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PERFORMANCE OF A GAS DISPERSION IMPELLER WITH VERTICALLY ASYMMETRIC BLADES

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Gas dispersion impellers, such as the Rushton turbine and the more recent concave blade turbines, all feature blades that are symmetric with respect to the plane of the disc. This despite the fact that the gas usually enters from the bottom, and thus causes a flow pattern that is distinctly asymmetric. This article discusses the performance of a gas dispersion impeller with blades that are vertically asymmetric, i.e. the blade shape above the disk is different from the shape below the disk. It is shown that this impeller has a gassed power curve that is flatter than that of other impellers. Furthermore, it can disperse more gas before flooding than the impellers with symmetric blades.

Keywords: gas dispersion impellers; Rushton turbine; concave blade turbine; asymmetric blades

INTRODUCTION

For several decades the so-called Rushton turbine was the standard impeller for gas dispersion applications. It features six flat blades mounted on a disc. Van't Riet[1] studied a variety of impeller styles, and introduced the concept of using concave blades. Warmoeskerken and Smith[2] extended that work and explained the improved performance of the concave blades compared to flat blades in terms of reduced cavity formation behind the blades. Impellers with a semicircular blade shape are now common in the industry, e.g. the Chemineer CD-6 (Bakker *et al.*[3]). Relatively recent, new blade designs with a deeper concavity have been proposed by Hjorth[4] and Middleton[5]. Saito *et al.*[6] studied the performance of such impellers, and found that under most conditions with these deeper blades the gas is being dispersed from the inside of the blade, instead of from large cavities behind the blade.

All of the disc-style gas dispersion impellers studied in the literature so far have blades that are symmetric with respect to the plane of the disc. This is not necessarily optimal, as the gas usually enters from the bottom, causing a distinctly asymmetric flow pattern. This paper discusses the performance of a new gas dispersion impeller with vertically asymmetric blades. The new impeller is designed to accommodate the different flow conditions above and below the impeller disc. The blade shape was optimized in a comparative study of more than twenty different geometries, see Meratla[7] and Thomas[8]. The details of these studies will not be reiterated here. Instead only the main results will be discussed.

EXPERIMENTAL

Results are reported here for the BT-6, PD-6, D-6, and CD-6 impellers. The D-6 and CD-6 are of standard design (Bakker *et al.*[3]). The BT-6 (Bakker[9]) is a new, commercially available, impeller design with vertically asymmetric blades shown in Figure 1. The BT-6 results reported here are for a nominal blade depth of 0.22 D and blade length of 0.3 D. The PD-6 is not a standard design and is not commercially available. It is a close copy of the designs by Hjorth[4] and Middleton[5]. It has a deep elliptically shaped blade that, unlike the BT-6, is symmetric with respect to the plane of the disc. It has a blade depth similar to that of the BT-6. Thus performance differences between the PD-6 and BT-6 will be mainly due to the difference in blade shape (symmetric vs. asymmetric). For all impellers, the nominal blade height was 0.2 D and the nominal disc diameter was 0.68 D.

The impeller performance was studied based on gassed and ungassed power draw measurements in vessels of 0.44 m, 0.60 m, and 1.52 m in diameter. In addition, flow visualization experiments, visual gas holdup measurements and dynamic mass transfer experiments were carried out. The dynamic mass transfer measurements were performed using the method described by Bakker[10] which includes the effects of oxygen probe response time and gas residence time.

In all experiments, the vessels were equipped with four flat baffles with a width of *T*/12 and a clearance with the wall of approximately *T*/72. The impellers were mounted at an off-bottom clearance of *T*/4. Impeller *D*/*T* was varied between 0.3 and 0.5.

A ring sparger was mounted below the impeller to introduce the air. The superficial gas velocity was varied between 0.007 and 0.07 $\mathrm{m\,s^{-1}}$. The impeller power draw was determined from the rotational speed and the torque; the latter being measured by means of a strain gauge on the shaft. Impeller power input was varied between 400 and 4000 $\mathrm{W\,m^{-3}}$. Water, aqueous glycerin, and aqueous corn syrup were utilized as test fluids for the study. The liquid viscosity varied between 0.001 Pa s and 99 Pa s, resulting in a Reynolds number range of 10 to 200,000. The gas handling capability of the impellers was studied by determining the complete dispersion point, which is the

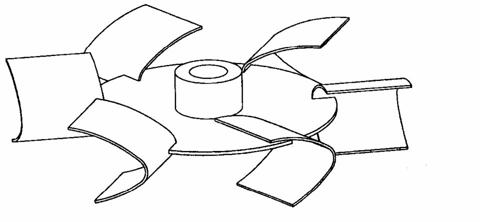

Figure 1. The BT-6 impeller with vertically asymmetric blades. The impeller shown is designed to rotate clockwise, when viewed from the top.

condition at which the air is driven to the wall and recirculated downwards, see Nienow[11]. More experimental details are available in Thomas[8].

RESULTS

The asymmetric blade impeller (Chemineer BT-6) is shown in Figure 1. The blades have a concave shape, which consists of three curves of different radii and length. The top part of the blade is longer than the bottom part. The back side of the blade is rounded, as opposed to the designs proposed by Hjorth[4] and Middleton[5], each of which have a sharp back edge. Visualization studies showed that gas is captured under the top overhang, and is dispersed from a deep vortex on the inside of the blade. No large gas filled cavities were observed behind the blade.

The ungassed power number of the BT-6 is plotted as a function of Reynolds number in Figure 2. It is compared with that of the CD-6 which has semi-circular blades, and the D-6 (or Rushton turbine) which has flat blades. The ungassed turbulent power number of the BT-6 is 2.3, which s lower than those of the other impellers. The CD-6 has a ully turbulent power number of approximately 2.8, and the D-6 has a fully turbulent power number of approximately 5.5, both depending on scale and the exact geometry. Although the power number of the CD-6 is relatively independent of impeller Reynolds number for Reynolds numbers greater than 200, its power number is ten percent higher than its fully turbulent value for Reynolds numbers between 1000 and 20,000. Conversely, the power number of the D-6 is only 75 percent of its fully turbulent value at impeller Reynolds numbers near 1000, and 60 percent of its fully turbulent value at impeller Reynolds numbers near 100. For impeller Reynolds numbers greater than 600, the power number of the BT-6 is essentially constant, varying by less than five percent from its fully turbulent value. Thus, the performance of this impeller will be less affected by changes in liquid viscosity during a typical industrial process. Therefore, design for processes with changing viscosity is inherently simpler than with other impellers since the power draw will remain constant. The lower power number of the BT-6, and its limited dependence on Reynolds number, is thought to be due to reduced flow separation on the back side of the blade.

The gassed power draw of the BT-6 is shown in Figure 3. It is again compared with power draw curves for the CD-6 and the D-6. It is clear that the relative gassed power draw of the asymmetric blade BT-6 impeller is significantly higher than that of the other impellers. It does not drop below 80 to 90% of the ungassed power draw, depending on the Froude number. This is of significant advantage, because most industrial agitators are designed to draw approximately 80% of the rated motor power under operating conditions. With the asymmetric blade impeller, the motor will not overload when the gas flow is accidentally interrupted, and no expensive dual speed or variable speed equipment is needed.

In Figure 4, the gas handling capability of the asymmetric blade impeller is compared with that of the D-6, CD-6, and the PD-6, which has deep concave blades that are symmetric with respect to the plane of the disk. The figure shows averages of many experiments in which the amount of air at the complete dispersion point was determined for a given geometry and impeller speed. All impeller comparisons were retrofit comparisons, where the impellers operate at the same speed, but have a different diameter to obtain an equal power draw and torque. The results show that on average the asymmetric blade BT-6 impeller can disperse more than five times as much air as the D-6, more than twice as much as the CD-6, and 68% more than the impeller with deep symmetric blades (PD-6).

In the comparison of Figure 4, the *D/T* ratio varied because of the different power numbers. There are

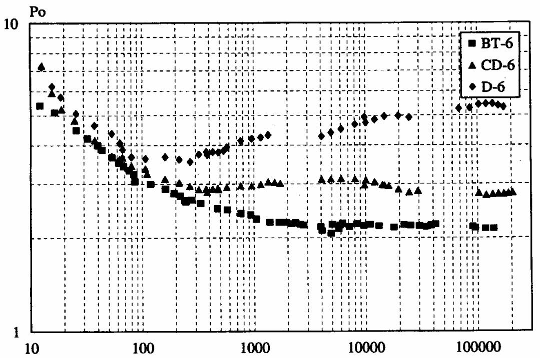

Figure 2. Impeller power number vs. Reynolds number curves for the BT-6, he CD-6 (semi-circular blades), and the D-6 (flat blades) impellers.

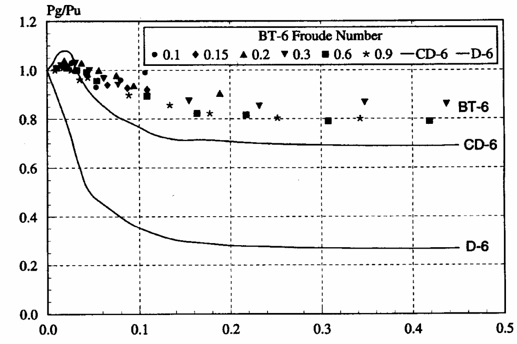

Figure 3. Relative gassed power draw as a function of the gas flow number and Froude number for the BT-6 impeller. Power draw curves at $Fr = 0.9$ are shown for the D-6 and CD6 impellers.

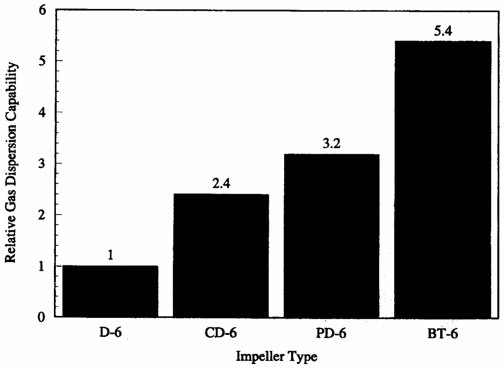

Figure 4. Gas dispersion capability relative to the D-6 impeller for the BT-6, PD-6 (deep concave, symmetric blades), and CD-6 impellers.

indications in the literature that large *D/T* impellers are more efficient for dispersing gas than impellers with a lower *D/T* (Nienow[12]). Indeed, when the impellers were compared at equal *D/T* and power input, the differences were smaller. Nevertheless, the general conclusions of the study remained the same as before; the relative gas-handling capabilities of the D-6, CD-6, PD-6, and BT-6 being 1, 1.73, 2.05, and 3.65, respectively.

Preliminary mass transfer studies indicate that in turbulent air-water systems for a given power draw and air flow rate, and under conditions where all impellers can disperse the gas, the mass transfer rate with the BT-6 is similar to that of the other impellers. However, because of the flatter power curve, this will result in a significant mass transfer advantage for systems where the agitator is designed to be fully loaded under ungassed conditions. Mass transfer under conditions where not all impellers are capable of dispersing the gas will be the subject of future studies.

CONCLUSIONS

It is concluded that gas dispersion performance of disc style impellers can be significantly improved by using deep blades that are vertically asymmetric. An overhang on the top of the blade captures the rising gas flow, which is then dispersed from the inside of the blade. No gas filled cavities were observed behind the blades. Because of the relatively flat power curves of this new impeller, it is ideally suited for applications in which the gas flow rate and liquid viscosity are not constant during the process.

NOMENCLATURE

D	impeller diameter, m
Fl_g	gas flow number Q_g/ND^3, (–)
Fr	Froude number N^2D/g, (–)
g	acceleration of gravity, $\mathrm{m\,s^{-2}}$
N	impeller rotational speed, $\mathrm{s^{-1}}$
P_g	impeller power draw under gassed conditions, W
P_u	impeller power draw under ungassed conditions, W
Q_g	gas flow rate, $\mathrm{m^3\,s^{-1}}$
Re	impeller Reynolds number, $(\rho ND^2/\eta)$, (–)

Greek letters

η	liquid viscosity, Pa s
ρ	liquid density, $\mathrm{kg\,m^{-3}}$

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