# ADV measurements in a flotation tank with bubble containing water

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Dissolved Air Flotation (DAF) is a method for separating suspended, microscopic particles in water and wastewater treatment. The basic idea is to generate huge amounts of microscopic bubbles, which should attach to the particles whereby less dense aggregates are obtained, rising to the water surface. The flow structure in a flotation tank is important for the separation efficiency. ADV measurements have been performed in a DAF pilot plant for different hydraulic loads and dispersion flows. The bubbles (volumetric fraction < 3-4 ‰ ) constitute a difficult environment for the ADV. Tests were performed to evaluate the ADV application. Direct measurements showed that the acoustic wave velocity was not affected. Velocity directions seemed to be fairly accurate, whereas magnitudes were underestimated. The measurement point seemed to be located very close to the ADV transmitter. Multiscattering of the acoustic waves was important. Mapping of the flow structures showed that three states existed – a low dispersion flow (< 4 %) giving a large rotational flow in the tank, higher dispersion flow and limited hydraulic load (< about 16 $m^3$/h) caused a stratified flow situation beneficial for the separation and finally a large hydraulic load (> 15-20 $m^3$/h) caused the stratified structure to break down with detrimental effect on the separation.

**Keywords:** Dissolved air flotation, bubbles, flow structure, ADV

## 1 INTRODUCTION

Production of drinking water/process water in water works or the treatment of municipal wastewater involves a very important and central process concerning the separation of suspended, microscopic particles or flocs from the water, for instance generated through biological or chemical treatment but also existing naturally. These particles/flocs have to be separated before the use or the discharge of the water. Dissolved Air Flotation (DAF) is a potentially efficient method for the separation process with a number of advantages compared to the conventional sedimentation technique. The basic idea with DAF is to generate huge amounts of microscopic air bubbles (size of the order of 50-100 µm), which should attach to the suspended flocs/particles. In this way less dense bubble/floc aggregates are generated, which should rise to the water surface in the flotation tank, where a sludge layer is formed. DAF is a relatively complex process and in order to utilize the full potential of the process a profound knowledge is required of the process and the effect of different factors on the separation ability. Several important basic aspects on the DAF process have been studied by the author, such as the flow structure, appearance and rise velocities of aggregates, separation in relation to particle sizes, bubble characteristics. Thus, it has been shown that the introduction of bubbles to the process strongly affects the flow structure and that this in turn strongly affects the separation efficiency.

Detailed studies and measurements using a laboratory Nortek Acoustic Doppler Velocimeter (ADV) have been performed on a DAF pilot plant, Fig 1 in order to get insight into the detailed characteristics of the flow structure for different hydraulic loadings and different dispersion flow rates. The presence of bubbles (volumetric proportion 2-4 ‰) constitutes a difficult environment for the ADV. Thus some tests were initially performed in order to assess the applicability of the ADV. The paper will discuss the following aspects on the ADV and on DAF

- ADV in bubbly water
- flow structure in the tank
  - * without bubbles
  - * with bubbles, internal waves
  - * with bubbles, stratified conditions, medium hydraulic load and sufficient dispersion flow
  - * with bubbles, high hydraulic load, breakdown of the stratification.

## 2 DAF PILOT PLANT

The pilot plant, Fig 1, was 1.2 m long, 0.7 m wide, 1.3 m high with a transparent side. The hydraulic load (0 – 17 $m^3$/h) was entered (no particles) to the bottom left into a riser shaft (contact zone) ending a few dm:s below the water surface. Huge amounts of micro bubbles were produced by depressurizing water saturated with air at 5 bar via valves into the contact zone where the hydraulic load was entered. The dispersion flow rate was about 10 % of the hydraulic load. The hydraulic load together with the bubble flow then entered the separation zone (the main part of the tank), where different flow structures could obtained. Fig 1 shows the case with a distinct stratified condition with an upper, less dense, bubble-containing layer and bottom layer with more or less clear water. Discharge of (clean) water took place at the bottom via two perforated pipes. The ADV was mounted on a moveable rig on the top of the tank.

Figure 1. The pilot plant with hydraulic load and dispersion flow (bubbles) entering the riser shaft to the left

## ADV PERFORMANCE

In normal circumstances (clean water with few scattering particles) the ADV works very well with the measurement point located 5 cm below the transducer. The ADV functioning is dependent on the behaviour of the acoustic waves (speed and attenuation) in the water. Thus, one might expect that the presence of microscopic air bubbles (≈ 50 μm, volumetric fraction ≤ 4 – 5 ‰) would affect wave propagation significantly. A number of tests were performed in order to evaluate the ADV performance in such conditions. In the first place a 10 MHz acoustic receiver was placed 5 cm below the ADV transmitter in bubbly water. A digital oscilloscope was triggered each time an acoustic pulse was emitted and the received pulse could be visualized on the scope together with the time passed. Fig 2 shows an example of the transmitted and the received pulses respectively. The time difference between the two pulses was constant irrespective of the amount of bubbles (≤ about 4 – 5 ‰) corresponding to a wave velocity of 1470 m/s, i.e. the same as for pure water. Theory [1] confirms this finding using relevant data – number of bubbles/unit volume of water ≈ $6.4 \cdot 10^{10}$, bubble radius ≈ $25 \cdot 10^{-6}$ m, acoustic frequency f = $10^7$ Hz. The wave speed is thus obviously not affected by the bubbles.

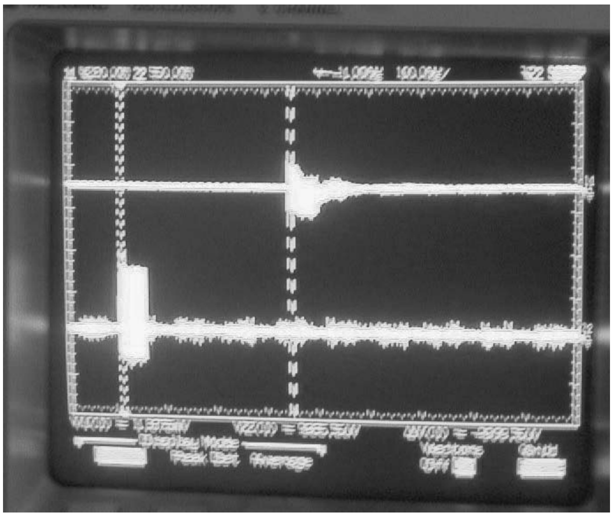

Figure 2. Direct measurement of the wave speed.

Another test was performed with the rig and the ADV moved horizontally about 30 cm at a fairly constant speed along the pilot plant with the ADV immersed into the bubbly water. The output from the ADV was recorded giving movement time and the ADV-recorded mean velocity. This latter velocity was corrected for the slow, horizontal water velocity and comparison could then be made with the rig velocity. A clear water test showed that there was almost no difference between the two velocities, for instance: $A_{rig}$ = 10.86 cm/s, $A_{ADV}$ = 10.42 cm/s. Tests with bubbly water showed significant differences, for instance: $A_{rig}$ = 9.51 cm/s, $A_{ADV}$ = 6.17 cm/s. A general result was that the ADV velocity was smaller than the rig velocity consistently, with less difference moving the rig upstream as compared to downstream movement.

A number of other tests with the ADV in bubbly water strongly indicated that the measurement point was dislocated to a point much closer to the transmitter. However, the operation of the ADV electronics - gating of the receivers to open only during the expected arrival of a pulse in normal conditions - meant that the acoustic waves could not propagate directly from the transmitter to the receiver horizontally (≈ 3 cm) but had to propagate about 10 cm. It was also found that the emitted pulses, although attenuated by the bubbles, were scattered in all directions in the neighbourhood of the transmitter. These facts strongly indicate that multiscattering on the bubbles takes place for the acoustic waves propagating from the transmitter to the receiver. Yet fairly good and reasonable velocity signals were obtained with SNS values 45 – 50 dB and correlation coefficients 90 – 98 %. A possible explanation is that the bubbles involved in the multiscattering process move in a very similar way during the short time for a pulse to propagate from the transmitter to the receiver. This means that the detected Doppler shift is not affected by the multiscattering process, only the first and the last scattering matter. The general conclusion of the ADV performance, based on tests and mapping of the flow structure in the tank, was that the measurement point seemed to be very close to the transmitter and the horizontal velocities were underestimated but that velocity directions seemed to be more or less correct. As the real velocities were small one has to bear in mind that the ADV measured the movement of the bubbles, which were assumed to move with the water flow in the horizontal direction. Vertical ADV velocities were offset by the rise velocity of the bubbles (≈ 1 mm/s).

## 3 FLOW STRUCTURE IN THE FLOTATION TANK

The existence of micro bubbles in the flotation tank has two implications – generation of aggregates and influence on the flow structure. The latter aspect is strongly related to the DAF separation efficiency. Detailed ADV measurements were performed in the pilot plant of the average horizontal ($v_x$) and the vertical ($v_z$) velocities for different hydraulic loads ($Q_l$) and different dispersion flows ($Q_d$) but without particles/flocs in order to study possible flow structures and their characteristics. Flow velocities were mainly in the interval 0 – 2 cm/s (ADV). Averaging time was at least 300 s. The measurements were performed in the longitudinal center plane only. Three significantly different flow structures were identified:

- S1: the case with no bubbles or a sufficiently small $Q_d$ giving a large, clockwise rotating flow, Fig 3
- S2: the case with sufficiently high $Q_d$ but sufficiently small $Q_l$ giving a stratified flow situation, Fig 4
- S3: the case with sufficiently high $Q_l$ where the stratified flow situation broke down, Fig 6.

Figures 3,4,6 have been produced using a software, which transforms the measurements into a vector plot on a regular x-z grid by means of the krieging technique.

### 3.1 Flow structure S1

The flow structure in Fig 3 represents the case with $Q_l$ = 12 $m^3$/h, $Q_d$ = 0 $m^3$/h, i.e. no bubbles. Inflow takes place horizontally to the left at the top 16 cm. Outflow at the bottom. The flow structure could basically, as expected, be described as a large, clockwise eddy encompassing the whole flotation tank. Particles/flocs entering the tank will be transported horizontally to the downstream wall and then vertically with fairly high velocities to the pipe outlet arrangement on the bottom, i.e. no good separation. The same flow situation will occur for

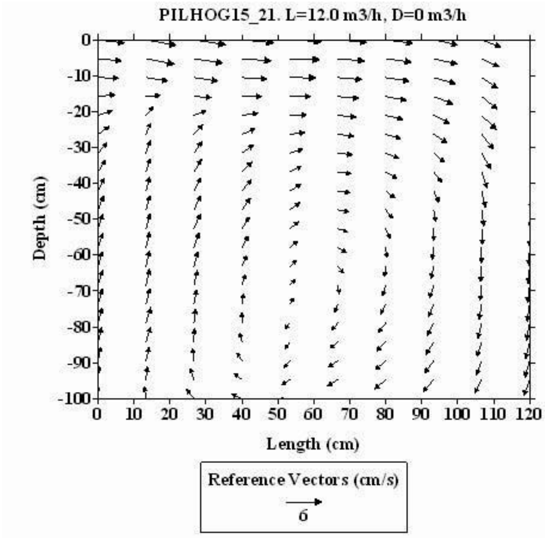


Figure 3. Case S1. ADV-determined flow structure in the pilot plant without any dispersion flow.

small $Q_d$ (< about 4 % of $Q_l$). A large amount of bubbles will thus also reach the bottom as the vertical downstream velocity is significantly larger than the bubble rise velocities.

### 3.2 Flow structure S2

The flow structure in Fig 4 represents the case with $Q_l$ = 10 $m^3$/h, $Q_l$ = 0.98 $m^3$/h, i.e. $Q_d$ ≈ 10% of $Q_l$. Inflow takes place horizontally to the left at the top 35 cm. Increasing $Q_d$ from 0 to about 4 % of $Q_{l,}$ maintaining $Q_l$ constant, will abruptly change the flow structure from S1 to a stratified situation, S2, according to Fig 4, due to density differences given by different volumetric air contents, Fig 5. There is an upper, bubble-containing, less dense layer, where water moves horizontally towards the downstream wall. After that a horizontal return flow occurs, containing less amount of bubbles. Beneath, a downward, bubble-free, denser plug- like, homogeneous flow with low velocities arises towards the outlet. Such a stratified situation is beneficial for the separation efficiency. Aggregates, particles entering the tank will tend to stay in the upper layers as the vertical, downward velocities are small as compared to S1 where a concentrated, vertical high-velocity region existed. Increasing $Q_l$ will tend to extend the upper layer downwards, thus causing aggregates, particles and bubbles to approach the outlet arrangement with possible deteriorating separation.

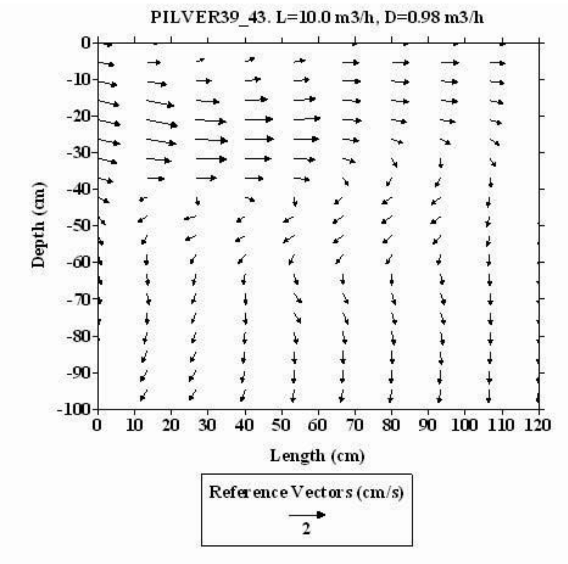


Figure 4. Case S2. ADV-determined flow structure in the pilot plant. $Q_d \approx 10$ % of $Q_l$ , $Q_l = 10$ m$^3$/h

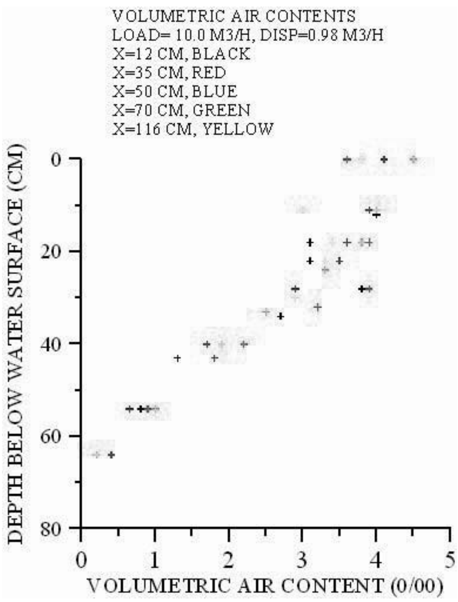


Figure 5. Case S2. Volumetric air contents in different verticals (x) from the riser shaft

### *3.3 Flow structure S3*

The flow structure in Fig 6 represents the case with $Q_l = 16.4$ m$^3$/h and $Q_d = 1.45$ m$^3$/h, i.e. $Q_d \approx 9$ % of $Q_d$. It is obvious that the stratified structure has broken down and the flow with aggregates, particles and bubbles has a high probability of reaching the bottom outlet thus causing a deteriorating separation. The reason for the breakdown of the stratified structure is not known. It is, however, important to understand the mechanism, as possible measures for maintaining the stratified situation at higher hydraulic loads would be of practical interest.

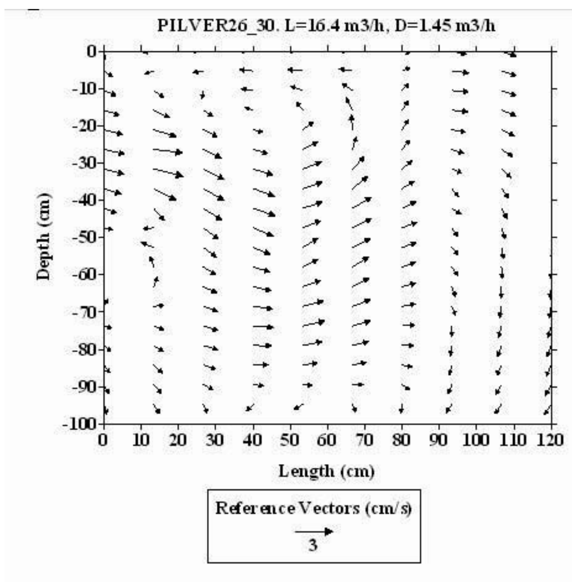


Figure 6. Case S3. ADV-determined flow structure in the pilot plant. $Q_d \approx 9$ % of $Q_l$, $Q_l = 16.4$ m$^3$/h

## 4 SUMMARY

The ADV has been used in micro bubble containing water in a flotation tank, which potentially is a difficult environment for the instrument. However, reasonable velocity data were obtained, at least qualitatively. Direct measurements showed that the acoustic wave velocity was not affected by the bubbles, also confirmed by theory. A number of different tests indicated that velocity directions were fairly correct, whereas velocity magnitudes were underestimated. The measurement point seemed to be located very close to the transmitter. A possible explanation is hypothesized

Three different kinds of flow structures were identified depending on the hydraulic load and/or the dispersion flow. Beneficial stratified flow conditions occurred for hydraulic loads less than about 16 m$^3$/h and dispersion flow rates larger than 4 % of the hydraulic load.

## REFERENCES

[1] Urick R: Principles of underwater sound. McGraw-Hill (1983), 3rd ed. ISBN 0-07-066087-5