Bakker A., Frijlink J.J. (1989) The Drawdown and Dispersion of Floating Solids in Aerated and Unaerated Stirred Vessels. Chem.Eng.Res.Des., Vol 67, March 1989, 208-210.

SHORTER COMMUNICATION

THE DRAWDOWN AND DISPERSION OF FLOATING SOLIDS IN AERATED AND UNAERATED STIRRED VESSELS

A. BAKKER and J. J. FRIJLINK

Laboratorium voor Fysische Technologie, Delft University of Technology, The Netherlands

The suspension of floating solids under gassed conditions has been studied in a fully baffled 1.20 m diameter stirred vessel. The performance of various impellers is compared at two immersion depths. It is concluded that impeller hydrodynamics, especially the formation of large gas filled cavities behind the blades, has a significant influence on the just suspended stirrer speed. Upward pumping pitched blade impellers turned out to be more energy efficient than disc turbines in our system, using tap water and expanded polystyrene spheres.

INTRODUCTION

Stirred vessels are often used for suspending solid particles in fluids. Therefore a lot of research has been done to establish design rules for such mechanically agitated two phase systems. The same holds for gas liquid processing. Some studies considered three phase (gas-liquid-solid) systems, but only with settling and neutrally buoyant particles[1,2,3]. So far only a few papers have been published about suspending floating solids. No literature is available on the introduction of floating particles in gassed systems, although examples of these processes have been mentioned, e.g. steroid oxidation. It is clear that besides the performance of the stirrer important factors are particle size, particle density, caking and wettability. The present study is limited to expanded polystyrene particles with low density, in order to achieve a first impression of the problems which can be met when suspending floating solids in gassed systems. These results are reported below. Emphasis is on the influence of gas sparging on the just suspended stirrer speed N_{js} and power input P_{js}. Attention was given to the possibility of parallels with the suspension of settling solids. Furthermore the energy efficiencies of various impeller types have been compared.

LITERATURE

As stated above the literature describes ungassed systems only. Joosten et al.[4] examined the influence of vessel geometry and impeller type on the minimum stirrer speed and associated power consumption. According to their results the standard vessel with four baffles and equipped with a disc turbine is rather inefficient. They correlated the minimum speed for drawdown for their preferred baffle arrangement—one wide baffle, in which case an eccentric vortex draws the solids down—by:

$$Fr_{js} = (D.N_{js}^2)/g = K.(D/T)^{-3.65}(\Delta\rho/\rho_l)^{-0.42} \qquad (1)$$

The proportionality constant K depends on stirrer type. They did not investigate the influence of volume fraction.

Edwards and Ellis[5] investigated the influence of baffle number, stirrer type, solids mass fraction and clearance. They observed no effect of solids concentration on N_{js} for low mass fractions. In general N_{js} and P_{js} increase with increasing immersion depth and increasing number of baffles.

Hemrajani et al.[6] studied the influence of baffle arrangement on the minimum impeller tip speed needed for suspension. According to their results, homogeneous suspension of floating solids can be achieved by controlled vortex formation.

The papers discussed above suggest that the creation of a vortex in which the particles are drawn down is the energetically most efficient way of suspending floating solids. In gassed systems, however, vortices are suppressed and the gas phase may affect the general flow pattern in the vessel considerably.

EXPERIMENTAL METHODS

The just-suspended stirrer speed N_{js} and associated power consumption P_{js} have been measured as a function of gassing rate under various circumstances.

The just-suspended speed was determined visually by observing the full liquid surface. The just-suspended state was defined as the state of the system in which no particles stayed at the surface longer than one second. This is similar to the Zwietering criterion[7]. Because the polystyrene is sticky when wet, the particles clogged. Therefore, in practice the just-suspended state corresponded with the breakup of the floating clots of polystyrene and the disappearance of all stagnant zones.

All experiments were carried out in a 1.20 m diameter standard vessel with four 10% baffles. Liquid volume was 1.36 m^3. The power input of the impeller was calculated from the torque on the shaft and the stirrer

0263-8762/89/$05.00 + 0.00

Table 1. N_{js}, P_{js} and Po_{js} for all tested impellers at various clearances in the two phase, water-floating solids system

Impeller	C/T	N_{js} s^{-1}	P_{js} W	Po_{js}
DT	0.65	2.59	2668	6.03
DT	0.50	2.30	1975	6.37
60↓	0.65	3.17	2431	3.00
60↓	0.50	>4	>4800	—
60↑	0.65	2.48	899	2.31
60↑	0.50	>4	>3700	—
45↓	0.65	>4	>2800	—
45↓	0.50	>4	>2800	—
45↑	0.65	2.54	679	1.62
45↑	0.50	3.46	1694	1.61

speed. The torque exerted by a DC motor is proportional to the anchor current. Therefore it was possible to determine the torque indirectly by measuring the anchor current. Empirical corrections for energy and friction losses in the motor, the gearing and shaft bearings were made. The stirrer speed was varied from 0.5 to 4 s^{-1}. Measuring the power number with this method of a six blade disc turbine mounted at a stirrer-bottom clearance $C = 0.50T$ gave $Po = 6.37$ (Table 1). Calculating the power number of this disc turbine with the correlation proposed by Bujalski et al.[8] yields $Po = 6.3$. Both data agree fairly well, giving confidence in the power data obtained in this way.

The solids consisted of small spheres, $1\text{ mm} < d < 4\text{ mm}$ of expanded polystyrene, $\rho_s = 27\text{ kgm}^{-3}$. An amount of 0.1 kg solid material was used, resulting in a layer on the liquid surface between one and two particle diameters high. The impellers used were a standard six blade disc turbine (DT) and two inclined blade impellers with 45° and 60° blade angle and six blades. The latter were used in downward and upward pumping modes. Impeller diameter D equalled $0.4\,T$ in all cases. Disc and/or blade thickness equalled 5 mm for all impellers. Two immersion depths ($C = 0.50\,T$ and $C = 0.65\,T$) were chosen. A ring sparger was mounted underneath the stirrer at a separation distance $S = 0.25\,\text{T}$.

RESULTS

Two phase system (liquid-solid)

The just-suspended stirrer speed N_{js}, the associated power consumption P_{js} and power number Po_{js} have been measured as a function of immersion depth and impeller type. However, with downward pumping impellers N_{js} mostly exceeded 4 s^{-1}. This led to a very high power consumption and made further experiments in this apparatus impossible. Data are presented in Table 1.

Although the downward pumping impellers did create a small vortex in the ungassed system, the liquid flow at the walls was insufficient to transport the particles along the surface to the centre, so stagnant zones formed behind the baffles.

With respect to N_{js} the *DT* is the most efficient (Table 1). It was observed that for the *DT* N_{js} was somewhat lower for $C = 0.50\,T$ than for $C = 0.65\,T$. This was explained by the presence of a small vortex near the shaft in the former case, that didn't occur when the impeller was raised to the position $C = 0.65\,T$.

Furthermore, when the impeller was raised, a reduction in power number occurred, as a result of substantial surface aeration (Table 1).

The 45° upward pumping impeller is the most energy efficient as a result of a low N_{js} and a low power number. However, the particles tended to concentrate in the upper half of the vessel and the suspension was not homogeneous in all cases.

Three phase system

For the upward pumping impellers and the disc turbine, N_{js} and P_{js} have been measured as a function of sparging rate Q_g and clearance C. The results are plotted as a function of Flow-number Fl defined by:

$$Fl = Q_g/(ND^3) \qquad (2)$$

In Figure 1a, N_{js} with floating solids is compared with the results for the same disc turbine at $C = 0.40\,T$ using settling solids, as published by Frijlink et al.[2] For both curves N_{js} increases with increasing flow-number, and a sharp rise in N_{js} is observed at $Fl = 0.015$ and $Fl = 0.03$ respectively. This sharp rise is due to the formation of large gas-filled cavities behind the stirrer blade, reducing

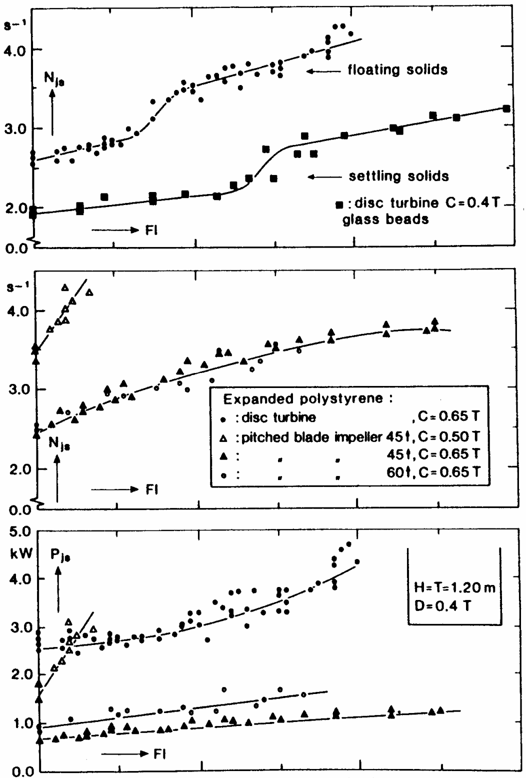

Figure 1a, b, c. N_{js} and P_{js} as a function of Fl for various impeller types (45↑, 60↑ pitched blade impellers with 45°, 60° blade angle, upward pumping).

the pumping capacity of the stirrer[2,9]. Qualitatively these suspension curves for floating and settling solids are very similar, indicating a relation between the suspension of floating and settling solids in gassed system. This is remarkable because at the surface a three phase process occurs, while at the bottom—even in a gassed system—particle transport is governed by the local flow conditions only. Clearly the hydrodynamics of the gassed impeller has a strong influence on the flow at the bottom as well as on the flow on the free surface and affects both types of solids suspension considerably.

The strong increase in N_{js} is not reflected in the just-suspended power versus Flow number curves (Figure 1c), due to the reduction of the gassed power number at increasing gassing rate.

The small vortex observed with the disc turbine (see previous section) disappeared in the gassed system. This resulted in higher values of N_{js} and P_{js} at $C = 0.50\,T$ as compared with $0.65\,T$ for the same impeller.

Although there is only a small difference between N_{js} for 60° and 45° upward pumping inclined blade impellers at $C = 0.65\,T$, there is a significant difference in just-suspended power, due to the lower power number of the 45° impeller.

Figure 1 clearly shows that the upward pumping impellers are more efficient than disc turbines for the suspension of floating particles under gassed conditions. This can be explained from the observed suspension mechanism. The solids move to places with a downward flow, are drawn down and dispersed through the vessel. If the downward flow is in the centre, it is counteracted by the rising gas flow. Vortices are dampened and no advantage of the rotation can be taken. With upward pumping impellers the flow pattern is stable and the particles are transported effectively to the walls, where a zone of rapid downward flow is found. This downward flow is sufficient to suspend the particles, even at this size of instrumentation. No stagnant zones are formed behind the baffles as in the other cases.

The use of upward pumping agitators for simultaneous gas dispersion and suspension of settling particles is recommended by Chapman et al.[1] and Bujalski et al.[3]. From the present work it comes forward that the stable flow pattern of gassed upward pumping agitators is not only advantageous in three phase systems in which settling solids have to be suspended but also in systems where floating solids have to be drawn down.

CONCLUSIONS

For disc turbines, stirrer hydrodynamics and particularly the formation of large gas filled cavities has significant influence on the just-suspended stirrer speed and power consumption, in a way similar to that in systems with settling solids.

In general N_{js} increases with increasing immersion depth of the impeller.

Although the creation of a vortex is advantageous in two-phase systems, this can not easily be achieved in three-phase systems.

Upward pumping impellers close to the surface are most efficient for the drawdown of floating solids in gassed stirred vessels. A six bladed 45° blade angle impeller offers the best compromise of gas handling and liquid pumping capacities.

The suspension process consists of two steps. The first step is the drawdown of the solids from the top surface. The second step is the dispersion of the solids through the vessel. The experiments reported in this paper considered the first step only. Further research considering the dispersion, homogenisation part of the process is necessary.

SYMBOLS USED

C	Stirrer-bottom clearance (m)
d	Particle diameter (m)
D	Stirrer diameter (m)
Fl	Flow number (−)
Fr	Froude number (−)
g	Acceleration of gravity ($\mathrm{m\,s^{-2}}$)
K	Constant in equation (1) (−)
N	Stirrer speed ($\mathrm{s^{-1}}$)
P	Power consumption (kW)
Po	Power number (−)
Q_g	Gas flow rate ($\mathrm{m^3\,s^{-1}}$)
S	Impeller-sparger separation (m)
T	Tank diameter (m)

The subscript *js* refers to the just suspended condition.

$\Delta\rho$	Density difference between liquid and solids ($\mathrm{kg\,m^{-3}}$)
ρ_s	Solid particle density ($\mathrm{kg\,m^{-3}}$)
ρ_l	Liquid density ($\mathrm{kg\,m^{-3}}$)
45(60) ↑ (↓)	Upward (Downward) pumping inclined blade impeller with 45°(60°) blade angle.

REFERENCES

1. Chapman, C. M., Nienow, A. W., Cooke, M., Middleton, J. C., 1983, *Chem Eng Res Des* 61: 82–95 and 167–181.
2. Frijlink, J. J., Bakker, A., Smith, J. M., Suspension of Solid Particles with Gassed Impellers. Submitted to *Chem Eng Sci.*
3. Bujalski, W., Konno, M., Nienow, A. W., 1988, *Proc. 6th Europ Mixing Conf, Italy 1988; AIDIC/BHRA Fluid Engineering, Cranfield, 1988*, 389–398.
4. Joosten, G. E. H., Schilder, J. G. M., Broere, A. M., 1977, *Trans I Chem E.*, 55 (3): 220–223.
5. Edwards, M. F., Ellis, D. I., 1984, *I. Chem E. Symp Series 89*, 1–13.
6. Hemrajani, R. R., Smith, D. L., Koros, R. M., Tarmy, B. L., 1988, *Proc. 6th Europ Conf on Mixing, Pavia, Italy*, 259–265.
7. Zwietering, Th. N., 1958, *Chem Eng Sci*, 8: 244–253.
8. Bujalski, W., Nienow, A. W., Chatwin, S., Cooke, M., 1987, *Chem Eng Sci*, 42 (2): 317–326.
9. Warmoeskerken M. M. C. G., Houwelingen van, M. C., Frijlink, J. J., Smith, J. M., 1984, *Chem Eng Res Des*, 62: 197–200.

ADDRESSES

Correspondence concerning this paper should be addressed to Ir. A. Bakker, Lab. voor Fysische Technologie, TU Delft, Prins Bernhardlaan 6, 2628 BW Delft, The Netherlands. J. J. Frijlink is now with the Akzo Research Laboratories.

The manuscript was communicated via our International Editor for Continental Europe, Dr. A. D. Barber. It was received 16 May 1988 and accepted for publication after revision 15 August 1988.