Interface tracking and velocity profile in an oil-water two-phase flow

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The main aim of this study is to assess the velocity distribution profiles in oil and water behind a containment barrier. A simultaneous study of the velocity profile in a two phase flow and the interfacial waves was performed in a laboratory flume using ultrasonic velocity profile (UVP) measurements. The increasing of the echo of ultrasonic pulses in the interface of two liquids was used to detect the interface and its fluctuations. Knowing the location of interface the velocity profile can be measured in each liquid phase.

Keywords: Velocity profile, oil water interface, interfacial waves, pulse echo, oil spill containment boom, droplet entrainment

1 INTRODUCTION

1.2 Applications of the UVP method

Velocity measurements are used in various fields of research. In hydraulics, different velocity measurement methods exist (spinner, Pitot-tube, electromagnetic field, laser technology (LDA), Particle Imaging Velocimetry (PIV), and Ultrasonic Velocity Profiling (UVP). The ultrasonic velocity profile (UVP) measurement (Takeda,1995) was developed to measure an instantaneous velocity profile of liquid flows, using Doppler shift frequency in echoes reflected at small particles flowing with the liquid.

Thanks to the UVP Method one can obtain velocity fields in space and time with a rapid data acquisition. 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. The interface between the turbidity current and the ambient clear water could also be detected using UVP. Other studies used either steady state measurement allowing a long acquisition time of several seconds or were performed in rather dirty water (De Cesare, 1999).

The applicability of the UVP method to the flow with large fluctuation both in the velocity and orientation of gas-liquid interface was confirmed by Nakamura et al. (1998). However, the capability of this method has not been verified to detect the interface of a two-phase flow.

1.2 Frame of the study

The main aim of an ongoing research project is to investigate the efficiency of oil spill containment booms. Oil spills represent a major environmental concern in coastal regions. The movement of oil slicks can cause long-term environmental damage by contaminating shoreline and marine life. Thus, it is important to improve techniques and equipments that facilitate spill cleanup in the water. Oil spill booms are known as an effective equipment to contain slicked oil and avoid its spreading over water surface. A schematic view of the Cavalli oil containment system is shown in Figure 1. In this system oil is trapped by the reservoir and can be pumped later using skimmers.

Several mechanisms can cause (a part of) the oil slick to pass under the barrier. One of these mechanisms is droplet entrainment failure. A high relative oil-water velocity may cause interfacial waves and oil droplets to be entrained from oil water interface (Wicks, 1996, and Jones, 1972).

In order to investigate the efficiency of an oil boom, it is important to evaluate the oil-water interfacial waves and velocity distribution in oil and water interfacial layers.

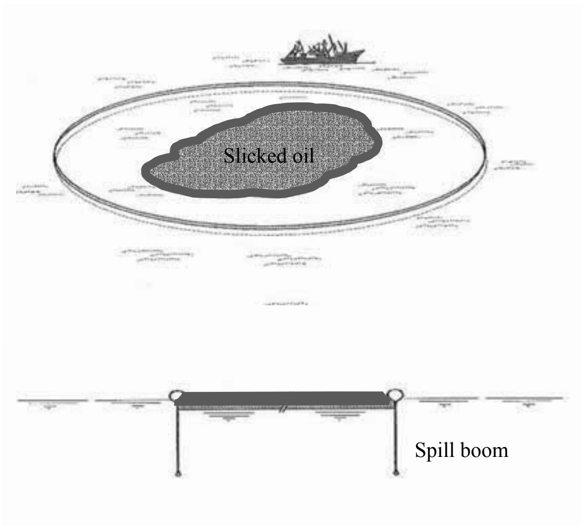

Figure 1: Schematic view of the Cavalli oil containment system; top: perspective of the system, bottom: cross section of the system.

2 EXPERIMENTAL SET UP

2.1 Channel

Experiments are undertaken in a 0.12 m wide, 6.5 m long and 1.1 m deep flume. For all experiments the water depth is fixed at 0.9 m. A rigid barrier is located in the middle of the flume and a certain volume of rapeseed oil is contained behind it (Figure 2).

The rapeseed oil has a viscosity of 88.8 cSt (mm^2/s) at room temperature (about 85 times the viscosity of water) with relative density of 0.91.

2.2 Measurements

As it is schematically depicted in Figure 2, the ultrasonic transducer is installed on the top of the oil, and it is inclined looking upstream with an angle β=20°. It is located at the point of maximum oil thickness.

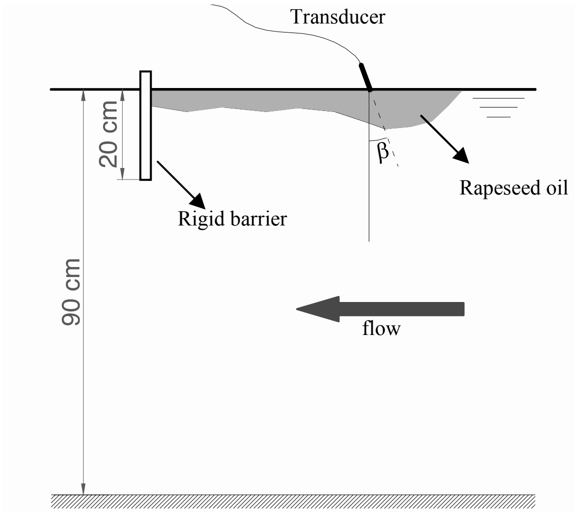

Figure 2: Experimental setup

The flow is not disturbed by the transducer as it just touches the oil surface. The main measurement parameters are listed in Table 1.

Table 1: Main measurement parameters

Parameter	Value
Number of channels	148
Number of profiles	2048
Sampling period	22 ms
Window start	3.7 mm
Window end	228.57 mm
Channel-distance / -width	1.02 mm /1.48 mm
Frequency	2 MHz
Cycles / Repetitions / Noise level	4 / 32 / 4

3 SELECTED RESULTS

The power spectrum showed a high value for the channels in the vicinity of the observed oil-water interface. For all of those channels the pick is observed for a frequency of about 2.5 Hz (Figure 3). Assuming that the maximum echo is produced in the oil-water interface, one can conclude that the high power spectrum value corresponds to the frequency of interfacial waves. It means that the interfacial waves fluctuate with a similar frequency.

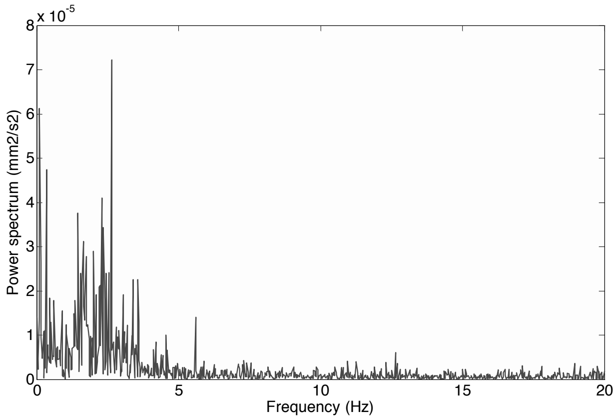

Figure 3: Power spectrum of the 22nd channel

In Figure 4 a series of picture during 0.8 s (with sequences of 0.2 s) are shown. Considering the white reference point, it can be seen that an interfacial wave forms in about 0.4 s. This means two consequent images.

Knowing the distance at which the high echo reflects, the location of oil-water interface is derived and illustrated in Figure 5 for duration of about five seconds. This figure confirms a frequency of about 2.5 Hz (period of 0.4 s) for oil-water interfacial waves. The values are smoothened with moving average method in order to remove the noise.

Figure 6 shows the interface derived from the US echo intensity superimposed on the velocity density plot. As shown on the pictures in Figure 4, smooth and breaking interfacial waves could be observed at a regular interval. The smooth waves induce an almost zero horizontal interfacial velocity, whereas the breaking waves move oil downstream with an intrusion of the velocity profile from the uniform flowing water.

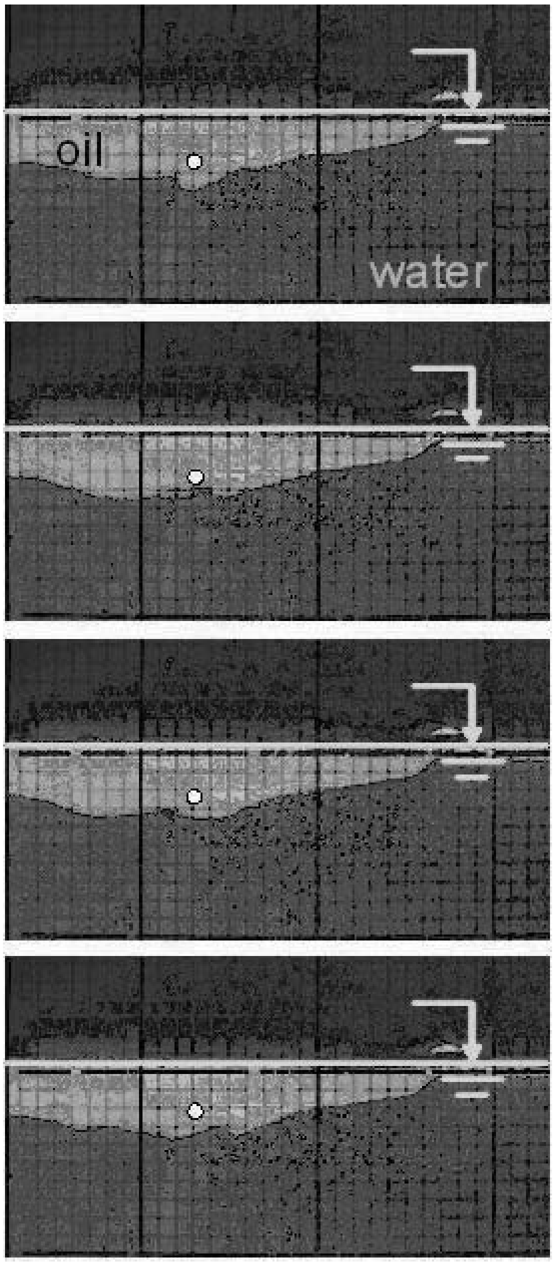

Figure 4: Sequence of pictures 0.2 s, grid size 10*10 mm, the white point is a reference point to follow the interfacial waves

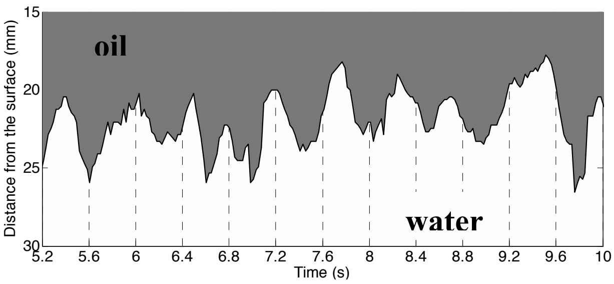

Figure 5: Oil-water interface derived from US echo

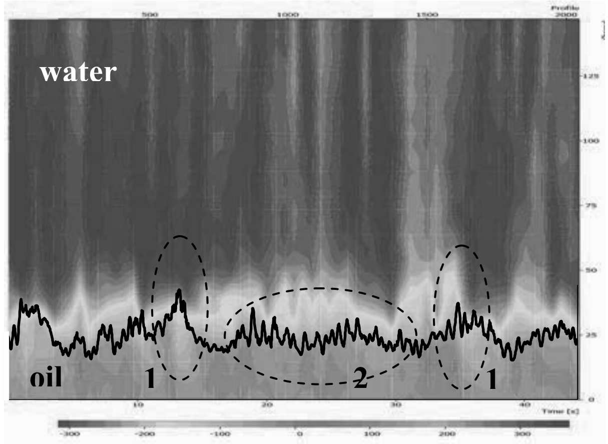

Figure 6: Velocity density plot in oil and water for a duration of 45 seconds; 1: breaking interfacial waves, 2: smooth interfacial waves.

To obtain the velocity profile in oil and water, the interface channel position is detected during a certain time and the measured instantaneous velocity profile shifted to have a constant position of the interface. Then the mean values of velocity in oil and water phases are calculated (Figure 7). As expected the friction layer happens in the water, since it is less viscous.

The visually observed weak circulation in the oil layer could not be measured by UVP.

A schematic velocity profile is shown in Figure 8.

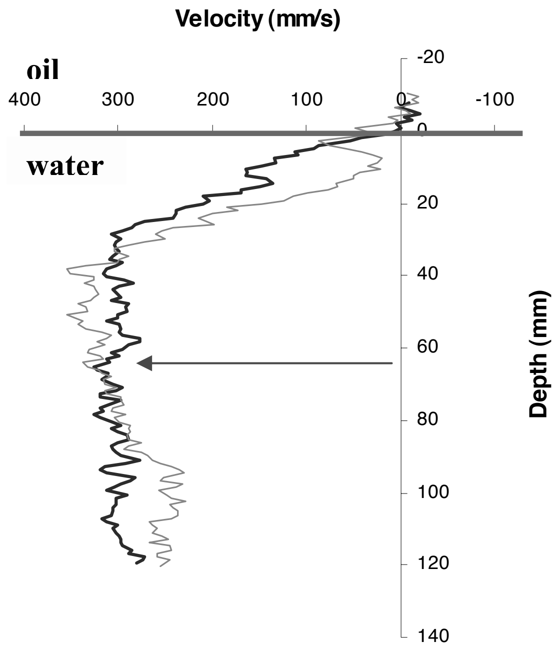

Figure 7: Mean velocity profile in water and oil; thick (blue) line: smooth waves, narrow (red) line: breaking waves

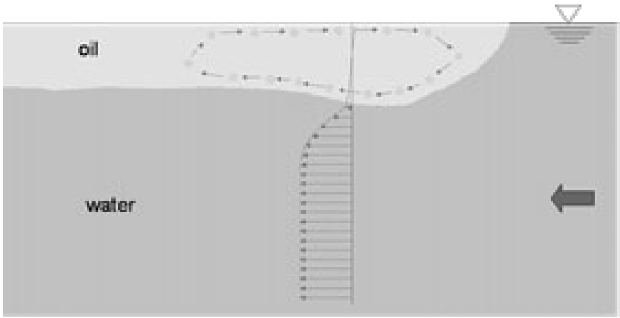

Figure 8: Schematic velocity profile in oil and water, a weak circulation of water bubbles was observed in the oil

4 CONCLUSIONS

In the framework of oil spill booms efficiency study the velocity profile in a two-phase flow was investigated. The oil-water interface is derived from ultrasonic echoes intensity and the velocity profile is determined in oil and water phases.

The capability of the UVP measurements was confirmed for detecting the velocity profile in interface of a two-phase fluid.

5 ACKNOLEDGMENTS

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