# Plastic fiber-optic probes for characterizing fluidized beds in bubbling regime

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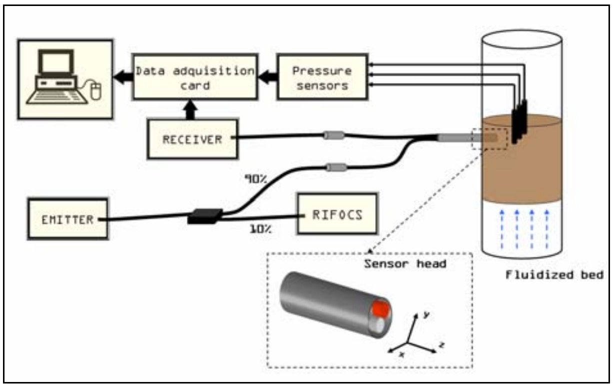
***Abstract:*** *Bubble measurements on a fluidized bed in bubbling regime using optical fibre probes (OFP) are reported. Comparisons between commercial pressure transducers (PT) measurements and OFP have also been carried out. OFP are able to detect smaller bubbles than the PT and reflect more localized phenomena in the bed.*

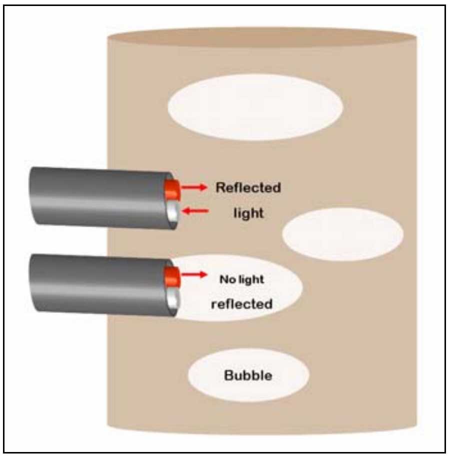
## 1. Introduction

Gas-solids fluidized beds are widely used in the industry for mixing, drying, catalytic and non-catalytic reactions and applications where high rates of heat and mass transfer between solids and a fluid phase are required.
Gas fluidized beds comprise typically a bed of granular solids supported on a porous or perforated plate in a vertical column, through which a gas flows upwards. The solids become fluidized when the pressure drop across the bed is enough to support the weight of the particles. Gas in excess of that required to just fluidize the bed generally forms bubbles. This bubbly flow condition is commonly found in the catalytic cracking of hydrocarbons and the combustion of coals. The bubble size encountered in this regime is an important index in fluidized-bed reactor design, since its influence in the main rate phenomena in the bed such as gas interchange rate between phases, particle circulation rate, heat transfer and elutriation is essential.

Experimental techniques are therefore applied to study the bubbles behaviour throughout the bed, in order to obtain the main bubble characteristics such as bubble shape and bubble size distribution [1]. In general, non-intrusive techniques such as digital image analysis using a high speed videocamera, are limited to 2D beds. X-ray photography and gamma-ray transmission are expensive and they are limited to regimes with a low concentration of bubbles. Several types of intrusive probes have been used to measure bubble properties, based on a variety of physical effects, such as electrical resistivity [2], capacitance [3-5], and pressure changes [6, 7]. Pressure differential transducers are the simplest and least expensive detection devices but the interpretation of the pressure records is difficult as the local pressure fluctuations are composed of multiple sources, including local bubble passage, global bed oscillations and propagating pressure waves originating in other locations. Capacitance probes have been used with some success but they must be calibrated for every fluid-solid system and operating conditions (in particular temperature and pressure). Probes based on sensing local electrical properties could be difficult to use when the fluidized bed operates over a range of temperatures and particle compositions. Those shortcomings of previous techniques are avoided when using optical probes [8]. Because of their simplicity, high accuracy and relatively low cost, optical fiber probes have been already used to determine local solids concentrations and velocities in fluidized beds [9-11].




(a)




(b)

Fig. 1 a: Schematic experimental set-up. b. Operation principle

Optical probes measurements are either based on forward light scattering between an emission probe and a detection sensor separated by a short distance [12], or on the backscattering principle using different optical fiber configurations, with the projecting and receiving fibers intermingled or in rows, in parallel or crossed [13,14].

Some of these probes have been tested in the past but some of them present an excessive intrusion and, in other cases, an incomplete signal interpretation methodology as stated in [8]. They have been used to measure void rise velocity and void size in fluidized beds, mainly in turbulent beds operating with Geldart A particles. Only few works are devoted to the study of bubble velocity and size in bubbling regime [15]. In this work we will focus in size measurements on the bubbling regime using low cost component based on telecom optical fiber technologies.

**2. Sensor probe description and measurements**

Optical probe developed is based on backscattering principle, with diameters of the fibre larger than the particle sizes. The optical fiber probe (OFP) is made of two standards step index plastic optical fibers (emitter and receiver fibers) embedded in a metallic coil for avoiding bending influences.

The emitter fibre is illuminated by a 650nm LED and a phototransistor is used at the reception, both encapsulated in ST connectors. A 90/10 passive splitter is used for monitoring purposes and different configurations of parallel fibres are considered. The probe was inserted into the fluidized bed (with a diameter of D=0.19m and an initial static height $H_0$=D) and OFP is placed perpendicular to the flow. A schematic of the experimental set-up can be seen in Fig. 1.a, including a RIFOCS power meter at 10% splitter output, and data acquisition system in the PC. Principle of operation is shown in Fig. 1.b. When particles in the emulsion phase pass in front of the OFP probe, a high percentage of the emitted light is reflected, and the phototransistor responds with a high current, which is converted to a voltage signal at a resistance. In contrast, when a gas void passes, relatively little light is reflected back to the probe and a low signal voltage is recorded.

Fluidized beds have been characterized at different points, near the walls and in the centre. Measurements have been taken with the reported optical probes and commercial pressure piezoelectric sensors.

An example of typical signal record from OFP, a voltage measurement proportional to optical power at the receiver, can be seen in Fig. 2. It has been marked the output voltage delimiting bubble detection (optical power closer to zero). This threshold voltage determining the frontier between the particle emulsion and gas or noise is obtained from the distribution of the acquisition points as a function of the voltage from the signal [7]. Fig. 3 shows a typical voltage histogram. Clearly, it can be seen a maximum peak related to the "dense phase", so the receiving fibre is collecting the particles reflected light. Threshold voltage is defined at 30% number of points below the maximum peak.

It has been tested that low variations of this threshold selection modifies the total amount of detected bubbles, especially in smaller size ranges.

Once the threshold voltage is selected, typical measurements as those reported in Fig. 2., a typical optical probe output voltage measurement, proportional to optical power at the receiver, are used to developed histograms with total number of bubbles related to a specific output voltage below a certain value, which means those having the same low voltage time duration, somehow related to those of a certain size (as the one shown in Fig. 4.b).

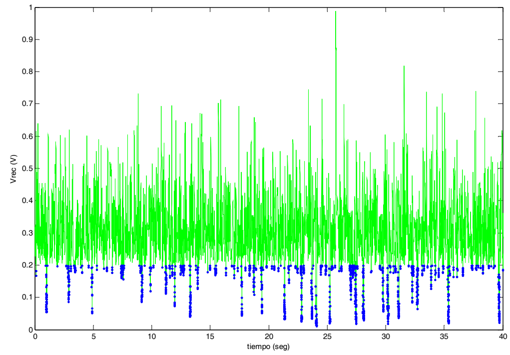



Fig. 2: Output voltage measurements versus time at POF optical probe.

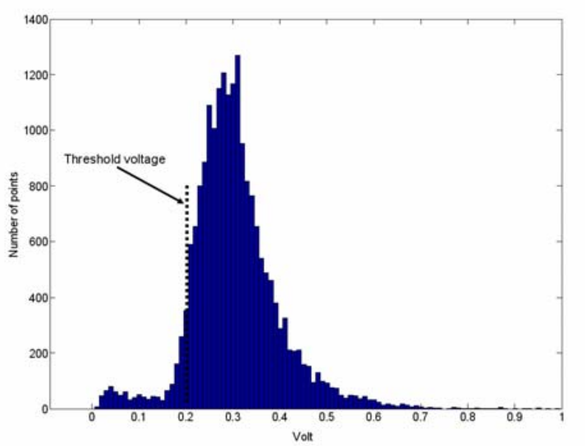



Fig. 3: Output voltage measurements histogram

Measurements with both type of sensors, OFP and conventional pressure sensors can be seen in Fig. 4. As expected, somehow smaller size bubbles (really with shorter duration) can be detected with optical probe and at different locations along the fluidized bed.

This type of measurements give us an idea of proper design of OFP, but for accurate measurements of bubble size and velocity, 2 OFP probes are going to be used in a configuration as the one reported in Fig. 5. In this new system, size and velocity measurements are obtained by correlation of voltage measurements at both OFPs; so small deviations previously reported and related to voltage threshold selection will also be overcome.

Bubbles going through both OFPs can be analyzed for determining its velocity and length as shown in Fig. 5.b. Knowing the velocity and the time it takes the bubble to cross each probe, bubble length can also be obtained.

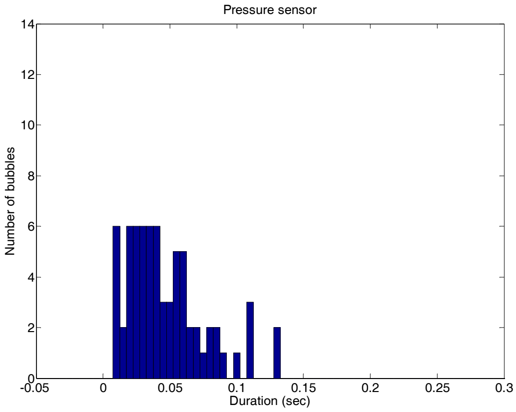



Figure 4: Histograms of bubble measurements: (a) pressure sensors

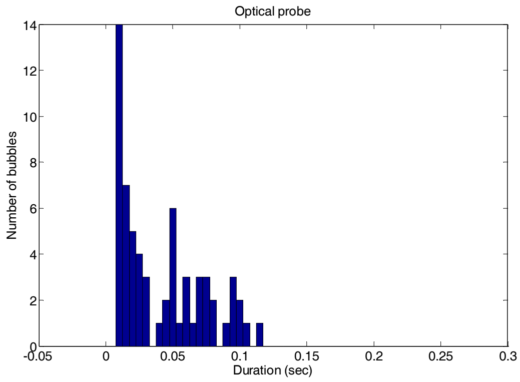



Figure 4: Histograms of bubble measurements: (b) optical probe.

First measurements show the capability of the system and the independence on voltage threshold selection. A zoom of typical measurement at both OPFs, OP1 and OP2 when a bubble is crossing can be seen at Fig. 6.

## 3. Conclusions

Simple and low cost optical fibre probes for characterizing fluidized beds in the bubbling regime are reported. Those probes are used for measuring bubbles presence at different radial positions in the fluidized bed. Comparisons with commercial pressure sensors are also reported showing new probes capability of detecting smaller bubbles. New configurations based on simultaneous measurements at two OFP probes vertically located at different heights of the fluidized bed, for measuring size and velocity have also been developed.

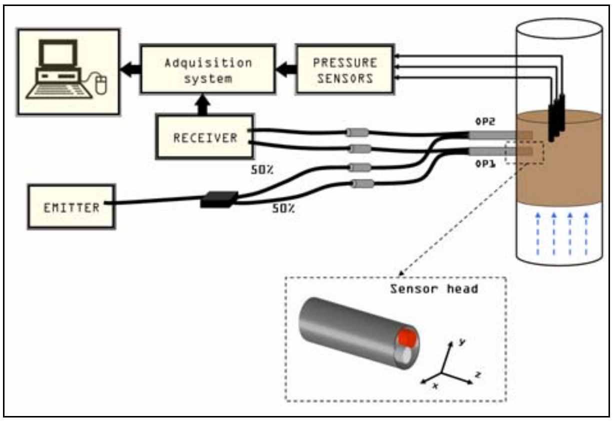



Figure 5: a. Experimental set-up for measuring bubbles sizes and velocity using two OFPs

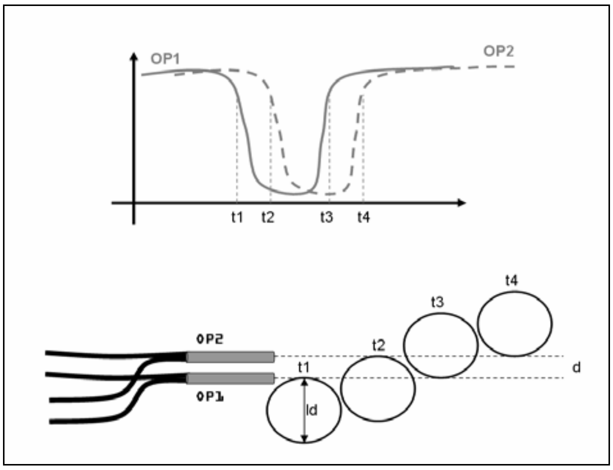



Figure 5: b. Operation principle for measuring bubbles sizes and velocity using two OFPs

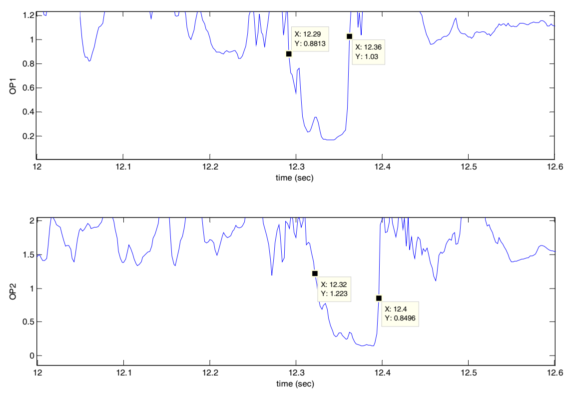



Figure 6: Zoom of output voltage measurements versus time at optical probes OP1 and OP2 in set-up shown at Fig. 5.a

## 4. Acknowledgement

This work was partially supported by projects: CICYT (TEC2006-13273-C03-03-MIC, and 2006/03983/001), FENIS-CCG06-UC3M/TIC-0619, CM:S0505/ESP/000417, CAM-UC3M 2007/04113/001

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