X-RAY BASED FLOW VISUALIZATION AND MEASUREMENT - APPLICATION IN MULTI-PHASE FLOWS

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A new non-intrusive method, which enables to measure the three-dimensional velocity of the liquid and the solid phase in a volume, is described here. The method works independently of the solid and void fraction.

INTRODUCTION

Multi-phase flows occur in many industrial applications. Examples are bubble columns and loop reactors which are used in biomedical and chemical engineering. However, the flow phenomena are not yet completely understood for lack of measurement techniques. Especially difficult is the measurement of the velocities of liquid and solid phases. The more complex the flow (e. g. bubble columns with a high void fraction) the more difficult is the measurement of the velocities. The main problem is that common optical methods fail in multi-phase flows having large void fractions. The reason is the different refraction indices of liquid phase and gaseous phases. On the other hand, optical methods fail in multi-phase flows having large solid phases, too. The reason is the opaqueness of the liquid.

METHODOLOGY

The new X-ray Particle Tracking Velocimetry (XPTV) described here, solves the visualization problem by the use of X-rays instead of light. X-rays penetrate a multi-phase flow in straight lines. They are neither disturbed by the different refraction indices of liquid and gas phase nor by the opaqueness of the solid (depending on X-ray absorption of the solid).
The use of X-rays in flow visualization and flow measurement is not a new idea. X-ray angiography is a common technique to visualize the flow in coronary vessels of human beings, where an optical access is impossible[1]. A radio opaque fluid is injected into the vessel to be visualized and their dispersion is recorded. X-rays are also used in multiphase flows - to assess the void fraction in bubble columns[2]. This is a tomographical method. The X-ray absorption in the bubble column is measured for different angles. This enables to calculate a local X-ray absorption coefficient. Since the X-ray absorption of fluid and gas differs enormously, the void fraction can be calculated from the absorption coefficient.
X-ray Particle Tracking Velocimetry works as follows: The liquid is seeded with X-ray absorbing particles. The particles have the same density as the liquid, if the liquid velocity is measured. They have the density of the solid, if the solid velocity is measured. Therefore, the particles move either with the liquid or they behave as solid particles. The velocity of the particles is measured by detection of their motion.

A typical experimental set-up is shown in Fig. 1. Two X-ray-sources S1 and S2 generate X-rays, which are directed through the bubble column onto the image intensifiers. A point P describing

the particle is mapped on the two image intensifiers I1 and I2 generating the points P1 and P2. The point P can be reconstructed from P1 and P2. By observing the motion of the particle, its velocity can be obtained by its displacement. The image intensifier converts X-ray into visible light in enlarges its intensity. The images are taken by a digital camera behind the image intensifier.
The device used for this experiments was a biplane X-ray device (Philips Integris BH 3000), which is usually used for visualization of flow in human coronary vessels, and was provided by the German Heart Institute in Berlin.

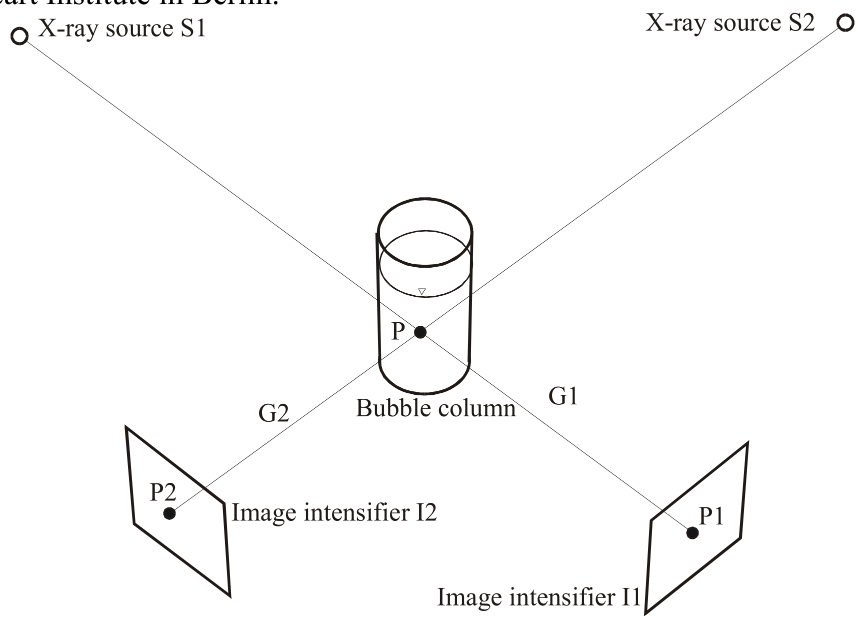

Figure 1. Experimental set-up.

Another application can be realized with that system, too - the measurement of the dispersion of a fluid in another fluid. An X-ray absorbing liquid is introduced into the same bubble column as described above. Since it absorbs X-rays much more than water and air, its dispersion can be observed. Flow structures can be assessed by the fluid dispersion.

RESULTS

At first, the new XPTV was tested and compared with optical methods at a flat bubble column with a small void fraction. The results of XPTV showed very good agreement with optical methods (Laser Doppler Velocimetry, Particle Tracking Velocimetry)[3].
Further measurements were performed in bubble columns with a two-phase flow (gas/liquid flow) and a three-phase flow (gas/liquid/solid). An example for a flow in a bubble column is shown in Fig.2. Glycerin with a viscosity of 850 mm2/s was used as liquid, which resulted in a slower flow and thus an easier particle tracking. The superficial gas velocity was set to 6 mm/s and the resulting overall void fraction was about 10.5 %. The vector field is the mean value of 465 image pairs having about 13700 3D-velocity vectors. Since 25 images were taken per second, the recording time was about 19 s. The flow was assumed as stationary during this time.

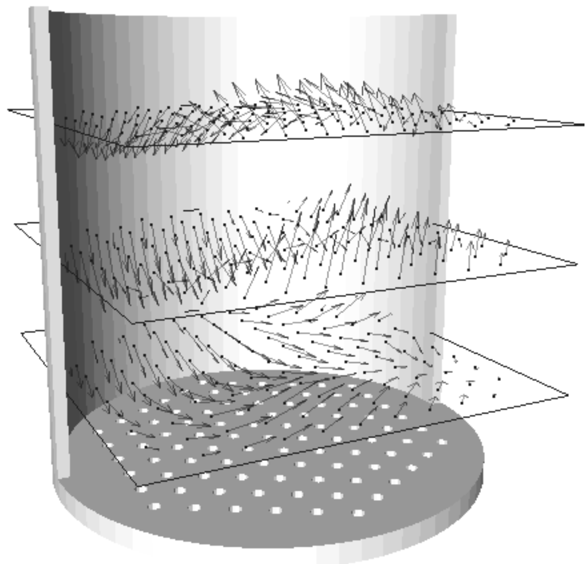

Figure 2. The vectors show the liquid velocity field in a bubble column. Glycerin with a viscosity of 850 mm2/s was used as liquid. The superficial gas velocity was set to 6 mm/s and the void fraction was about 10.5 %.

CONCLUSION

X-ray based techniques for flow visualization and flow measurement are powerful techniques where optical methods fail. The main advantages of X-ray based methods are that no reflection and refraction problems arise at phase boundaries and that the X-ray passes through opaque media (depending on the X-ray absorption coefficient). Therefore, their application is not limited by a large void fraction, opaque fluids or a lack of an optical access.

The new XPTV-method described here measures the liquid or solid velocity in multi-phase flows at many points in the volume, simultaneously and three-dimensionally. It is a non-intrusive technique - the flow is not disturbed by a probe.

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