PIV measurements in a shaken cylindrical bioreactor

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This study aims at characterising the flow occurring inside a cylindrical shaken bioreactor by means of phase-resolved PIV. 2D PIV measurements of the flow were obtained on a vertical plane bisecting the cylindrical bioreactor into two sections. The green diode laser, \( \lambda = 532 \text{ nm} \), and an intensified Dantec camera were rigidly mounted on the shaker table. A magnetic encoder was placed inside the Kühner shaker table, Lab LS-X, to be able to determine the position of the tray at any instant throughout its orbital trajectory. Experiments were carried out for orbital diameters \( d_o = 2.5 \) and \( 5 \) cm with a cylindrical reactor of internal diameter \( d_i = 10 \) cm. One of the major challenges that had to be faced during these experiments was due to the movement of the free surface, with problems related to the PIV adaptive cross correlation. Image analysis was carried out on PIV images seeded with silver coated hollow particles to determine the inclination of the free surface. This allowed to mask the images before they were post-processed. An example of the free surface inclination is given in Figure 1 for \( N = 60 \text{ rpm} \). It should be noted that at low speed, \( N < 110 \text{ rpm} \) the flow is in phase and the free surface inclination is constant, while at higher speed a wavy profile is observed. To minimise reflections at the free surface and at the cylinder walls rhodamine seeding particles along with an orange filter placed on the camera were employed. The Froude number, \( Fr \), which is defined in equation 1, was varied 0.025 \(< Fr < 0.3 \).

\[
Fr^2 = \left( \frac{2(\sigma N^2)}{d_o} \right) \frac{d_o}{g}
\]  

(1)

where \( d_o \) is the orbital diameter, \( g \) the gravitational acceleration, and \( N \) the shaker rotational speed. The velocity vector field and the contour plot of the tangential vorticity are shown in Figure 2 for \( h/d = 0.3 \), \( N = 70 \text{ rpm} \), \( d_o/d_i = 0.5 \) and phase angle, \( \phi = 0^\circ \). Two counter-rotating vortices are clearly present below the inclined free surface. The results show that these vortices increase in size as the rotational speed is increased until they extend to the bottom of the cylinder. Further increase of \( N \) results in a different flow pattern. The vortical structures shown in Figure 2 are in agreement with those found by the CFD simulation of Kim and Kizito (2009).

Figure 1: Instantaneous snapshot of the free surface inclination, \( N = 60 \text{ rpm}, d_o/d_i = 0.25 \).

Figure 2: Phase resolved vector field and contour plot of the tangential component of the vorticity, \( \omega_t \), for \( h/d = 0.3 \), \( N = 70 \text{ rpm}, d_o/d_i = 0.5 \) and \( \phi = 0^\circ \).

Reference: