Volumetric flow studies in a 4-stroke water-analogue IC-engine using high-speed scanning-PIV

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Experiments are carried out in a water analogue 4-stroke internal combustion engine (ICE) with 4 fully variable intake and outlet valves. Due to the incompressibility of the fluid only the intake stroke is determined. The main test rig, provided by Volkswagen AG, allows the investigation of different opening cycle’s equivalent to the different load cases of a real engine in a short period of time. For a reproducible ignition a constant rotational flow structure with its axis perpendicular to the cylinder axis, the so called tumble flow, is of great importance.

High-resolution scanning is used to measure a full 3D-field at sufficient spatiotemporal resolution. A high-speed Nd:YLF-LASER in combination with a rotating polygon mirror generates 100 parallel and partially overlapping light sheets per volume at 10 kHz. Each light-sheet has a shift of 0.5mm. The light sheet images are recorded by a Phantom 12.1 running at 10,000 fps with a resolution of 960 x 600 pixels. This leads to an illuminated volume of about 50 mm in scanning direction. This volume can be reconstructed using a so called stacking technique and then be analysed by 3D Least Squares Matching (LSM) to retrieve the velocities as well as the velocity gradient matrix.

2D flow studies show a shift of the tumble centre, as shown in The measurements show a shift of the tumble centre as well as weakened tumble strength during the piston stroke (see Fig. 1). Hence, the fully developed flow consists of different vortices interacting with the characteristic tumble flow, it is important to investigate fully time resolved 3D data.

An overview of the 3D-flow within the lower cylinder section is shown in Fig. 2. The time resolved image from 150° CAD shows the velocity magnitude normalized by the piston speed on the slices. The iso-surface shows constant value of the Vorticity, representing the tumble centre. Interestingly the three dimensional centre has not cylindrical shape, as expected. It is rather a cylinder bended to a u-profile with its ends facing to the cylinder head.

![Image](image_url)

**Fig. 1** Absolute flow velocities plotted through the cross section of the cylinder at the height of the tumble centre. Suddenly dropping and rising velocities indicate vortices as well as the tumble centre. The tumble centre gets shifted to the right as the crank shaft angle increases.

**Fig. 2** Overview of the 3D in-cylinder flow field at 160° CAD. The slices indicate the velocity magnitude normalized by the piston speed. The blue iso-surface shows a constant Vorticity indicating the tumble centre, also highlighted by stream traces.

The experiments show a deformation of the tumble at higher crank shaft angles, as Fig. 2 indicates. The tumble forms a u-profile shape, as the tumble starts interacting with the cylinder walls. The friction at the walls leads to a slowdown from the tumble ends. As the kinetic energy of the tumble diminishes, the u-like shape is formed.

This deformation has negative influence energy conservation during the compression stroke.