Fluid Flow Characteristics of Regular and Modified Blade Impellers

K. Steiros, Department of Aeronautics, Imperial College London, London, U.K.
P. J. K. Bruce, Department of Aeronautics, Imperial College London, London, U.K.
O. R. H. Buxton, Department of Aeronautics, Imperial College London, London, U.K.
J. C. Vassilicos, Department of Aeronautics, Imperial College London, London, U.K.

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Long Abstract

Stirred tank reactors are widely used by pharmaceutical, chemical and food industries in a variety of industrial applications that require highly turbulent flows, examples being homogenizers, emulsifiers and colloidal mills amongst others. In recent years research has been centred on modifying the impeller blades' shape, in order to achieve higher mixing efficiency (i.e. increased turbulence intensity with lower power injection) [3,4]. In this study, we investigate experimentally the flow fields produced by a flat blade turbine and four modifications (fig. 1) in an octagonal unbaffled tank (diameter $T = 0.45$m) and their power injection to the flow. The modifications include fractal blade impellers with one and two iterations, after the design of Nedic et. al [1]. This was done because recent wind tunnel experiments [1] have shown that, compared to square plates of same frontal area, fractal plates produce turbulent wakes with higher turbulence intensities, higher local Reynolds numbers and weaker vortex shedding, and are therefore promising for dynamic mixing applications. Also tested are impellers with perforated and slotted blades, as they have been shown to be possible alternatives to standard blades, by the antibiotic production experiments and RANS simulations of [4] and [3] respectively. All tested blades have the same frontal area.

Shaft torque and rotational speed were monitored for the three cases, using an in-line torquemeter, to determine the power number N_p (injected power non-dimensionalised with the turbine diameter D, the angular velocity N of the shaft and the density of the fluid ρ) for a range of Reynolds numbers from $50,000$ to $250,000$ (fig. 2). Comparison of the regular blades $N_p - Re$ curve with the formula of Furukawa et al. [2] showed that the results follow the expected trend, but are around 5% higher than the predicted values. This difference is attributed to the octagonal shape of the tank, since corners provide a baffling effect thus increasing power consumption. Regular and slotted blades have the highest power number values, being around 12% higher than fractal blades with one iteration, and around 17% higher than fractal blades with two fractal iterations, a result which is qualitatively different to the conclusions of the static experiments of [1].

Phase-locked PIV in the discharge region of the blades was performed to investigate the differences in the tip vortices emanating from the blades for $Re = 150,000$. The results show a direct connection between the energy input of the different impellers and the vortices: Regular and slotted blades create stronger and more coherent vortices compared to the other blades. An example of this can be seen in fig. 3.

In order to assess the mixing efficiency of the rectangular and the modified blades, turbulence intensity levels were measured using Planar PIV in the bulk of the tank. Fractal and perforated blades have higher turbulence intensity levels by over 15% compared to regular blades (fig. 4), showing that these modifications can find usage in industrial applications.

References

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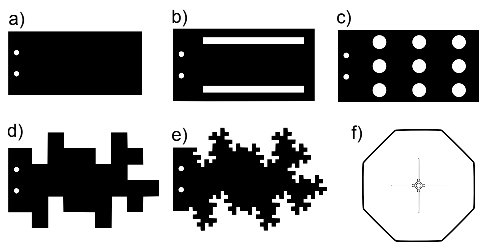

Figure 1. a) Regular-rectangular blades, b) slotted blades, c) perforated blades, d) fractal blades with one fractal iteration and e) fractal blades with two iterations. All blades have the same area. f) Horizontal cross section of the tank and the impeller.

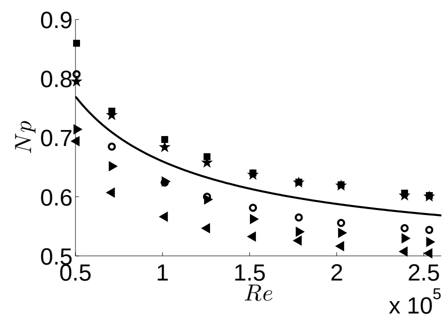

Figure 2. Variation of the power number, N_p, with Reynolds number for the different blades tested: ■ regular, ★ slotted, ∘ perforated, ▶ fractal1 and ◀ fractal2 blades. Also plotted is the correlation relation of Furukawa et al. [] for regular-rectangular blades.

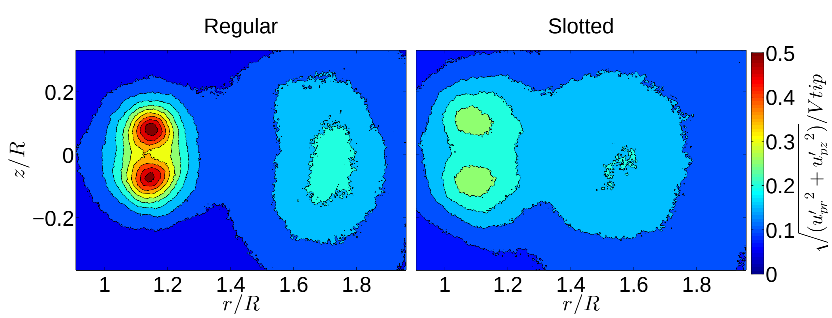

Figure 3. Contour plots of the phase-locked turbulence intensity at the impeller stream, measured via PIV for Re=150,000. The phase is 30° after the blade passage.

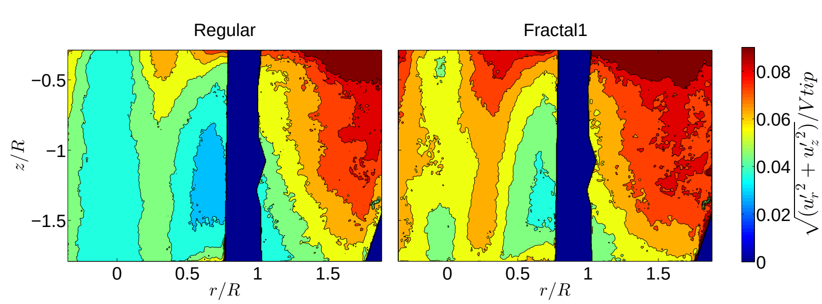

Figure 4. Contour plots of the turbulence intensity at bulk of the tank, measured via PIV for Re=150,000. The phase is 30° after the blade passage. The blue fields are areas were the camera view was blocked.