Improving Acoustic Doppler velocimetry in steady and unsteady flow by means of seeding with hydrogen bubbles

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Velocimetry is used in various fields of research. In hydraulics, Ultrasonic Velocimetry based on the Doppler Shift effect can accurately resolve the mean flow and the turbulence if the acoustic scattering level is sufficiently high. But Ultrasonic Velocity instruments are known to perform poorly in clear water with low acoustic scattering level, such as often found in laboratory applications.

Artificial seeding of the flow can be used to increase the acoustic scattering level. This paper reports how seeding of the flow with micro-bubbles generated by means of electrolysis improves the quality of velocity profile measurements under unsteady flow conditions.

Keywords: water, hydrogen bubbles, velocity measurement, steady flow, unsteady flow

1 INTRODUCTION

Velocimetry is used in various fields of research. In hydraulics, different velocimetry methods exist (spinner, Pitot tube, electromagnetic methods, Laser Doppler methods (LDA), Particle Imaging Velocimetry (PIV), Ultrasonic Doppler methods, etc). Ultrasonic velocimetry based on the Doppler effect can accurately resolve the mean and turbulent flow fields if the acoustic scattering level is sufficiently high (Takeda, 2002; Blanckaert and Lemmin, 2006).

Due to the inherent constraints of classical velocimetry, especially the intrusive character of measurement devices such as micro-propellers or Pitot-tubes and the point wise and non-directional measurement, there has been a clear need to develop and dispose of a non-intrusive measurement technique also for the hydraulic engineer. Thanks to the UVP Method one can obtain velocity fields in space and time.

This technique with its advantages compared to more classical measuring methods is now being widely exploited in the Laboratory of Hydraulic Constructions (LCH) of the Ecole Polytechnique Fédérale de Lausanne (EPFL). Among the first performed studies at the LCH was the flow mapping of turbidity currents in a laboratory flume (De Cesare and Schleiss, 1999), where the suspended sediments gave very good ultrasound echo. Other studies also used either steady state measurement allowing a long acquisition time or were performed in rather dirty water (De Cesare, 1999). Nevertheless, as Ultrasonic Doppler instruments are known to perform poorly in clear water, such as often found in laboratory applications, artificial seeding of the flow can be used to increase the acoustic scattering level.

This paper applies the simple, low-cost and non polluting seeding technique proposed by Blanckaert and Lemmin (2006), which consists of generating micro hydrogen bubbles in the flow by means of electrolysis. When a direct electric current is passed through water a chemical reaction takes place that produces two different gases at the cathodic and anodic electrodes. Elemental hydrogen (H_2) is formed at the cathode and elemental oxygen (O_2) at the anode. The size of the micro hydrogen bubbles is comparable to that of the cathodic electrode. The ideal size of acoustic tracers is about half of the wavelength of the acoustic signal.

This paper describes the set-up generating hydrogen bubbles and subsequently presents some results of velocity profile measurements under

1) Steady flow conditions with and without seeding

2) Highly unsteady flow conditions with seeding.

2 HYDROGEN BUBBLE GENERATION SETUP

2.1 Setup characteristics

The setup used for the hydrogen bubble generation and the data-acquisition are shown in Figure 1 and Figure 2.

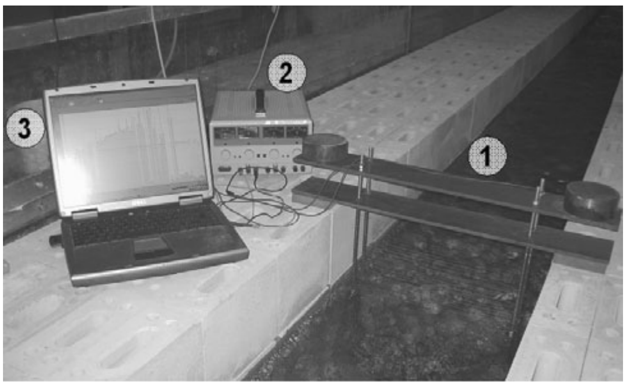

Figure 1: Setup for hydrogen bubble generation (1), electric direct current producer (2) and data-acquisition notebook (3).

The setup for the hydrogen bubble generation (1) is formed by two arrays of horizontal stainless steel wires (diameter 100 μm). The anode is placed upstream and the cathode downstream. The distance between anode and cathode is 5 cm. The average vertical spacing between the stainless steel wires is 0.8 cm with increased density in the lower part of the arrays. The distance between the two insulating stems of the anode respectively the cathode is 38 cm. The stems are insulated by a waterproof painting layer. Insulation is important to guarantee the production of the hydrogen bubbles on the stainless steel wires and not on the stems. The stems are hold by two PVC-plates with a vertical spacing of 8 cm. The setup has a total height of about 50 cm.

The setup for the hydrogen bubble generation must be placed sufficiently far upstream of the measuring volume to prevent flow disturbance.

2.2 Setup manufacturing

The setup manufacturing can be divided in three steps:

1. Preparation and assembling of the two PVC-plates and the four stems (Figure 2).
2. Winding of the stainless steel wires around the cathodic and anodic stems.
3. Insulation of the stems by a thick layer of waterproof painting.

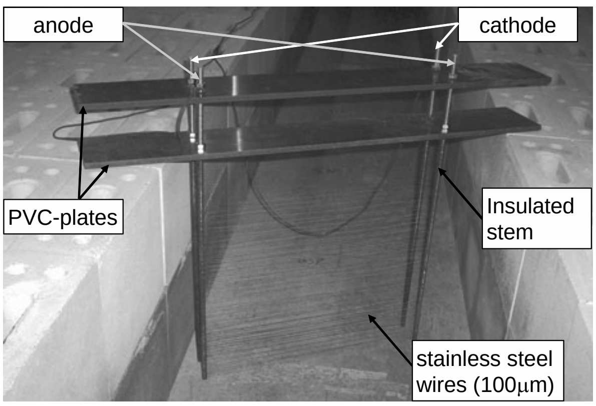

Figure 2: Hydrogen bubble generation set-up.

2.3 Power supply

An electric direct current producer (Instek GPC-3030 DC Power Supply 30-60V/3-6A) has been used with the following characteristics:

1. Constant tension of about 5 to 30 V, depending on flow depths (percentage of submerged wires).
2. Current from 0 to 3 A, also depending on flow depths.

The bubble generation is not efficient when the stainless steel wires are still clean. Only after few minutes of operation in water, a surface reaction is produced on the wires and the bubble generation becomes efficient.

2.4 Installation of the Ultrasonic (US) transducer

The experimental setup for the flow velocity measurements is schematically presented in Figure 3. The velocity was measured on the axis of a straight laboratory flume (width: 0.5 m; slope: 0.0014; length: 40 m) at a distance of 24.3 m from the entry.

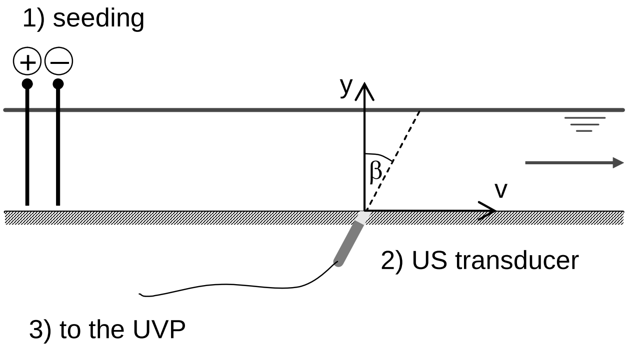

Figure 3: Velocimetry set up: (1) Setup for hydrogen bubble generation, (2) ultrasonic transducer.

The ultrasonic transducer (emitting frequency is 2 MHz) is installed in the bottom of the channel looking downstream with an angle β=30°. The flow is not significantly disturbed by the transducer which is installed about 10 mm under the bottom-level of the channel. The free space between the transducer and the bottom level is filled with a contact gel covered by a self-adhesive tape. Data acquisition has been done by the means of the UVP-DUO velocity profiler instrument from Met-Flow SA, Lausanne (Met-Flow SA, 2002) using the following main measurement parameters (Table 1):

Table 1: Utilized measurement parameters of UVP-DUO

Parameter	Value
Number of channels	80 to 280
Number of profiles	256
Sampling period (maximum speed)	163 to 205 ms
Window start	3.7 mm
Window end	120 to 420 mm
Channel-distance / -width	1.48 mm / 1.48 mm
Frequency	2 MHz
Cycles / Repetitions / Noise level	4 / 246 / 4

3 APPLICATION

The setup described above has been used to increase the quality of the velocity measurements in a flume of rectangular cross-section with macro-roughness at the side walls (Meile et al., 2006, Fig. 1) by means of an Ultrasonic Doppler instrument. Experiments in this flume aimed at investigating the influence of macro-roughness (or form roughness) at the side walls on steady and unsteady flows.

3.1 Steady flow

Steady flow tests have been performed for two different discharges and three different distances (0.75 m, 2 m, 4 m) between the ultrasonic probe and the location of seeding. Velocity profiles were measured with and without seeding. Hydraulic test parameters are summarized in Table 2.

Table 2: Hydraulic conditions

Q (l/s)	h (m)	U_{cal}=Q/(Bh) (m/s)	U_{UVP} (m/s)	Re (-)	Fr (-)
8	0.043	0.38	0.37 ± 0.02	14'000	0.60
60	0.175	0.71	0.71 ± 0.07	72'000	0.56

The results of the velocity measurements are presented for the two tested discharges in Figures 4 and 5.

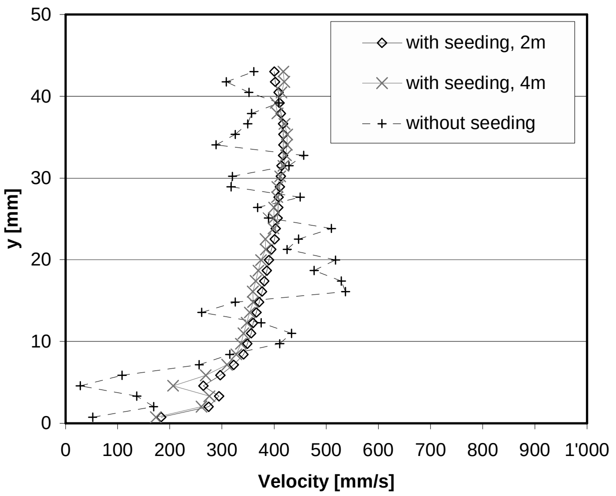

Figure 4: Velocity profiles (averaged over 10 s) with and without seeding for a discharge of 8 l/s.

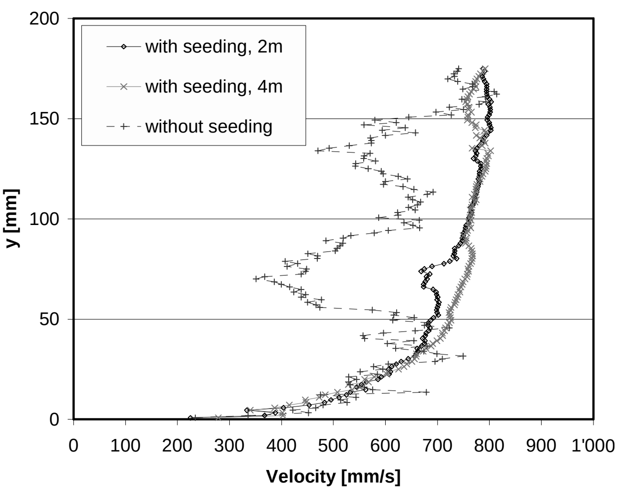

Figure 5: Velocity profiles (averaged over 10 s) with and without seeding for a discharge of 60 l/s.

Without seeding, velocity profiles are erroneous in both experiments, whereas they are rather well resolved with seeding. Remaining irregularities in the profiles may be attributed to the short sampling time (10sec).

The quality of the velocity profile remains more or less constant when the location of seeding moves upstream.

The effect of seeding is also well observable on a color plot (Figure 6). Seeding has been turned off during the measurements after 55 s. The period without seeding and therefore low acoustic scattering level is characterized by less homogeneous velocity measurements.

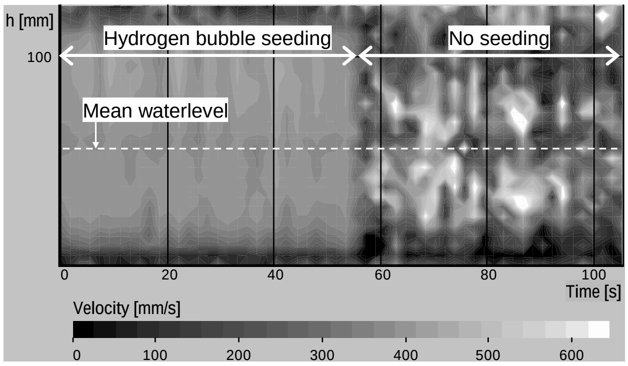

Figure 6: Time – flow depth - velocity plot for periods with seeding (left side) and without seeding (right side) of hydrogen bubbles. Steady flow test with 8 l/s.

3.2 Unsteady flow

Velocity measurement with seeding have been carried out under different unsteady flow conditions, schematically illustrated in Figure 7.

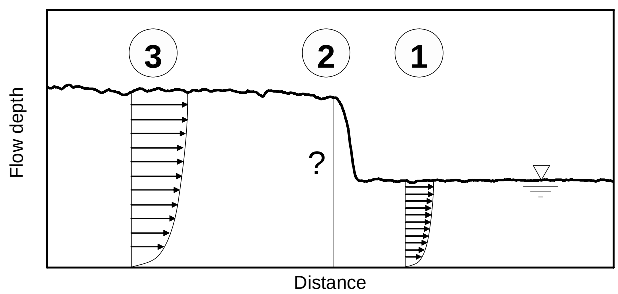

Figure 7: Velocity measurements before, during and after a positive surge wave.

Three different positive surge waves of 17.5 l/s, 30.6 l/s and 53.5 l/s have been added to a constant base flow of about 5.6 l/s (Figures 8 to 10).

For the smallest surge of 17.5 l/s, the time resolution of the measurements didn't allow to measure a velocity profile during the wave passing (Figure 8). For the second and third surge wave of 30.6 l/s and 53.5 l/s, respectively (Figures 9 and 10), non-logarithmic velocity profiles have been detected during a short period corresponding to the passage of a positive surge waves. In the lower part of the velocity profile, the velocities during the passage of the positive surge waves are always in between the velocities before and after the wave passing. In the upper part of the velocity profile the velocities are temporarily increased during the passage of the wave. This indicates a separation of the flow into a higher, faster part moving on a lower, slower part.

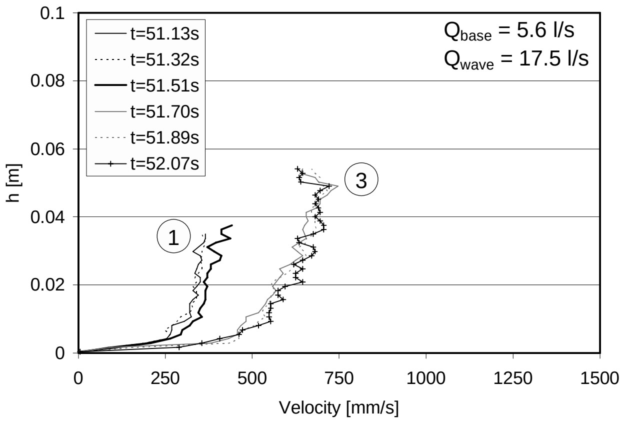

Figure 8: Velocity profiles for different times. Positive surge wave passes between t=51.32s and t=51.51s.

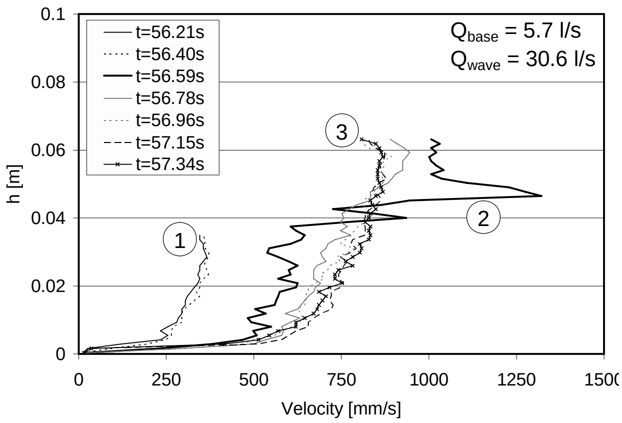

Figure 9: Velocity profiles for different times. Positive surge wave passes at about t=56.59s.

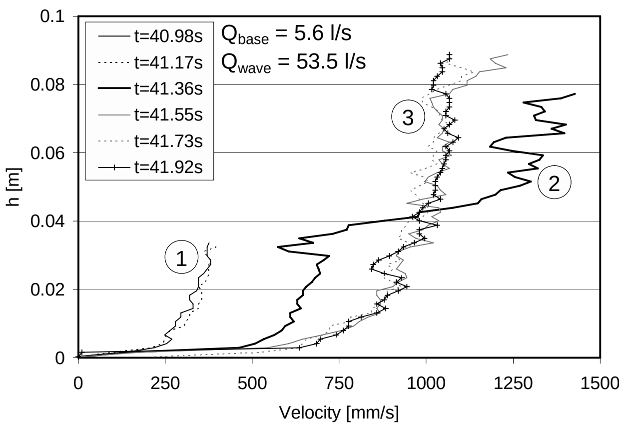

Figure 10: Velocity profiles for different times. Positive surge wave passes at about t=41.36s.

Nevertheless, it is interesting to note how fast the logarithmic velocity profile is re-established on the entire flow depth. Additional test would be interesting in order to see the influence of 1) absence of seeding 2) other base flows 3) breaking or non breaking waves on velocity profile measurements.

5 CONCLUSIONS AND SUGGESTIONS

Seeding of hydrogen bubbles allows significantly increasing the quality of flow velocity measurements.

The distance of the seeding from the ultrasonic transducer is not of paramount importance. Nevertheless, if the setup that generates hydrogen bubbles (seeding) is too close, the flow could be disturbed and if the seeding is introduced too far from the transducer, efficiency decreases.

Seeding allows to get good velocity measurements in highly unsteady flow conditions. Measurements of three different positive surge waves indicate non logarithmic velocity profiles during the wave passage. After a short moment, the distribution becomes logarithmic again.

Further developments should be related to a smaller setup having less influence on the flow and to a setup independent of the flow direction. Consequently it would be possible to place the setup closer to the measurement location and to increase the quality of velocity measurements for more applications (such as recirculation zones, …).

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