FEASIBILITY OF LDA MEASUREMENTS IN HIGH VOID FRACTION BUBBLY FLOW

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ABSTRACT

The measurement of the time averaged and the turbulent fluctuations of the liquid phase velocity in a high void fraction bubbly flow is an important issue for multiphase flow research. In this study the feasibility of performing LDA measurements with a 27 mm diameter back-scattering LDA probe in a packed bubbly flow is investigated. A stirred vessel of 230 mm diameter and equipped with a flat glass window is used to investigate the possibility of measuring the tangential component of the liquid velocity. A porous plate placed near to the LDA measurement volume generates bubbles of 2 to 6 mm diameter. An optical glass fibre probe is also introduced near to the measurement volume, allowing for the determination of the local void fraction.

The void fraction is varied from 0 to 20% . The measuring distance in bubbly flow is set to 30 and 50 mm. The data analysis diagnostic procedure described in Van Maanen (1999a) is applied to the raw data. The time interval distribution, auto-correlation (Van Maanen 1999b), velocity probability function and fitted power spectrum (Van Maanen 1998) are presented.

The time interval distribution shows a non random-distribution of scattering particles in the presence of bubbles. This is related to the influence of the bubbles: zero void fraction tests showed a random distribution of scattering particles. The signal to noise ratio is found to be reasonably good regarding the flow conditions. The lower value compared to one phase flow can be compensated by collecting a larger number of data. At large rotational speed of the impellers, the auto-correlation shows some quasi-periodic components probably due to some structure resonance phenomena. This is a good indication that physical measurements can be achieved by following this approach.

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INTRODUCTION

The possibility of measuring the continuous phase velocity in high void fraction bubbly flows is of practical importance for the model validation and the optimization of a number of industrial processes. Applications involving stirred vessels, reactors or pipe flows at 20% void fraction are far from being completely described. The use of numerical simulation for such problems is a challenging issue: Direct Numerical Simulation is computationally too expensive for large scale problems, while averaging approaches, such as two fluid Euler-Euler models, need accurate closure models for interfacial forces and dispersed phase turbulence modification. Devoted experiments in bubbly flow are therefore needed for the development of proper simulation models.
An interesting application for the oil and gas industry can be found in vertical bubbly pipe flows. The transverse profiles are strongly affected by the magnitude of the radial forces. Depending on the bubble size and turbulence conditions, the well-known wall peaking and core peaking void fraction profiles are observed (Liu, 1991). For high enough void fraction ε (typically $\varepsilon > 0.25$, Taitel et al. 1980), the flow exhibits a transition from a dispersed bubble flow to slug flow. The goal of this experimental project is to measure accurately the local dynamic of such flows, i.e. to measure the transverse profiles of phase fractions, velocities, and turbulence properties.

At high void fraction with low liquid input flow conditions, e.g. in gravity-driven bubbly flow, the use of Hot Film Anemometry is questionable, due to the associated difficulty for discriminating between phases (Farrar et al. 1995). Although the use of HFA had been shown to be suitable for individual bubble wake dynamic investigations (Ellingsen et al. 1997, Larue de Tournemine et al. 2001), the study of returning flows would be difficult due to its working principle, based on forced thermal convection. Two point HFA would then be needed to characterize the flow direction, thus increasing intrusiveness effects. Laser Doppler Anemometry had already been found to provide meaningful data in bubble columns when using the technique in the backscattering mode (Mudde et al. 1997), particularly for measuring near the wall boundary, where the data rate was high. Groen et al. (1999) have shown that bubble scattering (i.e velocity realizations associated with a bubble passage) was only occurring marginally.

In this contribution the results of a feasibility study to use LDA in a high void fraction bubbly flow are reported. The test case is a stirred tank (Fig.1), equipped with a four-blade impeller. A porous bubble inlet was inserted near to the LDA measurement volume. A backscattering LDA probe from Dantec of 27 mm diameter was used, positioned outside the tank. This allowed varying the depth in bubbly flow of the measurement volume. By controlling the gas flow rate through the porous bubble inlet, the void fraction in the bubble layer could also be changed. The use of an optical glass fiber probe positioned near to the measurement volume allowed for the determination of the void fraction conditions. Bubbly flow layers of 30 mm and 50 mm thick have been investigated, whereas the void fraction was varied from 0 to 20%.

The diagnostic testing procedure described in Van Maanen (1999a) has been applied to the sampled data. The raw velocity data are first presented to illustrate the clear distinction between single and two phase flow signals. The time interval distributions, velocity probability distributions and signal-to-noise ratio (SNR) are determined.
The technique used for power spectrum fitting is the following:
1-First, the auto-correlation function is determined from the raw data. The auto correlation evaluation is done by using a combination of the 'fuzzy' and the local normalization slotting technique, described more in detail in Van Maanen et al. (1999b).
2-Then, the time auto correlation function is fitted with a least square method by a continuous function which depends on six parameters. This analytical expression follows from network theory, and no particular shape needs to be assumed 'à priori' (Van Maanen et al., 1998).
3- Finally, the coefficients of the fitted auto-correlation function are used to generate the fitted turbulence spectrum. This fitting procedure had been shown to be flexible enough for a large range of flow situations.

In a high void fraction bubbly flow, the data rate can be expected to be significantly lower than in single phase flow, due to:
1-the low probability of simultaneous beam penetration through the medium (Mudde et al. 1998), and
2-the gaps in the signal due to bubble passages through the measurement volume itself (Mudde et al. 1999).

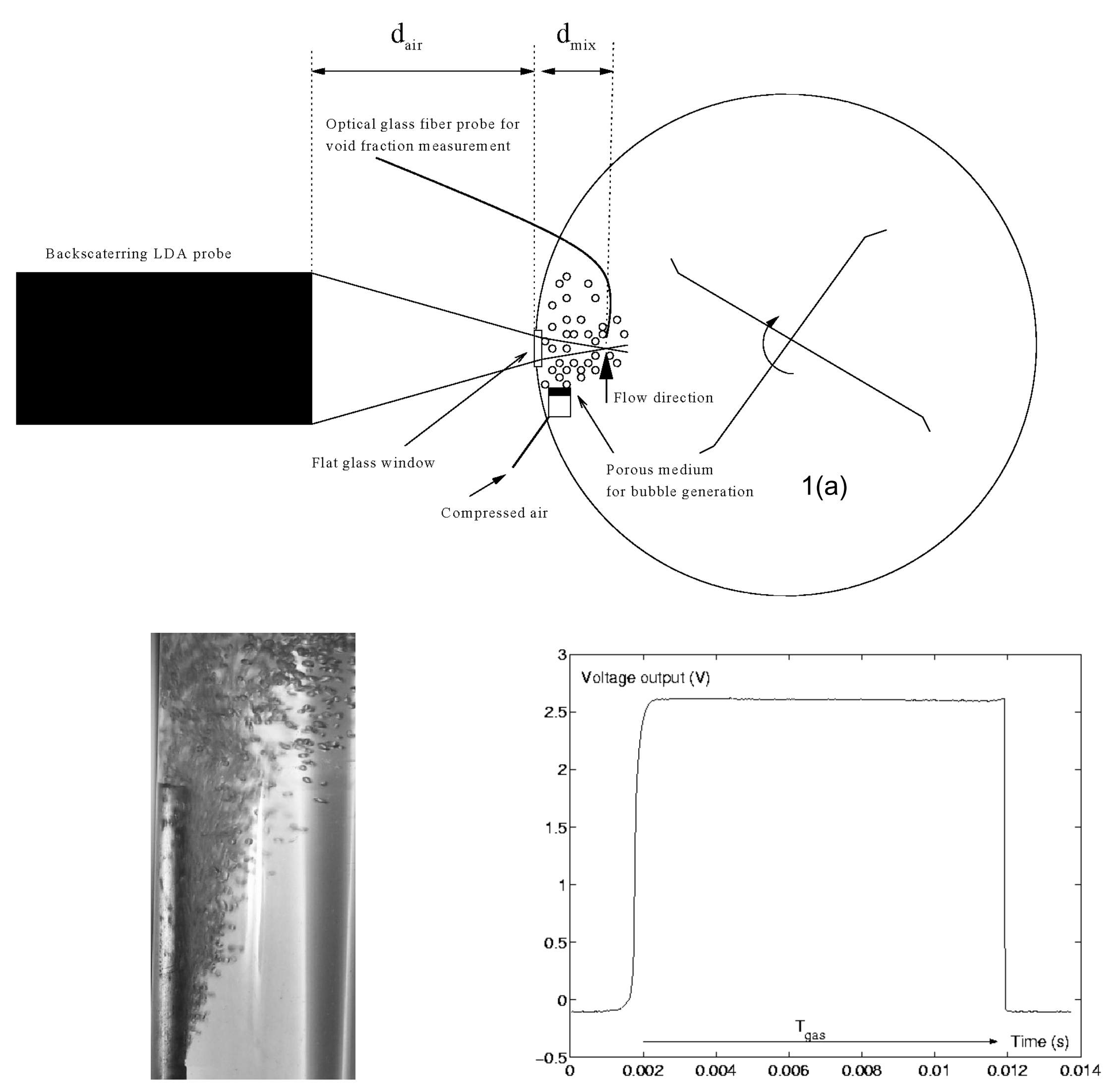
In the case of bubbly flow, re-sampling techniques would lead to non-physical results, since the physical gaps (generated by the bubble passages) would be replaced by interpolated liquid velocity data in the signal. The power spectrum curve-fit procedure, described above and in more detail in Van Maanen (1998), has been shown to provide reasonable accuracy for such low data rate experiments. Therefore, this approach is followed in the present contribution.

First, the experimental set-up arrangement is described in the paper. Next the results concerning the feasibility of measurements are presented. The physical meaning and recoverability of the experimental results is then outlined, and some conclusions are drawn.

EXPERIMENTAL ARRANGEMENT

1-Introduction

The experimental set-up is a stirring vessel of 270mm diameter, equipped with an impeller. The impeller consists of four blades of 121 mm diameter The rotational speed can be varied from 0 to 700 rpm. To generate the bubbles, a porous plate inlet is introduced in the near wall region. The resulting bubble size is between 2 and 6 mm. A typical photo of this bubble inlet (placed in a Perspex pipe) can be found in fig.(1b).



1(b) 1(c)

Figure1: (a) experimental set-up,
(b) porous plate used,
(c) a typical optical fibre signal.

2- LDA equipment

The LDA consists of a FiberFlow probe of 27mm diameter from Dantec (model 61X35). This probe is positioned on a three-axis traversing equipment. It is adjusted to measure through a flat glass window (fig. 1a), and the effect of the bubbly flow layer thickness (d_{mix} in fig. 1a) on the data quality and rate can be studied by adjusting the measuring distance in air d_{air}. The LDA is running in back-scattering mode, and the tangential component of the velocity is investigated. A 2 W (all-lines) Coherent Argon – Ion laser is used, with 514.5 nm wavelength. The measurement volume dimensions in water are 0.1 * 3 mm, the fringe spacing is 5.48 μm. The focal length is 160 mm in air. The bursts are processed with a Dantec FVA processor.

3-Void fraction determination

The void fraction is measured with an optical fibre probe. The fibre is conically shaped with an angle of 30 degrees with respect to its axis. Some light is sent into the fibre. Due to the low difference in refractive index between the fibre material and the water and its large value between air and the fibre, much more light is reflected when the fibre conical part is operating in air. A photo multiplier converts the collected light into a voltage output. This signal is sampled on a PC at a frequency of 20 KHz (a typical signal obtained from a bubble is presented in fig.1c). Next the local void fraction can be estimated by calculating the ratio of gas samples over the total number of samples.

RESULTS

1-Signal modification in bubbly flow compared to single phase flow

The bubbles introduce “drop-outs” in the signal. This can clearly be recognized in the time traces (figs. 2, 3 and 4). However, in between the bubbles information about the shorter time scales is still available. Also, the bubbles introduce a change in the time interval distribution, which is similar to velocity bias (figs. 6 and 7 compared to 5). However, the deviation from the situation corresponding to a random distribution of seeding particles, as demonstrated in Van Maanen (1999a), is not due to velocity bias in that particular situation. The situation of zero void fraction (fig. 5) shows a very acceptable time interval distribution, corresponding to a meaningful measurement (on a semi-log scale, the time interval distribution should be linear for a random distribution of scattering particles). This can be explained as follows: the bubbles are reducing the number of observations for the intermediate time scales, therefore contributing to the observed concavity deviation. A closer analysis of the optical fibre signal showed that it is the case: the time residence of the bubbles in the optical fibre probe or, similarly, in the measurement volume, is in the range of 1 to 10 ms, thus contributing to the intermediate time scales. The fact that the concavity in the time interval distribution of measurements is increasing with the void fraction (fig. 7 compared to 6) confirms that this is indeed due to the bubble residence times. The same type of deviations have been reported by Mudde et. al. (2001).

From figs 8 to 11, the temporal auto correlation function clearly points out the decreased SNR for an increased void fraction (the figure order was changed for ease of comparison between low and high void fraction tests). Reasonably good Signal to Noise Ratios (> 3) are found for all the flow conditions investigated. This lower value compared to single-phase flow can be compensated by measuring longer. The probability density function of velocity is also showing coherent properties for both low and high void fraction values (figs. 12 and 13). From a signal diagnostic perspective, such measurements are therefore feasible.

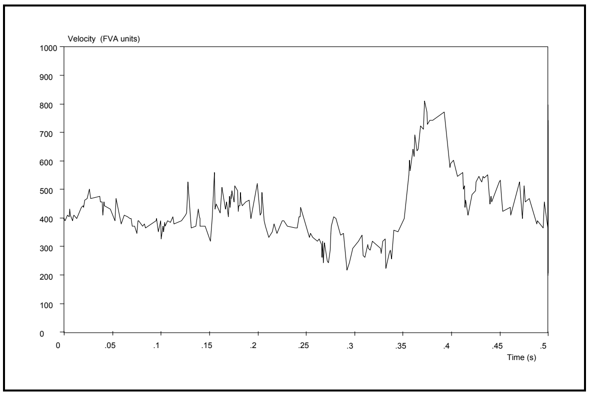


Figure 2: Time trace of a 0.08% void fraction test, bubble layer thickness of 50 mm.

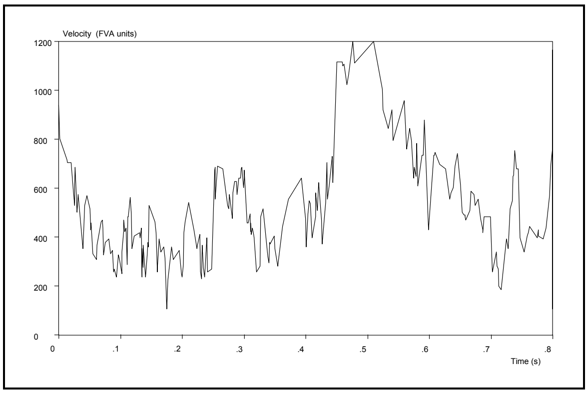


Figure 3: Time trace of a 5% void fraction test, bubble layer thickness of 30 mm.

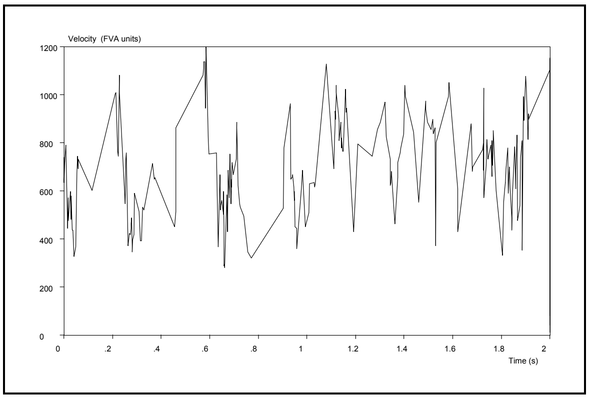


Figure 4: Time trace of a 20% void fraction test, bubble layer thickness of 30 mm.

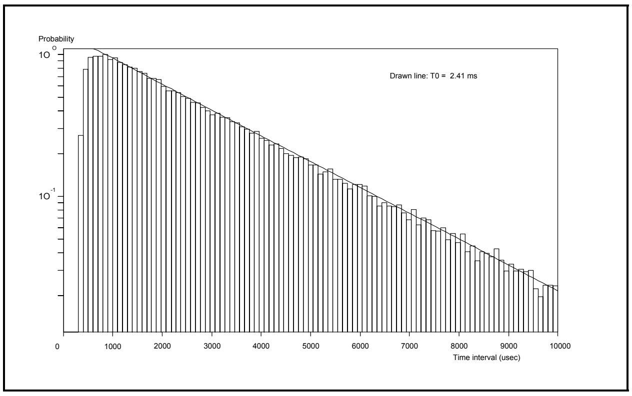


Figure 5: Time interval distribution of a 0.08% void fraction test, bubble layer thickness of 50 mm.

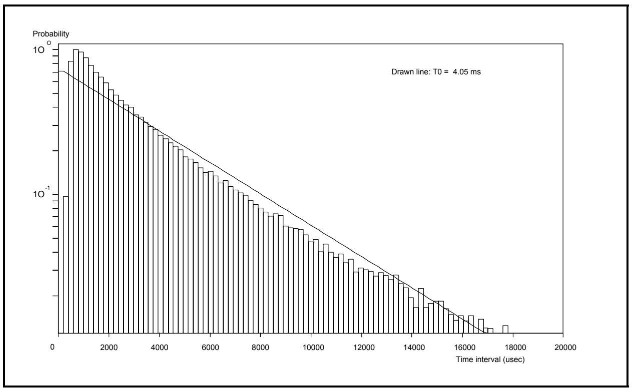


Figure 6: Time interval distribution of a 5% void fraction test, bubble layer thickness of 30 mm.

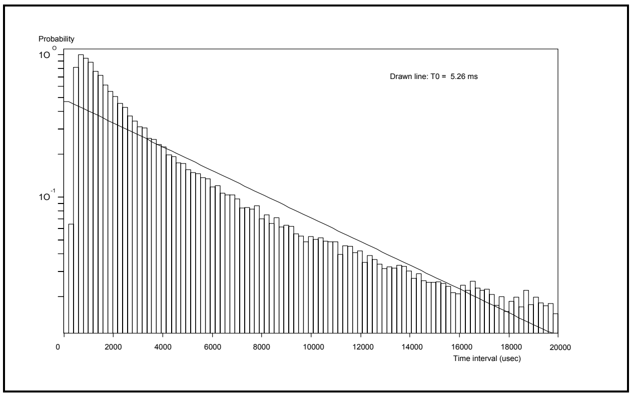


Figure 7: Time interval distribution of a 20% void fraction test, bubble layer thickness of 30 mm. The mean bubble residence time in the fibre probe is 1.5ms, and ranges up to 10ms.

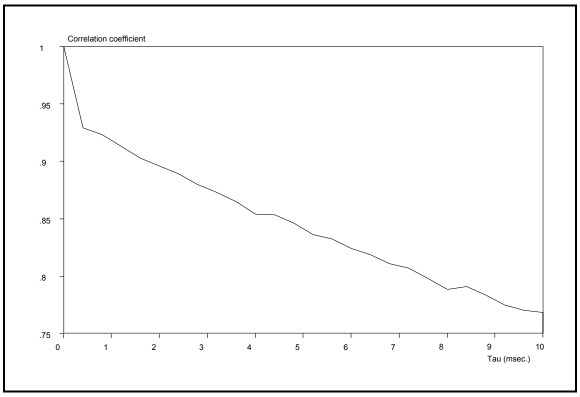


Figure 8: Auto correlation function of a 0.08% void fraction test, bubble layer thickness of 50 mm. The part around τ is enlarged.

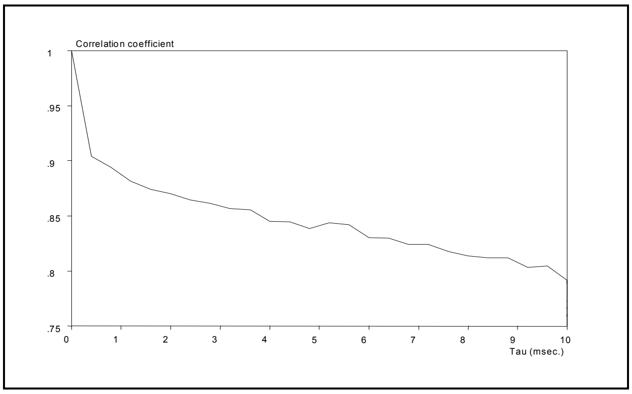


Figure 9: Auto correlation function of a 3.6%void fraction test, bubble layer thickness of 50 mm. The part around τ is enlarged.

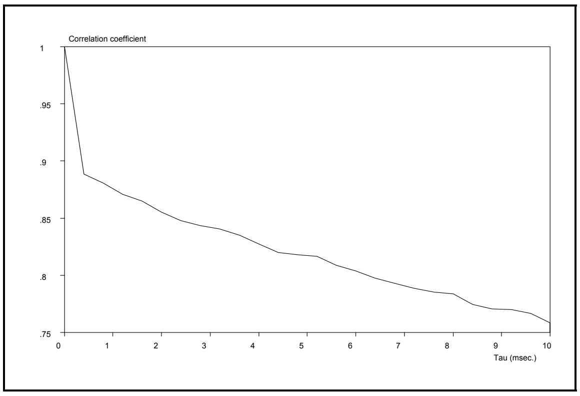


Figure 10: Auto correlation function of a 7.4% void fraction test, bubble layer of 50mm. The part around τ is enlarged.

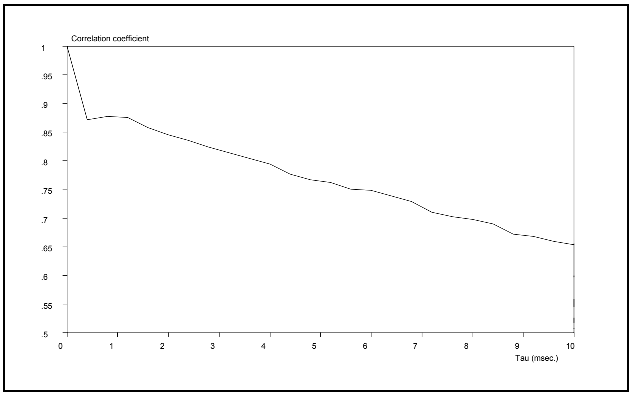


Figure 11: Auto correlation function of a 20% void fraction test, bubble layer thickness of 30 mm. The part around τ is enlarged.

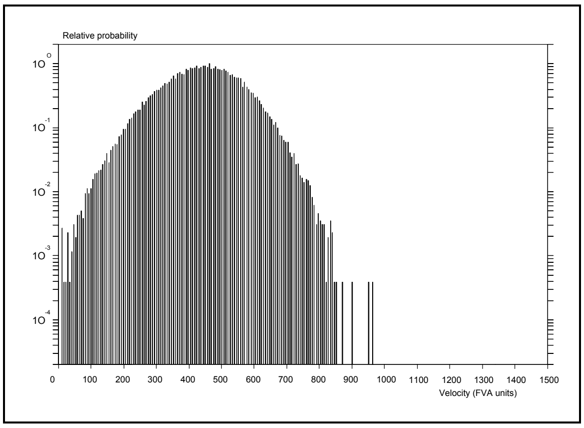


Figure 12: Logarithmic velocity probability distribution of a 0.08% void fraction test, bubble layer thickness of 50 mm.

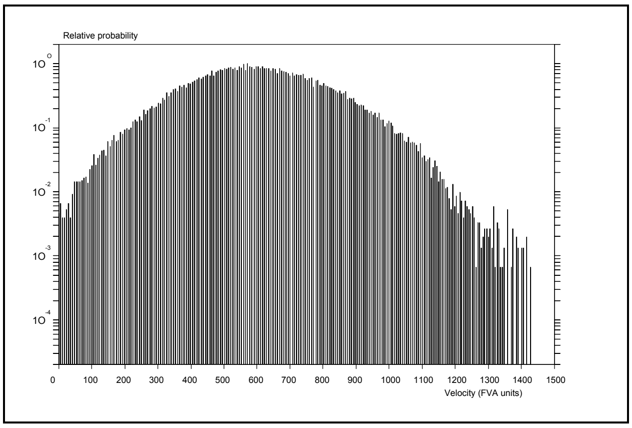


Figure 13: Logarithmic velocity probability distribution for a 20% void fraction test, bubble layer thickness of 30 mm.

2- Turbulence measurement feasibility

In most cases, the power spectra can be fitted by using the technique described in the introduction. Clear distinctions can be found between the low and high void fractions tests (figs. 14 to 17). The turbulence power spectrum corresponding to low void fraction (fig.14), done near to the impellers (db = 50 mm , i.e $\frac{r}{r_{blade}} \approx 1$), shows a slope between $-\frac{5}{2}$ and $-\frac{5}{3}$. This is in agreement with previous results on stirred tank in single-phase flow (Van der Molen et al. 1978): near to the impellers the non-equilibrium between turbulence production and dissipation affects the slope of the spectrum. The higher void fraction tests, done closer to the wall boundary, also show coherent properties. Improvements can be expected for a larger number of samples. The variance of the correlation coefficients at the smaller τ-scales needs improvement to estimate the power spectrum at the higher frequencies more accurately.

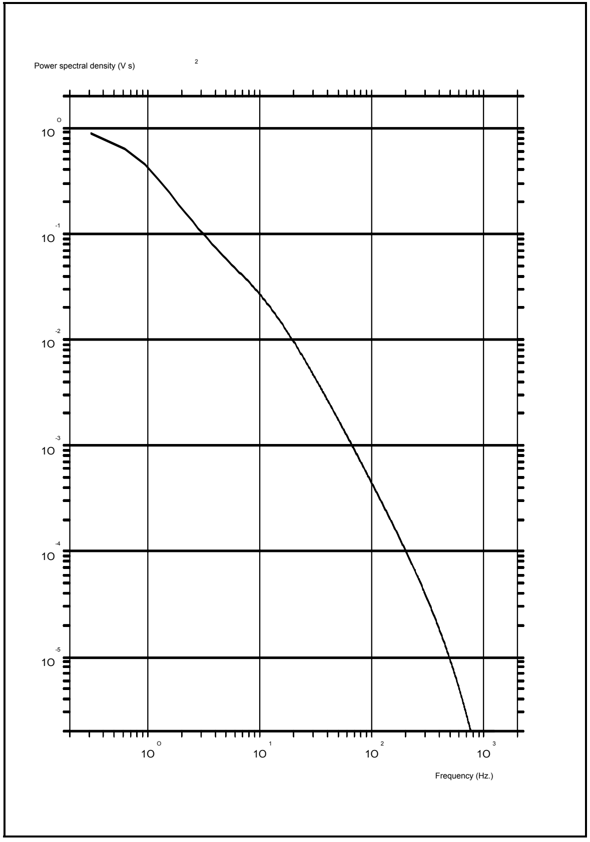


Figure 14: Fitted power spectrum of a 0.08% void fraction test, bubble layer thickness of 50 mm.

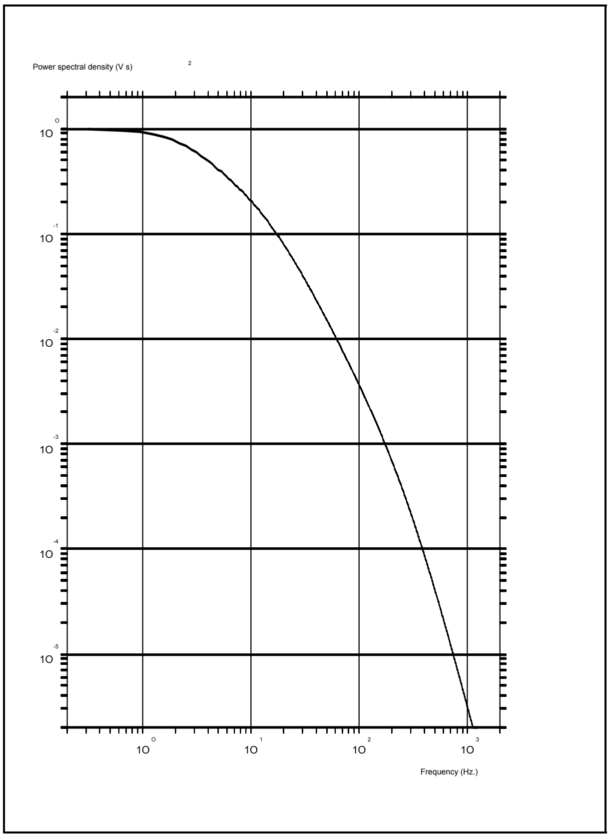


Figure 15: Fitted power spectrum of a 4.65% void fraction test, bubble layer thickness of 30 mm.

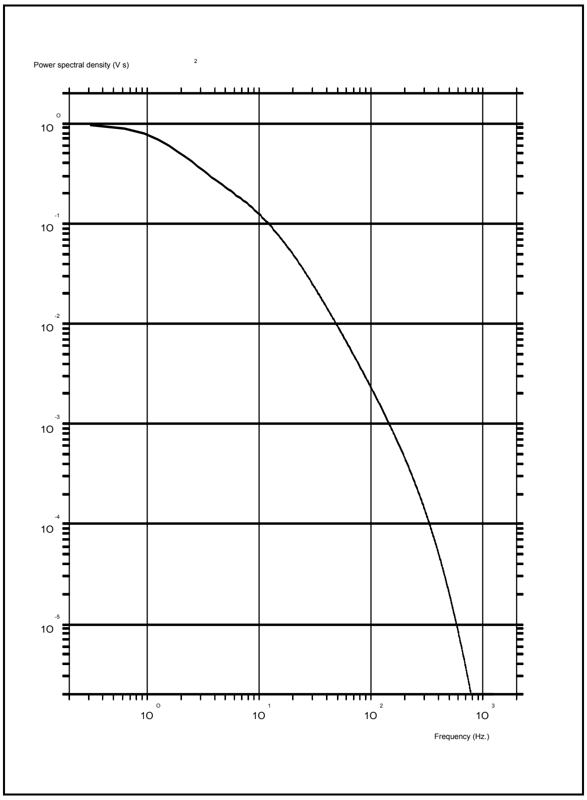


Figure 16: Fitted power spectrum of a 15.4% void fraction test, bubble layer thickness of 30 mm.

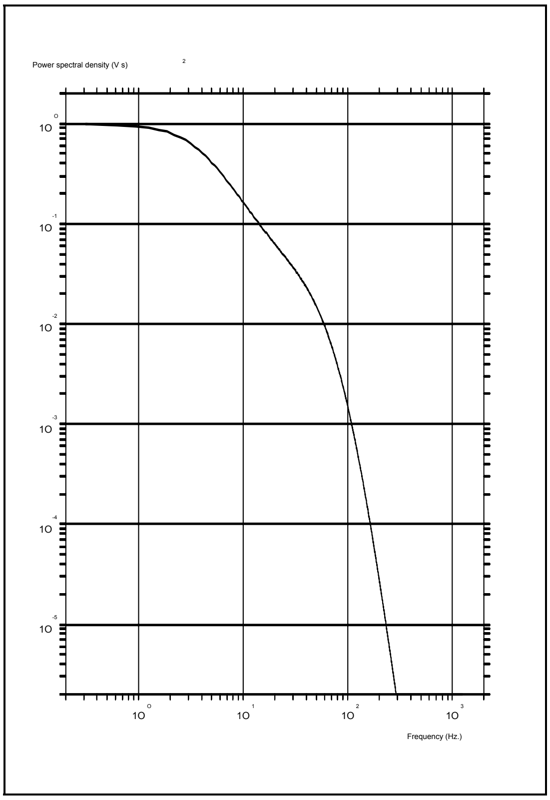


Figure 17: Fitted power spectrum of a 20% void fraction test, bubble layer thickness of 30 mm.

3- Periodic components

A periodic component in the velocity can be observed in single-phase flow stirred vessels. Van der Molen et al. (1978) reported that this effect was significant for $\frac{r}{r_{blade}} < 1.5$, due to the dominance of trailing vortices from the impeller blades. At large rotational speed (ω ~ 670 rpm , i.e. a blade passing frequency of 45 Hz) and for a bubbly flow layer of 30 mm ($\frac{r}{r_{blade}} \approx 1.4$), the enlarged time scale temporal auto-correlation functions for both low and high void fraction show quasi-periodic components (fig. 18 to 21). The frequency associated with those oscillations is of the order of 2 Hz. These low frequency components are probably due to some large-scale re-circulations in the vessel and some resonance effect at this large rotational speed. In high void fraction conditions, the auto correlation function shows a decaying periodic component (fig. 21). The rotational speed being the same, the frequencies associated with the two measurements are similar (fig. 21 compared to fig. 19). The fact that such components can be retrieved at 20 % void fraction enhances the trustworthiness of the results. The periodic component associated with the blades trailing vortices (f = 45Hz) was not observed at the measurement volume location.

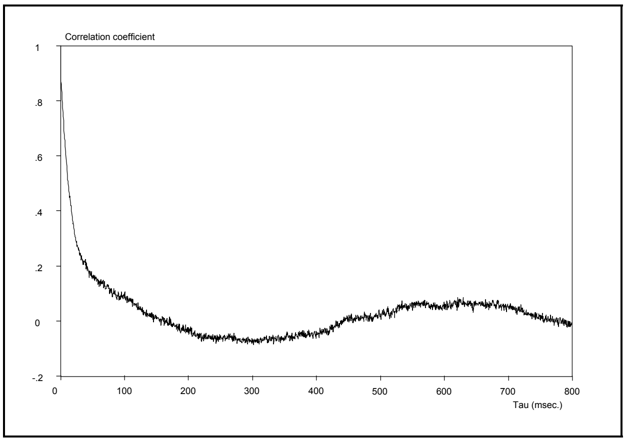


Figure 18: Auto correlation function of a 4.7% void fraction test, bubble layer thickness of 30 mm and w=670rpm.

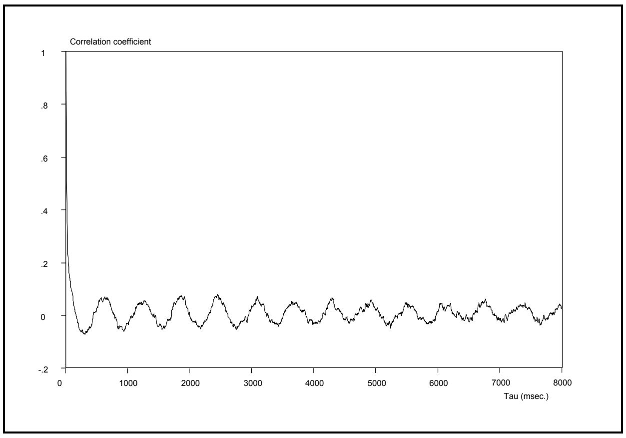


Figure 19: As figure 10, but with a larger scale to illustrate the periodic component induced by the blades.

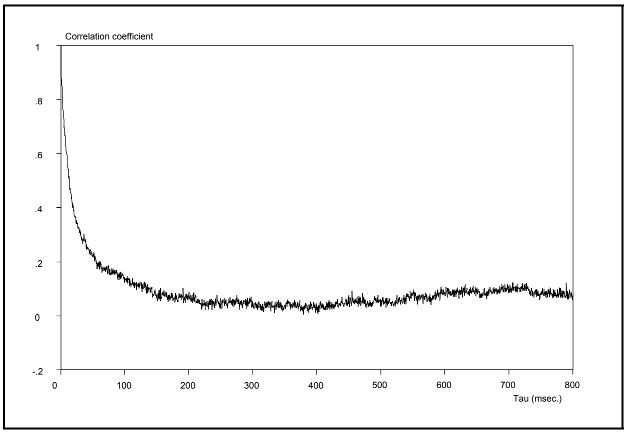


Figure 20: Auto correlation function of a 20% void fraction test, bubble layer thickness of 30 mm and w=670rpm.

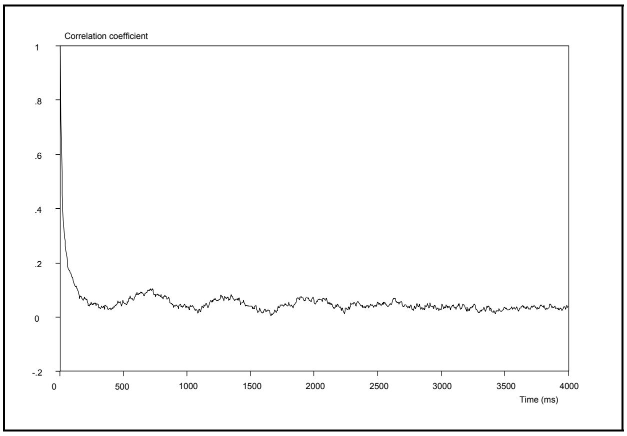


Figure 21: As figure 11, but with a larger time scale to illustrate the (decaying) periodic component at 20% void fraction.

CONCLUSION

The goal of this investigation was to study the feasibility of backscatter - mode LDA measurements in a complex, packed bubbly flow. Experimental tests performed in a stirred vessel in which bubbles were injected from a porous material showed that such measurements are feasible.

The diagnostic procedure described in Van Maanen (1999a) has been applied to the raw data. The main conclusions are the following:

- The bubbles introduce a change in the time interval distribution, which is similar to velocity bias. However, in this case the concavity in the Time Interval Distribution is physical. The liquid velocity distribution confirmed that physical measurements were performed.
- The auto correlation functions show a reasonably good Signal-to-Noise Ratio regarding the flow conditions.
- The diagnostic procedure and the turbulence fitting method developed by Van Maanen (1999a) are suitable for such a complex bubbly flow situation.

It can be concluded that the application of LDA in high void fraction bubbly flow is feasible, provided that the distance between the measurement volume and the transmitting and receiving optics is small enough to obtain sufficient Doppler signals from the liquid to allow further processing. In this case 50 mm showed to be feasible for void fractions of up to 10%. With a bubble layer thickness of 30 mm, it was possible to measure at void fraction values of up to 20%.

The next step of this project will be to measure the liquid velocity in a high void fraction, vertical bubbly pipe flow of 36 mm radius.

AKNOWLEDGMENTS

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