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A NEW TECHNIQUE FOR MEASURING THE DEGREE OF SUSPENSION IN MECHANICALLY AGITATED VESSELS

G.R. DREWER, G.J. JAMESON and N. AHMED

Department of Chemical Engineering
University of Newcastle, NSW 2308
AUSTRALIA

ABSTRACT

Little information is available on the suspension of solids at high concentrations in mechanically agitated tanks. Currently, the various criteria used to define the degree of suspension (or complete suspension) are based on visual observations, and therefore, are either subjective or difficult to monitor.

An experimental study is reported in which the degree of suspension (at solids concentrations of 25 to 55% w/w) is determined by measuring the pressure changes (caused by the suspension of particles) at the bottom of a stirred vessel. Good agreement between the observed pressure (after accounting for the dynamic pressure effects of agitation) and the pressure predicted from fluidisation theory at complete suspension, occurrs at positions on the base where the dynamic effects were minimal.

A new suspension criterion is suggested and, is defined as the impeller speed, N_{js}, beyond which the static pressure at the base of the vessel remains essentially constant.

NOMENCLATURE

D	Diameter of tank	[m]
g	Acceleration due to gravity	[ms^{-2}]
H	Height of suspension in tank	[m]
N	Impeller rotational speed	[rpm]
ΔP_d	Pressure change due to agitation	[Pa]
ΔP_{df}	Agitation pressure, fluid only	[Pa]
ΔP_{stat}	Static pressure variation	[Pa]
ΔP_{tot}	Total pressure variation	[Pa]
ρ_{av}	Average density of suspension	[kgm^{-3}]
ρ_f	Density of fluid	[kgm^{-3}]
ρ_s	Density of solid	[kgm^{-3}]
ε	Void fraction of suspended solids	[ ]

INTRODUCTION

Mechanically agitated vessels are widely used to suspend solids in the chemical and mineral processing industries. The degree of suspension required is dependent on the process itself. However a "good mixer", should at least bring about a degree of agitation which keeps the liquid phase well mixed, and keeps all the solid particles in suspension.

Most studies concerned with solids suspension in stirred tanks concentrate on solid concentrations less than 40% w/w. From these studies a number of suspension criteria have been developed. The most commonly used measure of suspension is the complete off bottom suspension (CBS) criterion. The criterion is met when no particle rests on the tank bottom for more than one second (Zwietering, 1958). Other criteria have been suggested based on various degrees of suspension. For example, the 1BM criterion which is the point of first sign of movement of particles on the vessel bottom (Porcelli and Marr, 1962), or the one suggested by Einenkel (1979) which is based on the solids being detected at a height equivalent to 0.9 of the tank diameter. One common factor in all these criteria, is the need for visual observation, which is subjective, and also impractical in opaque systems.

The aim of this study was to compare a newly defined suspension criterion based on the pressure at the bottom of an agitated tank (due to the suspension of solids), to the established CBS and 1BM criteria. A range of particle concentrations (25-55% w/w) and two impeller designs were evaluated.

THEORY

When a particle is suspended, the sum of the drag and buoyant forces on it must equal the gravitational force. From fluidisation theory, the theoretical pressure on the base of the containing vessel, due to the complete suspension of particles (ΔP_{stat}), would be given by:

$$\Delta P_{stat} = (\rho_s - \rho_f)(1-\varepsilon)\, g\, H. \qquad (1)$$

Because of the dynamic pressure effects inherent in an agitated vessel, the pressure observed would be different from the static pressure. Thus the pressure observed (ΔP_{tot}) would be:

$$\Delta P_{tot} = (\rho_s - \rho_f)(1-\varepsilon)\, g\, H + \Delta P_d \qquad (2)$$

If the dynamic pressure due to agitation (ΔP_d) could be accounted for, the pressure rise due to suspended solids would be determined by:

$$\Delta P_{stat} = \Delta P_{tot} - \Delta P_d . \qquad (3)$$

The dynamic pressure due to agitation in pure fluid is proportional to $\rho_f U^2$, but in the presence of solids, the change in density would need to be incorporated. Assuming that the local fluid velocities remain unchanged with the addition of solids, the dynamic pressure, in the presence of solids, at a given impeller speed may be estimated from

$$\Delta P_d = \Delta P_{df}\, \rho_{av} / \rho_f . \qquad (4)$$

For fluidisation theory to be applicable to agitated vessels, the observed pressures (equation (3)) should be comparable to the values predicted by equation (1) when complete suspension is observed visually. Also, if the observed and predicted pressures coincide, then most of the particles have been suspended even if complete suspension is yet to be observed visually.

EXPERIMENTAL

The experimental apparatus consisted of a cylindrical flat-bottomed tank of diameter 0.19 m. The tank had four equi-spaced 0.019 m wide vertical wall baffles. Five pressure tappings were placed in the base of the tank (Figure 1). Sensor 3 was located at the vertical axis in the centre of the tank, Sensors 1 and 2 were placed 0.06 and 0.03 m from the centre on a vertical plane passing through the centre and a baffle, with sensors 4 and 5 placed 0.08 and 0.04 m from the centre on a vertical plane passing through the centre and bisecting two baffles. The pressure sensors were connected to manometers which were accurate to ± 20 Pa.

The impellers used were, a six-bladed disc-turbine (commonly known as the Rushton turbine) and a marine propeller. These were used as typical examples of radial and axial flow impellers to compare the dynamic pressure effects of different impeller types. Both impellers were similar in geometry to the impellers used by Zwietering (1958) and Chudacek (1986). Impeller off-bottom clearance was constant at 1/3 of the liquid height in all cases.

A variable speed motor mounted above the tank was used to drive the impellers. Impeller speed was measured by a speed sensor attached to the impeller shaft. The general layout of the experimental arrangement is shown in Figure 2.

Glass ballotini (spheres), -355+250 μm in diameter, with a density of 2470 kg/m^3 was used as the solid phase, with tap water as the suspending medium. At each solids concentration the impellers were run at various speeds between 150 and 1500 rpm with the pressures and suspension condition being recorded at each speed. The solids concentrations used were: 0% (water only), 25%, 40% and 55% w/w.

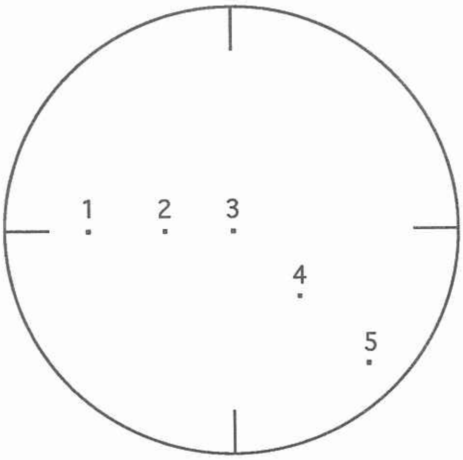

Figure 1. Plan view of stirred tank bottom showing the location of the pressure sensors. In the text the sensors are denoted by their respective numbers, as shown in the diagram.

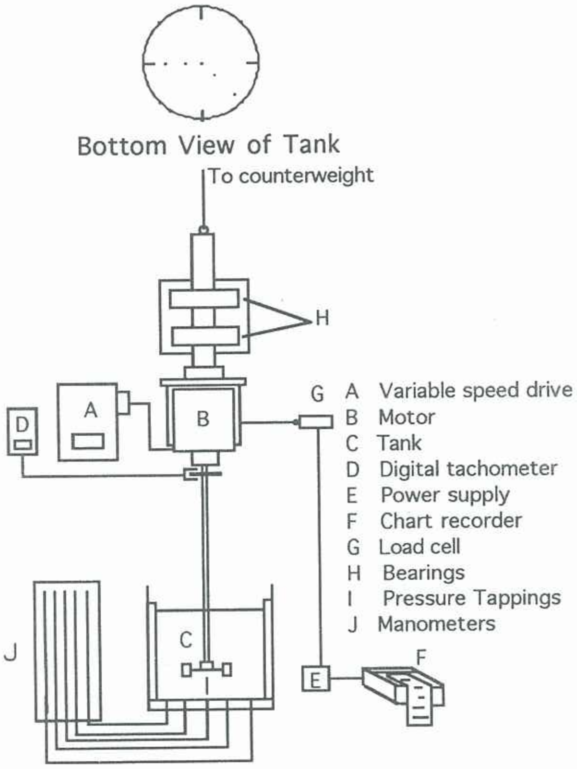

Figure 2. Schematic of the experimental arrangement.

RESULTS AND DISCUSSION

The dynamic pressure due to agitation in solid free water was found to be dependant on the impeller type and the sensor location (Drewer et al. 1992). By curve fitting it was established that the dynamic pressure is proportional to the square of the impeller rotational speed (Figures 3 and 4). On the tank bottom the dynamic pressure was minimal in regions away from the direct impingement of jets from the impeller, and where the fluid flow was expected to be parallel to the base of the tank.

With the addition of solids, the total pressure measured at any given impeller speed was greater than the pressure at the corresponding speed without solids (Figure 5). At any given solids concentration, the pressure rise with agitation increased rapidly until almost all the solids were suspended. The points where the pressures level off, at approximately 800 rpm, essentially indicates complete suspension. It should be mentioned however, that visual observations indicated that the CBS criterion was being met at around 1000 rpm.

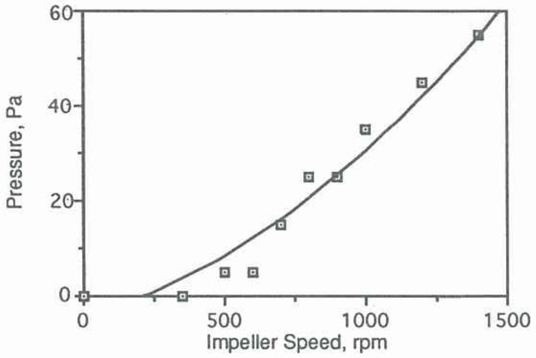

Figure 3. Dynamic pressure as a function of the impeller speed for the Rushton turbine.(sensor 4)

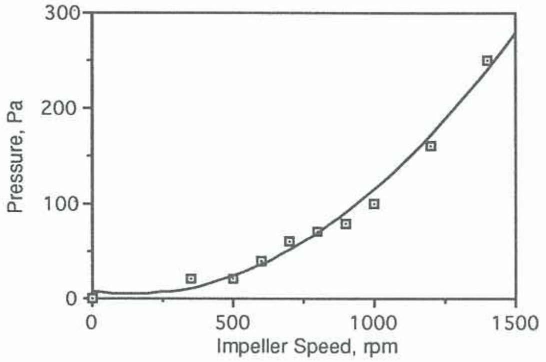

Figure 4. Dynamic pressure as a function of the impeller speed for the marine propeller. (sensor 5)

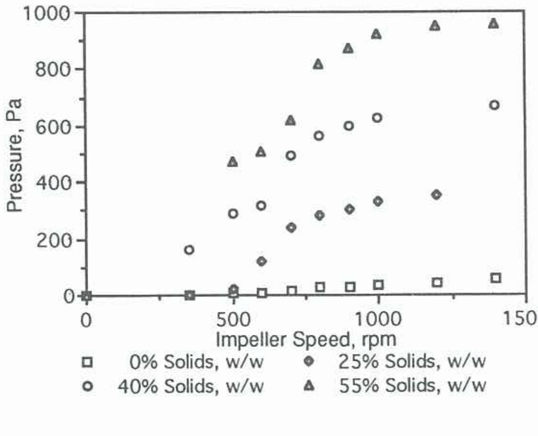

Figure 5. Pressure measured by sensor 4 as a function of the impeller speed, for the Rushton turbine, at various solids concentrations.

The static pressure due to the suspension of the solids was obtained by subtracting the dynamic pressure due to agitation (e.g. Figures 3 and 4) from the observed total pressure (e.g. Figure 5), by applying equations (3) and (4). Drewer et al. (1992) found that agreement between the observed and the predicted static pressures was dependent on the impeller type and sensor position. Sensors 1 and 4 were located at positions of minimal dynamic pressures on the tank base, and the correspondence between measured and predicted values was found to be extremely good with them. The correspondence was good to fair for the other locations. Similarly, the best sensor locations for the marine propeller were determined to be positions 1 and 5.

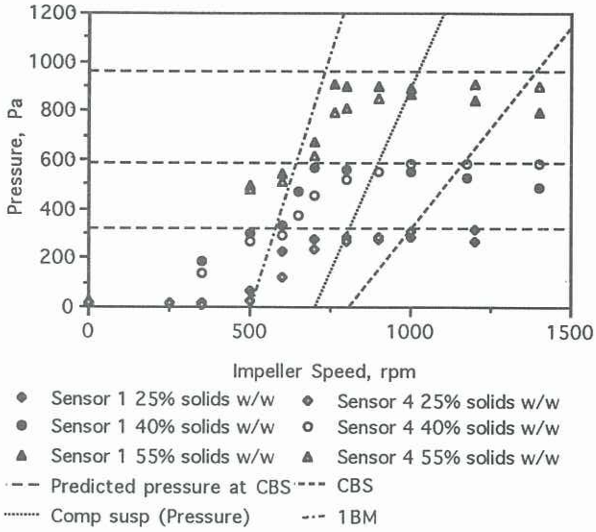

Figure 6. Static pressure as a function of the impeller speed for the Rushton turbine at various solids concentrations.

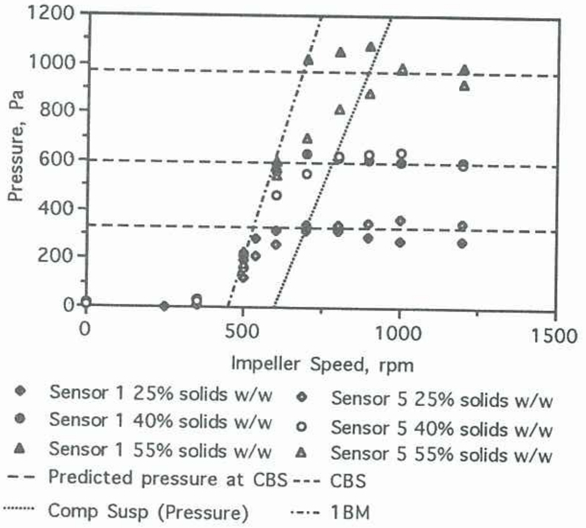

Figure 7. Static pressure as a function of the impeller speed for the marine propeller at various solids concentrations.

Figures 6 and 7 show the static pressure as a function of the impeller speed, at the optimum sensor locations, for various solids concentrations, and both the impellers. The agreement between the measured and predicted pressures at complete suspension [applying equation (1)] are within ± 5% in all cases. Two distinct regions were observed at each concentration, a region of increasing static pressure with impeller speed, followed by a constant pressure region.

By extending the concepts used in determining the point of incipient fluidisation in packed beds to stirred tanks, one could define the minimum suspension speed (N_{js}) as being the intersection of the increasing and constant static pressure regions. A typical example of the determination of N_{js} by pressure measurement is shown in Figure 8. The N_{js} values were found to be in between the impeller speeds at 1BM and CBS, which were determined visually (Figures 6 and 7). This observation is rational since the 1BM and CBS criteria represent the two extremes of solids suspension, i.e., the first movement of solid at the tank bottom and the point where no particle stays at the bottom for more than a second, respectively. However, almost all of the particles are suspended at N_{js}, so for many applications it may not be necessary to expend the additional power required to meet CBS conditions.

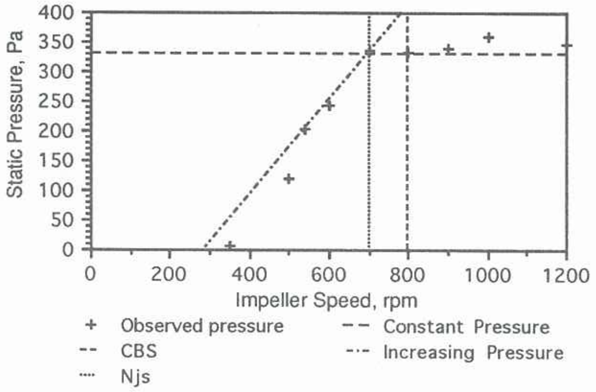

Figure 8 Diagram illustrating how to determine N_{js} by static pressure measurements.

CONCLUSIONS

A pressure based suspension criterion, N_{js}, has been defined and compared with the CBS and 1BM criteria, over a wide range of solids concentrations, for a radial and an axial flow impeller. The CBS criterion is the impeller speed at which no particle rests on the bottom for more than one second, while N_{js} is defined as the impeller speed beyond which the static pressure at the base of the vessel remains essentially constant .

The static pressures observed at the base of the vessel, due to the suspension of solids, correlated well with those predicted from fluidisation theory in regions where the dynamic pressure was small. Within those regions, for 0 - 55% solids w/w, the point where most of the particles were suspended, was clearly defined as the intersection of the increasing and constant static pressure regions. At complete suspension, the static pressures observed were within ± 5% of those predicted by the theory.

The measurement of pressure at the base of mechanically agitated vessels offers a viable and more objective method of detecting complete suspension, especially for opaque systems.

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