two impellers, a Lightnin A310 impeller and a 45° pitched-blade turbine. A range of off-bottom clearances, and six mixtures of solids up to 27 wt% solids loading completed the data set. The power model accurately predicts mixture N_{js} for both impellers over the full range of clearances and up to 27 wt% mixtures.

Keywords: Just suspended speed; Stirred tank; Power model; Momentum model; Mixture; High solids loading

1. Introduction

In many solid–liquid mixing operations the main objective is mass transfer between the two phases. To maximize the mass transfer the entire surface area of the solids should be exposed. This can be achieved by operating at the complete off-bottom suspension condition. The key operating parameter for this condition is the impeller speed, which is called the just suspended speed (N_{js}). N_{js} is defined as the impeller speed at which no solids remain stationary at the bottom of the tank for more than 1 or 2 s (Zwietering, 1958). Solid–liquid mixing is a power intensive operation, so accurate prediction of N_{js} is important. Current correlations are limited to unimodal slurries at low solids loadings, but many industrial slurries are composed of mixtures of solids with varying densities and particle sizes at high concentrations. The gap between research and industry is vast, and the need for an accurate design model for mixed slurry N_{js} is clear.

Current correlations have significant limitations because many parameters play an active role in solids suspension. Geometry is by far the most important factor. The effects of impeller and tank diameter, impeller type, off-bottom clearance of the impeller, shape of the tank bottom, and the presence, shape, and clearance of the baffles have been studied by many authors (Baldi et al., 1978; Ibrahim and Nienow, 1996; Myers and Fasano, 1992; Armenante and Nagamine, 1998). N_{js} is also a function of particle and liquid properties, such as the particle density, particle diameter and shape, and liquid density and viscosity (Nienow, 1968; Baldi et al., 1978). The behavior of the particles is different when there are many other particles around them; therefore, solids loading is also very important (Ayranci and Kresta, 2011).

The large number of parameters affecting N_{js} makes it difficult to determine a robust design correlation. The first correlation was suggested by Zwietering (1958) and it is still the correlation that is most often used in calculations.

$$N_{js} = S\left(\frac{g(\rho_S-\rho_L)}{\rho_L}\right)^{0.45}\frac{d_p^{0.2}\nu^{0.1}X^{0.13}}{D^{0.85}} \quad (1)$$

Abbreviations: A310, axial impeller provided by Lightnin; B, bronze; LG, large glass beads; Ni, nickel; PBT, pitched blade turbine; R, ion exchange resin; S, sand; SG, small glass beads or specific gravity; UF, urea formaldehyde; wt%, weight percent.

* *Corresponding author at*: Department of Chemical and Materials Engineering, University of Alberta, 7th Floor ECERF, 9107-116 Street, Edmonton, Alberta, Canada T6G 2V4. Tel.: +1 780 492 9221; fax: +1 780 492 2881.

E-mail address: iayranci@ualberta.ca (I. Ayranci).

Received 8 February 2012; Received in revised form 10 July 2012; Accepted 1 August 2012

http://dx.doi.org/10.1016/j.cherd.2012.08.002

Nomenclature

Roman characters

C	off-bottom clearance (m)
D	impeller diameter (m)
d_p	particle diameter (m)
g	acceleration due to gravity (m/s^2)
H	liquid height (m)
M	momentum (kg m/s^2)
M_{js}	momentum at just suspended conditions (kg m/s^2)
$M_{js,1}$	M_{js} for particle one (kg m/s^2)
$M_{js,2}$	M_{js} for particle two (kg m/s^2)
$M_{js,mix}$	M_{js} for mixture (kg m/s^2)
Mo	momentum number
N	impeller rotational speed (rps or rpm)
N_{js}	just suspended speed (rps or rpm)
$N_{js,1}$	N_{js} for particle 1 (rps or rpm)
$N_{js,2}$	N_{js} for particle 2 (rps or rpm)
$N_{js,max}$	N_{js} maximum (rps or rpm)
$N_{js,mix}$	mixture N_{js} (rps or rpm)
N_p	power number
P_{js}	power consumption at just suspended speed conditions (W)
$P_{js,1}$	P_{js} for particle 1 (W)
$P_{js,2}$	P_{js} for particle 2 (W)
$P_{js,mix}$	P_{js} for mixture (W)
r	radius (m)
S	Zwietering's N_{js} constant
T	tank diameter (m)
V_z	velocity in the axial direction
W_b	baffle width (m)
x_S	mass fraction of the solids in the slurry
x_L	mass fraction of the liquid in the slurry
X	Zwietering's mass ratio percent (mass of solid/mass of liquid × 100)

Greek characters

ν	kinematic viscosity (m^2/s)
ρ_L	liquid density (kg/m^3)
ρ_S	solid density (kg/m^3)
ρ_{sl}	slurry density (kg/m^3)
$\rho_{sl,1}$	unimodal slurry density for particle 1 (kg/m^3)
$\rho_{sl,2}$	unimodal slurry density for particle 2 (kg/m^3)
$\rho_{sl,mix}$	mixture slurry density (kg/m^3)

Some of the parameters that affect N_{js} are included in this correlation but the accuracy of the exponents has been questioned by many authors. Kasat and Pandit (2005) compiled the different exponents on the common parameters suggested by various authors. Their comparison showed that the Zwietering correlation is still the one that predicts the data most closely. The Zwietering correlation, however, does not provide an answer for mixed slurry N_{js}.

The literature on mixed slurry suspension is only beginning to be developed, and initial studies focused on dilute slurries. Baldi et al. (1978) studied a mixture of glass beads with two particle sizes and found that N_{js} can be predicted using an average particle size, at low solids loadings. Montante and Magelli (2007) did a computational study on the distribution of solids for dilute slurries with two solid phases which have different densities but same particle sizes. They showed that the two solids phases are not affected by each other. Recently Ayranci and Kresta (2011) reported results for a wide variety of binary mixtures at high solids loadings (up to 56 wt%). Their study showed that the presence of a second solid phase may significantly affect the mixture N_{js}. This effect is amplified for mixtures above 20 wt% solids, because at that point the particle–particle interactions start to dominate. The particle sizes and the densities of the two solid phases play an important role in the mixture N_{js}.

The current design heuristic for mixed slurries is to assume that the mixture is composed of only the particle fraction that is hardest to suspend. The N_{js} for that fraction is predicted using the Zwietering correlation, and treated as the mixture N_{js}. This design heuristic has many flaws, some of which were shown by Ayranci and Kresta (2011). Of the five mixtures they tested, only one mixture followed the design heuristic up to high solids loadings, and a second mixture followed it up to 13 wt%, but then failed. The other mixtures did not follow the design heuristic. The ratio of the particle size, the particle density, and the solids loadings of the two solid phases all had an effect on mixture N_{js}. A more robust and physically realistic model for predicting mixture N_{js} is needed.

In this study we propose and test two models that are based on the total power and the total momentum required to suspend solids in a stirred tank.

2. Model development

2.1. Current design heuristic

The current design heuristic is based on the maximum unimodal N_{js} in a mixture:

$$N_{js,mix} = \max(N_{js,1}, N_{js,2}) \tag{2}$$

For example, if a mixture N_{js} needed to be determined for a mixture of 1.5 wt% SG with 1.5 wt% B, the N_{js} of the unimodal slurries of the two particles should be calculated and the maximum value should be used as the mixture N_{js}. The unimodal slurry N_{js} is predicted from the Zwietering correlation (Eq. (1)). In the example the unimodal slurry N_{js} is 318 rpm for 1.5 wt% SG and 1142 rpm for 1.5 wt% B. The mixture N_{js} is the maximum of the two values, which is 1142 rpm.

2.2. Power model

The power model is proposed based on a hypothesis that the power required to suspend a mixture is the sum of the power required to suspend each of the solid phases in the mixture.

$$P_{js,mix} = P_{js,1} + P_{js,2} \tag{3}$$

where $P_{js,mix}$ is the power required to suspend the mixture, and $P_{js,1}$ and $P_{js,2}$ are the power required to suspend the first and the second solid phases, respectively. The power required to suspend each solid phase is calculated at the just suspended condition based on the unimodal slurry density:

$$P_{js} = \rho_{sl} N_{js}{}^3 D^5 N_p \tag{4}$$

$$\rho_{sl} = \frac{1}{(x_S/\rho_S) + (x_L/\rho_L)} \tag{5}$$