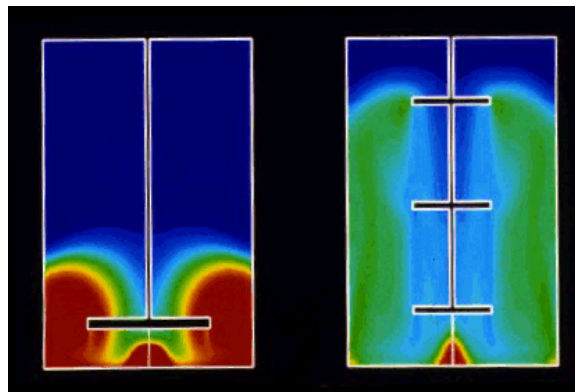


Effects of Flow Pattern on the Solids Distribution in a Stirred Tank

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The relation between the flow pattern and the spatial distribution of the solids in a stirred tank has been investigated. Both single impeller systems and multiple impeller systems were studied in tanks with a liquid level of up to 1.75 times the tank diameter, using pitched blade turbines and high efficiency impellers.

The solids distribution is strongly affected by certain flow transitions. When the impeller diameter and/or impeller-bottom clearance are too large, the flow direction at the bottom reverses, seriously hampering solids suspension.

Adding a second impeller does not decrease the just-suspended speed. A second impeller does increase the homogeneity of the suspension, provided that the spacing between the impellers is not too large.

Keywords: Mixing, Solids Distribution, Suspension, Computational Modeling, Stirred Tank.

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INTRODUCTION

Traditionally stirred tanks for solids suspension applications have been designed using the just-suspended impeller rotational speed N_{js} , as defined by Zwietering [1]. Although much work about solids suspension has been published, most of it concentrated on correlating N_{js} in a form similar to Equation (1):

$$N_{js} = s X^a D^{-b} \alpha_p^c \left(\frac{\rho_s - \rho_l}{\rho_l} \right)^d \left(\frac{D}{T} \right)^e \left(\frac{C}{T} \right)^f u_t^g \quad (1)$$

The proportionality constant s is assumed to be a function of impeller type only. Attempts to develop mathematical models for the solids suspension process are often based on the total power draw of the impeller or the average liquid velocity in the tank, without taking local effects into account.

The effect of the flow pattern on the spatial distribution of the solids has received relatively little attention. This relation is the topic of this paper. A variety of techniques is used including visual observation, streakline photography, and mathematical modeling. Both single impeller systems and multiple impeller systems are studied, using pitched blade turbines and high efficiency axial flow impellers.

Several tanks, ranging in size from 0.15 m diameter to 1.5 m diameter were used in the solids suspension studies. N_{js} , fillet volume and cloud height were all determined visually. Various solids were studied, with terminal settling velocities ranging from 1.3E-03 to 0.33 m/s.

Fluent V4 was used to calculate the single phase flow patterns. Experimental velocity data, obtained through laser Doppler velocimetry (LDV), were used as boundary conditions for the impellers.

SINGLE IMPELLER SYSTEMS

Two axial flow impellers were studied, a pitched blade turbine (P-4) and a high efficiency impeller (Chemineer HE-3), see Fig. 1. For both impellers the just-suspended speed, the cloud height and the fillet volume were measured for a variety of solids and various D/T and C/T ratios.

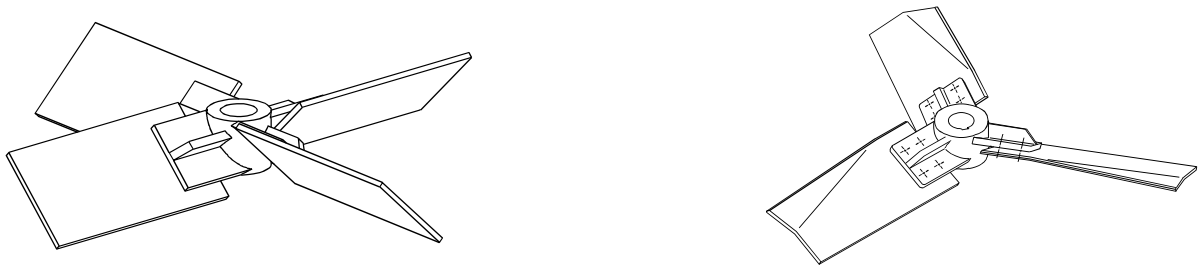


Figure 1 Four blade pitched blade turbine (P-4) and three blade high efficiency impeller (Chemineer HE-3).

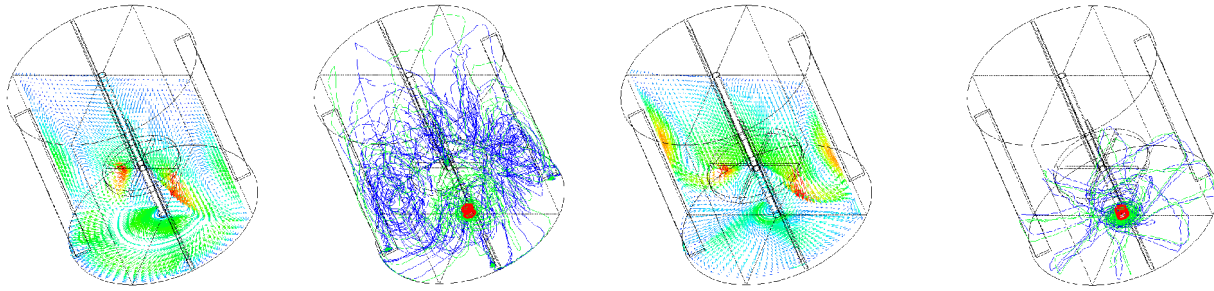


Figure 2a,b,c,d The effect of flow reversal with a P-4 impeller.

Provided that the C/T and/or D/T ratios are not too large, both types of impeller will generate an axial jet that sweeps the tank bottom of settled solids. This type of flow pattern is depicted in Figure 2a for a P4 impeller with $D/T=0.4$ and $C/T=0.33$. The flow at the bottom is mainly directed outward. The Fluent particle tracking model was used to study the movement of particles through the tank for this situation, see Figure 2b. The particles move throughout the whole tank, only temporarily settling in slow moving regions in the center of the tank and behind the baffles. Particles that settle behind the baffles are swept up by the vortex motion in this region, which is also visible in Figure 2b.

When the clearance and/or the impeller diameter are increased, a flow transition occurs, as shown in Figure 2c for a P-4 with $D/T=0.5$. The outflow of the impeller is now more radial and the jet from the impeller is directed towards the vessel wall. The flow direction at the tank bottom is reversed and is now directed inward, rather than outward as was the case with the axial flow pattern. Such a reversed flow at the vessel base was also found by Jaworski *et al.* [2], using laser Doppler Velocimetry. Also the velocities at the bottom are lower than with the axial flow pattern. As a result, complete solids suspension is much more difficult to obtain with this flow pattern. Figure 2d shows that now the solids mainly move around at the tank bottom, instead of being suspended throughout the vessel.

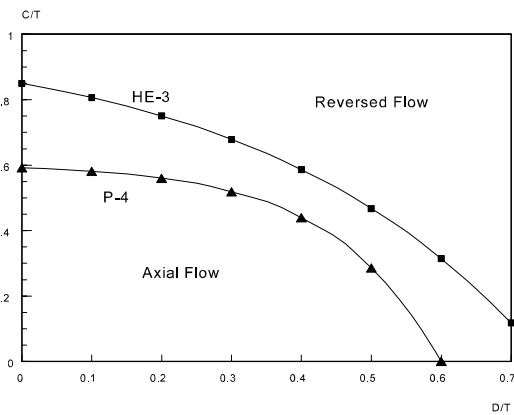


Figure 3 Flow regime as a function of C/T and D/T .

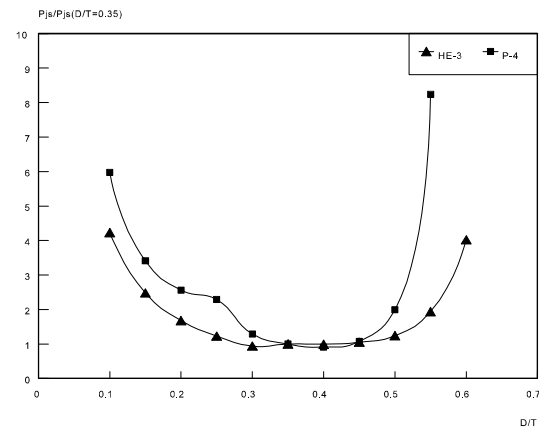


Figure 4 Power draw at just-suspended conditions vs. D/T . Power draw normalized with P_{js} at $D/T=0.35$.

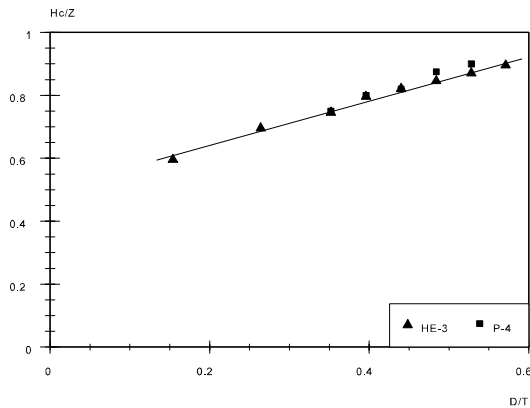


Figure 5 Cloud height H_c at N_{js} vs. D/T .

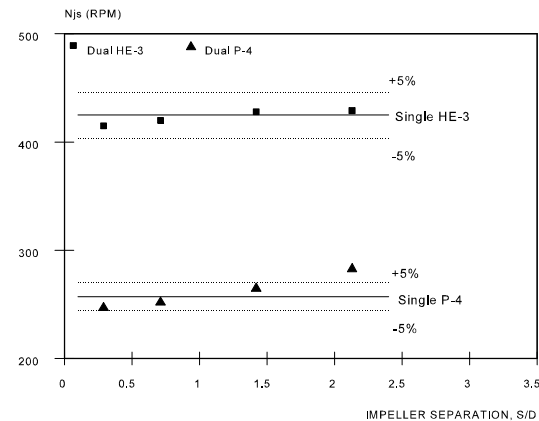


Figure 6 N_{js} (RPM) for dual impeller systems vs. impeller separation distance. Lines are for the single impeller systems. $T=0.29$ m; $D/T=0.35$; $C_l/T=0.25$; $X=3.33\%$; $U_i=0.077$ m/s.

This flow reversal causes an impractical increase in N_{js} , that can not easily be correlated with an equation of the form of Equation (1). For most solids suspension applications the impellers should therefore be operated in the axial flow regime. Figure 3 shows the flow regime of the impeller as a function of C/T and D/T . Notice that the HE-3 impeller can be used at larger values of C/T and D/T than the P-4, thus providing greater flexibility when designing a solid-liquid system.

Figure 4 shows the power draw at just-suspended conditions as a function of D/T ratio. Both the P-4 and the HE-3 have a minimum around $D/T = 0.35$. The just-suspended power draw increases at very small and very large D/T ratios. At small D/T ratios the velocities at the vessel base near the tank wall are too small to suspend the solids. When the D/T ratio is very large the outflow of the impeller becomes more radial and solids settle at the center of the vessel base. As a result, models that are only based on overall power draw of the impeller system will not be able to accurately predict the just-suspended speed and power draw.

Figure 5 (from [3]) shows the cloud height as measured visually at N_{js} as a function of D/T ratio. At just-suspended conditions, the cloud height increases with increasing D/T ratio. This shows that although N_{js} gives information about the events on the tank bottom, N_{js} is not directly related to the uniformity of the suspension.

MULTIPLE IMPELLER SYSTEMS

The effect of adding a second impeller on N_{js} was studied. Figure 6 (from [3]) shows that the effect of the second impeller is small and generally less than 5%. However, the second impeller can increase the uniformity of the suspension. Mak and Ruszkowki [4] obtained similar results for pitched blade turbines.

Figures 7a, 7b and 7c show the flow pattern in a tank with one HE-3 impeller, two HE-3 impellers with a spacing of $S = 3 D$ and a tank with two HE-3 impellers with a spacing of

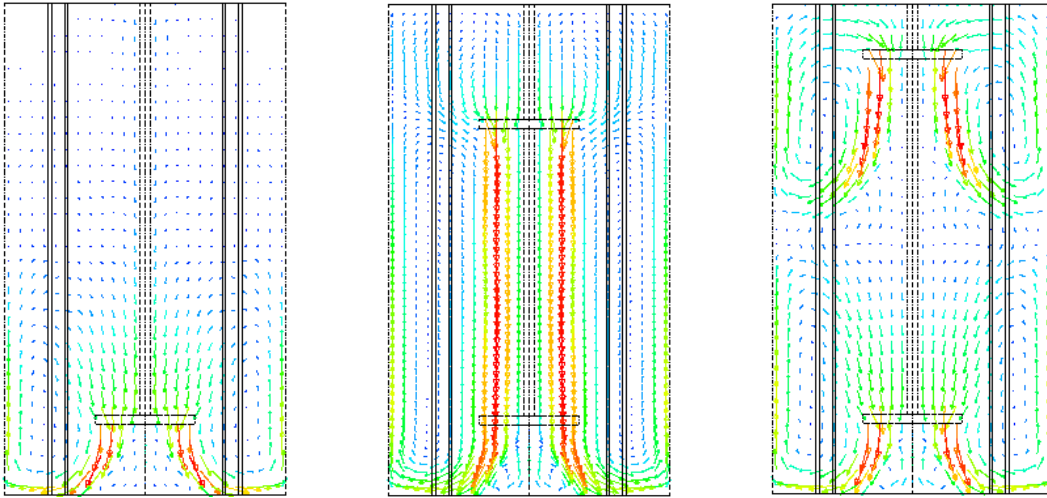


Figure 7a,b,c Simulated flow patterns for a single HE-3, a dual HE-3 system with a spacing of $S/D = 3$ and a dual HE-3 system with a spacing of $S/D=3.7$.

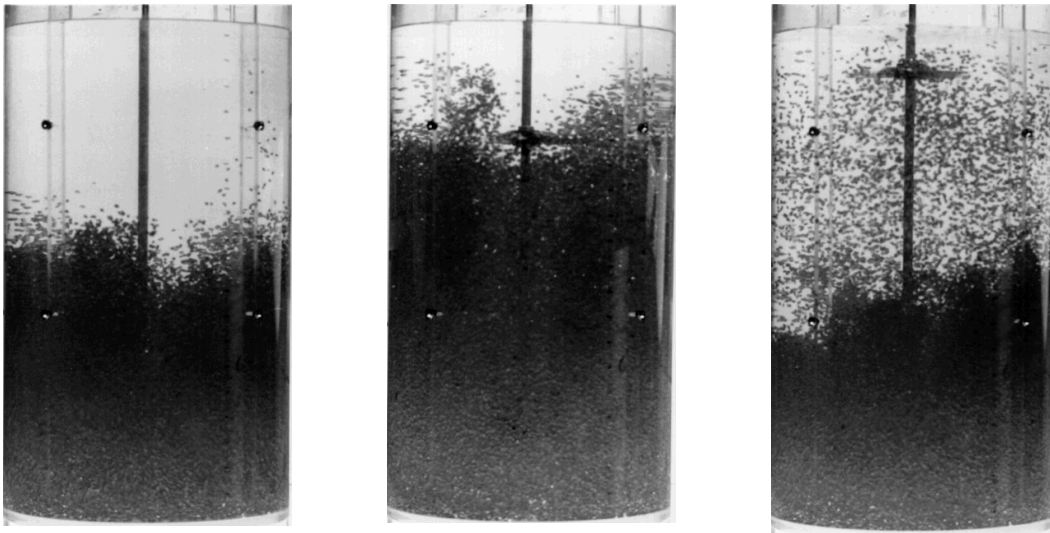


Figure 8a,b,c Experimental visualization of the solids concentration at the tank wall for the impeller systems of Figure 7.

$S = 3.7 D$. All three impeller systems have the same D/T ratio and draw the same power. The multiple impeller systems were operated at $N_{js} = 7.6 \text{ s}^{-1}$ and the single impeller system was operated at $1.27 N_{js} = 9.6 \text{ s}^{-1}$. Figure 7 shows that the single impeller generates one flow loop, extending about half the liquid level. The two impellers spaced at $S/D = 3$ generate one large flow loop. When the impeller spacing is increased to $S/D = 3.7$, the flow between the impellers separates and two flow loops are formed.

The flow pattern has a profound effect on the solids distribution in the tank. With the single impeller the solids do not move up higher than about half the liquid level, as shown in Figure 8a.

When a second impeller is added such that one long flow loop is formed, the solids reach the level of the second impeller, as shown in Figure 8b. When the second impeller is placed too far above the first impeller and zoning occurs, the solids do not reach the upper impeller. From the differences between the solids suspension performance of the three impeller systems it can be concluded that designing based on only N_{js} or on power draw does not necessarily lead to an optimum design. The impeller system has to be designed such that it provides the optimum flow pattern for the suspension duty to be performed.

CONCLUSIONS

The solids spatial distribution is strongly affected by certain flow transitions. When the impeller diameter to tank diameter ratio (D/T) and/or impeller off bottom clearance are too large, a flow transition with reversed flow directions at the vessel base may occur. This results in an impractical increase in the just suspended impeller speed N_{js} .

With respect to power draw, the optimum D/T ratio to achieve just-suspended conditions is around $D/T = 0.35$ for both the P-4 and the HE-3.

Adding a second impeller has a very small effect on the just suspended speed. In multiple impeller systems zoning occurs when the impeller separation distance is too large. It is found that the most efficient axial solids mixing occurs just before the flow between the impeller separates.

Designing on the basis of N_{js} or on the basis of power consumption does not necessarily lead to an optimum impeller system. To design an optimum impeller system the effects of the flow pattern on the solids distribution must be taken into account. Computer simulation provides an excellent tool to quickly study the effect of impeller system on solids distribution.

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NOTATION

C	Impeller off-bottom clearance	(m)
D	Impeller diameter	(m)
d_p	Particle diameter	(m)
H_c	Cloud height	(m)
N_{js}	Impeller rotational speed at just-suspended conditions	(s^{-1})
P_{js}	Impeller power draw at just-suspended conditions	(W)
s	Impeller dependent proportionality constant in N_{js} correlation	(-)
S	Impeller separation distance in multiple impeller systems	(m)
T	Tank diameter	(m)
u_t	Particle terminal settling velocity	($m s^{-1}$)
X	Solids mass fraction	(-)
Z	Liquid level	(m)
ρ_l	Liquid density	($kg m^{-3}$)
ρ_s	Solids density	($kg m^{-3}$)