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# ASSESSMENT OF THE MINIMUM POWER REQUIREMENTS FOR COMPLETE SUSPENSION IN TOP-COVERED UNBAFFLED STIRRED TANKS

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**Abstract.** Particle suspensions into liquids is a unit operation commonly encountered in industrial operations. Although it is usually carried out in *baffled* stirred tanks, there are some specific applications where the presence of baffles may be undesirable. As a consequence, in the present work solids suspension is investigated in an unbaffled tank provided with a top-cover in order to avoid the formation of the well known central vortex.
The minimum impeller speed at which all solid particles get suspended ($N_{js}$) as well as the relevant power requirements ($P_{js}$) are assessed. The dependence of these two parameters on particle physical properties (concentration and size) and system geometrical configurations (impeller diameter and clearance) is investigated.
Results show that a tank stirred by a D=T/3 six-bladed Rushton turbine offset by T/3 from tank bottom appears to be the most convenient configuration among those here investigated.
Present results are finally compared with literature information on solids suspension in baffled or unsteadily agitated unbaffled systems. In both cases, top-covered unbaffled stirred vessels are found to be the most convenient choice, at least for processes where mixing times are not a controlling factor.

**Keywords**: Complete suspension, power number, unbaffled stirred tanks, solid liquid suspension, mixing.

## 1. INTRODUCTION

Mechanically agitated vessels are widely employed for a variety of chemical processes involving particulate solids suspension. Many efforts have been devoted so far to assess the minimum impeller speed for guaranteeing the suspension of all solid particles, $N_{js}$ [1,2,3,4 and many others]. Most of these efforts have focused on stirred systems provided with baffles, although there are many applications, such as crystallization, precipitation processes, mixing within viscous fluids, biological and pharmaceutical processes, where the presence of baffles may lead to significant drawbacks [5,6].

The minimum impeller speed for complete suspension is not the most important parameter regarding solid-liquid suspensions within stirred tanks. As a matter of fact, minimum power requirements to achieve complete suspension conditions (power drawn at $N_{js}$, $P_{js}$ ) is more directly linked to operation costs.

In solid-liquid mixing operations it is essential to guarantee suspension of all the particles in order to enhance mass transfer processes as well as to minimize the mechanical power dissipation. As a consequence, the minimization of $P_{js}$ represents one of the main aims of an optimization procedure concerning solid-liquid suspension processes in stirred vessels [7].

Very little attention has been paid so far to the estimation of this parameter for tanks unprovided with baffles [7,8,9]. The present work is aimed at finding the optimal geometrical configuration (impeller diameter and clearance) able to provide the lowest value of $P_{js}$ for the case of a mono-dispersed particle suspension in a top-covered unbaffled tank stirred by six-bladed Rushton turbines.

## 2. EXPERIMENTAL

The experimental system consisted of a T=0.19m cylindrical flat bottomed baffled tank with a total liquid height (H) equal to T. Standard six-bladed Rushton turbines (D=T/3 or T/2) were used in the suspension experiments. Offset from vessel bottom (C) was either T/3 or T/10. Deionized water and silica particles were employed as the liquid and solid phases respectively. The influence of particle mean diameter ($d_p$) and concentration (B) was assessed by employing two different particle sizes (250-300μm or 600-710μm) and four different particle loadings (2.5%, 5%, 10% or 20% weight of solid/weight of liquid). The tank was provided with a top-cover in order to avoid the formation of the central vortex which characterizes unbaffled uncovered stirred tanks. The seal between top-cover and vessel was guaranteed by an o-ring gasket.

### 2.1 $N_{js}$ assessment

$N_{js}$ was assessed by the well known “one second criterion” [1]. A camera was placed underneath vessel bottom in order to collect a number of images (~20) at each impeller speed. According to Zwietering’s criterion, camera exposure time was set to one second so allowing to get images where moving particle were blurred while motionless particles were well defined. $N_{js}$ was defined as the minimum impeller speed at which only blurred particles were observable in all pictures. Employing the camera and the relevant collected images for the $N_{js}$ assessment largely reduces the subjectivity of the visual application of Zwietering’s criterion, as pointed out by Brucato et al. [7]. In that work the slightly different *Steady Cone Radius Method* (*SCRM*) was employed for the assessment of $N_{js}$ in the case of a top-covered unbaffled vessel stirred by a Rushton turbine with D=T/2 and C=T/3. In the present work, the different configurations investigated inhibited a general use of *SCRM*. As a consequence, the original Zwietering’s criterion (athough *picture assisted*) was employed here.

### 2.2 Mechanical power measurement

Power measurements were finally performed by assessing the torque transmitted by the impeller to the tank with the apparatus described in Grisafi et al. [10]. It is a “static-frictionless” turntable consisting of a granite dish able to rotate around its central axis on a granite table. The arrangement practically deleted the static friction between the surfaces, yet allowing the dynamic friction to be present in order to dump undesired torque fluctuations. The tank was placed on the granite dish in order to rotate integrally with it. This rotation (induced by the stirrer rotation during experiments) was hampered by a flexible nylon thread, tightly attached to the external vessel wall and connected by a pulley to a weight (of about 2 kg) which was placed upon an electronic scale. Practically, the torque exerted by the stirrer on the vessel was assessed by measuring the force acting on the flexible string in order to inhibit vessel rotation. This force was measured by subtracting the reading of the balance in agitation conditions from that observed without agitation (still stirrer).

## 3. RESULTS AND DISCUSSION

For each geometrical configuration the dependence of $N_{js}$ and of $P_{js}$ on particle concentration B was investigated. In the followings the $N_{js}$ and $P_{js}$ results found in this work for top-covered unbaffled tanks are compared with results (in the form of relevant correlations) concerning either baffled tanks or unsteadily operated unbaffled vessels.

The dependence of $N_{js}$ on solids concentration B for D=T/3 Rushton turbine offset by 1/3 from vessel bottom (small-impeller/large-clearance case) is shown in Figure 1A. $N_{js}$ slightly increases as average solids concentration increases, as expected. In particular $N_{js}$ is approximately proportional to $B^{0.13}$, the same dependence predicted by Zwietering's correlation for the case of baffled vessels, whose predictions are also reported in the same graph for the sake of comparison. Notably, a quite similar dependence ($N_{js} \propto B^{0.10}$) was found by Tezura et al. [8] for the case of the unsteadily stirred unbaffled tank. As it can be seen, present $N_{js}$ values are significantly lower than those pertaining to the baffled and the unsteady-unbaffled tanks.

Interestingly, as already found by Brucato et al. [7] in the case of a top-covered unbaffled vessel stirred by Rushton turbine with D=T/2 and C=T/3, the dependence of $N_{js}$ on particle mean diameter appears to be rather small if not nil, as can be deduced observing the two data sets for 275 and 675 μm size. This clearly suggests that unbaffled tanks may be particularly convenient for supending large particles.

The $P_{js}$ values relevant to Fig.1A are reported in Figure 1B. These values are found to be well above an order of magnitude lower than the corresponding $P_{js}$ values for both baffled and unsteadily-unbaffled systems. This may be due to the different suspension mechanisms involved: for baffled and unsteadily stirred unbaffled vessels the suspension phenomenon is linked to velocity/pressure turbulent fluctuations near tank bottom, while for steadily agitated unbaffled vessels it might rather be linked to fluid mean velocities near tank bottom.

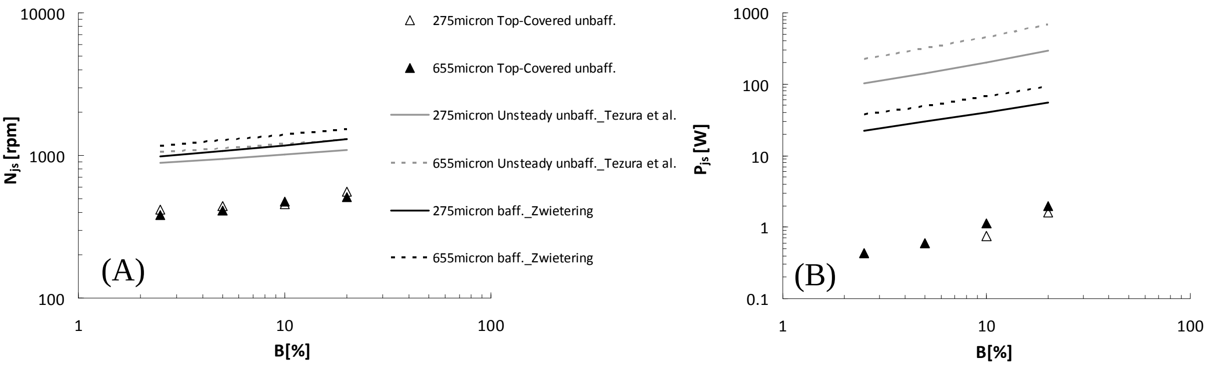

**Figure 1**: Rushton turbine with D=T/3 and C=T/3. (A) $N_{js}$ vs B; (B) $P_{js}$ vs B.

As concerns the data obtained with the lower impeller clearance (C=T/10, small-impeller/small clearance case), these are reported in Figure 2. As it can be seen, the difference between the collected $N_{js}$ values and those pertaining to baffled and unsteady-unbaffled systems is greatly reduced: the collected $N_{js}$ values are found to be fairly lower than those pertaining baffled system (as predicted by Armenante et al. correlation [2]) and comparable-to-larger than those predicted by the Tezura et al. correlation [8] for the case of the unsteady-unbaffled system. For the case of baffled vessels $N_{js}$ is much lower at C=T/10 with respect to C=T/3 (Armenante et al. [2]), a feature possibly due to the flow pattern transition from double to single loop. Similarly, a reduction of $N_{js}$ with impeller clearance was found by Tezura et al. [8] for unsteady-unbaffled systems. As a difference, by comparing Figs 1A and 2A, one can see that for the case of this impeller (D=T/3) at the lowest impeller clearance higher $N_{js}$ values are found. Relevant $P_{js}$ values are reported in Fig. 2B, where it can be seen that they still are much lower (by about one order of magnitude) than those pertaining to the other two systems. Notably, as a difference from the C=T/3 case, a non negligible dependence of $N_{js}$ on particle size is found at C=T/10.

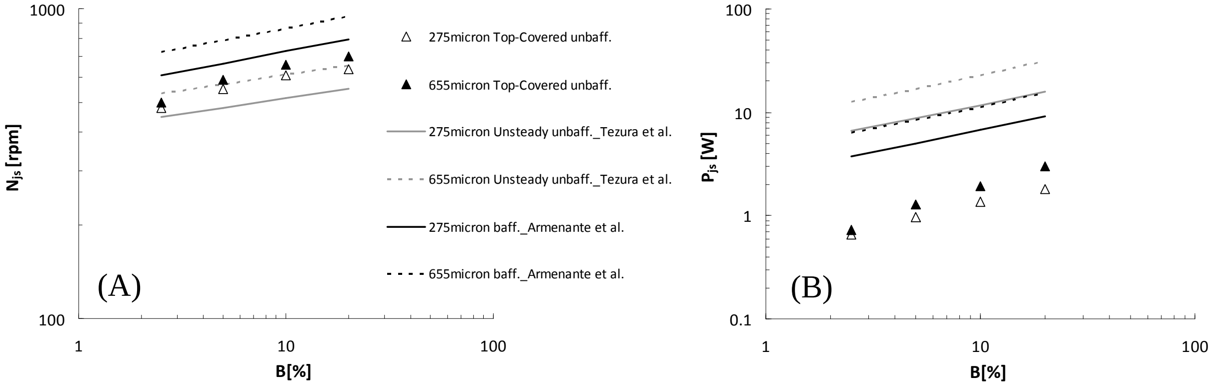

**Figure 2**: Rushton turbine with D=T/3 and C=T/10. (A) $N_{js}$ vs B; (B) $P_{js}$ vs B.

Results relevant to the Rushton turbine with D=T/2 and C=T/3 (large-impeller/large-clearance case) are shown in Figure 3. As already observed for the case of the Rushton turbine with D=T/3 and C=T/10, although all the $N_{js}$ values are quite similar, the $P_{js}$ required by the top-covered unbaffled systems are largely lower the corresponding $P_{js}$ relevant to both unsteadily-unbaffled and baffled systems, due to the smaller power number exhibited by unbaffled systems with respect to baffled tanks.

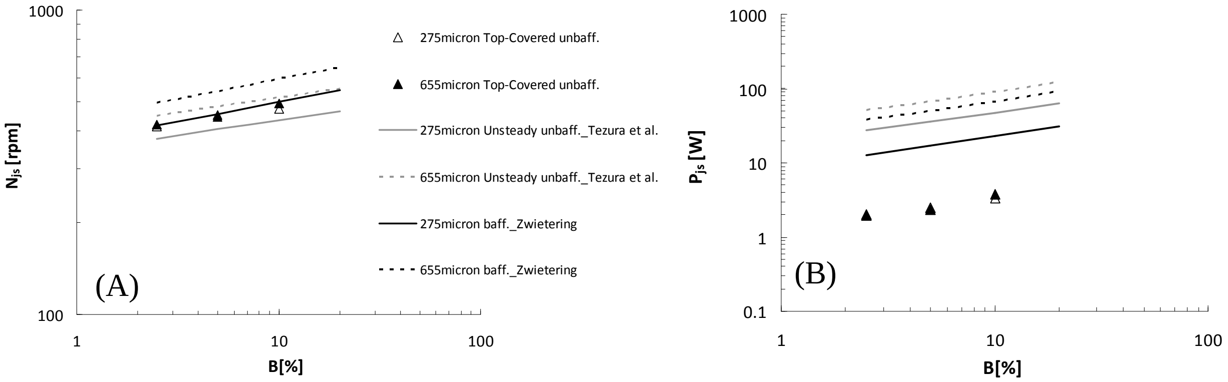

**Figure 3**: Rushton turbine with D=T/2 and C=T/3. (A) $N_{js}$ vs B; (B) $P_{js}$ vs B.

As far as the large-impeller/low-clearance case (D=T/2, C=T/10) is concerned, the dependence of $N_{js}$ on B% appears to be somewhat lower ($N_{js} \propto B^{0.07}$) than that in the case of baffled and unsteadily-agitated unbaffled tanks, as it can be observed in Fig.4A. As a difference from the D=T/3 impeller, the $N_{js}$ values obtained for the case of the top-covered unbaffled vessels are smaller than those pertaining to the larger clearance (Figure 4A). However, this reduction is much smaller than that exhibited by both baffled and unsteadily-stirred tanks, thus leading to larger $N_{js}$ values with respect to these systems. Nevertheless, in Figure 4B the relevant $P_{js}$ values are lower than in baffled and unsteadily agitated tanks, although with a smaller gap in comparison with the other impeller-tank configurations.

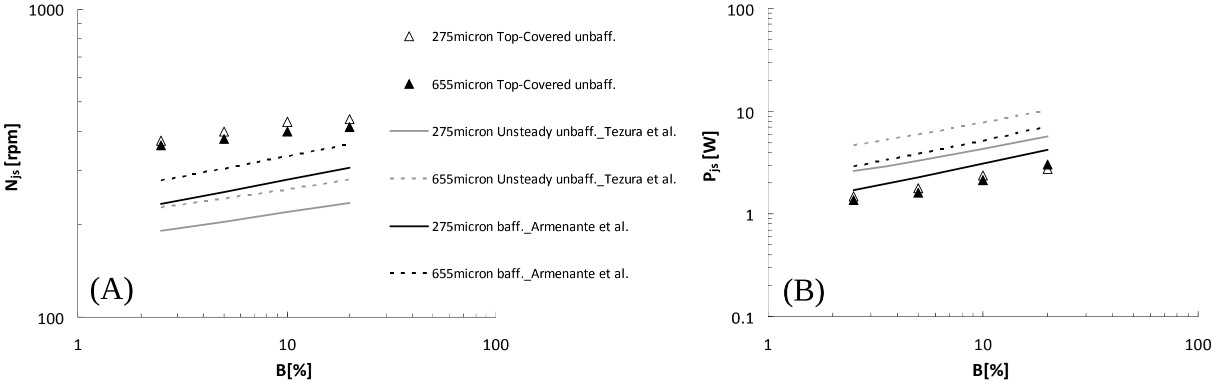

**Figure 4**: Rushton turbine with D=T/2 and C=T/10. (A) $N_{js}$ vs B; (B) $P_{js}$ vs B.

Results obtained for the smaller particles with the four different configurations here investigated are compared with each other in Figure 5. As far as $N_{js}$ results are concerned, it can be seen that the Rushton turbine with D=T/3 and C=T/10 requires the highest agitation speeds to suspend all solid particles, while the larger impeller with the same offset from vessel bottom provides the best results (Figure 5A).

However, Figure 5B shows that although large impellers exhibit lower $N_{js}$ values, they require larger power requirements to be operated. Quite surprisingly, the smaller-size/larger-clearance case (D=T/3, C=T/3) comes out to be the best option among the four geometrical configurations here investigated

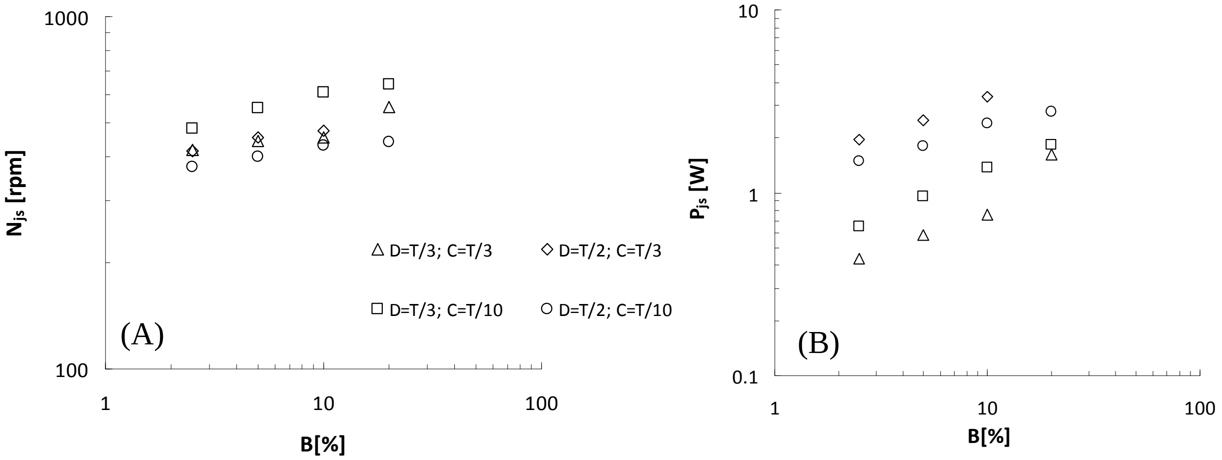

**Figure 5**: Comparison among the four different Rushton turbines employed for the 250-300μm suspension case: (A) $N_{js}$ vs B; (B) $P_{js}$ vs B.

## 3. CONCLUSIONS

Silica particle water suspensions in an unbaffled tank stirred by Rushton turbines were investigated. The tank was provided with a top cover in order to avoid the central vortex formation, typical of uncovered unbaffled stirred tanks.

The minimum impeller speed for complete suspension ($N_{js}$) as well as the relevant power consumption ($P_{js}$) were measured for four different system configurations (small/large impeller - small/large impeller clearance). Influence of particle size ($d_p$) and concentration ($B$) on these two parameters was also investigated. Results were compared with the corresponding $N_{js}$ and $P_{js}$ values pertaining to an identical tank either unsteadily operated or provided with baffles. Results show that the dependence of $N_{js}$ on $B$ is similar to that predicted by Zwietering's correlation for baffled vessels, while a smaller dependence on $d_p$ was found.

Present work findings suggest that, for all processes where mixing time is not the controlling factor, a top-covered unbaffled tank stirred by a Rushton turbine with D=T/3 and C=T/3 may be regarded as a particularly convenient choice for solid-liquid suspension operations.

## 4. REFERENCES

[1] Zwietering T. N., 1958. “Suspending of solid particles in liquids by agitators”, *Chem. Eng. Sci.*, **8**, 244-253.

[2] Armenante, P.M., Nagamine, E.U., Susanto, J., 1998. “Determination of correlations to predict the minimum agitation speed for complete solid suspension in agitated vessels”, *Can. J. Chem. Eng.*, **76**, 413-419.

[3] Ibrahim, S. and Nienow, A.W., 1996. “Particle suspension in the turbulent regime: the effect of impeller type and impeller/vessel configuration”, *Chem. Eng. Res. Des.*, **74**, 679-688.
[4] Wong, C.W., Wang, J.P., Huang, S.T., 1987. “Investigations of fluid dynamics in mechanically stirred aerated slurry reactors”, *Can. Jour. Chem. Eng.*, **65**, 412-419.
[5] Assirelli, M., Bujalski,W., Eaglesham, A., Nienow, A.W., 2008. “Macro- and micromixing studies in an unbaffled vessel agitated by a Rushton turbine”, *Chem. Eng. Sci.*, **63**, 35-46.
[6] Pacek, A. W., Ding, P., Nienow, A.W., 2001. “The effect of volume fraction and impeller speed on the structure and drop size in aqueous/aqueous dispersions”, *Chem. Eng. Sci.*, **56**, 3247-3255.
[7] Brucato, A., Cipollina, A., Micale, G., Scargiali, F., Tamburini, A., 2010. “Particle suspension in top-covered unbaffled tanks”, *Chem. Eng. Sci.*, **65**, 3001-3008.
[8] Tezura, S., Kimura, A., Yoshida, M., Yamagiwa, K., Ohkawa, A., 2007. “Agitation requirements for complete solid suspension in an unbaffled agitated vessel with an unsteadily forward–reverse rotating impeller”, *Jour. Chem. Technol. Biotechnol.*, **82**, 672-680.
[9] Tamburini, A., Cipollina, A., Micale, G., Brucato A., 2011. “Dense solid-liquid suspensions in top-covered unbaffled stirred vessels”, *Chem. Eng. Trans.*, **24** , 1441-1446.
[10] Grisafi, F., Brucato, A., Rizzuti, L., 1998. “Solid–liquid mass transfer coefficients in gas–solid–liquid agitated vessels”, *Can. J. Chem. Eng.*, **76**, 446-455.